A Practical Guide to JUNOS Software and Enterprise Certification

JUNOS Enterprise Routing

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Doug Marschke & Harry Reynolds

Networking

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JUNOS Enterprise Routing

“Harry Reynolds and Doug Marschke combine their many years of teaching JUNOS to give you this wonderfully lucid book directed at the enterprise JUNOS user.”

—Jeff Doyle, President, Jeff Doyle and Associates, Inc.

“This book is a brilliantly practical guide for implementing Juniper routers in the enterprise environment. Every vendor's routers have a thought process, and this book puts you right in line with figuring out how your enterprise should *be thinking.”*

—Scott Morris, Vice President of Technical Training, IPexpert Inc., and Consulting Über-Geek

Written by the instructors and creators of the JNTCP-ER Certification Exams, *JUNOS Enterprise Routing* is the only comprehensive book for Juniper enterprise and edge routing environments. This book offers complete coverage of all the services available to the JUNOS™ administrator, including the new set of enhanced services.

This highly recommended book also serves as the official study guide for Juniper Enterprise Routing certification exams. Yet, with its field guide emphasis, you can easily take it beyond the classroom and into working networks as a design, maintenance, and troubleshooting reference.

JUNOS Enterprise Routing covers:

- Juniper Networks Technical Certification Program tracks for enterprise routing, including Internet Associate (JNCIA-ER), Internet Specialist (JNCIS-ER), and Internet Expert (JNCIE-ER)
- IP multicast, including Protocol Independent Multicast static, Bootstrap, and Anycast RP
- Migration strategies and routing policy implementation for IGP and BGP routing protocols
- Hardware and software architecture on Juniper enterprise routers
- JUNOS interfaces, with advanced troubleshooting techniques
- JUNOS Protocol Independent Properties (PIPs) and routing policy
- Security concepts and the tools to deploy them
- Introduction to the Layer 2 and Layer 3 JUNOS services, with working case studies
- IP class of service (CoS), with a DiffServ deployment and operational verification case study
- Coverage of the new JUNOS software with enhanced services

Along with a list of examination topics covered—and a series of review questions to test your comprehension—*JUNOS Enterprise Routing* gives you a practical foundation to ensure effective use of JUNOS software in your day-to-day job.

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JUNOS Enterprise Routing
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Foreword

In 1998, Juniper Networks launched its first product, the M40 router, and in doing so sparked a period of innovation in IP routing that continues to accelerate. Although the M40 was designed to carry Internet traffic for Internet service providers (ISPs), the benefits of IP networking were becoming apparent to other companies as well, and a short time later Juniper began to build routers with the specific goals of the rapidly developing IP business network market in mind.

The book you're holding exists to help you understand and implement the most critical elements of business networking using Juniper Networks routers running the JUNOS operating system. JUNOS contains a set of powerful tools that allow intelligent policies to replace large amounts of basic configuration, which gives the engineer a brilliantly practical way to deploy services beyond simple routing. JUNOS represents the most valuable contribution to networking that Juniper has made: it's reliable, flexible, secure, and simple to use, and an increasing numbers of businesses are finding that these qualities are compelling enough to move to Juniper and away from legacy "first-generation" routers and their less capable operating systems.

Why Enterprise Routing?

Many books have been written about JUNOS, but this book is unique in that it will prepare you to use JUNOS in an enterprise-centric sense. *Enterprise* is a term that equipment manufacturers and others use to distinguish the internal networks of "normal" businesses from the typically larger ones run by service providers, phone companies, and other network providers. Although there are, of course, similarities, every type of business requires its own unique set of capabilities from its network infrastructure regardless of its size: financial institutions have different needs from those of retail chains, which themselves differ from governments and universities.

Enterprise business networks are not simply small service provider networks. Although some aspects of networking technology—such as faster interfaces and greater degrees of reliability—continue to be attributes of both environments, their design goals and operational techniques differ greatly. A service provider usually maintains a network for the benefit of *paying customers who produce revenue*, whereas the network of an enterprise such as a bank has traditionally been viewed as an *investment whose operational expense should be minimized*. This essential difference has meant that service providers have usually been seen as the custodians of network innovation, with enterprises reluctant to invest more than the bare minimum in their infrastructure because of the uncertainty of real return on their investment.

There are signs that this attitude is changing. Companies in virtually every industry have embraced the idea that more effective use of their IT infrastructure can make them more competitive and efficient. To that end, enterprise executives are increasingly interested in innovative ways to capitalize on their investments in data networks. This trend is most pronounced in data-intensive industries such as banking, finance, and insurance, but it extends into even less obvious areas such as manufacturing and transportation.

Service provider and enterprise networks continue to be different in terms of their customer base and their relationship to technology, but networking in general is becoming increasingly important to the competitiveness of all types of companies. Some of the most outstanding examples of the ways that networking can improve business fundamentals are those related to developments in IP routing, and many of those developments have recently come from Juniper Networks.

Why Is Routing So Important?

Routing is the hub around which all of IP connectivity revolves. At the simplest level, routing establishes basic internetwork communications, implements an addressing structure that uniquely identifies each device, and organizes individual devices into a hierarchical network structure. Traditionally, routers have also served as the media adapters that have connected remote offices to the headquarters via a WAN. The most recent trend, though, is to see routers as the integration platforms for a wide variety of network enhancements such as security, policy, and services that extend the capabilities of IP to support telephony, video, legacy service integration, and other applications over a converged network.

This means the router has become the primary control point in the increasingly complex network environment, holding responsibility for service quality and security, monitoring and efficiency, and other attributes that allow networks to add value. If you control the routers, you control the network. This is true in a static network, of course, but even more so in today's typical case of a rapidly evolving enterprise, where migration to fully IP-based services is underway. This book will show you how you can use Juniper routers to ease this migration and arrive at a more successful outcome with less work than other platforms would require. This is important because although the basics of routing remain somewhat the same, the more advanced aspects are under constant development, and the authors have done a great job of showing you how to address the continually changing enterprise network environment.

Juniper has long understood that constant change is a fact of today’s networks, and has worked to bring new levels of performance, dependability, and scalability to routing platforms and the software that runs them. CIOs and IT departments realize that by deploying a more powerful, flexible tool at their networks’ control points, they enable their networks to address new challenges more easily and economically, and that’s the best way to support the competitiveness of their company.

How This Book Will Help You

I have known and worked with Doug and Harry for years, and have watched both of them add to their earlier careers in telecommunications with outstanding work for Juniper and SNT. Both have extensive experience in training and certification, and both are established authors of educational materials, course guides, and books that have helped thousands of networking engineers obtain knowledge to set them apart from the competitive field. Their students and readers have gone on to form an elite group.

This book will serve two purposes for you. First, it will allow you to quickly acquire the knowledge to succeed in implementing enterprise networks, no matter how advanced, with Juniper Networks routers. Second, it will help you to prove your knowledge by passing the Juniper Networks Certified Internet Expert (JNCIE-ER) examination, one of the most highly regarded certifications in the industry. Each chapter’s tutorial trains you in the most essential elements of the subject, and the review questions at the end of each chapter allow you to confirm the knowledge you’ve acquired. Doug and Harry have extensive experience in both the practical and the pedagogical components of this mission, and this book is an excellent example of how theory and practice can come together in one comprehensive yet concise package.

Juniper Networks routers and the JUNOS operating system are changing the way IT departments are regarding their IP networks, allowing them to put greater trust in the capabilities of their routing infrastructures and thereby deliver much greater value to the bottom lines of their organizations. With this book, Doug and Harry have delivered the tools necessary for every network engineer to add valuable knowledge and skills to his professional portfolio, and to help his company reap the benefits of the enterprise IP revolution. All that’s required is for you to accept the challenge!

—Matt Kolon
Hong Kong, January 2008

Credits

About the Authors

Doug Marschke is an engineering graduate from the University of Michigan currently working with various consulting firms, including Strategic Networks Training and Cubed Networks. He is JNCIE-ER #3-, JNCIE-M #41-, and JNCIS-FW-certified. He was heavily involved in the Juniper certification exams from the start, having contributed to test writing, and he is a coauthor of the current JNCIE Enterprise Exam. Doug currently spends his time working with both service providers and enterprises to optimize their IP networks for better performance, cost, and reliability. He also flies around the world sharing his knowledge in a variety of training classes and seminars with topics ranging from troubleshooting to design and certification preparation. If Doug is not on the road, you can find him at his bar in San Francisco, Underdogs Sports Bar, discussing a wide variety of topics.

Harry Reynolds has more than 25 years of experience in the networking industry, and for the past 15 years has focused on LANs and LAN interconnection. He is CCIE #4977- and JNCIE #3-certified, and holds various other industry and teaching certifications. Harry was a contributing author on the *Juniper Networks Complete Reference* (McGraw-Hill), and he wrote the JNCIE and the JNCIP *Juniper Networks Certification Study Guides* for Sybex Books. Prior to joining Juniper, Harry served time in the U.S. Navy as an avionics technician, worked for equipment manufacturer Micom Systems, and spent much time developing and presenting hands-on technical training curricula targeted to both enterprise and service provider needs. Harry has presented classes for organizations such as American Institute, American Research Group, Hill Associates, and Data Training Resources. He is currently employed by Juniper Networks, where he functions as a senior test engineer in the JUNOS software Core protocols group. Harry also functioned at Juniper as a consulting engineer on an aerospace routing contract, and as a senior education services engineer working on courseware and certification offerings.

About the Lead Technical Reviewers

Mario Puras is a Juniper Networks systems engineer supporting major enterprise and state government accounts in Florida. He has more than 10 years of experience in the networking industry, focusing on providing routing, switching, and security solutions for large enterprise and service providers. He is JNCIP #119-certified and holds a JNCIA-FW, JNCIA-WX, and various other industry certifications. Prior to joining Juniper Networks, Mario served in the U.S. Army and worked at Metrolink, Duro Communications, and Solunet Inc. He is married to his best friend of 12 years, Stacy.

Jack W. Parks has more than 15 years of experience in IT and has worked in almost every position known in the realm of IT. Most recently, he has focused on enterprise routing and switching, service provider routing, and MPLS and VPNs. Jack holds a BS in business information systems from John Brown University and has received several industry certifications, including CCI #11685, JNCIS-M, JNCIA-SSL, and JNCIA-FWV. After serving eight years in the U.S. Air Force, Jack transitioned into the corporate world working for service providers in the enterprise and ISP market spaces. Jack is currently a Juniper systems engineer based in Atlanta.

Preface

The world of enterprise routing with Juniper Networks devices is getting very exciting—new technologies, products, and network developments are making the enterprise network environment one of the most dynamic places to be. However, we, the authors, hope to focus that energy by providing you with a detailed and practical foundation that ensures effective use of JUNOS software in your day-to-day job.

Because we are also involved in the development and testing of certification exams, including those for enterprise routing, this book does double duty. It is both a field guide and a certification study guide. Readers who are interested in attaining a Juniper Networks certification level are wise to note that we discuss and cover topics that are relevant to the official exams (hint, hint), and the end of each chapter provides a listing of examination topics covered as well as a series of review questions that allow you to test your comprehension.

Regardless of one's certification plans, this one-of-a-kind book will not be obsolete just because you pass an exam. In fact, we wrote this material to serve as a field guide to be useful almost anytime you log on to a Juniper Networks router. The extensive use of tutorials, samples of actual command output, and detailed theoretical coverage go well beyond any certification exam, to provide you with something that can't be tested—getting things to work the right way, and on the first time. When plan A fails, the material also provides the steps needed to monitor network operation and quickly identify and resolve the root cause of malfunctions.

As trainers who deal with large numbers of both experienced and inexperienced users on a regular basis, we have seen it all. Within this guide, you will find the many pearls of our accumulated wisdom, any one of which can easily pay for this book many times over in increased network uptime and performance.

Some of our chapters tend to be on the longer side, simply because they are packed with detailed information regarding theory, configuration, and troubleshooting for each topic. Rather than create more chapters, "soft breaks" and summaries within the chapters are used to identify boundaries within the material that afford a convenient place to take a breather, or as we often provide in our training classes, a "biology break and stretch." Dog-ear the pages, write notes in the margins, augment the topology illustrations with something more akin to your network—just remember that this is a beastly JUNOS book: part exam, part training class, part knowledge base. It's meant to be used, abused, and put to work. Let's get going.

What Is Enterprise Routing?

After you've spent some time in the networking field, you tend to notice that there is rarely a single way to do things, and in many cases, a single precise definition for terms. After all, often a network engineer's best answer is "it depends." Such is the case with enterprise routing, so let's start off with a definition question: what is an enterprise network? Is it a large multinational network used by a manufacturing company; is it a government network supporting a state or a county; is it a regional network used by a parts distributor; or is it a network that supports your local dentist's office?

Of course, it's probably all of these, and many more. At a very high level, you can state that an enterprise network is one that is used to support activities as opposed to generating revenue, as in a service provider's network. Some might say that if someone pays you to access your network, you are providing a service to him and you're no longer an enterprise network. But that sweeping statement doesn't really apply if that someone is paying you to cover your costs to provide that service. So, as you can see, it depends.

Defining an enterprise network also manifests itself into how Juniper Networks defines its products within the enterprise world. On the one hand, Juniper designates certain hardware platforms as enterprise routers, but then many enterprise networks require density and throughput options from a platform listed as a service provider product. From the software side of things, the same issue arrives. Whereas a technology such as IPSec is used by all types of networks around the globe, is it used more by enterprise networks than by service provider networks? Some engineers would answer yes to that question, but then, you can't say that a service provider will never use IPSec.

From the perspective of hardware platforms, Juniper Networks has designated the following as enterprise products:

- J-series routers to include the J2300, J2320, J2350, J4350, and J6350
- M7i and M10i routers
- M120 routers

However, larger enterprise networks may find platforms such as the M320 and MX960/480 very useful for their environments. In fact, the reverse is also true in that a traditional service provider network may very well find an appropriate need and use for platforms designated as enterprise routers.

The good news in all this is that you have a well-thought-out operating system in JUNOS. The JUNOS software is a single train of features that operates across all of the various routing platforms. So, whether you run an enterprise network or a service provider network, and regardless of your actual hardware platform, there is a single version of software code to load. Although this single code train has lots of hidden benefits, such as stability, ease of expandability, lower total operational costs, and more, what it really means is the ability to have the same features available on all devices. So, from a learning perspective, we can talk about the software and its features without having to constantly caveat our discussion with "except for on this platform" or "only on these particular platforms." Although such exceptions do occur, and they result from hardware enhancements that are unique to a particular platform, these cases tend to be exceptions and are infrequent enough to remember.

Throughout this book, we will attempt to simplify the discussion by limiting ourselves to the J-series platforms and the M7i router as we discuss the various features and options available to configure. We also focus on those topics that the vast majority of enterprise networks care about and actually use. We will also define an enterprise network as one that uses an Internet connection as opposed to a network that provides connectivity to the Internet as its sole function.

Juniper Networks Technical Certification Program (JNTCP)

This book is an official study guide for the JNTCP Enterprise Routing tracks. Use it to prepare and study for the JNCIA-ER, JNCIS-ER, and JNCIE-ER certification exams. For the most current information on Juniper Networks' Enterprise Routing certification tracks, visit the JNTCP web site at *http://www.juniper.net/certification*.

How to Use This Book

Let's look at some specifics on how this book can help you. We'll talk about what we cover in the various chapters, how the book is laid out, and some resources to help you along the way. To start, let's discuss what you should know before you begin to read this book.

We are assuming a certain level of knowledge on the reader's part. This is important because we are assuming you to be conversant in the following topic areas:

OSI model

The Open Systems Interconnection (OSI) model defines seven different layers of technology: Physical, Data Link, Network, Transport, Session, Presentation, and Application. This model allows network engineers and network vendors to easily discuss and apply technology to a specific OSI level. This segmentation lets engineers divide the overall problem of getting one application to talk to another into discrete parts and more manageable sections. Each level has certain attributes that describe it and each level interacts with its neighboring levels in a very well-defined manner.

Switches

These devices operate at Layer 2 of the OSI model and use logical local addressing to move frames across a network. Devices in this category include Ethernet, Asynchronous Transfer Mode (ATM), and Frame Relay switches.

Routers

These devices operate at Layer 3 of the OSI model and connect IP subnets to each other. Routers move packets across a network in a hop-by-hop fashion.

Ethernet

These broadcast domains connect multiple hosts together on a common infrastructure. Hosts communicate with each other using Layer 2 media access control (MAC) addresses.

Point-to-point links

These network segments are often thought of as WAN links in that they do not contain any end users. Often, these links are used to connect routers together in disparate geographical areas. Possible encapsulations used on these links include ATM, Frame Relay, Point-to-Point Protocol (PPP), and High-Level Data Link Control (HDLC).

IP addressing and subnetting

Hosts using IP to communicate with each other use 32-bit addresses. Humans often use a dotted decimal format to represent this address. This address notation includes a network portion and a host portion, which is normally displayed as 192.168.1.1/24.

TCP and UDP

These Layer 4 protocols define methods for communicating between hosts. The Transmission Control Protocol (TCP) provides for connection-oriented communications, whereas the User Datagram Protocol (UDP) uses a connectionless paradigm. Other benefits of using TCP include flow control, windowing/buffering, and explicit acknowledgments.

ICMP

Network engineers use this protocol to troubleshoot and operate a network as it is the core protocol used by the ping and traceroute (on some platforms) programs. In addition, the Internet Control Message Protocol (ICMP) is used to signal error and other messages between hosts in an IP-based network.

JUNOS CLI

The command-line interface (CLI) used by Juniper Networks routers, which is the primary method for configuring, managing, and troubleshooting the router. JUNOS documentation covers the CLI in detail, and it is freely available on the Juniper Networks web site (*http://www.juniper.net*).

What's in This Book?

The ultimate purpose of this book is to be the single, most complete source for working knowledge related to Juniper Networks enterprise routing. Although you won't find much focus on actual packet formats and fields, topics for which there is already plentiful coverage on the Internet and in bookstores, you will find how to effectively deploy JUNOS technology in your network.

Here's a short summary of the chapters and what you'll find inside:

Chapter 1, *Introduction to JUNOS Enterprise Routing*
: This chapter provides an overview of the hardware and software architecture on Juniper enterprise routers, as well as an overview of the JUNOS CLI for both new and experienced users.

Chapter 2, *Interfaces*
: This chapter provides an overview of JUNOS interface organization. Then it dives into some of the most common interface types and configurations seen in networks today. Finally, it concludes with a troubleshooting section with real-life scenarios seen every day.

Chapter 3, *Protocol Independent Properties and Routing Policy*
: This chapter provides a condensed but comprehensive overview of JUNOS Protocol Independent Properties (PIPs), such as static and aggregate route, and of routing policy, which is used to control route advertisement, redistribution, and attribute manipulation.

Chapter 4, *Interior Gateway Protocols and Migration Strategies*
: This chapter provides a detailed review of Interior Gateway Protocol (IGP) operation, and then focuses on multivendor deployments of the Routing Information Protocol (RIP) and Open Shortest Path First (OSPF). The material also focuses on IGP migration strategies and includes an EIGRP-to-OSPF migration case study.

Chapter 5, *Border Gateway Protocol and Enterprise Routing Policy*
: After providing a detailed review of what the Border Gateway Protocol (BGP) is and how it can benefit an enterprise, this chapter provides a series of case studies that build in complexity, starting with a single homed network with no Internal BGP (IBGP) speaker and ending with a multihomed-to-multiple-providers scenario, to include a redundant IBGP route reflection design that avoids running IBGP on all internal routers. The policy treatment is focused on practical enterprise routing goals, and it details both inbound and outbound policy that includes autonomous system (AS) path regex matching and BGP attribute manipulation.

Chapter 6, *Access Security*

This chapter provides an overview of a large variety of security concepts and the tools available to deploy them. These tools include user authentication and authorization, remote access, firewall filters, policers, Unicast Reverse Path Forwarding, the Simple Network Management Protocol (SNMP), and syslog.

Chapter 7, *Introduction to JUNOS Services*

This chapter provides an overview of the Layer 2 and Layer 3 services that can be deployed on a Juniper Networks router. Layer 2 services include features such as link bundling and Generic Routing Encapsulation (GRE), whereas Layer 3 services include stateful firewalls, IPSec, and Network Address Translation (NAT). This chapter also lays the CLI foundation to discuss more scenarios in Chapter 8.

Chapter 8, *Advanced JUNOS Services*

This chapter dives into the complex scenarios of the features discussed in Chapter 7. It walks through various deployed NATs, IPSec virtual private networks (VPNs), IPSec over GRE, and all possible Layer 3 services combined.

Chapter 9, *Class of Service*

This chapter provides an overview of IP class of service (CoS) and includes a detailed primer on IP DiffServ. The material then details the similarities and differences in CoS handling between the J-series and M7i routers, which is a common source of confusion. A practical CoS case study serves as the foundation for CoS deployment and operational verification. The chapter also demonstrates the J-series-specific Virtual Channel CoS feature.

Chapter 10, *IP Multicast in the Enterprise*

Multicast tends to see little deployment and is a common area of confusion. This chapter details IP multicast concepts, provides an overview of multicast protocols, and then demonstrates several Physical Interface Module (PIM) sparse mode scenarios, to include PIM sparse mode with static, bootstrap, and Anycast-RP. Through all the examples, practical verification and fault isolation steps are provided.

Chapter 11, *JUNOS Software with Enhanced Services*

This hot-off-the-press chapter includes the first official coverage of the new JUNOS software with enhanced services release. This chapter gives you the heads-up needed to understand what JUNOS software with enhanced services offers, how to migrate from JUNOS to JUNOS software with enhanced services, and the various things you need to know before deploying JUNOS software with enhanced services.

In addition, you can also use this book to attain one of the Juniper Networks certification levels related to enterprise routing. To that end, each chapter in the book includes a set of review questions and exam topics that have been covered, all of it designed to get you thinking about what you've just read and digested. If you're not in the certification mode, the questions will provide a mechanism for critical thinking, potentially prompting you to locate other resources to further your knowledge.

Topology of This Book

Figure P-1 displays the topology of the book that appears beginning in Chapter 3. It consists of 11 J-series routers running version 8.0R1.9 and 2 Cisco routers running IOS Release 12.3(15b). The Cisco routers are primary employed in Chapter 4, where they are used for both RIP interoperability and as part of an EIGRP-to-OSPF migration exercise. The topology uses only Fast Ethernet and T1 interfaces; however, other interface types are examined in Chapter 2. You might recognize the hostnames of the routers—they all relate to a beverage that was created more than 7,000 years ago (with evidence to consumption) in Mesopotamia. The names are chosen due to the international appeal of the resultant product and for the resultant food value only, as beer is an excellent way to preserve the nutritional value of grain.

Conventions Used in This Book

The following typographical conventions are used in this book:

Italic

Indicates new terms, URLs, email addresses, filenames, file extensions, pathnames, directories, and Unix utilities

`Constant width`

Indicates commands, options, switches, variables, attributes, keys, functions, types, classes, namespaces, methods, modules, properties, parameters, values, objects, events, event handlers, XML tags, HTML tags, macros, the contents of files, and the output from commands

`Constant width bold`

Shows commands and other text that should be typed literally by the user, as well as important lines of code

`Constant width italic`

Shows text that should be replaced with user-supplied values

This icon signifies a tip, suggestion, or general note.

This icon indicates a warning or caution.

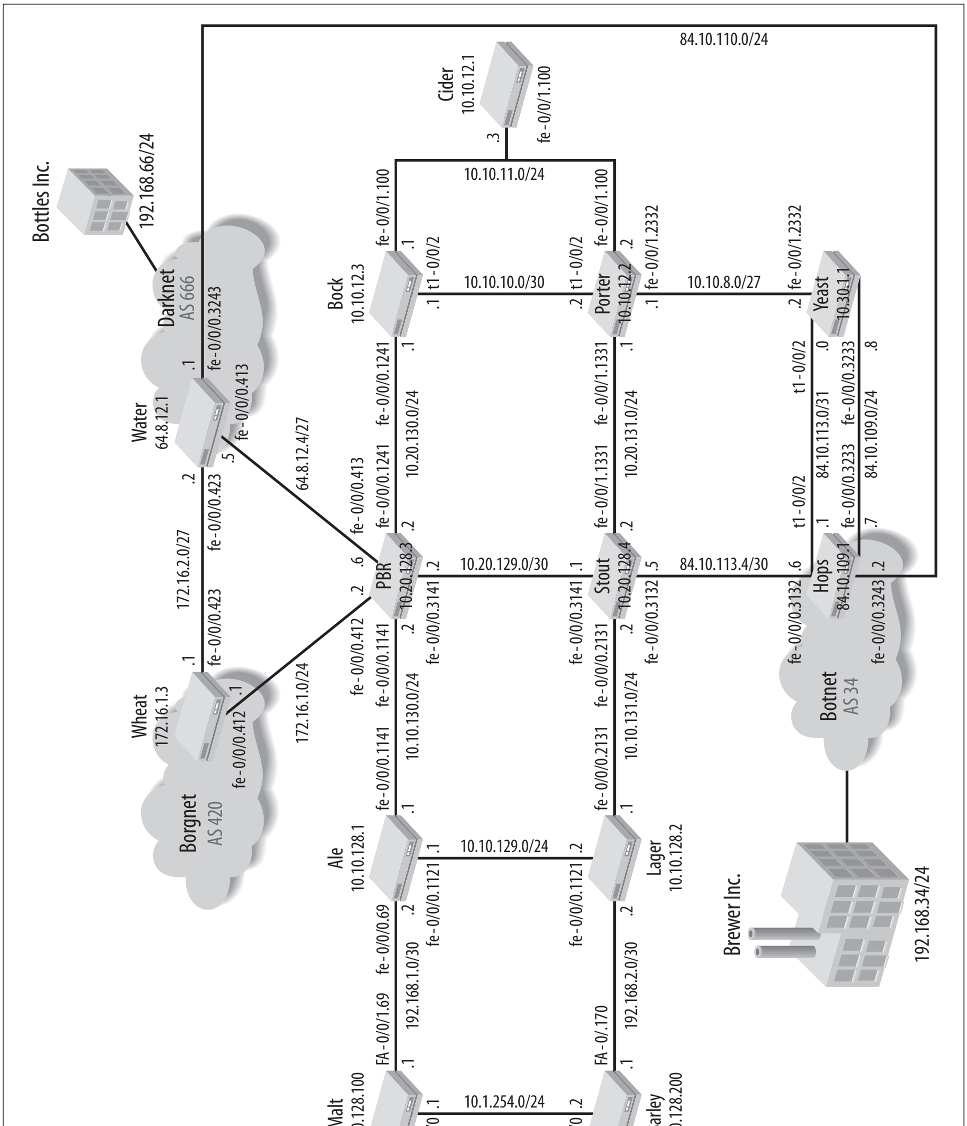

Figure P-1. This book's topology

Using Code Examples

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From Doug Marschke

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From Harry Reynolds

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CHAPTER 1
Introduction to JUNOS Enterprise Routing

When the founding engineers of Juniper decided to create routers, they took the view of forwarding packets as quickly as possible (line rate) with services enabled, which spawned the marketing decree “Service without Compromise.”

All Juniper Networks routers share the same common design philosophy, which is to have a clean separation of the control and forwarding planes. In the M-series, this separation is created in hardware, whereas the J-series maintains this divide in software. The forwarding plane is referred to as the Packet Forwarding Engine (PFE), and the control plane is called the Routing Engine (RE).

The RE’s primary functions are to manage the PFE, control the router’s software (JUNOS), manage the command-line interface (CLI), provide troubleshooting tools, and maintain the route tables and the master forwarding table. This forwarding table is passed down to the PFE and is used to forward any transit packet to the next hop destination. In this way, the RE never has to be directly involved in packet forwarding (i.e., process switching), which allows more resources for the actual control functions (see Figure 1-1). One example is the ability to issue “debug” commands without degrading the performance of the router!

> The route table in JUNOS software is defined as all routes learned from *all* protocols (Open Shortest Path First [OSPF], Border Gateway Protocol [BGP0, static, interfaces, etc.]). The forwarding table provides the “best” routes that will be used to forward packets based on protocol preference and metrics.

The PFE’s sole purpose in life is to forward packets as fast as it can. In an M-series router, the PFE consists of several application-specific integrated circuits (ASICs) contained on various cards that are placed into the chassis. In the J-series, the PFE is a virtualized real-time thread with the ASIC functionality modeled with various APIs and sockets. Since the J-series’ PFE is implemented in software, we will examine it in the software section, but let’s take a brief look at the M-series now to better understand the PFE.

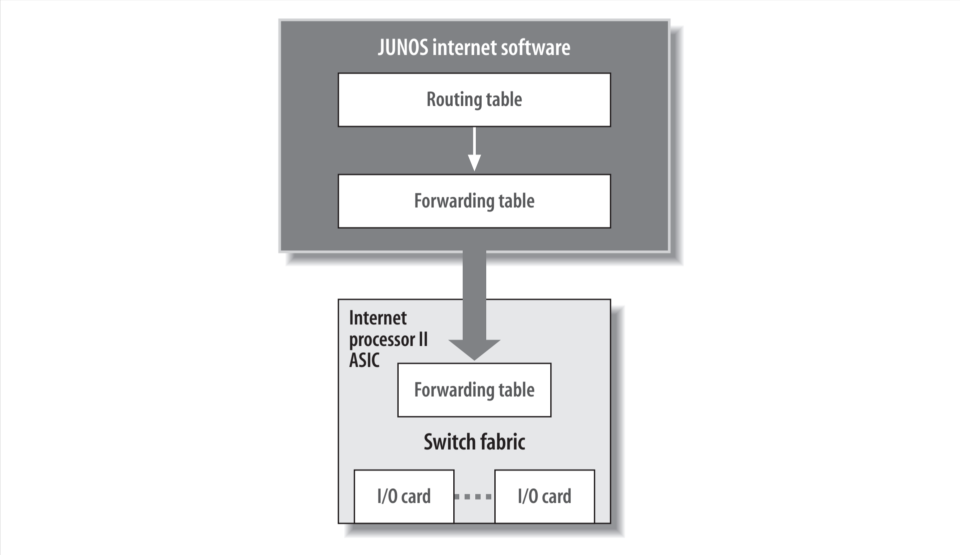


Figure 1-1. Juniper architecture design philosophy

In an M-series router, the PFE is not just one physical card in the router, but a series of cards, each containing a different ASIC. The fundamental building block of the PFE on any M-series router is the Physical Interface Card (PIC). The PIC is the card that the physical media such as Ethernet, Serial, or Asynchronous Transfer Mode (ATM) will plug into. This PIC contains an ASIC that will pull and place data on the wire as well as deal with the actual interface framing. The final piece of the PFE is the compact Forwarding Engine Board (cFEB), which contains several ASICs that deal with packet storage, forwarding, queuing, and filtering. An M7i contains just a single cFEB, whereas an M10i will contain both a primary and a backup cFEB.

> The M120 router contains six FEBs that are mapped to chassis slots and provide N+1 standby redundancy.

As previously mentioned, the PFE of a J-series router is *virtualized*. However, like any router in our networking universe, it must contain interfaces. The J2320, J2350, J4350, and J6350 enterprise routers have changeable cards similar to the PIC of an M-series router, called Physical Interface Modules (PIMs) or Enhanced Physical Interface Modules (EPIMs). The primary difference between a PIM and an EPIM is that EPIMs support higher-speed interfaces and must be installed in certain slots on the router.

> It may seem that the two modules, PIC and PIM, essentially do the same thing, but with different nomenclature. Although this is true, there is a method behind all the madness, as PIMs can be used only in J-series routers and PICs can be used only in M/T-series devices.

JUNOS Overview

JUNOS software is cool. It just is. The designers of JUNOS software put tremendous thought into making a stable, robust, and scalable operating system that would be a positive for the router. They were able to learn from previous vendors' mistakes, and created an OS that other companies will forever use as their model.

The core philosophy of JUNOS software was to create a modular *and* stable operating system. The modularization was created by the use of software daemons, and the stability was achieved by choosing a well-known, open source, and stable kernel of FreeBSD. This kernel is usually hidden to the user, but many features of FreeBSD have been ported to the command line of JUNOS. The kernel also maintains the forwarding table synchronization between the RE and the PFE.

Riding on top of the kernel are all the fully independent software processes for routing, CLI, interfaces, and so forth. Figure 1-2 shows a small subset of these processes; you can show a complete list in the router by issuing a `show system processes` command. These processes are fully independent, so a failure of one process will not affect the other. For example, Figure 1-2 shows the Simple Network Management Protocol (SNMP) process pulling information from the interface, chassis, and routing processes. If this SNMP process fails or contains a software bug, it affects only this process and not the others. This is a major shift from other routing vendors that operated monolithic code where one change in the interface code could affect just about anything without reason.

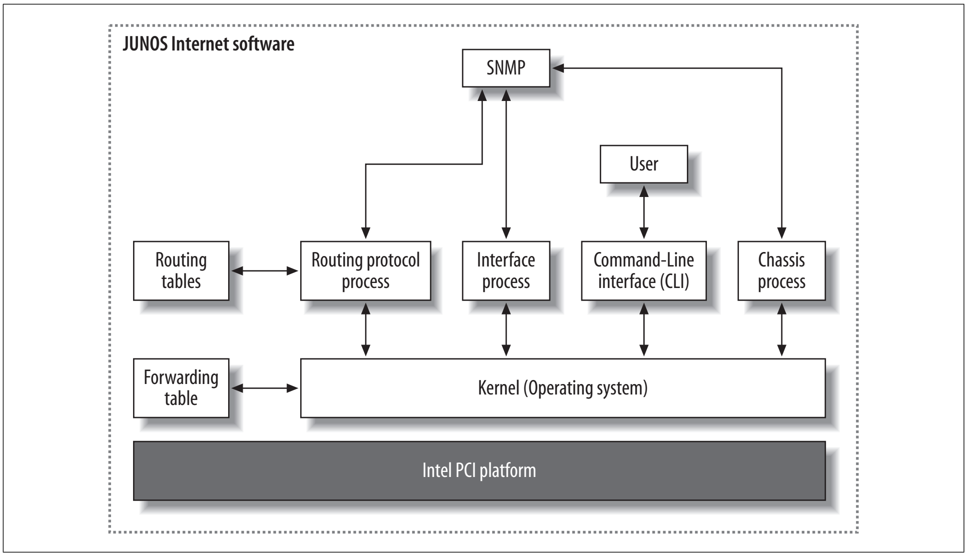


Figure 1-2. JUNOS software architecture

Every Juniper Networks router is created from the same code base, so all run JUNOS software. Since the J-series did not contain any ASICs for the PFE and certain interface drivers such as high-speed OC-192 links were deemed unnecessary, a new image had to be created for these devices. This is still JUNOS, however, with almost the same feature set as the ASIC-driven image.

> This means that there is a single image per version for all M/T-series routers regardless of model number, and a single image per version for all J-series routers. The days of creating and maintaining large spreadsheets or lists per router are now gone.

The major difference in the J-series image is the inclusion of a new software process called *fwdd* (forwarding devices daemon), which acts as the virtualized PFE. It is essentially a series of real-time threads operating over the kernel, as shown in Figure 1-3. Instead of an ASIC providing the functionality of the PFE, sockets and APIs will interface with the kernel, providing a deterministic performance.

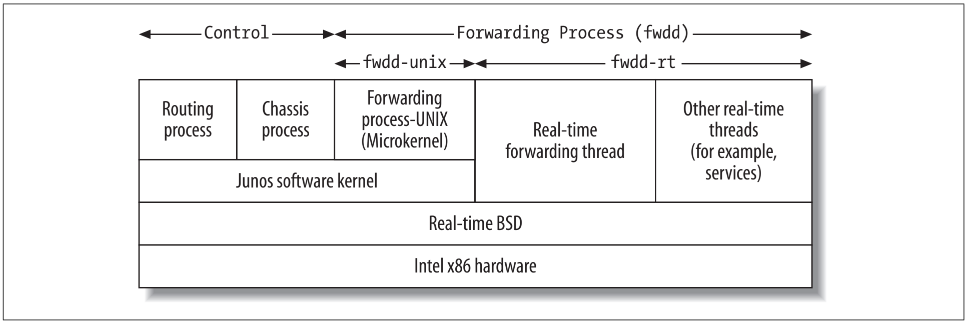
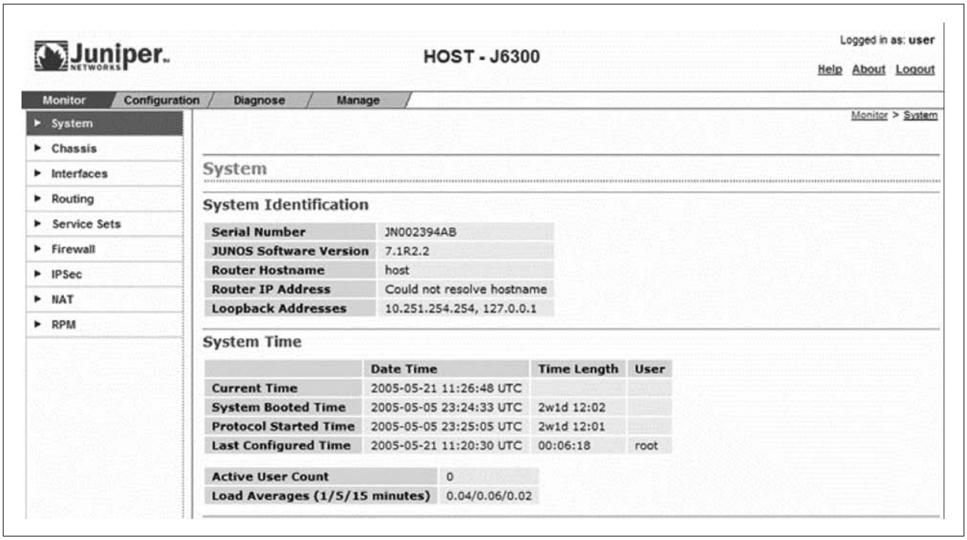

Control
Forwarding Process (fwdd)
fwdd-unix
fwdd-rt
Routing process
Chassis process
Forwarding process-UNIX (Microkernel)
Real-time forwarding thread
Other real-time threads (for example, services)
Junos software kernel
Real-time BSD
Intel x86 hardware

Figure 1-3. J-series software architecture

CLI Review

The tool that will most often be used to configure and troubleshoot the router is the CLI. The JUNOS software CLI is one of the most user-friendly and feature-rich in the industry. Most users spend years attempting to master other router vendors' CLIs, whereas JUNOS software can be mastered in just a few hours. Other configuration methods do exist, such as a web GUI called *Jweb* (see Figure 1-4), which is often used on the J-series routers. Note that the operation of Jweb is beyond the scope of this book, so all configuration examples will be shown via CLI commands instead.



System

System Identification

Serial Number	JN002394AB
JUNOS Software Version	7.1R2.2
Router Hostname	host
Router IP Address	Could not resolve hostname
Loopback Addresses	10.251.254.254, 127.0.0.1

System Time

	Date Time	Time Length	User
Current Time	2005-05-21 11:26:48 UTC		
System Booted Time	2005-05-05 23:24:33 UTC	2w1d 12:02	
Protocol Started Time	2005-05-05 23:25:05 UTC	2w1d 12:01	
Last Configured Time	2005-05-21 11:20:30 UTC	00:06:18	root

Active User Count	0
Load Averages (1/5/15 minutes)	0.04/0.06/0.02

Figure 1-4. Jweb

General CLI Features

The CLI has two modes: operational and configuration. Operational mode is where you can troubleshoot and monitor the software, router, and network. Configuration mode is where the actual statements for interfaces, routing protocols, and others are placed.

> Every command that can be run in operational mode can also be used in configuration mode with the additional keyword `run`. For example, if the command `show route` is issued in operational mode, it can be issued as `run show route` in configuration mode.

When a user first enters the router via Telnet, Secure Shell (SSH), or direct console access, the user will see a login prompt. After entering the correct username and password, the user will be placed directly into operational mode. Operational mode will be designated by the > (chevron) character at the router prompt of `username@hostname`. As shown here, user `doug` logs into a router called `Hops`:

```
Hops (ttyd0)

login: doug
Password:

--- JUNOS 8.0R1.9 built 2006-08-11 16:25:40 UTC
doug@Hops>
```

An exception to being automatically placed into operational mode occurs when you log in as user root. In this case, the user will actually be placed into the shell (designated by the percent sign) and will have to start the CLI process manually:

```
Hops (ttyd0)

login: root
Password:

--- JUNOS 8.0R2.8 built 2006-09-29 09:22:36 UTC
root@Hops% cli
root@Hops>
```

Most of the commands that you will run in operational mode are show commands, which allow you to gather information about the routing protocols, interfaces, router's software, and router's hardware. Ping, traceroute, telnet, and ssh can also be performed from this mode. Finally, some very JUNOS-specific commands, such as request, restart, and test, may be issued. Request commands perform system-wide functions such as rebooting, upgrading, and shutting down the router. Restart commands are similar to the Unix-style kill commands, which allow you to restart certain software processes. Test commands allow verifications for save configuration files, proactive testing of policies, and interface testing such as BERT (bit error rate testing) and FEAC (far-end alarm and control) loopbacks.

> You should use the restart command with great caution! Depending on the software process being restarted, the consequences could be severe. Restarting the SNMP process would probably get you a slap on the wrist, but restarting the routing process could be a reason to go into hiding on a remote island!

There are a few general JUNOS software CLI features worth mentioning, including command completion, EMACs-style keys, and pipe commands.

Command completion

The command completion feature will save you lots of time and energy, as it provides syntax checking as you type. Gone are the days when a command is typed on a line and, after pressing Enter, the command is either invalid or not supported on that version of software. Any error or ambiguity will be detected early, and the router will present a list of possible valid completions. Command completion is accomplished by using either the Space bar or the Tab key. Either one will complete a command for you, but the Tab key can also complete variables such as interface names, IP addresses, filter names, and filenames. For example, to view the configuration of a certain ATM interface, you would type the following:

```
doug@Hops> sh<space>ow conf<space>iguration int<space>erfaces
at<tab>-0/2/1 <enter>
```

Notice that the Space bar is used until a variable is reached and the interface name is used when the Tab key *must* be used (as the Space bar completes only commands and not variables).

> For the reader with experience using Cisco's IOS, command completion makes for an easy transition. First, forget about the word *IP*, as the IOS command `show ip route` simply becomes `show route` in JUNOS. Also, common IOS abbreviations such as `sh int` will still work in JUNOS if you type **`doug@hops> sh<space>ow int<enter>`**.

In the previous example, the syntax checker went word by word each time the Space bar or Tab key was pressed, and the minimum characters were typed to avoid ambiguity. What would happen if the syntax checker noticed an error or incomplete word? It would state this ambiguity and list the possible completions:

```
user@host> show ip<space>
                   ^
'ip' is ambiguous.
Possible completions:
  ipsec                Show IP Security information
  ipv6                 Show IP version 6 information
```

EMACs

Another useful JUNOS feature set in the router itself is the use of EMACs-style keystrokes when in vt100 mode. This allows you to move the cursor around the command line or to edit the command line. Some useful EMACs keystrokes are:

Ctrl-b
: Move the cursor back one character.

Ctrl-a
: Move the cursor to the beginning of the command line.

Ctrl-e
: Move the cursor to the end of the command line.

Ctrl-k
: Delete all words from the cursor to the end of the line.

Ctrl-x
: Delete or clear the entire line.

Ctrl-l
: Redraw the current line.

Ctrl-p
: Scroll backward through the previously typed commands. You also can use the Up arrow for this purpose.

Ctrl-n
: Scroll forward through the previously typed commands. You also can use the Down arrow for this purpose.

Ctrl-r
: Search the previous CLI history for a search string.

Pipe commands

The last important feature to call out in the JUNOS software CLI is the use of pipe commands to control the output of any command. For example, when a command such as `show` is issued, the data is placed into a buffer and is displayed when the Enter key is pressed. A pipe command allows the display buffer to be altered. Many pipe commands can be used on the router, but let's examine the most common applications and pipe commands:

`count`

Count the lines in the output:

```
doug@Hops> show interfaces terse | count
Count: 29 lines
```

`display`

Show additional data; for example, XML tags or set commands:

```
doug@Hops> show configuration | display set
set version 8.0R2.9
set system host-name Hops
set system backup-router 10.210.8.30
set system backup-router destination 0.0.0.0/0
set system ports console type vt100
set system root-authentication encrypted-password "$1$G/
pd5odz$eYJi89TZkRxDWitUBB3ofO"
set system login class view-only permissions view
set system login user doug uid 2019
set system login user doug class super-user
set system login user doug authentication encrypted-password "$1$sr.a1nvE$K573iU.
bHSZkLiW9SMWwg."
set system login user lab uid 2021
set system login user lab class super-user
set system login user lab authentication encrypted-password "$1$/
z4qeiUp$ocnPhXAbz1xzDoTUKRhgm."
set system login user restricted uid 2022
set system login user restricted class view-only
set system login user restricted authentication encrypted-password "$1$tYpOu.
Hv$tpeTOxf.3pIrlsOZEPNlsO"
set system services ftp
set system services ssh
set system services telnet
set system syslog user * any emergency
set system syslog file messages any notice
set system syslog file messages authorization info
set system syslog file cli-commands interactive-commands any
set system syslog file cli-commands archive size 1m
set system syslog file cli-commands archive files 10
set system syslog file config-changes change-log any
set system compress-configuration-files
set interfaces lo0 unit 0 family inet address 192.168.16.1/32
set routing-options static route 0.0.0.0/0 next-hop 10.210.8.30
set routing-options static route 0.0.0.0/0 retain
set routing-options static route 0.0.0.0/0 no-readvertise
```

except

Omit lines from the output:

```
doug@Hops> show interfaces terse | except fe
Interface               Admin Link Proto    Local           Remote
at-0/2/0                up    up
at-0/2/0.100            up    up   inet     10.0.16.1/24
at-0/2/1                up    up
at-0/2/1.100            up    up   inet     10.0.15.2/24
dsc                     up    up
fxp0                    up    up
fxp0.0                  up    up   inet     10.210.8.1/27
fxp1                    up    up
fxp1.0                  up    up   inet     10.0.0.4/8
                                   tnp      4
gre                     up    up
ipip                    up    up
lo0                     up    up
lo0.0                   up    up   inet     192.168.16.1    --> 0/0
lo0.16385               up    up   inet
lsi                     up    up
mtun                    up    up
pimd                    up    up
pime                    up    up
tap                     up    up
```

find

Begin the output at the specified string:

```
Doug@Hops> show interfaces fe-0/0/2 extensive | find traffic
  Traffic statistics:
   Input  bytes  :                 8574                    0 bps
   Output bytes  :                11923                    0 bps
   Input  packets:                   88                    0 pps
   Output packets:                  127                    0 pps
  Input errors:
    Errors: 0, Drops: 0, Framing errors: 0, Runts: 0, Policed
    discards: 0, L3 incompletes: 0, L2 channel errors: 0, L2 mismatch
    timeouts: 0, FIFO errors: 0, Resource errors: 0
  Output errors:
    Carrier transitions: 1, Errors: 0, Drops: 0, Collisions: 0, Aged
    packets: 0, FIFO errors: 0, HS link CRC errors: 0, MTU errors: 0,
    Resource errors: 0
  Active alarms  : None
  Active defects : None
```

`hold`

Retain the output in the buffer until cleared:

```
doug@Hops> show route | hold

inet.0: 10 destinations, 10 routes (10 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[Static/5] 03:47:27
                    > to 10.210.8.30 via fxp0.0
10.0.15.0/24       *[Direct/0] 03:02:54
                    > via at-0/2/1.100
10.0.15.2/32       *[Local/0] 03:02:54
                      Local via at-0/2/1.100
10.0.16.0/24       *[Direct/0] 03:05:15
                    > via at-0/2/0.100
10.0.16.1/32       *[Local/0] 03:05:15
                      Local via at-0/2/0.100
10.0.21.0/24       *[Direct/0] 03:14:56
                    > via fe-0/0/2.0
10.0.21.1/32       *[Local/0] 03:14:56
                      Local via fe-0/0/2.0
10.210.8.0/27      *[Direct/0] 03:47:27
                    > via fxp0.0
10.210.8.1/32      *[Local/0] 03:47:27
                      Local via fxp0.0
192.168.16.1/32    *[Direct/0] 03:14:56
                    > via lo0.0

__juniper_private1__.inet.0: 2 destinations, 2 routes (2 active,
0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.0.0.0/8         *[Direct/0] 08:39:21
                    > via fxp1.0
10.0.0.4/32        *[Local/0] 08:39:21
                      Local via fxp1.0

__juniper_private1__.inet6.0: 5 destinations, 5 routes (5 active,
0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

fe80::/64          *[Direct/0] 08:39:21
                    > via fxp1.0
fe80::200:ff:fe00:4/128
                   *[Local/0] 08:39:21
                      Local via fxp1.0
fe80::2a0:a5ff:fe12:2775/128
                   *[Direct/0] 08:39:21
                    > via lo0.16385
fec0::/64          *[Direct/0] 08:39:21
                    > via fxp1.0
fec0::10:0:0:4/128 *[Local/0] 08:39:21
                      Local via fxp1.0
---(more 100%)---
```

`match`

Display only lines with the specified string:

```
doug@Hops> show log messages | match "jun  4"
Jun  4 09:04:13  HongKong login: LOGIN_PAM_AUTHENTICATION_ERROR: PAM
authentication error for user lab
Jun  4 09:04:13  HongKong login: LOGIN_FAILED: Login failed for user
lab from host
Jun  4 09:04:16  HongKong login: LOGIN_INFORMATION: User lab logged
in from host [unknown] on device ttyd0
Jun  4 09:07:04  HongKong sshd[3685]: Accepted publickey for root from
10.210.8.28 port 58349 ssh2
Jun  4 09:07:08  HongKong sshd[3690]: Accepted publickey for root from
10.210.8.28 port 62534 ssh2
Jun  4 10:50:45  HongKong mgd[3681]: UI_RESTART_EVENT: User 'lab'
restarting daemon 'Routing protocol daemon'
Jun  4 10:50:45  HongKong rpd[3083]: RPD_SIGNAL_TERMINATE: first
termination signal received
Jun  4 10:50:45  HongKong snmpd[3108]: SNMPD_CLOSE_SA_IPC:
ipc_free_local: closed IPC socket /var/run/rpd_s
```

`no-more`

Do not paginate the output:

```
doug@Hops> show system statistics arp | no-more
arp:
        3429 datagrams received
        32 ARP requests received
        243 ARP replys received
        17 resolution requests received
        0 unrestricted proxy requests
        0 received proxy requests
        0 proxy requests not proxied
        0 with bogus interface
        0 with incorrect length
        0 for non-IP protocol
        0 with unsupported op code
        0 with bad protocol address length
        0 with bad hardware address length
        0 with multicast source address
        0 with multicast target address
        0 with my own hardware address
        3 for an address not on the interface
        0 with a broadcast source address
        0 with source address duplicate to mine
        3151 which were not for me
        10 packets discarded waiting for resolution
        16 packets sent after waiting for resolution
        269 ARP requests sent
        32 ARP replys sent
        0 requests for memory denied
        0 requests dropped on entry
        0 requests dropped during retry
```

`save`

Save the output to a file to the user home directory:

```
doug@Hops> show interfaces | save interface_hops
Wrote 272 lines of output to 'interface_hops'
```

Multiple pipe commands are treated as a logical AND, meaning the output must match *both* of the commands listed. This could come in the form of different pipe commands in the command list or as the same pipe command listed multiple times. To count how many /27 masks are in your route table, issue this command:

```
doug@Hops> show route | match /27 | count
Count: 1 lines
```

In comparison, use the same pipe command on a single line to show all /32 routes that start with a 10.0 prefix:

```
doug@Hops> show route | match /32 | match 10.0
10.0.15.2/32       *[Local/0] 03:18:28
10.0.16.1/32       *[Local/0] 03:20:49
10.0.21.1/32       *[Local/0] 03:30:30
10.0.0.4/32        *[Local/0] 08:54:55
```

Pipe commands are not limited to a logical AND, however, as a logical OR operation can also be performed. Do this by wrapping the string in quotation marks and using the OR operator:

```
doug@Hops> show route | match "/32|10.0"
10.0.15.0/24       *[Direct/0] 03:22:46
10.0.15.2/32       *[Local/0] 03:22:46
10.0.16.0/24       *[Direct/0] 03:25:07
10.0.16.1/32       *[Local/0] 03:25:07
10.0.21.0/24       *[Direct/0] 03:34:48
10.0.21.1/32       *[Local/0] 03:34:48
10.210.8.1/32      *[Local/0] 04:07:19
192.168.16.1/32    *[Direct/0] 03:34:48
10.0.0.0/8         *[Direct/0] 08:59:13
10.0.0.4/32        *[Local/0] 08:59:13
fec0::10:0:0:4/128 *[Local/0] 08:59:13
```

Configuration Mode

To actually configure the router, enter configuration mode by typing the word **`configure`** in operational mode. The router prompt will change to the octothorpe (#) symbol:

```
doug@Hops> configure
Entering configuration mode

[edit]
doug@Hops#
```

By default, when entering configuration mode, multiple users can enter the router and make changes at the same time. To avoid any issues that may arise, you can use the `configure exclusive` or `configure private` command. The former command allows only a single user to configure the router, whereas the latter command allows multiple users to configure *different* pieces of the configuration. If you use `configure exclusive`, no other users can make changes to the configuration besides the single user that entered exclusively. Using private mode, each user will get a copy of the current configuration and only changes that they make will be applied. If two users attempt to make the same change, such as adding an IP address to the same interface, the change will be rejected and both users will exit configuration mode to resolve their conflict.

In configuration mode, you can add configuration by using a `set` command. For example, to enable the Telnet server application on the router, issue this command:

```
doug@Hops# set system services telnet
```

The CLI is actually composed of many directories and subdirectories, which will eventually contain the command that is input. You can think of this as you would a PC, where the hard drive is normally named *C:\* and it is partitioned into directories such as Windows, program files, drivers, and so on. These directories may contain subdirectories, which will eventually contain files or applications.

```
C:\>dir/w
 Volume in drive C has no label.
 Volume Serial Number is 7806-197A

 Directory of C:\

AUTOEXEC.BAT                 [Backup]
bi-admin.dat                 Catalog.LiveSubscribe
[Config.Msi]                 CONFIG.SYS
[dell]                       [Dell962]
dlbx.log                     dlbxscan.log
[Documents and Settings]     [drivers]
DVDPATH.TXT                  [ERDNT]
[f403a5940e14ba07a40a99897c] [HP LJ1160-LJ1320]
HuskyInstallerLog.txt        [i386]
INFCACHE.1                   [ipv0011]
[ipv0021]                    [My Downloads]
[nslabs]                     [Program Files]
[reg_backup]                 statusclient.log
tmuninst.ini                 ut.bat
ut9x.bat                     [WINDOWS]
[Xitami]                     YServer.txt
              14 File(s)      4,055,509 bytes
              18 Dir(s)  26,173,308,928 bytes free
```

In JUNOS software, the top level, or *C:\*, is named `edit`, with multiple directories partitioned below it. You can view these directories by using the set ? command:

```
[edit]
doug@Hops# set ?
Possible completions:
> access               Network access configuration
> accounting-options Accounting data configuration
> applications         Define applications by protocol characteristics
+ apply-groups         Groups from which to inherit configuration data
> chassis              Chassis configuration
> class-of-service     Class-of-service configuration
> event-options        Event processing configuration
> firewall             Define a firewall configuration
> forwarding-options Configure options to control packet sampling
> groups               Configuration groups
> interfaces           Interface configuration
> policy-options       Routing policy option configuration
> protocols            Routing protocol configuration
> routing-instances    Routing instance configuration
> routing-options      Protocol-independent routing option configuration
> security             Security configuration
> services             Service PIC applications settings
> snmp                 Simple Network Management Protocol configuration
> system               System parameters
```

So, when you issue the command `set system services telnet`, the system directory is accessed, followed by the subdirectory services and ending in the command `telnet` to enable the Telnet service. Figure 1-5 shows a partial directory tree to illustrate this process. Thankfully, you do not need to memorize the entire hierarchical tree structure, but it is important to understand the hierarchical structure and how it relates to configuration mode commands.

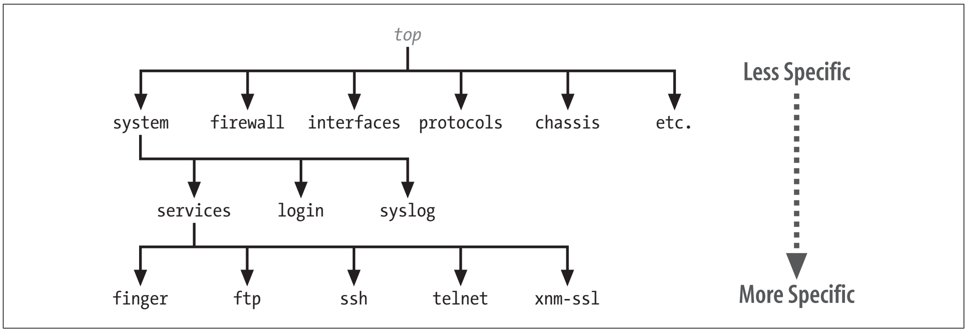


Figure 1-5. Subsection of JUNOS configuration tree

The opposite of the set command to remove configuration from the router is the `delete` command. Usually this command is used to remove a single line, but you also can use it to remove an entire hierarchy. In the simplest case, for example, to remove the Telnet service from the router, change the previous set command to a `delete` command:

```
doug@Hops# delete system services telnet
```

Be careful when issuing a delete command without noting any specific command, as this could remove an entire directory and have less than desirable consequences.

You can issue configuration commands such as set and delete from the top root level or from inside a subdirectory. To navigate to a subdirectory, issue an edit command, which is essentially a change directory command. If the Telnet service needed to be enabled, you could use an alternative method of moving into the subdirectory system services and then issuing a short set command:

```
[edit]
doug@Hops# edit system services

[edit system services]
doug@Hops# set telnet
```

Using the edit command is not necessary, but it allows the user to issue shorter set commands when compared to the top level. Just like choosing a color for a new car, you can choose how you want to configure the router as long as the desired result is achieved. Once in a certain directory, there are multiple ways to navigate the directory tree using commands such as up, top, and even exit. The up command will move you up one level in the directory tree or multiple levels if a numerical value is given after the up command:

```
[edit system services]
doug@Hops# up

[edit system]
doug@Hops# edit services

[edit system services]
doug@Hops# up 2

[edit]
doug@Hops#
```

From any hierarchy, you can issue the top command to move you up to the root level of the configuration tree. It has the added functionality of allowing multiple configuration statements after issuing the command, such as top edit or top set:

```
[edit system services]
doug@Hops top

[edit]
doug@Hops# edit system services

[edit system services]
doug@Hops# top edit protocols ospf

[edit protocols ospf]
doug@Hops#
```

Another nice feature of configuration mode allows you to view the configuration that was just completed by issuing a show command. For instance, to view the configuration of the system services, issue this command:

```
[edit]
doug@Hops# show system services
ftp;
ssh;
telnet;
```

Or try yet another way to view the system services, by issuing the show command inside the subdirectory in question. A show command with no additional arguments shows the configuration from that hierarchy and below:

```
[edit]
doug@Hops# edit system services

[edit system services]
doug@Hops# show
ftp;
ssh;
telnet;
```

After issuing a plethora of set and delete commands, the keen user will notice that no changes have actually occurred in the router! To apply the changes, a special word—one that is often difficult to say in the real world—must be used: *commit*. To understand what is occurring when issuing the commit command, it's best to examine the different types of configurations that occur in the JUNOS router.

A Juniper Networks router has two configuration files that are always present: the *candidate configuration* and the *active configuration*. The active configuration is the current *running* configuration in the router, whereas the candidate configuration is the temporary text file that is being modified while in configuration mode. When the commit command is issued, the candidate configuration becomes the active configuration if no syntax errors are detected. In addition, the old active configuration is archived into a file called a rollback 1. So, if a mistake is made, you can easily recover the old active configuration by issuing a rollback 1. This causes the candidate configuration to be replaced by the *old* active configuration. A commit command must then be issued to activate this rollback file. JUNOS saves not only this last active configuration, but also the previous 49 configurations. Each time a commit is issued, the archived file shifts down the list of 49. The first commit creates a rollback 1, the second commit (the old active) becomes rollback 1, the old rollback 1 becomes rollback 2, and so on, down the line. Figure 1-6 illustrates this rollback process.

Another important rollback command that can be useful is a *rollback 0*, which copies the active configuration to the candidate configuration. As an example, imagine that user doug logs into a router and issues a command to change the hostname of the router to a less desirable name, but does not actually activate the change.

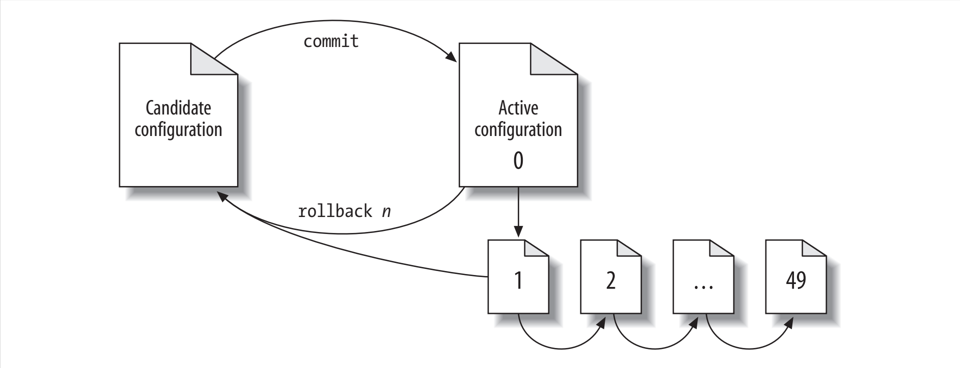


Figure 1-6. Configuration and rollback

```
doug@Hops> configure
Entering configuration mode

[edit]
doug@Hops# set system host-name yousmell

[edit]
doug@Hops# exit
The configuration has been changed but not committed
Exit with uncommitted changes? [yes,no] (yes) yes

Exiting configuration mode

doug@Hops> exit
```

A new user logs into the router, enters configuration mode, and observes that changes have occurred:

```
doug@Hops> configure
Entering configuration mode
The configuration has been changed but not committed

[edit]
lab@Hops#
```

It would seem at first glance that the new user is in between a rock and a hard place, but JUNOS has a very useful pipe command you can use—the compare command. This command allows *any* two files, including rollback files, active files, and candidate files, to be compared and the differences displayed. In this example, the candidate and active configurations will be compared:

```
[edit]
doug@Hops# show | compare
[edit system]
-  host-name Hops;
+  host-name yousmell;
```

It appears that user doug has been up to his old pranks again, attempting to change the hostname of the router. If a commit is issued, the hostname Hops will be removed and the hostname yousmell will be added. To wipe out these statements, a rollback 0 could be issued to stop doug and his mischievous ways:

```
doug@Hops# rollback 0
load complete

[edit]
lab@Hops# show | compare
```

One last key point of the two configuration types is that any operational mode command can be issued in configuration mode as long as the keyword run is issued before the command. For instance:

```
lab@Hops# ping
          ^
unknown command.

[edit]
dougHops# run ping 10.210.8.2
PING 10.210.8.2 (10.210.8.2): 56 data bytes
64 bytes from 10.210.8.2: icmp_seq=0 ttl=64 time=0.387 ms
64 bytes from 10.210.8.2: icmp_seq=1 ttl=64 time=0.296 ms
^C
--- 10.210.8.2 ping statistics ---
2 packets transmitted, 2 packets received, 0% packet loss
round-trip min/avg/max/stddev = 0.296/0.342/0.387/0.045 ms
```

Loading and Saving Configurations

To save the candidate configuration to the user's home directory, you must issue the save command while in configuration mode.

> To save an active configuration, issue a show configuration command and pipe to save.

It is important to realize which configuration directory you are located in when issuing the save command, as the command saves from the *current* hierarchy. To save the entire candidate configuration, issue the save command from the top of the directory tree:

```
[edit]
doug@Hops# save junos_is_cool
Wrote 413 lines of configuration to 'junos_is_cool'
```

Sometimes it is not desirable to save the entire configuration, so to save a portion, simply navigate into the desired directory to be saved. For instance, if every router in your network has the same system login information, you may want to save only that portion to load into other routers later:

```
[edit system login]
doug@Hops# save only_system_login
Wrote 31 lines of configuration to 'only_system_login'
```

It would be fantastic to eliminate the need to issue manual saves, so system archival allows for the automatic saving of configurations when issuing a commit or at a set time interval:

```
doug@Hops# set archival configuration ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
> archive-sites
  transfer-interval    Frequency at which file transfer happens (minutes)
  transfer-on-commit   Transfer after each commit
```

These files can be FTP'd or scp'd off to a server under the archivel-sites configuration. In the example that follows, every time a `commit` is issued, the configuration file is sent to an FTP server with user `doug`, password `okemos123`, and IP address `66.17.3.254`, and then into the */config/junos* directory:

```
archival {
    configuration {
        transfer-on-commit;
        archive-sites {
            "ftp://doug:okemos123@66.17.3.254/config/junos";
        }
```

The opposite of saving a configuration is loading a configuration, which you can accomplish by the `load` command. There are several variations of the `load` command:

```
doug@Hops# load ?
Possible completions:
 factory-default Override existing configuration with factory default
 merge           Merge contents with existing configuration
 override        Override existing configuration
 patch           Load patch file into configuration
 replace         Replace configuration data
 set             Execute set of commands on existing configuration
 update          Update existing configuration
```

Although each type of `load` command has its advantages, we will examine only the most common command variations here. One of the most common loads is the `override` command, which replaces the current candidate configuration with the specified file:

```
[edit]
doug@Hops# load override junos_is_cool
load complete
```

The merge switch will also be used often when just a small piece of configuration needs to be added to the candidate configuration. For instance, you can issue the following command to add the system login configuration saved previously:

```
[edit]
doug@Hops# load merge only_system_login
load complete
```

Since it is highly likely that more than one router will exist in a network, cutting and pasting configurations can give you a few more hours of free time in your life. There are several ways to cut and paste configurations into the router, including using variations of the load command, or copying set commands directly into the router. The oldest JUNOS software method is to use the load command with the terminal option, which opens a terminal buffer, allowing full or partial configurations to be pasted in:

```
doug@Hops# load merge terminal
[Type ^D at a new line to end input]
system {
services {
        ftp;
        ssh;
        telnet;
    }
}
load complete
```

Cutting and pasting using this method definitely takes some practice, as the proper number of levels and braces must always be present. The terminal command always assumes that the entire top-level hierarchy is known. If the upper-level directories are not included, errors will occur and the relative keyword could become very useful:

```
[edit]
doug@Hops# load merge terminal
[Type ^D at a new line to end input]
services {
    ftp;
  terminal:2:(7) syntax error: ftp
   [edit services]
    'ftp;'
      syntax error
 ssh;
    telnet;
}
[edit]
  'services'
    warning: statement has no contents; ignored
load complete (1 errors)
```

Since the pasting started at the services level and not at the system level, the pasting causes errors and does not complete. One solution is to navigate to the system directory and indicate that the configuration will be loaded relative to that directory:

```
[edit]
doug@Hops# edit system

[edit system]
doug@Hops# load merge terminal relative
[Type ^D at a new line to end input]
services {
    ftp;
    ssh;
    telnet;
}
load complete
```

Or perhaps a simpler method would be to load set commands directly into the router by simply pasting a carriage return after each set command or by using the load set command:

```
doug@Hops load set terminal
[Type ^D at a new line to end input]
set system services ftp
set system services ssh
set system services telnet
load complete
```

S.O.S., I Need Help!

If the router is causing you problems, simply ask it for help. You can accomplish this in a few ways. The first is with a question mark (?) to display possible command completions:

```
doug@Hops# set system login ?
Possible completions:
  announcement         System announcement message (displayed after
login)
+ apply-groups         Groups from which to inherit configuration
data
+ apply-groups-except  Don't inherit configuration data from these
groups
> class                Login class
  message              System login message
> password
> user                 Username
```

The > character indicates a directory that contains subdirectories, + indicates a command that takes multiple arguments, and no symbol means the command takes a single argument or is in fact the end statement of a command.

The help command is a secret resource of which few are aware. This displays the same technical documentation that can also be located online. Sometimes a small piece of a command is remembered but not the full statement; help can aid in finding that full command by searching through the JUNOS software configuration tree for a particular string:

```
doug@Hops# help apropos host-name
set system host-name <host-name>
    Hostname for this router
set system static-host-mapping <host-name>
    Fully qualified name of system
set system services dhcp static-binding <mac-address> host-name
<host-name>
    Hostname for this client
set system syslog host
    Host to be notified
set interfaces <interface_name> services-options syslog host
<host-name>
    Name of host to notify
set accounting-options routing-engine-profile <profile-name> fields
host-name
    Hostname for this router
set services l2tp tunnel-group <name> syslog host <host-name>
    Name of host to notify
set services service-set <service-set-name> syslog host <host-name>
    Name of host to notify
```

If you encounter a command in the router that needs clarification, you can obtain more information by issuing the `help topic` or `help reference` command. The former will display general usage guidelines for that command:

```
doug@Hops# help topic ospf hello-interval
 Modifying the Hello Interval

  Routers send hello packets at a fixed interval on all interfaces,
  including virtual links, to establish and maintain neighbor
  relationships. This interval, which must be the same on all routers
  on a shared network, is advertised in the hello interval field in
  the hello packet. By default, the router sends hello packets every
  10 seconds.

  To modify how often the router sends hello packets out of an
  interface, include the hello-interval statement:
    hello-interval seconds;

  For a list of hierarchy levels at which you can configure this
  statement, see the statement summary section for this statement.

  On nonbroadcast networks, the router sends hello packets every 120
  seconds until active neighbors are detected by default. This
  interval is long enough to minimize the bandwidth required on slow
  WAN links. To modify this interval, include the poll-interval
  statement: poll-interval seconds;

+--------------------------------------------------------------+
|NOTE:  The poll-interval statement is valid for OSPFv2 only. |
+--------------------------------------------------------------+

   For a list of hierarchy levels at which you can configure this
   statement, see the statement summary section for this statement.
```

```
      Once the router detects an active neighbor, the hello packet
      interval changes from the time specified in the poll-interval time
      statement to the specified in the hello-interval statement.
```

After you've learned what a certain command accomplishes and when you should use it, you can view the actual syntax and possible options using the `help reference` command. It's similar to the manual command seen on other operating systems:

```
[edit]
doug@Hops# help reference ospf hello-interval
hello-interval

      Syntax

   hello-interval seconds;

      Hierarchy Level

   [edit logical-routers logical-router-name protocols ospf area area-id
   peer-interface
       interface-name],
   [edit logical-routers logical-router-name protocols (ospf | ospf3) area
   area-id
       interface interface-name],
   [edit logical-routers logical-router-name protocols (ospf | ospf3) area
   area-id virtual-link],
   [edit logical-routers logical-router-name routing-instances
   routing-instance-name
       protocols (ospf | ospf3) area area-id interface interface-name],
   [edit logical-routers logical-router-name routing-instances
   routing-instance-name
       protocols (ospf | ospf3) area area-id virtual-link],
   [edit protocols ospf area area-id peer-interface interface-name],
   [edit protocols (ospf | ospf3) area area-id interface interface-name],
   [edit protocols (ospf | ospf3) area area-id virtual-link],
   [edit routing-instances routing-instance-name protocols (ospf | ospf3)
   area area-id
       interface interface-name],
   [edit routing-instances routing-instance-name protocols (ospf | ospf3)
   area area-id
       virtual-link]

      Release Information

   Statement introduced before JUNOS Release 7.4.

      Description

   Specify how often the router sends hello packets out the interface.
   The hello interval must be the same for all routers on a shared
   logical IP network.

      Options
```

```
seconds--Time between hello packets, in seconds.
Range: 1 through 255 seconds
Default: 10 seconds; 120 seconds (nonbroadcast networks)

   Usage Guidelines

See "Modifying the Hello Interval".

   Required Privilege Level

routing--To view this statement in the configuration.
routing-control--To add this statement to the configuration.

   See Also

dead-interval
```

Advanced CLI and Other Cool Stuff

Lots of other fantastic configuration options are available, but explaining them all would require a separate book. The JUNOS documentation contains many time-saving tips, and the *JUNOS Cookbook* by Aviva Garrett (O'Reilly) is a great resource too. To whet your appetite, here are three JUNOS software CLI tips.

Most changes that you need to make on a router can be done at only certain times, often referred as *maintenance windows*. Since these windows are often at the most inconvenient times for those who have to use them, changes represented by `commit` can actually be scheduled:

```
[edit]
doug@Hops# commit at 07:05
configuration check succeeds
commit at will be executed at 2007-06-10 07:05:00 UTC
Exiting configuration mode
```

When the `commit` has been scheduled, other users cannot change any piece of the new locked configuration:

```
joe@Hops> configure
Entering configuration mode
Users currently editing the configuration:
  doug terminal d0 (pid 11035) on since 2007-06-05 05:04:51 UTC
      commit-at

[edit]
joe@Hops# set system host-name foo
error: configuration database locked by:
  doug terminal d0 (pid 11035) on since 2007-06-05 05:04:51 UTC
      commit at

[edit]
joe@Hops# commit
error: Another commit is pending
```

If the system needs to be unlocked before the specified time, a clear command can stop the timed action:

```
joe@Hops# run clear system commit
Pending commit cleared
```

You can take advantage of another fantastic shortcut when large common pieces of configuration need to be removed from the router. The router can search through the entire configuration looking for a string and delete every line that contains that string:

```
[edit]
jane@R1# wildcard delete interfaces fe-
  matched: fe-0/0/1
  matched: fe-2/0/0
  matched: fe-2/0/1
Delete 3 objects? [yes,no] (no) yes
```

Lastly, you can make common configuration changes in one large swoop with the replace command. Any string can replace any other string, with a string being anything from a character to any POSIX 1003.2 expression. For example, this command could be useful is when IPs referenced in filters, policies, and so on need to be updated to a new value:

```
[edit]
jane@R1# replace pattern 172.17.30.254 with 172.17.30.200
```

Conclusion

This chapter provided a quick definition of what enterprise routing is and how Juniper routers fit into this environment. Then we examined the router's hardware and software design, stressing the key components that will help make your life easier. Lastly, we reviewed the actual CLI and illustrated the important features. The CLI is one of the most flexible and user-friendly in the industry, allowing expert status to be achieved in record time. As your familiarity with the CLI increases, you will discover even more features. Now that we've established the groundwork, the rest of the book will dive into the specific configuration details.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- List the enterprise router product line.
- Describe transit and host processing.
- Identify the difference between packet flow on the M7i/M10i and on the J-series routers.
- Identify key differences between the M7i/M10i and J-series routers.

- Describe configuration management.
- Identify the features of the JUNOS CLI (CLI modes, prompts, auto-complete, EMACs shortcuts, help, and pipe).
- Identify the commands used in configuration mode (`edit`, `set`, `delete`, and `commit`).
- Identify options for manipulating "saved" configuration files. Include rollback options, load options, and rollback file locations.
- Describe the configuration hierarchy.
- Describe active, candidate, and rollback configurations.

Chapter Review Questions

1. Which of the following two Juniper Networks routers are classified as enterprise routers? (Choose two.)
   a. T640
   b. M7i
   c. J4350
   d. M320
2. Which hardware component controls debugging on the router?
   a. Packet Forwarding Engine
   b. Route Processor
   c. System Control Board
   d. Routing Engine
3. True or False: Since the J-series has only a single processor, there is no Packet Forwarding Engine.
4. Which JUNOS software daemon controls the CLI?
   a. clid
   b. rpd
   c. mgd
   d. inetd
5. Which command would be issued to reboot the router?
   a. `request system reboot`
   b. `reload`
   c. `reboot`
   d. `restart router`

6. Which pipe command can you use to find every occurrence of the word *error* in the syslog file messages?
    a. `match`
    b. `find`
    c. `search`
    d. `hold`
7. What is the default password to enter configuration mode on the router?
    a. `juniper`
    b. `enable`
    c. There is no password
    d. `root`
8. Which CLI command should be issued to navigate to the *[edit protocols ospf]* directory?
    a. `cd protocols ospf`
    b. `edit protocols ospf`
    c. `cd /edit/protocols/ospf`
    d. `dir protocols ospf`
9. Which CLI command must be issued to activate configuration changes in the router?
    a. `apply`
    b. `copy`
    c. `save`
    d. `commit`
10. What is the top level of the configuration tree called?
    a. *C:/*
    b. */var*
    c. *edit*
    d. *root*
11. Which CLI command should be issued to return to the previously activated configuration?
    a. `rollback 1`
    b. `rollback 0`
    c. `rollback active`
    d. `rollback previous`

12. Which command should be issued in the router to find out information about Layer 3 VPNs?

    a. `layer 3 vpn ?`

    b. `help topic layer3-vpns overview`

    c. `help reference layer3-vpn overview`

    d. `man layer3-vpn`

Chapter Review Answers

1. Answer: B, C. The T640 and M320 are valid Juniper Networks router models but are usually deployed in service provider networks.
2. Answer: D. The Routing Engine is the component in the router that controls all management functions, including commands that would be used to debug the router.
3. Answer: False. The J-series routers do contain a virtualized PFE with API and sockets replacing the ASICs that are found in the M-series routers.
4. Answer: C. The CLI is actually a process that runs off the kernel, called mgd. Of the other services listed, clid is invalid, rpd controls the routing process, and inetd manages network services.
5. Answer: A. `Request` commands are used to issue system-wide functions such as rebooting the router. The rest of the options are invalid CLI commands.
6. Answer: A. The pipe command `match` will find every occurrence of a string in the output of the command. The `find` command will locate the first occurrence of the string, `search` is an invalid option, and `hold` will hold text without exiting the `-More--` prompt.
7. Answer: C. There is no password to enter configuration mode. Users are allowed into configuration mode based on access privileges.
8. Answer: B. To change the directory in configuration mode, use the `edit` command.
9. Answer: D. To activate the changes in the router, issue a `commit` command. Of the remaining options, `copy` and `save` are valid CLI commands but are used for configuration management.
10. Answer: C. When at the top level of the configuration tree, the CLI banner will display the `[edit]` prompt.
11. Answer: A. The first archive is stored in `rollback 1`. `rollback 0` is used to copy the active configuration to the candidate configuration, and the other options are not valid rollback commands.

12. Answer: B. The `help topic` command displays general information about any topic referenced in the Juniper documentation. The actual output of the command is as follows:

```
lab@P1R1> help topic layer3-vpns overview
Layer 3 VPN Overview

   In JUNOS software, Layer 3 VPNs are based on RFC 2547bis. RFC
   2547bis defines a mechanism by which service providers can use
   their IP backbones to provide VPN services to their customers. A
   VPN is a set of sites that share common routing information and
   Layer 3 whose connectivity is controlled by a collection of
   policies. The sites that make up a Layer 3 VPN are connected over
   a provider's existing public Internet backbone.

   RFC 2547bis VPNs are also known as BGP/MPLS VPNs because BGP is
   used to distribute VPN routing information across the provider's
   backbone, and MPLS is used to forward VPN traffic across the VPN
   backbone to remote sites.

   Customer networks, because they are private, can use either public
   addresses or private addresses, as defined in RFC 1918, Address
   Allocation for Private Internets. When customer networks that use
   private addresses connect to the public Internet infrastructure,
   overlap with the same private addresses used by other network
   users the private addresses might MPLS/BGP VPNs solve this problem
   by adding a VPN identifier prefix to each address from a
   particular VPN site, thereby creating an address that is unique
   to the VPN and within the public Internet. In addition, each VPN has
   both within its own VPN-specific routing table that contains the
   routing information for that VPN only.
```

CHAPTER 2
Interfaces

This chapter describes the interface configurations for a Juniper Networks router. It starts with a description of the types of interfaces, the naming conventions, and the interface properties. It then identifies how to configure a large variety of interface media, such as T1 interfaces, Fast Ethernet, and Serial interfaces. Lastly, we will examine common interface problems, concentrating on the tools available to detect these issues.

Before you begin to design a network's routing topology, you should ensure that all the proper physical connections are in place and are operational. With such a large variance in interface types, this can often be a challenging task, so it is important to understand how an interface is organized within the JUNOS software.

Juniper Networks routers contain two major categories of interfaces: *permanent* and *transient*. Users cannot remove permanent interfaces, whereas they can move, change, and remove transient interfaces. Other technical differences exist that are evident when you examine the applications for each interface type.

The interface topics covered in this chapter include:

- Permanent interfaces
- Transient interfaces
- Interface properties
- Interface configuration examples
- Interface troubleshooting

Permanent Interfaces

A permanent interface is any interface that is always present on the router (it cannot be altered). These interfaces can be management interfaces such as Ethernet, software pseudointerfaces such as tunnel interfaces, or fixed-port LAN/WAN interfaces.

On an M/T-series router, two management interfaces exist:

`fxp0`

This is an Out of Band (OOB) management Ethernet interface. It is connected to the router's Routing Engine (RE) and can be used for Out of Band management access to the router. It can also be used to send management messages such as syslog or Simple Network Management Protocol (SNMP) traps. This interface is a *nontransit interface*, which means that traffic cannot enter this interface and exit via a LAN/WAN interface, nor can it enter a LAN/WAN interface and exit through the management interface.

> When running routing protocols, be very careful when using the `fxp0` interface. If you don't configure the routing protocol correctly, you could have a route in your route table that points to the `fxp0` interface and blackhole traffic, since this is a nontransit interface. To protect yourself from these types of situations, you should not run any routing protocols over this interface.

`fxp1`

This is an internal Fast Ethernet or Gigabit Ethernet (depending on the model of router) interface between the RE and the Packet Forwarding Engine (PFE). This interface is never configured but can be helpful when troubleshooting router issues. It is only in application-specific integrated circuit (ASIC) platforms (M/T-series) and not in the virtualized PFE J-series platforms.

Many software pseudointerfaces also exist that the router will create at startup. We will examine many of these interfaces in depth in Chapter 7. Here is a short list of these interfaces:

`lo0`

This is a loopback interface that ties to the router itself and not to any one physical interface. This is often assigned an address to provide a stable address for management traffic and routing protocols, which allows your router to adapt to network and physical interface failures. Also, when configured with firewall filters, this interface serves to protect the RE from attacks destined to the router.

`sp`

This service interface is used when configuring features such as Network Address Translation (NAT), IPSec, and stateful firewalls.

`pd`

This Physical Interface Module (PIM) de-encapsulation interface allows a multicast rendezvous point (RP) to process PIM register messages.

`pe`

This PIM encapsulation interface is used in multicast to create a unicast PIM register message to send to the RP.

`ip`

This is an IP-over-IP encapsulation interface to create IP-in-IP tunnels.

`dsc`

This is a discard interface, which can be used to silently discard packets. This is often used to create a choke point for denial of service (DoS) attacks.

`tap`

This is a virtual Ethernet interface historically used for monitoring on FreeBSD systems. This interface could be used to monitor discarded packets on a router but is no longer officially supported.

The last type of permanent interface is the fixed LAN/WAN ports found on J-series routers and M7i routers. We will examine these in depth in the next section.

Transient Interfaces

Transient interfaces are any interfaces that the user can remove, move, or replace. These include ports on M-series routers, Physical Interface Cards (PICs), and J-series PIMs. Examples of transient interfaces are Fast Ethernet, Asynchronous Transfer Mode (ATM), SONET, and T1/E1, as well as service PICs such as tunnels, multilinks, link services, Adaptive Services PICs (ASPs), and passive monitoring.

Interface Naming

All JUNOS interfaces follow the same naming convention—the interface name followed by three numbers that indicate the location of the actual interface. The general convention is illustrated by the interface sequence MM-F/P/T, where:

- MM = media type
- F = chassis slot number
- P = PIC slot number
- T = port number

Media type

The first part of the interface name is the interface media name (MM) indicating the type of interface. Common interface media names include:

`ae`

Aggregated Ethernet, a logical linkage of multiple Ethernet interfaces defined in the IEEE 802.3ad standard.

`at`

ATM, which sends fixed 53-byte cells over the transport media. This interface could also be used for ATM over digital subscriber line (DSL) connections.

`br`

Physical Integrated Services Digital Network (ISDN) interface.

`e1`

Standard digital communication standard over copper at a rate of 2.048 Mbps, used mostly in Europe.

`e3`

Standard digital communication standard over copper at a rate of 34.368 Mbps, used mostly in Europe.

`t1`

Basic physical layer standard used by the digital signal level 1 at a rate of 1.544 Mbps, used extensively in North America.

`t3`

Basic physical layer standard used by the digital signal level 3 at a rate of 44.736 Mbps, used extensively in North America.

`fe`

100 Mbps standard initially created by Xerox in the 1970s for connecting multiple computers together; referred to as a LAN today.

`ge`

Higher-speed Ethernet standard at 1 Gbps or 10 Gbps.

`se`

Interface used for serial communications (one bit at a time). Serial interfaces include standards such as EIA 530, V.35, and X.21.

`ct1`

T1 interface that is channelized by splitting the interface into 24 DSO channels.

Chassis slot number

The next part of the interface name is F, a chassis slot number represented by a Flexible PIC Concentrator (FPC) slot number on an M-series router or a PIM slot number on a J-series router. The M-series routers have two possible FPC alignments: horizontal slots or vertical slots. The larger M-series routers (M40e, M320) have vertically mounted FPCs with slot numbers starting at slot 0 and counting from left to right (see Figure 2-1). The smaller M-series routers (M7i, M10i) have horizontal slots starting at slot 0 and counting from top to bottom (see Figure 2-2).

> The M7i slot 1 is reserved for the Fixed Interface Card slots.

A J-series router does not contain any FPCs but does have PIM slots that are represented by the variable F. All fixed-port slots are always assigned slot 0, and PIM slots are assigned 1–6 numbering from top to bottom and left to right (see Figure 2-3).

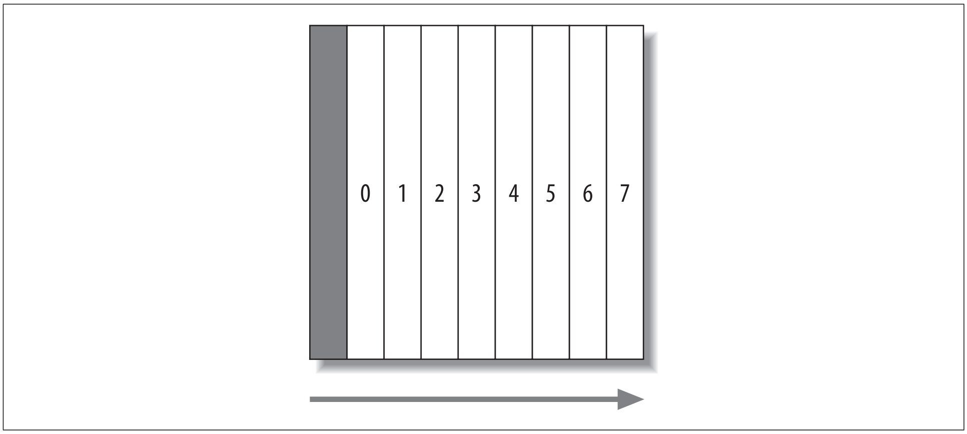


Figure 2-1. Vertical FPC slots (M40e and M320)

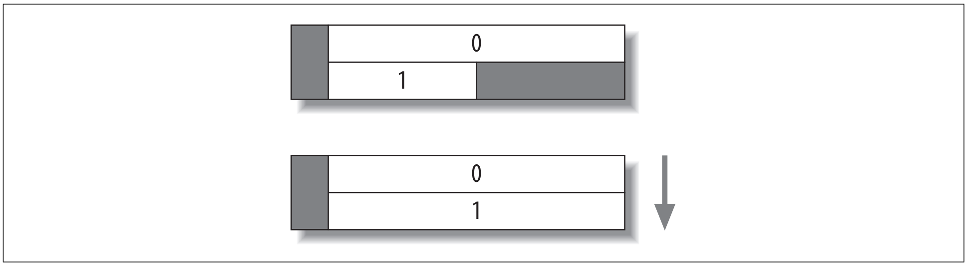


Figure 2-2. Horizontal FPC slots (M7i and M10i)

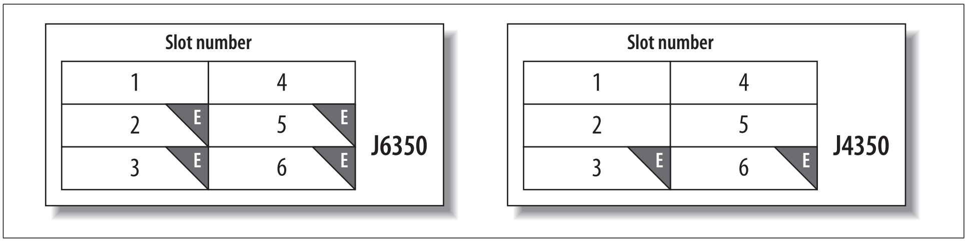


Figure 2-3. J6350 and J4350 PIM slot numbers

PIC slot number

The next part of the interface name is the PIC slot number, represented by the variable P. In M-series routers, four PICs can fit into a single FPC slot. The slot numbers begin at 0 and continue to the final slot, 3. In M-series routers, the direction of PIC slot numbering depends on whether the chassis slots are vertically or horizontally aligned. In a vertically aligned M-series router, the PIC slot number is counted from top to bottom, as shown in Figure 2-4.

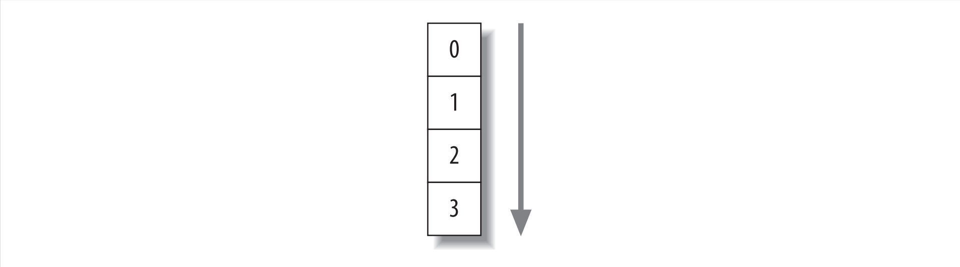


Figure 2-4. PIC slot numbers for M40e and M320

PIC slot numbering in horizontally aligned systems such as the M7i and M10i is a little less standard. In these systems, the PIC slot numbering goes from right to left, starting at 0 and ending at slot 3, as shown in Figure 2-5. The M7i's second FPC slot contains only two possible PIC slot numbers, and as shown in Figure 2-6, slot 2 is used for the built-in tunnel interface, or Adaptive Services Module (ASM), and slot 3 is used for the fixed Ethernet interfaces.

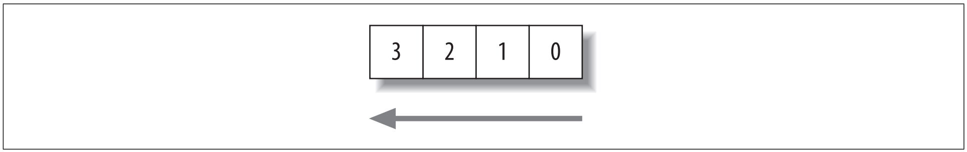


Figure 2-5. PIC slot numbers for M7i, M10i, and M20

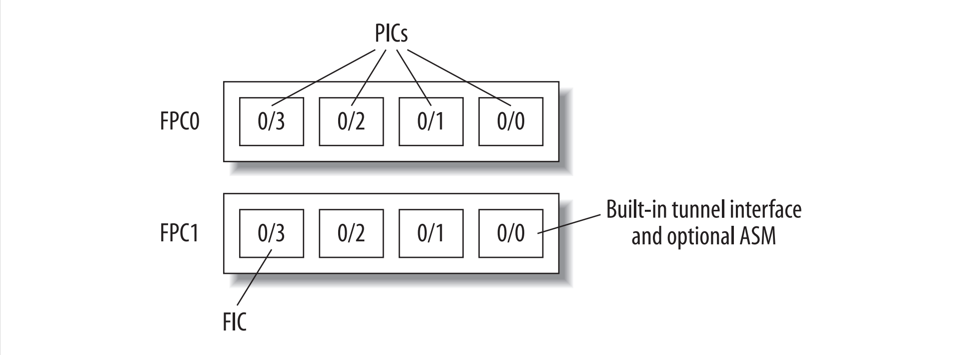


Figure 2-6. M7i PIC slot numbering

Life is much simpler in a J-series router that does not have any PIC slot numbers; thus, the interface naming (F) convention is always set to a value of 0.

It seems counterintuitive that PIC slot numbering is counted from right to left. The reason harkens back to the first routers (m40), which were vertically aligned FPC slots with PIC slot numbering from top to bottom. Next came the horizontally aligned FPC slot (m20), which was essentially a vertically aligned router turned on its side, which caused the PIC slot to shift to right to left.

Port number

The last part of the interface name is represented by the variable T, or the actual physical port number. M-series routers have port numbers with a variety of schemes depending on the PIC and the router model (horizontal versus vertical slots). For vertical FPC routers (m40e, M320), port numbers start from the top right and continue from the bottom to the top and then move right to left. For horizontal FPC routers (m20, m7i, m10i), port numbers start from the bottom right and then move right to left and from the bottom to the top. It's easier to see by examining Figures 2-7 through 2-10, which show this sequence in the different chassis types.

To avoid any confusion or spontaneous brain combustions, remember that the port number is always written on the PIC itself.

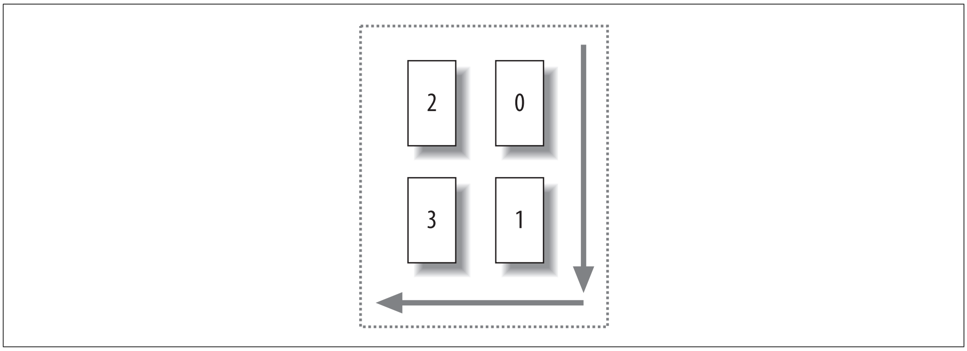


Figure 2-7. Port numbers on a vertical FPC chassis starting at the top right

The fixed Ethernet ports on the M7i follow the convention of Figure 2-10 and count from right to left, starting at port 0.

Port numbers are greatly simplified in a J-series router, as all ports are always numbered from left to right. This includes ports on a PIM (see Figure 2-11) as well any fixed ports on the chassis (see Figure 2-12).

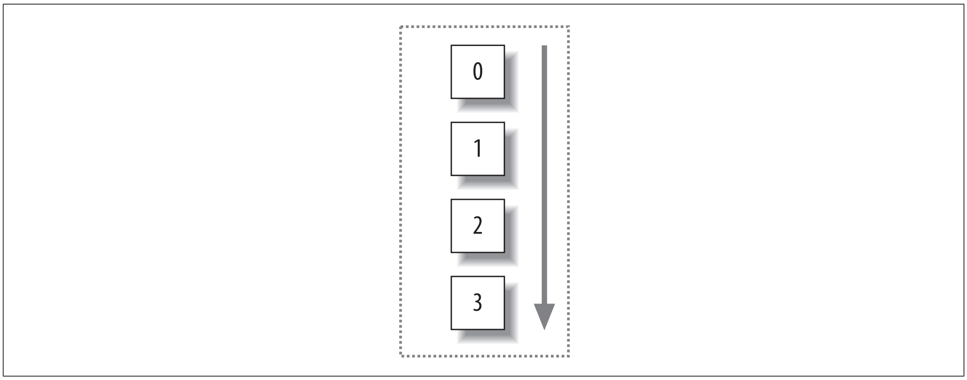


Figure 2-8. Port numbers on a vertical FPC chassis starting at the top

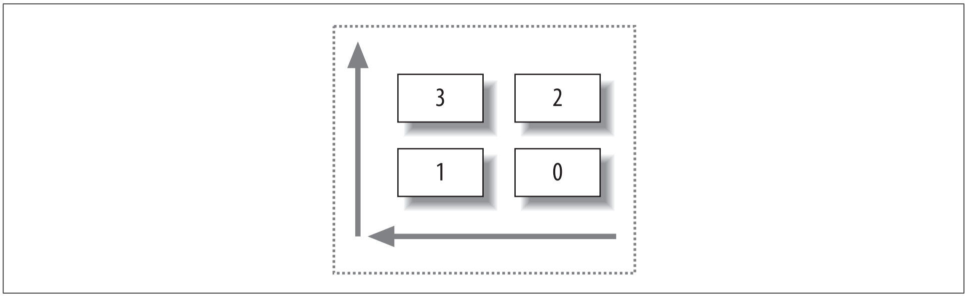


Figure 2-9. Port numbers on a horizontal FPC chassis starting at the bottom right

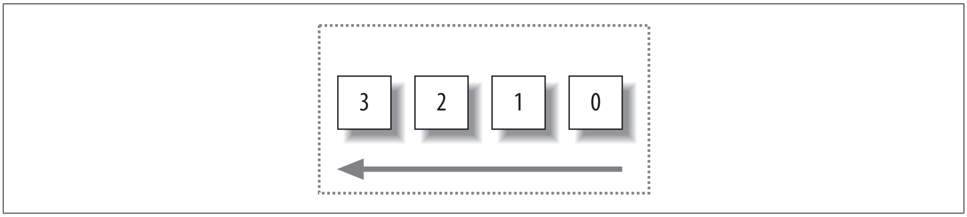


Figure 2-10. Port numbers on a horizontal FPC chassis starting on the right

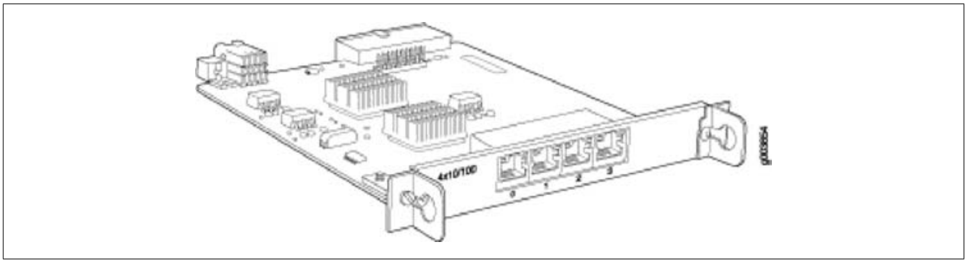


Figure 2-11. Four-port Fast Ethernet E-PIM

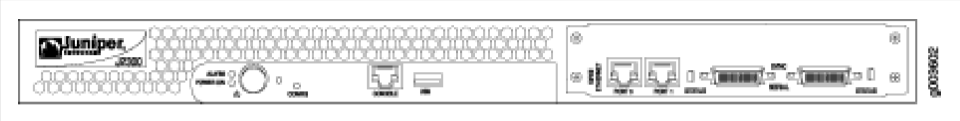


Figure 2-12. J2300 dual FE/serial ports with right-to-left numbering

Here are a few M-series example interfaces:

`se-1/0/0`
: Serial interface in FPC slot 1, PIC slot 0, and port 0

`fe-0/2/1`
: Fast Ethernet interface in FPC slot 0, PIC slot 2, and port 2

`t1-1/0/1`
: T1 interface in FPC slot 1, PIC slot 0, and port 1

Logical unit and channel numbers

Interfaces also have a logical portion of the name represented by either a unit number or a channel number. A *logical unit* is a numerical number that represents the subinterface properties of the router and can be configured in the range of 0–16,385. This is designated by a period (`.`) in the interface name. For example:

`fe-0/0/0.0`
: Unit 0 configured on the Fast Ethernet interface

`e3-1/0/2.12`
: Unit 12 configured on the `e3` interface

The other logical division could be a channel number—for example, when breaking up a T1 interface into multiple DS0 channels (up to 24). Channel values are represented using a colon (`:`). For example:

`ct-1/1/2:14`
: Channel 14 on a channelized T1 interface

We will cover logical units in depth in "Logical Properties," later in this chapter.

Interface Properties

Each interface has two types of properties assigned to it: physical properties and logical properties. *Physical properties* are tied to the entire physical port, whereas *logical properties* affect only that logical portion of the interface represented by unit numbers or channel numbers.

Physical Properties

A physical property on an interface is any property that should be assigned to the entire physical port. Depending on the interface media, a large range of properties can be configured, but they can be divided into a few major categories:

Clocking
: This aligns the bits as they are transmitted out of the interface. The clocking can be learned either from an external source or from the router itself.

Encapsulation
: This is the Layer 2 encapsulation that is going to be used on the interface. Examples include Frame Relay, Point-to-Point Protocol (PPP), and Cisco High-Level Data Link Control (HDLC).

MTU
: This is the maximum transmission unit, which is the maximum size of the frame transmitted from the interface.

Keepalives
: These are mechanisms used to verify the operation of the interface. Most encapsulations have keepalives enabled by default, but you can disable them to aid in troubleshooting.

Layer 1/2 options
: These are various bit and byte settings for the interface media. For a T1 interface, this includes byte encodings, framing, frame check sequences (FCSs), and line buildouts. In comparison, a Fast Ethernet interface might have options such as flow control, loopbacks, and source address filters.

A physical property should always be configured before any logical identifier, such as a unit number. For example, the following is a serial interface with *no* logical properties configured but with physical properties of `encapsulation cisco-HDLC` and `no-keepalives`, and with clocking set to `internal`:

```
se-0/0/2 {
    no-keepalives;
    encapsulation cisco-hdlc;
    serial-options {
        clocking-mode internal;
    }
    unit 0;
}
```

Logical Properties

All router interfaces that will send and receive transit traffic require a logical unit to be configured. This logical unit creates a division of the physical interface into multiple parts. For instance, an Ethernet interface can be subdivided into multiple virtual LANs (VLANs), each requiring its own logical unit.

Many router vendors refer to a logical unit as a *subinterface*; they do not require a subinterface on every physical interface, whereas a Juniper Networks router does.

Some interface types, such as point-to-point interfaces and non-VLAN-tagged Ethernet interfaces, still require a logical unit to be configured. This is a unique feature of JUNOS software and may take a little getting used to if you're coming from other router vendors' hardware. These interfaces require a unit number because any logical property that needs to be configured *must* be defined after the unit number definition. The most common types of logical properties include:

Protocol family

Indicates which Layer 3 protocols can be sent and received on the interface. The router can have one protocol family per logical unit or multiple families per logical unit configured. The most common family configured is `family inet`, which enables the sending and receiving of all packets in the Transmission Control Protocol/Internet Protocol (TCP/IP) suite (e.g., TCP, User Datagram Protocol [UDP], Internet Control Message Protocol [ICMP], and IP). Other common families are inet6 (IPv6), Multiprotocol Label Switching (MPLS), and ISO (ISIS packets).

Protocol address

The Layer 3 family address, such as a `family inet` IP address.

Virtual circuit address

Circuit identifier used when dividing the physical interface into multiple logical interfaces. These could be the VLAN ID, Frame Relay data-link connection identifiers (DLCIs), or ATM virtual path/Virtual Channel Identifier (VP/VCIs).

The logical unit number when configuring VLAN, Frame Relay, or ATM can be any value from 0–16,385. The current best practice, however, is to keep the circuit address the same as the unit number for easier troubleshooting. So, if you have a VLAN ID of 40 configured on your interface, the logical interface should also be a unit of 40, although it's not required. If you are configuring a point-to-point circuit or non-VLAN-tagged Ethernet, the logical unit number *must* be zero. Think of this unit as a placeholder for all the logical properties that will need to be configured on that interface.

Here is an example of a T1 interface configuration with the default parameters (PPP encapsulation), `family inet` support, and an IP address of 66.32.3.2/30. Note that since this is a point-to-point circuit, the unit number must be configured as `unit 0`.

```
t1-0/0/2 {
    unit 0 {
        family inet {
            address 66.32.3.2/30;
        }
    }
```

Interface Configuration Examples

A walkthrough of configuration examples, starting with basic examples and then getting into a few more complex configurations, will help to put this into perspective. The order of the walkthrough uses the following configuration example:

Fast Ethernet interfaces
Fast Ethernet with VLAN tagging
T1 interface with Cisco HDLC
Serial interface with PPP
Serial interface with Frame Relay
DSL
ISDN
MLPPP

Initially, we will use a step-by-step approach to establish the configuration fundamentals. Then the walkthrough will move toward configuration results that build on the fundamentals and become advanced. Once you grasp the fundamentals, you should be able to follow the advanced configurations. At the end of this section, we will discuss the use of the Virtual Router Redundancy Protocol (VRRP).

Fast Ethernet Interface

First, let's build an interface on router `Lager` that connects directly to router `Porter` over the `fe-2/0/1` interface.

Check the status of the `fe-2/0/1` interface by issuing a `show interfaces fe-2/0/1 terse` command. JUNOS software interfaces are automatically "enabled" when the physical connection is wired.

```
root@Lager> show interfaces terse fe-2/0/1
Interface               Admin Link Proto    Local           Remote
fe-2/0/1                up    up
```

> If an interface needs to be administratively disabled, issue the `set interfaces` *`<interface name>`* `disable` command.

The interface appears to be physically up, so next, configure the interface to allow IP traffic to flow as well as add an IP address. Begin by entering configuration mode, dropping down to the hierarchy of the interface, and configuring the correct family and local IP address:

```
root@Lager> configure
Entering configuration mode
```

```
[edit]
root@Lager# edit interfaces fe-2/0/1

[edit interfaces fe-2/0/1]
root@Lager# set unit 0 family inet address 10.10.20.122/24
```

Since this is a non-VLAN-tagged Ethernet interface, unit 0 *must* be used when configuring the logical properties of family inet.

Also, note that JUNOS software requires a mask for every IP address in the classless interdomain routing (CIDR) “slash” notation. An absence of the mask can lead to the less desirable result of configuring a /32 subnet on your interface. (Look for other JUNOS software address issues in “Interface Troubleshooting,” later in this chapter.)

Verify the configuration and activate the changes by issuing a `commit and-quit` command:

```
[edit interfaces fe-2/0/1]
root@Lager# show
unit 0 {
    family inet {
        address 10.10.20.122/24;
    }
}

[edit interfaces fe-2/0/1]
root@Lager# commit and-quit
commit complete
Exiting configuration mode
```

Verify the status of the interface. Note that the status now includes the logical portion as well as the physical portion of the interface:

```
root@Lager> show interfaces terse fe-2/0/1
Interface               Admin Link Proto    Local              Remote
fe-2/0/1                up    up
fe-2/0/1.0              up    up   inet     10.10.20.122/24
```

Lastly, test connectivity by issuing a `ping` command toward the other end of the link of `Porter`:

```
root@Lager> ping 10.10.20.121
PING 10.10.20.121 (10.10.20.121): 56 data bytes
64 bytes from 10.10.20.121: icmp_seq=0 ttl=64 time=7.758 ms
64 bytes from 10.10.20.121: icmp_seq=1 ttl=64 time=10.394 ms
^C
--- 10.10.20.121 ping statistics ---
2 packets transmitted, 2 packets received, 0% packet loss
round-trip min/avg/max/stddev = 7.758/9.076/10.394/1.318 ms
```

Notice the Ctrl-C sequence used to break out of the ping command. JUNOS software will send an endless number of pings unless a break is issued or a specific number of ping packets are specified with the count command:

```
root@Lager> ping 10.10.20.121 count 3
PING 10.10.20.121 (10.10.20.121): 56 data bytes
64 bytes from 10.10.20.121: icmp_seq=0 ttl=64 time=16.822 ms
64 bytes from 10.10.20.121: icmp_seq=1 ttl=64 time=20.382 ms
64 bytes from 10.10.20.121: icmp_seq=2 ttl=64 time=10.370 ms

--- 10.10.20.121 ping statistics ---
3 packets transmitted, 3 packets received, 0% packet loss
round-trip min/avg/max/stddev = 10.370/15.858/20.382/4.144 ms
```

Fast Ethernet with VLAN Tagging

Continuing with our example, let's add VLAN tagging between Lager and Porter, which is already configured with a VLAN ID of 100. The first step is to enable VLAN tagging on the physical interface of Lager:

```
root@Lager> configure
Entering configuration mode

[edit]
root@Lager# edit interfaces fe-2/0/1

[edit interfaces fe-2/0/1]
root@Lager# set vlan-tagging
```

Next, add a VLAN ID of 100 on logical unit 0:

```
 [edit interfaces fe-2/0/1]
root@Lager# set unit 0 vlan-id 100

[edit interfaces fe-2/0/1]
root@Lager# show
vlan-tagging;
unit 0 {
    vlan-id 100;
    family inet {
        address 10.10.20.122/24;
    }
}
```

Juniper routers do not have a default VLAN, as every VLAN must be explicitly configured. Many switches use a default VLAN of 1, so make sure you explicitly configure a vlan-id of 1 on the router for connectivity.

Although this is a valid configuration on unit 0, the best practice is to always keep the same unit number as the VLAN tag, so let's change the unit number with the rename command:

```
[edit interfaces fe-2/0/1]
root@Lager# rename unit 0 to unit 100

[edit interfaces fe-2/0/1]
root@Lager# show
vlan-tagging;
unit 100 {
    vlan-id 100;
    family inet {
        address 10.10.20.122/24;
    }
}
```

Lastly, activate the changes, verify the interface status, and test connectivity:

```
[edit interfaces fe-2/0/1]
root@Lager# commit
commit complete

[edit interfaces fe-2/0/1]
root@Lager# run show interfaces terse fe-2/0/1
Interface               Admin Link Proto    Local          Remote
fe-2/0/1                up    up
fe-2/0/1.100            up    up   inet     10.10.20.122/24

[edit interfaces fe-2/0/1]
root@Lager# run ping 10.10.20.121 count 1
PING 10.10.20.121 (10.10.20.121): 56 data bytes
64 bytes from 10.10.20.121: icmp_seq=0 ttl=64 time=46.668 ms

--- 10.10.20.121 ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max/stddev = 46.668/46.668/46.668/0.000 ms

 [edit interfaces fe-2/0/1]
root@Lager# run show interfaces terse fe-2/0/1
Interface               Admin Link Proto    Local           Remote
fe-2/0/1                up    up
```

Notice the use of the command run to issue the operational mode command ping in configuration mode.

T1 Interface with Cisco HDLC Encapsulation

The T1 interface is the most popular basic physical layer protocol used by the Digital Signal level 1 (DS1) multiplexing method in North America. For point-to-point interfaces on Juniper Networks routers, the default Layer 2 encapsulation is PPP, which differs from many other vendors' default behavior. To quickly interoperate with those vendors, change the encapsulation to their default setting, which is usually Cisco HDLC. Since we already showed the step-by-step configuration in the previous configuration, we show here only the result of adding the correct encapsulation:

```
t1-0/0/2 {
    encapsulation cisco-hdlc;
    unit 0 {
        family inet {
            address 10.200.8.9/30;
        }
    }
}
```

An inquiring mind may wonder why the encapsulation has the word *cisco* in it. Is there a non-Cisco HDLC? As a matter of fact, there is! There is a standard HDLC protocol (ISO 13239), used in protocols such as X.25 and SDLC. The original specification did not have multiprotocol support, so Cisco decided to create its own version with this support with different header fields and definitions. Although this protocol is officially proprietary, the workings are open and have been implemented by many different router vendors.

Serial Interface with PPP

A serial interface can come in a variety of different physical forms, such as V.35, X.21, and EIA-530. The choice of physical media often depends on geographical location; V.35 is the most common choice in the United States and Europe, and X.21 is more common in Japan. Regardless of physical media, all serial interfaces have the same idea of defining a data circuit-terminating equipment (DCE) device and a data terminal equipment (DTE) device. The DTE device is the end unit that receives data encoding, clocking, and signal conversion from the DCE device. In modern communications, the DCE device often takes the form of a channel service unit/data service unit (CSU/DSU) or a modem; however, when connecting two routers in a back-to-back fashion, one of the routers takes the role of a DCE.

Router `Ale` and router `Bock` have a back-to-back serial connection using V.35 with the default encapsulation of PPP. Normally, a router will default to DTE mode, but in this case, `Ale` is automatically chosen as the DCE based on the detection of a DCE cable. You can observe this detection in the `Local mode` field of the `show interfaces` command:

```
root@ale# run show interfaces se-1/0/0 extensive | find "serial media"
  Serial media information:
    Line protocol: v.35
    Resync history:
      Sync loss count: 0
    Data signal:
      Rx Clock: OK
```

```
        Control signals:
          Local mode: DCE
          To DTE: CTS: up, DCD: up, DSR: up
          From DTE: DTR: up, RTS: up
        DCE loopback override: Off
        Clocking mode: internal
        Clock rate: 8.0 MHz
        Loopback: none
        Tx clock: non-invert
        Line encoding: nrz
```

Since one of the roles of the DCE is to provide clocking to the DTE, an internal clocking mode needs to be configured on Ale. This allows Ale to generate a clocking signal toward Bock using the internal clock with a default clock rate of 8 MHz:

```
[edit interfaces]
root@ale# show se-1/0/0
serial-options {
    clocking-mode internal;
}
unit 0 {
    family inet {
        address 172.16.1.1/30;
    }
}
```

Bock has no clocking mode configured and takes the default clock mode of loop-timed, which takes the transmitted clock from Ale. Bock could also have been configured for DCE mode, which would have the same result in this case. Here is the Bock configuration:

```
[edit interfaces se-1/0/1]
root@Bock# show
unit 0 {
    family inet {
        address 172.16.1.2/30;
    }
}
```

You can verify the local mode, clocking mode, and clock rate on Bock by using the show interfaces command:

```
[edit interfaces se-1/0/1]
root@Bock#run show interfaces se-1/0/1 extensive | find "serial media"
  Serial media information:
    Line protocol: v.35
    Resync history:
      Sync loss count: 0
    Data signal:
      Rx Clock: OK
    Control signals:
      Local mode: DTE
      To DCE: DTR: up, RTS: up
      From DCE: CTS: up, DCD: up, DSR: up
    Clocking mode: loop-timed
    Clock rate: 8.0 MHz
    Loopback: none
    Tx clock: non-invert
    Line encoding: nrz
```

Clocking can often be a confusing topic for many users. For back-to-back router connections, Juniper made it simple by allowing multiple different clocking modes to be configured and still "do the right thing." The only combinations that will not work for back-to-back connections are the DCE in loop mode and the DTE in loop or DCE mode. However, when connecting to a CSU/DSU or a modem, proper care must be taken to configure the correct clock mode.

Serial Interface with Frame Relay

Frame Relay is a Layer 2 encapsulation that enables the connection of your LAN via a WAN connection to a Frame Relay node. Frame Relay creates a tunnel called a permanent virtual circuit (PVC) over a private or leased line to provide connectivity to other sites over the Internet service provider's (ISP's) infrastructure. With the emergence of DSL and IP-based networks, Frame Relay is not often seen anymore, except in rural areas as a cheaper, "always on" connection.

To establish a Frame Relay connection with the Frame Relay node, the proper encapsulation of `frame-relay` (RFC 1490) must be configured as well as the local circuit identifier for the PVC represented by the logical property of a `dlci` number:

```
se-1/0/0 {
    encapsulation frame-relay;
    unit 645 {
        description "to R3";
        dlci 645;
        family inet {
            address 172.17.24.130/30;
        }
    }
}
```

The router can also support back-to-back router connections by configuring one router to operate in DCE mode or by turning off keepalives on each router. If keepalives are disabled, the router will not wait for any local management messages to enable that interface. Also, turning keepalives off can help in troubleshooting by allowing for loopback testing, which we'll discuss later in this chapter.

FRF.15 and FRF.16 are also supported standards that we will discuss in Chapter 7.

ADSL Using PPPoE over ATM

DSL is one of the more popular connection media for both companies and consumers due to the fact that the local service is provided via a normal phone line with a DSL modem. This connection terminates at the telco digital subscriber line access multiplexer (DSLAM), a device that concentrates multiple DSL connections together. Some J-series routers have support for ATM over asymmetrical digital subscriber line (ADSL)—Annex A for DSL over POTS or Annex B for DSL over ISDN—and symmetric high-speed digital subscriber line (SHDSL) configurations that allow them to act as the DSL modem at the customer site. The interfaces appear to be ATM connections but do not support native ATM, only the use of ATM over a DSL connection.

Router `PBR` has an ADSL Annex A PIM installed in slot 6 and will act as a client to the DSLAM. This connection is using Point-to-Point Protocol over Ethernet (PPPoE) over ATM for the DSL connection, which requires that two different interfaces be configured. The first interface that is configured is the physical ATM interface of `at-6/0/0`. To configure the interface, the ATM virtual path and virtual channel identities must be the same values that are provisioned at the DSLAM. The rest of the parameters can be learned from the DSLAM by setting an operating mode of auto. Since `PBR` will be using PPPoE, the encapsulation *must* be configured at *both* the physical and the logical layers:

```
 [edit]
doug@PBR# show interfaces
at-6/0/0 {
    encapsulation ethernet-over-atm;
    atm-options {
        vpi 0;
    }
    dsl-options {
        operating-mode auto;
    }
    unit 0 {
        encapsulation ppp-over-ether-over-atm-llc;
        vci 0.39;
    }
}
```

The next interface that must be configured is the PPPoE internal router interface. This interface maps the physical interface where PPPoE will be running, sets the access server's name and underlying service to be requested, and sets an IP address. The IP address can be learned automatically from the access server by specifying the `negotiate-address` command, as seen in the configuration of `PBR` that follows, or by setting the IP address to be static:

```
pp0 {
    unit 0 {
        pppoe-options {
            underlying-interface at-6/0/0.0;
            access-concentrator mgmgrand;
```

```
                service-name "pppserv@mgmgrand";
                auto-reconnect 5;
            }
            family inet {
                negotiate-address
                }
            }
        }
    }
```

Verify the correct operation of the PPPoE negotiation by issuing the `show pppoe interfaces` command:

```
[edit]
doug@PBR# run show pppoe interfaces
pp0.0 Index 68
  State: Session up, Session ID: 4,
  Service name: pppserv@mgmgrand, Configured AC name: mgmgrand,
  Session AC name: mgmgrand, AC MAC address: 00:05:85:ca:7a:a8,
  Session uptime: 00:22:43 ago,
  Auto-reconnect timeout: 5 seconds, Idle timeout: Never,
  Underlying interface: at-6/0/0.0 Index 66
```

ISDN

ISDN is a protocol designed to run over the circuit-switched telephone network. It allows digital transmission of both voice and video over your telephone circuit. With the advent of DSL, ISDN is starting to see less deployment, and today it is common mostly in rural areas or for backup links. When ISDN is configured on a Juniper Networks router, two interfaces must be configured: a physical interface (`br`) and a logical dialer interface (`dl0`). The physical interface will contain the dialing number information and switch type. In the following example, `br-0/0/4` is configured to use a switch type of `etsi`, which indicates NET3 for Europe. Also, a dial pool of `pool1` is mapped to the physical interface to tie the interface to a logical unit in the dialer interface.

```
Dialer filter:
-------------
[edit interfaces]
   br-0/0/4 {
       isdn-options {
           switch-type etsi;
       }
       dialer-options {
           pool pool1;
       }
   }
```

The logical dialer interface also needs to be configured. This interface contains the number that needs to be dialed, an IP address, and a pool to map the logical unit to the physical interface. In the following code snippet, the `dl0` interface is mapped with pool1, which is also configured on the physical interface. The number 12345 is being dialed, and an IP address of 12.12.12.1 is configured. Also, this ISDN interface is set to establish the connection only when there is interesting traffic that will be defined in the dialer filter, called dial_filter:

```
dl0 {
    unit 0 {
        dialer-options {
            pool pool1;
            dial-string 12345;
        }
        family inet {
            filter {
                dialer dial_filter;
            }
            address 12.12.12.1/24;
        }
    }
}
```

This simple filter creates the connection when there are packets that are destined for the IP address of 12.12.12.2 by specifying the note action. All other destinations are ignored by term b because this term contains no from statement:

```
[edit]
  firewall {
      family inet {
          dialer-filter dial_filter {
              term a {
                  from {
                      destination-address {
                          12.12.12.2/32;
                      }
                  }
                  then note;
              }
              term b {
                  then ignore;
              }
          }
      }
  }
```

Recall that an ISDN interface could be used as a backup for other interfaces. To configure backup links, the dl0 interface will be mapped to the interface that requires the backup. In this case, fe-0/0/1 is being backed up by dl0.0:

```
[edit interfaces fe-0/0/1 unit 0]
     backup-options {
         interface dl0.0;
     }
```

The ISDN interface will be used if the fe-0/0/1 interface is down. Since Ethernet interfaces are often connected to switches, the interface could stay in the up state even if the entire path is not reachable.

> A protocol called *Bidirectional Forwarding Detection* (BFD) was developed to solve Ethernet path issues when the connection is via a hub or switch. BFD is essentially a fast hello protocol that is media-independent. For details on how BFD operates, see *http://www.ripe.net/ripe/meetings/ripe-48/presentations/ripe48-eof-bfd.pdf*.

In this case, it is wise to configure a listing of IP networks that should be reachable when the primary interface is working. If there is no route to these networks, the ISDN interface will be used. In the following example, a single network of 13.13.13/24 is used to verify that the primary interface is working by listing that network in a watch list:

```
dl0 {
    unit 0 {
        dialer-options {
            pool pool1;
            dial-string 12345;
            watch-list {
                13.13.13.0/24;
            }
        }
        family inet {
            address 12.12.12.1/24;
        }
    }
}
```

An ISDN interface may dial and accept calls from other ISDN devices. To accept a call, an incoming map can be configured on the dl0 interface:

```
dl0 {
    unit 0 {
        dialer-options {
            pool pool1;
            incoming-map {
                caller 384030;
            }
        }
        family inet {
            address 12.12.12.1/24;
        }
    }
}
```

To verify whether the ISDN interface is working properly, issue the show isdn and show dialer commands. The show isdn status command verifies that the ISDN connection is up from Layer 1 to Layer 3, as well as the type of switch to which the call is connected:

```
doug@PBR> show isdn status
Interface: br-0/0/4
 Layer 1 status: active
 Layer 2 status:
  CES: 0, Q.921: up, TEI: 64
 Layer 3 status: 1 Active calls
  Switch Type          : NI1
  Interface Type       : USER
  T310                 : 10 seconds
  Tei Option           : Power Up
```

The show dialer command will indicate each ISDN channel's individual status. In this case, only channel 2 is currently active:

```
doug@PBR> show dialer pools brief
Pool             Dialer interface      Subordinate interface
                 Name  State         Name        Flags     Priority
1                dl0.0 Active        bc-0/0/4:1  Inactive  1
                                     bc-0/0/4:1  Inactive  1
                                     bc-0/0/4:2  Active    1
```

MLPPP

To incrementally increase the speed of individual PPP links without adding speed to the physical interfaces, the Multilink Point-to-Point Protocol (MLPPP) was created under RFC 1990. This is essentially a "software" bond of multiple physical PPP interfaces to form one larger logical link, called a *bundle*. JUNOS software allows for up to eight physical interfaces to be assigned to a bundle.

To support MLPPP on any Juniper Networks router, the router must support this special service. This support could be in the form of an additional hardware PIC on an M-series router, or it could inherit software support on a J-series router. We discuss services in detail in Chapters 7 and 8.

The first step is to configure the pseudolink service interface, which takes the form of ls-0/0/0 on a J-series router, or an ml, lsq, or ls interface on an M-series router depending on the PIC type (see Table 7-2 in Chapter 7 for a summary). This interface will take all the same characteristics of a normal PPP interface, such as an IP address, but will have a logical encapsulation of multilink-ppp. This is configured at the logical layer of the interface to allow multiple bundles and types of bundles on the same router by configuring multiple unit numbers. As shown here, the bundle is assigned to logical unit 0:

```
ls-0/0/0 {
    unit 0 {
        encapsulation multilink-ppp;
        family inet {
            address 172.8.17.30/30;
            }
        }
    }
```

Next, configure the physical interfaces to link the newly created link service interface. In the following example, interfaces `se-1/0/0` and `se-1/0/1` are linked to the logical bundle unit 0 on the `ls-0/0/0` interface:

```
    se-1/0/0 {
        unit 0 {
            family mlppp {
                bundle ls-0/0/0.0;
            }
        }
    }
    se-1/0/1 {
        unit 0 {
            family mlppp {
                bundle ls-0/0/0.0;
            }
        }
    }
```

To verify the status, issue the `show interfaces terse` command. Notice that both the serial interfaces and the link service interfaces are tracked. The link service will be in the up state as long as one of the physical interfaces is also in the up state. You can modify this by configuring the `minimum-links number` command under the link service interface. This command sets the number of physical links that must be in the up state for the bundle to be labeled up.

```
    root@Bock# run show interfaces terse | match "se|ls-"
    ls-0/0/0              up    up
    ls-0/0/0.0            up    up   inet     172.17.8.30/30
    se-1/0/0              up    up
    se-1/0/0.0            up    up   mlppp    ls-0/0/0.0
    se-1/0/1              up    up
    se-1/0/1.0            up    up   mlppp    ls-0/0/0.0
```

GRE

Generic Routing Encapsulation (GRE) is a tunneling protocol that enables the transport of a variety of Layer 3 protocols. The tunnel created by GRE was designed to be "stateless" with no monitoring of the tunnel endpoint. GRE tunnels are used for a variety of applications, including providing backup links, transporting non-IP protocols over an IP network, and connecting "islands" of IP networks.

To create a GRE tunnel on a Juniper Networks router, the router must be equipped with Layer 2 service capabilities, which are native in a J-series router or are available via a hardware PIC in an M-series router. When these services are enabled on a router, a pseudointerface called `gr` is created. The interface must be configured with the source IP address for the GRE packets, the destination of the tunnel, and the families of protocols that will be carried in the protocol. The GRE tunnel configured in the following case is carrying IP traffic and is using a source IP address of 10.20.1.38 and a destination of 172.66.13.1. An IP address for the gr-0/0/0 interface is not required but could be useful for management purposes.

```
gr-0/0/0 {
    unit 0 {
        tunnel {
            source 10.20.1.38;
            destination 172.66.13.1;
        }
        family inet
    }
}
```

It is important not to mistake the internal gre interface with the gr interface on the router. The gre interface is used by the router internally and should not be configured to create GRE tunnels.

The final piece is mapping actual traffic for use by the GRE tunnel. This is accomplished in a variety of methods depending on the type of traffic entering the GRE tunnel. Common mapping examples for IP include creating a static route with a next-up of the gr interface or even running a routing protocol such as Open Shortest Path First (OSPF) over the interface!

VRRP

Anybody that is using a PC for Internet surfing, music downloads, or gaming uses IP as the network protocol. The PC will have an IP address assigned as well as a default gateway address to reach any destinations that are not on the local subnet. In the following code snippet, a PC is using an IP address of 10.70.129.36 with a mask of 255.255.255.0 and a default gateway of 10.70.129.1:

```
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.

C:\Documents and Settings\Douglas Marschke>ipconfig

Ethernet adapter Local Area Connection 3:

        Connection-specific DNS Suffix  . : eu-af.regus.local
        IP Address. . . . . . . . . . . . : 10.70.129.36
        Subnet Mask . . . . . . . . . . . : 255.255.255.0
        Default Gateway . . . . . . . . . : 10.70.129.1
```

This default gateway address is either statically defined by the user or learned via the Dynamic Host Configuration Protocol (DHCP) process. Regardless of the method, the default gateway will be used as the next hop address for the default route that will be created to reach remote destinations:

```
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.

C:\Documents and Settings\Douglas Marschke>netstat -r

Route Table
================================================================
Interface List
0x1 ........................ MS TCP Loopback interface
0x2 ...00 12 f0 ac 46 d5 ..... Intel(R) PRO/Wireless 2200BG Network
Connection - Packet Scheduler Miniport
0x3 ...00 12 3f 12 d7 59 ...... Broadcom NetXtreme 57xx Gigabit
Controller - Packet Scheduler Miniport
0x20005 ...00 ff e8 25 91 85 ..... Juniper Network Connect Virtual
Adapter
================================================================
Active Routes:
Network Destination        Netmask      Gateway    Interface  Metric
          0.0.0.0          0.0.0.0  10.70.129.1 10.70.129.36     20
      10.70.129.0    255.255.255.0 10.70.129.36 10.70.129.36     20
     10.70.129.36  255.255.255.255    127.0.0.1    127.0.0.1     20
   10.255.255.255  255.255.255.255 10.70.129.36 10.70.129.36     20
        127.0.0.0        255.0.0.0    127.0.0.1    127.0.0.1      1
        224.0.0.0        240.0.0.0 10.70.129.36 10.70.129.36     20
  255.255.255.255  255.255.255.255 10.70.129.36 10.70.129.36      1
  255.255.255.255  255.255.255.255 10.70.129.36            2      1
  255.255.255.255  255.255.255.255 10.70.129.36        20005      1
Default Gateway:       10.70.129.1
==============================================================
Persistent Routes:
  None
```

If the default gateway was a single device and that device failed, a PC would not be able to reach destinations outside the local subnet. In a fault-tolerant network, it would be ideal to have a backup gateway device, without having to modify the configuration on the PC, as well as being able to load-share with multiple PCs on the LAN.

VRRP was created to eliminate single points of behavior that are inherent to static default routed networks. VRRP creates a logical grouping of multiple physical routers to a "virtual" router that will be used as the default gateway for end hosts. This allows the PC to always maintain the same gateway address even if the physical gateway has changed (see Figure 2-13). The routers that are part of the same VRRP logical group will share this "virtual" IP address as well as a "virtual" media access control (MAC) address. Essentially VRRP describes an election protocol to maintain ownership of this virtual IP (VIP) address and MAC address. One router in the VRRP group will be the master router, which controls this VIP address unless a failure occurs that results in a release of that ownership. This failure causes another router to claim ownership of the VIP by issuing a VRRP message and a gratuitous Address Resolution Protocol (ARP) to claim the virtual MAC address. Once a router becomes the master, it will periodically advertise VRRP messages to indicate its overall health and reachability.

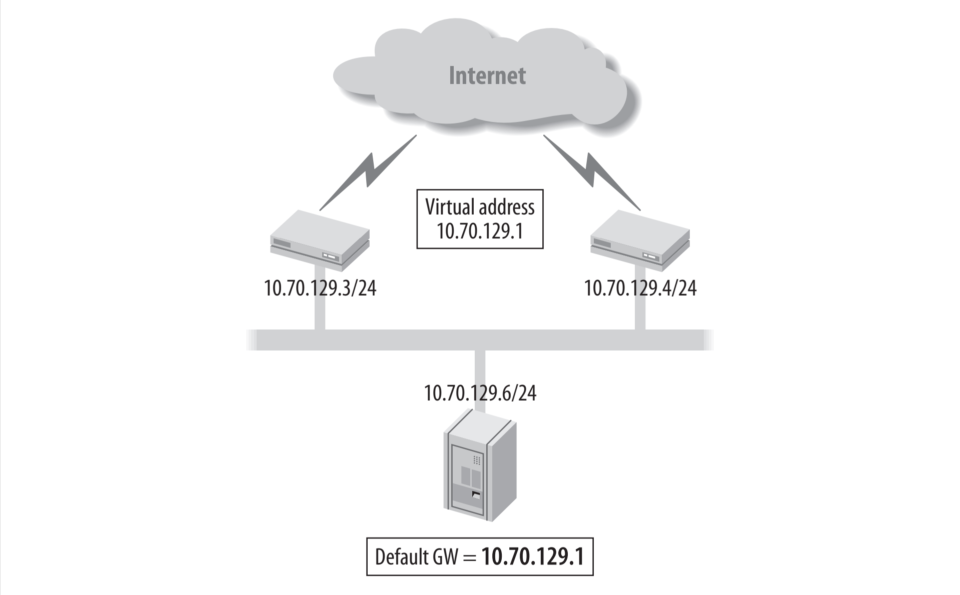


Figure 2-13. VRRP example

When configuring VRRP for the first time on a Juniper Networks router, it can seem like locating the configuration is similar to trying to find a needle in a haystack. The configuration will be within the logical property and will be configured after the family inet address. A VRRP group value (1–255) is assigned on every router that needs to be part of the virtual router. Also, a VIP address is assigned that the hosts will use as their gateway address. This could be an address owned by one of the routers in the group or an address taken out of the address block owned by the LAN. Lastly, a priority value can be configured to change the default value of 100, which is used to elect the master router of the VRRP group. The router with the highest priority value becomes the master for that group; if the priorities are equal, the tie breaker goes to the highest local LAN IP address.

```
lab@LAGER# show interfaces
fe-0/0/1 {
    vlan-tagging;
    speed 100m;
    link-mode full-duplex;
    unit 1115 {
        description LAGER-to-ALE;
        vlan-id 1115;
        family inet {
            address 10.40.1.2/24 {
                vrrp-group 1 {
                    virtual-address 10.40.1.200;
                    priority 200;

                }
            }
        }
    }
```

Verify the operation of VRRP with the `show vrrp summary` command. Router `Lager` is the master for group 1 due to a higher priority.

```
[edit interfaces fe-0/0/1]
lab@LAGER# run show vrrp summary
Interface   Unit  Group  Type  Address        Int state    VR state
fe-0/0/1    1115  1      lcl   10.40.1.2      up           master
                         vip   10.40.1.200
```

Priority values range from 0–255; however, only values 1–254 are configurable. Priority 0 is reserved for the master router to issue an immediate release of mastership. A priority of 255 is used if the VIP is an actual interface IP that is owned by that router.

Another option that can be configured is the ability to track the interface priority settings. If an interface goes down, the advertised priority will be subtracted by a configured value. This could result in a new master router for the virtual router. This is very useful to ensure upstream reachability. In the example on `Lager`, a T1 interface is being tracked. If this interface goes down, 150 will be subtracted from the configured priority of 200.

```
lab@LAGER# show interfaces
fe-0/0/1 {
    vlan-tagging;
    speed 100m;
    link-mode full-duplex;
    unit 1115 {
        description LAGER-to-ALE;
        vlan-id 1115;
        family inet {
            address 10.40.1.2/24 {
                vrrp-group 1 {
                    virtual-address 10.40.1.200;
                    priority 200;
                    track {
                        interface t1-0/0/2.0 priority-cost 150;
                    }
                }
            }
        }
    }
```

You can force an interface failure by administratively disabling the T1 interface:

```
lab@LAGER# top set interfaces t1-0/0/2 disable

[edit interfaces fe-0/0/1]
lab@LAGER# commit
commit complete
```

The result of this failure is a mastership change, as Lager is now the backup router:

```
[edit interfaces fe-0/0/1]
lab@LAGER# run show vrrp summary
Interface   Unit  Group  Type  Address       Int state    VR state
fe-0/0/1    1115  1      lcl   10.40.1.2     up           backup
                         vip   10.40.1.200
```

Notice in the show vrrp track command that Lager has a configured (cfg) priority value of 200, but a priority of 50 is currently being used because we've subtracted the cost of 150 from the downed T1 interface:

```
lab@LAGER# run show vrrp track
Track if         State  Cost  Interface    Group  Cfg  Run  VR State
t1-0/0/2.0       down   150   fe-0/0/1.11151      200  50   backup
```

The default behavior of VRRP is to use *preemption*, which causes a router with a higher priority to become the master at any time. When Lager's T1 interface is reenabled, it will again become the master for the virtual router:

```
[edit]
lab@LAGER# rollback 1
load complete

[edit]
lab@LAGER# commit
commit complete

[edit]
lab@LAGER# run show vrrp track
Track if         State  Cost  Interface    Group  Cfg  Run  VR State
t1-0/0/2.0       up     150   fe-0/0/1.11151      200  200  master
```

Since preemption could cause a temporary disruption in the network, a no-preempt command can also be configured.

Lastly, according to RFC 3768, "A VRRP router SHOULD not forward packets addressed to the VIP Address(es) it becomes Master for if it is not the owner." That means if we have an IP address that is not owned by any router and is simply an address from the subnet that was used as the VIP, operational issues may appear. The most common issue is not being able to ping the virtual address. In the case just examined, 10.40.1.200 was the VIP address chosen out of the 10.40.1/24 subnet, but it was not actually configured on either Lager or Ale. Juniper routers allow you to break this rule by configuring the accept-data command to allow the master router to respond to the VIP address. This will allow testing to occur toward the VIP; however, care must be taken to avoid unnecessary traffic on the LAN.

Interface Troubleshooting

Interfaces can have a variety of issues depending on the actual interface type, and listing all the possibilities would require a separate book! Instead, in this section, we will discuss a few common issues that illustrate the types of troubleshooting commands available on the router.

Address Configuration Issues

Since Juniper Networks routers allow multiple IP addresses to be configured on a single logical unit, configuration errors can occur if care is not taken. Lager has an IP address of 10.10.20.122 configured on its fast Ethernet interface with a subnet mask of /24. This was noticed to be a configuration error as the mask should have been configured for /27.

```
[edit interfaces fe-2/0/1]
root@Lager# show
vlan-tagging;
unit 100 {
    vlan-id 100;
    family inet {
        address 10.10.20.122/24;
    }
}
```

Here, the address of 10.10.20.122 is added with the correct subnet of /27:

```
[edit interfaces fe-2/0/1]
root@Lager# set unit 100 family inet address 10.10.20.122/27
```

When you view the resultant interface configuration the router appears to contain the duplicate IP addresses with varying subnet masks. This illustrates the fact that IP addresses are not overridden per logical unit, but simply are added to the logical unit.

```
[edit interfaces fe-2/0/1]
root@Lager# show
vlan-tagging;
unit 100 {
    vlan-id 100;
    family inet {
        address 10.10.20.122/24;
        address 10.10.20.122/27;
    }
}
```

To correct this, the old address with the /24 mask is removed by use of the delete command:

```
[edit interfaces fe-2/0/1]
root@Lager# delete unit 100 family inet address 10.10.20.122/24
```

Another solution with the same result is to use the rename command to change the subnet mask from /24 to /27:

```
[edit interfaces fe-2/0/1 unit 100]

root@Lager# rename address 10.10.20.122/24 to address 10.10.20.122/27
```

Since Juniper Networks routers allow placement of multiple addresses on a single logical interface, care must also be taken to allow for the router to choose the correct source IP address for outgoing packets on that interface. By default, the source IP address is chosen by using the primary and preferred addresses assigned to the interface. Each unit can have only one primary address, but each interface can have multiple preferred addresses. Simply put, a primary address is the address chosen to source local packets out of the interface destined for a remote network. As shown in the following output, 10.20.20.122 is the only address on the interface, and as such, it contains both a primary and a preferred flag:

```
root@Lager# run show interfaces fe-2/0/1.100
  Logical interface fe-2/0/1.100 (Index 67) (SNMP ifIndex 45)
   Flags: SNMP-Traps 0x4000 VLAN-Tag [0x8100.100] Encapsulation: ENET2
    Input packets : 2215
    Output packets: 23
    Protocol inet, MTU: 1500
      Flags: None
      Addresses, Flags: Is-Preferred Is-Primary
        Destination: 10.10.20.96/27, Local: 10.10.20.122,
        Broadcast: 10.10.20.127
```

Now configure two additional IP addresses, 6.6.6.6 and 6.6.6.4, on the interface and observe the results:

```
root@Lager# set address 6.6.6.4/24
root@Lager# set address 6.6.6.6/24
[edit interfaces fe-2/0/1 unit 100 family inet]
root@Lager# commit
commit complete

[edit interfaces fe-2/0/1 unit 100 family inet]
root@Lager# run show interfaces fe-2/0/1.100 | find protocol
    Protocol inet, MTU: 1500
      Flags: None
      Addresses, Flags: Is-Preferred Is-Primary
        Destination: 6.6.6/24, Local: 6.6.6.4, Broadcast: 6.6.6.255
      Addresses
        Destination: 6.6.6/24, Local: 6.6.6.6, Broadcast: 6.6.6.255
      Addresses, Flags: Is-Preferred
        Destination: 10.10.20.96/27, Local: 10.10.20.122,
        Broadcast: 10.10.20.127
```

The primary address has changed to 6.6.6.4, and now two addresses contain the preferred flag: addresses 6.6.6.6 and 10.10.20.122. The preferred address is used as the source IP address if you're trying to reach a network that is locally attached. In this case, if traffic is destined for 172.16.1.2, the source IP address of 6.6.6.4 is used, but if the destination address is 10.10.20.121, the source IP address of 10.10.20.122 will be used. JUNOS software by default will choose the primary and preferred addresses based on the lowest IP address that is configured. The primary address will be the lower IP address configured on the interface, and the preferred address will be the lowest IP address configured for each local subnet. In the earlier example, traffic destined to a host on the 6.6.6/24 subnet is sourced from 6.6.6.4. You can modify these defaults by configuring the appropriate flag (primary or preferred) to the address of choice:

```
[edit interfaces fe-2/0/1 unit 100 family inet]
root@Lager# set address 10.10.20.122/27 primary

[edit interfaces fe-2/0/1 unit 100 family inet]
root@Lager# commit
commit complete
```

The 10.10.20.122 address has now been configured for the primary address of the interface, as indicated by the `show interfaces` command:

```
[edit interfaces fe-2/0/1 unit 100 family inet]
root@Lager# run show interfaces fe-2/0/1.100 | find protocol
    Protocol inet, MTU: 1500
      Flags: None
      Addresses, Flags: Is-Preferred
        Destination: 6.6.6/24, Local: 6.6.6.4, Broadcast: 6.6.6.255
      Addresses
        Destination: 6.6.6/24, Local: 6.6.6.6, Broadcast: 6.6.6.255
      Addresses, Flags: Primary Is-Preferred Is-Primary
        Destination: 10.10.20.96/27, Local: 10.10.20.122,
        Broadcast: 10.10.20.127
[edit interfaces fe-2/0/1 unit 100 family inet]
root@Lager# set address 6.6.6.6/24 preferred
```

Encapsulation Mismatches

For two routers' interfaces to communicate properly, the same Layer 2 encapsulation must be configured on each device; depending on the type of encapsulation, this could be a difficult error to determine. A common interface medium where this could occur is Ethernet. The interface on router `Lager` is configured to send VLAN tagged frames on the 10.10.20/24 subnet; however, a ping to router `Hangover` in that segment fails:

```
[edit interfaces fe-2/0/1 unit 100]
root@Lager# run ping 10.10.20.121
PING 10.10.20.121 (10.10.20.121): 56 data bytes
^C
--- 10.10.20.121 ping statistics ---
3 packets transmitted, 0 packets received, 100% packet loss
```

Looking at the statistics on Lager's Ethernet interface, a number of Layer 2 channel errors are recorded:

```
root@Lager# run show interfaces fe-2/0/1 extensive
Physical interface: fe-2/0/1, Enabled, Physical link is Up
  Interface index: 142, SNMP ifIndex: 37, Generation: 143
  Link-level type: Ethernet, MTU: 1518, Speed: 100mbps, Loopback:
Disabled,
  Source filtering: Disabled, Flow control: Enabled
  Device flags   : Present Running
  Interface flags: SNMP-Traps Internal: 0x4000
  CoS queues     : 8 supported, 8 maximum usable queues
  Hold-times     : Up 0 ms, Down 0 ms
  Current address: 00:12:1e:76:1e:29, Hardware address:
00:12:1e:76:1e:29
  Last flapped   : 2007-04-05 22:01:18 UTC (1w0d 10:11 ago)
  Statistics last cleared: 2007-04-13 08:10:48 UTC (00:02:18 ago)
  Traffic statistics:
   Input  bytes  :                     0                    0 bps
   Output bytes  :                   230                    0 bps
   Input  packets:                     0                    0 pps
   Output packets:                     5                    0 pps
  Input errors:
   Errors: 0, Drops: 0, Framing errors: 0, Runts: 0, Policed discards:
   0, L3 incompletes: 0, L2 channel errors: 42, L2 mismatch timeouts:
   ,0 FIFO errors: 0, Resource errors: 0
 Output errors:
   Carrier transitions: 0, Errors: 0, Drops: 0, Collisions: 0, Aged
   packets: 0, FIFO errors: 0, HS link CRC errors: 0, MTU errors: 0,
   Resource errors: 0
 Egress queues: 8 supported, 8 in use
.....
```

To see whether the Layer 2 channel errors are currently increasing or whether they are older counters that have not been cleared, the monitor interface fe-2/0/1 command is issued. The second column in the following code snippet shows the interface counter statistics, and the current delta column indicates real-time statistics recorded since issuing the monitor command. Layer 2 channel errors are currently increasing, as the current delta counter indicates:

```
Lager                             Seconds: 14         Time: 08:13:54
                                                    Delay: 0/0/50
Interface: fe-2/0/1, Enabled, Link is Up
Encapsulation: Ethernet, Speed: 100mbps
Traffic statistics:                                    Current delta
  Input bytes:                     0 (0 bps)                     [0]
  Output bytes:                  230 (0 bps)                     [0]
  Input packets:                   0 (0 pps)                     [0]
  Output packets:                  5 (0 pps)                     [0]
Error statistics:
  Input errors:                    0                             [0]
  Input drops:                     0                             [0]
  Input framing errors:            0                             [0]
```

```
    Policed discards:             0                        [0]
    L3 incompletes:               0                        [0]
    L2 channel errors:          105                       [18]
    L2 mismatch timeouts:         0  Carrier transit       [0]
```

An additional monitor command is now used to verify that the router is sending out the correct packets. The monitor traffic command is the router's tcpdump[*] utility that allows local router traffic to be observed on a particular interface. Since Ethernet requires the IP address to MAC address mapping before sending the FRAME, a series of ARP requests with an 801.1Q (VLAN) header are sent out to the interface with no response received. The layer2-header switch is used to obtain some Ethernet header information as the monitor command is usually Layer 3 and Layer 4 only:

```
[edit interfaces fe-2/0/1 unit 100]
root@Lager# run monitor traffic interface fe-2/0/1 layer2-headers
verbose output suppressed, use <detail> or <extensive> for full protocol decode
Listening on fe-2/0/1, capture size 96 bytes

08:18:09.764757 Out 0:12:1e:76:1e:29 > Broadcast, ethertype 802.1Q (0x8100), length
46: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.121 tell 10.10.20.122
08:18:10.564781 Out 0:12:1e:76:1e:29 > Broadcast, ethertype 802.1Q (0x8100), length
46: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.121 tell 10.10.20.122
08:18:12.214889 Out 0:12:1e:76:1e:29 > Broadcast, ethertype 802.1Q (0x8100), length
46: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.121 tell 10.10.20.122
08:18:12.814634 Out 0:12:1e:76:1e:29 > Broadcast, ethertype 802.1Q (0x8100), length
46: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.121 tell 10.10.20.122
08:18:13.414648 Out 0:12:1e:76:1e:29 > Broadcast, ethertype 802.1Q (0x8100), length
46: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.121 tell 10.10.20.122
08:18:14.314858 Out 0:12:1e:76:1e:29 > Broadcast, ethertype 802.1Q (0x8100), length
46: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.121 tell 10.10.20.122
^C
7 packets received by filter
0 packets dropped by kernel

[edit interfaces fe-2/0/1 unit 100]
root@Lager#
```

Router Hangover is then accessed and a ping command toward Lager is issued. The monitor traffic command is issued at Hangover with similar output, except for a single important difference. While router Lager is sending out the ARP packets with an 802.1Q header (0×8100), router Hangover appears to be sending a non-VLAN-tagged Ethernet frame (0×0806), which is the cause of the Layer 2 channel errors that were previously discovered:

```
doug@hangover> monitor traffic interface fe-2/0/0 layer2-headers
verbose output suppressed, use <detail> or <extensive> for full protocol decode
Listening on fe-2/0/0, capture size 96 bytes
```

[*] tcpdump is a common debugging tool that allows the user to intercept and display IP packets being transmitted or received over a network interface.

```
08:20:32.901733 Out 0:12:1e:75:fa:28 > Broadcast, ethertype ARP (0x0806), length 42:
arp who-has 10.10.20.122 tell 10.10.20.121
08:20:33.801530 Out 0:12:1e:75:fa:28 > Broadcast, ethertype ARP (0x0806), length 42:
arp who-has 10.10.20.122 tell 10.10.20.121
08:20:34.601659 Out 0:12:1e:75:fa:28 > Broadcast, ethertype ARP (0x0806), length 42:
arp who-has 10.10.20.122 tell 10.10.20.121
08:20:35.301622 Out 0:12:1e:75:fa:28 > Broadcast, ethertype ARP (0x0806), length 42:
arp who-has 10.10.20.122 tell 10.10.20.121
08:20:36.001475 Out 0:12:1e:75:fa:28 > Broadcast, ethertype ARP (0x0806), length 42:
arp who-has 10.10.20.122 tell 10.10.20.121
08:20:36.941611 Out 0:12:1e:75:fa:28 > Broadcast, ethertype ARP (0x0806), length 42:
arp who-has 10.10.20.122 tell 10.10.20.121
^C
7 packets received by filter
0 packets dropped by kernel
```

After correcting the configuration error on Hangover to allow for VLAN encapsulation with the correct VLAN ID, the ping succeeds and is verified:

```
root@Lager# run monitor traffic interface fe-2/0/1 layer2-headers
verbose output suppressed, use <detail> or <extensive> for full protocol decode
Listening on fe-2/0/1, capture size 96 bytes

08:20:55.076174  In 0:12:1e:75:fa:28 > Broadcast, ethertype 802.1Q (0x8100), length
60: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.122 tell 10.10.20.121
08:20:55.076308 Out 0:12:1e:76:1e:29 > 0:12:1e:75:fa:28, ethertype 802.1Q (0x8100),
length 46: vlan 100, p 0, ethertype ARP, arp reply 10.10.20.122 is-at 0:12:1e:76:1e:
29
08:20:55.096237  In PFE proto 2 (ipv4): 10.10.20.121 > 10.10.20.122: ICMP echo
request seq 0, length 64
08:20:55.096272 Out 0:12:1e:76:1e:29 > 0:12:1e:75:fa:28, ethertype 802.1Q (0x8100),
length 102: vlan 100, p 0, ethertype IPv4, 10.10.20.122 > 10.10.20.121: ICMP echo
reply seq 0, length 64
```

Path MTU Issues

When an IP packet is transiting a network, it is often fragmented so that it can transverse interfaces with varying sizes of MTUs. However, some applications do not allow this fragmentation, so you must ensure that the ingress MTU is not larger than a transit MTU for those applications. One simple tool you can use to test whether the proper MTU is assigned is the *packet internet groper* (ping) command. Connectivity to a remote system is confirmed on router Lager by issuing a ping command to an address of 172.17.20.2:

```
root@Lager> ping 172.17.20.2
PING 172.17.20.2 (172.17.20.2): 56 data bytes
64 bytes from 172.17.20.2: icmp_seq=0 ttl=62 time=7.133 ms
64 bytes from 172.17.20.2: icmp_seq=1 ttl=62 time=10.375 ms
^C
--- 172.17.20.2 ping statistics ---
2 packets transmitted, 2 packets received, 0% packet loss
round-trip min/avg/max/stddev = 7.133/8.754/10.375/1.621 ms
```

Issue the traceroute command to check the path these packets take to reach the destination. Router Lager appears to be located two IP systems away from the destination of 172.17.20.2:

```
root@Lager> traceroute 172.17.20.2
traceroute to 172.17.20.2 (172.17.20.2), 30 hops max, 40 byte packets
 1  10.10.20.121 (10.10.20.121)  18.572 ms  12.953 ms  35.782 ms
 2  172.17.20.2 (172.17.20.2)  9.804 ms  9.497 ms  10.003 ms
```

The application that is being tested requires an MTU of 1,508 bytes, so a ping of size 1,500 is sent with 8 bytes of overhead to the remote station:

```
root@Lager> ping 172.17.20.2 size 1500 count 3
PING 172.17.20.2 (172.17.20.2): 1500 data bytes
1508 bytes from 172.17.20.2: icmp_seq=0 ttl=63 time=11.591 ms
1508 bytes from 172.17.20.2: icmp_seq=1 ttl=63 time=10.580 ms
1508 bytes from 172.17.20.2: icmp_seq=2 ttl=63 time=20.939 ms

--- 172.17.20.2 ping statistics ---
3 packets transmitted, 3 packets received, 0% packet loss
round-trip min/avg/max/stddev = 10.580/14.370/20.939/4.663 ms
```

The ping succeeds, and at first glance, all appears well, but let's not count our chickens before they hatch! Some observation into the operation of the ping command is needed before giving the green light of approval. By default, the ping packet will be sent out with the do-not-fragment bit cleared in the IP header. This means that although the ping packet will exit the router with a size of 1,508 bytes, it could be fragmented along the way. So, now issue the ping command with the do-not-fragment flag set and observe the results:

```
root@Lager> ping 172.17.20.2 size 1500 count 3 do-not-fragment
PING 172.17.20.2 (172.17.20.2): 1200 data bytes
36 bytes from 10.10.20.121: frag needed and DF set (MTU 1119)
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 04cc af90   2 0000  40  01 a809 10.10.20.122  172.17.20.2

36 bytes from 10.10.20.121: frag needed and DF set (MTU 1119)
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 04cc af91   2 0000  40  01 a808 10.10.20.122  172.17.20.2

^C
--- 172.17.20.2 ping statistics ---
2 packets transmitted, 0 packets received, 100% packet loss
```

It appears that the intermediate station cannot handle a packet larger than 1,119 bytes on its outgoing interface toward the destination, as observed by the ICMP message that is returned. Luckily, we found this out before the application was deployed, so we were able to correct this problem!

If the *outgoing* interface on an intermediate system did not contain the proper MTU size, an ICMP error message will be generated. If the *incoming* interface was configured with a smaller-than-needed MTU, the observation will be different. Since the packet is dropped at input, no ICMP MTU message will be received. Instead, oversize frame errors would increase on the intermediate system's input interface.

Looped Interfaces

Creating a physical loop on an interface has been a troubleshooting tool for many years. Since the physical path of a leased line frequently consists of multiple segments, often a problem can be localized by testing the circuit segment by segment. The idea is to create a loop at the endpoint of the circuit and send a series of tests toward that endpoint that can determine whether packets are lost or corrupted during transmission. Two types of loops are supported on most types of interfaces: a remote loop and a local loop. A *local loop* creates a loop toward the router, whereas a *remote loop* is a line loop that is created toward the downstream network device (see Figure 2-14).

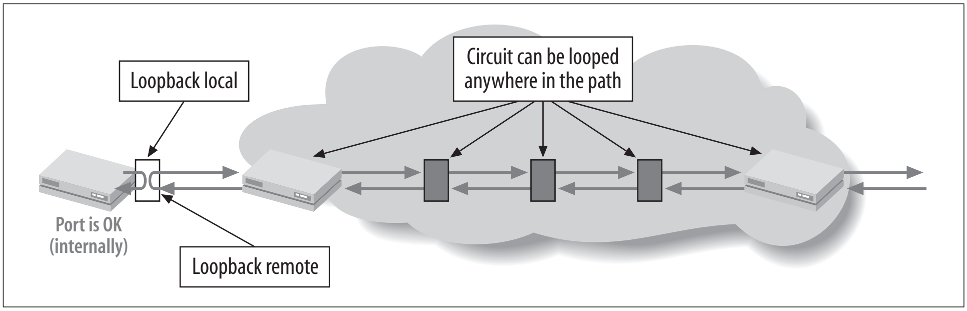


Figure 2-14. Loopback types

Often, the local LEC will go through a series of tests during the provisioning process to ensure that the circuit integrity includes loopback testing. The circuit may also be left in the looped state to avoid any local alarm generation. To see whether a loop is still in place, issue a ping toward the remote end of the circuit. If the remote end is looped (remote), the ping packets will continue until the Time to Live (TTL) expires, resulting in ICMP TTL expiration messages.

```
[edit]
doug@PBR# run ping 10.200.8.10
PING 10.200.8.10 (10.200.8.10): 56 data bytes
36 bytes from 10.200.8.9: Time to live exceeded
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 0054 30e2   0 0000  01  01 6325 10.200.8.9  10.200.8.10
```

```
36 bytes from 10.200.8.9: Time to live exceeded
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 0054 30e3   0 0000  01  01 6324 10.200.8.9  10.200.8.10

36 bytes from 10.200.8.9: Time to live exceeded
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 0054 30e6   0 0000  01  01 6321 10.200.8.9  10.200.8.10

^C
--- 10.200.8.10 ping statistics ---
4 packets transmitted, 0 packets received, 100% packet loss
```

On the remote device, a loop will be indicated (remote or local) by examining the `loopback` flag in the `show interfaces` command:

```
dougl@closing_time# run show interfaces  t1-0/0/2
Physical interface: t1-0/0/2, Enabled, Physical link is Up
  Interface index: 139, SNMP ifIndex: 37
  Link-level type: Cisco-HDLC, MTU: 1504, Clocking: Internal, Speed: T1,
  Loopback: Remote, FCS: 16, Framing: ESF
  Device flags   : Present Running
  Interface flags: Point-To-Point SNMP-Traps 16384
  Link flags     : No-Keepalives
  CoS queues     : 8 supported
  Last flapped   : 2007-04-17 16:55:37 UTC (00:02:01 ago)
  Input rate     : 200 bps (0 pps)
  Output rate    : 224 bps (0 pps)
  DS1   alarms   : None
  DS1   defects  : None
```

Conclusion

An interface is the fundamental building block of any router with a large variety of possible interface types. Although JUNOS software allows for many different interface types, the general configuration process is consistent across each type. This also helps when it is time to troubleshoot the problem interface. The specifics of the media signals will vary, but the operational commands used are the same. Once a router has all its interfaces, operational routes to remote networks can be configured via routing protocols. We will examine these protocols in subsequent chapters.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- Identify valid options for interface names, logical units, and protocol families within the JUNOS software.
- Describe how to monitor interfaces in real time.
- Describe the information contained within the `show interfaces extensive` command.

- Describe the uses of network utilities such as ping and traceroute.
- Configure MLPPP.
- Configure IPv4 addressing.
- Implement Frame Relay.
- Create VLAN-tagged interfaces.
- Provide redundancy and high availability with VRRP.
- Link bundling and aggregated interfaces.
- Establish point-to-point or point-to-multipoint links with a variety of Layer 2 encapsulations.

Chapter Review Questions

1. On a J-series router interface, what are the possible values for the PIC slot number?
    a. 1
    b. 0
    c. Variable, depending on the physical location of the interface
    d. A range of 0–4
2. Which two interfaces are considered permanent interfaces on a Juniper Networks router? (Choose two.)
    a. `lo0`
    b. `fe-0/1/0`
    c. `fxp3`
    d. `fxp0`
    e. `loopback0`
3. On a point-to-point interface, which logical unit(s) can be assigned to an interface?
    a. None
    b. 4095
    c. 100
    d. 0
4. Which interface name indicates that it is a serial interface in a J-series router that is located in PIM slot 1 and port number 1?
    a. `se-1/1`
    b. `se-1/0/1`
    c. `serial1/1`
    d. `se-0/1/1`

5. Which JUNOS software command allows for real-time display of interface statistics?

    a. `monitor interface`

    b. `show interface statistics`

    c. `monitor traffic`

    d. `monitor statistics`

6. True or False: an interface must be administratively enabled before it is operationally in the up status.

7. What is the default Layer 2 encapsulation for a serial interface?

    a. SDLC

    b. HDLC

    c. X.121

    d. PPP

8. What is the maximum number of interfaces that can be added to an MLPPP bundle?

    a. 8

    b. 6

    c. 16

    d. 4

9. What is the default clocking mode on a serial interface?

    a. DCE

    b. Internal

    c. Loop

    d. DTE

10. Which CLI command would administratively disable the `fe-0/0/0` interface?

    a. `no shutdown`

    b. `set interface fe-0/0/0 disable`

    c. `deactivate interface fe-0/0/0`

    d. `disable interface fe-0/0/0`

11. True or False: all Juniper Networks routers contain an `fxp0` OoB management interface.

12. Which type of interface would be used to create a GRE tunnel?

    a. `gre`

    b. `tunnel.0`

    c. `gr`

    d. `ip.0`

Chapter Review Answers

1. Answer: B. J-series routers do not contain PICs, so this value in the interface name is always set to zero and is sometimes referred to as the virtual PIC value.
2. Answer: A, D. `fe-0/1/0` is a transient interface, whereas `fxp3` and `loopback0` are invalid media types.
3. Answer: D. A point-to-point interface has only one valid logical unit number, which is unit 0.
4. Answer B. Every transient interface always takes the form of MM-F/P/T, with F indicating the PIM slot and T representing the port number.
5. Answer: A. The `monitor statistics` command in an invalid command, whereas `monitor traffic` displays local TCP/IP traffic and `show interfaces` does not display information dynamically.
6. Answer: False. Juniper interfaces are always administratively enabled when installed.
7. Answer: D. The default encapsulation is PPP on all point-to-point interfaces.
8. Answer: A. As of JUNOS software version 8.3, eight interfaces are allowed in a single bundle.
9. Answer: C. A serial interface always attempts to obtain its transmit timing from the line itself, using what is called *loop timing*. Other valid options that can be configured include `internal` and `dce`. DTE is not a configurable option.
10. Answer: B. The only other valid JUNOS software command listed in the answer choices is the `deactivate` command. This command comments out the configuration that the running system will ignore.
11. Answer: False. Only M/T series routers contain an `fxp0` OoB management interface. J-series routers must be managed via console, auxiliary ports, or regular PFE interfaces.
12. Answer: C The software pseudointerface that is used to create GRE tunnels is the `gr` interface. The `gre` interface is used internally by the router and should not be configured. The `ip.0` and `tunnel.0` interfaces are not valid interface types.

CHAPTER 3

Protocol Independent Properties and Routing Policy

This chapter is divided into two main sections. The first section details routing capabilities and features that are not specific to any particular routing protocol, hence the phrase *protocol independent*. Although termed *independent*, these features often interact with one or more routing protocols, and in some cases may be required for proper protocol operation! The second half of the chapter investigates JUNOS software routing policy. Routing policy provides a toolbox that facilitates the control of route distribution, including route filtering and route attribute manipulation.

In many cases, you combine the functions of Protocol Independent Properties (PIPs) and routing policy to achieve some goal. For example, a static route is defined using PIP, but this same static route can then be redistributed, perhaps with a modified attribute such as a route tag or Border Gateway Protocol (BGP) community, as a result of routing policy.

This chapter exposes the reader to PIP and routing policy in a manner that is analogous to a mechanic being introduced to each tool comprising a complete toolbox. To continue the analogy, the ways in which tools can be used, either alone or in combinations, are virtually limitless. For example, your hammer can be used as part of the repair of a hole in a boat's hull, or it can be used to make the hole, perhaps in an effort to scuttle the craft. Although the boat may have some opinion, it's safe to say that the tool—the hammer, in this case—is just happy to be used, with no real concern as to the nature of the task.

The routing and service examples covered in subsequent chapters of this book all make use of the PIP and policy tools to solve some requirement specific to the example being discussed in that chapter. Since practical PIP and policy-related applications are provided throughout the remainder of this book, the goal of this chapter is to expose the reader to the general capabilities and configuration of PIP and policy so that subsequent case study examples are fully understood.

The PIP topics include:

- Static, aggregated, and generated routes
- Global preference
- Martian routes
- Route tables and routing information base (RIB) groups
- Autonomous system (AS) number and router ID

Routing policy topics include:

- Policy overview, import and export policy
- Policy components (terms, match conditions, actions, policy chains)
- Route filters
- Advanced policy concepts

Protocol Independent Properties

PIPs are used for a variety of functions, such as static and aggregate routes, protocol preferences, route tables, router ID, and so forth. The range of PIPs is configured at the `[edit routing-options]` hierarchy.

Static, Aggregate, and Generated Routes

Although the use of static routing is sometimes considered bad form, especially during a routing-protocol-based practical examination, there are many practical applications for static routes, along with their aggregate/generated counterparts.

Static routing suffers from a general lack of dynamism (though Bidirectional Forwarding Detection [BFD] can mitigate this issue), which often leads to loss of connectivity during network outages due to the inability to reroute. Static routes can quickly become maintenance and administration burdens for networks that have frequent adds, moves, or changes. With that said, static routing is often used at the network edge to support attachment to stub networks, which, given their single point of entry/egress, are well suited to the simplicity of a static route.

Static routes are often used to promote stability through advertisement into a routing protocol, such as BGP, where a single route that is always up is used to represent the connectivity of numerous, more specific routes, which individually may come and go (flap) due to instability in the attached network's infrastructure. By suppressing the specifics in favor of a single static route, the world is shielded from the day-to-day flapping while overall connectivity is preserved.

Static, aggregate, and generated routes are similar in that all are defined statically, and all can have mask lengths that represent *super-nets* (aggregated network prefixes), or *subnets* (extending the network ID into the host field of a classful address to gain more networks, each with fewer hosts). As such, there is often confusion about the differences, and why all three types of static routing are needed. Table 3-1 summarizes how these route types differ.

Table 3-1. Static, aggregate, and generated route comparison

Route type	Next hop type	Comment
Static	Discard, reject, IP/interface next hop, label-switched path (LSP) next hop	Global preference of 5; can be used for forwarding. Supports qualified and indirect next hops. Activated by valid next hop.
Aggregate	Reject (default), discard	Global preference of 130; not used for forwarding, activated by contributing route. Default reject for matching traffic.
Generated	Preferred contributer (default) or discard	Default forwarding next hop based on prefered contributer.

Next hop types

Static and aggregate routes support various next hop types, some of which provide forwarding and others which do not. Understanding the differences between one next hop type and another is critical to achieving desired goals. Here are the specifics for each type of next hop:

Discard

A discard next hop results in the silent discard of matching traffic. *Silent* here refers to the fact that no Internet Control Message Protocol (ICMP) error message is generated back to the source of the packet. You normally choose a discard next hop when the goal is to advertise a single aggregate that represents a group of prefixes, with the expectation that any traffic attracted by the aggregate route will longest-match against one of the more specific routes, and therefore be forwarded according to the related next hop rather than the reject or discard next hop of the aggregate route itself.

The use of discard is best current practice when advertising an aggregate because the generation of ICMP error messages can consume system resources and may end up bombarding an innocent third party, as in the case of spoofed source addressing as part of a distributed denial of service (DDoS) attack.

Reject

A reject next hop results in the generation of an ICMP error message reporting an unreachable destination for matching traffic. This is the default next hop type of an aggregated route and for a generated route when it has no contributors.

Forwarding

A forwarding next hop is used to move traffic to a downstream node, and it is typically specified as the IP address of a directly connected device. Matching traffic is then forwarded to the specified next hop. On a multiaccess network such as a LAN, this involves the resolution of the IP address to a link layer address through the Address Resolution Protocol (ARP) or some form of static mapping.

When directing traffic over a point-to-point interface, the next hop can be specified as an interface name; however, LAN interface types require an IP address next hop due to their multipoint nature.

Forwarding next hop qualifiers. When defining a static route with a forwarding next hop, you can use qualifiers that influence how the next hop is resolved and handled. Specifically:

`resolve`
: The `resolve` keyword allows you to define an indirect next hop for a static route, which is to say an IP forwarding address that does not resolve to a directly connected interface route. For example, you could specify a static route that points to a downstream neighbor's loopback address. In this case, matching traffic will result in a recursive lookup against the specified (`lo0`) next hop to select a directly connected forwarding next hop. If a parallel connection exists, the failure of the currently used link results in a new recursive lookup and selection of the remaining link for packet forwarding.

`qualified-next-hop`
: The `qualified-next-hop` keyword allows you to define a single static route with a list of next hops that are individually qualified with a preference. In operation, the most preferred qualified next hop that is operational—that is, the next hop can be resolved and the interface that is operational is used. When that next hop is no longer usable, the next-best-qualified next hop is selected. That is to say, when the primary link is down, the router selects the next preferred next hop, which may point to a low-speed backup facility.

Static versus aggregate routes

Simply realizing that an aggregate/generated route supports a subset of the next hop options supported by a simple static route does not really explain the real operational mode differences between these route types. A static route is active whenever it has a viable next hop. This next hop can take the form of discard/reject, which effectively nails the route up.

Aggregates need contributing routes. In contrast, both aggregate and generated routes require at least one *contributing* route to become active. A contributing route is simply a more specific route that is learned through some other mechanism, such as static definition or dynamic learning through a protocol such as Open Shortest Path First (OSPF). A route is more specific, and is therefore able to contribute to an aggregate route (when it has a mask length longer than the associated aggregate) while sharing the same prefix as the aggregate (as indicated by the aggregate route's mask length). For example, the aggregate route 10.1/16 can be activated by route 10.1.1/24 because it has a longer (more specific) mask and shares the same 16 high-order prefix bits as the aggregate route. In contrast, the route 10.2.2/24 does not contribute to a 10.1/16 aggregate as it does not share the same aggregate prefix.

You can use routing policy to filter the set of routes that are allowed to contribute to an aggregate, which helps you control when the corresponding aggregate becomes active. Because only active routes are subject to routing policy, this in turn can influence when a given aggregate is advertised in a routing protocol. For example, you can filter all other contributes so as to advertise an aggregate for 10.1/16 into BGP based strictly on the absence or presence of a 10.1.1.0/30 route. By default, the preferred or primary contributing route is selected from the pool of viable candidates based on global preference. To break preference ties, the numerically smallest contributing route is preferred.

A given route can contribute only to a single aggregate route. However, an active aggregate route can recursively contribute to a less specific matching aggregate route. For example, an aggregate route to the destination 10.1.0.0/16 can contribute to an aggregate route to 10.0.0.0/8.

Aggregate versus generated routes

People often get confused about aggregate and generated routes—because both require contributors to become active and both are assigned the same routing preference of 130. The key difference between the two types of routes is that an aggregate route is *never* used for forwarding. Although it may attract plenty of traffic, the next hop of an aggregate route is either a discard or a reject—no ifs, ands, or buts. In contrast, a generated route installs the next hop associated with the preferred contributor, and therefore can be used to forward matching traffic. For this reason, a generated route is sometimes called a route of last resort. This is because in the general case, traffic typically matches a more specific route and is routed appropriately, just as in the case of an aggregate route—when the most specific (longest) match is against the generated route itself, it is forwarded to a gateway of last resort, as identified by the next hop associated with the currently preferred contributor route.

These operational differences are shown via the command-line interface (CLI) at Cider using a 10.10/16 aggregate versus a 10.10/16 generated route:

```
[edit routing-options]
lab@Cider# show aggregate
route 10.10.0.0/16;

[edit routing-options]
lab@Cider# run show route protocol aggregate detail

inet.0: 10 destinations, 10 routes (10 active, 0 holddown, 0 hidden)
10.10.0.0/16 (1 entry, 1 announced)
        *Aggregate Preference: 130
                Next hop type: Reject
                Next-hop reference count: 2
                State: <Active Int Ext>
                Age: 1:50
                Task: Aggregate
                Announcement bits (1): 0-KRT
                AS path: I (LocalAgg)
                Flags:                  Depth: 0        Active
                AS path list:
                AS path: I Refcount: 2
                Contributing Routes (2):
                        10.10.11.0/24 proto Direct
                        10.10.12.1/32 proto Direct
```

A 10.10/16 aggregate is activated by the presence of directly connected routes that contribute to the aggregate. Direct routes for multiaccess networks cannot contribute to an aggregate because a forwarding next hop can not be derived from the mere presence of the local interface, as is possible in the case of a point-to-point link, where the interface itself can be specified as a next hop.

To reiterate, a generated route remains hidden when only direct multiaccess routes are present to contribute:

```
[edit routing-options]
lab@Cider# show generate
route 10.10.0.0/16;

[edit routing-options]
lab@Cider# run show route protocol aggregate detail hidden

inet.0: 10 destinations, 10 routes (9 active, 0 holddown, 1 hidden)
10.10.0.0/16 (1 entry, 0 announced)
         Aggregate
                Next hop type: Reject
                Next-hop reference count: 1
                State: <Hidden Int Ext>
                Age: 3:10
                Task: Aggregate
                AS path: I
                            Flags: Generate Depth: 0        Inactive
```

This is because the next hop for a generated route is based on the forwarding next hop of the preferred contributor, and for a multiaccess type of network, this requires a static or learned route that identifies a next hop on one of the direct interface routes. In this example, a static route with a forwarding next hop pointing out `Cider`'s `fe-0/0/1.100` interface toward `Bock` is used to activate the generated route:

```
[edit routing-options]
lab@Cider# set static route 10.10.1/24 next-hop 10.10.11.1

[edit routing-options]
lab@Cider# commit
commit complete

[edit routing-options]
lab@Cider# run show route 10.10.1/24 detail

inet.0: 11 destinations, 11 routes (11 active, 0 holddown, 0 hidden)
```

```
10.10.1.0/24 (1 entry, 1 announced)
        *Static Preference: 5
                Next-hop reference count: 5
                Next hop: 10.10.11.1 via fe-0/0/1.100, selected
                State: <Active Int Ext>
                Age: 17
                Task: RT
                Announcement bits (2): 0-KRT 1-Aggregate
                AS path: I

[edit routing-options]
lab@Cider# run show route protocol aggregate detail

inet.0: 11 destinations, 11 routes (11 active, 0 holddown, 0 hidden)
10.10.0.0/16 (1 entry, 1 announced)
        *Aggregate Preference: 130
                Next-hop reference count: 5
                Next hop: 10.10.11.1 via fe-0/0/1.100, selected
                State: <Active Int Ext>
                Age: 11:34
                Task: Aggregate
                Announcement bits (1): 0-KRT
                AS path: I
                              Flags: Generate Depth: 0        Active
                Contributing Routes (1):
                        10.10.1.0/24 proto Static
```

Note that both the 10.10.1.0/24 static route and the resultant generated route share the same forwarding next hop. As the only viable contributing route, the 10.10.1.0/24 route is the preferred contributor in this example.

Route attributes and flags

When you define a static route, you can include various route attributes such as AS path, BGP community, route tag, metric, and so forth. These attributes may or may not come into play later when the route is redistributed into a specific routing protocol. For example, OSPF has no notion of a BGP community or AS path, and therefore these attributes are not injected into OSPF despite being attached to the route. The route attributes can be defined individually for each route or as part of a default template that is inherited by all related routes, unless specifically overwritten by a competing attribute.

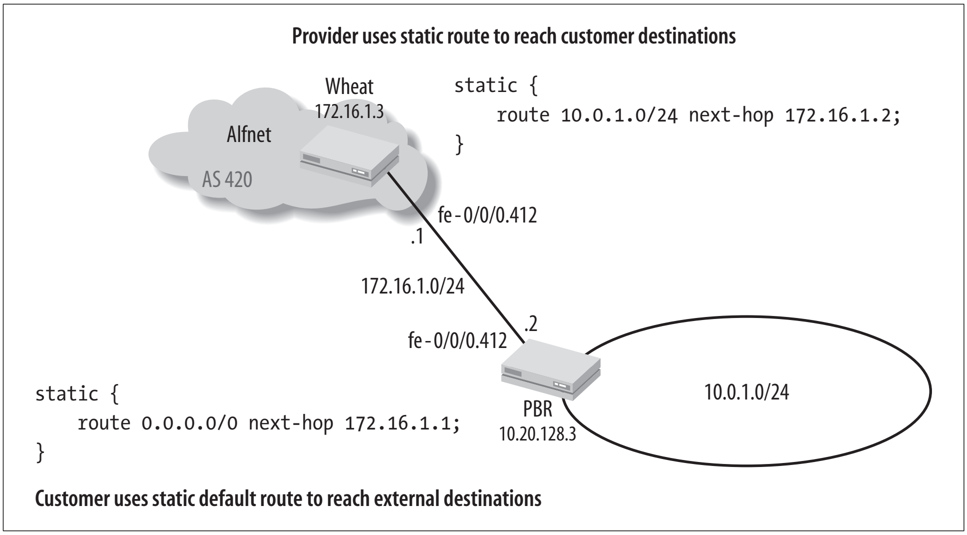
You can also attach flags to a static route that controls various aspects of how the route is handled or operates. For example, the `no-advertise` flag prevents the associated route from being exported into routing protocols, even when the policy configuration otherwise selects that route for redistribution. You can display the list of available route attributes and flags with the CLI's ? feature:

```
lab@Cider# set static route 10/8 ?
Possible completions:
  active               Remove inactive route from forwarding table
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
> as-path              Autonomous system path
> bfd-liveness-detection  Bidirectional Forwarding Detection (BFD) options
> color                Color (preference) value
> color2               Color (preference) value 2
+ community            BGP community identifier
  discard              Drop packets to destination; send no ICMP unreachables
  install              Install route into forwarding table
> lsp-next-hop         LSP next hop
> metric               Metric value
> metric2              Metric value 2
> metric3              Metric value 3
> metric4              Metric value 4
+ next-hop             Next hop to destination
  next-table           Next hop to another table
  no-install           Don't install route into forwarding table
  no-readvertise       Don't mark route as eligible to be readvertised
  no-resolve           Don't allow resolution of indirectly connected next hops
  no-retain            Don't always keep route in forwarding table
  passive              Retain inactive route in forwarding table
> preference           Preference value
> preference2          Preference value 2
> qualified-next-hop   Next hop with qualifiers
  readvertise          Mark route as eligible to be readvertised
  receive              Install a receive route for the destination
  reject               Drop packets to destination; send ICMP unreachables
  resolve              Allow resolution of indirectly connected next hops
  retain               Always keep route in forwarding table
> tag                  Tag string
> tag2                 Tag string 2
```

The reader is encouraged to consult JUNOS software documentation at *http://www.juniper.net/techpubs/software/junos/junos81/swconfig81-routing/html/routing-tables-config.html* for details on the various attributes and flags that can be attached to static or aggregated routes. The commonly used attributes are demonstrated either in this chapter or within the various scenarios demonstrated throughout this book. Figure 3-1 illustrates a typical application of a static route via a sample routing topology.

Global Route Preference

Routing information can be learned from multiple sources. In order to break ties among equally specific routes learned through multiple sources, each source is assigned a global preference. It can be said that the global preference determines the overall believability or “goodness” of a routing source. As such, routes that are learned through local administrative action—for example, static routes—are more believable than the same routes learned through a routing protocol such as OSPF. In Cisco IOS, this concept is called *administrative distance*. Table 3-2 shows the default protocol preferences for JUNOS software.



Provider uses static route to reach customer destinations

```
static {
    route 10.0.1.0/24 next-hop 172.16.1.2;
}
```

```
static {
    route 0.0.0.0/0 next-hop 172.16.1.1;
}
```

Customer uses static default route to reach external destinations

Figure 3-1. Static routing configuration

Table 3-2. Global protocol preference values

Source	Purpose	Default preference
Local	Local IP address of the interface	0
Directly connected network	Subnet corresponding to the directly connected interface	0
Static	Static routes	5
RSVP	Routes learned from the Resource Reservation Protocol used in Multiprotocol Label Switching (MPLS)	7
LDP	Routes learned from the Label Distribution Protocol used in MPLS	9
OSPF internal route	OSPF internal routes such as interfaces that are running OSPF	10
IS-IS Level 1 internal route	Intermediate System-to-Intermediate System Level 1 internal routes such as interfaces that are running ISIS	15
IS-IS Level 2 internal route	Intermediate System-to-Intermediate System Level 2 internal routes such as interfaces that are running ISIS	18
Redirects	Routes from ICMP redirect	30
Kernel	Routes learned via route socket from kernel	40
SNMP	Routes installed by Network Management System through the Simple Network Management Protocol	50
Router discovery	Routes installed by ICMP Router Discovery	55
RIP	Routes from Routing Information Protocol (IPv4)	100
RIPng	Routes from Routing Information Protocol (IPv6)	100
PIM	Routes from Protocol Independent Multicast	105
DVMRP	Routes from Distance Vector Multicast	110
Aggregate	Aggregate and generated routes	130

Table 3-2. Global protocol preference values (continued)

Source	Purpose	Default preference
OSPF AS external routes	Routes from Open Shortest Path First that have been redistributed into OSPF	150
IS-IS Level 1 external route	Routes from Intermediate System-to-Intermediate System Level 1 that have been redistributed into ISIS	160
IS-IS Level 2 external route	Routes from Intermediate System-to-Intermediate System Level 2 that have been redistributed into ISIS	165
BGP	Routes from Border Gateway Protocol	170

As with a route metric, numerically lower preference values are preferred. You can alter the default preference values when needed to accommodate some specific goal, such as route redistribution during an Interior Gateway Protocol (IGP) migration, which is demonstrated in Chapter 5.

Readers familiar with Cisco Systems may note a few differences between how the two vendors assign distance/preference. For example, Cisco has a separate distance for Internal BGP (IBGP) versus External BGP (EBGP) (200 versus 20), whereas Juniper uses the same value. In this case, there is no operational impact because in the route selection process JUNOS software prefers EBGP over IBGP, resulting in the same behavior for both vendors. One area where the vendors differ is in regard to IGP versus EBGP distance. Here, Cisco assigns an OSPF IGP distance of 110; since this is higher than the EBGP distance of 20, it results in the selection of an EBGP route over an equivalent OSPF route. In the same setup, a Juniper router chooses the OSPF route, owing to the preference values shown in Table 3-2.

Although you could alter JUNOS software preference to mimic IOS behavior, Juniper created a compatibility knob for this situation, called `advertise-inactive`. When applied to an EBGP peering session, this knob results in the advertisement of the best BGP route that happens to be inactive because of IGP preference. When using the `advertise-inactive` option, the JUNOS device continues to use the OSPF copy for forwarding, and the IOS device uses the EBGP copy to forward. However, from the perspective of an EBGP peer in a neighboring AS, both vendors appear to behave the same.

Floating static routes

A floating static route is nothing more than a static route that has a modified preference, causing it to be less preferred than a dynamically learned copy. The defaults cause a static route to always be preferred over a dynamic route. A floating static route is often used to provide backup in the event of a network or protocol malfunction. When all is operating normally, the static route remains idle because the dynamically learned routing is preferred. When routing protocol disruption results in the loss of a learned route, the previously inactive static route becomes active.

The following code sample creates a floating static route by assigning a modified preference that makes the route *less* preferred than an OSPF internal route, which has a default preference of 10:

```
[edit routing-options static route 0.0.0.0/0]
lab@PBR# show
next-hop 172.16.1.1;
preference 11;

[edit routing-options static route 0.0.0.0/0]
lab@PBR# run show route 200.0.0.0

inet.0: 12 destinations, 12 routes (12 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[Static/11] 00:00:06
                    > to 172.16.1.1 via fe-0/0/0.412
```

Martian Routes

JUNOS software supports the concept of martian routes, which is a euphemistic way to describe a route that should not be present. Most network operators consider local use addressing, as defined in RFC 1918, "Address Allocation for Private Internets," as an example of martian routes, at least when received outside of the context of a virtual private network (VPN).

Routes contained in the martian table are excluded from route update processing, which prevents them from ever being installed into the route table. The martian mechanism provides a consolidated way to filter bogus routing information from all protocol sources without the use of explicit policy.

You can display martian entries with a `show route martians` command. In this example, only entries for the main `inet.0` route table are displayed through the `table` keyword:

```
[edit routing-options]
lab@Bock# run show route martians table inet.0

inet.0:
             0.0.0.0/0 exact -- allowed
             0.0.0.0/8 orlonger -- disallowed
             127.0.0.0/8 orlonger -- disallowed
             128.0.0.0/16 orlonger -- disallowed
             191.255.0.0/16 orlonger -- disallowed
             192.0.0.0/24 orlonger -- disallowed
             223.255.255.0/24 orlonger -- disallowed
             240.0.0.0/4 orlonger -- disallowed
```

The default entries permit private use of RFC 1918 private addressing space while filtering prefixes that should never appear in a route update—for example, the 127.0.0.1 loopback address or the IANA reserved 192.0.0.0/24 network block. You can add entries to the table, which can later be removed using `set` and `delete`, respectively.

You cannot explicitly remove predefined martian entries, but you can add new entries that negate their effect. For example, rather than trying to delete the `0/0 exact allow` entry, you negate its effect by *adding* a new entry with a competing action. For instance, the default martian table allows the default route, which in this example is being advertised via OSPF from `Bock` to `Cider`:

```
[edit]
lab@Cider# run show route protocol ospf

inet.0: 11 destinations, 11 routes (11 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/150] 00:00:07, metric 0, tag 0
                    > to 10.10.11.1 via fe-0/0/1.100
. . .
224.0.0.5/32       *[OSPF/10] 00:00:27, metric 1
                      MultiRecv
```

The martian table for the `inet.0` route table is modified with a `set 0/0 exact deny` statement, which overrides the previous entry for the 0/0 exact route. Note that a `deny` action is the default for any entry in the martian table:

```
[edit routing-options martians]
lab@Cider# set 0/0 exact

[edit routing-options martians]
lab@Cider# show
0.0.0.0/0 exact;
```

After the change is committed, the results are confirmed:

```
[edit routing-options martians]
lab@Cider# run show route martians table inet.0

inet.0:
             0.0.0.0/0 exact -- disallowed
             0.0.0.0/8 orlonger -- disallowed
             127.0.0.0/8 orlonger -- disallowed
             128.0.0.0/16 orlonger -- disallowed
             191.255.0.0/16 orlonger -- disallowed
             192.0.0.0/24 orlonger -- disallowed
             223.255.255.0/24 orlonger -- disallowed
             240.0.0.0/4 orlonger -- disallowed

[edit routing-options martians]
lab@Cider# run show route protocol ospf | match 0.0.0.0
```

The lack of an OSPF-learned default route at `Cider` confirms the modified martian table results in ignoring routing information for the 0/0 route.

Routing Tables and RIB Groups

All JUNOS-based routers maintain a number of route tables that are used for specific purposes. In addition to the automatically created tables, you can create your own route tables, either indirectly through the use of virtual routers or Layer 2/Layer 3 VPNs and the related Virtual Route and Forwarding (VRF) tables, or directly through the use of RIB groups.

Generally speaking, each route table/RIB populates a designated portion of the forwarding table. This creates a single forwarding table that is partitioned based on a specific route table context. Packets are forwarded based on this route table context, which allows for distinct forwarding behavior on a per-route-table basis. It's a key component of any VPN type of service, where per-VRF (per VPN site) route tables are maintained along with a corresponding VPN-specific forwarding table context.

You can view the contents of a particular route table using the command `show route table <table name>`. The general naming convention for route tables takes the form of the protocol family such as `inet` (Internet) or `inet6`, `iso` (ISO), or `mpls`, followed by a period and a nonnegative integer. Routing instance table names are somewhat the exception here, taking the form of `instance-name.inet.0`, where the first part consists of a user-assigned symbolic name, followed by the protocol family and table ID, which is `inet.0` in this example.

Default route tables

The default route tables created by JUNOS software include:

`inet.0`

The `inet.0` table is the default unicast route table for the IPv4 protocol. This is the main route table used to store unicast routes such as interface local/direct, static, or dynamically learned routes.

`inet.1`

The `inet.1` table serves as a multicast forwarding cache. This table constrains the various IPv4 (S,G) group entries that are dynamically created as a result of join state.

`inet.2`

The `inet.2` table houses unicast routes that are used for multicast reverse path forwarding (RPF) lookup, typically as learned through MP-BGP using SAFI 2. The IPv4 unicast routes stored in this table can be used by multicast protocols such as the Distance Vector Multicast Routing Protocol (DVMRP), which requires a specific RPF table. In contrast, PIM does not need an `inet.2` because it can perform RPF checks against the `inet.0` table. You can import routes from `inet.0` into `inet.2` using RIB groups, or install routes directly into `inet.2` from a multicast routing protocol.

`inet.3`
: The `inet.3` table contains MPLS LSP information. This table contains the egress address of the MPLS LSP, along with the LSP name and outgoing interface, and is populated by both RSVP and LSP. The `inet.3` table is used when the local router functions as the ingress to an LSP.

`instance_name.inet.0`
: When you configure a VRF or VR routing instance, the resultant instance creates a route table based on the routing instance's name. For example, defining a Layer 3 VPN instance called `ce1` results in the creation of a route table named `ce1.inet.0`. A routing instance differs from a logical router in that various routing instances share a single instance of the routing protocol daemon (rpd), whereas each LR gets its *own* instance of rpd, which in turn provides greater isolation. Note that LRs are not supported on J-series platforms with the 8.0 release used to write this book.

`inet6.0`
: The `inet6.0` table is used to house IPv6 unicast route tables.

`bgp.l3vpn.0`
: The `bgp.l3vpn.0` table contains routes learned from other Provider Edge (PE) routers in a Layer 3 VPN environment via BGP. Routes in this table are copied into a particular Layer 3 VRF when there is a matching route table.

`bgp.l2vpn.0`
: The `bgp.l2vpn.0` table contains routes learned from other PE routers in a Layer 2 VPN environment via BGP. The related Layer 2 routing information is copied into Layer 2 VRFs based on matching target communities.

`mpls.0`
: The `mpls.0` table houses the MPLS label-switching operations used when the local router is acting as a transit label-switching router (LSR) in support of LSPs.

`iso.0`
: The `iso.0` table houses IS-IS routes, which consist of a network entity title (NET) and a host ID. When using IS-IS in support of IP routing, you can expect to see only the local router's NET, which is typically assigned to the loopback interface, because in this context the IS-IS protocol is used to convey IP, not IS-IS routes.

`juniper_private`
: JUNOS software needs to communicate internally with service Physical Interface Cards (PICs). The `juniper_private` tables are created as needed to facilitate these internal communications between the RE and service PIC hardware.

When you issue a `show route` command, all tables are listed chronologically starting with `inet.0`. Within each table, you will also see the total number of routes in the table and a listing further breaking down active routes and hidden routes. The following sample output from a `show route` command displays many of the tables described earlier, and it is taken from a router configured to support a BGP-signaled Layer 3 VPN using RSVP-based LSP transport. The router also has the `inet6` and `iso` families enabled on its loopback interface.

The purpose of the following output display is simply to show a real-world example in which many of the default route tables are populated and used. The specific details of which routes are present or how a given entry in some particular table is actually used, are not the focus here, hence a related topology diagram is not needed for the purpose of simply observing the presence of multiple route tables. Subsequent chapters in this book expand on these specifics as needed in the context of enterprise routing:

```
user@L3_VPN_router> show route

inet.0: 23 destinations, 23 routes (22 active, 0 holddown, 1 hidden)
+ = Active Route, - = Last Active, * = Both

1.12.1.0/24        *[Direct/0] 00:33:41
                    > via ge-1/0/0.0
1.12.1.1/32        *[Local/0] 00:33:41
                      Local via ge-1/0/0.0
. . .
10.255.66.50/32    *[OSPF/10] 00:32:53, metric 1
                    > to 1.12.1.2 via ge-1/0/0.0
. . .
192.168.64.0/21    *[Direct/0] 5d 02:42:28
                    > via fxp0.0
192.168.66.47/32   *[Local/0] 5d 02:42:28
                      Local via fxp0.0
192.168.102.0/23   *[Static/5] 5d 02:42:28
                    > to 192.168.71.254 via fxp0.0
. . .
224.0.0.5/32       *[OSPF/10] 00:33:41, metric 1
                      MultiRecv

__juniper_private1__.inet.0: 2 destinations, 2 routes (2 active,
0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.0.0.0/8         *[Direct/0] 5d 02:41:34
                    > via fxp1.0
10.0.0.4/32        *[Local/0] 5d 02:42:28
                      Local via fxp1.0

__juniper_private2__.inet.0: 1 destinations, 1 routes (0 active,
0 holddown, 1 hidden)

ce1.inet.0: 3 destinations, 3 routes (3 active, 0 holddown,
0 hidden)
+ = Active Route, - = Last Active, * = Both

1.1.1.0/24         *[Direct/0] 00:33:41
                    > via fe-1/2/0.0
```

```
1.1.1.2/32         *[Local/0] 00:33:41
                      Local via fe-1/2/0.0
10.255.66.52/32    *[BGP/170] 00:33:24, localpref 100
                      AS path: I
                    > to 1.1.1.1 via fe-1/2/0.0

iso.0: 1 destinations, 1 routes (1 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

47.0005.80ff.f800.0000.0108.0001.0102.5506.6047/152
                   *[Direct/0] 5d 02:42:28
                    > via lo0.0

mpls.0: 3 destinations, 3 routes (3 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0                  *[MPLS/0] 00:33:41, metric 1
                      Receive
1                  *[MPLS/0] 00:33:41, metric 1
                      Receive
2                  *[MPLS/0] 00:33:41, metric 1
                      Receive

inet6.0: 2 destinations, 2 routes (2 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

abcd::10:255:66:47/128
                   *[Direct/0] 5d 02:42:28
                    > via lo0.0
fe80::2a0:a5ff:fe12:47ed/128
                   *[Direct/0] 5d 02:42:28
                    > via lo0.0

__juniper_private1__.inet6.0: 4 destinations, 4 routes (4 active,
0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

fe80::/64          *[Direct/0] 5d 02:41:34
                    > via fxp1.0
fe80::200:ff:fe00:4/128
                   *[Local/0] 5d 02:42:28
                      Local via fxp1.0
fec0::/64          *[Direct/0] 5d 02:41:34
                    > via fxp1.0
fec0::a:0:0:4/128  *[Local/0] 5d 02:42:28
                      Local via fxp1.0
```

User-defined RIBs and RIB groups

You can define additional route tables with the rib keyword. This capability is rarely used, but it is demonstrated here for completeness. In the following example, the user has configured a custom IPv4 RIB called inet.69, in which a single static route had been defined:

```
[edit routing-options]
lab@PBR# show
rib inet.69 {
    static {
        route 10.1.0.0/16 discard;
    }
}
```

The contents of the user-defined RIB are displayed with a `show route table <table name>` command:

```
[edit routing-options]
lab@PBR# run show route table inet.69

inet.69: 1 destinations, 1 routes (1 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.1.0.0/16        *[Static/5] 00:15:53
                      Discard
```

You can group together multiple route tables (RIBs) to form a *route table group*. Within a group, a routing protocol can import routes into all the route tables in the group, and it can export routes from a single route table. Simply put, RIB groups provide a way to copy routing information from one route table to another. In operation, a RIB group consists of one primary and one or more secondary route tables—the first route table specified is the *primary* route table, and any additional route tables function as *secondary* route tables. The primary route table determines the address family of the route table group. To configure an IPv4 route table group, specify `inet.0` as the primary route table. To configure an IPv6 route table group, specify `inet6.0` as the primary route table.

Each RIB group must contain one or more route tables that JUNOS software uses as the source of any imported routes, as specified with the `import-rib` statement.

In the following example, a `rib-group` called `my_interface_routes` is configured to import interface route entries from `inet.0` into `inet.2`. The `my_interface_routes` RIB group is defined under the `interface-routes` hierarchy, which specifies the protocol (direct) that is used to match against when copying the routes into `inet.2`:

```
[edit routing-options]
lab@PBR# show
interface-routes {
    rib-group inet my_interface_routes;
}
rib-groups {
    my_interface_routes {
        import-rib [ inet.0 inet.2 ];
    }
}
```

The result of the interface routes RIB group definition is confirmed with a display of the `inet.2` table both before and after the changes are committed:

```
[edit routing-options rib-groups]
lab@PBR# run show route table inet.2

[edit routing-options rib-groups]
lab@PBR# commit
commit complete
```

After the commit, the `inet.2` table is correctly populated with interface routes, as copied from the `inet.0` table:

```
[edit routing-options rib-groups]
lab@PBR# run show route table inet.2

inet.2: 11 destinations, 11 routes (11 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.130.0/24     *[Direct/0] 00:00:04
                    > via fe-0/0/0.1141
10.10.130.2/32     *[Local/0] 00:00:04
                      Local via fe-0/0/0.1141
10.20.128.3/32     *[Direct/0] 00:00:04
                    > via lo0.0
10.20.129.0/24     *[Direct/0] 00:00:04
                    > via fe-0/0/0.3141
10.20.129.2/32     *[Local/0] 00:00:04
                      Local via fe-0/0/0.3141
10.20.130.0/24     *[Direct/0] 00:00:04
                    > via fe-0/0/0.1241
. . .
```

If desired, you can use import policy to add additional control over which routes are copied between RIBs.

Router ID and Antonymous System Number

The last PIP-related configuration to be discussed is related to the router ID (RID) and BGP AS number.

Router ID

Many routing protocols require that the source of routing information be uniquely identified using the concept of a RID. A RID normally takes the form of an IPv4 address, and in most cases does not have to be reachable to correctly function as a RID. Stated differently, a router can receive a BGP or OSPF route update from a router identified as 1.1.1.1, and correctly process the related routing information, even though it may not have a route to 1.1.1.1. With that said, it is common to use a routable IP address as the RID because this can simplify operations by enabling pings or telnet to the RID.

You can specify only one RID, and the same value is used by all protocols that require a RID (OSPF, OSPFv3, and BGP). The current best practice is to base the

RID on the router's globally routable lo0 address. You explicitly configure a RID as follows:

```
[edit routing-options]
lab@PBR# set router-id 1.1.1.1

[edit routing-options]
lab@PBR# show
router-id 1.1.1.1;
```

When you explicitly configure a RID that is based on an address assigned to the router's lo0 interface, you will have to run an explicit IGP instance (typically passive) on that interface to advertise reachability to the RID, when desired. When a RID is not explicitly configured, the router obtains its RID from the primary address of the first interface that comes online. This is typically the loopback interface, when it has been assigned a nonmartian (non-127.0.0.1) address. Because changes in RID are disruptive to protocol operation, it's a good practice to manually configure a RID to ensure that changes to lo0 addressing do not cause unanticipated churn.

Historically, JUNOS software automatically advertised a stub route to the interface from which the RID is obtained. This meant that you did not need to run an IGP instance on the loopback interface to advertise reachability to the RID. Starting with JUNOS Release 8.5, this behavior has changed. Now, whether you use an explicit or an automatically generated RID that is lo0-based, you need to enable OSPF on the loopback interface to advertise reachability to the related loopback address, even when it is the source of an automatically selected RID.

Autonomous system number

An autonomous system (AS) number is required for BGP operation; you cannot commit a BGP-related configuration without also defining the local router's AS number. In this regard, it can be said that the AS number is not really protocol-independent, but for whatever reason it is configured under [routing-options], rather than under BGP itself.

Chapter 5 provides a detailed description of what an AS number is and how BGP uses it. The following is a sample AS number configuration:

```
lab@PBR# set autonomous-system ?
Possible completions:
  <as_number>          Autonomous system number (1..65535)
  loops                Maximum number of times this AS can be in an AS path
[edit routing-options]
lab@PBR# set autonomous-system 100

[edit routing-options]
lab@PBR# show
autonomous-system 100;
```

The `loops` option allows you to configure tolerance for occurrences of the local ASN in received route updates; normally such an occurrence indicates a BGP routing loop and results in the related route being discarded. There are certain corner-case scenarios, mostly related to VPNs and the support of EBGP on the PE-CE customer links, where you might need to alter the default value. Note that the default value of 1 indicates that a route with a single instance of the local ASN should be discarded. Therefore, to support reception of routes with a single instance of the local ASN, specify a loop value of 2.

Summary of Protocol-Independent Properties

This section discussed common PIPs that are typically used in enterprise networks. Topics included the creation of static, aggregate, and generated routes, along with their differences and associated various next hop options. Global preference, which is used to break ties between competing sources of routing information, was discussed, as was the configuration of a floating static route—which is simply a static route with an altered global preference that makes it less preferred than a route learned via a dynamic routing protocol. This section also described the use and purpose of the default JUNOS software route tables, and how RIBs and RIB groups are used to create and link route tables. We ended with a description of how the RID can be explicitly configured or automatically computed, in addition to how the local AS number is configured to support BGP operation.

The next section delves into JUNOS software routing policy, which provides you with complete control over route exchanges and attribute modification.

Routing Policy

This section details JUNOS software routing policy operation and configuration. The actual application of policy to solve some specific networking requirement is generally left to the protocol-specific coverage found in subsequent chapters. You configure policy-related options and statements at the `[edit policy-options]` hierarchy. Routing policy and firewall filters have a similar syntax in JUNOS software. The former deals with routes in the control plane, whereas the latter deals with packets in the data plane.

What Is a Routing Policy, and When Do I Need One?

Simply put, routing policy is used to:

- Control what routes are installed into the route table for possible selection as an active route
- Control what routes are exported from the route table, and into which protocols

- Alter attributes of routes, either at reception or at the time of advertisement to other peers

Given that routing policy is used to control the reception and transmission of routing information and to alter route attributes, it's safe to say that you need routing policy when the default policy does not meet your requirements.

The specifics of the various default policies are covered later, but to provide an example, consider that, by default, directly connected routes are not advertised into any routing protocol; in the case of RIP, not even when RIP is configured to run on those directly connected interfaces. If your goal is to get direct routes advertised into RIP, the default policy obviously does not meet your needs, and a custom policy must be written, and applied, to achieve your goal of redistributing direct routes into RIP.

Where and How Is Policy Applied?

You can apply policy in one of two places: either at import or at export. Generally speaking, use a command of the form `set protocols` *`<protocol-name>`* `import` to apply an import policy, or use `set protocols` *`<protocol-name>`* `export` to apply an export policy. Figure 3-2 illustrates this concept.

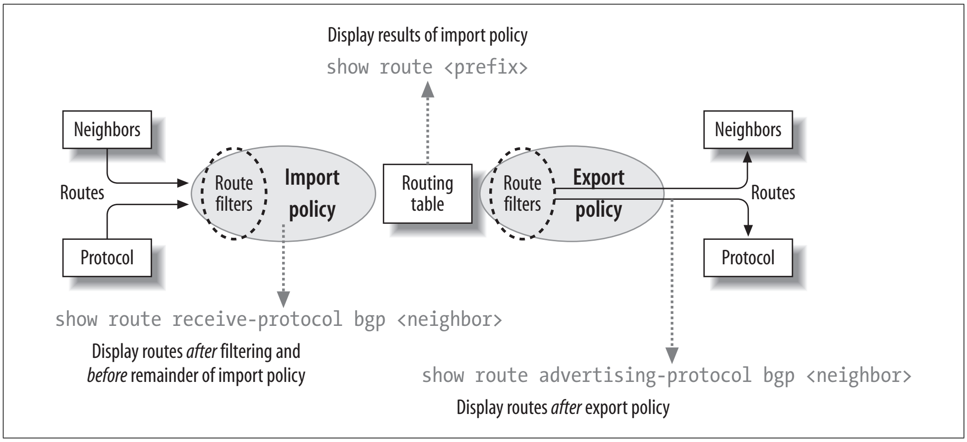

Display results of import policy
show route <prefix>
Neighbors
Routes
Protocol
Route filters
Import policy
Routing table
Route filters
Export policy
Neighbors
Routes
Protocol
show route receive-protocol bgp <neighbor>
Display routes *after* filtering and *before* remainder of import policy
show route advertising-protocol bgp <neighbor>
Display routes *after* export policy

Figure 3-2. Policy application and monitoring points

Figure 3-2 shows routes being received through some protocol, and how import policy serves to filter and adjust route attributes before they are copied into the route table. In contrast, export policy comes into play when routes are being selected from the route table for inclusion in transmitted route updates. Once again, the export policy serves to filter and adjust route attributes to meet the specific needs of the networking environment.

It is worth noting that distance vector protocols such as BGP and RIP actually support the notion of received and transmitted routes. These protocols support the `show route receiving-protocol <protocol-name> <neighbor-address>` and `show route advertising-protocol <protocol> <neighbor-address>` commands, which are very useful when troubleshooting or analyzing policy operation. Figure 3-2 shows how the receiving-protocol form of the command is used to display routes *after* route filtering, but *before* attribute manipulation. In contrast, the advertising-protocol form of the command is executed after all export policy operations, including route filtering and attribute modification. Simply issue a `show route <prefix>` command to display a route as it exists in the route table, which will include any modified attributes resulting from import policy operations.

Applying policy to link state routing protocols

Link state (LS) protocols such as OSPF and IS-IS do not send and receive routes directly. Instead, they flood link-state advertisement (LSA) packets, which are used to build a topological database from which each router computes a route table. As such, LS protocols do not support much in the way of import policy. Support for OSPF import policies that prevent installation of external routes into the route table was only recently added; and supported in the 8.0 JUNOS software release; it's interesting to note that the current (8.5) documentation has not yet caught up, and still indicates that OSPF does not support application of import policy (for more information, see *http://www.juniper.net/techpubs/software/junos/junos85/swconfig85-policy/id-10148641.html#jN1272A*). Documentation PR 262917 was raised to get this corrected, by the way.

If you wish to filter LSAs, protocol-specific mechanisms are required to ensure that LS database consistency is maintained. Chapter 4 covers the concepts of OSPF stub areas and LSA filtering.

You can apply export policy to an LS protocol to effect route redistribution, but the external route is still flooded in an LSA rather than being sent outright; the result is that the `show route receiving protocol` and `show route-advertising protocol` commands are not effective when dealing with LS protocols.

When you apply policy to an LS protocol, you do so globally, which is to say the policy is not applied to particular interfaces or areas. In the case of OSPF, you apply export policy at the `[edit protocol ospf]` hierarchy:

```
[edit protocols ospf]
lab@PBR# show
export test_export; ## 'test_export' is not defined
```

The CLI warning provides a nice reminder that the related `test_export` policy does not yet exist. Because the presence (or absence) or a policy can have a dramatic effect on overall network operation, you will not be able to commit a configuration with this type of omission. You can define a policy that is never applied—but once applied, the policy must exist before you can commit the changes.

Applying policy to BGP and RIP

Both BGP and RIP support the application of import and export policy, and both support policy application at different hierarchies. Focusing on BGP for the moment, you can apply a policy at one of three different hierarchies—global, group, or neighbor. The following code snippet provides an example of this concept:

```
[edit protocols bgp]
lab@PBR# show
export global_export;
group internal {
    export internal_export;
    neighbor 1.1.1.1 {
        export neighbor_1.1.1.1_export;
}
    neighbor 2.2.2.2;
}
group other {
    neighbor 3.3.3.3;
}
```

In this example, a policy named global_export is applied at the global level, another policy named internal_export is applied at the group level, and yet a third policy named neighbor_1.1.1.1_export is applied at the neighbor level.

A key point, and one that is often misunderstood and that can lead to problems, is that in such a configuration, *only* the most explicit policy is applied. A neighbor-level policy is more explicit than a group-level policy, which in turn is more explicit than a global policy. Hence, neighbor 1.1.1.1 is subjected only to the neighbor_1.1.1.1_export policy, whereas neighbor 2.2.2.2, lacking anything more specific, is subjected only to the internal_export policy. Meanwhile, neighbor 3.3.3.3 in group other has no group- or neighbor-level policy, so it uses the global_export policy.

So, what if you need to have neighbor 1.1.1.1 perform the function of all three policies? Simple—you could write and apply a new neighbor-level policy that encompasses the functions of the other three, or simply apply all three *existing* policies, as a chain, to neighbor 1.1.1.1. Note the use of brackets in the following command to open a set of values; if desired, each policy can be specified individually:

```
[edit protocols bgp group internal]
lab@PBR# set neighbor 1.1.1.1 export [global-export internal_export]

[edit protocols bgp]
lab@PBR# show group internal neighbor 1.1.1.1
export [ neighbor_1.1.1.1_export global_export internal_export];
```

As with access control lists (ACLs) or firewall filters, chained policy statements are evaluated in a specific left-to-right order and only up to the point when a route is either accepted or rejected. As a result, you must consider factors such as whether a policy makes use of a match-all deny term at its end, which is common for a standalone policy. However, when applied at the front of a policy chain, the match-all aspect of such a policy prevents route processing by any remaining policies. To help illustrate this point, consider two policies, one named *deny*, which denies all, and another named *accept*, which accepts all. Given the nature of the two policies, you will see a dramatic difference between these two policy chains, even though they are composed of the same parts:

```
export [accept deny];
export [deny accept];
```

Here, the first policy chain results in *all* routes being *accepted*, whereas the reverse application results in *all* routes being *denied*. You can use the CLI's insert feature to rearrange the order of applied policies, or simply delete and reapply the policies to get the order needed. Note that a newly applied policy always takes the leftmost place in a policy chain, where it becomes the first in line for route evaluation.

> We covered a few critical points here, so much so that they bear repeating in another form. The first point is that when multiple policies are applied at different CLI hierarchies for the same protocol, only the most specific application is evaluated, to the exclusion of other, less specific policy applications. Second, a given route is evaluated against a chain of policies starting with the leftmost policy, up until the route meets a terminating action of either accept or reject. This leads to ordering sensitivity of both terms within a policy, and for policies when they are chained together.
>
> Although these points always seem to make sense when you are learning them, they are somehow easily forgotten during router configuration, when two policies that individually worked as expected suddenly break when they are combined, or when you mistakenly believe that a neighbor-level policy is combined with a global or group-level policy, only to find that your policy behavior is not as anticipated.

Policy Components

Generally speaking, a policy statement consists of one or more named terms, each consisting of two parts: a `from` statement that defines a set of match criteria, and a corresponding `then` statement that specifies the set of actions to be performed for matching traffic. It is possible to create a policy with a single term, in which case the term can be unnamed, such as in these two examples:

```
[edit policy-options]
lab@PBR# show
policy-statement explicit_term {
    term 1 {
        from protocol direct;
        then accept;
    }
}
policy-statement implict_term {
    from protocol direct;
    then accept;
}
```

The two policy statements perform identical functions; both have a match criterion of `direct`, and both have an associated action of `accept`. The explicit term format is generally preferred, because new terms can be added without the need to redefine the existing term. Note that any new terms are added to the end of the policy statement, as shown here, where, oddly enough, a new term named `new` is added to the `explict_term` policy statement:

```
[edit policy-options]
lab@PBR# set policy-statement explicit_term term new from protocol direct

[edit policy-options]
lab@PBR# set policy-statement explicit_term term new then reject

[edit policy-options]
lab@PBR# show policy-statement explicit_term
term 1 {
    from protocol direct;
    then accept;
}
term new {
    from protocol direct;
    then reject;
}
```

As with policy chains, term ordering within a policy is significant. In the example, `explict_term` policy, term `1`, and term `new` are diametrically opposed, with one accepting and the other denying the same set of direct routes. Although making little practical sense, it does afford the opportunity to demonstrate term resequencing with the `insert` function:

```
[edit policy-options]
lab@PBR# edit policy-statement explicit_term

[edit policy-options policy-statement explicit_term]
lab@PBR# insert term new before term 1

[edit policy-options policy-statement explicit_term]
lab@PBR# show
term new {
    from protocol direct;
    then reject;
}
term 1 {
    from protocol direct;
    then accept;
}
```

There is no practical limit to the number of terms that can be specified in a single policy, or to how many policies can be chained together.

Logical OR and AND functions within terms

It's possible to define a term with multiple match criteria defined under a single `from` statement. For a match to occur, all of the `from` conditions must be met, which is a logical AND. However, for a specific match type, such as `protocol`, you can specify multiple values, in which case each protocol match condition functions as a logical OR. Consider this example:

```
[edit policy-options]
lab@PBR# show
policy-statement test {
    term 1 {
        from {
            protocol [ bgp rip ]; ##logical OR within brackets
            interface fe-0/0/0.0; ## logical AND with other match criteria
        }
        then next term;
    }
}
```

In this case, a match will occur when a route is learned over the `fe-0/0/0` interface *and* is learned from BGP *or* RIP.

Policy Match Criteria and Actions

JUNOS software policy provides a rich set of criteria you can match against, and an equally rich set of actions that can be performed as a result of a match. The various match and action functions are well documented, so the goal here is not to re-create the wheel by rehashing each option—as noted at the beginning of this chapter, the object is to acquaint you with a box of tools; later chapters will provide specific examples of those tools being used.

Policy match criteria

The list of available match criteria is long in the JUNOS software 8.0 release:

```
lab@PBR# set policy-statement test term 1 from ?
Possible completions:
  aggregate-contributor  Match more specifics of an aggregate
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  area                 OSPF area identifier
+ as-path              Name of AS path regular expression (BGP only)
+ as-path-group        Name of AS path group (BGP only)
  color                Color (preference) value
  color2               Color (preference) value 2
+ community            BGP community
> external             External route
```

```
  family
  instance             Routing protocol instance
+ interface            Interface name or address
  level                IS-IS level
  local-preference     Local preference associated with a route
  metric               Metric value
  metric2              Metric value 2
  metric3              Metric value 3
  metric4              Metric value 4
> multicast-scope      Multicast scope to match
+ neighbor             Neighboring router
+ next-hop             Next-hop router
  origin               BGP origin attribute
+ policy               Name of policy to evaluate
  preference           Preference value
  preference2          Preference value 2
> prefix-list          List of prefix-lists of routes to match
> prefix-list-filter   List of prefix-list-filters to match
+ protocol             Protocol from which route was learned
  rib                  Routing table
> route-filter         List of routes to match
  route-type           Route type
> source-address-filter  List of source addresses to match
+ tag                  Tag string
  tag2                 Tag string 2
```

The key takeaway here is that you can match on things such as interface, protocol, route tag, AS path, communities, source address, metric, and so on. Route filtering based on prefix and mask length is performed with the `route-filter` keyword. There is significant power (and complexity) in router filtering, and it is covered in the section "Route Filters," later in this chapter.

Policy actions

When a match occurs, a wide range of actions are available:

```
[edit policy-options]
lab@PBR# set policy-statement test term 1 then ?
Possible completions:
  accept               Accept a route
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
> as-path-expand       Prepend AS numbers prior to adding local-as (BGP only)
  as-path-prepend      Prepend AS numbers to an AS path (BGP only)
  class                Set class-of-service parameters
> color                Color (preference) value
> color2               Color (preference) value 2
> community            BGP community properties associated with a route
  cos-next-hop-map     Set CoS-based next-hop map in forwarding table
  damping              Define BGP route flap damping parameters
  default-action       Set default policy action
> external             External route
  forwarding-class     Set source or destination class in forwarding table
```

```
> install-nexthop      Choose the next hop to be used for forwarding
> load-balance         Type of load balancing in forwarding table
> local-preference     Local preference associated with a route
> metric               Metric value
> metric2              Metric value 2
> metric3              Metric value 3
> metric4              Metric value 4
  next                 Skip to next policy or term
> next-hop             Set the address of the next-hop router
  origin               BGP path origin
> preference           Preference value
> preference2          Preference value 2
  reject               Reject a route
> tag                  Tag string
> tag2                 Tag string 2
  trace                Log matches to a trace file
```

Actions include AS path prepending, changing route color (internal tie-breaker), evoking damping, altering local preference, specifying metric and community, altering a packet's forwarding class, adding a route tag, and so forth. Key actions include `accept` and `reject`, which are termination actions. The `next` keyword allows you to skip to the next term, or policy in the chain, and it is useful for shunting routes from one term or policy into another.

Route Filters

The ability to match on specific routes to accept or reject them or to modify some attribute is a critical aspect of virtually any networking scenario. The majority of JUNOS software routing policy strikes most users as intuitive and logical, given the easy-to-follow *if, then* construct of policy syntax.

The exception always seems to be route filtering, because to truly understand how this is performed in JUNOS software, you must first understand the binary radix tree nature of the route lookup table and how the binary tree is used in conjunction with route filters.

Binary trees

Binary trees have been used in computer science for several decades as a way to quickly locate a desired bit of information. In the case of route lookup, the goal is to quickly find the longest match for some prefix, with the corresponding next hop being the information that is sought. The Juniper Networks implementation of a binary tree is called the J-Tree, and it forms the basis of both route lookup and policy-based route filtering. Figure 3-3 shows the root of a binary tree, along with a few of its branches.

Figure 3-3 shows a binary to powers of a decimal chart, to help with understanding the structure of the J-Tree. For example, the binary sequence 0100 000 equates to a decimal 64, whereas 0110 0000 codes a decimal 96. In this example, bit 8, which has

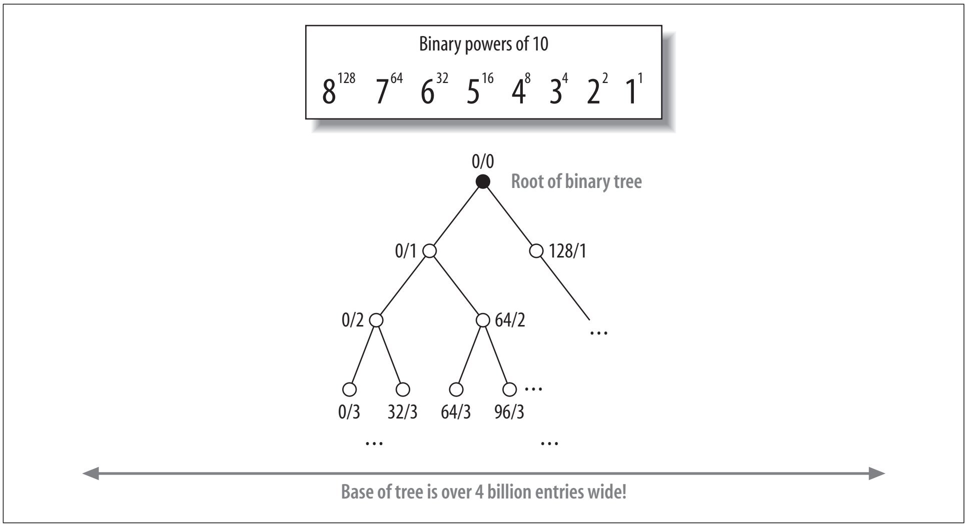


Figure 3-3. A binary tree

the decimal power of 128, represents the second set of nodes from the top of the tree. The top of the tree represents no bit, and the first pair of nodes down represents a test of the MSB, which is bit 8 in this example, as either 0 (0), or 1 (128).

The binary tree is based on nodes that test the state of a particular bit that makes up the 32-bit IP address or route prefix. The bit being tested is indicated by the related prefix (mask) length. For example, the top of the tree is testing no bits, as indicated by the /0 prefix length. All prefixes match when you do not bother to test any bits, so the top of the tree effectively represents a default route, which is to say when no other patterns match you are guaranteed to match the first node. Whether such a match, actually results in forwarding depends on whether a default route has been installed, but that is another story.

The tree branches to the left when a given bit is a 0, and it branches to the right for a 1. As a result, the first two nodes below the root represent the state of the most significant bit in the most significant byte, which is either a 0 or a 1. If it is a 0, you have a 0/1 match, which codes a decimal 0. If that bit is a 1, you have a 1/1 match, which codes a decimal 128. Each node then branches out, based on the test of the next bit, until you reach the bottom of the tree, which represents a test of all 32 bits (which is *sometimes* necessary when doing a route lookup or route filter that is based on a /32 prefix length).

In actual operation, the J-Tree is optimized and can quickly jump to a longest match when other portions of the tree are eliminated. It could be said that the act of finding a longest match against a binary tree is not so much finding what you seek as it is quickly eliminating all that cannot be what you want, and then simply looking at what is left. By way of example, a 32-bit IP address can take more than 4 billion combinations.

However, half of these (2 billion) will have a 0 in the high-order bit position, whereas the other half will have a 1. By simply testing the status of one bit, you have effectively eliminated one-half of the tree as not being possible to match. With each subsequent bit test eliminating one-half of the remaining possibilities, you quickly arrive at a node that either matches all 32 bits of the prefix, or does not match the prefix being evaluated, in which case you back up one node. That is the longest match for this prefix.

Route filters and match types

When you configure a route filter, you specify a starting prefix and initial prefix length, and then include a match type to indicate whether routes with prefixes longer than the initial value should be considered as matching. Put another way, a route filter is based on a match against the specified prefix bits, as based on the provided mask, in addition to the overall mask length of the prefix being evaluated. As such, it can be said that a Juniper route filter cares as much about the prefix *length* as it does the *prefix itself*.

Figure 3-4 illustrates the supported `route-filter` match types in the context of a J-Tree; it was said before, and is stated here again, that you cannot effectively use route filters if you do not first understand the operation of the J-Tree. This is especially true for the `through` match type, which 99.9% of the time is applied incorrectly, and therefore does *not* do what the operator wanted.

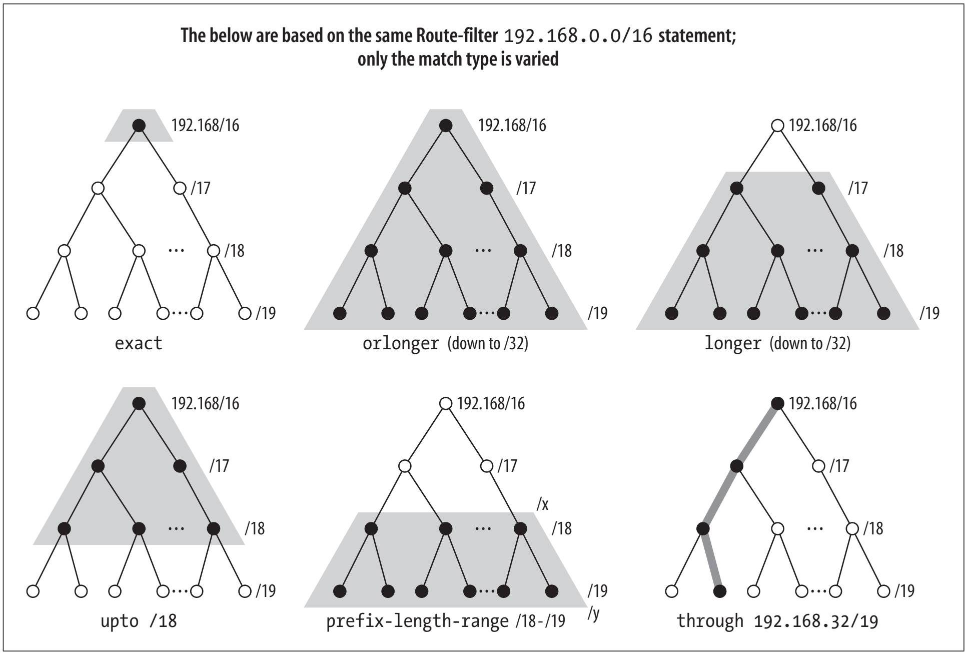

The below are based on the same Route-filter 192.168.0.0/16 statement;
only the match type is varied
192.168/16
/17
/18
/19
exact
orlonger (down to /32)
longer (down to /32)
upto /18
/x
/y
prefix-length-range /18-/19
through 192.168.32/19

Figure 3-4. Route filter match types and the J-Tree

Figure 3-4 is based on a portion of the J-Tree that represents route 192.168/16. Entries below the starting node all share the same high-order 16 bits of 192.168, but differ from the root prefix in that they have longer mask lengths, as shown by the two nodes below the first, each of which is testing bit 17, therefore indicating a /17 mask length.

Each route filter match type is described against the corresponding portion of the figure:

`exact`
: The `exact` match type is just what it sounds like. To match with `exact`, both the initial prefix bits must match, and the prefix length must be equal to the value specified. If the prefix bits do not match, or if the prefix length is either shorter or longer, the `exact` match type does not match. Figure 3-4 shows that route filter 192.168.0.0/16 `exact` matches only on that node of the J-Tree, to the exclusion of all others.

`or-longer`
: The `or-longer` match type matches the specified prefix and initial mask length and matches on prefixes with longer mask lengths when they share the same high-order bits, as indicated by the specified prefix. In this example, the result is a match against 192.168.0.0/16 itself, as well as 192.168.0/17 and 192.168.128/18 and all longer mask lengths, up to /32.

`longer`
: The `longer` match type excludes the exact match and catches all routes with the same prefix bits, but only when their masks are longer than the prefix length specified. The difference between `or-longer` and `longer` is shown in Figure 3-4, where the latter excludes the `exact` match, which is prefix 192.168.0.0/16 in this case.

`upto`
: The `upto` match type matches against the initial prefix and mask length, as well as matching prefixes with masks that are longer than the initial value, `upto` the ending mask length value. In the example, the initial prefix of 192.168.0.0/16 matches, as well as all other 192.168 prefixes that have mask lengths `upto` the specified value, which is 18 in this example. Therefore, 192.168.192/18 will match, whereas 192.168.1/24 will not.

`prefix-length-range`
: The `prefix-length-range` match type matches against routes with the same prefix as specified in the initial mask length, but only when the associated mask falls between the starting and ending values. The result is that the `exact` match is excluded, whereas routes with the same high-order prefix bits, but masks that fall within the specified range, are accepted. This match type is especially useful when the goal is to filter the route based on mask length alone, which is a common policy within service provider networks, as many refuse to carry routes with

masks longer than 28 in an effort to keep route table size manageable. To prevent installation of any route with a mask length longer than /28, you can use a `route-filter 0/0 prefix-length-range /28-/32 reject` statement. Because the initial prefix length is 0, all prefix values match, making the decision to reject one that is based strictly on mask length.

> It's worth noting that route-filter syntax supports a short form of action linking, in which the related `then` action can be specified directly on the `route-filter` line. Functionally there is no difference between the short form and adding an explicit `then` action.

`through`

The `through` match type is generally misunderstood, and it rarely works the way folks think it should. This is not to say that it is broken, but it has led to this somewhat humorous rule of thumb: "When you are thinking of using `through`, think again." In most cases, when people use `through`, what they wanted is more of the `upto` or `prefix-length-range` type of match. The statement is intended to warn the user that in most cases, `through` is not what you really want, and that the decision to use it should be carefully thought, pardon the pun, through.

A `through` match type matches the initial prefix and mask length exactly, as well as the ending prefix and mask length, and matches on the *contiguous* set of nodes between the two points. The `through` match type was originally offered to meet a corner case, in which a customer was found to be using 32 exact matches, all based on some form of a default route. Although a true default is 0/0, the customer wanted to ensure that they did not install any 0.0.0.0 prefixes, regardless of mask length. So, rather than a `0.0 exact`, `0/1 exact`, `0/2 exact` ... `0/32 exact`, the `through` match type was created to allow the same effect with a single `0/0 through 0/32` statement. This matches the top of the tree, all the way down the left side to the very bottom, and all contiguous points in between.

In Figure 3-4, the `through` match type is specified as 192.168.0.0/16 through 192.168.32.0/19. The line shows the sequence of contiguous matches between the two points, which in this case includes 192.168.0.0/16, 192.168.0.0/17, 192.168.0.0/18, and 192.168.32.0/19. Now ask yourself (and be honest) is this what you expected a 192.168/16 through 192.168.32/19 to match?

Longest match wins, but may not.... As with routing in general, route filter processing is based on finding a longest match, and then performing the action associated with that match. There are cases where this may lead to unexpected behavior because users do not always take into account the consequences of different match types. Recall that the longest-match function is based on the high-order prefix bits, whereas the match type focuses more on mask length. Consider this route-filter example, and what will happen when route 200.0.67.0/24 is evaluated against it:

```
[edit policy-options policy-statement test_me]
user@host# show
from {
    route-filter 200.0.0.0/16 longer reject;
    route-filter 200.0.67.0/24 longer;
    route-filter 200.0.0.0/8 orlonger accept;
}
then {
    metric 10;
    accept;
}
```

The question is, will route 200.0.67.0/24 match this term, and if so, is it accepted, is it rejected, or does it have its metric set to 10 before being accepted? Think carefully, and consider how longest matching is performed, along with how the match type comes into play.

If you answered "The route does not match, and is neither accepted, nor rejected, and no metric modification is made," give yourself a well-deserved pat on the back. It's quite OK if you answered differently—this little tidbit alone may well justify the expenditure for this book (you did pay for this book, right?). The key here is that the longest match, as based on specified prefix, is against the second route-filter statement—here the first 24 bits of the prefix do in fact match 200.0.67/24, which is more exact than either 200/8 or 200.0/16. However, the longest match in this example has a match type of `longer`, meaning that only a route with a mask length of /25–/32 with the 24 high-order bits set to 200.0.67 is considered to match.

Because this route has a mask length that is equal to the value specified, it does not match. A given route is only evaluated against the longest match in a given term. This is to say that if the longest match ends up not really matching, as shown in this example, other route-filter statements within that same term are not evaluated. Instead, the route falls through to the next term or policy—or lacking any of those, to the default policy for the routing protocol in question.

Default Policies

The last hurdle in understanding JUNOS software policy is to be familiar with the default policy associated with each protocol used in your network. Understanding the default policy is important because it ultimately decides the fate of any route that is not matched against in your user-defined policy. Some operators rely on the default policy to do something, and others prefer to ensure that their policy is written to match on *all* possible routes, which means the default policy is negated because it never gets a chance to come into play.

OSPF (and IS-IS) default policy

The default import policy for LS protocols is to accept all routes learned through that protocol. Recent JUNOS software releases support explicit import policy, but only for OSPF, and then *only* to filter external routes from being installed into the route table. Such an import policy does not filter external route LSAs from the database, however.

The default LS export policy is to reject everything. LSA flooding is not affected by export policy, and it is used to convey routing in an indirect manner in an LS protocol. The result of this flooding is the advertisement of local interfaces that are enabled to run OSPF, as well as the readvertisement (flooding) of LSAs received from other routers.

RIP default policy

The default RIP import policy is to accept all received RIP routes that pass a sanity check. In contrast, the default export policy is to advertise no routes. None, zip, nada, zilch. Not even RIP learned routes are advertised with the default RIP export policy. Although it may be an odd choice of default behavior, the net effect is that for any practical RIP deployment, you will need to create and apply a custom export policy to readvertise RIP learned and direct routes for interfaces running RIP to other RIP speakers.

BGP default policy

The default BGP import policy is to accept all received BGP routes that pass a sanity check—for example, those routes that do not have an AS loop, as indicated by the AS path attribute.

The default BGP export policy is to readvertise all learned BGP routes to all BGP speakers, while obeying protocol-specific rules that prohibit one IBGP speaker from readvertising routes learned from another IBGP speaker, unless it is functioning as a route reflector.

Advanced Policy Concepts

Congratulations. You have made it to this point, and therefore you now possess an in-depth and practical understanding of routing policy. This section explores some advanced policy concepts, some of which are quite interesting but rarely used. The use of regular expressions (regexes) is treated as an advanced topic, but differs from the remaining topics because the use of AS path or community regex matching is somewhat common, especially in large networks such as those operated by service providers.

Testing policy results

Making a mistake in a route-filter statement can have a dramatic impact on network stability, security, and overall operation. For example, consider the operator that does not notice that, in the following policy example (appropriately called `whoops`), rather than adding the then accept to term 1, as intended, the accept action is mistakenly added as part of a final, *unnamed* term. Because this term has no from statement, it matches on *all* possible routes and routing sources!

```
[edit policy-options]
lab@Wheat# show policy-statement whoops
term 1 {
    from {
        route-filter 0.0.0.0/0 prefix-length-range /8-/24;
    }
}
then accept; ###this action is part of an unnamed match all term!
```

Applying a broken policy such as this in a production network that deals with multiple live BGP feeds could result in network meltdown when all routes, rather than the expected subset, are suddenly advertised within your network.

JUNOS software offers a test policy feature that is designed to avoid this type of problem. You use the test command to filter routes through the identified policy to determine which routes are accepted (those displayed) versus rejected.

The test policy command is primarily useful for route-filter testing. You cannot test route redistribution policies, because the default policy for a policy test is to *accept all* protocol sources. This means that a given route filter policy might match against static routes, but the same policy when applied to BGP may *not* result in the advertisement of the same static routes. This is because the default policy for BGP does not accept static routes, whereas the default for the test policy does. As an example, consider this policy:

```
[edit policy-options]
lab@Wheat# show policy-statement test_route_filter
term 1 {
    from {
        route-filter 0.0.0.0/2 orlonger;
    }
    then next policy;
}
term 2 {
    then reject;
}
```

With the test_route_filter policy shown, the test policy command will match on and accept static, direct, OSPF, BGP, and routes that match the route filter (routes in the range of 0–63), while the same policy applied to BGP results in the advertisement of only BGP routes that match the filter. Again, this is because the matching routes are not explicitly accepted by the test_route_filter policy in this example, and would therefore be subjected to the default policy for BGP.

A number of static routes that range from 0–192 have been added to router Wheat. The test_route_filter policy is run against these routes:

```
lab@Wheat> test policy test_route_filter 82.137.128.0/18

Policy test_route_filter: 0 prefix accepted, 1 prefix rejected
```

The result confirms that a prefix outside the range of 0–63 is rejected:

```
lab@Wheat> test policy test_route_filter 6.1.0.0/16

inet.0: 815 destinations, 1500 routes (815 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

6.1.0.0/16         *[Static/5] 00:44:51
                      Discard

Policy test_route_filter: 1 prefix accepted, 0 prefix rejected
```

This result confirms that a prefix inside the range of 0–63 is accepted. To test against all possible routes, use 0/0:

```
lab@Wheat> test policy test_route_filter 0/0

inet.0: 815 destinations, 1500 routes (815 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

6.1.0.0/16         *[Static/5] 00:45:05
                      Discard
6.2.0.0/22         *[Static/5] 00:45:05
                      Discard
. . .
10.0.0.0/8         *[BGP/170] 20:42:56, localpref 100
                      AS path: 1282 I
                    > to 172.16.1.2 via fe-0/0/0.412
                    [BGP/170] 20:42:44, localpref 80
                      AS path: 666 1282 I
                    > to 172.16.2.2 via fe-0/0/0.423
12.0.48.0/20       *[Static/5] 00:45:05
                      Discard
. . .
                      Discard
63.207.252.0/22    *[Static/5] 00:45:05
                      Discard

Policy test_route_filter: 58 prefix accepted, 759 prefix rejected
```

The output confirms that both static and BGP routes are matching the route-filter in the test_route_filter policy. Note again that the policy being tested does not have an explicit accept action, and instead uses the next policy for matching routes; the acceptance in this case is the result of the default accept-all policy for the test policy. It's worth stating again that the same policy applied to BGP will advertise only BGP routes that match the filter, unless you add an explicit accept action to the first term.

Community and AS path regex matching

Complete coverage of regex matching is outside the scope of this book. The reader should consult technical documentation for a full description of the supported matching operators (e.g., *http://www.juniper.net/techpubs/software/junos/junos85/swconfig85-policy/id-10256235.html#id-10256235*, which describes AS path regex matching).

Here are some general things to be aware of when dealing with regex matching:

- Regex matching provides a powerful tool to filter routes based on virtually any conceivable pattern of AS path or community attributes.
- In JUNOS software, community regex matching is POSIX 1003.2-compliant. In contrast, AS path regex matching is not, because in an AS path regex, a dot, `.` (the wildcard character), represents an entire AS number, rather than an atom or specific digit in the AS number.
- You can test your regular expression syntax against routes *already* present in the route table using a `show route community` *`<community-regex>`* or `show route aspath-regex` *`<as-path-regex>`* command. Once you feel the expression syntax results in the matches you expect, you can write a policy that uses the same regex.
- To use a community of AS path regexes in a policy, you must first define the regex using a symbolic name, which is then referenced in the policy.

The following example demonstrates a basic AS path regex:

```
[edit policy-options]
lab@PBR# show
policy-statement as_path_filter {
    term 1 {
        from {
            protocol bgp;
            as-path sample_as_regex;
        }
        then reject;
    }
}
as-path sample_as_regex "^. 1234 . 1111$";
```

Note that the symbolic name `sample_as_regex` is defined outside of any particular policy statement. In this example, the specified regex will match when the associated route has an AS path consisting of exactly four entries. The AS path can begin with any AS number, as indicated by the `.` wildcard (a wildcard matches a complete AS number in JUNOS software). The second AS number has to be 1234 and can be followed by any other AS number, but the final AS number entry must be 1111 to match. The `^` and `$` characters are anchors, which force the initial and final matches to be against the beginning and end of the line, respectively.

The `as_path_filter` policy statement makes use of the defined AS path regex by matching against it in term 1. Here the result of an AS path regex match is rejection.

Here is a community regex matching example:

```
[edit policy-options]
lab@PBR# show
policy-statement community_regex_test {
    term 1 {
        from community comm_regex;
        then accept;
    }
}
community comm_regex members "^(.*):(.*)1:(11.1)(.*):(.*)$";
```

In this example, the comm_regex expression is written to match on a sequence of three community strings, but only when the first is from any AS number and any community value, and the second is from AS 1 with a community value of 11*x*1, where the *x* represents any decimal value between 0 and 9. This example shows that for community regex matching, the . wildcard represents a single digit, rather than a complete AS number, as was the case with AS path regex matching. Lastly, a match is declared only when one additional community value is present, and like the first community match, any AS number and community string will match given the use of the wildcard and repetition operators (. and *, respectively).

Additional details and examples of community regex matching are available at *http://www.juniper.net/techpubs/software/junos/junos85/swconfig85-policy/id-10223306.html#id-10223306*.

Policy subroutines (nesting)

Routes that match a given term in a policy can reference another policy as the associated action. The policy is called a policy *subroutine*, or a *nested policy*. This is a powerful capability that allows you to build modular policies that, rather than being applied as a policy chain, are called from within a master policy.

A common usage of a policy subroutine takes the form of a martian or bogon filter. Rather than applying the same martian filter as part of each policy chain, or rather than adding the complete martian filter logic to every policy you write, you could simply have a term in all your policies that calls the martian policy as a subroutine.

The key to effectively using policy subroutines lies in understanding the result code that is handed back from the calling policy by the called policy. Figure 3-5 illustrates policy subroutine behavior.

In Figure 3-5, things begin in the upper left, where a route is handed to the *master* or *calling policy* for evaluation. In this example, the first term in the calling policy has a match criterion specifying from policy *<sub-routine-name>*. This directive evokes the called policy for route evaluation; meanwhile, the main policy suspends its processing pending a result code that is handed back to the calling policy once the called policy completes its evaluation.

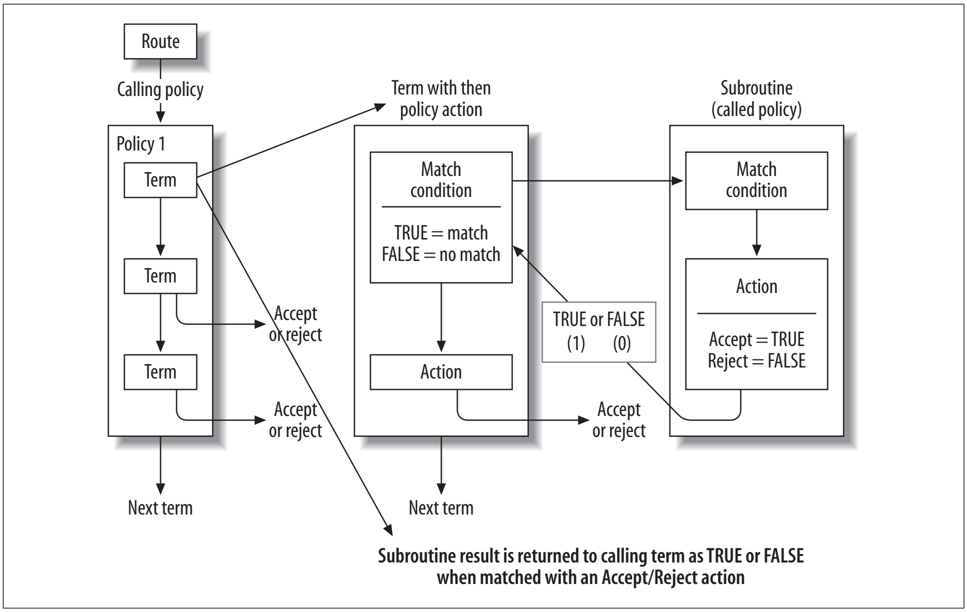


Figure 3-5. Policy subroutines

When the called policy/subroutine completes its evaluation, the result is either a 1 or a 0. Here, the former indicates an `accept` action by the called policy, and the latter represents a `reject` action. When the result code is handed back to the calling policy, a 1 is interpreted as a positive match, which results in the execution of the calling term's `then` action. A return of 0 indicates no match, and policy processing continues with the next term.

> For reliable operation, you must make sure that all policy subroutines match *all* routes with either an `accept` or a `reject` action.
>
> You will encounter inconsistent behavior with policy subroutines if the subroutine is not written to match against *all* possible routes. This is because when a route is not matched, the subroutine cannot perform an `accept` or a `reject` action, and therefore returns an empty value to the calling policy. The lack of a definitive result from the called policy often leads to unpredictable operation in the calling policy.

Boolean grouping

We covered the use of policy chains previously—a policy chain is a grouping of policies that are evaluated in sequence until an `accept` or `reject` action is encountered. JUNOS software also supports policy expressions, which provide Boolean grouping functionality. This is a fancy way to say you can logically AND, OR, or NOT a given policy. You can find details on policy expressions at *http://www.juniper.net/techpubs/software/junos/junos85/swconfig85-policy/id-10418934.html#id-10418934*.

By way of an example, consider the following policy:

```
[edit policy-options]
lab@PBR# show
policy-statement community_regex_test {
    term 1 {
        from community comm_regex;
        then accept;
    }
}
community comm_regex members "^(.*):(.*)1:(11.1)(.*):(.*)$";
```

As previously described, this policy matches on, and as a result, accepts routes with a particular community sequence. What do you feel will happen if a `community_regex_test` policy is applied as an import with a Boolean NOT?

```
[edit protocols bgp]
lab@PBR# set import (!community_regex_test)

[edit protocols bgp]
lab@PBR# show
import ( ! community_regex_test );
```

If you guessed that all routes that were formerly accepted will now be rejected, you are correct. The Boolean NOT inverts the results of policy evaluation, changing an `accept (1)` to a `reject (0)`, and vice versa.

As a final example, consider this policy expression:

```
[edit protocols ospf]
lab@PBR# show
export ( policy1 && policy2 );
```

The use of the logical AND indicates that for a route to be exported into OSPF, it must be evaluated as true by *both* `policy1` and `policy2`. Any route that is evaluated as false or rejected by either policy is not considered viable for export into OSPF.

Summary of Routing Policy

We just detailed JUNOS software routing policy. The policy framework provides a consistent and easy-to-fathom environment for all of your route-exchange and attribute-manipulation needs. Although route filters and the whole J-Tree thing can be a bit daunting when first encountered, the overall logic of a JUNOS policy is easy to follow, and the consistent way in which they are applied to routing protocols makes network administration that much easier. With Juniper policy rather than a collection of network statements, default-information-originate statements, distribute lists, route maps, and so on, you create and advertise a static route into OSPF, or BGP, or RIP, using the same approach and syntax.

Advanced features such as regex-based AS path and community matching, policy subroutines, and policy expressions ensure that you can never run out of creative and elegant ways to meet your network's policy goals.

This section also covered the commands and procedures used to monitor and debug the operation of your import and export policies.

Conclusion

JUNOS software PIPs and routing policy may not be very sexy by themselves, but together they form the foundation of virtually all sophisticated network configurations.

The PIP toolbox provides many useful tools that allow you to create static and aggregate routes, create and group route tables, and alter protocol preferences. Routing policy provides a powerful and consistent set of rules and syntax that supplies fine-grained control over the exchange of routes, along with modification of route attributes. Once you understand the basic concepts of import and export policy, you quickly come to appreciate the elegance of being able to perform similar tasks on different protocols, using the same policy framework, rather than a collection of mechanisms such as route maps, distribute lists, network statements, and so on, which may or may not work in a given protocol context.

When combined, PIP and policy yield a powerful mechanism that enables you to bend a network's operation to suit your will. The skills and concepts covered in this chapter are demonstrated throughout the remainder of this book, in various real-world and practical scenarios.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- PIPs:
  - Identify static, aggregate, and generated routes.
  - Describe the configuration of static routes.
  - Describe the purpose of the default JUNOS software route tables.
  - Describe global route preference and the concept of a floating static route.
- Routing policy:
  - Identify the two types of policy application.
  - Identify policy components (terms, match conditions, actions, and policy chains).
  - Identify points where routing policy may be applied.
  - Describe the processing of routing policies.
  - Evaluate the result of a given routing policy.

Chapter Review Questions

1. After defining an aggregate route for 0/0, you note that the M7i's system board CPU utilization increases. What might account for this?
    a. The default route is attracting traffic that is not specifically matched, leading to a `reject` action and corresponding ICMP error packet generation
    b. The default route is attracting traffic that is not specifically matched, leading to discard and ICMP error packet generation
    c. The default route is attracting traffic that matches more specific prefixes and is being forwarded, hence the increased CPU usage
    d. The default route is attracting traffic that matches more specific prefixes and is being dropped, hence the increased CPU usage
2. Which of the following defines a floating static route that backs up an OSPF externally learned route?
    a. Set static route 1.1.10/24, next hop `t1-0/0/2`
    b. Set static route 1.1.10/24, next hop `t1-0/0/2`, preference 11
    c. Set static route 1.1.10/24, next hop `t1-0/0/2`, preference 151
    d. Set static route 1.1.10/24, next hop `t1-0/0/2`, qualified next hop
    e. None of the above
3. You issue the command `set routing-options autonomous-system loops 3`. What does it do?
    a. Tolerates as many as three instances of the local AS number in transmitted route updates
    b. Tolerates as many as three instances of the local AS number in received route updates
    c. Tolerates as many as two instances of the local AS number in transmitted route updates
    d. Tolerates as many as two instances of the local AS number in received route updates
4. After defining a generated route for 10/8, you find that the route is inactive, despite having interfaces that are locally numbered from the 10.*x*.*x*.0/24 space. What could account for this?
    a. Your interfaces are all multipoint, and you have not learned any routes over any of them, so there is no forwarding next hop for the generated route
    b. Your interfaces are all point-to-point, and you have not learned any routes over any of them, so there is no forwarding next hop for the generated route
    c. You must define an explicit policy to list which routes are allowed to contribute
    d. Your interfaces are all multipoint, and you have learned routes over them, which makes the generated route unneeded

5. What command displays the route table for a Layer 3 VPN routing instance named `l3_vpn`?

    a. `show route`

    b. `show route table l3_vpn`

    c. `show route table l3_vpn.inet.0`

    d. All of the above

6. You have configured RIP between three routers connected in a serial chain, but no RIP routes are being learned. Which policy results in full RIP connectivity for all direct routes?

    a. A RIP import policy of the form:

    ```
    term 1 {
        from protocol [ rip direct ];
        then accept;
    }
    ```

    b. A RIP export policy of the form:

    ```
    term 1 {
        from protocol [ rip direct ];
        then accept;
    }
    ```

    c. A RIP import policy of the form:

    ```
    term 1 {
        from protocol direct;
        then accept;
    }
    ```

    d. A RIP export policy of the form:

    ```
    term 1 {
        from protocol direct;
        then accept;
    }
    ```

7. What happens when the static route 192.168.10/24 is evaluated by this policy?

    ```
    [edit policy-options policy-statement test]
    lab@PBR# show
    term 1 {
        from {
            protocol bgp;
            route-filter 192.168.0.0/16 orlonger reject;
            route-filter 192.168.10.0/24 exact {
                metric 10;
                accept;
            }
        }
    }
    ```

    a. Nothing, because no match occurs

    b. The route is longest-matched against the first route filter and rejected

c. The route is longest-matched against the second route filter and has its metric set to 10

d. Both b and c

8. What happens if the not policy matches a route with a reject action in the following policy expression?

```
[edit protocols ospf]
lab@PBR# show
export (( ! not ) && and );
```

a. The result is inverted to an accept, and the second policy is evaluated

b. The reject action in the not policy ensures that the AND condition cannot be met, so the second policy is never evaluated

c. Both policies are evaluated, and the logical result, which is false because of the reject in the not policy, is inverted, so the route is accepted

d. None of the above

9. What type of import policy can you apply to OSPF?

a. None; LS protocols do not support the notion of import policies because it breaks database consistency

b. You can apply policy to filter certain LSA types, such as AS externals to create a stub area

c. Import policy for OSPF can only be used to filter AS external LSAs from being flooded

d. Import policy for OSPF can be used to prevent installation of AS external routes into the route table, but has no effect on flooding

10. In the following configuration, which export policy is peer 1.1.1.1 subjected to?

```
[edit protocols bgp]
lab@PBR# show
import ( ! community_regex_test );
export globalize;
group internal {
    export keep_it_on_down_low;
    neighbor 1.1.1.1;
    neighbor 1.1.1.2 {
        export bad_peer_filter;
    }
}
```

a. The `globalize` policy

b. The `keep_it_on_down_low` policy

c. The `bad_peer_filter` policy

d. The `globalize` and `keep_it_on_down_low` policies

e. First the `keep_it_on_down_low`, and then the `globalize` policy

11. From where does a Juniper router obtain its RID?
    a. From explicit configuration at the `[edit routing-options]` hierarchy
    b. From the first nonmartian address found on the first interface that is found
    c. Both a and b
    d. Either a or b
12. You were provided a network diagram that told you to number your network from the 191.255.0.0/16 space. OSPF is enabled and adjacencies are up, but no routers are learning any routes. What can explain this?
    a. The default OSPF export policies advertise nothing, so you need to apply export policy
    b. The default OSPF import policy rejects all OSPF routes, so you need to apply import policy
    c. You need to modify the martian table with a `191.255.0.0/16 accept` statement
    d. You need to enable OSPF on the `lo0` interface to provide a route to the RID of each router in the network

Chapter Review Answers

1. Answer: A. The default next hop type for an aggregate route is `reject`, which when matched does result in the M7i's system board having to create an ICMP error. Even with rate-limiting safeguards, these messages consume system processing, but not forwarding resources.
2. Answer: C. A floating static needs to have a preference that is less preferred than the route it backs up. OSPF externals have a preference of 150, so you need a value that is higher; otherwise, the static route will take precedence over the OSPF route.
3. Answer: D. The `loops` argument to the `autonomous-system` statement affects received route updates only. Further, whatever value is specified, subtract one for the number of local AS instances that are permitted. The default setting of 1 will reject any route with 1 instance of the local AS number.
4. Answer: A. Point-to-point interfaces can contribute to a generated route because an explicit next hop is not required. LAN interfaces require some route—either static or learned—to activate an aggregate or generated route. Policy is used to exclude routes from contributing, not to include.
5. Answer: D. All of the commands listed will display the Layer 3 VPN instance route table. Some are simply more verbose or more direct by displaying only the table desired.

6. Answer: B. The default RIP import policy accepts RIP routes. To send direct routes, you need the direct protocol, and to readvertise RIP learned routes, you need the RIP protocol. The default RIP export policy is to reject all.
7. Answer: A. A static route can never match a from protocol BGP condition, so it does not match the term. There is a logical AND for distinct conditions such as `route-filter` and `protocol` when listed under the same statement.
8. Answer: A. The negative/reject result of the `not` policy is inverted, which becomes true, and this enables the evaluation of the second policy. When the first policy is false, a logical AND can never be satisfied, so without the `!` function, the second policy would not be evaluated in this case.
9. Answer: D. You cannot use policy to control LSA flooding. Until recently, no import could be applied, and even now IS-IS does not support any import policy.
10. Answer: B. Only the most explicit policy is executed, which in this case is the group-level policy because neighbor 1.1.1 has no neighbor-level export policy.
11. Answer: D. There can be only one RID in effect at any time, and it is disruptive to change it. The router uses an explicit value when present; otherwise, it automatically derives one. There is no need to be able to route to the RID, at least not for proper protocol operation.
12. Answer: C. You really have to watch those pesky martians....

CHAPTER 4

Interior Gateway Protocols and Migration Strategies

This chapter reviews key concepts and characteristics of Interior Gateway Protocols (IGPs) commonly deployed in enterprise networks. It starts with a brief description of the three most common enterprise IGPs and provides examples of IGP configuration and operational analysis in a JUNOS software environment. The chapter also discusses current best practices to minimize network disruption when migrating from one IGP to another, with configuration examples for Routing Information Protocol to Open Shortest Path First (RIP to OSPF) and Enhanced Interior Gateway Routing Protocol to OSPF (EIGRP to OSPF) migration. The topics discussed in this chapter include:

- IGP overview
- RIP deployment case study
- IGP migration
- RIP to OSPF migration case study
- EIGRP migration case study

From an IGP perspective, a Juniper Networks router supports RIP, the OSPF protocol, and the Intermediate System-to-Intermediate System (IS-IS) routing protocols. This chapter does not address IS-IS given that it is normally seen in service provider networks and rarely is found in the enterprise.

It should be noted that Juniper Networks routers do not support the Cisco Systems proprietary Interior Gateway Routing Protocol (IGRP), or the updated version known as EIGRP. Technical merits aside, licensing restrictions combined with the closed nature of these protocols prevent Juniper Networks from implementing either of these IGPs. Given that IGRP/EIGRP was commonly deployed in many small to medium-size enterprises, a large portion of this chapter focuses on migration strategies designed to ease such a transition between the two vendors.

IGP Overview

As its name would imply, the role of an IGP is to provide routing connectivity *within* or *interior* to a given routing domain (RD). An RD is defined as a set of routers under common administrative control that share a common routing protocol. An enterprise network, which can also be considered an autonomous system (AS), may consist of multiple RDs, which may result from the (historic) need for multiple routed protocols, scaling limitations, acquisitions and mergers, or even a simple lack of coordination among organizations making up the enterprise. *Route redistribution*, the act of exchanging routing information among distinct routing protocols, is often performed to tie these RDs together when connectivity is desired.

IGP functions to advertise and learn network prefixes (routes) from neighboring routers to build a route table that ultimately contains entries for all sources advertising reachability for a given prefix. A route selection algorithm is executed to select the best (i.e., the shortest) path between the local router and each destination, and the next hop associated with that path is pushed into the forwarding table to affect the forwarding of packets that longest-match against that route prefix. The IGP wants to provide full connectivity among the routers making up an RD. Generally speaking, IGPs function to promote, not limit, connectivity, which is why we do not see IGPs used between ASs—they lack the administrative controls needed to limit connectivity based on routing policy. This is also why inter-AS routing is normally accomplished using an Exterior Gateway Protocol (EGP), which today takes the form of Border Gateway Protocol (BGP) version 4. We discuss enterprise application of BGP in Chapter 5.

When network conditions change, perhaps due to equipment failure or management activity, the IGP both generates and receives updates and recalculates a new best route to the affected destinations. Here, the concept of a "best" route is normally tied to a route metric, which is the criterion used to determine the relative path of a given route. Generally speaking, a route metric is significant only to the routing protocol it's associated with, and it is meaningful only within a given RD. In some cases, a router may learn multiple paths to an identical destination from more than one routing protocol. Given that metric comparison between two different IGPs is meaningless, the selection of the best route between multiple routing sources is controlled by a route preference. The concept of route preference is explored in detail later in this chapter in "IGP Migration: Common Techniques and Concerns" and is also known as *administrative distance* (AD) on Cisco Systems routers.

In addition to advertising internal network reachability, IGPs are often used to advertise routing information that is external to that IGP's RD through a process known as *route redistribution*. Route redistribution is often used to exchange routing information between RDs to provide intra-AS connectivity. Route redistribution can be tricky because mistakes can easily lead to lack of connectivity (black holes) or, worse yet, routing loops. To ensure identical forwarding paths, you may also need to map the metrics used by each routing protocol to ensure that they are meaningful to the IGP into which they are redistributed. Route redistribution is performed via routing policy in JUNOS software. We introduce routing policy later in this chapter and cover it in detail in Chapter 3. On Cisco Systems platforms, redistribution is often performed through some combination of the `redistribute` command, through distribute lists, or through route maps and their associated IP access lists. Although there is a learning curve, it's often a delight for those familiar with the IOS way of performing redistribution when they realize that JUNOS software routing policy provides the same functionality with a consistent set of semantics/syntax, for all protocols, and all in one place!

The reader of this book is assumed to have an intermediate level understanding of the IP protocol and the general operation and characteristics of IGPs that support IP routing. This section provides a review of major characteristics, benefits, and drawbacks of the IGPs discussed in this chapter to prepare the reader for the configuration and migration examples that follow.

Routing Information Protocol

RIP is one of the oldest IP routing protocols still in production network use and is a true case of "if something works, why fix it?" The original specification for RIP (version 1) is defined in RFC 1058, originally published in June 1988! RIP version 2 (RIPv2) was originally defined in RFC 1388 (1993) and is currently specified in RFC 2453 (1998).

RIP is classified as a Distance Vector (DV) routing protocol because it advertises reachability information in the form of distance/vector pairs—which is to say that each route is represented as a cost (distance) to reach a given prefix (vector) tuple. DV routing protocols typically exchange entire route tables among their set of directly connected peers, on a periodic basis. This behavior, although direct and easy to understand, leads to many of the disadvantages associated with DV routing protocols. Specifically:

- Increased network bandwidth consumption stemming from the periodic exchange of potentially large route tables, even during periods of network stability. This can be a significant issue when routers connect over low-speed or usage-based network services.
- Slow network convergence, and as a result, a propensity to produce routing loops when reconverging around network failures. To alleviate (but not eliminate) the potential for routing loops, mechanisms such as split horizon, poisoned reverse, route hold downs, and triggered updates are generally implemented. These stability features come at the cost of prolonging convergence.

- DV protocols are normally associated with crude route metrics that often will not yield optimal forwarding between destinations. The typical metric (cost) for DV protocols is a simple hop count, which is a crude measure of actual path cost, to say the least. For example, most users realize far better performance when crossing several routers interconnected by Gigabit Ethernet links, as opposed to half as many routers connected over low-speed serial interfaces.

On the upside, DV protocols are relatively simple to implement, understand, configure, and troubleshoot, and they have been around *forever*, allowing many network engineers a chance to become proficient in their deployment. The memory and processing requirements for DV protocols are generally less than those of a link state (LS) routing protocol (more on that later).

To help illustrate what is meant by *slow to converge*, consider that the protocol's architects ultimately defined a *hop count* (the number of routers that need to be crossed to reach a destination) of 16 to be infinity! Given the original performance of initial implementations, the designers believed that networks over 16 hops in dimension would not be able to converge in a manner considered practical for use in production networks; and those were 1980s networks, for which demanding applications such as Voice over IP were but a distant gleam in an as yet grade-school-attending C-coder's eye. Setting infinity to a rather low value was needed because in some conditions, RIP can converge only by cycling through a series of route exchanges between neighbors, with each such iteration increasing the route's cost by one, until the condition is cleared by the metric reaching infinity and both ends finally agree that the route is not reachable. With the default 30-second update frequency, this condition is aptly named a *slow count to infinity*.

Stability and performance tweaks

Hold downs serve to increase stability, at the expense of rapid convergence, by preventing installation of a route with a reachable metric, after that same route was recently marked as unreachable (cost = 16) by the local router. This behavior helps to prevent loops by keeping the local router from installing route information for a route that was *originally* advertised by the local router, and which is now being *readvertised* by another neighbor. It's assumed that the slow count to infinity will complete before the hold down expires, after which the router will be able to install the route using the lowest advertised cost.

Split horizon prevents the advertisement of routing information back over the interface from which it was learned, and poisoned reverse alters this rule to allow readvertisement back out the learning interface, as long as the cost is explicitly set to infinity: a case of "I can reach this destination, NOT!" This helps to avoid loops by making it clear to any receiving routers that they should not use the advertising router as a next hop for the prefix in question. This behavior is designed to avoid the need for a slow count to infinity that might otherwise occur because the explicit indication that "I cannot reach destination X" is less likely to lead to misunderstandings when compared to the absence of information associated with split horizon. To prevent unnecessary bandwidth waste that stems from bothering to advertise a prefix that you cannot reach, most RIP implementations use split horizon, except when a route is marked as unreachable, at which point it is advertised with a poisoned metric for some number of update intervals (typically three).

Triggered updates allow a router to generate event-driven as well as ongoing periodic updates, serving to expedite the rate of convergence as changes propagate quickly. When combined with hold downs and split horizon, a RIP network can be said to receive bad news fast while good news travels slow.

RIP and RIPv2

Although the original RIP version still works and is currently supported on Juniper Networks routers, it's assumed that readers of this book will consider deploying only RIP version 2. Although the basic operation and configuration are the same, several important benefits are associated with RIPv2 and there are no real drawbacks (considering that virtually all modern routers support both versions and that RIPv2 messages can be made backward-compatible with v1 routers, albeit while losing the benefits of RIPv2 for those V1 nodes).

RIPv2's support of Variable Length Subnet Masking/classless interdomain routing (VLSM/CIDR), combined with its ability to authenticate routing exchanges, has resulted in a breath of new life for our old friend RIP (pun intended). Table 4-1 provides a summary comparison of the two RIP versions.

Table 4-1. Comparing characteristics and capabilities of RIP and RIPv2

Characteristic	RIP	RIPv2
Metric	Hop count (16 max)	Hop count (16 max)
Updates/hold down/route timeout	30/120/180 seconds	30/120/180 seconds
Max prefixes per message	25	25 (24 when authentication is used)
Authentication	None	Plain text or Message Digest 5 (MD5)
Broadcast/multicast	Broadcast to all nodes using all 1s, RIP-capable or not	Multicast only to RIPv2-capable routers using 224.0.0.9 (broadcast mode is configurable)
Support for VLSM/CIDR	No, only classful routing is supported (no netmask in updates)	Yes
Route tagging	No	Yes (useful for tracking a route's source; i.e., internal versus external)

Open Shortest Path First

The OSPF routing protocol currently enjoys widespread use in both enterprise and service provider networks. If OSPF can meet the needs of the world's largest network operators, it's safe to say that it should be more than sufficient for even the largest enterprise network. OSPF version 2 is defined in RFC 2328, but numerous other RFCs define enhanced capabilities for OSPF, such as support of not-so-stubby areas (NSSAs) in RFC 3101, Multiprotocol Label Switching (MPLS) Traffic Engineering Extensions (MPLS TE) in RFC 3630, and in RFC 3623, which defines graceful restart extensions that minimize data plane disruption when a neighboring OSPF router restarts. OSPF supports virtually all the features any enterprise could desire, including VLSM, authentication, switched circuit support (suppressed hellos), and MPLS TE extensions, among many more.

OSPF is classified as an LS routing protocol. This is because, unlike a DV protocol that exchanges its entire route table among directly connected neighbors, OSPF exchanges *only* information about the local router's links, and these updates are flooded to *all routers* in the same area. Flooding ensures that all the routers in the area receive the new update at virtually the same time. The result of this flooding is a link-state database (LSDB) that is replicated among all routers that belong to a given area. Database consistency is critical for proper operation and the assurance of loop-free forwarding topologies. OSPF meets this requirement through reliable link-state advertisement (LSA) exchanges that incorporate acknowledgment and retransmission procedures. Each router performs a Shortest Path First (SPF) calculation based on the Dijkstra algorithm, using itself as the root of the tree to compute a shortest-path graph containing nodes representing each router in the area, along with its associated links. The metrically shortest path to each destination is then computed, and that route is placed into the route table for consideration to become an active route by the path selection algorithm.

OSPF advertises and updates prefix information using LSA messages, which are sent only upon detection of a change in network reachability. LSAs are also reflooded periodically to prevent their being aged out by other routers. Typically, this occurs somewhere between 30 and 45 minutes, given the default 3,600-second LSA lifetime. In addition, rather than sending an entire route table or database, these LSAs carry only the essential set of information needed to describe the router's new LS. Upon sensing a change in their local LSDBs, other routers rerun the SPF and act accordingly.

OSPF dynamically discovers and maintains neighbors through generation of periodic hello packets. An adjacency is formed when two neighbors decide to synchronize their LSDBs to become routing peers. A router may choose to form an adjacency with only a subset of the neighbors that it discovers to help improve efficiency, as described in the subsequent section, "Neighbors and adjacencies."

It should be no wonder that OSPF has dramatically improved convergence characteristics when one considers its event-driven flooding of small updates to all routers in an area. This is especially true when contrasted to RIP's period exchange of the entire route table among directly connected neighbors, who then convey that information to their neighbors at the next scheduled periodic update.

The downside to all this increased performance is that CPU and memory load are increased in routers as compared to the same router running a DV protocol. This is because an LS router has to house *both* the LSDB and the resulting route table, and the router must compute these routes by executing an SPF algorithm each time the LSDB changes. Considering that router processing capability and memory tend to increase, while actual costs tend to decrease for the same unit of processing power, these drawbacks are a more-than-acceptable trade-off for the benefit of ongoing reduced network loading and rapid convergence. Another drawback to LS routing protocols is their relative complexity when compared to DV protocols, which can make their operation difficult to understand, which in turn can make fault isolation more difficult.

OSPF was designed to support Type of Service (ToS)-based routing, but this capability has not been deployed commercially. This means that a single route table is maintained, and that for each destination, a single path metric is computed. This metric is said to be *dimensionless* in that it serves only to indicate the relative goodness or badness of a path, with smaller numbers considered to be better. Exactly what is better cannot be determined from the OSPF metric, LSDB, or resulting route table. Whether the OSPF metric is set to reflect link speed (default), hop count, delay, reliability, or some combination thereof is a matter of administrative policy.

Neighbors and adjacencies

Previously, it was noted that OSPF dynamically discovers neighbors using a periodic exchange of hello packets. It should also be noted that OSPF contains sanity checks that prevent neighbor discovery (and therefore, adjacency formation) when parameters such as the hello time, area type, maximum transmission unit (MTU), or subnet mask are mismatched. The designers of the protocol felt it was much easier to troubleshoot a missing adjacency than the potential result of trying to operate with mismatched parameters, and having dealt with more than a few misconfigured OSPF networks, the protocol architects were absolutely right.

The designated router. To maximize efficiency, OSPF does not form an adjacency with every neighbor that is detected, because the maintenance of an adjacency requires compute cycles and because on multiaccess networks such as LANs, a full mesh of adjacencies is largely redundant. On multiaccess networks, an election algorithm is performed to first elect a designated router (DR), and then a backup designated router (BDR). The DR functions to represent the LAN itself and forms an adjacency with the BDR and all other compatible neighbors (DRother) on the LAN segment.

The DRother routers form two adjacencies across the LAN—one to the DR and one to the BDR. The neighbor state for DRother neighbors on a DRother router itself is expected to remain in the "two-way" state. This simply means that the various DRothers have detected each other as neighbors, but an adjacency has not been formed.

The DR is responsible for flooding LSAs that reflect the connectivity of the LAN. This means that loss of one neighbor on a 12-node LAN results in a single LSA that is flooded by the DR, as opposed to each remaining router flooding its own LSA. The reduced flooding results in reduced network bandwidth consumption and reduced OSPF processing overhead. If the DR fails, the BDR will take over and a new BDR is elected.

OSPF elects a DR and BDR based on a priority setting, with a lower value indicating a lesser chance at winning the election; a setting of 0 prevents the router from ever becoming the DR. In the event of a tie, the router with the highest router ID (RID) takes the prize. The OSPF DR Election algorithm is nondeterministic and nonrevertive, which means that adding a new router with a higher, more preferred priority does not result in the overthrow of the existing DR. In other words, router priority matters only during active DR/BDR election. This behavior minimizes the potential for network disruption/LSA flooding when new routers are added to the network. Thus, the only way to guarantee that a given router is the DR is to either disable DR capability in all other routers (set their priority to 0), or ensure that the desired router is powered on first and never reboots. Where possible, the most stable and powerful router should be made the DR/BDR, and a router should ideally be the DR for only one network segment.

OSPF router types

OSPF describes various router roles that govern their operation and impact the types of areas in which they are permitted. To become proficient with OSPF operation and network design, you must have a clear understanding of the differences between OSPF area types and between the LSAs permitted within each area:

Internal router

Any router that has all its interfaces contained within a single area is an internal router. If attached to the backbone area, the router is also known as a backbone router.

Backbone router

Any router with an attachment to area 0 (the backbone area) is considered a backbone router. This router may also be an internal or area border router depending on whether it has links to other, nonbackbone areas.

Area border router (ABR)

A router with links in two or more areas is an ABR. The ABR is responsible for connecting OSPF areas to the backbone by conveying network summary information between the backbone and nonbackbone areas.

Antonymous system boundary router (ASBR)

A router that injects external routing information into an OSPF domain is an ASBR.

Areas and LSAs

As previously noted, LS protocols flood LSAs to all routers in the same area in order to create a replicated LSDB from which a route table is derived through execution of an SPF algorithm. The interplay of these processes can lead to a downward-scaling spiral in large networks, especially when there are large numbers of unstable links.

As the number of routers and router links within an area grows, so too does the size of the resulting LSDB. In addition, more links means a greater likelihood of an interface or route flap, which leads to greater need for flooding of LSAs. The increased probability of LSDB churn leads to an increased frequency of the SPF calculations that must be performed each time the LSDB changes (barring any SPF hold downs for back-to-back LSA change events). These conditions combine to form the downward spiral of increased flooding, larger databases, more frequent SPF runs, and a larger processing burden per SPF run, due to the large size of the LSDB.

But don't fear: OSPF tackles this problem through the support of areas, which provides a hierarchy of LSDBs. As a result, LSA flooding is now constrained to each area, and no one router has to carry LS for the entire RD. Because each area is associated with its own LSDB, a multiarea OSPF network will, for the average router, result in a smaller LSDB. Each router must maintain an LSDB only for its attached areas, and no one router need attach to every area. This is a key point, because in theory it means OSPF has almost unlimited scaling potential, especially when compared to nonhierarchical protocols such as Cisco's EIGRP or RIP. In addition, with fewer routers and links, there is a reduced likelihood of having to flood updated LSAs, which in turn means a reduced number of SPF runs are needed—when an SPF run is needed, it is now executed against a smaller LSDB, which yields a win-win for all involved.

Routers that connect to multiple areas are called ABRs and maintain an LSDB for each area to which they attach. An ABR has a greater processing burden than an internal router, by virtue of maintaining multiple LSDBs, but the processing burden associated with two small LSDBs can still be considerably less than that associated with a single, large database, for reasons cited earlier. It is common to deploy your most powerful routers to serve the role of ABRs, because these machines will generally have to work harder than a purely internal router, given that they must maintain an LSDB per attached area, and have the greater chance of a resulting SPF calculation. However, the trade-off is being able to use smaller, less powerful routers within each area (internal routers), because of the reduced LSDB size that results from a hierarchical OSPF design.

Interestingly, OSPF is truly link-state *only within* a single area due to the scope of LSA flooding being confined to a single area. An ABR runs SPF for each attached area's LSDB and then summarizes its intraarea LS costs into other areas in DV-like fashion. This behavior is the reason OSPF requires a backbone area that is designated as area 0—generally speaking, each ABR generates and receives summaries *only* from the backbone, which exists to provide a loop-free environment over which these summaries can be exchanged. Put another way, the backbone serves to prevent loop formation that could result from the information that is hidden by ABRs when they summarize the contents of their nonbackbone area LSDBs into simple distance/vector pairs. A router receiving a summary advertisement uses SPF against that area's LSDB to compute the shortest path to the router that generated the summary advertisement, and then it simply adds the summary cost, as originally calculated by the advertising router, to obtain the total path cost.

Having said all this, it is not unheard of to see large, globally spanning OSPF networks consisting of hundreds of routers successfully deployed within a single OSPF area. There simply are no hard rules regarding the age-old question of "how many routers can I put into a single area," because too many variables exist. In addition to a simple router count, one must also consider factors such as link count, link stability, router processing power, the percentage of external versus internal LSAs, and the general robustness of the protocol's implementation. The significance of the latter should not be underestimated. A poorly implemented OSPF instance running on the world's fastest hardware will likely not perform very well, unless, of course, you consider the number of core files dumped and/or reboots per unit of time, which is a significant IGP benchmark. Seriously, it's bad enough when one network node keeps rolling over to play dead, but it's worse when instability in a single node rapidly ripples out to affect the operation of other routers, even those with well-behaved code.

OSPF area types. OSPF defines several different area types. To truly understand OSPF operation, you must have a clear understanding of the differences between OSPF area types, and between the LSAs permitted within each area:

Backbone

To ensure loop-free connectivity, OSPF maintains a special area called the backbone area, which should always be designated as area 0. All other OSPF areas should connect themselves to the backbone for interarea connectivity; normally, interarea traffic transits the backbone.

Stub

Stub areas do not carry AS external advertisements, with the goal being a reduction of LSDB size for internal routers within that stub area. Because routers in a stub area see only LSAs that advertise routing information from *within* the OSPF RD, a default route is normally injected to provide reachability to external destinations. Stub area routers use the metrically closest ABR when forwarding to AS external prefixes.

Totally stubby area

A totally stubby area is a stub area that *only* receives the default route from the backbone. Routers in the totally stubby area do not see OSPF internal routes from other OSPF areas. Their LSDBs represent their own area and the injected default route, which is now used to reach both AS external and interarea destinations.

NSSAs

As noted previously, an OSPF stub area does not carry external routes, which means you cannot redistribute routes into a stub area because redistributed routes are always treated as AS externals in OSPF. An NSSA bends this rule and allows a special form of external route within the NSSA. Although an NSSA can originate AS externals into OSPF, external routes from other areas are still not permitted within the NSSA. This is a case of having one's cake (small LSDB due to not being burdened by externals from other areas) while eating it too (being allowed to burden other routers with the external routes you choose to generate). The NSSA's ABRs can translate the special form of external route used in an NSSA for flooding over the rest of the OSPF domain.

Transit areas

Transit areas pass traffic from one adjacent area to the backbone or to another area if the backbone is more than two hops away from an area.

Primary LSA types. LSAs are the workhorse of OSPF in that they are used to flood information regarding network reachability and form the basis of the resulting LSDB. Table 4-2 describes the LSA types used by modern OSPF networks. It bears restating that a true understanding of OSPF requires knowledge of what type of routing information is carried in a given LSA, in addition to understanding each LSA's flooding scope. For example, an LSA with area scope is never seen outside the area from which it was generated, whereas an LSA with global scope is flooded throughout the entire OSPF RD, barring any area type restrictions; that is, AS externals are never permitted within a stub area. Figure 4-1 provides a graphical summary of the purpose and scope of the most common LSA types.

Table 4-2. Common OSPF LSA types

LSA type	Generated by/contents/purpose	Flooding scope
Type 1, router	Generated by all OSPF routers, the Type 1 LSA describes the status and cost of the router's links.	Area
Type 2, network	Generated by the DR on a LAN, the Type 2 LSA lists each router connected to the broadcast link, including the DR itself.	Area
Type 3, network summary	Generated by ABRs, Type 3 LSAs carry summary route information between OSPF areas. Typically, this information is exchanged between a nonbackbone area and the backbone area, or vice versa. Type 3 LSAs are not reflooded across area boundaries; instead, a receiving ABR generates its own Type 3 LSA summarizing its interarea routing information into any adjacent areas.	Area

Table 4-2. Common OSPF LSA types (continued)

LSA type	Generated by/contents/purpose	Flooding scope
Type 4, ASBR summary	Each ABR that forwards external route LSAs must also provide reachability information for the associated ASBR so that other routers know how to reach that ASBR when routing to the associated external destinations. The Type 4 LSA provides reachability information for the OSPF domain's ASBRs. As with Type 3 LSAs, each ABR generates its own Type 4 when flooding external LSAs into another area.	Area
Type 5, AS external LSA	Generated by ASBRs, the Type 5 LSA carries information for prefixes that are external to the OSPF RD.	Global, except for stub areas
Type 7, NSSA	Generated by ASBRs in an NSSA, the Type 7 LSA advertises prefixes that are external to the OSPF RD. Unlike the Type 5 LSA, Type 7 LSAs are not globally flooded. Instead, the NSSA's ABR translates Type 7 LSAs into Type 5 for flooding throughout the RD.	Area
Type 9 and Type 10, opaque LSAs	Generated by enabled OSPF routers to carry arbitrary information without having to define new LSA types, the Type 9 LSA has area scope and is currently used to support graceful restart extensions, whereas the Type 10 LSA has global scope and is used for MPLS TE support.	Type 9, area; Type 10, global

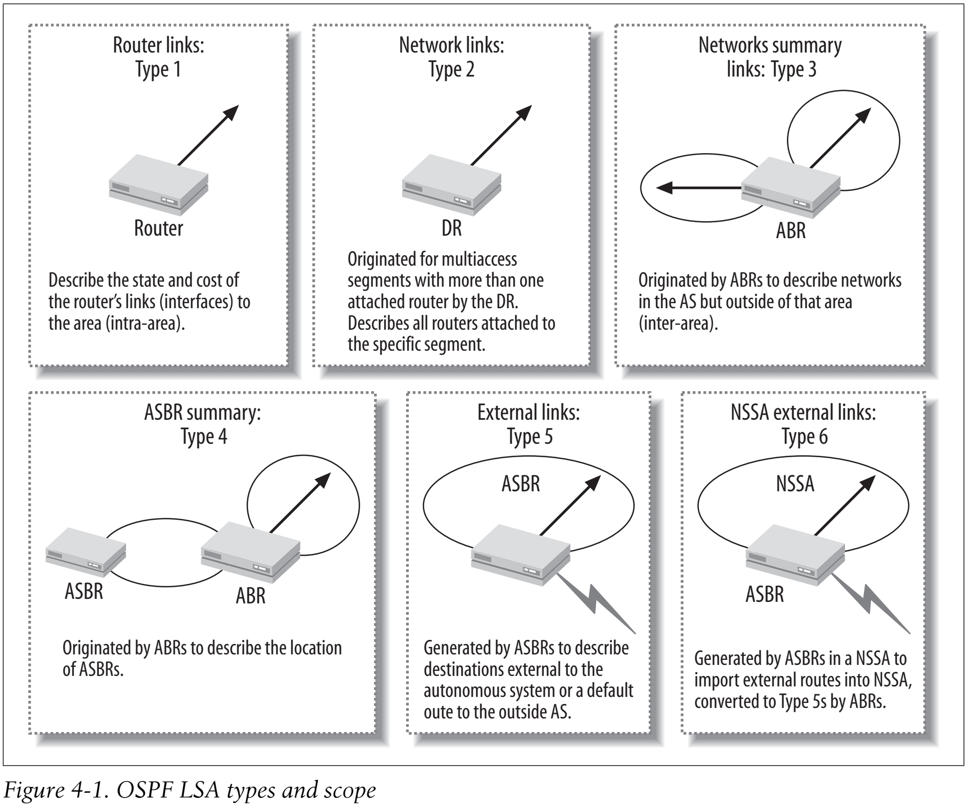

Router links:
Type 1
Router
Describe the state and cost of the router's links (interfaces) to the area (intra-area).
Network links:
Type 2
DR
Originated for multiaccess segments with more than one attached router by the DR. Describes all routers attached to the specific segment.
Networks summary links: Type 3
ABR
Originated by ABRs to describe networks in the AS but outside of that area (inter-area).
ASBR summary:
Type 4
ASBR
ABR
Originated by ABRs to describe the location of ASBRs.
External links:
Type 5
ASBR
Generated by ASBRs to describe destinations external to the autonomous system or a default oute to the outside AS.
NSSA external links:
Type 6
NSSA
ASBR
Generated by ASBRs in a NSSA to import external routes into NSSA, converted to Type 5s by ABRs.

Figure 4-1. OSPF LSA types and scope

OSPF stability and performance tweaks

Breaking a large OSPF domain into multiple areas can have a significant impact on overall performance and convergence. In addition, most OSPF implementations support various timers to further tune and tweak the protocol's operation.

The Juniper Networks OSPF implementation is quite optimized and lacks many of the timers and hold downs that readers may be familiar with in IOS. It is not uncommon to see users new to Juniper asking for JUNOS software analogs and receiving the standard answer that "they do not exist because they are not needed." The development engineers at Juniper feel that artificially delaying transmission of an LSA—ostensibly to alleviate the processing burden associated with its receipt—does nothing except prolong network convergence.

Table 4-3 maps OSPF-related knobs from IOS to their JUNOS software equivalent, when available.

Table 4-3. IOS versus JUNOS software OSPF timers

IOS name	JUNOS software name	Comment
`carrier-delay` (0)	`hold-time` (0)	Delay notification of interface up/down events to damp interface transitions. Default is 0, but notification times can vary based on interrupt versus polled.
`timers throttle spf (spf-start, spf-hold, spf-max-wait)`	`spf-delay` (200)	Control the rate of SPF calculation. In JUNOS software, the value is used for as many as three back-to-back SPF runs, and then a 5-second hold down is imposed to ensure stability in the network.
`timers throttle lsa all (lsa-start, lsa-hold, lsa-max` *`((0, 5000, 5000))`*`)`	N/A	By default, JUNOS software sends 3 back-to-back updates with a 50 msec delay, and then a five-second hold down.
`timers lsa arrival`	N/A	Controls the minimum interval for accepting a copy of the same LSA.
`timers pacing flood` (33 msec)	`transmit-interval` (30 msec)	Delay back-to-back LSA transmissions out the same interface.
`ispf`	N/A	Enable incremental SPF calculations; JUNOS software does not support ISPF but does perform partial route calculations when the ospf topology is stable and only routing information changes.

JUNOS software has added an additional optimization in the form of a periodic packet management process daemon (ppmd) that handles the generation and processing of OSPF (and other protocol) hello packets. The goal of ppmd is to permit scaling to large numbers of protocol peers by offloading the mundane processing tasks associated with periodic packet generation. The ppmd process can run directly in the PFE to offload RE cycles on application-specific integrated circuit (ASIC)-based systems such as the M7i.

In addition to the aforementioned timers, both vendors also support Bidirectional Forwarding Detection (BFD), which is a routing-protocol-agnostic mechanism to provide rapid detection of link failures, as opposed to waiting for an OSPF adjacency timeout. Note that interface hold time comes into play only when a physical layer fault is detected, as opposed to a link-level issue such as can occur when two routers are connected via a LAN switch, where the local interface status remains up even when a physical fault occurs on the remote link. As of this writing, IOS support for BFD is limited and varies by platform and software release; Cisco Systems recommends that you see the Cisco IOS software release notes for your software version to determine support and applicable restrictions.

Enhanced Interior Gateway Routing Protocol

The EIGRP is an updated version of Cisco Systems' proprietary IGRP. The original version of EIGRP had stability issues, prompting the release of EIGRP version 1, starting in IOS versions 10.3(11), 11.0(8), and 11.1(3). This chapter focuses strictly on EIGRP because it has largely displaced IGRP in modern enterprise networks.

EIGRP is sometimes said to be a "DV protocol that thinks it's an LS." EIGRP does in fact share some of the characteristics normally associated with LS routing, including rapid convergence and loop avoidance, but the lack of LSA flooding and the absence of the resulting LSDB expose EIGRP's true DV nature. This section highlights the major operational characteristics and capabilities of EIGRP. The goal is not an exhaustive treatment of EIGRP's operation or configuration—this subject has been covered in numerous other writings. Instead, the purpose here is to understand EIGRP to the degree necessary to effectively replace this proprietary legacy protocol with another IGP, while maintaining maximum network availability throughout the process.

The operational characteristics of EIGRP are as follows:

- It uses nonperiodic updates that are partial and bounded. This means that unlike typical DV protocol operation, EIGRP generates *only* triggered updates, that these updates report *only* affected prefixes, and that the updates are sent to a bounded set of neighbors.
- It uses a Diffusing Update Algorithm (DUAL) to guarantee a loop-free topology while providing rapid convergence. The specifics of DUAL operation are outside the scope of this book; suffice it to say that DUAL is the muscle behind EIGRP's rapid converge and loop guarantees.
- It uses a composite metric that, by default, factors delay and throughput. Also, it supports the factoring of dynamically varying reliability and loading, but users

are cautioned not to use this capability. EIGRP uses the same metric formula as IGRP, but it multiplies the result by 256 for greater granularity.

- It supports VLSM/CIDR and automatic summarization at classful boundaries by default.
- It supports unequal cost load balancing using a *variance* knob.
- It supports neighbor discovery and maintenance using multicast.
- It automatically redistributes to IGRP when process numbers are the same.
- It features protocol-independent modules for common functionality (reliable transport of protocol messages).
- It features protocol-dependant modules for IP, IPX, and AppleTalk that provide multiprotocol routing via the construction of separate route tables using protocol-specific routing updates.

At first glance, the multiprotocol capabilities of EIGRP may seem enticing. After all, this functionality cannot be matched by today's *standardized* routing protocols. There was a time when many enterprise backbones were in fact running multiple network protocols, and the lure of a single, high-performance IGP instance that could handle the three most common network suites was hard to resist. However, there has been an unmistakable trend toward IP transport for virtually all Internetworking suites, including IBM's SNA/SAA. (We have a hard time recalling the last time we knew of an enterprise still deploying the native Netware or AppleTalk transport protocols.) In contrast, these proprietary-routed protocols are being phased out in favor of native IP transport, which serves to render EIGRP's multiprotocol features moot in this modern age of *IP* internetworking.

EIGRP can load-balance across paths that are not equal in cost, based on a variance setting, which determines how much larger a path metric can be as compared to the minimum path metric, while still being used for load balancing. This characteristic remains unique to IGRP/EIGRP given that neither RIP nor OSPF supports unequal cost load balancing.

EIGRP metrics

EIGRP uses a composite metric that lacks a direct corollary in standardized IGPs. EIGRP metrics tend to be large numbers. Although providing great granularity, these huge numbers represent a real issue for a protocol such as RIP, which sees any metric greater than 16 as infinity. It's quite unlikely that any enterprise would migrate from EIGRP to RIP anyway, given the relatively poor performance of RIP and the widespread availability of OSPF on modern networking devices, so such a transition scenario is not addressed in this chapter.

For reference, the formula used by EIGRP to calculate the metric is:

> Metric = [K1 * Bw + K2 * Bw/(256 – Load) + K3 * Delay] * [K5/(Reliability + K4)]

Although the MTU is not used in the calculation of the metric, it is tracked across the path to identify the minimum path MTU. The K parameters are used to weigh each of the four components that factor into the composite metric—namely, bandwidth, load, delay, and reliability. The default values for the weighing result in only K1 and K3 being nonzero, which gives the default formula of Bw + Delay for the metric.

> Note that Cisco Systems does not recommend user adjustment of the metric weighting. So, in practical terms, EIGRP's metric is a 32-bit quantity that represents the path's cumulative delay (in tens of microseconds) and the path's minimum throughout in Kb/s, divided by 10^7 (scaled and inverted).

For EIGRP, the result is then multiplied by 256 to convert from IGRP's 24-bit metric to EIGRP's 32-bit metric. It should be obvious that one cannot perform a simple one-to-one mapping of legacy EIGRP metrics to OSPF, given that EIGRP supports a 32-bit metric and OSPF's is only 16-bit. This is not a significant shortcoming in practice, given that few enterprise networks are composed of enough paths to warrant 4 billion levels of metric granularity anyway!

Figure 4-2 shows an example network to help illustrate how EIGRP calculates a path metric.

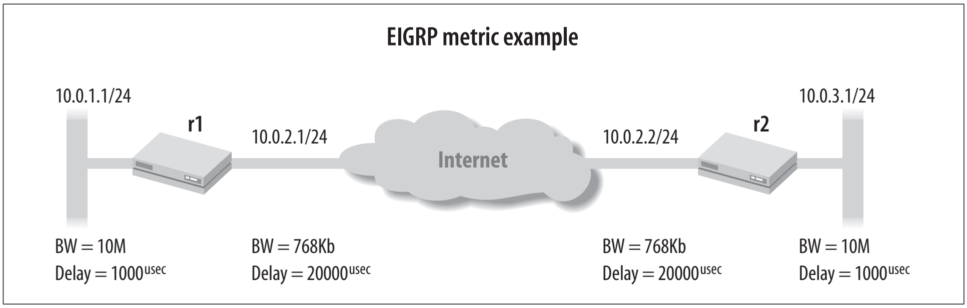


Figure 4-2. EIGRP metric example

Using the default composite metric weighting for the topology shown in Figure 4-2, router `r1`'s metric to reach 10.0.3.0/24 is computed based on the minimum bandwidth and the sum of the path delay, using the formula:

Metric = 256 * (10^7/minBW Kbs) + (delay sum usec/10)

Plugging in the specifics for this example yields a path metric of 3,870,976 for the path to 10.0.3.0/24, from the perspective of `r1`:

Metric = 256 * (10^7/768) + (20,000 + 1,000 /10)
Metric = 256 * (13021) + (2100)
Metric = 256 * 15121
Metric = 3,870,976

By way of comparison, the same network running OSPF with JUNOS software defaults for OSPF reference bandwidth yields a path metric of only 137! A key point here is that although 137 is certainly much smaller than the 3,870,976 value computed by EIGRP, the range of OSPF metrics, from 1–65,534, should be more than sufficient to differentiate among the number of links/paths available in even the largest enterprise network.

Also, recall that the OSPF metric is said to be dimensionless, which is to say that a smaller value is always preferred over larger values, but the exact nature of *what* is smaller is not conveyed in the metric itself. By default, OSPF derives its metric from interface bandwidth using a scaling factor, but the scaling factor can be altered, and the metric can be administratively assigned to reflect any parameter chosen by the administrator. When all is said and done, as long as a consistent approach is adopted when assigning OSPF metrics, the right thing should just happen. By way of example, consider a case where OSPF metrics are assigned based on the economic costs of a usage-based network service. The resultant *shortest path* measures distance as a function of economic impact and will result in optimization based on the least expensive paths between any two points. Thus, OSPF has done its job by locating the *shortest* path, which in this example means the *least expensive* path, given that the administration considers distance to equate to money. We revisit the subject of EIGRP to OSPF metric conversions in "EIGRP-to-OSPF Migration Summary," later in this chapter.

EIGRP: A grand past and a dubious future

It's worth restating that, unlike open standards protocols such as RIP and OSPF, EIGRP is proprietary to Cisco Systems. As a result, only Cisco Systems products can speak EIGRP, both because of the closed nature of the specification and because of the licensing and patent issues that prevent others from implementing the protocol. Most enterprise customers (and service providers, for that matter) prefer not to be locked into any solution that is sourced from a single vendor, even one as large and dominant as Cisco Systems.

EIGRP's lack of hierarchical support significantly limits its use in large-scale networks due to scaling issues. EIGRP lacks the protocol extensions needed to build a traffic engineering database (TED), as used to support MPLS applications. Although MPLS is still somewhat rare in the enterprise, it currently enjoys significant momentum and is in widespread use within service provider networks across the globe. Considering that many of the requirements of service providers three or four years ago are the same requirements that we are seeing in the enterprise today, an enterprise would be wise to hedge its bets by adopting protocols that can support this important technology, should the need later arise.

Support is an important factor that must be considered when deploying any protocol. At one point, it was difficult to find off-the-shelf or open source protocol analysis for IGRP/EIGRP. Cisco could change the specification at any time, making obsolete any such tools that exist. At the time of this writing, the Wireshark analysis program (*http://www.wireshark.org/*) lists EIGRP support; however, it's difficult to confirm the decode accuracy without an open standard to reference against.

Given the drawbacks to a single-vendor closed solution, an enterprise should consider the use of open standard protocols. In the case of IGPs, you gain higher performance, vendor independence, and off-the-shelf support capabilities. EIGRP's multiprotocol capability aside, the largest IP networks on the planet (those of Internet service providers [ISPs]) generally run OSPF. Service provider networks are all about reliability, stability, rapid convergence at a large scale, and the ability to offer services that result in revenue generation—given these IGP requirements, the reader is left to ponder why service provider networks are never found to be running EIGRP within their networks.

IGP Summary

IGPs provide the indispensable service of maintaining internal connectivity throughout the myriad link and equipment failures possible in modern IP internetworks. IGP performance and stability in the face of large volumes of network change can provide a strategic edge by quickly routing around problems to maintain the highest degree of connectivity possible.

This section overviewed the RIP, OSPF, and EIGRP protocols to prepare the reader for the following deployment and IGP migration scenarios. Now is a good time to take a break before you head into the RIP deployment case study that follows.

RIP Deployment Scenario

OK, that's enough of an IGP overview. There's little doubt that the router-jockey readers of this book are chomping at the bit to start routing some packets! Let's demonstrate basic RIP configuration and operational mode commands that assist in troubleshooting a RIP operation in a JUNOS software environment.

Figure 4-3 depicts the topology for the Cisco Systems/IOS to Juniper Networks/JUNOS software RIP integration scenario. It shows the existing Beer-Co RIP network, which currently consists of two Cisco Systems 2600 series routers running IOS version 12.3(15b) and interconnected by a serial link. Beer-Co is expanding its widget operation and plans to add two additional locations. Despite the existing infrastructure, the CIO has opted to become a multivendor shop, and a decision has been made to deploy two Juniper Networks J-series routers. The existing (and planned) IP addressing is shown and contains a mix of subnetted class A and class C addresses (just to keep things interesting). Each router's loopback address is also shown, along with a simulated customer network that is instantiated via a static route (labs commonly use a static route to represent a customer network for purposes of reducing equipment requirements). Note that the last digit of each router's loopback address is tied numerically to that router's simulated customer network to help ease requirements on the reader's memory.

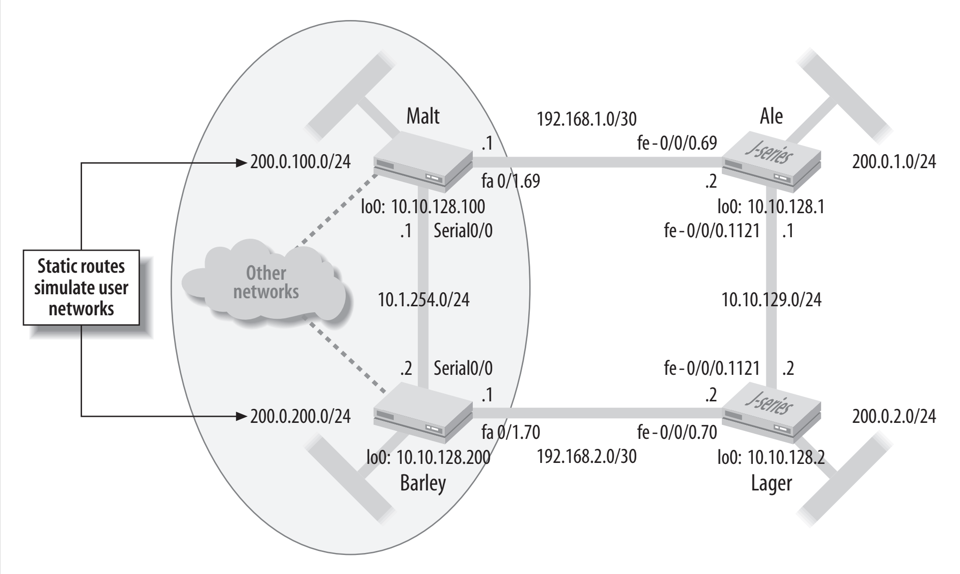


Figure 4-3. RIP topology

As a reminder, recall that in this lab, each router's Fast Ethernet interface is tied to a virtual LAN (VLAN) switch, and VLAN tags are used to establish links between communicating routers. The subinterface/logical unit of each interface match the associated VLAN tag value, which is also shown in the figure. You may assume that all router interface properties are correctly configured to permit communication with directly attached neighbors. The following code snippets show the Fast Ethernet interface configuration at Cisco router `Malt` and Juniper router `Ale`.

`Malt`'s `FastEthernet0/1` interface and subinterface configuration:

```
interface FastEthernet0/1
 no ip address
 duplex auto
 speed auto
!
interface FastEthernet0/1.69
 encapsulation dot1Q 69
 ip address 192.168.1.1 255.255.255.252
 ip rip authentication mode md5
 ip rip authentication key-chain test
 no snmp trap link-status
```

`Ale`'s `fe-0/0/0` interface and logical unit configuration:

```
[fe-0/0/0 {
    vlan-tagging;
```

```
        unit 69 {
            description Ale-to_Malt;
            vlan-id 69;
            family inet {
                address 192.168.1.2/30;
            }
        }
        unit 1121 {
            description Ale-to_Lager;
            vlan-id 1121;
            family inet {
                address 10.10.129.1/24;
            }
        }
    }
```

Existing RIP Configuration

Before adding the new RIP routers, it makes sense to first inspect the related RIP configuration in the Cisco platform to get a feel for what RIP configuration tasks will be needed on the Juniper Networks boxes. The RIP-related configuration parts from router Malt are shown, along with some inline comment as to what each part is doing:

```
Malt#show run
Building configuration...
. . .
!
key chain test
 key 1
  key-string jncie
. . .
```

The key chain configuration is used to provide authentication to various routing protocols, ostensibly RIP, in this example. The named key chain has a single key that is numbered as 1 using a key value of jncie. Key chains provide the ability to rotate the current key, based on start and end times (which are not specified in this example). As of this writing, JUNOS software supports authentication key chains only for the Label Distribution Protocol (LDP), OSPF, and BGP. RIP supports a single password-MD5 key, which is good for us because that is just what's needed here:

```
interface FastEthernet0/1.69
 encapsulation dot1Q 69
 ip address 192.168.1.1 255.255.255.252
 ip rip authentication mode md5
 ip rip authentication key-chain test
 no snmp trap link-status
!
. . .
```

The two subinterface-level IP rip authentication statements configure RIP authentication for messages sent out, or received from, the related interface. The commands specify the associated key chain and authentication approach, which again is MD5 in this example:

```
router rip
 version 2
 redistribute connected
 redistribute static route-map TAGGING
 network 10.0.0.0
 network 192.168.1.0
 distribute-list 3 out static
 no auto-summary
. . .
```

This portion of the configuration actually enables the RIP process. Things begin with the specification that RIP version 2 is to be run. Considering the VLSM in effect, this is a very good choice. The `network` statements, which are assumed to fall on classful boundaries, define the set of interfaces on which RIP should operate. Rather than listing interfaces directly by name, they are indirectly identified through the interface's IP address. Notice the two forms of route redistribution in effect. The `redistribute connected` and `redistribute static` statements, the latter with an associated route map, serve to redistribute connected and static routes, respectively. A distribution list could also have been used to control the routes advertised into RIP. The connected routes will catch the router's serial, Fast Ethernet, and loopback interface subnets. You will have to wait and see what static route redistribution is doing when you inspect the related route map.

The `no-auto-summary` statement disables the default (Cisco) behavior of automatically summarizing at classful network boundaries. When combined with RIP version 2, which conveys a network mask, VLSM/CIDR is supported.

```
ip route 0.0.0.0 0.0.0.0 Null0
ip route 200.0.100.0 255.255.255.0 Null0
!
access-list 3 permit 200.0.100.0
access-list 4 permit 0.0.0.0
!
```

> The whole classful addressing concept is totally alien to a Juniper Networks router, as the boxes were designed in an era well after the concept of class-based addressing had come and gone. To help illustrate this point, JUNOS software has no need for an `ip classless` statement as always seen in IOS, and consistently uses CIDR `/` notation for prefix lengths.

This portion of the configuration defines two static routes: the former is a default route and the latter is the simulated customer network associated with `Malt`. Both are pointed to `null0` as a next hop, which means that any traffic that longest-matches either of these two routes will be discarded.

This may strike the reader as odd, so some additional explanation is warranted. The assumption is that the real customer network will be assigned a mask longer than the /24 used by the static route that currently represents it—for example, a /28. Therefore, packets actually sent to hosts within the customer network will longest-match against the customer network interface route (longest-match rules), and are thereby spared the ignominious treatment of a one-way trip to `null0` land. If, on the other hand, the customer network interface is down, these packets are discarded as they now longest-match against the static route—meanwhile, the presence of the static route is preventing route churn in the rest of the network because it's always being advertised in RIP. This stability comes with the downside that, during a customer network interface outage, other routers in the RIP domain have a false belief that hosts on the customer network are still reachable, and the resultant traffic is forwarded over the enterprise network only to be discarded by the last hop. This technique is somewhat common in service provider networks, because control plane stability is generally more important than the network bandwidth that is wasted by forwarding packets across a network only to shunt them to `null0`.

In the RIP scenario, the two Cisco routers are attached to some other network cloud. Rather than run a routing protocol or define numerous static routes, the administrator relies on a default route to direct matching traffic into this cloud. The dotted lines on the drawing represent that this cloud is not part of the actual test bed.

Also, note the two related IP access control lists (ACLs), each matching on one of the two static routes. These ACLs are in turn referenced by the route map:

```
route-map TAGGING permit 10
 match ip address 3
 set metric 3
!
route-map TAGGING permit 20
 match ip address 4
 set tag 100
. . .
End
```

The `TAGGING` route map first matches against ACL 3 and sets the outgoing metric to 3 for matching prefixes (the simulated customer network route in this case). The default metric would be 1, so this action simulates a network that is two router hops farther away than it actually is. This might be done to cause another source of this route to be preferred (the lower hop count wins), or, perhaps, to limit the scope of stations that can reach this network (recall that in RIP, 16 means you cannot get there). Like it or not, this is an example of how route maps are used in IOS to alter route attributes, perhaps just to keep the scenario interesting.

The `permit 20` statement evokes ACL 4, which matches the default route for purposes of setting a route tag. In this example, the tag happens to be based on the router's loopback address. It's common to tag routes that are redistributed for purposes of tracking down the source of the route when troubleshooting, or for use in policy matching based on tag values. This is especially important when performing mutual route redistribution, which is a process prone to routing loops when route filtering precautions are not exercised.

Baseline operation

A quick look at the state of the IP route table at router Malt is performed before any modifications are made. This will serve as the network baseline for future comparison:

```
Malt#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS
level-2
       ia - IS-IS inter area, * - candidate default, U - per-user s
tatic route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is 0.0.0.0 to network 0.0.0.0

R    200.0.200.0/24 [120/3] via 10.1.254.2, 00:00:03, Serial0/0
S    200.0.100.0/24 is directly connected, Null0
     10.0.0.0/8 is variably subnetted, 4 subnets, 2 masks
C       10.10.128.100/32 is directly connected, Loopback0
R       10.10.128.200/32 [120/1] via 10.1.254.2, 00:00:03, Serial0/0
C       10.1.254.0/24 is directly connected, Serial0/0
C       10.1.254.2/32 is directly connected, Serial0/0
     192.168.1.0/30 is subnetted, 1 subnets
C       192.168.1.0 is directly connected, FastEthernet0/1.69
     192.168.2.0/30 is subnetted, 1 subnets
R       192.168.2.0 [120/1] via 10.1.254.2, 00:00:04, Serial0/0
S*   0.0.0.0/0 is directly connected, Null0
```

No real surprises here. Malt has several directly connected routes, in the form of its FA 0/1.69, loopback 0, and serial 0/0 interfaces. And the two locally defined static routes, 0.0.0.0 and 200.0.0.100, are both pointing to null0. Lo and behold, Malt has learned three routes via RIP: Barley's FA 0/1.70 route (192.168.2.0), its loopback interface route (10.10.128.200), and the simulated customer route (200.0.200.0). Note that the customer route received from Barley demonstrates the effects of the route map. This route's received hop count is 3 whereas the other two routes advertised by Barley were received with the default value of 1. The hop count/metric is displayed just after the administrative distance, which for RIP is 120. Here is a summary view of the RIP routes at Barley:

```
Barley#show ip route rip
R    200.0.100.0/24 [120/3] via 10.1.254.1, 00:00:14, Serial0/0
     10.0.0.0/8 is variably subnetted, 4 subnets, 2 masks
R       10.10.128.100/32 [120/1] via 10.1.254.1, 00:00:14, Serial0/0
     192.168.1.0/30 is subnetted, 1 subnets
R       192.168.1.0 [120/1] via 10.1.254.1, 00:00:14, Serial0/0
```

With Barley displaying the same type and number of routes, baseline operation is confirmed.

Summary of RIP Requirements

The operational aspects of the RIP network design, as determined through analysis of the legacy RIP configuration, are as follows:

- RIPv2 (without auto-summarization).
- Defaults are in place for update, hold down, and route timeout timers.
- MD5 authentication is in effect using key ID 1 with string jncie.
- Direct networks are being redistributed.
- The static route representing an attached customer network is redistributed with an artificially escalated hop count of 3.

Enter Juniper Networks

Based on the analysis of the IOS RIP configuration, we know what needs to be done at Ale and Lager. To help mitigate any operational impacts, it is decided to first bring up the RIP peerings between Ale and Lager before attaching them to the existing RIP backbone.

Configure static routes

The configuration begins with the definition of the static route that simulates an attached customer network. The configuration steps for Ale are:

```
lab@Ale> configure
Entering configuration mode

[edit]
lab@Ale# edit routing-options

[edit routing-options]
lab@Ale# set static route 200.0.1/24 discard

[edit routing-options]
lab@Ale# show
static {
    route 200.0.1.0/24 discard;
}
```

With the static route defined, the change is committed and the result confirmed (while still in configuration mode). In this example, traffic matching the static route is directed to a discard next hop, which means that no responses will be generated for matching traffic—a true black hole from which nothing will escape. Another option would be reject, which generates an Internet Control Message Protocol

(ICMP) error reporting that the destination is unreachable. This creates functionality similar to IOS's null0, in that matching traffic will generate host unreachable error messages. The reject option can assist in troubleshooting, but it consumes router resources in the form of message generation, which can be an issue during a large-scale denial of service (DoS) attack, making discard the preferred target for such a route:

```
[edit routing-options]
lab@Ale# commit
commit complete

[edit routing-options]
lab@Ale# run show route protocol static

inet.0: 6 destinations, 6 routes (6 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

200.0.1.0/24       *[Static/5] 00:00:37
                      Discard
```

Configure RIP

The RIP configuration is now added to Ale. Start by moving to the RIP configuration hierarchy, where the general options are shown:

```
[edit routing-options]
lab@Ale# top edit protocols rip

[edit protocols rip]
lab@Ale# set ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  authentication-key   Authentication key (password)
  authentication-type  Authentication type
  check-zero           Check reserved fields on incoming RIPv2 packets
> graceful-restart     RIP graceful restart options
> group                Instance configuration
  holddown             Hold-down time (10..180 seconds)
+ import               Import policy
  message-size         Number of route entries per update message (25..255)
  metric-in            Metric value to add to incoming routes (1..15)
  no-check-zero        Don't check reserved fields on incoming RIPv2 packets
> receive              Configure RIP receive options
> rib-group            Routing table group for importing RIP routes
  route-timeout        Delay before routes time out (30..360 seconds)
> send                 Configure RIP send options
> traceoptions         Trace options for RIP
  update-interval      Interval between regular route updates (10..60 seconds)
[edit protocols rip]
lab@Ale# set
```

It should be apparent that many aspects of RIP are configurable within JUNOS software. Some options are global, such as the authentication key/type or import/export policy, which means they apply to all groups (unless negated by a more specific group setting, if available). Other parameters can be specified only at a subsequent hierarchy. For example, a neighbor can be defined only within a group. You can quickly explore the options available under send and receive using the command-line interface's (CLI's) ? help utility:

```
[edit protocols rip]
lab@Ale# set send ?
Possible completions:
  broadcast            Broadcast RIPv2 packets (RIPv1 compatible)
  multicast            Multicast RIPv2 packets
  none                 Do not send RIP updates
  version-1            Broadcast RIPv1 packets
[edit protocols rip]
lab@Ale# set receive ?
Possible completions:
  both                 Accept both RIPv1 and RIPv2 packets
  none                 Do not receive RIP packets
  version-1            Accept RIPv1 packets only
  version-2            Accept only RIPv2 packets
```

It's apparent from the display that the send and receive settings globally control the RIP version and whether multicast (default for v2) or broadcast packets are sent. It just so happens that these same settings can also be specified on a per-neighbor (interface) basis—recall that in JUNOS software, the more-specific group-level configuration hierarchy settings override the less-specific global values. Let's take a quick look at the options available under a group, which is where you can define neighbors (interfaces) that run RIP:

```
[edit protocols rip]
lab@Ale# set group rip ?
Possible completions:
  <[Enter]>            Execute this command
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
> bfd-liveness-detection  Bidirectional Forwarding Detection options
+ export               Export policy
+ import               Import policy
  metric-out           Default metric of exported routes (1..15)
> neighbor             Neighbor configuration
  preference           Preference of routes learned by this group
  route-timeout        Delay before routes time out (30..360 seconds)
  update-interval      Interval between regular route updates (10..60 seconds)
|                    Pipe through a command
```

Configuration options found at the neighbor level include the import or export keyword, which is used to apply routing policy to receive or transmit route updates, respectively. Note that when applied at the neighbor level, any globally defined import or export policies are negated. The router runs *either* the global or the group policy, never both, and the router always chooses the most specific application—a neighbor level is more specific than a global level, of course. You may recall that policy is used to control route exchange and alter route attributes. The global preference for routes learned from a particular neighbor can also be configured here. Note that in JUNOS software, the concept of global preference is equivalent to that of IOS's administrative distance—this value is altered to make a source of routing information more (lower value) or less (higher value) preferred.

> The terminology of groups and neighbors may seem a bit confusing at first, given the way RIP is configured in IOS. JUNOS software is optimized when routing peers with similar export policy are placed into the same group. As a result, even if you have only one peer, that neighbor needs to belong to a RIP group. Also, the term *neighbor* here actually means *interface*, given that RIP messages are not unicast to specific machines, but instead are broadcast or multicast to all RIP speakers on a given link. This means that specifying a single neighbor in the form of a multiaccess interface results in RIP communications with all RIP-capable routers on that LAN segment.

Ale's RIP configuration. `Ale`'s RIP stanza is now configured in accordance with the RIP design guideline discovered when analyzing the legacy RIP configuration. Recall that the plan is to first establish RIP peerings between `Ale` and `Lager` before trying route exchanges to the Cisco routers (see Figure 4-3). Here is the resulting RIP stanza, along with the `set` commands used to create it courtesy of the `display set` function in the CLI:

```
[edit protocols rip]
lab@Ale# show
send multicast;
receive version-2;
authentication-type md5;
authentication-key "$9$cf3rK84oGiHm-VgJ"; ## SECRET-DATA
group rip {
    inactive: neighbor fe-0/0/0.69;
    neighbor fe-0/0/0.1121;
}
[edit protocols rip]
lab@Ale# show | display set
set protocols rip send multicast
set protocols rip receive version-2
set protocols rip authentication-type md5
set protocols rip authentication-key "$9$cf3rK84oGiHm-VgJ"
deactivate protocols rip group rip neighbor fe-0/0/0.69
set protocols rip group rip neighbor fe-0/0/0.1121
```

The global `send multicast` statement ensures that we will only speak to RIPv2 nodes, as RIPv1 routers will not see multicast updates. The `receive version-2` ensures that we process only multicast updates, thereby configuring the router for RIPv2-only operation. The authentication settings specify a (now ciphered) text string of jncie and indicates that MD5-based authentication should be used.

> JUNOS software always encrypts passwords; IOS requires that the password encryption service be enabled for the same functionality.

Lastly, notice the two neighbor statements that identify what interfaces RIP should run on. Note that the link to Malt is currently deactivated (inactive), which means that portion of the configuration will be ignored. This will result in Ale running RIP only on the fe-0/0/0.1121 interface to Lager. Once RIP has been confirmed between Ale and Lager, this link will be activated to enable RIP exchanges with the Cisco routers.

The one part of Ale's configuration yet to be addressed is the redistribution into RIP of its connected and simulated customer static routes. Recall that in JUNOS software, control over what routes enter and leave the route table and the modification of attributes associated with these routes, is controlled by routing policy. Here is an example of the JUNOS route policy needed to match the Cisco router's redistribution of connected (direct) routes and the route map function that sets the metric on a redistributed static route:

```
[edit policy-options policy-statement rip_export]
lab@Ale# show
term 1 {
    from protocol direct;
    then accept;
}
term 2 {
    from {
        protocol static;
        route-filter 200.0.1.0/24 exact;
    }
    then {
        metric 3;
        accept;
    }
}
[edit policy-options policy-statement rip_export]
lab@Ale# show | display set
set policy-options policy-statement rip_export term 1 from protocol direct
set policy-options policy-statement rip_export term 1 then accept
set policy-options policy-statement rip_export term 2 from protocol static
set policy-options policy-statement rip_export term 2 from route-filter 200.0.1.0/24
exact
set policy-options policy-statement rip_export term 2 then metric 3
set policy-options policy-statement rip_export term 2 then accept
```

The newly created RIP policy is applied to the RIP group (alternatively, it could be applied globally in this example) as export, where it will control the exchange of routes that are advertised into RIP. The default RIP import policy, which is to accept RIP routes, is left unaltered.

```
[edit]
lab@Ale# set protocols rip group rip export rip_export

[edit]
lab@Ale# show protocols rip
send multicast;
receive version-2;
authentication-type md5;
authentication-key "$9$cf3rK84oGiHm-VgJ"; ## SECRET-DATA
group rip {
    export rip_export;
    inactive: neighbor fe-0/0/0.69;
    neighbor fe-0/0/0.1121;
}
```

You may assume that a compatible RIP policy configuration has been added to Lager and that the changes are committed.

Confirm RIP Operation: Ale and Lager

With the RIP and related static route/policy configuration in place at Ale and Lager, the operation of RIP can be confirmed. Start with the confirmation that RIPv2 is running, and that it is doing so on the expected interfaces:

```
lab@Ale> show rip neighbor
                     Source       Destination    Send   Receive   In
Neighbor      State  Address      Address        Mode   Mode      Met
--------      -----  -------      -----------    ----   -------  ---
fe-0/0/0.1121    Up 10.10.129.1  224.0.0.9      mcast  v2 only    1
```

The output of the show rip neighbor command confirms that Ale is set for v2 operation, and that RIP is running on its link to Lager. The Up status indicates that the interface is operational, but not that any particular neighbor has been detected. The In Met column displays the metric value that will be added to any route updates received over the associated interfaces; by default, each received update has its metric incremented by one before being placed into the route table.

The general RIP statistics confirm that updates are being sent and received, that no errors are occurring, and that in the case of Ale, three routes have been learned via RIP, indicating that RIP is operating correctly between Ale and Lager:

```
lab@Ale> show rip statistics
RIPv2 info: port 520; holddown 120s.
    rts learned  rts held down  rqsts dropped  resps dropped
              3              0              0              0

fe-0/0/0.1121:  3 routes learned; 3 routes advertised; timeout 180s;
update interval 30s
Counter                         Total   Last 5 min  Last minute
-------                   -----------  -----------  -----------
```

```
Updates Sent                       25            11            2
Triggered Updates Sent              1             0            0
Responses Sent                      0             0            0
Bad Messages                        0             0            0
RIPv1 Updates Received              0             0            0
RIPv1 Bad Route Entries             0             0            0
RIPv1 Updates Ignored               0             0            0
RIPv2 Updates Received             17            11            2
RIPv2 Bad Route Entries             0             0            0
RIPv2 Updates Ignored               0             0            0
Authentication Failures             1             0            0
RIP Requests Received               1             0            0
RIP Requests Ignored                0             0            0
```

And now we confirm the presence of RIP routes in Ale's route table:

```
lab@Ale> show route protocol rip

inet.0: 10 destinations, 10 routes (10 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.128.2/32     *[RIP/100] 00:09:54, metric 2, tag 0
                    > to 10.10.129.2 via fe-0/0/0.1121
192.168.2.0/30     *[RIP/100] 00:09:54, metric 2, tag 0
                    > to 10.10.129.2 via fe-0/0/0.1121
200.0.2.0/24       *[RIP/100] 00:09:54, metric 4, tag 0
                    > to 10.10.129.2 via fe-0/0/0.1121
224.0.0.9/32       *[RIP/100] 00:10:57, metric 1
                      MultiRecv
```

Ale's route table contains the expected RIP routes, considering that RIP is not yet enabled to Malt and Barley. Notice that Lager has advertised its directly connected loopback interface (10.10.128.2) route to Ale. Also of note is that the JUNOS software route table displays the local RIP cost, as opposed to the metric received in the route update. This differs a bit from IOS, which displays the received RIP metric rather than local cost (received + 1 by default). The 200.0.0.2/24 static route defined at Lager has been injected into RIP with a metric of 3 due to the action of its export policy—this route is installed in Ale's route table with a local cost of 3 + 1, or 4. You'll also see that the RIP global preference in JUNOS software is 100.

A later section details additional operational mode commands that assist in debugging RIP operation. But right now, all seems to be working as expected, so there is not much to debug. Of course, things might change when tying into the Cisco portion of the network.

Confirm RIP: Juniper Networks to Cisco Systems Integration

With RIP operation in the Juniper and Cisco domains confirmed, it's time to fire up RIP between the two vendors' boxes to see what happens. RIP is a simple protocol, so what could go wrong? Things start with the activation of the RIP neighbor (interface) linking Ale to Malt. Similar steps are performed at Lager for its RIP interface to Barley:

```
lab@Ale> configure
Entering configuration mode

[edit]
lab@Ale# activate protocols rip group rip neighbor fe-0/0/0.69

[edit]
lab@Ale# commit
commit complete
```

Confirm route exchange

After a few minutes, RIP updates should have propagated. Let's start with a quick look at RIP statistics at router Lager, as any problems will likely manifest in the form of an incrementing error counter:

```
[edit]
lab@Lager# run show rip statistics
RIPv2 info: port 520; holddown 120s.
    rts learned  rts held down  rqsts dropped  resps dropped
             10              0              0              0

fe-0/0/0.1121:  3 routes learned; 3 routes advertised; timeout 180s;
update interval 30s
Counter                          Total   Last 5 min  Last minute
-------                    -----------  -----------  -----------
Updates Sent                        29           11            2
Triggered Updates Sent               1            0            0
Responses Sent                       0            0            0
Bad Messages                         0            0            0
RIPv1 Updates Received               0            0            0
RIPv1 Bad Route Entries              0            0            0
RIPv1 Updates Ignored                0            0            0
RIPv2 Updates Received              29           10            2
RIPv2 Bad Route Entries              0            0            0
RIPv2 Updates Ignored                0            0            0
Authentication Failures              0            0            0
RIP Requests Received                0            0            0
RIP Requests Ignored                 0            0            0

fe-0/0/0.70:  7 routes learned; 3 routes advertised; timeout 180s;
update interval 30s
Counter                          Total   Last 5 min  Last minute
-------                    -----------  -----------  -----------
Updates Sent                        29           11            2
Triggered Updates Sent               1            0            0
Responses Sent                       0            0            0
Bad Messages                         0            0            0
RIPv1 Updates Received               0            0            0
RIPv1 Bad Route Entries              0            0            0
RIPv1 Updates Ignored                0            0            0
RIPv2 Updates Received              31           11            2
RIPv2 Bad Route Entries              0            0            0
```

```
RIPv2 Updates Ignored              0             0             0
Authentication Failures            0             0             0
RIP Requests Received              0             0             0
RIP Requests Ignored               0             0             0
```

The RIP statistics indicate that all is normal. Lager is confirming that 10 routes have been learned via RIP, with three coming from its link to Ale and the balance learned from its link to Barley. Authentication is clearly working, given the learned routes and no indication of message discards or errors.

Next, confirm whether any RIP routes are present in the route table of Lager:

```
[edit]
lab@Lager# run show route protocol rip

inet.0: 18 destinations, 18 routes (18 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[RIP/100] 00:16:35, metric 2, tag 200
                    > to 192.168.2.1 via fe-0/0/0.70
10.1.254.0/24      *[RIP/100] 00:16:35, metric 2, tag 0
                    > to 192.168.2.1 via fe-0/0/0.70
10.1.254.1/32      *[RIP/100] 00:16:35, metric 2, tag 0
                    > to 192.168.2.1 via fe-0/0/0.70
10.10.128.100/32    *[RIP/100] 00:16:35, metric 3, tag 0
                    > to 192.168.2.1 via fe-0/0/0.70
10.10.128.200/32    *[RIP/100] 00:16:35, metric 2, tag 0
                    > to 192.168.2.1 via fe-0/0/0.70
10.10.128.1/32     *[RIP/100] 00:16:29, metric 2, tag 0
                    > to 10.10.129.1 via fe-0/0/0.1121
192.168.1.0/30     *[RIP/100] 00:16:29, metric 2, tag 0
                    > to 10.10.129.1 via fe-0/0/0.1121
200.0.1.0/24       *[RIP/100] 00:16:29, metric 4, tag 0
                    > to 10.10.129.1 via fe-0/0/0.1121
200.0.100.0/24     *[RIP/100] 00:16:35, metric 5, tag 0
                    > to 192.168.2.1 via fe-0/0/0.70
200.0.200.0/24     *[RIP/100] 00:11:44, metric 4, tag 0
                    > to 192.168.2.1 via fe-0/0/0.70
224.0.0.9/32       *[RIP/100] 00:16:50, metric 1
                      MultiRecv
```

RIP routes are present. The routes learned through RIP include the serial link between Malt and Barley (10.1.254.0/24 and associated host routes), the two simulated customer networks (200.0.100/24 and 200.0.200/24), and the RIP peering network for the link between Malt and Ale (192.168.2.0/30). Also present are the /32 routes for Malt's and Barley's loopback 0 interfaces (10.10.128.100 and 10.10.128.200). The default route is present, and it's correctly pointing to neighbor Barley, given the metric should be less via this path than forwarding through Ale to reach the default advertised by Barley.

The RIP routes at Barley are examined next:

```
Barley#show ip route rip
R    200.0.1.0/24 [120/4] via 10.1.254.1, 00:00:27, Serial0/0
```

```
R    200.0.2.0/24 [120/3] via 192.168.2.2, 00:00:25, FastEthernet0/1.70
R    200.0.100.0/24 [120/3] via 10.1.254.1, 00:00:27, Serial0/0
     10.0.0.0/8 is variably subnetted, 7 subnets, 2 masks
R       10.10.128.100/32 [120/1] via 10.1.254.1, 00:00:27, Serial0/0
R       10.10.129.0/24 [120/1] via 192.168.2.2, 00:00:25, FastEthernet0/1.70
R       10.10.128.1/32 [120/2] via 10.1.254.1, 00:00:27, Serial0/0
R       10.10.128.2/32 [120/1] via 192.168.2.2, 00:00:25, FastEthernet0/1.70
     192.168.1.0/30 is subnetted, 1 subnets
R       192.168.1.0 [120/1] via 10.1.254.1, 00:00:27, Serial0/0
```

The display confirms that RIP exchanges are working between the Juniper Networks routers and the Cisco boxes; Barley has a RIP route for both of Ale's and Lager's simulated customer networks (200.0.1/24 and 200.0.2/24) as well as the link between Ale and Lager (10.10.129.0/24), in addition to the /32 loopback addresses assigned to Ale and Lager (10.10.128.1 and 10.10.128.2).

Confirm forwarding path

A traceroute is performed from Lager to the simulated network on Barley to validate the data plane and resulting forwarding paths (the no-resolve switch ensures that the local router does not waste time trying to perform reverse Domain Name System [DNS] lookups on the resulting IP addresses in the event that DNS is not configured in the lab):

```
[edit]
lab@Ale# run traceroute no-resolve 200.0.200.1
traceroute to 200.0.200.1 (200.0.200.1), 30 hops max, 40 byte packets
 1  192.168.1.1  9.498 ms  9.705 ms  10.127 ms
 2  10.1.254.2  19.700 ms  20.004 ms  20.073 ms
 3  10.1.254.2  19.772 ms !H *  20.392 ms !H
```

The traceroute results are as expected; router Ale crossed two routers to reach the simulated customer network, and as previously noted, the null0 action of the longest match resulted in ICMP host unreachable messages, as indicated by the !H in the return. The results seem to indicate that RIPv2 is working between JUNOS software and IOS. Congratulations!

RIP troubleshooting scenario. Actually, nothing in the realm of internetworking works the first time. In fact, the results of that traceroute should have gotten you thinking a bit. Given the RIP topology, Ale *should* have two equal cost paths to the simulated customer network attached to Barley. After all, it's two hops to reach Barley via Malt, but also two hops to reach Barley via Lager. Knowing that JUNOS software automatically performs load balancing over as many as 16 equal cost paths, you'd expect to see Ale with two equal cost routes for the 200.0.200/24 route. Unfortunately, previous displays confirm this is not the case. A similar condition exists at Lager with regard to the simulated customer route at Malt.

There are a few tools for troubleshooting this type of issue in JUNOS software. One approach is protocol tracing, used to show the RIP messages being sent and received, and the overall results of RIP message processing. Tracing is similar to the IOS *debug* feature. Given that RIP is a DV protocol, you can also avail yourself of the show route advertising-protocol and the show route receiving-protocol commands. As their names imply, these commands display what routes the local router is advertising out a given interface or what routes are being received (learned) from a particular neighbor. The process begins at router Lager:

```
[edit]
lab@Lager# run show route advertising-protocol rip ?
Possible completions:
<neighbor>         IP address of neighbor (local for RIP and RIPng)
```

The command syntax help string of ? is useful here because it reminds us that for the RIP form of this command, you must specify the *local interface address*; recall that RIP generates broadcast or multicast updates to all neighbors on the link, so unlike BGP, where a specific neighbor address is specified, it's the local IP address for RIP.

```
[edit]
lab@Lager# run show route advertising-protocol rip 10.10.129.2

inet.0: 18 destinations, 18 routes (18 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.128.2/32     *[Direct/0] 02:31:29
                    > via lo0.0
192.168.2.0/30     *[Direct/0] 02:31:29
                    > via fe-0/0/0.70
200.0.2.0/24       *[Static/5] 02:32:10
                       Discard
```

The result leaves something to be desired—something such as a route advertisement for the 200.0.200/24 route, that is! The receiving-protocol form of the command is used to confirm that whatever is wrong is at least symmetrical:

```
lab@Lager# run show route receive-protocol rip ?
Possible completions:
  <peer>             IP address of neighbor
```

Note that for the receiving-protocol command, RIP requires the specification of a *specific neighbor IP* address, which in turn is reachable via a RIP-enabled interface (a good way to look at this is to consider that transmitted updates are sent to all neighbors, but received updates come from a specific neighbor—a source IP address is never of the multicast/broadcast form):

```
[edit]
lab@Lager# run show route receive-protocol rip 10.10.129.1

inet.0: 18 destinations, 18 routes (18 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.128.1/32     *[RIP/100] 01:01:13, metric 2, tag 0
                    > to 10.10.129.1 via fe-0/0/0.1121
```

```
192.168.1.0/30     *[RIP/100] 01:01:13, metric 2, tag 0
                    > to 10.10.129.1 via fe-0/0/0.1121
200.0.1.0/24       *[RIP/100] 01:01:13, metric 4, tag 0
                    > to 10.10.129.1 via fe-0/0/0.1121
```

The preceding output proves that, like Lager, Ale is not readvertising the 200.0.100/24 route learned from Malt. For added verification, we configure RIP tracing at Ale.

```
[edit protocols rip]
lab@Ale# set traceoptions file rip_trace

[edit protocols rip]
lab@Ale# set traceoptions flag ?
Possible completions:
  all                  Trace everything
  auth                 Trace RIP authentication
  error                Trace RIP errors
  expiration           Trace RIP route expiration processing
  general              Trace general events
  holddown             Trace RIP hold-down processing
  normal               Trace normal events
  packets              Trace all RIP packets
  policy               Trace policy processing
  request              Trace RIP information packets
  route                Trace routing information
  state                Trace state transitions
  task                 Trace routing protocol task processing
  timer                Trace routing protocol timer processing
  trigger              Trace RIP triggered updates
  update               Trace RIP update packets
[edit protocols rip]
lab@Ale# set traceoptions flag update detail

[edit protocols rip]
lab@Ale# commit
```

No one wants a tool he can't use when he needs it. JUNOS software protocol tracing is much like Cisco Systems' debug in that it's a great way to gain insight into the operation of a given protocol, especially when things are not working. The upside is that you can deploy tracing on a Juniper Networks router, in a production network, with little to no operational impact—that is, the manual does not warn against using tracing, which is the case for debug in IOS. With that said, it is a best practice to enable tracing only when needed and only at the level of detail needed, and then to remove the tracing configuration when the job is done.

Also note that the Juniper Networks architecture cleanly separates the control and forwarding planes, which means that you can monitor interface traffic (tcpdump) or trace protocol operation only when it is sourced from or destined to the local router's Routing Engine (RE). You cannot monitor or trace transit traffic unless a sampling configuration is used to sample/mirror such traffic out of a specific interface.

This example shows the RIP tracing options along with a sample RIP tracing configuration. Here, traffic matching the update flag is written to a file called *rip_trace*. Various other trace flags exist and are useful when dealing with specific issues, such as using the auth flag when you suspect an authentication problem. The *rip_trace* file is monitored in real time with the monitor start command:

```
[edit protocols rip]
lab@Ale# run monitor start rip_trace
. . .
Aug 15 02:00:30.039884 Update job: sending 20 msgs; nbr: fe-0/0/0.1121;
group: rip; msgp: 0x876a000.
Aug 15 02:00:30.039916  nbr fe-0/0/0.1121; msgp 0x876a000.
Aug 15 02:00:30.039985                0.84.1.20/0x46c25e20: tag 3, nh
0.0.0.0, met 0.
Aug 15 02:00:30.040011              10.10.128.1/0xffffffff: tag 0, nh
0.0.0.0, met 1.
Aug 15 02:00:30.040027              192.168.1.0/0xfffffffc: tag 0, nh
0.0.0.0, met 1.
Aug 15 02:00:30.040041                200.0.1.0/0xffffff00: tag 0, nh
0.0.0.0, met 3.
Aug 15 02:00:30.040053          sending msg 0x876a004, 4 rtes
(needs MD5)
Aug 15 02:00:30.040691 Update job done for nbr fe-0/0/0.1121
group: rip
Aug 15 02:00:32.560426 received response: sender 10.10.129.2,
command 2, version 2, mbz: 0; 5 routes.
Aug 15 02:00:32.560579      10.10.128.2/0xffffffff: tag 0, nh
0.0.0.0, met 1.
Aug 15 02:00:32.560645      192.168.2.0/0xfffffffc: tag 0, nh
0.0.0.0, met 1.
Aug 15 02:00:32.560694        200.0.2.0/0xffffff00: tag 0, nh
0.0.0.0, met 3.

*** monitor and syslog output disabled, press ESC-Q to enable ***
```

You can enter the Esc-q key sequence to suspend trace output to the screen while information is still being written to the trace field. Pressing Esq-q again resumes output to the screen. It's nice to be able to enable tracing and suspend it on demand so that you can read what has been painted to the screen, without having to type something such as "undebug IP rip," all while your screen is overflowing with debug data. Use the monitor stop command to stop tailing the logfile. The monitor list command shows any logfiles that are being monitored.

The RIP tracing information relating to neighbor fe-0/0/0.1121 confirms the results of the show route-advertising protocol command; namely that Lager is not readvertising routes that it learns via RIP to other RIP neighbors. Having seen what there is to be seen, RIP tracing is diligently removed:

```
[edit protocols rip]
lab@Ale# delete traceoptions
```

```
[edit protocols rip]
lab@Ale# commit
commit complete
```

The Problem

Think back to your knowledge of JUNOS software routing policy; you'll recall that an export policy is the entity responsible for taking *active* routes from the route table and placing them into outgoing protocol updates. Because the problem route is in the route table, is active, and is confirmed as not being advertised to another RIP neighbor, it would seem to be a classic case of broken export policy. But why is our export broken?

In JUNOS software, all protocols have a default import and export policy. The default import policy for RIP is to accept all (sane) RIP routes, as you might expect. However, the default RIP export policy is to *advertise nothing*; not even routes learned through RIP! Put another way, and for whatever reason, the configuration of RIP in JUNOS software is not a simple matter of `router rip` combined with a few `network` statements. You will almost always want the RIP router to propagate routes learned via RIP; to do this you will need to add explicit export policy.

You already have a RIP export policy in effect to advertise the direct (connected) and the simulated customer static routes. Therefore, a quick modification will put things right again in RIP land:

```
[edit policy-options policy-statement rip_export]
lab@Ale# show
term 1 {
    from protocol direct;
    then accept;
}
term 2 {
    from {
        protocol static;
        route-filter 200.0.1.0/24 exact;
    }
    then {
        metric 3;
        accept;
    }
}

[edit policy-options policy-statement rip_export]
lab@Ale# set term 3 from protocol rip

[edit policy-options policy-statement rip_export]
lab@Ale# set term 3 then accept

[edit policy-options policy-statement rip_export]
lab@Ale# show
```

```
term 1 {
    from protocol direct;
    then accept;
}
term 2 {
    from {
        protocol static;
        route-filter 200.0.1.0/24 exact;
    }
    then {
        metric 3;
        accept;
    }
}
term 3 {
    from protocol rip;
    then accept;
}
```

A similar change is also made (and committed) to the export policy at Lager. After a few minutes, the results are confirmed:

```
[edit]
lab@Lager# run show route receive-protocol rip 10.10.129.1

inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.1.254.2/32      *[RIP/100] 00:01:22, metric 3, tag 0
                    > to 10.10.129.1 via fe-0/0/0.1121
10.10.128.100/32    *[RIP/100] 01:31:13, metric 3, tag 0
                      to 192.168.2.1 via fe-0/0/0.70
                    > to 10.10.129.1 via fe-0/0/0.1121
10.10.128.1/32     *[RIP/100] 01:31:07, metric 2, tag 0
                    > to 10.10.129.1 via fe-0/0/0.1121
192.168.1.0/30     *[RIP/100] 01:31:07, metric 2, tag 0
                    > to 10.10.129.1 via fe-0/0/0.1121
200.0.1.0/24       *[RIP/100] 01:31:07, metric 4, tag 0
                    > to 10.10.129.1 via fe-0/0/0.1121
200.0.100.0/24     *[RIP/100] 01:31:13, metric 5, tag 0
                    > to 192.168.2.1 via fe-0/0/0.70
                      to 10.10.129.1 via fe-0/0/0.1121

__juniper_private1__.inet.0: 2 destinations, 2 routes (2 active,
0 holddown, 0 hidden)
```

The show route-receiving protocol rip command at Lager confirms that Ale is now correctly readvertising RIP routes learned from Malt. You can also see the effects of the modified export policy in the show route-advertising protocol rip command issued at Lager:

```
[edit]
lab@Lager# run show route advertising-protocol rip 10.10.129.2

inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[RIP/100] 01:31:24, metric 2, tag 200
                    > to 192.168.2.1 via fe-0/0/0.70
10.1.254.0/24      *[RIP/100] 01:31:24, metric 2, tag 0
                    > to 192.168.2.1 via fe-0/0/0.70
10.1.254.1/32      *[RIP/100] 01:31:24, metric 2, tag 0
                    > to 192.168.2.1 via fe-0/0/0.70
10.10.128.200/32    *[RIP/100] 01:31:24, metric 2, tag 0
                    > to 192.168.2.1 via fe-0/0/0.70
10.10.128.2/32     *[Direct/0] 03:05:21
                    > via lo0.0
192.168.2.0/30     *[Direct/0] 03:05:21
                    > via fe-0/0/0.70
200.0.2.0/24       *[Static/5] 03:06:02
                      Discard
200.0.200.0/24     *[RIP/100] 01:26:33, metric 4, tag 0
                    > to 192.168.2.1 via fe-0/0/0.70
```

Lager's output confirms that it too is now readvertising RIP learned routes. As a final verification, the route table at Lager is inspected for the customer network associated with Malt:

```
[edit]
lab@Lager# run show route 200.0.100.0

inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

200.0.100.0/24     *[RIP/100] 01:33:57, metric 5, tag 0
                    > to 192.168.2.1 via fe-0/0/0.70
                      to 10.10.129.1 via fe-0/0/0.1121
```

The route's presence with two forwarding next hops confirms the earlier suspicion that there should be multiple equal cost paths for some RIP destinations in this lab topology. From Lager's there are now two equal cost paths to 200.0.100/24—one via Barley and the other through Ale.

RIP Deployment Summary

RIP really is a simple protocol, and configuring JUNOS software to interoperate with IOS for RIP was, for the most part, pretty straightforward. The most common problem you'll encounter with this scenario is unfamiliarity with the default RIP export policy, which is not intuitive, to say the least. This section demonstrated basic RIP configuration and operational mode commands that assist in troubleshooting RIP operation in a JUNOS software environment.

The next section addresses ways to migrate a network from one IGP to another, a concept called *IGP migration*. Once again, now is an opportune time to take a break before moving on.

IGP Migration

This section examines current best practices for IGP migration, referring to the exchange of a network's existing, or legacy, IGP with a different version of IGP. Generally, the overall goals are to minimize network disruption while also taking the opportunity to improve on the network's design and operation. The IGP plays a critical role in the operation of any IP network. Upgrading a legacy network's IGP can result in dramatic performance improvements and new service capabilities, and can align a company with an open standards-based solution, which in turn facilitates a best-of-breed decision among networking boxes.

IGP migration is an excellent time to clean house, so to speak, by reevaluating all aspects of the current network's design. Some factors to consider include:

- The potential for readdressing to better accommodate hierarchical design and route summarization
- The number and types of routers needed
- How those routers interconnect (WAN/LAN technologies may have evolved since the original network deployment)
- Ways to improve reliability

The need to maintain high network availability may preclude significant redesign. Usually a compromise must be reached between the need for availability versus potential optimizations, based on the specifics unique to each enterprise. In some cases, a new backbone is deployed in parallel (the integration model), which affords the luxury of complete redesign at the cost of additional gear.

IGP Migration: Common Techniques and Concerns

Before discussing specific migration approaches, it makes sense to examine some of the issues and considerations common to all approaches. General factors and concepts applying to IGP migrations include the following:

Global route preference

IGP transitions often touch on the concept of *global route preference*, which is known as *administrative distance* in IOS. A route's global preference indicates the overall *goodness* of a source of routing information and is used to break ties when two or more protocols announce reachability to the same prefix. Recall that longest match always rules; therefore, a longest-matching RIP route will always be preferred over a less specific version (a shorter netmask) that is learned from a more preferred protocol. For example, a /24 OSPF internal route will lose to a /32 RIP route every day of the week despite its much lower, and therefore preferred, preference. Global preference breaks ties *only* when routes with the *same level of specificity* are learned by multiple routing protocols.

Route redistribution

Route redistribution is the act of exchanging route information among different routing protocols and is a common aspect of most IGP migration strategies. In many cases, you will not configure all routers for the new IGP at the same time and will maintain connectivity between IGP domains by redistributing routes between the new and legacy IGPs at select routers. Because this will typically be mutual, also known as bidirectional route redistribution, you must remain ever-vigilant or else fall victim to the effects of routing loops. Accurate policy is needed to ensure that routes originating within IGP A that are sent into IGP B are never redistributed back into IGP A, and vice versa.

Concurrent IGP operation

Many migration scenarios will require that a device be configured to run instances of both the old and the new IGPs at the same time. The first issue here is whether the device offers support for both protocols. For example, running EIGRP on a Juniper Networks router is simply not an option. Then there are matters of performance—can the device be expected to run two instances of an IGP and still operate reliably? There are numerous cases of IGP migration (ones that were planned to occur with little or no disruption, we might add) that instead melted down when a box started rebooting or peers start flapping, all because of insufficient memory or CPU power when tasked with running both IGPs concurrently. This is something that is often not considered when testing a migration scenario in a lab, where boxes may be running at far lower memory and CPU levels than they would in the production environment.

As a general rule, you can safely run both IGPs concurrently if an existing device's CPU load is less than 50% while its memory load is less than 60%. If the device's CPU or memory load is higher, you should consider a device upgrade or a migration approach that does not place both IGPs in service at the same time.

Network cleanup and design

IGP migration is an opportune time to rid your network of excess baggage and poor design characteristics that may have evolved in an ad hoc fashion over the years. Before migration, you should make sure your network documentation is accurate and that you have reduced as much clutter as possible by removing any unauthorized or unneeded addresses, networks, peers, protocols, and so forth. Careful thought should be leveled at the design of the new IGP. Will it be flat or hierarchical? Does the existing addressing model accommodate? How will metrics be mapped between the old and new IGPs? Where will you place ABRs and ASBRs, and which routers should function as the DRs on LAN segments?

IGP Migration Models

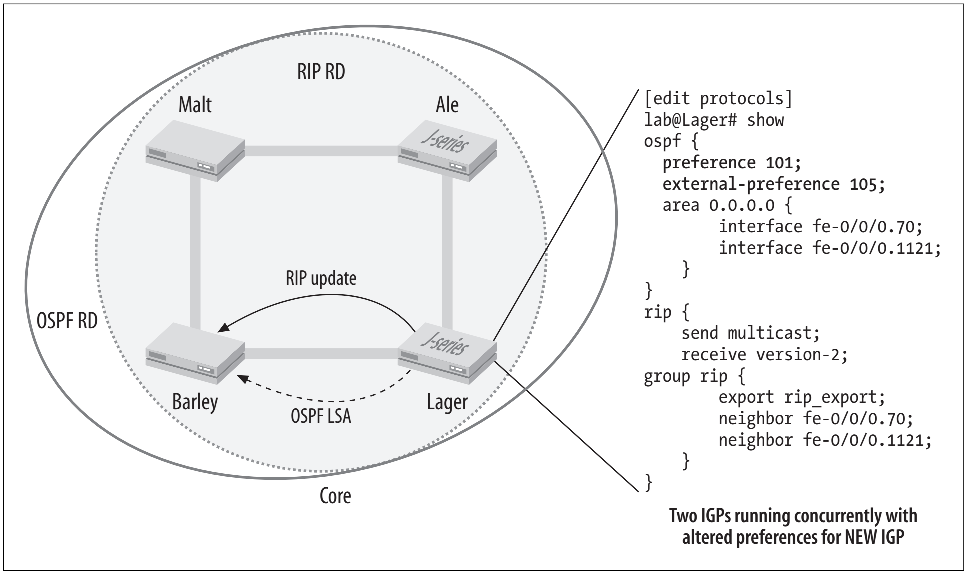
Several proven approaches to IGP transitions have been developed over the years, and most of these approaches share common elements to one degree or another. Each enterprise network is unique, and the specifics of your network design, your standards for acceptable levels of disruption, and your budget will come into play when deciding on a specific approach. The migration strategies are presented in an order representing easiest to most difficult. The more difficult strategies are often combined with a more extensive network redesign given the work already being performed.

The Overlay Model

The overlay model is generally considered the most straightforward IGP migration approach. The overlay is best suited to networks that have a similar *before and after* logical topology. For example, if the legacy network is a flat RIP network and the proposed design is a single area OSPF network, logically both networks are flat and IGP migration will be straightforward. Using an overlay approach to move from a flat to a hierarchical network can be rife with difficulties. For example, a flat network's addressing scheme may not accommodate a sound hierarchical design, and the placement of nodes may not accommodate the desired location or level of redundancy for things such as ABRs.

Figure 4-4 illustrates a network running both the legacy (RIP) and the new (OSPF) IGPs. Because Layer 2 switching is often used in the access and aggregation layers, the focus of most IGP migrations is centered on the core layer—the techniques demonstrated here are applicable for access and aggregation layer migrations as well. Note how both IGPs are configured at the same time, that the new IGP is initially set to be less preferred (both OSPF preference values are larger than RIP's default 100), and that each router sends updates for both IGPs in a ships-in-the-night fashion, meaning that neither IGP is aware of the other's operation.

The overlay model hinges on all devices having the ability to run both the old and the new IGPs concurrently, and it makes heavy use of route preference to keep the new IGP's routes from becoming active, and therefore installed in the forwarding table, until all aspects of the new IGP's operation are determined to be satisfactory. When ready to make the cutover, the route preference is altered to have the routers prefer the new IGP's routes. Ideally, this is all done in parallel, because having some devices use one IGP's routes while other routers use a different IGP's routes can lead to loops stemming from variances between each protocol's take on the best route. In many cases, the odds of which can be improved by the careful mapping of old to new metrics, the forwarding paths of both protocols will be identical and you can get away with an incremental, box-at-a-time shift in protocol preference. When the new IGP's operation is deemed stable, the old IGP is decommissioned by removing its configuration from each router (there is no need to perform this in parallel, as you



```
[edit protocols]
lab@Lager# show
ospf {
  preference 101;
  external-preference 105;
  area 0.0.0.0 {
        interface fe-0/0/0.70;
        interface fe-0/0/0.1121;
     }
}
rip {
    send multicast;
    receive version-2;
group rip {
        export rip_export;
        neighbor fe-0/0/0.70;
        neighbor fe-0/0/0.1121;
     }
}
```

Two IGPs running concurrently with altered preferences for NEW IGP

Figure 4-4. The overlay model

are now using the new IGP). It's a good idea to keep a copy of the old configuration around, and you should consider using the `deactivate` function of the JUNOS software CLI to comment out the old IGP's stanza, all the while knowing that you can safely bring it back at any time by activating that portion of the configuration.

The Redistribution Model

The redistribution model is often used when an overlay approach is not workable due to a migration from a flat to a hierarchical design or because some of the devices cannot run both IGPs concurrently. The latter condition may be due to lack of device support or because of performance limitations. Figure 4-5 illustrates a before-and-after view of a network that, given the shift to a hierarchical design, represents a good candidate for the route redistribution model.

The first phase of the migration from RIP to OSPF is shown in Figure 4-6. Here, backbone routers `Ale` and `Lager` are configured to run both RIP and OSPF concurrently, with the OSPF backbone being formed as a result. The arrow shows a RIP update sent by `Malt` and received by `Ale`, where it will be injected into the nascent backbone as a Type 5 AS external LSA. Though not shown, routes originating in the OSPF backbone undergo a similar process whereby they are injected into the RIP domain to maintain full connectivity. It is critical to stress that controls must be in place to ensure that routes are never redistributed back into the RD from where they originated, unless your goal is a network-wide test of the IP Time to Live (TTL) mechanism. A well-planned addressing approach always makes the filtering of route updates easier, as does a consistent approach to route tagging (where supported by the protocol). The use of route tags makes control over route redistribution much easier to configure and consequently far less prone to human error.

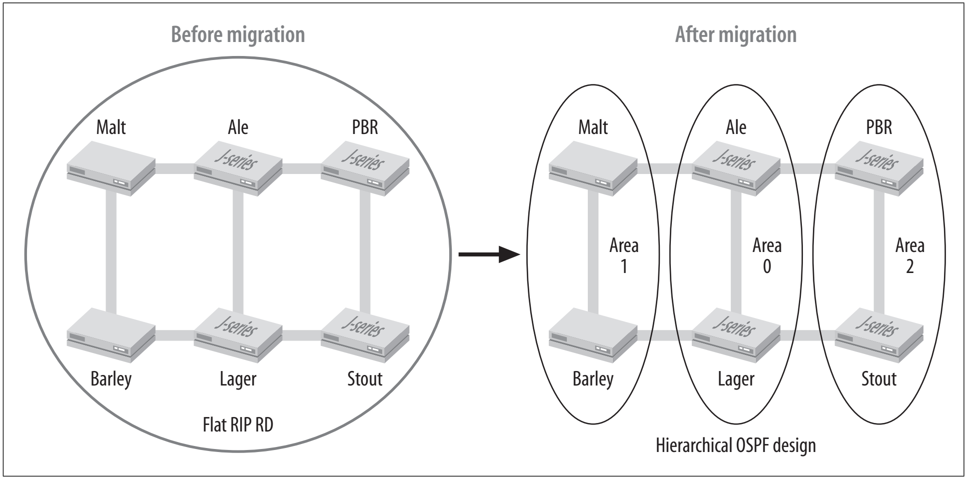


Figure 4-5. The redistribution model

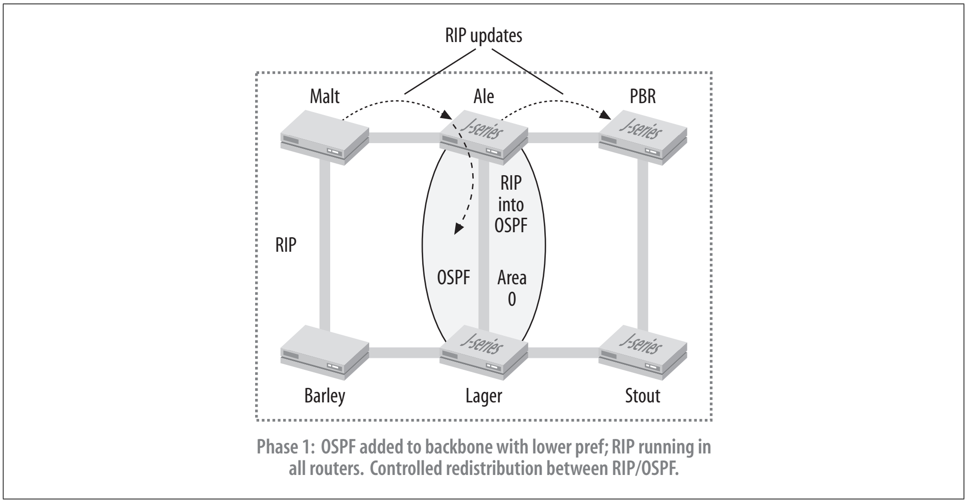

RIP updates
Malt
Ale
PBR
J-series
RIP
RIP into OSPF
OSPF
Area 0
Barley
Lager
Stout
Phase 1: OSPF added to backbone with lower pref; RIP running in all routers. Controlled redistribution between RIP/OSPF.

Figure 4-6. Route tagging in the redistribution model to control route exchange

Once again, the OSPF preference is altered to be *less preferred* than that of the original IGP, as was the case in the overlay model. The default global preference for JUNOS software is 100 for RIP and 10/150 for OSPF internal and AS external, respectively. Setting these preferences to 101/110 achieves the goal of ensuring that RIP is preferred. This step ensures that the backbone will always prefer routes in their native RIP form, thus avoiding routing loops and suboptimal routing. By way of example, consider that without this step, router `Barley`'s 200.0.200/24 route might be initially learned by Lager as an OSPF route, via a RIP update that was generated by Malt and then redistributed into OSPF by Ale. By this time, Lager should have also received a RIP update for the same prefix direct from Barley. If the preferences are such that Lager prefers OSPF externals over RIP, we would have an extra hop as Lager forwards packets for 200.0.200/24 route over the OSPF backbone through Ale, rather than the direct shot via Barley.

> In this example, the default JUNOS software route preferences would have resulted in the desired behavior. When redistributed into OSPF, the RIP routes take the form of AS externals, which by default have a preference of 150, which makes them less preferred than RIP anyway. Nonetheless, it's recommended that you always explicitly set preferences. It's rarely a good idea to leave such things to chance in your network!

The next phase of the migration is depicted in Figure 4-7, where routers PBR and Stout have been converted to OSPF and placed into Area 2. The specific approach taken to make this change could have been that of an overlay, where the routers run RIP and OSPF concurrently, or as a hot cutover that removed the old and added the new IGP in one fell swoop. Such cutovers are made a little less stressful with the "nothing happens until you commit" nature of JUNOS software. IOS users would likely paste such changes in from a configuration file to try to minimize disruption. It ends with routers Barley and Malt remaining in the RIP domain along with the associated interfaces on Ale and Lager. The next phase of the migration is an iterative process that repeats the same procedure on Barley and Malt to create Area 1. The IGP migration is completed with removal of any RIP remnants from the configurations of Area 0 routers Ale and Lager.

The Integration Model

The integration model is also well suited to IGP migrations that transition from a flat to a hierarchical design, especially when a significant IP readdressing and/or network infrastructure upgrade is planned as part of the migration. In the integration model, a new backbone network is deployed and tied to the legacy backbone, where mutual route redistribution is performed. Portions of the legacy network are transitioned to the new backbone in a phased manner. This type of migration is not hitless, but its does afford a near green-field chance to redesign your IGP while confining down time to those segments that are actively being transitioned. Once all segments have been migrated to the new backbone, the legacy backbone is decommissioned. This process is shown in Figure 4-8, which begins with the legacy backbone and moves on to the buildout of a new backbone and the migration of one network segment. The process ends with the rightmost diagram showing all network segments transitioned to the new backbone and removal of the legacy backbone infrastructure.

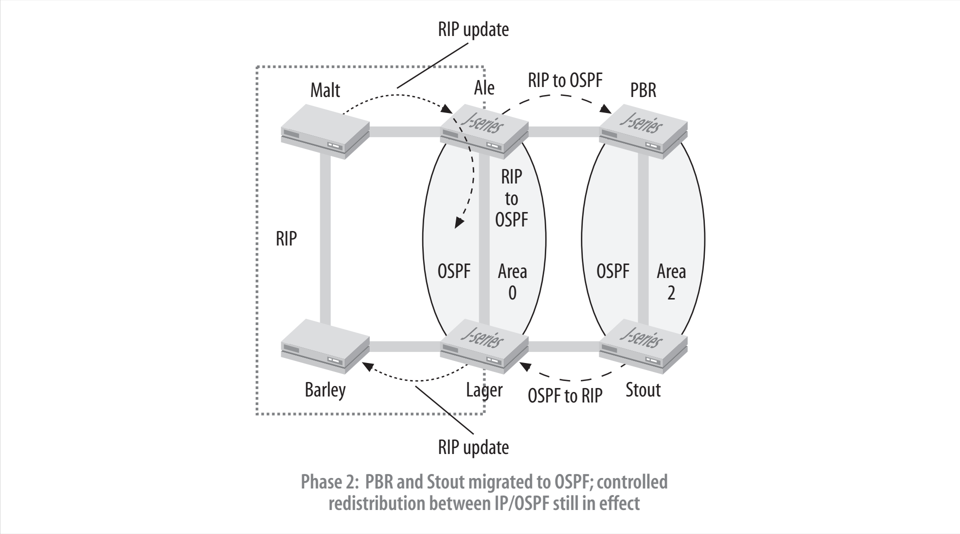


Figure 4-7. Route redistribution IGP migration: Phase 2

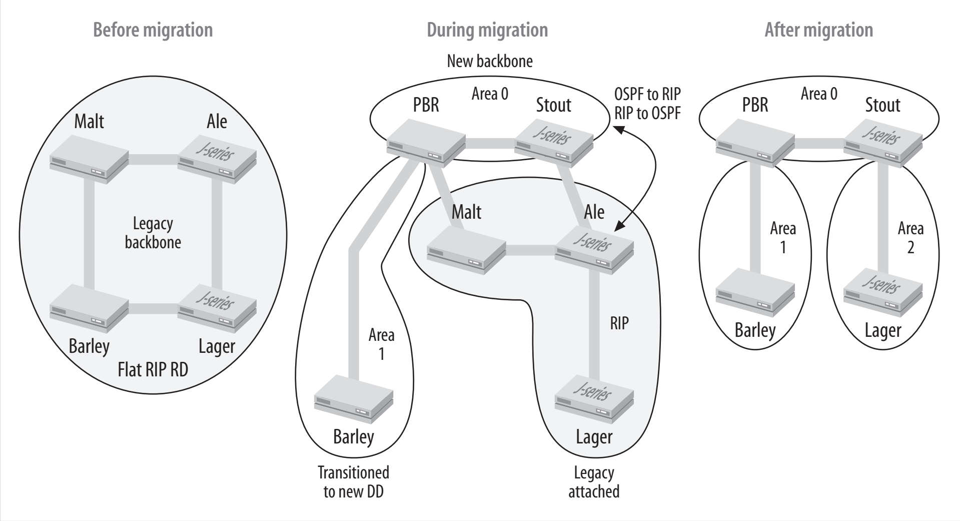


Figure 4-8. The integration model

You'll again find mutual route redistribution at play, and also this requires strict control to prevent routes from being sent back to their originating IGP. As each network segment is transitioned, you may be able to deploy an overlay approach or you might be forced into a hot cutover based on equipment capability and the level of network redesign (e.g., any renumbering that is also planned).

It goes without saying, but we will state it here anyway, that the integration model represents the largest degree of effort and capital expenditure. There is the cost of new equipment and new backbone buildout, and then the sustaining costs of both the legacy and new backbones as segments are transitioned. During these transitions, there may be significant renumbering and a need to deploy the new backbone protocol on routers as they become part of the new IGP.

IGP Migration Summary

Networks, like people, evolve and change over time. Many networks are still running yesterday's IGP and could benefit from a facelift in the interior routing department. Or maybe your network is running some proprietary routing protocol and you have decided that it is time to add another vendor to the network, for whatever reason. Either way, the techniques and concepts discussed here can help to minimize disruption and make the shift to a new IGP as pain-free as possible.

In the next section, you will put this theory into practice as you migrate a network from RIP to the OSPF protocol.

Overlay Migration Scenario: RIP to OSPF

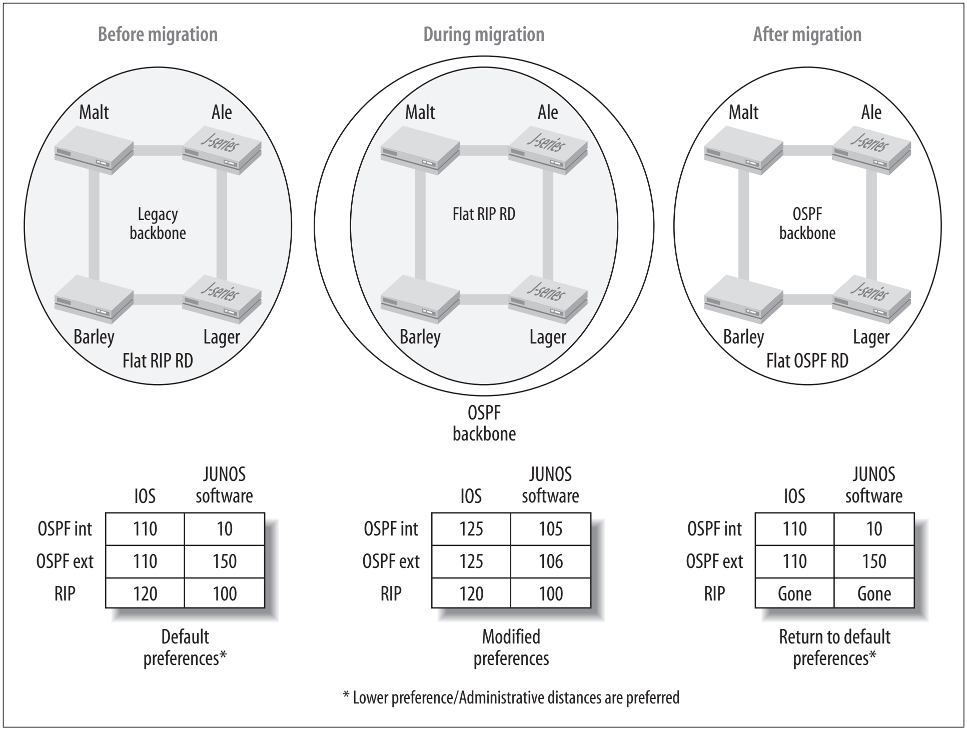
Just when you are considering some well-deserved time off, given the success of the recently deployed RIPv2 internetwork, you receive notification from the new CIO that the Beer-Co network must migrate to OSPF as part of a modernization initiative. Beer-Co has conducted a design review and determined that a single OSPF area with the ability to expand to a hierarchal design in the near future is required.

Considering the migration methods described in the previous section and the current design criteria, you propose an overlay-based migration. The reasons for this recommendation include the following:

- Both the legacy and planned networks are flat.
- Both the legacy Cisco and new Juniper Networks gear support the legacy and new IGPs.
- It's the most direct migration strategy, and you are still smarting from tilting at RIP.

Figure 4-9 shows the before, during, and after networks. In the middle, both IGPs are running, but altered preferences ensure that RIP routes remain active, which provides you the chance to verify all aspects of OSPF *before* its routes become active. The key to the overlay model is altered protocol preferences, and the figure also shows the beginning, initial modification, and final preference values for RIP and OSPF internal/external routes.

The critical point occurs before OSPF is activated (especially in IOS, where changes take effect immediately as they are entered). Both the internal and external preferences are set so that RIP remains unperturbed until you are ready to retire it.



	IOS	JUNOS software
OSPF int	110	10
OSPF ext	110	150
RIP	120	100

Default preferences*

	IOS	JUNOS software
OSPF int	125	105
OSPF ext	125	106
RIP	120	100

Modified preferences

	IOS	JUNOS software
OSPF int	110	10
OSPF ext	110	150
RIP	Gone	Gone

Return to default preferences*

* Lower preference/Administrative distances are preferred

Figure 4-9. RIP-to-OSPF overlay topology

Failing to ensure that OSPF external preference is set lower (is more preferred) than RIP leads to a Frankenstein-like forwarding model that has the simulated customer networks and redistributed loopback routes forwarding over OSPF paths while the internal routes continue to forward via RIP.

The Juniper boxes are configured first (recall that, until you commit, no change takes effect, so you have a safety net of rollback or commit confirmed in case you do not like the results). The OSPF stanza is displayed at `Ale` along with the associated `set` commands using the CLI's `show | display set` command. The authentication key value `jncie` is reused here. Also of note are the altered preference values for OSPF internal and external routes—that authentication is configured at the area level while the specifics are set on a per-interface basis:

```
[edit protocols ospf]
lab@Ale# show
preference 105;
external-preference 106;
export ospf_export; ## 'ospf_export' is not defined
area 0.0.0.0 {
    authentication-type md5;
    interface fe-0/0/0.69 {
        authentication {
            md5 1 key "$9$Yb4JD3nCuOI.PF/"; ## SECRET-DATA
        }
    }
    interface fe-0/0/0.1121 {
        authentication {
            md5 1 key "$9$WitXNbiHmTQn4ajq"; ## SECRET-DATA
        }
    }
}

[edit protocols ospf]
lab@Ale# show | display set
set protocols ospf preference 105
set protocols ospf external-preference 106
set protocols ospf export ospf_export
set protocols ospf area 0.0.0.0 authentication-type md5
set protocols ospf area 0.0.0.0 interface fe-0/0/0.69 authentication
md5 1 key "$9$Yb4JD3nCuOI.PF/"
set protocols ospf area 0.0.0.0 interface fe-0/0/0.1121 authentication
md5 1 key "$9$WitXNbiHmTQn4ajq"
```

Like RIP, OSPF requires an export policy for route redistribution, and the CLI's copy feature is evoked to save some effort:

```
[edit protocols ospf]
lab@Ale# top edit policy-options

[edit policy-options]
lab@Ale# copy policy-statement rip_export to policy-statement
ospf_export

[edit policy-options]
lab@Ale# edit policy-statement ospf_export

[edit policy-options policy-statement ospf_export]
lab@Ale# show
term 1 {
    from protocol direct;
    then accept;
}
term 2 {
    from {
        protocol static;
        route-filter 200.0.1.0/24 exact;
    }
    then {
        metric 3;
        accept;
    }
}
term 3 {
    from protocol rip;
    then accept;
}
```

Looking over the copy of the RIP policy, now in its renamed ospf_export form, it seems that the only term that is out of place is term 3 and the bit about matching RIP. You certainly do not want any RIP-to-OSPF redistribution in this example! We remove term 3 (committing the changes) and make similar changes to Lager:

```
[edit policy-options policy-statement ospf_export]
lab@Ale# delete term 3
```

After a few moments, the OSPF adjacency status is confirmed between Ale and Lager. Recall that Malt and Barley have not been configured with OSPF at this time:

```
[edit]
lab@Ale# run show ospf interface
Interface        State     Area       DR ID         BDR ID       Nbrs
fe-0/0/0.1121    DR       0.0.0.0   10.10.128.1  10.10.128.2     1
fe-0/0/0.69      DR       0.0.0.0   10.10.128.1  0.0.0.0         0
```

The output from the show ospf interface command confirms that OSPF is running on the desired interfaces and that local router Ale has won the DR election on both of its interfaces. Considering that Ale is alone (zero neighbors have been detected) on its fe-0/0/0.69 interface, its DR status on that segment should be no surprise. You can also verify the area 0 setting and that the only other router on the fe0-0/0/0.1121 link has delegated itself to be the backup DR. Remember that priority and RID factor only during an active election. Given the matched priority and Ale's lower RID (its lo0 address is lower than Lager's), this must be a case of Ale having been configured for OSPF first. The first non-0 priority router up always becomes the DR:

```
[edit]
lab@Ale# run show ospf neighbor
  Address         Interface        State      ID           Pri  Dead
10.10.129.2      fe-0/0/0.1121     Full      10.10.128.2   128    38
```

The show ospf neighbor command verifies that a full adjacency has been formed between Ale and Lager, which is a very good sign indeed:

```
[edit]
lab@Ale# run show route protocol ospf

inet.0: 19 destinations, 22 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.128.2/32      [OSPF/105] 00:01:03, metric 1
                    > to 10.10.129.2 via fe-0/0/0.1121
192.168.2.0/30      [OSPF/105] 00:01:03, metric 2
                    > to 10.10.129.2 via fe-0/0/0.1121
200.0.2.0/24        [OSPF/106] 00:01:03, metric 3, tag 0
                    > to 10.10.129.2 via fe-0/0/0.1121
224.0.0.5/32       *[OSPF/10] 00:07:52, metric 1
                      MultiRecv
```

Showing the routes learned via OSPF confirms several important points. One is simply that routes are being learned via OSPF (Lager's 10.10.126.2 loopback and the

192.168.2.0 link to Barley), and equally significant is that none of these learned OSPF route are currently active.

> Unlike IOS, which requires that you run OSPF on the loopback interface to advertise its associated route, JUNOS software automatically advertises a stub route to the *default* address used as the source of the RID, assuming that a RID has not been explicitly set under [routing-options]. Because the lo0 interface is the first to be activated, the lo0 interface's *primary* address is used as the RID. In contrast, for IOS it is common to either run a passive OSPF instance on the loopback interface or to redistribute the connected router into OSPF, as shown in the following example.

A final confirmation that our route preference changes are working comes when we display the route to Lager's customer network at Ale:

```
[edit]
lab@Ale# run show route 200.0.2.0

inet.0: 19 destinations, 22 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

200.0.2.0/24       *[RIP/100] 02:47:22, metric 4, tag 0
                    > to 10.10.129.2 via fe-0/0/0.1121
                    [OSPF/106] 00:09:29, metric 3, tag 0
                    > to 10.10.129.2 via fe-0/0/0.1121
```

Perfect! Ale has both OSPF and RIP copies of the customer route. The key thing here is that the original RIP version is, and has always been, active. Unlike RIP, the displayed OSPF route metric does not reflect Ale's interface costs to reach Lager. With the default scaling factor of 100,000,000, the cost for Ale's Fast Ethernet interface is 1 (you can confirm this with a show ospf interface detail command), so you might expect to see Ale display a cost of 4 for the 200.0.0.2/24 prefix. The reason for this situation is that the OSPF_export policy at Lager did not bother to specify a Type 1 external metric, so the default Type 2 metric is generated, and by OSPF standards this metric is never incremented by other routers. A sample of a policy modification that alters the metric type is provided, along with the results observed back at Ale. These changes are then rolled back to restore the initial behavior:

```
[edit policy-options policy-statement ospf_export]
lab@Lager# show
term 1 {
    from protocol direct;
    then accept;
}
term 2 {
    from {
        protocol static;
        route-filter 200.0.2.0/24 exact;
    }
    then {
        metric 3;
        external {
            type 1;
        }
        accept;
    }
}
[edit]
lab@Ale# run show route 200.0.2.0

inet.0: 19 destinations, 22 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

200.0.2.0/24       *[RIP/100] 03:03:06, metric 4, tag 0
                    > to 10.10.129.2 via fe-0/0/0.1121
                    [OSPF/106] 00:02:35, metric 4, tag 0
                    > to 10.10.129.2 via fe-0/0/0.1121
```

With the OSPF overlay working on the Juniper Networks portion of the network, we place the equivalent configuration into effect at the Cisco boxes. It is critical that the modified OSPF preference (setting both the internal and external to a distance higher than RIP's) be the first thing configured to help ensure that RIP is not impacted—in IOS land, changes go into effect as soon as they are entered. By default, IOS assigns the same administrative distance to OSPF internals and externals (and interarea, for that matter), so we should adopt the same approach—as long as the distance for all OSPF routes is less preferred than RIP, it will be OK. The commands entered on Malt are shown. Similar commands are also entered on Barley.

```
Malt# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Malt(config)#router ospf 10
Malt(config-router)#distance 125
Malt(config-router)# area 0 authentication message-digest
Malt(config-router)# redistribute static route-map TAGGING
% Only classful networks will be redistributed
Malt(config-router)# network 10.0.0.0 0.255.255.255 area 0
Malt(config-router)# network 192.168.2.0 0.0.0.3 area 0
Malt(config-router)# default-information originate route-map FOO
Malt(config-router)#exit
Malt(config)#interface fastEthernet 0/1.69
Malt(config-subif)#ip ospf message-digest-key 1 md5 jncie
Malt(config-router)#exit
Malt(config)#interface serial 0/0
Malt(config-subif)#ip ospf message-digest-key 1 md5 jncie
Malt(config)#route-map FOO permit 20
Malt(config-route-map)# match ip address 4
Malt(config-route-map)# set tag 100
Malt(config-subif)#^Z
Malt#
*Mar  1 04:01:28.603: %SYS-5-CONFIG_I: Configured from console by
console
```

```
*Mar  1 04:01:30.495: %OSPF-5-ADJCHG: Process 10, Nbr 10.10.128.1 on FastEthernet0/1.
69 from LOADING to FULL, Loading Done
```

The resultant OSPF portion of the configuration is shown next, along with the new route map. Note the log message in the previous capture reporting an up adjacency on Malt's fa 0/1.69 interface. This is a good indication that we have compatible OSPF settings between the Cisco and Juniper routers.

```
router ospf 10
 log-adjacency-changes
 area 0 authentication message-digest
 redistribute static route-map TAGGING
 network 10.0.0.0 0.255.255.255 area 0
 network 192.168.2.0 0.0.0.3 area 0
 default-information originate route-map FOO
 distance 125
!
. . .
route-map FOO permit 20
 match ip address 4
 set tag 100
!
```

The configuration creates an OSPF instance identified as 10, enables MD5 authentication in area 0, redistributes and route-maps the same routes used in the RIP example, and enables OSPF area 0 in the serial 0/0 and fa 0/1.60 interfaces. Note that in the IOS implementation, OSPF will not redistribute a default static route. You must use the default-information originate command instead. Using the preexisting TAGGING route map did not work, so a new route map named FOO was created. It's things such as this that make you appreciate the consistent nature of JUNOS software routing policy.

In an approach that is similar to JUNOS software OSPF configuration, the specific MD5 key ID and key value are set under each interface. The difference is that for JUNOS software, this was done within the OSPF configuration proper, whereas for IOS, it is under the interface configuration. The OSPF authentication settings are also shown for one of Malt's interfaces:

```
interface FastEthernet0/1
 no ip address
 duplex auto
 speed auto
!
interface FastEthernet0/1.69
 encapsulation dot1Q 69
 ip address 192.168.1.1 255.255.255.252
 ip rip authentication mode md5
 ip rip authentication key-chain test
 ip ospf message-digest-key 1 md5 jncie
 no snmp trap link-status
!
```

After a few moments, the OSPF status is analyzed on Malt:

```
Malt#show ip ospf interface fastEthernet 0/1.69
FastEthernet0/1.69 is up, line protocol is up
  Internet Address 192.168.1.1/30, Area 0
  Process ID 10, Router ID 10.10.128.100, Network Type BROADCAST,
Cost: 1
  Transmit Delay is 1 sec, State BDR, Priority 1
  Designated Router (ID) 10.10.128.1, Interface address 192.168.1.2
  Backup Designated router (ID) 10.10.128.100, Interface address
192.168.1.1
  Timer intervals configured, Hello 10, Dead 40, Wait 40,
Retransmit 5
    oob-resync timeout 40
    Hello due in 00:00:05
  Index 3/3, flood queue length 0
  Next 0x0(0)/0x0(0)
  Last flood scan length is 1, maximum is 1
  Last flood scan time is 0 msec, maximum is 4 msec
  Neighbor Count is 1, Adjacent neighbor count is 1
    Adjacent with neighbor 10.10.128.1  (Designated Router)
  Suppress hello for 0 neighbor(s)
  Message digest authentication enabled
    Youngest key id is 1
```

The show ip ospf interface command for Malt's fa 0/1.69 verifies the presence of a neighbor with RID 10.10.128.1 (Ale's loopback address/RID) and confirms the authentication and timer settings that are in effect. As expected, Ale remains the DR because in OSPF, this DR election is not revertive.

```
Malt#show ip ospf neighbor
Neighbor ID   Pri  State    Dead Time  Address     Interface
10.10.128.1   128  FULL/DR  00:00:38   192.168.1.2 FastEthernet0/1.69
10.10.128.200   0  FULL/  - 00:00:36   10.1.254.2  Serial0/0
```

The show ip ospf neighbor command confirms the expected adjacencies to both Barley and Ale. We next display a simulated customer route to confirm that the RIP copy is still being used at the Cisco boxes:

```
Malt#show ip route 200.0.2.0
Routing entry for 200.0.2.0/24
  Known via "rip", distance 120, metric 4
  Redistributing via rip
  Last update from 10.1.254.2 on Serial0/0, 00:00:03 ago
  Routing Descriptor Blocks:
  * 10.1.254.2, from 10.1.254.2, 00:00:03 ago, via Serial0/0
      Route metric is 4, traffic share count is 1
    192.168.1.2, from 192.168.1.2, 00:00:14 ago, via FastEthernet0/1.69
      Route metric is 4, traffic share count is 1
```

The output confirms that the RIP version of the route is still active. Unfortunately, IOS displays *only* the active route, making it hard to confirm that OSPF shadow versions also exist. The LSDB is inspected to make this determination:

```
Malt#show ip ospf database external adv-router 10.10.128.2

            OSPF Router with ID (192.168.1.1) (Process ID 120)

            OSPF Router with ID (10.10.128.100) (Process ID 10)

                Type-5 AS External Link States

  LS age: 97
  Options: (No TOS-capability, DC)
  LS Type: AS External Link
  Link State ID: 10.10.128.2 (External Network Number )
  Advertising Router: 10.10.128.2
  LS Seq Number: 80000006
  Checksum: 0x2858
  Length: 36
  Network Mask: /32
        Metric Type: 2 (Larger than any link state path)
        TOS: 0
        Metric: 0
        Forward Address: 0.0.0.0
        External Route Tag: 0

  Routing Bit Set on this LSA
  LS age: 397
  Options: (No TOS-capability, DC)
  LS Type: AS External Link
  Link State ID: 200.0.2.0 (External Network Number )
  Advertising Router: 10.10.128.2
  LS Seq Number: 80000006
  Checksum: 0x92B6
  Length: 36
  Network Mask: /24
        Metric Type: 2 (Larger than any link state path)
        TOS: 0
        Metric: 3
        Forward Address: 0.0.0.0
        External Route Tag: 0
```

The external (in fixed code) argument to the `show ip ospf database` command filters the output such that only AS LSAs sent by `Lager` are shown. The `adv-router` argument specified `Lager`'s OSPF RID to identify it from all other sources of AS external LSAs in the OSPF RD. The output confirms that `Lager`'s customer route (200.0.2/24) is being advertised into OSPF.

RIP-to-OSPF Migration: Cutover to OSPF

With various aspects of OSPF operation confirmed, it's time to make the cut from RIP to OSPF. This should be a nondisruptive process, but as with all IGP migration procedures, it's best to perform the cutover in a maintenance window as added insurance—the interplay of complex internetworking protocols is sometimes hard to predict.

The actual transition normally occurs in two phases. First, make the OSPF routes active, and then, after you confirm proper operation, remove all traces of the legacy protocol and reset the new protocol to its default preference values.

To achieve the first goal you could reconfigure the OSPF internal and external preferences to be more preferred than RIP, or you could alter RIP's preference to be less preferred than OSPF. Either way, if something blows up, you can roll back or simply remove the OSPF configuration, and return to RIP operation while determining what went wrong. Given that IOS is now set with a single preference for both OSPF and RIP, the amount of change is a wash. On the JUNOS devices, it will be easier to change the one RIP preference rather than both OSPF values. Therefore, the plan is to set the RIP administrative distance to 126 on the IOS devices, while setting the RIP preference to 107 on the JUNOS devices. In both cases, the change will make RIP a less-preferred protocol.

The changes are shown for the Juniper router `Ale`. Similar commands are also executed at `Lager`:

```
[edit protocols]
lab@Ale# set rip group rip preference 107
```

The RIP administrative distance is altered on both IOS boxes:

```
Malt#conf terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Malt(config)#router rip
Malt(config-router)#distance 126
```

After a few moments, it's confirmed that the OSPF version of `Lager`'s 200.0.2.0 route is now preferred at `Barley`:

```
Barley#show ip route 200.0.2.0
Routing entry for 200.0.2.0/24
  Known via "ospf 10", distance 125, metric 3, type extern 2, forward
metric 1
  Last update from 192.168.2.2 on FastEthernet0/1.70, 00:03:42 ago
  Routing Descriptor Blocks:
  * 192.168.2.2, from 10.10.128.2, 00:03:42 ago, via FastEthernet0/1.70
      Route metric is 3, traffic share count is 1
```

Back at the Juniper side of things, you should make a similar determination as to which set of routes is preferred. Note how routes learned through multiple sources are clearly shown in JUNOS software, and that the active versions of these routes are now OSPF-based:

```
lab@Ale# run show route

inet.0: 19 destinations, 26 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/106] 00:00:25, metric 1, tag 200
                    > to 10.10.129.2 via fe-0/0/0.1121
```

```
                        [RIP/107] 06:14:07, metric 2, tag 100
                        > to 192.168.1.1 via fe-0/0/0.69
    10.1.254.0/24      *[OSPF/105] 00:08:03, metric 66
                        > to 10.10.129.2 via fe-0/0/0.1121
                        [RIP/107] 06:14:07, metric 2, tag 0
                        > to 192.168.1.1 via fe-0/0/0.69
    10.1.254.1/32      *[RIP/107] 04:14:22, metric 3, tag 0
                        > to 10.10.129.2 via fe-0/0/0.1121
    10.1.254.2/32      *[RIP/107] 06:14:07, metric 2, tag 0
                        > to 192.168.1.1 via fe-0/0/0.69
    10.10.128.100/32    *[OSPF/105] 00:08:03, metric 67
                        > to 10.10.129.2 via fe-0/0/0.1121
                        [RIP/107] 06:14:07, metric 2, tag 0
                        > to 192.168.1.1 via fe-0/0/0.69
    10.10.128.200/32    *[OSPF/105] 00:08:03, metric 3
                        > to 10.10.129.2 via fe-0/0/0.1121
    10.10.128.1/32     *[Direct/0] 3d 21:34:05
                        > via lo0.0
    10.10.128.2/32     *[OSPF/105] 00:08:03, metric 1
                        > to 10.10.129.2 via fe-0/0/0.1121
                        [RIP/107] 05:45:43, metric 2, tag 0
                        > to 10.10.129.2 via fe-0/0/0.1121
    10.10.129.0/24     *[Direct/0] 2d 22:32:39
                        > via fe-0/0/0.1121
    10.10.129.1/32     *[Local/0] 3d 21:34:05
                          Local via fe-0/0/0.1121
    192.168.1.0/30     *[Direct/0] 2d 22:32:39
                        > via fe-0/0/0.69
    192.168.1.2/32     *[Local/0] 3d 06:03:32
                          Local via fe-0/0/0.69
    192.168.2.0/30     *[OSPF/105] 00:08:03, metric 2
                        > to 10.10.129.2 via fe-0/0/0.1121
                        [RIP/107] 05:45:43, metric 2, tag 0
                        > to 10.10.129.2 via fe-0/0/0.1121
    200.0.1.0/24       *[Static/5] 2d 07:10:57
                          Discard
    200.0.2.0/24       *[OSPF/106] 00:08:03, metric 3, tag 0
                        > to 10.10.129.2 via fe-0/0/0.1121
                        [RIP/107] 05:45:43, metric 4, tag 0
                        > to 10.10.129.2 via fe-0/0/0.1121
    200.0.100.0/24     *[OSPF/106] 00:08:03, metric 3, tag 0
                        > to 10.10.129.2 via fe-0/0/0.1121
                        [RIP/107] 06:14:07, metric 4, tag 0
                        > to 192.168.1.1 via fe-0/0/0.69
    200.0.200.0/24     *[OSPF/106] 00:08:03, metric 3, tag 0
                        > to 10.10.129.2 via fe-0/0/0.1121
    224.0.0.5/32       *[OSPF/10] 03:14:39, metric 1
                          MultiRecv
    224.0.0.9/32       *[RIP/100] 00:08:03, metric 1
                          MultiRecv
```

The display shows the default route in its OSPF and RIP forms, both of which are tagged due to route-map actions. Here, Ale has installed the default generated by

Barley (tag 200), with the RIP version learned directly from Malt also listed (tag 100). The JUNOS software CLI's matching function is used to identify any remaining active RIP routes. The \ is used here to escape the * character, so it is not incorrectly expanded as a shell wildcard, rather than a specific match condition:

```
[edit protocols]
lab@Ale# run show route protocol rip | match \*
+ = Active Route, - = Last Active, * = Both
10.1.254.1/32      *[RIP/107] 04:16:48, metric 3, tag 0
10.1.254.2/32      *[RIP/107] 06:16:33, metric 2, tag 0
224.0.0.9/32       *[RIP/100] 00:10:29, metric 1
```

Besides the multicast route associated with RIPv2, only the /32 host routes from the Malt–Barley serial link are still active as a RIP route. This is not an issue, as the related subnet 10.1.254.0/24 is correctly advertised into OSPF (see the previous route display). These results confirm that it's safe to remove RIP from the internetwork. Things begin first at the Juniper Networks boxes:

```
[edit]
lab@Ale# delete protocols rip
```

And then the change occurs at the Cisco boxes:

```
Malt#conf terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Malt(config)#no router rip
Malt(config)#^Z
Malt#
```

Though not shown, the related RIP policy and route maps can now be safely removed. After a few moments of waiting, no angry users surface, and OSPF routing is verified at Ale. Perhaps it's now time for that vacation....

```
[edit]
lab@Ale# run show route protocol rip

inet.0: 16 destinations, 16 routes (16 active, 0 holddown, 0 hidden)

__juniper_private1__.inet.0: 2 destinations, 2 routes (2 active,
0 holddown, 0 hidden)
```

No more RIP routes, as planned:

```
[edit]
lab@Ale# run show route 200.0.200.0

inet.0: 16 destinations, 16 routes (16 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

200.0.200.0/24     *[OSPF/106] 00:16:20, metric 3, tag 0
                    > to 10.10.129.2 via fe-0/0/0.1121
```

The active route is still OSPF, and a traceroute confirms identical connectivity:

```
[edit]
lab@Ale# run traceroute 200.0.200.1 no-resolve
traceroute to 200.0.200.1 (200.0.200.1), 30 hops max, 40 byte
packets
 1  10.10.129.2  17.647 ms  14.877 ms  14.854 ms
 2  192.168.2.1  8.879 ms  10.982 ms  9.878 ms
 3  192.168.2.1  10.287 ms !H *  10.282 ms !H
```

Before You Go, Can You Set Up Area 1 Real Quick?

So, the CIO of Beer-Co is so impressed with the success of the RIP-to-OSPF migration that you have been asked to bring up an Area 1 attachment to router PBR. This is to be a stub area, with a default route injected by the area's ABR so that PBR can reach the various OSPF external destinations now present in the new network. Figure 4-10 shows the new topology. You may assume that interface parameters are correctly set.

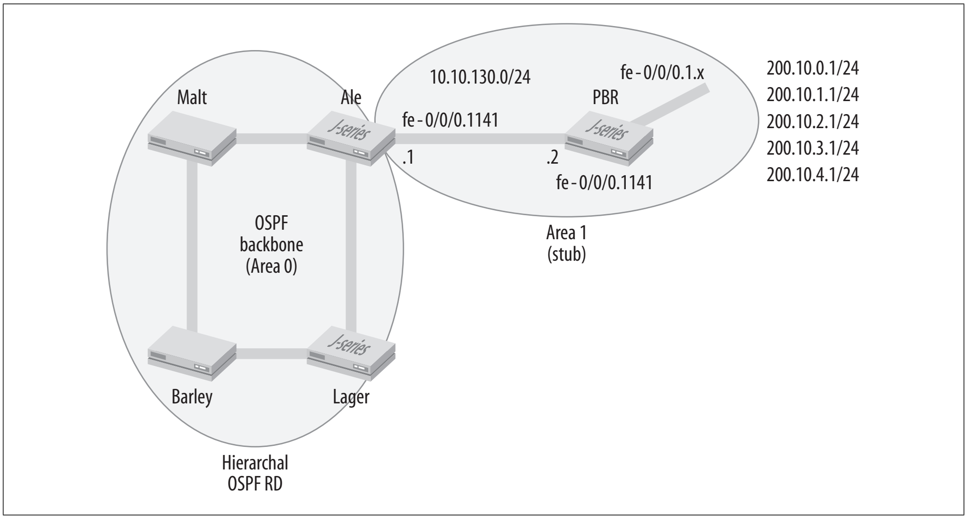


Figure 4-10. A hierarchical OSPF network

In Figure 4-10's example, PBR's fe-0/0/1 interface has been looped back (to ensure that it's declared up, even if not connected), and five VLANs have been created, each with an IP address in the form of 200.10.*x*.1/24. All five of these logical interfaces have been placed into OSPF area 1, which has been set as a stub area. PBR's OSPF and fe-0/0/1 configuration is as follows:

```
[edit]
lab@PBR# show interfaces fe-0/0/1
vlan-tagging;
fastether-options {
    loopback;
}
unit 1 {
    vlan-id 1;
    family inet {
        address 200.10.1.1/24;
    }
}
unit 2 {
    vlan-id 2;
    family inet {
        address 200.10.2.1/24;
    }
}
unit 3 {
    vlan-id 3;
    family inet {
        address 200.10.3.1/24;
    }
}
unit 4 {
    vlan-id 4;
    family inet {
        address 200.10.4.1/24;
    }
}
unit 5 {
    vlan-id 5;
    family inet {
        address 200.10.5.1/24;
    }
}

[edit]
lab@PBR# show protocols ospf
area 0.0.0.1 {
    stub;
    interface fe-0/0/1.1;
    interface fe-0/0/1.2;
    interface fe-0/0/1.3;
    interface fe-0/0/1.4;
    interface fe-0/0/1.5;
    interface fe-0/0/0.1141;
}
```

Meanwhile, a compatible OSPF area 1 configuration has been added at Ale:

```
[edit protocols ospf area 0.0.0.1]
lab@Ale# show
stub default-metric 10;
interface fe-0/0/0.1141;
```

Note that to inject a default route into the stub, you must specify a default metric. After a few moments, OSPF operation is confirmed at PBR. The show ospf neighbor command confirms that the adjacency to Ale is established:

```
[edit protocols ospf]
lab@PBR# run show ospf neighbor
  Address         Interface      State      ID              Pri  Dead
10.10.130.1      fe-0/0/0.1141   Full      10.10.128.1      128    39
```

The display of OSPF routes verifies the presence of the default route, injected by ABR router Ale, and reveals an absence of AS externals, which are not permitted in a stub network. *Only* LSA types 1, 2, and 3 are permitted in a stub area—the OSPF route table at PBR contains only intraarea and interarea routes, thus confirming this aspect of OSPF stub area operation:

```
[edit]
lab@PBR# run show ospf route
Prefix         Path   Route    NH   Metric  NextHop        Nexthop
               Type   Type     Type         Interface      addr/label
10.10.128.1    Intra  Area BR  IP   1       fe-0/0/0.1141 10.10.130.1
0.0.0.0/0      Inter  Network  IP   11      fe-0/0/0.1141 10.10.130.1
10.10.128.1/32 Intra  Network  IP   1       fe-0/0/0.1141 10.10.130.1
10.10.128.2/32 Inter  Network  IP   2       fe-0/0/0.1141 10.10.130.1
10.10.129.0/24 Inter  Network  IP   2       fe-0/0/0.1141 10.10.130.1
10.10.130.0/24 Intra  Network  IP   1       fe-0/0/0.1141
10.10.131.0/24 Inter  Network  IP   3       fe-0/0/0.1141 10.10.130.1
192.168.1.0/30 Inter  Network  IP   2       fe-0/0/0.1141 10.10.130.1
192.168.2.0/30 Inter  Network  IP   3       fe-0/0/0.1141 10.10.130.1
200.10.1.0/24  Intra  Network  IP   1       fe-0/0/1.1
200.10.2.0/24  Intra  Network  IP   1       fe-0/0/1.2
200.10.3.0/24  Intra  Network  IP   1       fe-0/0/1.3
200.10.4.0/24  Intra  Network  IP   1       fe-0/0/1.4
200.10.5.0/24  Intra  Network  IP   1       fe-0/0/1.5
```

PBR relies on the ABR-generated default route to reach external destinations because AS external LSAs are not advertised into stub areas:

```
[edit protocols ospf]
lab@PBR# run show route 200.0.200.1

inet.0: 21 destinations, 21 routes (21 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/10] 00:04:31, metric 11
                    > to 10.10.130.1 via fe-0/0/0.1141
```

You can add the no-summaries keyword to the area 1 configuration at the stub area's ABR (Ale) to also filter Type 3 network summary LSAs, which also result in the use of a default route for interarea destinations. With this change, a totally stubby area is born:

```
[edit protocols ospf area 0.0.0.1]
lab@Ale# set stub no-summaries

[edit protocols ospf area 0.0.0.1]
lab@Ale# commit
```

The results are confirmed at PBR, whose LSDB just got much smaller:

```
[edit]
lab@PBR# run show ospf route
Prefix          Path   Route    NH   Metric  NextHop       Nexthop
                Type   Type     Type      Interface     addr/label
10.10.128.1     Intra  Area BR IP    1    fe-0/0/0.1141 10.10.130.1
0.0.0.0/0       Inter  Network IP    11   fe-0/0/0.1141 10.10.130.1
10.10.128.1/32  Intra  Network IP    1    fe-0/0/0.1141 10.10.130.1
10.10.130.0/24  Intra  Network IP    1    fe-0/0/0.1141
200.10.1.0/24   Intra  Network IP    1    fe-0/0/1.1
200.10.2.0/24   Intra  Network IP    1    fe-0/0/1.2
200.10.3.0/24   Intra  Network IP    1    fe-0/0/1.3
200.10.4.0/24   Intra  Network IP    1    fe-0/0/1.4
200.10.5.0/24   Intra  Network IP    1    fe-0/0/1.5

[edit protocols ospf]
lab@PBR# run show route 192.168.1.1

inet.0: 16 destinations, 16 routes (16 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/10] 00:01:41, metric 11
                    > to 10.10.130.1 via fe-0/0/0.1141
```

A final task: Aggregate network summaries into the backbone

Area 1 is now quite optimized, but it has been called to your attention that the five 200.10.*x*.1/24 networks owned by PBR are being flooded into the backbone as individual Type 3 network summary LSAs. This is normal for OSPF, but your CIO wants to run a tight ship and has asked that you generate a single summary LSA into area 0 in place of the current five. Before making changes, you confirm that the CIO has correctly described the network summary situation by displaying Type 3 LSAs generated by ABR Ale. Note that these summaries are in backbone area 0.

```
[edit]
lab@Lager#run show ospf database netsummary advertising-router
10.10.128.1

    OSPF link state database, Area 0.0.0.0
 Type       ID           Adv Rtr       Seq     Age  Opt  Cksum  Len
Summary  10.10.130.0  10.10.128.1  0x80000003 421  0x22 0xc449  28
Summary  10.20.128.3  10.10.128.1  0x80000002 421  0x22 0x46bd  28
Summary  200.10.1.0   10.10.128.1  0x80000002 421  0x22 0xb11f  28
Summary  200.10.2.0   10.10.128.1  0x80000002 421  0x22 0xa629  28
Summary  200.10.3.0   10.10.128.1  0x80000002 421  0x22 0x9b33  28
Summary  200.10.4.0   10.10.128.1  0x80000002 421  0x22 0x903d  28
Summary  200.10.5.0   10.10.128.1  0x80000002 421  0x22 0x8547  28
```

Taking note of Lager's current area 0 LSDB state, you make a change to the area 1 portion of Ale, which results in the summarization of matching network summary LSAs:

```
[edit protocols ospf area 0.0.0.1]
lab@Ale# set area-range 200.10/16

[edit protocols ospf area 0.0.0.1]
lab@Ale# show
stub default-metric 10 no-summaries;
area-range 200.10.0.0/16;
interface fe-0/0/0.1141;
```

The area-range statement replaces individual network summaries that fall within the configured range with a single network summary representing the entire range. Adding the restrict keyword as part of the area-range statement serves to block any network summaries that are equal in length to the area-range's mask. In other words, the area-range is normally a *longer* function with regard to prefix length, but adding the restrict keyword alters this match type to that of orlonger. The latter results in filtering of any summaries *equal* in length to the specified area-range prefix length.

Your work is confirmed with a look at the network summaries now advertised into area 0 by Ale:

```
[edit]
lab@Lager# show ospf database netsummary advertising-router
10.10.128.1
    OSPF link state database, Area 0.0.0.0
 Type       ID             Adv Rtr      Seq     Age  Opt  Cksum  Len
Summary  10.10.130.0   10.10.128.1 0x8000000a   9  0x22 0xb650  28
Summary  10.20.128.3   10.10.128.1 0x80000009   9  0x22 0x38c4  28
Summary  200.10.0.0    10.10.128.1 0x80000001   9  0x22 0xbe14  28
```

As a final check, the connectivity from Cisco router Barley to one of the 200.10.*x*.1/24 networks on PBR is confirmed:

```
Barley#traceroute 200.10.1.1

Type escape sequence to abort.
Tracing the route to 200.10.1.1

  1 192.168.2.2 4 msec 4 msec 12 msec
  2 10.10.129.1 8 msec 4 msec 12 msec
3 200.10.1.1 4 msec 8 msec 8 msec
```

Awesome! This result completes the RIP-to-OSPF migration. This example also touched on stub area and area-range summarization configuration.

RIP Migration with the Overlay Model Summary

This section demonstrated a typical RIP-to-OSPF IGP migration using the overlay model. This was demonstrated in a multivendor environment to help show that the principles and procedures are somewhat universal, albeit with slightly varied command syntax that serves only to confuse the innocent. The modification of global route preferences allowed a smooth, hitless transition. Once the new IGP was found to be operating as expected, a quick change of preference resulted in use of the new IGP's forwarding paths while retaining the legacy IGP's configuration (and legacy protocol neighbors/adjacency state), in the event that the change needs to be backed out quickly. The migration ends with the removal of all legacy IGP traces from the router configurations.

This section also showed the conversion of a flat OSPF network into a hierarchical design that included the function of stub networks, totally stubby networks, and area-range syntax to consolidate network summaries as they enter the backbone.

Now is a good time to take another break. The next section continues our discussion of IGP migration, but this time in the context of an EIGRP-to-OSPF scenario.

EIGRP-to-OSPF Migration

This section demonstrates a smooth migration from a legacy EIGRP network to a hierarchical OSPF IGP. You could take many approaches to facilitate such a migration. The best approach will depend on numerous factors, such as device support of old and new IGPs and whether new equipment is being added, and if so, whether it's added to replace or augment an existing network's infrastructure. Also of consideration is the legacy network's design with regard to addressing and hierarchy, in combination with the design goals for the new network's efficiency and scalability.

The tactic demonstrated here is of the route redistribution variety. But considering that Juniper Networks routers have never spoken EIGRP, a bit of the integration model has to be at work as well—after all, a new backbone is being built out. It is acknowledged that leveraging existing network infrastructure will be of prime concern for most enterprises, and therefore that a typical EIGRP-to-OSPF migration will center on the phased reconfiguration of existing IOS devices to begin running the new and stop running the old IGP. This chapter demonstrates a migration approach in which Juniper Networks routers are added to form a new OSPF backbone while *minimal* changes are made to the legacy infrastructure to accommodate communications between the EIGRP and OSPF domains.

The solution demonstrated accommodates graceful growth of the OSPF backbone while the legacy EIGRP backbone is phased out. The migration goals for this scenario are as follows:

- There should be a minimal impact to the existing IOS configurations and existing EIGRP backbone operation.
- The solution should accommodate a phasing out of the legacy backbone IGP (though not necessarily the current devices) toward an all-OSPF backbone.
- The solution should be as simple as possible and be workable for small-to-large-scale enterprise migrations.
- The design must minimize the impact of large numbers of AS external LSAs for low-end routers.

Mutual Route Redistribution

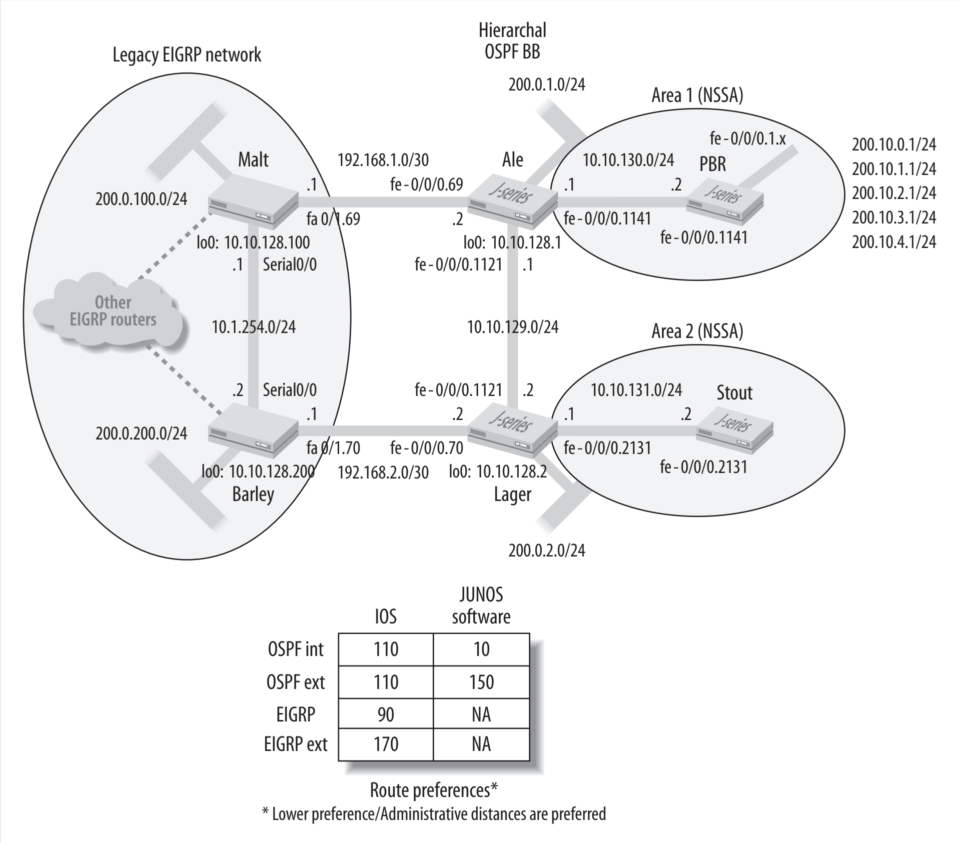
To make this scenario work, mutual route redistribution is needed between EIGRP and OSPF. As always, you must ensure that routes are redistributed only once, because loops will violate the “minimal impact to existing backbone” criterion. In addition, route preference adjustments may be needed to ensure optimal routing, depending on the default preferences for internal versus external EIGRP and OSPF between the two vendors.

> As much as you might prefer to have all this happen on the JUNOS software devices, the simple fact is that they cannot run EIGRP, while the Cisco boxes support both EIGRP and OSPF. This means the redistribution work will have to occur in IOS land. From the viewpoint of the Juniper routers, however, this is just another OSPF network, albeit one with a lot of tagged AS externals.

Figure 4-11 provides the topology and addressing specifics to assist the reader in tracking down which devices and IGPs own which routes.

Figure 4-12 provides the summary plan of action, as derived from the design criteria provided.

The overall plan is to *add* an OSPF process on the Cisco routers that redistributes connected, static, and EIGRP learned routes *after* adding a tag value to these routes. In this case, the tag chosen is based on the EIGRP domain’s AS (process) number (it could be any unique value, however). In addition, the existing EIGRP configuration is modified to redistribute OSPF into EIGRP *after* tagging these routes in a similar fashion. In both cases, the *first* step in the respective route maps is to *deny* any routes that already have the EIGRP process tag value. It’s critical that the deny action occur first, as the whole point of the route tags is to simplify the blocking of routes that originated in EIGRP from being redistributed back onto EIGRP from OSPF. Likewise, we need to block routes that originated in OSPF from being sent back into OSPF by EIGRP; the same tag value is also used for this filtering requirement.



	IOS	JUNOS software
OSPF int	110	10
OSPF ext	110	150
EIGRP	90	NA
EIGRP ext	170	NA

Route preferences*

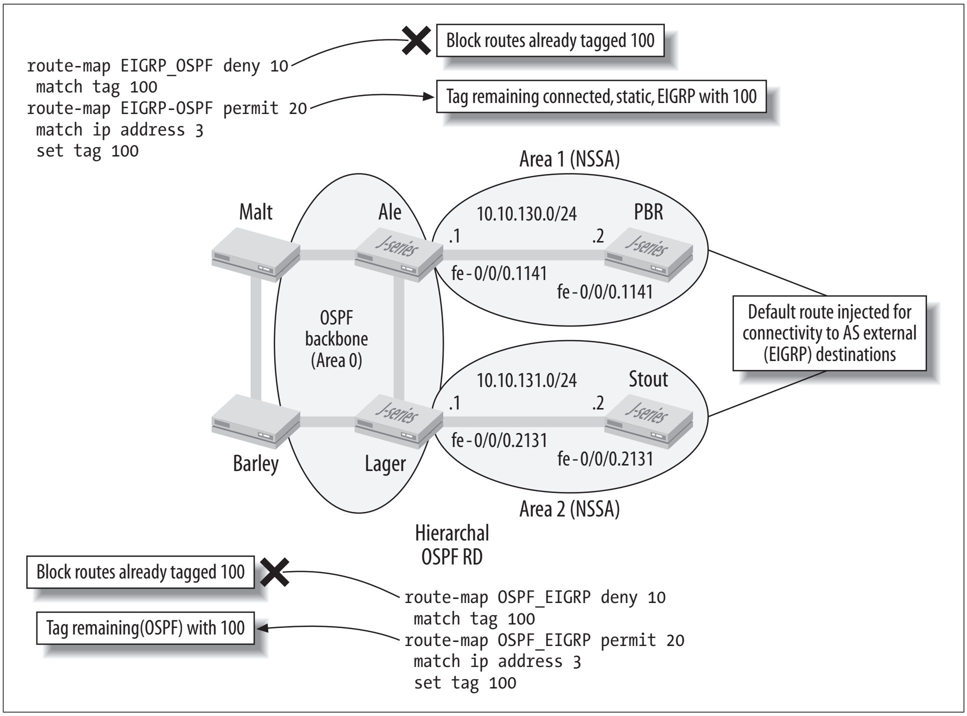
* Lower preference/Administrative distances are preferred

Figure 4-11. EIGRP-to-OSPF migration topology

Recall that redistribution of connected, static, or EIGRP routes into OSPF results in Type 5 AS external LSAs, which are in turn flooded over the entire OSPF domain (except stub areas). This is a significant point, because one of the design goals is to minimize the impact of large numbers of external LSAs on low-end routers. This is why the new, nonbackbone OSPF areas are configured as NSSA areas in this example. As with the stub area example, the default route injected by the ABRs provides connectivity to the external destinations—for example, EIGRP—and the NSSA capability accommodates future placement of an ASBR to originate AS external routes from these areas as needed.

The JUNOS software OSPF configuration

On the JUNOS software side, things are pretty straightforward, and the OSPF and related policy bits are shown for `Ale`.



```
route-map EIGRP_OSPF deny 10
 match tag 100
route-map EIGRP-OSPF permit 20
 match ip address 3
 set tag 100
```

```
route-map OSPF_EIGRP deny 10
 match tag 100
route-map OSPF_EIGRP permit 20
 match ip address 3
 set tag 100
```

Figure 4-12. EIGRP-to-OSPF migration plan overview

```
[edit]
lab@Ale# show protocols ospf
export static;
area 0.0.0.0 {
    interface fe-0/0/0.69;
    interface fe-0/0/0.1121;
}
area 0.0.0.1 {
    nssa {
        default-lsa default-metric 10;
    }
    interface fe-0/0/0.1141;
}

[edit]
lab@Ale# show policy-options policy-statement static
term 1 {
    from {
        protocol static;
        route-filter 200.0.1.0/24 exact;
    }
    then accept;
}
```

The OSPF export policy redistributes the simulated customer static route into OSPF. No route tagging is being performed here, because if tag 100 were added, these routes would be filtered from redistribution into the EIGRP domain. Area 1 is configured as an NSSA, and a default route is configured (via the `default-metric` statement) for use by routers within the NSSA when routing AS external destinations. Recall that all the EIGRP routes will be become AS externals once they are injected into the OSPF domain, making the presence of the default route in stub areas critical for maintaining connectivity. The configuration of JUNOS software router `Stout` is shown for completeness, but there is not much to say, except that its area 2 is compatibly configured as an NSSA.

```
[edit]
lab@stout# show protocols ospf
area 0.0.0.2 {
    nssa;
    interface fe-0/0/0.2131;
}
```

The IOS configuration

The real work is being done on the IOS side because these devices are able to run both the old and the new IGPs.

Before adding the new OSPF process to any of the legacy Cisco routers, you must first verify that they have the capacity to run both IGPs without encountering performance issues. The current best practice is to confirm that CPU and memory use are less than 50% to 60%, respectively. If the router is already running short of resources, adding a new IGP and related redistribution may well push it over the limit. Older routers that are already having trouble keeping up should be replaced or upgraded before proceeding.

The `show memory` and `show processes` command output indicates that Beer-Co's IOS boxes are not heavily taxed, so we are free to proceed:

```
Malt#show mem stat
              Head Total(b)  Used(b)   Free(b) Lowest(b) Largest(b)
Processor 82B00CC0 18493864  6288376  12205488  12000052   11685420
      I/O  3C00000  4194304  2013112   2181192   2174960    2181148
Malt#show processes cpu sorted
CPU utilization for five seconds: 0%/0%; one minute: 0%;
five minutes: 0%
 PID Runtime(ms)  Invoked uSecs   5Sec   1Min   5Min TTY Process
   3       15492     3513  4409  0.31%  0.80%  0.26%   0 Exec
   1           0        2     0  0.00%  0.00%  0.00%   0 Chunk Manager
   2           4     2527     1  0.00%  0.00%  0.00%   0 Load Meter
   4         320     2958   108  0.00%  0.00%  0.00%   0 OSPF Hello
. . . .
```

Having determined sufficient resource capacity, the migration proceeds; the modified portions of Cisco router `Malt` are shown here:

```
router eigrp 100
 redistribute connected
 redistribute static
 redistribute ospf 10 metric 10 100 255 1 1500 route-map OSPF_EIGRP
 network 10.0.0.0
 no auto-summary
!
router ospf 10
 network 192.168.1.0 0.0.0.3 area 0
 redistribute eigrp 100 metric 4 route-map EIGRP_OSPF subnets
 redistribute static metric 3 route-map EIGRP_OSPF subnets
 redistribute connected tag 100 subnets metric 2
!
access-list 3 permit any
!
route-map OSPF_EIGRP deny 10
 match tag 100
!
route-map OSPF_EIGRP permit 20
 match ip address 3
 set tag 100
!
route-map EIGRP_OSPF deny 10
 match tag 100
!
route-map EIGRP_OSPF permit 20
 match ip address 3
 set tag 100
```

The modified portions of the IOS configuration are highlighted to help to call out the delta. The EIGRP process was instructed to redistribute routes from the OSPF process identified as "10," setting the EIGRP bandwidth, delay, reliability, loading, and MTU values to 10, 100, 255, 1, and 1500, respectively. The redistribution is controlled by the logic in the route map named OSPF_EIGRP.

The entire OSPF process is new and was added to integrate with the new Juniper router-based backbone. Because connected routes could not be filtered through the existing EIGRP_OSPF route map, tagging for the connected routes is configured directly on the distribute line.

In contrast, both static and EIGRP routes are being redistributed through the control of the common EIGRP_OSPF route map. The subnet keyword inverts the default behavior of redistributing only classful networks. Lastly, you'll see that OSPF area 0 is configured to run on the link connecting Malt to Ale.

Both route maps make use of an initial deny term for any route with a tag value of 100. Remaining routes are then matched against the match-all IP access list 3, with the result being the addition of tag value 100. When combined, the operation of the two route maps serves to ensure that a route is never redistributed back into the IGP from where it originated, which should prevent loop formation.

You use JUNOS software routing policy to combine the various effects of IOS's distribute, distribute-list, ACL, and route-map functions. For example, here is a policy example that functions to reject and tag routes, much as the EIGRP_OSPF route map does, albeit for RIP and OSPF given the lack of EIGRP support. The RIP_to_OSPF policy is applied to the OSPF protocol as an export policy to redistribute only untagged RIP routes into OSPF, at which time a tag value of 100 is added:

```
[edit policy-options]
regress@plato# show policy-statement RIP_to_OSPF
term 1 {
    from tag 100;
    then reject;
}
term 2 {
    from protocol rip;
    then {
        tag 100;
        accept;
    }
}

[edit policy-options]
regress@plato# show policy-statement RIP_to_OSPF | display
set
set policy-options policy-statement RIP_to_OSPF term 1 from
tag 100
set policy-options policy-statement RIP_to_OSPF term 1 then
reject
set policy-options policy-statement RIP_to_OSPF term 2 from
protocol rip
set policy-options policy-statement RIP_to_OSPF term 2 then
tag 100
set policy-options policy-statement RIP_to_OSPF term 2 then
accept
```

To better understand how the tagging works, refer back to Figure 4-12 and then consider an EIGRP (or connected, or static) route *x* that originates in the EIGRP domain and is evaluated for redistribution into OSPF. According to the EIGRP_OSPF route map, the first action is to deny any route with the tag value 100. Because route *x* originates within EIGRP, it has no tag and therefore the route falls to the next term. Action 20 adds tag 100 to the route and sends it into OSPF. Route *x*, which is now an OSPF Type 5 LSA, is then flooded into the OSPF RD, where it arrives at Cisco router Barley. In most cases, Barley will already have a more preferred EIGRP route to this destination (recall that it originated in EIGRP to begin with), but if not, it will install the OSPF route to *x*, as learned from Malt's OSPF advertisement.

Now Barley's OSPF process considers OSPF route *x* for redistribution into EIGRP. Fortunately, the first term in its OSPF_EIGRP route map denies any routes with tag 100. This action serves to prevent route *x* from being sent back into its originating EIGRP IGP. Any routes that originate in the OSPF domain, regardless of whether they are internal or AS external, arrive at Barley with no tag. This permits the redistribution of these routes into the EIGRP process, after they have been tagged. This tag will in turn keep router Malt from sending the route back into the OSPF domain.

What about route preferences? Referring back to Figure 4-11, you can see the default preferences for the route sources used in this example. At first glance, it seems that we want both Malt and Barley to prefer all OSPF routes regardless of whether they are internal or external. This is to ensure that both Cisco routers forward directly into the OSPF cloud when routing to OSPF originated routes, rather than backhauling over the EIGRP backbone because they prefer a redistributed EIGRP version of the same route. This is fortunate here because the OSPF routes redistributed into EIGRP are considered EIGRP externals, and the default distance for these routes is 170, making them less preferred than the native OSPF copy with a default distance of 110.

The default settings mean that the EIGRP domain will always prefer a learned OSPF route over the same copy in the (redistributed) external EIGRP form. The JUNOS software boxes have only one IGP, so there is no need to alter any preference there, of course. Time will tell whether we need to revisit this thinking....

Confirm EIGRP/OSPF Mutual Route Redistribution

With all routers configured, confirm proper redistribution and forwarding. Begin at Cisco router Malt, where the IP route table is displayed:

```
Malt# show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

O E2 200.0.200.0/24 [110/3] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
O IA 200.10.4.0/24 [110/3] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
O IA 200.10.5.0/24 [110/3] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
O E2 200.0.1.0/24 [110/0] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
```

```
O IA 200.10.1.0/24 [110/3] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
O E2 200.0.2.0/24 [110/0] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
O IA 200.10.2.0/24 [110/3] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
S    200.0.100.0/24 is directly connected, Null0
O IA 200.10.3.0/24 [110/3] via 192.168.1.2, 00:05:10, FastEthernet0/1.69
     10.0.0.0/8 is variably subnetted, 11 subnets, 2 masks
D       10.10.128.200/32 [90/2297856] via 10.1.254.2, 03:10:02, Serial0/0
O       10.10.129.0/24 [110/2] via 192.168.1.2, 00:05:10, FastEthernet0/1.69
O       10.10.128.1/32 [110/1] via 192.168.1.2, 00:05:10, FastEthernet0/1.69
O IA    10.10.130.0/24 [110/2] via 192.168.1.2, 00:05:14, FastEthernet0/1.69
O       10.10.128.2/32 [110/2] via 192.168.1.2, 00:05:14, FastEthernet0/1.69
O IA    10.10.131.0/24 [110/3] via 192.168.1.2, 00:05:14, FastEthernet0/1.69
O IA    10.20.128.4/32 [110/3] via 192.168.1.2, 00:05:14, FastEthernet0/1.69
O IA    10.20.128.3/32 [110/2] via 192.168.1.2, 00:05:14, FastEthernet0/1.69
C       10.10.128.100/32 is directly connected, Loopback0
C       10.1.254.0/24 is directly connected, Serial0/0
C       10.1.254.2/32 is directly connected, Serial0/0
     192.168.1.0/30 is subnetted, 1 subnets
C       192.168.1.0 is directly connected, FastEthernet0/1.69
     192.168.2.0/30 is subnetted, 1 subnets
O       192.168.2.0 [110/3] via 192.168.1.2, 00:05:14, FastEthernet0/1.69
```

From a quick look, it seems that all the routes are there: PBR's five 200.10.*x*/24 routes as network summaries (interarea), the simulated customer routes from Ale and Lager as AS externals, and their loopback/OSPF interface routes appearing as OSPF internals (intraarea). It certainly appears that these routes are preferred in their OSPF form, despite their being redistributed into EIGRP at Barley, which is desired behavior for optimal routing between the EIGRP and OSPF domains. Note how Barley's loopback 0 address (10.10.128.200) is displayed as an EIGRP learned internal route with a distance of 90.

To confirm that the OSPF routes are really being redistributed into EIGRP (IOS displays only the active route), the EIGRP topology table for one of PBR's 200.0.1.0/24 routes is shown here:

```
Malt# show ip eigrp topology 200.0.1.0
IP-EIGRP (AS 100): Topology entry for 200.0.1.0/24
  State is Passive, Query origin flag is 1, 1 Successor(s), FD is
256025600
  Routing Descriptor Blocks:
  192.168.1.2, from Redistributed, Send flag is 0x0
      Composite metric is (256025600/0), Route is External
      Vector metric:
        Minimum bandwidth is 10 Kbit
        Total delay is 1000 microseconds
        Reliability is 255/255
        Load is 1/255
        Minimum MTU is 1500
        Hop count is 0
      External data:
        Originating router is 10.10.28.100 (this system)
        AS number of route is 10
        External protocol is OSPF, external metric is 0
        Administrator tag is 100 (0x00000064)
```

The route's presence is confirmed in the EIGRP topology table, and the tag value of 100 proves that the OSPF_EIGRP route map is working.

Troubleshoot a preference issue

Overall, the output from the show ip route command at Malt is what you want to see. There is one problem, however, with respect to the simulated customer route owned by Barley: the display shows that Malt prefers the OSPF external version of the 200.0.200/24 route because the EIGRP external distance is higher (less preferred) than OSPF's (as noted previously, this is part of the migration plan). This occurs *only* for the simulated customer routes because EIGRP is set to run on the serial and loopback interfaces as a result of the network 10.0.0.0 statement. These routes are therefore considered *internal* to the EIGRP process and they have a distance of 90. In contrast, the simulated customer static route is *redistributed* into EIGRP, making it an EIGRP external. This situation results in an extra hop when Malt tries to reach Barley's customer network, and vice versa:

```
Malt#trace 200.0.200.1
Type escape sequence to abort.
Tracing the route to 200.0.200.1

  1 192.168.1.2 4 msec 8 msec 8 msec
  2 10.10.129.2 8 msec 8 msec 8 msec
  3 192.168.2.1 12 msec 8 msec 12 msec
4 192.168.2.1 !H  !H  *
```

Rethinking the default preferences, it was correct to assert that *all* OSPF routes would be preferred over EIGRP externals, which for the majority of our routes is exactly what is desired. The redistributed statics are causing issues with this plan, however. Changing OSPF external preferences may fix the issue with the problematic static routes, but will then create problems for the other OSPF routes that are now doing what they should be doing.

Some possible solutions include running EIGRP passively on the related customer interface so that the route is advertised as an EIGRP internal. This solution requires an actual interface (or loopback instance), and these statics were used to reduce gear requirements in the first place. Still, no new gear is needed for an IOS loopback 1 interface. Or, you could define a static route, but this represents administrative work and may lead to a black hole if the legacy EIGRP backbone fails. Using a qualified/recursive static should result in traffic falling back to the learned OSPF version should the static route's next hop become unreachable, but this would need to be tested to make sure of failover behavior. Yet another solution would be to simply tolerate the inefficient routing, given that connectivity is still provided and the condition should be transient as the EIGRP network is phased out. Being a purist, you opt to alter the IOS configurations to add a new loopback instance that will run EIGRP on behalf of the simulated customer network. Such changes are shown here:

```
!
interface Loopback1
 ip address 200.0.100.1 255.255.255.0
!
. . .
router eigrp 100
 redistribute connected
 redistribute static
 redistribute ospf 10 metric 10 100 255 1 1500 route-map OSPF_EIGRP
 network 10.0.0.0
network 200.0.100.0
passive-interface Loopback1
 no auto-summary
```

A new loopback instance has been defined to represent the simulated customer network that previously was represented by a static route. The static route has also been removed (not shown), and the EIGRP process is configured to run passively on the loopback 1 interface. The passive declaration ensures that CPU cycles are not wasted on the EIGRP neighbor discovery that is doomed to fail, given the lonely neighborhood that is loopback 1. And yes, loopback 0 should be set to be passive for the same reasons, but that is saved for another day. After similar changes are made at Barley, the active EIGRP routes are displayed and the previous traceroute is repeated:

```
Malt#showip route eigrp
D    200.0.200.0/24 [90/2297856] via 10.1.254.2, 00:11:42, Serial0/0
     10.0.0.0/8 is variably subnetted, 11 subnets, 2 masks
D       10.10.128.200/32 [90/2297856] via 10.1.254.2, 04:24:16,
Serial0/0
Malt#traceroute 200.0.200.1

Type escape sequence to abort.
Tracing the route to 200.0.200.1

1 10.1.254.2 16 msec 12 msec *
```

Excellent, just what you wanted to see. Before moving on, traceroutes to a few other destinations in the OSPF domain are executed for added confirmation. Note that the simulated customer network routes at Ale and Lager are set to discard, so you should expect no reply from them:

```
Malt#trace 10.20.128.3

Type escape sequence to abort.
Tracing the route to 10.20.128.3

  1 192.168.1.2 4 msec 4 msec 12 msec
  2 10.20.128.3 4 msec 8 msec 8 msec
Malt#trace 200.10.5.1
```

```
Type escape sequence to abort.
Tracing the route to 200.10.5.1

  1 192.168.1.2 8 msec 8 msec 8 msec
  2 200.10.5.1 4 msec 20 msec 100 msec
```

The traceroutes to the loopback address and OSPF area 1 routes on PBR are successful and are observed to take a reasonable forwarding path. Similar results are observed at Barley:

```
Barley# trace 200.10.2.1

Type escape sequence to abort.
Tracing the route to 200.10.2.1

  1 192.168.2.2 20 msec 4 msec 12 msec
  2 10.10.129.1 4 msec 28 msec 12 msec
3 200.10.2.1 8 msec 8 msec 8 msec
```

Let's temporarily down the OSPF adjacency at Malt (traffic will reroute through Barley) to confirm that Malt falls back to the EIGRP versions of the OSPF domain's routes and actually begins to forward through Barley:

```
Malt(config)#interface fastEthernet 0/1
Malt(config-if)#sh
Malt(config-if)#^Z
. . .
```

After a few moments, the route table is again displayed at Malt:

```
Malt#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

D    200.0.200.0/24 [90/2297856] via 10.1.254.2, 00:31:34, Serial0/0
D EX 200.10.4.0/24 [170/256537600] via 10.1.254.2, 00:00:36, Serial0/0
D EX 200.10.5.0/24 [170/256537600] via 10.1.254.2, 00:00:36, Serial0/0
D EX 200.0.1.0/24 [170/256537600] via 10.1.254.2, 00:00:36, Serial0/0
D EX 200.10.1.0/24 [170/256537600] via 10.1.254.2, 00:00:36, Serial0/0
D EX 200.0.2.0/24 [170/256537600] via 10.1.254.2, 00:00:36, Serial0/0
D EX 200.10.2.0/24 [170/256537600] via 10.1.254.2, 00:00:36, Serial0/0
C    200.0.100.0/24 is directly connected, Loopback1
D EX 200.10.3.0/24 [170/256537600] via 10.1.254.2, 00:00:37, Serial0/0
     10.0.0.0/8 is variably subnetted, 11 subnets, 2 masks
D       10.10.128.200/32 [90/2297856] via 10.1.254.2, 04:44:10, Serial0/0
D EX    10.10.129.0/24 [170/256537600] via 10.1.254.2, 00:00:37, Serial0/0
D EX    10.10.128.1/32 [170/256537600] via 10.1.254.2, 00:00:37, Serial0/0
D EX    10.10.130.0/24 [170/256537600] via 10.1.254.2, 00:00:39, Serial0/0
```

```
D EX    10.10.128.2/32 [170/256537600] via 10.1.254.2, 00:00:39, Serial0/0
D EX    10.10.131.0/24 [170/256537600] via 10.1.254.2, 00:00:39, Serial0/0
D EX    10.20.128.4/32 [170/256537600] via 10.1.254.2, 00:00:39, Serial0/0
D EX    10.20.128.3/32 [170/256537600] via 10.1.254.2, 00:00:39, Serial0/0
C       10.10.128.100/32 is directly connected, Loopback0
C       10.1.254.0/24 is directly connected, Serial0/0
C       10.1.254.2/32 is directly connected, Serial0/0
     192.168.1.0/30 is subnetted, 1 subnets
D EX    192.168.1.0 [170/256537600] via 10.1.254.2, 00:00:34, Serial0/0
     192.168.2.0/30 is subnetted, 1 subnets
D EX    192.168.2.0 [170/2172416] via 10.1.254.2, 00:00:40, Serial0/0
```

The display confirms that the EIGRP versions of the redistributed OSPF routes are now active. A traceroute confirms the expected forwarding path, given the down `fa 0/0` interface at `Malt`:

```
Malt#traceroute 200.10.5.1
Type escape sequence to abort.
Tracing the route to 200.10.5.1

  1 10.1.254.2 12 msec 12 msec 12 msec
  2 192.168.2.2 20 msec 16 msec 20 msec
  3 10.10.129.1 116 msec 24 msec 20 msec
  4 200.10.5.1 48 msec 28 msec 36 msec
Malt#
```

`Malt`'s `fa 0/1` interface is returned to operation and the OSPF adjacency is allowed to reform. You should then inspect the route table to ensure that the network state has returned to the initial state. Issues with route redistribution/preference are often timing-dependent, and you may find that after a failure, the network does not return to the desired state. Here, expect to find that the OSPF versions of the routes are again preferred over the EIGRP version:

```
Malt#
*Mar  1 06:02:24.202: %OSPF-5-ADJCHG: Process 10, Nbr 10.10.128.1 on FastEthernet0/1.
69 from LOADING to FULL, Loading Done
Malt#
Malt#show ip route eigrp
D    200.0.200.0/24 [90/2297856] via 10.1.254.2, 00:36:14, Serial0/0
     10.0.0.0/8 is variably subnetted, 11 subnets, 2 masks
D       10.10.128.200/32 [90/2297856] via 10.1.254.2, 04:48:48, Serial0/0
Malt#
```

The display confirms that the native OSPF routes are again active, being they are preferred over redistributed EIGRP copies. This validates that the network is able to fail over, and then switch back to a steady state. Connectivity between the two RDs has already been demonstrated, so let's conclude our IGP migration verification with some selective captures in the OSPF domain, starting by examining the "large" external LSA database now on backbone routers:

```
[edit]
lab@Ale# run show ospf database extern
    OSPF AS SCOPE link state database
```

```
 Type      ID            Adv Rtr       Seq      Age  Opt  Cksum  Len
Extern  10.1.254.0    10.10.28.100 0x8000000b   850  0x20 0xe0c4  36
Extern  10.1.254.0    10.10.28.200 0x8000000b   783  0x20 0x86ba  36
Extern  10.1.254.1    10.10.28.200 0x8000000b   783  0x20 0x7cc3  36
Extern  10.1.254.2    10.10.28.100 0x8000000b   850  0x20 0xccd6  36
Extern  10.10.128.100 10.10.28.100 0x80000009  1607  0x20 0xfbbc  36
Extern  10.10.128.100 10.10.28.200 0x80000009  1531  0x20 0xb59c  36
Extern  10.10.128.200 10.10.28.100 0x80000009  1607  0x20 0x242e  36
Extern  10.10.128.200 10.10.28.200 0x80000009  1531  0x20 0xb53a  36
Extern *200.0.1.0     10.10.128.1  0x80000005  2101  0x22 0x87c7  36
Extern  200.0.2.0     10.10.128.2  0x80000005  2427  0x22 0x76d6  36
Extern  200.0.100.0   10.10.28.100 0x8000000d   592  0x20 0xdda2  36
Extern  200.0.100.0   10.10.28.200 0x80000002   526  0x20 0xad77  36
Extern  200.0.200.0   10.10.28.100 0x80000002   351  0x20 0xb76d  36
Extern  200.0.200.0   10.10.28.200 0x80000002   526  0x20 0x4979  36
```

Well, it seems that *large* truly is a subjective term. However, more than 10 Type 5 LSAs are in the backbone area's database, and considering the small scope of the EIGRP network in this lab example, it's safe to say that a large enterprise could easily generate hundreds if not thousands of these AS external LSAs.

```
[edit]
lab@Ale# run show ospf database extern detail | match tag
  Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
  Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
  Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
  Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
  Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
  Type 2, TOS 0x0, metric 4, fwd addr 0.0.0.0, tag 0.0.0.100
  Type 2, TOS 0x0, metric 4, fwd addr 0.0.0.0, tag 0.0.0.100
  Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
  Type 2, TOS 0x0, metric 0, fwd addr 0.0.0.0, tag 0.0.0.0
  Type 2, TOS 0x0, metric 0, fwd addr 0.0.0.0, tag 0.0.0.0
  Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
  Type 2, TOS 0x0, metric 4, fwd addr 0.0.0.0, tag 0.0.0.100
  Type 2, TOS 0x0, metric 4, fwd addr 0.0.0.0, tag 0.0.0.100
  Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
```

Next, the CLI's matching function, combined with the `detail` switch, allows confirmation that most of these externals originated in the EIGRP domain, given that the majority are sporting a tag with an EIGRP process number.

The new OSPF network was designed to be hierarchical to promote scaling. To take this a step further, let's also deploy NSSAs to reduce the processing demands on nonbackbone routers. Internal routers within a stub area do not see any AS external LSAs, which in this type of a migration can substantially reduce their load. Confirm this fact at router PBR:

```
[edit]
lab@PBR# run show ospf database

    OSPF link state database, Area 0.0.0.1
```

```
 Type       ID          Adv Rtr       Seq      Age  Opt  Cksum  Len
Router   10.10.128.1  10.10.128.1  0x8000000c  273  0x20 0xac79  48
Router  *10.20.128.3  10.20.128.3  0x80000008  928  0x20 0x6124 108
Network *10.10.130.2  10.20.128.3  0x80000007  928  0x20 0x7b49  32
Summary  10.10.128.2  10.10.128.1  0x80000008 2223  0x20 0xda30  28
Summary  10.10.129.0  10.10.128.1  0x80000008 2073  0x20 0xe328  28
Summary  10.10.131.0  10.10.128.1  0x80000008 1773  0x20 0xd731  28
Summary  10.20.128.4  10.10.128.1  0x80000007 1473  0x20 0x5aa4  28
Summary  192.168.1.0  10.10.128.1  0x8000000b  625  0x20 0x9a9c  28
Summary  192.168.2.0  10.10.128.1  0x80000006  573  0x20 0xa396  28
NSSA     0.0.0.0      10.10.128.1  0x80000008  423  0x20 0xa1ea  36
NSSA     200.0.1.0    10.10.128.1  0x80000005 2373  0x20 0x89c5  36
```

Note the absence of Type 4 and Type 5 LSAs, and the presence of the default route, which provides the internal stub area routers with a route to external destinations.

```
[edit]
lab@PBR# run show route 200.0.200.4

inet.0: 23 destinations, 23 routes (23 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/150] 04:26:43, metric 11, tag 0
                    > to 10.10.130.1 via fe-0/0/0.1141
```

This last display confirms the use of the default route for AS external destinations by the internal NSSA router PBR.

With initial connectivity confirmed, the EIGRP-to-OSPF migration can proceed through a phased movement of legacy EIGRP segments to the new OSPF backbone. Alternatively, the EIGRP domain can be shrunk back by increasing the scope of the OSPF domain and moving the EIGRP redistribution points until there is no EIGRP left.

EIGRP-to-OSPF Migration Summary

This section demonstrated how you can integrate a new OSPF backbone into an existing EIGRP infrastructure, while maintaining loop-free connectivity through careful use of route filtering. Filtering is needed to ensure that those routes are redistributed only once. The example used route tags to simplify filtering. Address-based filters can also work, especially if the two IGP domains have distinct numbering that can easily be summarized.

Mutual route redistribution is always a bit tricky, and careful thought should be leveled against any migration plan to try to head off potential issues stemming from protocol preferences or incomplete route filtering. In this example, the interaction of OSPF and EIGRP external preferences created a problem for static routes redistributed into EIGRP. Although connectivity was maintained and no loops were formed, the condition resulted in suboptimal forwarding for some destinations. The specifics of this example allowed the creation of a new loopback interface, which then ran a passive instance of EIGRP to stand in for the static route, yielding optimal connectivity for all destinations in the test bed.

Conclusion

The IGP is a critical component in any enterprise network. The IGP functions to provide optimal connectivity to interior destinations in the face of changing network conditions. To perform this function, the IGP must balance the opposing forces of rapid convergence against instability and routing loops. A well-designed and implemented IGP can easily spell the difference between a high-performing network and an ongoing litany of trouble tickets and support calls.

Historically, enterprise networks needed to support multiple routed protocols, and the dominance of Cisco Systems in these early years resulted in widespread deployment of its proprietary IGRP and EIGRP IGP solutions. Since that time, most enterprise networks have completed a migration to an all-IP routing infrastructure. Simply stated, the world seems to have settled on the mantra "IP over everything, and everything over IP." Although EIGRP does a good job at routing IP, its closed nature, coupled with its lack of routing hierarchy and MPLS TE support, cast serious concerns over its future high-performance enterprise networks.

Over the years, several tried and proven strategies have been developed to ease the pain and disruption that often accompany IGP migration. Whether an enterprise chooses to deploy JUNOS software or not, these migration techniques can get your legacy network weaned off of EIGRP and onto an open standard such as OSPF.

Juniper Networks routers support all standardized IGPs, and their implementation has been successfully battletested in the planet's largest service provider networks. The same OSPF code running in the multiterabit iron of the Juniper Networks flagship TX Matrix core router can also be found purring away in the smallest enterprise-targeted Juniper devices. Although historically designed for service provider networks, Juniper Networks continues to evolve its IGP implementation to meet the needs of both its service provider and enterprise customers.

Exam Topics

We covered the following Enterprise Exam Topics in this chapter:

- The role and function of an IGP
- Operational characteristics of RIP, RIPv2, OSPF, and IGRP/EIGRP
- RIP and OSPF configuration on Juniper Networks routers
- Operational analyses of RIP and OSPF on Juniper Networks routers
- The overlay, redistribution, and integrated IGP migration models

Chapter Review Questions

1. Which of the following defines *split horizon*?
    a. Sending routes out the interface they were learned from
    b. Sending routes out the interface they were learned from with infinite metric
    c. Holding a recently unreachable route in the table for a fixed time to allow other routers to be notified
    d. Not sending routes out the interface they were learned from
2. When you configure RIP on a Juniper Networks router, how do you specify what interfaces the protocol should operate on?
    a. You use a network statement with a network mask
    b. You use a network statement with a wildcard mask
    c. You specify interface names and logical units explicitly as part of RIP neighbor configuration
    d. You use routing policy
    e. None of the above
3. What command displays the RIP routes a Juniper Networks router is sending out to a given interface?
    a. This is not possible given the LS nature of RIP
    b. `show route protocol rip`
    c. `show route advertising-protocol rip` *`<neighbor>`*
    d. `show route receiving-protocol rip` *`<neighbor>`*
4. Which type of router generates a Type 2 LSA?
    a. Internal
    b. ABR
    c. ASBR
    d. DR
5. Which is true regarding a stub area in OSPF?
    a. A stub area uses a default to reach interarea destinations
    b. A stub area imports external routes as Type 7 LSAs
    c. A stub area does not receive Type 3 summary LSAs from the backbone
    d. A stub area has no OSPF routers in it
6. When you add a new OSPF router to a LAN, what factor(s) determine whether it will become the DR?
    a. Its priority setting
    b. The RID

   c. Whether any other routers are already operating on that LAN
   d. All of the above
7. What determines which route will be active when a given prefix is learned by multiple routing protocols?
   a. The lowest metric
   b. The path with the fewest hops
   c. The protocol with the highest numerical preference is chosen
   d. The protocol with the lowest numerical preference is chosen
8. Which syntax at an ABR would suppress individual summaries for routes in the 10.0/16 block in area 1 while replacing them with a single summary?
   a. `[edit protocols ospf area 0.0.0.1]`

      `set area-range 10.0/16 restrict`
   b. `[edit protocols ospf area 0.0.0.0]`

      `set area-range 10.0/16`
   c. `[edit protocols ospf area 0.0.0.1]`

      `set area-range 10.0/16`
   d. This is not possible; LSAs cannot be filtered without breaking LS protocol operation
9. Which is true regarding the overlay migration model?
   a. You first set the legacy IGP to be less preferred than the new IGP
   b. You first set the new IGP to be less preferred than the legacy IGP
   c. Route redistribution is needed to maintain connectivity through the migration
   d. A new backbone is needed
10. What is the primary mechanism for loop prevention in the redistribution model?
    a. A common LSDB ensures a loop-free topology
    b. Strict controls that ensure routes are not redistributed back to their originating IGP
    c. Setting the new IGP to be more preferred than the legacy IGP
    d. A careful mapping of metrics between originating and receiving IGPs
11. What types of authentication are supported in JUNOS software for OSPF?
    a. Simple password
    b. MD5 checksum
    c. Hitless key chain of MD5 keys/checksums
    d. All of the above

12. Which configuration will inject a default route into stub area 1?

    a.
    ```
    area 0.0.0.1 {
    stub default-metric 10 no-summaries;
    area-range 10.0.0.0/16 restrict;
    }
    ```

    b.
    ```
    area 0.0.0.0 {
    stub default-metric 10;
    }
    ```

    c.
    ```
    area 0.0.0.1 {
    stub no-summaries;
    area-range 10.0.0.0/16 restrict;
    }
    ```

    d.
    ```
    area 0.0.0.1 {
    stub default-metric;
    area-range 10.0.0.0/16 restrict;
    }
    ```

Chapter Review Answers

1. Answer: D. Split horizon rules prevent a router from readvertising routing information back out the same interface it was learned from; poisoned reverse alters this behavior to permit such updates as long as they have an infinite metric.
2. Answer: C. You specify RIP-enabled interfaces by name and unit number, under the `[edit protocols rip group <name> neighbor]` hierarchy.
3. Answer: C. The `show route advertising protocol <protocol> <neighbor>` command is used to display the route the local router is sending out an interface to a neighbor for RIP/BGP, respectively. The `receiving-protocol` form of this command shows the routes being learned over an interface.
4. Answer: D. Only designated routers, which are elected only on multiaccess networks, generate Type 2 network summary LSAs. This LSA type is used to report the list of OSPF neighbors (including the DR itself) attached to the multiaccess segment.
5. Answer: C. Stub areas do not receive summary LSAs from the backbone. They rely on an injected default route to reach interarea and AS external destinations.
6. Answer: D. All of the factors listed influence whether a given router can become the DR. Recall that DR election is not revertive. A router's ID and priority come into play only during an active DR election.

7. Answer: D. The protocol with the numerically lowest preference (or administrative distance) is considered more “reliable” and is chosen as the source of the active route.
8. Answer: A. Your goal is to filter from area 1 into area 0, so the `area-range` statement needs to be applied to area 1. The `restrict` keyword filters the specifics, leaving on the summary.
9. Answer: B. To avoid disruption, the legacy protocol must operate until all aspects of the new IGP have been put in place and confirmed. The new IGP has to be less preferred than the original until you are ready to actually make the switchover.
10. Answer: B. You must diligently use filtering mechanisms to ensure that routes are never redistributed back into the IGP from where they originated, or else loops will likely form.
11. Answer: D. For OSPF, JUNOS software supports simple passwords, MD5, and a key chain of MD5 secrets. RIP does not support key chain authentication as of the JUNOS software 8.3 release.
12. Answer: A. JUNOS software will generate a default route only when a metric value is specified using the `default-metric` command.

CHAPTER 5

Border Gateway Protocol and Enterprise Routing Policy

This chapter reviews the Border Gateway Protocol (BGP) version 4 operation and key attributes to accommodate a detailed discussion of BGP enterprise applications. BGP is all about the *control* of routing information *between* autonomous systems (ASs). Emphasis is placed on the use of routing policy to facilitate load balancing and common enterprise applications of inbound and outbound routing requirements when customers are dual-homed to different service providers. The topics covered include:

- BGP overview and enterprise applications
- External BGP (EBGP) peering with asymmetric load balancing
- BGP policy for the enterprise
- BGP dual-homing scenario with route reflection and outbound policy
- Implementation of a dual-homed inbound policy by manipulating BGP attributes

Juniper Networks routers offer extensive feature support for BGP. In fact, the list of supported standards is too long to be valuable here. Consult the BGP overview in the JUNOS documentation to confirm the list of supported RFCs and drafts for your particular JUNOS software release.

What Is BGP?

BGP is an interdomain routing protocol, which means it operates between networks that are under different administrative control—making BGP an Exterior Gateway Protocol (EGP) that operates between ASs. An AS is defined as a group of IP networks operated by one or more network operators that has a single, clearly defined routing policy.

BGP is a path-vector routing protocol that relies on the uniqueness of AS path numbers for loop prevention. Rather than advertising a simple vector (prefix), as in the case of the Routing Information Protocol (RIP), BGP's reachability information is a prefix with associated attributes that describe the *path* to that prefix. The rich set of supported attributes in turn allows for an equally rich set of policy actions.

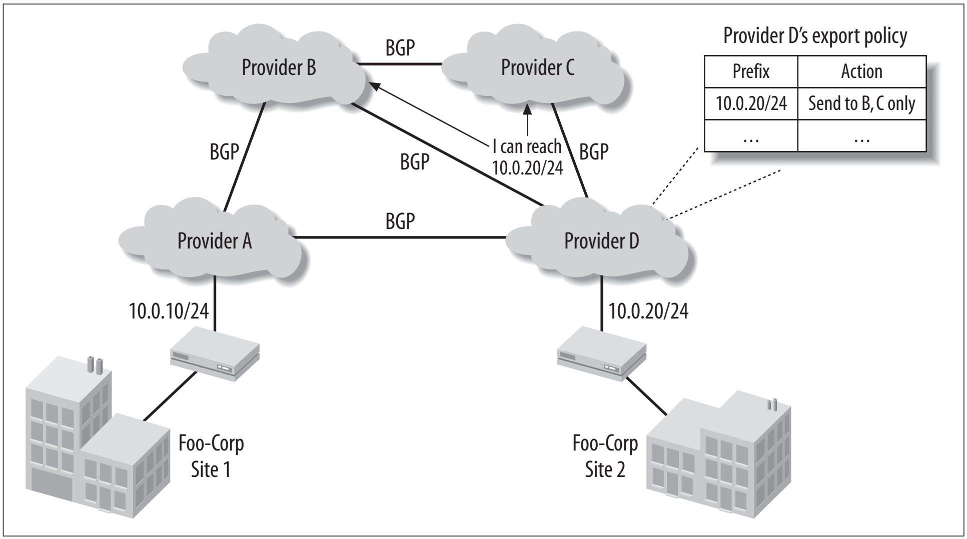
BGP is somewhat unique in that it uses a reliable Transmission Control Protocol (TCP)-based transport for its control and update messages. Reliable transport means there is no need for periodic route updates, which is really, really good, considering that a full BGP table typically comprises more than 220,000 routes! BGP does generate periodic keepalive traffic in the absence of route update activity to ensure that the underlying TCP transport is still functional.

BGP version 4 has been in use for more than two decades, with the current version (BGP 4) originally defined in RFC 1654 back in 1994. This RFC was obsoleted by RFC 1771, which in turn was obsoleted by the current specification, RFC 4271. The fact that BGP still enjoys a growing deployment base, with no replacement looming on the horizon, is a testament to the architects' forward-thinking design. BGP is based on the use of parameter type, parameter length, and parameter value tuples (sometimes called *tag length values*, or TLVs). It is these TLVs that provide the inherent extensibility without the need for significant protocol changes. You want IPv6 address family support? Simple; just define a new network layer reachability information (NLRI) attribute. You need route reflection? No problem; add some new attributes to communicate cluster and originator ID information. Meanwhile, the basic operation and protocol mechanisms remain unaltered and, in many cases, backward-compatible.

Inter-AS Routing

In several regards, you can think of BGP as the antithesis of an Interior Gateway Protocol (IGP). For example, an IGP functions *within* an AS and strives to *promote* connectivity, whereas a BGP operates *between* ASs and tends to *limit* connectivity. That last point may require a bit more clarification. An IGP normally actively seeks to discover routing peers (neighbor discovery). Once the neighbors are found, routes are exchanged and connectivity is promoted by virtue of always seeking the best path between endpoints. BGP, on the other hand, has to be explicitly told which neighbors to peer with, and then the use of administrative policy is used to filter and modify routing information to select the "best" route that meets the network operator's defined policy. The word *best* is quoted here because when routing between ASs, the concept of what constitutes a best path is cloudy at best. For example, a company may choose to filter large portions of BGP connectivity from best path consideration, based solely on a local policy that does not allow the use of a specific competitor's backbone. Exactly why such a policy is in place is not the question, although many good answers spring to mind, including potential concerns of corporate espionage. The point here is that with BGP, you are normally as concerned about restriction/ignoring routing information as you are about receiving it in the first place. The IGP is focused on getting you there, whereas BGP is more concerned with *how* you get there.

Figure 5-1 illustrates a simple interdomain routing scenario, where each AS is represented by a cloud. The cloud is, of course, the universal symbol for “don’t ask, don’t tell.” This is to say that specifics of each AS are left to the administrators of that network and are generally not known outside of that scope. It might be possible for a transit network to deploy an avian-based transport technology, as per RFC 1149;[*] as long as they meet their service level agreements (SLAs), the details of how they manage to pull it off are typically not a matter of concern.



Provider D’s export policy

Prefix	Action
10.0.20/24	Send to B, C only
...	...

Figure 5-1. Interdomain routing with BGP

BGP operates on the links that tie these networks together, in effect serving as the *public face* of each network. The BGP speakers in each AS advertise network reachability to the ASs they are configured to peer with, under the confines of their specific export policy. In like fashion, each BGP speaker filters received information through its respective import policy before placing what remains into its route table for consideration for the active route selection process. Figure 5-1 shows that Provider D’s policy prevents the advertisement of the 10.0.20/24 prefix from Site 2 to Provider A. Provider A will have to receive the Site 2 prefix from Provider B. As a result, the two customer sites will be forwarding over additional AS hops to reach each other. This point helps to demonstrate that for BGP, connectivity is as much a matter of politics as it is performance.

[*] RFC 1149 is one of the more notorious “less than serious” RFCs, as indicated by its April 1 publication date.

BGP Route Attributes

BGP advertises route reachability (NLRI), along with various attributes that describe the path to that prefix. The terms *NLRI*, *route*, and *prefix* are synonymous and are used interchangeably in this chapter. This section describes key BGP path attributes. Policy discussions later in this chapter require that you understand what these attributes do and how you work with them to achieve your routing goals.

All BGP route attributes fall into one of the following categories based on whether all BGP speakers are expected to understand the attribute and whether the attribute has local-AS or end-to-end scope:

Well-known mandatory
: A well-known mandatory attribute must be supported by all BGP speakers and must be present in all BGP updates that contain an NLRI.

Well-known discretionary
: A well-known discretionary attribute must be supported by all BGP speakers and may or may not be present in a given NLRI update.

Optional transitive
: An optional transitive attribute is an optional attribute that may not be understood by all speakers and is expected to transit the local AS, even if it is not understood by the local speaker.

Optional nontransitive
: An optional nontransitive attribute is an optional attribute that may not be understood by all speakers and does not transit the local AS—that is, it is not readvertised to another, remote AS.

Common BGP path attributes include:

Next hop
: The next hop is a mandatory attribute that carries the IP address of a BGP speaker (or a third party when permitted) to identify where packets should be forwarded when using the associated route. The next hop is changed by default for EBGP and is unchanged for Internal BGP (IBGP); however, this default behavior can be altered with policy.

Local preference
: Local preference is a well-known discretionary attribute used to influence BGP path selection with regard to the desired egress point for traffic from within an AS. Traffic flows toward the peer advertising the highest (most preferred) local preference. Local preference is present only in IBGP updates (nontransitive).

AS path
: The mandatory attribute AS path lists the AS numbers that will be crossed when forwarding to the associated NLRI. The AS path attribute is used for loop prevention and influences path selection in accordance with the motto "the fewer

ASs in a path, the better." Each AS adds its AS number to the front of the current AS sequence when generating *EBGP* updates; the lack of updated AS path information in IBGP updates is why IBGP speakers are not permitted to readvertise routes learned from IBGP back to other IBGP speakers. By default, BGP discards any route advertisement that contains its local AS number in the AS path, because this indicates that the route has already passed through the local AS once; that is, a loop has formed.

Origin

The origin code is a well-known, mandatory attribute that identifies the original source of a route as being learned from an IGP, EGP, or unknown source. In route selection, a BGP speaker will prefer IGP to EGP, and EGP to unknown. Origin is present in all route updates and is subject to modification with policy (transitive).

Multiple exit discriminator

The multiple exit discriminator (MED) attribute is an optional, nontransitive attribute, which means that some BGP speakers may not understand or use MED. MED is added on updates sent over EBGP links, and is then advertised by IBGP within the receiving AS to influence its outbound routing. However, the MED attribute does not transit beyond the AS into which it was originally advertised—BGP speakers in upstream ASs either receive no MED or receive a new MED value created by that peering AS.

MED functions like a conventional routing metric in that speakers prefer the route with the lowest MED when all preceding decision points are equal. The MED advertised by the originating AS to an adjacent AS provides a clue to the adjacent AS regarding what links should be used for *egress* from the neighbor AS back toward the originating AS, and therefore what links are used as *ingress* to the local AS. Stated differently, the MED is used by the local AS to influence the routing decisions in an adjacent AS for traffic that is inbound to the local AS. When absent, JUNOS software assumes an MED value of 0, which is the most preferred setting. In contrast, the absence of a local preference is assumed to be a value of 100.

Community

The community attribute allows for the arbitrary grouping of routes that share one or more characteristics via the addition of a common community tag value. The community tags can be used for a variety of purposes, such as route filtering and attribute modification. For example, all routes learned from customers may be assigned the community value of 65000:100. When this community is seen on a route, the local policy will set a more preferred local preference. As another example, consider the well-known community, *no-export*. When attached to a route, this community tells the adjacent AS that the associated route should not be readvertised to any remote ASs.

BGP Path Selection

A BGP speaker that is presented with two or more updates, specifying the same prefix, performs a route selection process to select the best BGP path for that prefix. Once the best path is selected, the route is installed in the route table, where it may become active if the same prefix is not being learned by a protocol with a better global preference. The JUNOS software BGP path selection process consists of the following decision steps:

1. Can the BGP next hop be resolved?
2. Prefer the path with the highest local preference value.
3. Prefer the path with the shortest AS-path length.
4. Prefer the path with the lowest origin value.
5. Prefer the path with the lowest MED value.
6. Prefer the path learned using EBGP over paths learned using IBGP.
7. Prefer paths with the lowest IGP metric:
    a. Examine route tables `inet.0` and `inet.3` for the BGP next hop, and then install the physical next hop(s) for the route with the better preference.
    b. For preference ties, install the physical next hop(s) found in `inet.3`.
    c. For preference ties within the same route table, install the physical next hop(s) where the greater number of equal-cost paths exists.
8. Prefer paths with the shortest cluster length.
9. Prefer routes from the peer with the lowest router ID (RID), unless multipath is enabled:
    a. For external routes from different ASs, do not alter the active route based on the lowest RID to prevent MED oscillation.
10. Prefer routes from the peer with the lowest peer ID (BGP peering address), unless multipath is enabled.

Configuring the multipath option deactivates the last two decision points, which are normally used as tie breakers. When multipath is enabled, all paths that are equal up to step 9 are installed in the route table. Multipath supports EBGP and IBGP, but is normally associated with EBGP sessions because IBGP will often achieve its load-balancing functionality through the underlying IGP when equal cost paths to the IBGP speaker exist. Use multipath for IBGP when two or more IBGP speakers advertise the same prefix and you wish to install both speakers as viable next hops.

Figure 5-2 demonstrates the BGP path selection process at work.

Here, NLRI 10.0.20/24 is originated into BGP by AS 65000. Note that when advertised to ASs 65010 and 65069, this NLRI is associated with an AS path attribute that consists of a single AS and has an origin value of “I” indicating IGP learned.

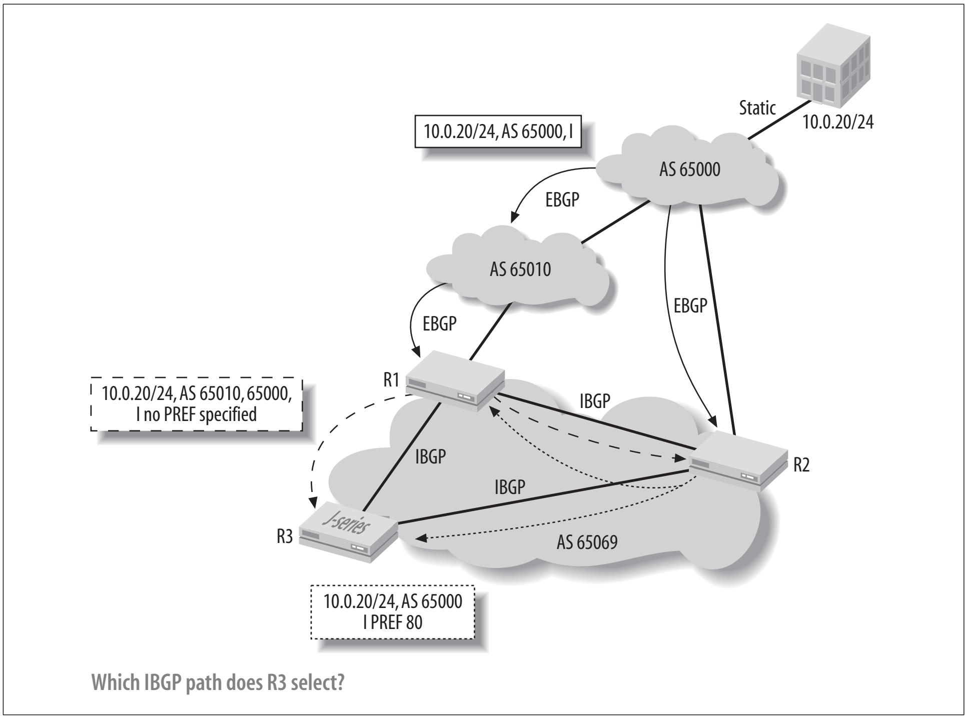


Figure 5-2. BGP path selection

This value could be a default value for redistribution of static routes into BGP or the result of policy setting. The NLRI is then readvertised into AS 65069 by AS 65010. Initially, routers R1 and R2 prefer their local copy of this path, so both R1 and R2 select it as active and advertise the NLRI to all IBGP peers, which means that R3 receives two updates for the same path. In this example policy, R2 causes the route to be sent into IBGP with a modified local preference value of 80. Also note that the route received from AS 65010 has an AS sequence that is one AS longer than the route sent to R2 directly from AS 65000.

Running through the path selection process steps listed previously, it's safe to assume that R3 will make a decision early in the process, preferring the copy of the route with a default local preference of 100. Had both local preference values been the same, the selection criterion would now become the shortest AS path length, resulting in R3 forwarding through R2. Note that R1 and R2 will also send their 10.0.20/24 updates to each other. This means that R2 prefers the path through R1, and therefore now sends another update to R1 and R3, withdrawing its earlier IBGP update for 10.0.20/24. The example also helps to demonstrate how local preference is used to influence the egress point in the local AS.

JUNOS software is designed to display all valid BGP paths, and even includes the reason why a given path was not selected. This greatly simplifies the network administrator's job when the goal is to make a currently inactive path the active path; policy can be applied to alter the criterion that leads to the original path being preferred. Here's the output from a show route detail command, to illustrate this point:

```
user@host> show route 10.0.20/24 detail
inet.0: 52 destinations, 94 routes (52 active, 0 holddown, 0 hidden)
10.0.20.0/24 (3 entries, 1 announced)
        *BGP    Preference: 170/-201
                Source: 192.168.32.1
                Next hop: 10.222.28.2 via fe-0/0/0.0, selected
                Protocol next hop: 192.168.32.1 Indirect next hop:
858b4e0 73
                State: <Active Int Ext>
                Local AS: 65069 Peer AS: 65069
                Age: 18:57      Metric2: 3
                Task: BGP_65432.192.168.32.1+1042
                AS path: 65000 65010 I
                Localpref: 100
                Router ID: 192.168.32.1
         BGP    Preference: 170/-101
                Source: 10.222.29.2
                Next hop: 10.222.29.2 via ge-0/1/0.0, selected
                State: <Ext>
                Inactive reason: Local Preference
                Local AS: 65069 Peer AS: 65069
                . . .
                Localpref: 80
```

From the sample output, it is quite clear that because of the local preference comparison, the path through 192.168.32.1 is preferred. Knowing that this BGP route was not chosen due to the local preference value makes it a relatively simple task to change the selection of the path through 192.168.32.1 by setting its preference to be higher than 100.

Internal and External BGP

We have already used the terms *Internal BGP* and *External BGP* (IBGP/EBGP) a few times leading up to this point. It's time to explore what this terminology signifies. For the most part, BGP operation is the same when operating internally to an AS versus externally to a remote AS, but Table 5-1 summarizes the key differences.

Table 5-1. IBGP and EBGP

Characteristic/attribute	IBGP	EBGP
Local AS added to AS path	No	Yes
Next hop overwritten	No	Yes

Table 5-1. IBGP and EBGP (continued)

Characteristic/attribute	IBGP	EBGP
New MED added	No; the MED received on an EBGP link can be advertised via IBGP within the local AS	Yes
Local preference	Yes	No
Peering address	Normally loopback, recursive lookup provided by IGP, Time to Live (TTL) = 64	Normally peers directly to interface address, no recursion or IGP needed, TTL = 1
Update received from EBGP, is sent to:	All IBGP peers	Other EBGP peers
Update received from IBGP, is sent to:	No IBGP peers	All EBGP peers

Although the differences may seem trivial, they can have a significant impact. For example, because IBGP updates do not alter the AS path attribute, loops become a concern, and this leads to the restriction that IBGP speakers cannot readvertise an IBGP update to other IBGP speakers, which leads to the requirement that IBGP speakers must be fully meshed.

The next hop-handling differences often lead to IBGP routes that are hidden because the receiver cannot resolve the associated BGP next hop. By default, the next hop identifies the EBGP speaker in the adjoining AS, and often the IGP will not carry this route, thereby leading to an unreachable next hop. An IBGP export policy that overwrites the BGP next hop, typically to the IBGP peering address, is normally used to resolve this issue (no pun intended).

The MED attribute is normally added only when a route is advertised over an EBGP peering, and its absence may be interpreted as the lowest or highest possible value, depending upon implementation—Juniper assumes the lowest value, which is 0. In contrast, local preference is present only in IBGP updates, and by standard is assumed to be 100 when absent. When received from an EBGP peer, the MED value can be advertised to other speakers within that AS using IBGP.

The peering differences are significant for several reasons. EBGP normally peers to a neighbor using an address on the directly connected link between the routers. As a result, no route recursion is needed to resolve the BGP peering address to a next hop forwarding address, given that they are one and the same. This means that an IGP, to include static routing, is normally *not* required to support EBGP peering. It also means that loss of the directly connected network/peering interface results in loss of the EBGP session. For security reasons, the TTL for EBGP sessions is set to 1 by default, which prevents attempts to peer from a remote link. This behavior is altered by configuring multihop on the EBGP session. Lastly, a `local-address` (referred to as *update-source* in IOS) is normally *not* used for an EBGP session, because by default, it is sourced from the same directly connected network interface that the two BGP routers are peering over; therefore, the source and destination addresses for the BGP session will be from the same, directly connected subnet.

IBGP, in contrast, is normally configured to peer between the loopback addresses of the routers. This provides resiliency from the failure of individual networks or interfaces. IBGP inherently supports multihop, which is good because IBGP neighbors can be located anywhere with the AS and often do not share a link. A recursive route lookup is needed to resolve the loopback peering address to an IP forwarding next hop, and thus this service is normally provided by the network's underlying IGP. When defining a BGP loopback peering session, you need to correctly match the source address used by the local peer to ensure that it matches the session definition at the remote peer. Recall that by default, the router will source traffic from its egress interface, which will not be the loopback interface, and this can make the incoming connection request appear to come from an undefined peer.

Scaling IBGP with Route Reflection

The previous sections touched on the fact that IBGP speakers should be fully meshed due to the restrictions that IBGP has on readvertising updates to other IBGP speakers. When BGP was first envisioned more than 20 years ago, conventional wisdom was that the global Internet would consist of only a few ASs, and that each AS would have a few BGP speakers, and that these speakers would be dealing with a few hundred routes. Recall also that the VP of IBM once announced a worldwide market for mainframes to be around 10 units! Maintaining a full IBGP mesh among a few routers is trivial, but doing so among hundreds of routers is nearly impossible.

Given the modern reality of transit provider networks needing to run IBGP on virtually every router in their AS, and that there may be hundreds of these routers, you can quickly conclude that maintaining a full mesh of IBGP sessions quickly becomes unmanageable. The formula to compute the number of sessions required for a full mesh is $v * (v - 1)/2$, where v is the number of BGP speakers. Using the formula, we see that for 10 IBGP speakers, a total of 45 IBGP sessions are needed (10 * (9)/2 = 45). Increase the number of speakers by a mere 50%—to 15—and the number of sessions required increases geometrically to 105! It's clear that the full-mesh model simply does not scale; soon routers would exhaust all their control plane resources just maintaining all their BGP sessions. A solution was needed, and route reflection, as currently defined in RFC 4456, provides a remarkably elegant solution to what could have been a significant protocol shortcoming. Figure 5-3 shows a small IBGP cloud before and after route reflection is added.

Note that in the first example, an IBGP session is missing, resulting in a less than full mesh, which in turn leads to holes in the BGP topology. In the second example, however, R2 has been configured to perform reflection, using but a single command to assign a cluster ID. The only change made to clients R1, R3, and R4 is the removal of their now unneeded IBGP sessions.

Route reflection adds two new attributes to IBGP updates to address concerns about BGP loops that would otherwise occur, given that IBGP updates do not modify the

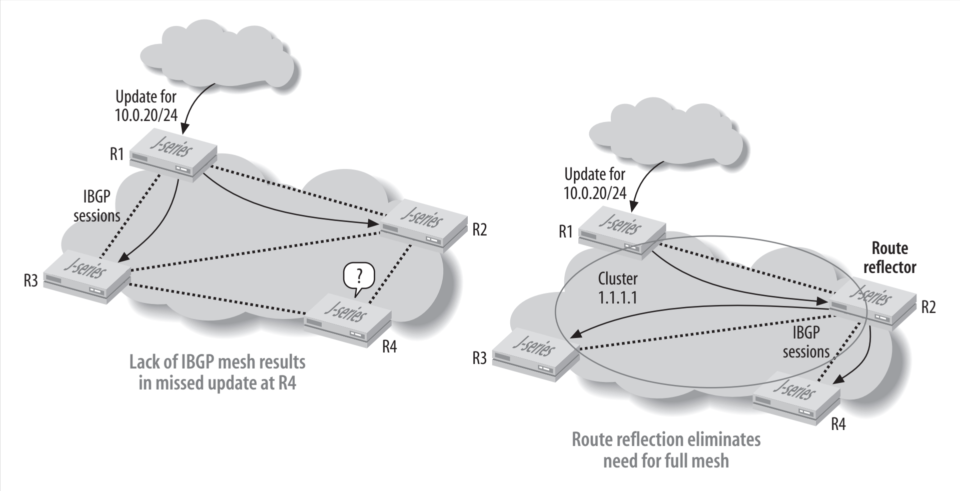


Figure 5-3. BGP route reflection

AS path. These attributes are added by the route reflector when it first touches a client's route. Configuration of reflection is performed only on the route reflector itself; no configuration changes are needed for a route reflector client, other than perhaps to decommission unneeded IBGP peering definitions to other clients in the same cluster.

The cluster list attribute identifies the route reflection clusters that the route has visited, whereas the originator ID attribute identifies the route's original source. These attributes are processed by route reflectors to prevent loops by ensuring that IBGP updates are echoed only once to each reflector client and nonreflector client. Simply put, a cluster's reflector will not readvertise an IBGP update into cluster ID *n*, when cluster ID *n* is already present in the cluster list attribute. The reflector also uses the originator ID attribute to ensure that updates are never sent back to the client that originated the route. Note that the route reflector first performs the best path selection process on all updates and reflects only the paths it chooses as best.

You typically want the forwarding topology to differ from the reflection topology, which is to say that packets can be forwarded directly between two BGP speakers, despite their learning each other's routes through a reflector. If the IGP's shortest path does not lead through the reflector, the packets should not flow through the reflector. Care must be taken with any next hop self-policy applied to a reflector to ensure that it does not rewrite the next hop on IBGP routes that it is reflecting—doing so will force extra hops on packets that now need to cross the reflector. A next hop self-policy is often applied to IBGP updates to rewrite the BGP next hop of EBGP learned routes with the peering address of the local speaker. This prevents problems with internal speakers not being able to resolve the next hop originally received in the EBGP update, which is set to the remote EBGP speaker's peering address and normally not altered in IBGP updates.

Route reflection and redundancy

Reflection can represent a single point of failure, making it common to add redundancy by deploying multiple reflectors. Normally, each reflector IBGP peers with each client in the cluster, and the two route reflectors are then joined via a nonclient IBGP session. There always seems to be endless debate in such designs as to whether each reflector should be assigned the same or a unique cluster ID. Figure 5-4 illustrates the two design alternatives.

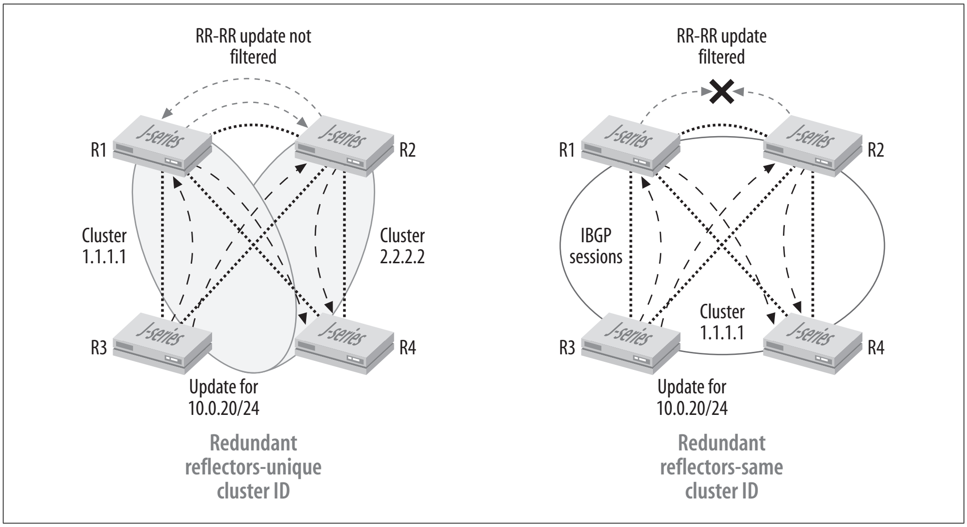


Figure 5-4. Route reflection redundancy

In most cases, a design using unique cluster IDs—which technically results in two route reflector clusters, each having one reflector—is considered the best approach for maintaining connectivity in the event of failures. This is because the reflectors do not see their own cluster ID in the updates they send each other via the route reflector–route reflector IBGP session, and therefore the reflectors will learn of both their intracluster and intercluster paths, resulting in a more complete BGP table at the reflectors. For example, if the R3–R1 IBGP session should fail, R1 is still able to reach R3 via the path learned from R2 in cluster 2.2.2.2. The dual-cluster approach does have the drawback of increased BGP route state at the reflectors, prompting some to prefer the shared cluster ID model.

We discussed the main drawback to the shared cluster ID approach earlier—namely, the potential for client-to-reflector session loss and the resultant lack of connectivity. However, if we assume loopback-based peering, there is actually little risk to the shared cluster model. This is because it's extremely unlikely that a client-to-reflector IBGP session will be lost while the client is still able to maintain connectivity to the rest of the network. You should use unique cluster IDs if you're using interface-based peering so as to provide tolerance for failure of individual interfaces.

Scaling IBGP: Confederations

A BGP confederation effectively divides a large AS into smaller, mini ASs known as a *member ASs*. Within each member AS, you normally find a full IBGP mesh, but route reflectors can also be deployed as part of a confederation solution. It's normal to see member ASs assigned AS numbers from the private numbering space because member AS numbers are not seen external to the AS confederation anyway. Because the number of routers within each sub-AS is relatively small, maintaining a full IBGP mesh is manageable. To the outside world, all these confederation shenanigans are hidden, and the entire AS confederation is represented by a single AS number.

Confederation use is rare in enterprise networks, and we will not explore the subject here other than to mention that Juniper routers offer full support for BGP confederations. For more information on BGP confederations, consult JUNOS software documentation or RFC 3065, "Autonomous System Confederations for BGP."

BGP and the Enterprise

The preceding section provided a targeted review of BGP's operational characteristics and scaling approaches. BGP is normally associated with Internet service provider (ISP) networks that offer transit services for Internet traffic. This section focuses on how BGP can be applied to meet the routing needs of enterprise networks.

When Should an Enterprise Run BGP?

BGP is a sophisticated routing protocol that can help to optimize an enterprise's routing, but that doesn't mean all enterprise networks will see a benefit from its deployment. An enterprise decision to run BGP normally hinges on the benefits that can be gained by making intelligent outgoing routing decisions and by using BGP attributes in an attempt to influence how upstream networks route toward your network to help control which links are used for ingress traffic. The common factor to both of these scenarios is a network with at least two external connections—such a network is considered to be *dual-homed*. Enterprise networks with a single attachment to a service provider will normally not benefit by running BGP and should simply use a static default route. When dual-attached to the same provider, two static defaults can be used to achieve some measure of outbound load balancing.

A word about AS numbers

Although likely obvious by now, we must state that to run BGP you must first have an AS number. Like IP addresses, there are both public and private AS number pools. Public AS numbers are assigned by a Regional Internet Registry—for example, ARIN for the Americas, Caribbean, and sub-Saharan Africa, APNIC for Asia Pacific, or RIPE for Europe, the Middle East, and Northern Africa.

Historically, the ASN space was limited by the use of a 2-byte value, which permitted a maximum of 65,535 ASs. Support of 4-byte coding for ASNs, which can provide more than 4 billion unique ASNs, is defined in draft-ietf-idr-as4 and is supported in JUNOS software.

An enterprise should expect to justify its need to the Regional Internet Registry when applying for a public ASN. Requirements vary, but normally you qualify for a public ASN only when your network is multihomed and has a single, clearly defined routing policy that is different from its providers' routing policies. This brings up a key point about BGP, policy, and dual homing. When you are attached to a single upstream provider, from the perspective of the rest of the world your policy must, by definition, match that of your provider. This is because only one external view of that enterprise's routes is being made available, and this view is based on your provider's policy. BGP can still be used when connected to a single upstream provider, but in these cases, you will often configure the routers with an ASN from the private AS space. The provider will then strip the private ASN and replace it with its ASN when announcing these routes to other networks. The private ASN space, which is technically allocated to the IANA itself, ranges from 64,512–65,534, inclusive. These numbers are often used to number subconfederations within a confederated AS.

ASN Portability

An organization may obtain its ASN directly from a regional numbering authority or as part of its service agreement with a local provider, which in this case functions as a Local Internet Registry (LIR) by delegating ASNs (and address blocks) from its assigned pool. In most cases, ASNs obtained from an LIR will not be portable if you later decide to move to a new provider. This situation is similar to nonportable IP address blocks, which stay with the provider should you choose to obtain service elsewhere. Although AS renumbering is certainly less work than IP renumbering, both can be disruptive and time-consuming—careful thought should be given to the potential need for ASN portability when planning your BGP deployment.

Dual-homed: Single versus multiple providers

Being dual-homed is a great way to improve performance and reliability. But do all dual-homed environments warrant use of BGP? In most cases, this is a function of whether the enterprise is dual-homed to the same or to different upstream providers. Figure 5-5 shows the two types of dual-homing arrangements. Note that both models support multiple attachments to the same ISP, whether for reasons of redundancy or added capacity. In fact, the simplest form of the dual-homed single-provider/dual-provider model is to use a single router with dual links. Relying on a single device for all external connectivity suffers obvious reliability concerns, and it is assumed rare for all but the smallest of enterprise networks.

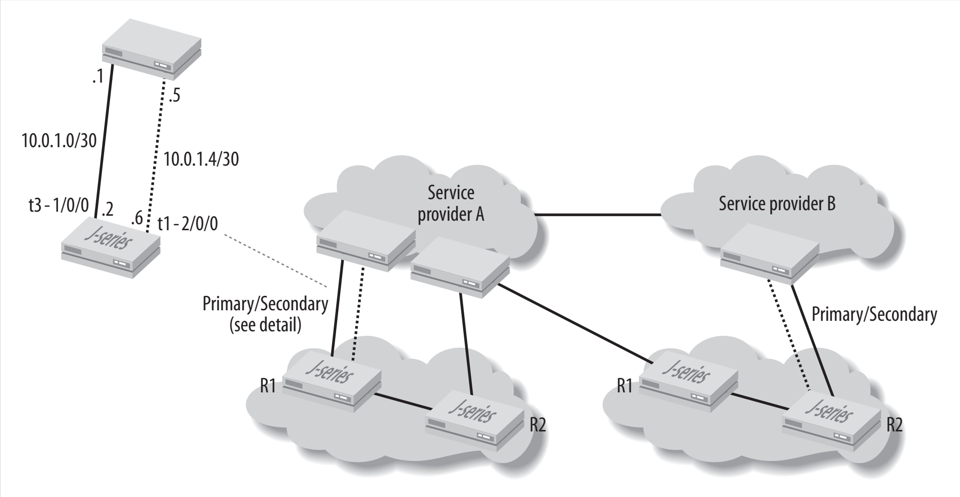


Figure 5-5. BGP dual homing

Running BGP is normally overkill when you are dual-homed to the same provider, especially when the parallel connections are in close geographic proximity. This is because you are pretty much at the mercy of your provider's policy, and BGP cannot do much to alter the way traffic enters or exits your network—your global view of the Internet must match that of your provider because it is the only view you receive. An enterprise with this type of connectivity is often well served with a simple static default route. Load balancing can occur in one of two ways. For a single router with dual attachments, the load balancing occurs at that router, using the underlying IGP (static) to map prefixes or flows to one of the two links. This router is in turn configured to advertise a default route into the IGP to attract nonlocal traffic. When dual routers are used, each with a single provider uplink, it's common to see each router generate and advertise a default route into the IGP, while they in turn each have a static default pointing toward that router's provider uplink.

Asymmetric Link Speed Support

The use of asymmetric link speeds for redundant attachment to the same provider is common in both models. When running BGP, the bandwidth community can be used to provide unequal cost load balancing proportionate to the link speed. In contrast, static routing over asymmetric links is typically done by directing all traffic over the high-speed link until it becomes unavailable, at which point the traffic is switched to the lower-speed secondary. In JUNOS software, this is accomplished with a static route along with a *qualified next hop*. A qualified next hop is a list of next hops with varying preferences/metrics that are used in order of their preference, based on the ability to resolve the associated next hop. The following code snippet shows how a dual-homed customer could configure all traffic to egress on a high-speed T3 link, unless the T3 interface/next hop becomes unavailable, at which point the traffic will switch to the qualified next hop with the next most preferred (next lowest) preference:

```
[edit routing-options static]
ruser@router# show
route 0.0.0.0/0 {
    qualified-next-hop 10.0.1.1 {
        preference 20;
        interface t3-1/0/0.0;
    }
    qualified-next-hop 10.0.1.5 {
        preference 30;
        interface t1-2/0/0.0;
    }
}
```

Which Routers Should Run IBGP?

Great! You've made it this far, which shows that you still feel your network either justifies use of BGP, or simply needs a puppy. From this point forward, this chapter assumes a network that is dual-homed to multiple providers, as is your desire for fine-grained control over how traffic enters and exits your network. Having reached this determination, the next logical question is, "Where should I configure BGP?" Knowing where to run EBGP is pretty straightforward; you must configure EBGP on the routers that peer to other ASs. The real question is where do you have to run IBGP, and this is a very, very good question indeed.

First, consider that most service provider networks run *both* an IGP and an IBGP on *all* of their core routers.[*]

Service providers need to run BGP on all their routers to ensure that the Internet core remains a default free routing zone, and because no service provider in its right mind would (intentionally) try to redistribute a full BGP table into its IGP. For the first point, any transit network that does not carry full Internet routing, and therefore relies on some type of default route, will be prone to loops. If the network is not running BGP on all transit routers, and there is no default route, the implication is that the IGP is in fact carrying a full Internet route table. Even the best implemented IGPs are not intended to carry hundreds of thousands of external routes, making such a design implausible given the sheer size of Internet route tables.

[*] The notable exception here is the "BGP free core," typically based on Multiprotocol Label Switching (MPLS) to avoid the need for full routing state in the core.

> It's interesting to note that JUNOS software does not have the concept of IGP–BGP synchronization, making a `no synchronization` configuration statement unnecessary. In IOS, the BGP process expects the IGP to have a copy of each route before that route can be advertised by BGP, unless, of course, you have turned off synchronization. This is why disabling synchronization is the first step in almost any IOS configuration. Consider this one less command to get BGP up and running on a Juniper!

By running BGP on all its routers, a service provider does not rely on a default route, and it can mercifully spare its IGP an ignoble meltdown. By running both protocols, the IGP is left to do what it does best: providing connectivity between the loopback interfaces used for IBGP peering, while BGP routes keep the transit traffic from looping about and also provide needed administrative policy controls.

No Transit Services

Service provider networks are richly interconnected to the outside world, and they are optimized for making money by transporting traffic that neither originates on nor terminates in their networks. This is, after all, what makes them *transit* service providers. In contrast, an enterprise network is concerned with the transport of its own traffic, albeit sometimes needing to venture offsite to obtain required information. By not providing transit services, an enterprise can avoid running IBGP on every router. When possible, the network should be designed so that the BGP speakers are geographically localized, thus minimizing the portions of the network that need to run BGP. Figure 5-6 provides a sample topology to illustrate this concept.

The figure shows a network topology that runs BGP for its own connectivity, not for providing transit/connectivity services to other networks. The BGP speakers have been positioned near the network's edge and in geographic proximity, in an effort to constrain the scope of routers that need to run BGP. Routers R1 through R3 are BGP-enabled and speak EBGP to their attached service providers and IBGP among themselves. BGP is needed between these routers because Internet-destined traffic originating within the enterprise can arrive at any of these, and the consistent BGP tables ensure that traffic egresses the network according to local policy, even if some additional hops across the backbone are needed to reach the desired egress point.

A default route is generated by two of the IBGP speakers and is injected into the IGP to provide the non-BGP-speaking routers with external connectivity. The use of a generated route, as opposed to a simple static route, allows the withdrawal of an advertised default when the BGP speaker has problems with its EBGP session—the generated route is made active by the presence of learned EBGP routes. Internal routers simply select the remaining default route that is metrically closest to maintain their external connectivity.

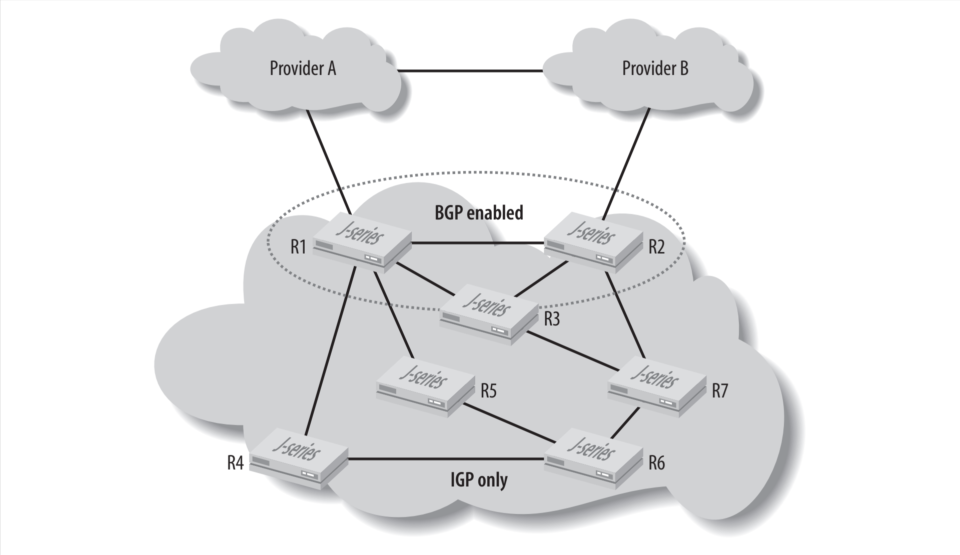


Figure 5-6. Which routers need to run IBGP?

The Impact of Accepting Specifics Versus a Default from Your Provider

The need to run IBGP on routers that do not speak EBGP is normally a function of whether the enterprise's import policy accepts only a default route or is configured to accept specific routes. In the latter case, you will need to run BGP on any routers that are used to interconnect your EBGP/IBGP-speaking nodes to prevent routing loops. Figure 5-7 provides an example of how inconstant routing knowledge can lead to a routing loop. The inconsistency arises from forwarding state that is known to the BGP speakers only while other routers rely on a default route. If all routers accepted only a default or the same set of specifics, this condition would not arise.

In this example, routers R1 and R2 are running EBGP with import policies that accept specific routes. Both routers IBGP-peer to each other. All other routers are running an IGP only. Things begin at step 1 in Figure 5-7, where both R1 and R2 generate a default route that is injected into Open Shortest Path First (OSPF). Step 2 shows Provider B advertising the 10.0.1/24 prefix, which is accepted by R2, given its import policy that accepts specifics and rejects the default route. R2 advertises this route to R1 over the IBGP session at step 3. R1 installs this route as active in this example because the same route learned from ISP A will have a longer AS path length.

Things begin to go wrong at step 4 in Figure 5-7, when R4 decides to avail itself of the default route to forward a packet to destination 10.0.1.1. In this example, R4 sends the packet to R3, but sending it directly to R1 would not change things in the

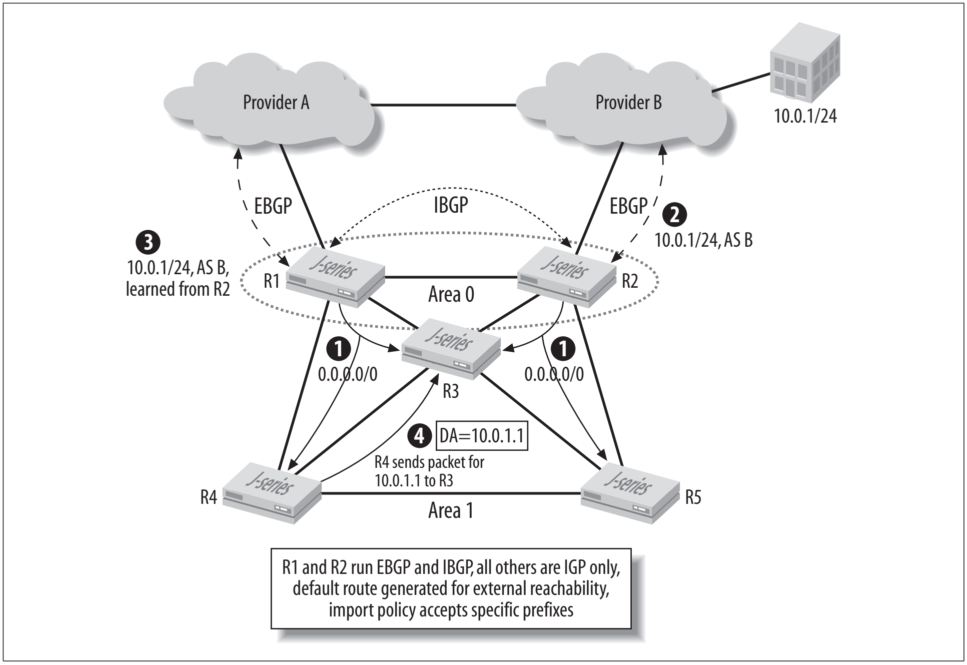


Figure 5-7. Routing loop from lack of BGP routing knowledge

long run. Recall that R3 is not running BGP and is therefore relying on the default route to reach this destination, as did R4. If R3 decides to forward to the default it learned from R2, everything is alright. But there is a 50% chance that it will decide to forward to the default route it learns from R1. As a BGP speaker, R1 has specific routing information for this prefix, which it learned over its IBGP session to R2. R1's routing decision determines that the packet should be forwarded toward the protocol next hop advertised by R2, that is, R2's loopback address. The result of R1's recursive route lookup on R2's loopback address may be the decision to forward the packet over the R1–R2 link or over the set of R1–R2–R3 links, as determined by IGP metrics. If R1 forwards the packet back to R3, a loop is formed, given that R3 has already handled this packet and decided to send it to R1.

Two solutions present themselves:

Enable IBGP on R3

If you enable IBGP on R3, and then fully mesh the IBGP speakers, R3 would have never used the default route to forward this packet and would have sent it directly to R2 for dispatch into AS B.

Reject specifics

If the import policy at R1 and R2 is altered to accept only a default, this route could be redistributed into the IGP. The EBGP learned version of the default route will remain active at both R1 and R2, even if the BGP speakers readvertise the default route to each other, owing to the route selection step that prefers EBGP learned over IBGP learned routes. Now, when a packet addressed to 10.0.1.1 arrives at R1, it longest-matches against the default route learned from Provider A and is not sent back to either R2 or R3, so no loops form.

Although the second solution prevents a routing loop, sending to ISP A is probably not the optimal way for this enterprise to reach prefix 10.0.1.0/24. This helps to illustrate why accepting specific routes, and then running IBGP among the routers that can be used to transit between EBGP speakers, is generally the optimal way for an enterprise to deploy BGP.

Summary of Enterprise BGP Requirements

To summarize, an enterprise should consider running EBGP when it is multihomed, to take advantage of the optimal routing and routing controls provided by BGP. The enterprise should run IBGP on any router that runs EBGP, and it must carefully consider what other routers should be IBGP-enabled. Recall that IBGP requires a full mesh or the use of route reflection/confederations for proper operation. Because BGP is not redistributed into your IGP, failing to run IBGP on all routers will result in those routers not having a complete view of BGP reachability. Normally, a generated default route is injected into the IGP to accommodate external routing for the non-BGP speakers. Remember that BGP will need to be enabled on routers that are expected to provide transit service *between* your EBGP speakers when the enterprise policy is to accept specific routes from your service providers to prevent against routing loops. Rejecting specifics and accepting only a default route lessens this requirement, as described earlier.

This section gave a comprehensive review of BGP and its key capabilities and operational characteristics. We also discussed how BGP can benefit an enterprise by helping to make optimized outbound routing decisions, and when all goes to plan, to also help influence your peer's outbound decisions to effect better control of how traffic arrives at your network's boundaries.

You may consider taking a brief break before diving into the next section. Some of the hands-on scenarios are a bit lengthy because of the numerous inclusions of actual router output, which are added to ensure that the reader is able to follow the details of the case study.

BGP Deployment: Asymmetric Load Balancing

Having made it through the protocol overview and enterprise application section, it is now time to apply your knowledge of BGP and JUNOS software to the first of three practical BGP deployment scenarios.

The first scenario begins when the CIO at Beer-Co seizes upon the organization's newfound appreciation for all things BGP by applying for a public ASN and detailing a BGP deployment plan that ultimately involves dual-homing to multiple providers. BGP deployment will occur in a phased approach, and you have been selected to head up phase 1: establishment of the initial BGP peering and related policy to Botnet in AS 34.

The deployment goals for initial BGP peering with Botnet are as follows:

- Establish EBGP interface-based peering to Botnet/AS 34.
- Use import policy to reject all but the default route that originates within Botnet/AS 34.
- Use export policy to advertise a single aggregate route that represents Beer-Co's internal prefixes.
- Use a static route to direct traffic to the backup link *only* in the event of BGP session disruption, and to ensure that traffic switches back to the primary upon service restoration.
- Redistribute a default route to provide external reachability for internal Beer-Co routers.

Figure 5-8 details the current Beer-Co internal topology and the newly activated access links to Botnet.

Figure 5-8 shows that Botnet is attached to other service providers, and to a particular customer, Brewer Inc., which has been assigned a 192.168.34.0/24 address block. The numbers enclosed within parentheses represent the range of route prefixes that Botnet is expected to advertise. In this example, these routes are instantiated as locally defined static routes, complete with associated AS numbers and origin code. This technique helps to simulate the learning, and subsequent readvertisement, of BGP routes between Botnet and its BGP peers. The customer route shown for provider Brewer, which is 192.168.34.0/24 in this case, is set to a reject next hop so that reachability can be confirmed, even when the customer site does not exist. Note that you expect to receive an Internet Control Message Protocol (ICMP) destination unreachable message due to the reject-style next hop, but this error message serves to validate reachability for our purposes.

Note also that Beer-Co has redundant links to Botnet. The huge disparity in link speed (100 Mbps versus 1.5 Mbps) drives the decision to use the faster link as a primary with the second link used only in the event of problems on the primary interface or a related BGP peering session. Care must be taken to ensure that the static route used to direct traffic over the secondary link is *less preferred* than any BGP routes learned from AS 34, which is not the default behavior given that a static route is more preferred than any dynamically learned one. A mistake here could easily mean paying for a 100 Mbps pipe while throughput is limited to a paltry 1.544 Mbps!

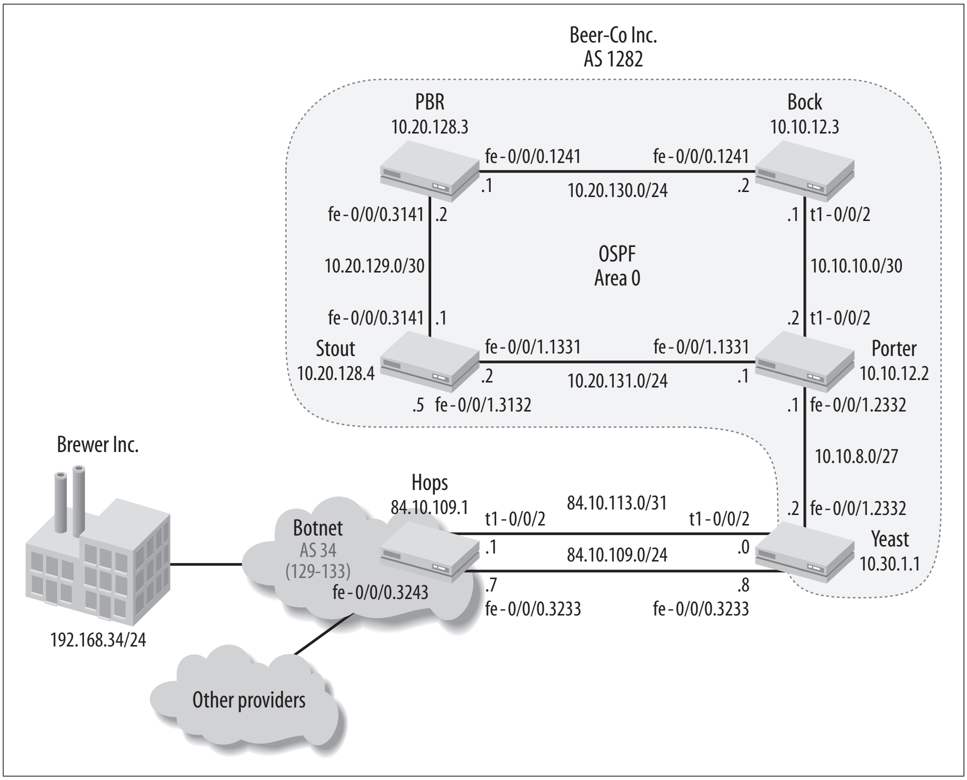


Figure 5-8. Beer-Co to Botnet peering

Validate Baseline Operation

Configuration gets underway at router Yeast with the definition of a generated static route. Recall that a generated route differs from an aggregated route in that the former has a forwarding next hop determined by the most preferred contributing route. In contrast, an aggregate route can only point to a discard or reject next hop. The generated route is redistributed into OSPF to provide connectivity to Internet destinations for Beer-Co's internal routers.

The OSPF configuration for area 0 is preexisting, and all routers have a similar configuration—the OSPF stanza at Porter is displayed, along with its adjacency status:

```
lab@Porter> show configuration protocols ospf
area 0.0.0.0 {
    interface fe-0/0/1.1331;
    interface fe-0/0/1.2332;
    interface t1-0/0/2.0;
}
lab@Porter> show ospf neighbor
```

```
  Address         Interface        State      ID            Pri  Dead
10.20.131.2      fe-0/0/1.1331    Full      10.20.128.4   128    33
10.10.8.2        fe-0/0/1.2332    Full      10.30.1.1     128    36
10.10.10.1       t1-0/0/2.0       Full      10.10.12.3    128    32
```

The single-area OSPF configuration at Porter matches the topology in Figure 5-8, and the router has all three expected OSPF adjacencies; one each to routers Stout, Yeast, and Bock. The routes being learned by OSPF are displayed and piped through the command-line interface's (CLI's) match function to show only those routes with a /32 network mask. These routes represent the loopback addresses assigned to each router (they are the only /32 IP addresses assigned), and therefore provide a quick sanity check of internal reachability.

```
lab@Porter> show route protocol ospf | match /32
10.10.12.3/32      *[OSPF/10] 00:05:54, metric 3
10.20.128.3/32     *[OSPF/10] 00:05:54, metric 2
10.20.128.4/32     *[OSPF/10] 00:23:46, metric 1
10.30.1.1/32       *[OSPF/10] 00:22:18, metric 1
224.0.0.5/32       *[OSPF/10] 01:03:03, metric 1
```

The output confirms a route to the loopback addresses of Stout, Yeast, PBR, and Bock. The metric values associated with each route seem reasonable in this topology. The default scaling factor of 100 Mbps assigns a Fast Ethernet interface a cost of 1, which results in avoidance of the T1 link between Bock and Porter. Porter therefore sees an OSPF cost of 3 to reach the loopback interface of Bock via Stout and PBR. Next, the route to Brewer Inc. is displayed:

```
lab@Porter> show route 192.168.34.0

lab@Porter>
```

The output confirms that Porter cannot route to the 192.168.34/24 route associated with Brewer Inc., which also confirms the lack of a default route in area 0. As a final verification step, reachability is confirmed to the EBGP peering addresses on both the primary and secondary links between Botnet and Yeast:

```
lab@Yeast> ping 84.10.113.1 count 1
PING 84.10.113.1 (84.10.113.1): 56 data bytes
64 bytes from 84.10.113.1: icmp_seq=0 ttl=64 time=26.887 ms

--- 84.10.113.1 ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max/stddev = 26.887/26.887/26.887/0.000 ms

lab@Yeast> ping 84.10.109.7 count 1
PING 84.10.109.7 (84.10.109.7): 56 data bytes
64 bytes from 84.10.109.7: icmp_seq=0 ttl=64 time=12.255 ms

--- 84.10.109.7 ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max/stddev = 12.255/12.255/12.255/0.000 ms
```

Configure Generated Route

A generated default route that uses policy to constrain the set of contributing routes to the direct route associated with the backup peering link to Botnet. The premise here is that in normal operation, Yeast will have two default routes: one learned through BGP that points to the primary Botnet peering, and a second, generated default route pointing to the secondary peering. Route preference adjustments are made to ensure that the BGP route will be preferred when available. Loss of the BGP session results in the generated static route becoming active. Either way, an OSPF export policy redistributes the default route, be it learned or generated, into OSPF. The default route is withdrawn only in the event that Yeast loses its BGP session at the same time as its t1-0/0/2 interface goes down, in which case the decision to forego guaranteed diverse routing for the primary and secondary circuits may come into question.

The configuration starts with the static route and, at this stage, is quite straightforward. By beginning with the generated default, you have a chance to test failover to secondary link behavior before the primary link is brought up. It's always a good idea to periodically confirm operation of backup links during a maintenance window, rather than waiting until your primary fails. The generated route portion of Yeast's configuration is displayed:

```
[edit]
lab@Yeast# show routing-options generate
route 0.0.0.0/0 policy gen_default;

[edit]
lab@Yeast# show policy-options policy-statement gen_default
term 1 {
    from {
        protocol direct;
        route-filter 84.10.113.0/31 exact;
    }
    then accept;
}
term 2 {
    then reject;
}
```

The configuration results in the generation of a 0/0 route that, when matched, will forward over the next hop assigned to the preferred contributing route. Here, the set of possible contributors is constrained by the policy named gen_default, which matches only on the 84.10.113.0/31 route assigned to the t1-0/0/2 interface. The policy's second term guarantees that no other route can contribute by rejecting all remaining routes and sources. Operation of the generated route is verified:

```
[edit]
lab@Yeast# run show route protocol aggregate detail
```

```
inet.0: 17 destinations, 17 routes (17 active, 0 holddown, 0 hidden)
0.0.0.0/0 (1 entry, 1 announced)
        *Aggregate Preference: 130
                Next-hop reference count: 2
                Next hop: via t1-0/0/2.0, selected
                State: <Active Int Ext>
                Age: 10:07
                Task: Aggregate
                Announcement bits (1): 0-KRT
                AS path: I
                                Flags: Generate Depth: 0      Active
                Contributing Routes (1):
                        84.10.113.0/31 proto Direct
```

The highlighted portions of the output confirm that all is working to plan with the generated route. A default route is present, it is currently active (there is no BGP learned version yet), and traffic matching this route will be directed out the t1-0/0/2 interface. Further, the expected number of contributing routes, 1, is shown, and that route matches the direct route for the secondary peering. Note that the route is considered to be of the type aggregate, and that the preference for this route is 130. Thinking ahead, you'll recall that this route ultimately needs to be less preferred than any BGP learned version, and that the default preference for BGP is 170. The generated route's preference is set to be just higher than BGP's, so it will be less preferred when a BGP learned version becomes available.

```
[edit]
lab@Yeast# set routing-options generate route 0.0.0.0/0 preference 175
```

The T1 interface is briefly brought down, and the show route command is repeated to validate that the generated route's fate tracks that of the t1-0/0/2 interface.

```
[edit]
lab@Yeast# set interfaces t1-0/0/2 disable

[edit]
lab@Yeast# commit
commit complete

[edit]
lab@Yeast# run show route protocol aggregate detail

inet.0: 16 destinations, 16 routes (15 active, 0 holddown, 1 hidden)
```

The command output does not display any active aggregate routes. The highlight calls out that one route, of an as-yet-unknown type, is hidden, however. To display a hidden route, add the hidden switch. Here, the display confirms that the hidden route is, in fact, the generated default—the route is now hidden because of a lack of contributors:

```
[edit]
lab@Yeast# run show route protocol aggregate detail hidden
```

```
inet.0: 16 destinations, 16 routes (15 active, 0 holddown, 1 hidden)
0.0.0.0/0 (1 entry, 0 announced)
         Aggregate
                Next hop type: Reject
                Next-hop reference count: 3
                State: <Hidden Int Ext>
                Age: 1:19:04
                Task: Aggregate
                AS path: I
                            Flags: Generate Depth: 0       Inactive
```

The change is rolled back and committed (not shown) at Yeast to ensure that the t1-0/0/2 interface is no longer disabled. Next, a policy is written to redistribute a default route from any protocol source. The ospf_default policy is applied to the OSPF protocol as export:

```
[edit]
lab@Yeast# show policy-options policy-statement ospf_default
term 1 {
    from {
        route-filter 0.0.0.0/0 exact;
    }
    then accept;
}

[edit]
lab@Yeast# show protocols ospf export
export ospf_default;
```

The ospf_default policy is written to be protocol-agnostic, because the goal is to have an active default route stemming from *either* BGP or the aggregate protocol sources. If you prefer a tight ship, you could always add a logical OR match condition for the two protocols, aggregate and bgp. After committing the changes, an OSPF learned default route is confirmed in area 0 at router PBR:

```
lab@PBR> show route 192.168.34.0

inet.0: 20 destinations, 20 routes (20 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/150] 00:03:04, metric 0, tag 0
                    > to 10.20.129.1 via fe-0/0/0.3141
```

Great! As planned, the longest match for the 192.168.34/24 route to Brewer Inc. at PBR is now the OSPF learned default route. A traceroute verifies connectivity to Botnet customers from within Beer-Co. The traceroute has an auspicious beginning, but it soon degrades to timeouts:

```
lab@PBR> traceroute 192.168.34.1 no-resolve
traceroute to 192.168.34.1 (192.168.34.1), 30 hops max, 40 byte
packets
 1  10.20.129.1  14.345 ms  9.916 ms  8.099 ms
 2  10.20.131.1  11.864 ms  30.002 ms  20.016 ms
 3  10.10.8.2  9.901 ms  29.991 ms  9.984 ms
 4  * * *
5  *^C
lab@PBR>
```

The traceroute result shows the expected routing path through Beer-Co's intranet—from PBR to Stout, and then to Porter—and it makes it as far as the 10.10.8.2 address assigned to Yeast's fe-0/0/1.2332 interface. This makes it seem like there's a problem on the Porter–Yeast link, except that previous observations showed that the OSPF adjacency was stable. To narrow down the issue, a ping is generated from Yeast, but this time it is sourced from the router's loopback interface. This is an important point because it will reveal any potential routing issues that may impact Botnet's ability to route back into Beer-Co's 10/8 address block.

```
lab@Yeast> ping 84.10.113.1 count 1
PING 84.10.113.1 (84.10.113.1): 56 data bytes
64 bytes from 84.10.113.1: icmp_seq=0 ttl=64 time=16.750 ms

--- 84.10.113.1 ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max/stddev = 16.750/16.750/16.750/0.000 ms

lab@Yeast> ping 84.10.113.1 count 1 source 10.30.1.1
PING 84.10.113.1 (84.10.113.1): 56 data bytes

--- 84.10.113.1 ping statistics ---
1 packets transmitted, 0 packets received, 100% packet loss
```

Eureka! The default ping, as sourced from the shared direct connection, succeeds, whereas the loopback sourced ping fails. This demonstrates a routing problem within Botnet. It is not uncommon to encounter difficulties such as this. After a few phone calls, you are assured that everything is (now) in order with the newly installed static route back to your network; it seems that confusion stemmed from Botnet's misunderstanding that BGP would be used to advertise an aggregate for your network, and it shall—once it's up and running, that is. The traceroute is repeated, and its successful completion indicates that you are ready to move on to BGP configuration.

```
lab@PBR> traceroute 192.168.34.1 no-resolve
traceroute to 192.168.34.1 (192.168.34.1), 30 hops max, 40 byte
packets
 1  10.20.129.1  14.807 ms  9.827 ms  9.949 ms
 2  10.20.131.1  19.967 ms  40.010 ms  13.579 ms
 3  10.10.8.2  16.439 ms  10.131 ms  9.777 ms
 4  84.10.113.1  39.727 ms !N  40.154 ms !N  17.789 ms !N
```

Recall that in this lab, you expect an ICMP unreachable error message for the final hop because a static route pointing to a reject next hop is used within Botnet to simulate the Brewer Inc. network.

Configure Initial BGP Peering

With the backup link and its associated static routing/generated route confirmed, you'll move on to the task of configuring BGP. In addition to the BGP session, you also need to create an aggregate route representing Beer-Co's internal reachability, along with the export policy needed to advertise it into EBGP. The aggregate route is critical because it enables remote ASs to route toward Beer-Co. An import policy that rejects all but a Botnet-originated default route is also needed. In most cases, you will want to write and apply policy before the BGP session is actually activated to guard against unwanted side effects that stem from receiving or advertising undesired routes, or worse yet, before hitting a platform scaling limit that leads to an unpredictable operation.

> We must emphasize that enterprise routing platforms are not always capable of handling a full BGP table, especially when the same platform is also taxed with value-added services such as stateful firewalls, Network Address Translation (NAT), virtual private network (VPN) tunnels, and so on. Exceeding platform scaling limits can result in control plane instability and possible forwarding plane impact. Care should be exercised to factor the effects of route table size, the number of routing peers, the impact of enabled services, and internal resource consumption for managing interfaces (IFDs/IFLs) and Address Resolution Protocol (ARP) tables before adding a new protocol or service to any production router. When in doubt, simulation testing should be performed. When simulation is not possible, you should closely monitor device operation and resource usage as new peers and services are activated to prevent operational problems caused by resource exhaustion.

As of this writing, Juniper Networks recommends that J-series routers expected to handle a full BGP route table, in conjunction with services being enabled, have 1 GB of memory. The J2300 platform serving the role of `Yeast` in this network is equipped with only 256 MB of DRAM. However, the limited set of BGP routes known to exist in this lab, combined with the absence of enabled services and lack of need for scaling in other dimensions such as support of large numbers of interfaces or ARP entries, affords the liberty of adding the import policy *after* the EBGP session is established. This method is adopted here to help demonstrate the effects of import policy using a before-and-after approach.

We've already stated this, but we will say it one more time. It is highly recommended that you write and apply *both* your export and import policies *before* you attempt to establish any EBGP peerings. Failing to do this could result in router meltdown due to excessive BGP table size or the potential for unwanted routing exchange/forwarding behavior. The JUNOS software candidate configuration and commit functionality makes it easy to build and apply a policy before any of the changes take effect at commit time.

The BGP configuration begins at Yeast with configuration of the local router's ASN. The ASN is configured under the [edit routing-options] hierarchy, rather than within the BGP stanza, where you may expect to find it when you are familiar with the IOS way of configuring BGP:

```
[edit]
lab@Yeast# edit routing-options

[edit routing-options]
lab@Yeast# set autonomous-system 1282
```

You next define a BGP group to house the 84.10.109.7 neighbor associated with the Botnet peering. At a minimum, you must create the group, declare the group type as internal or external, specify the peer, and in the case of an external group, specify the ASN associated with the peer. The resulting BGP stanza is displayed along with the set commands that created it:

```
[edit protocols bgp]
lab@Yeast# show
group as_34 {
    type external;
    peer-as 34;
    neighbor 84.10.109.7;
}

[edit protocols bgp]
lab@Yeast# show | display set
set protocols bgp group as_34 type external
set protocols bgp group as_34 peer-as 34
set protocols bgp group as_34 neighbor 84.10.109.7
```

To better evaluate the impact of adding EBGP to Yeast, the current memory and CPU usage is examined before the changes are committed:

```
[edit protocols bgp]
lab@Yeast# run show task memory summary
Memory InUse: 3101 kB [2%] Max: 3383 kB [2%]

[edit protocols bgp]
lab@Yeast# run show chassis routing-engine
Routing Engine status:
  Temperature           56 degrees C / 132 degrees F
  CPU temperature       56 degrees C / 132 degrees F
  DRAM                 256 MB
  Memory utilization    88 percent
  CPU utilization:
    User                 0 percent
    Real-time threads   10 percent
    Kernel               4 percent
    Idle                86 percent
  Model                    RE-J.1
  Serial ID                AA06500394
  Start time               2007-08-07 07:04:45 UTC
  Uptime                    21 days, 17 hours, 52 minutes, 44 seconds
  Load averages:            1 minute   5 minute  15 minute
                                0.27       0.15       0.09
```

The output from the show task memory command displays memory usage from the perspective of rpd, the routing daemon. In this case, it's rather low, indicating that rpd is having an easy time. The show chassis routing-engine command output shows that the Routing Engine's (RE's) CPE is largely idle. J-series platforms preallocate a chunk of physical memory to the real-time forwarding thread, which accounts for the seemingly high memory usage of 88% on an otherwise idle box.

With the pre-BGP resource snapshot in place, the new BGP configuration is committed at Yeast. After a few moments, BGP session status is determined with a show bgp summary command:

```
[edit protocols bgp]
lab@Yeast# commit and-quit
commit complete
Exiting configuration mode

lab@Yeast> show bgp summary
Groups: 1 Peers: 1 Down peers: 1
Table  Tot Paths  Act Paths Suppressed  History Damp State   Pending
inet.0          0          0          0         0          0         0
Peer       AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
84.10.109.7         34          0        0        0      0   11 Active
```

The command output shows that Yeast is actively trying to establish its BGP session to peer 84.10.109.7. This is a good sign, but it's not as good as an established session. A status of *idle*, for example, indicates that the router cannot even begin to initiate a session, likely because of no route to the peering address. BGP will retry its connection every 30 seconds or so, making patience a virtue here. About a minute later, the status is again displayed:

```
lab@Yeast> show bgp summary
Groups: 1 Peers: 1 Down peers: 0
Table  Tot Paths  Act Paths Suppressed  History Damp State   Pending
inet.0       434        434           0         0          0         0
Peer       AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
84.10.109.7         34        285        7        0       0   2:25
801/801/0         0/0/0
```

The output confirms BGP session establishment—the highlighted display indicates that a total of 801 routes have been learned from the 84.10.109.7 peering, and that all of the received routes have been selected as active. It also notes the total number of routes learned from this peer and the number of routes currently damped, respectively. In this example, Botnet has advertised a total of 831 routes, all of which are currently active at Yeast.

As of this writing, a full BGP feed is approximately 230,000 routes. Obviously, the BGP table used in this lab is a bit smaller. The goal here is to have enough routes to simulate a real BGP experience, without the hassle of obtaining a live feed.

You can view details for the peering session with a show bgp neighbor command. The display includes any negotiated options, session hold time, supported NLRI queued messages, and so on:

```
lab@Yeast> show bgp neighbor
Peer: 84.10.109.7+179 AS 34    Local: 84.10.109.8+2333 AS 1282
  Type: External    State: Established    Flags: <ImportEval Sync>
  Last State: OpenConfirm   Last Event: RecvKeepAlive
  Last Error: None
  Options: <Preference PeerAS Refresh>
  Holdtime: 90 Preference: 170
  Number of flaps: 0
  Peer ID: 84.10.109.1    Local ID: 10.30.1.1    Active Holdtime: 90
  Keepalive Interval: 30         Peer index: 0
  Local Interface: fe-0/0/0.3233
  NLRI advertised by peer: inet-unicast
  NLRI for this session: inet-unicast
  Peer supports Refresh capability (2)
  Table inet.0 Bit: 10000
    RIB State: BGP restart is complete
    Send state: in sync
    Active prefixes:              801
    Received prefixes:            801
    Suppressed due to damping:    0
    Advertised prefixes:          0
  Last traffic (seconds): Received 8    Sent 8    Checked 8
  Input messages:  Total 296   Updates 280  Refreshes 0   Octets 15175
  Output messages: Total 18    Updates 0    Refreshes 0   Octets 368
  Output Queue[0]: 0
```

Here the output shows that the EBGP session to Botnet is in the established state, that it supports IPv4 unicast NLRI, that the session has negotiated the BGP refresh option, and that the hold time is 90 seconds, which leads to a 30-second keepalive timer. The refresh option allows a BGP speaker to request that its peer resend previously advertised routing information. This is useful when a change in import policy may result in acceptance of a route that was previously denied. Without refresh, the BGP session would have to be bounced to force the peer to resend routes. Recall that BGP uses TCP transport, so there is, in theory, no reason for a BGP speaker to ever readvertise routing information that it has already sent.

The receipt of valid BGP routing is confirmed by displaying BGP routes in the route table:

```
lab@Yeast> show route protocol bgp detail

inet.0: 818 destinations, 819 routes (818 active, 0 holddown, 0 hidden)
0.0.0.0/0 (2 entries, 1 announced)
        *BGP    Preference: 170/-101
                Next-hop reference count: 1602
                Source: 84.10.109.7
                Next hop: 84.10.109.7 via fe-0/0/0.3233, selected
                State: <Active Ext>
                Local AS:  1282 Peer AS:    34
                Age: 2:26:23
                Task: BGP_34.84.10.109.7+179
                Announcement bits (2): 0-KRT 3-OSPFv2
                AS path: 34 I
                Localpref: 100
                Router ID: 84.10.109.1

6.1.0.0/16 (1 entry, 1 announced)
        *BGP    Preference: 170/-101
                Next-hop reference count: 1602
                Source: 84.10.109.7
                Next hop: 84.10.109.7 via fe-0/0/0.3233, selected
                State: <Active Ext>
                Local AS:  1282 Peer AS:    34
                Age: 9:04
                Task: BGP_34.84.10.109.7+179
                Announcement bits (1): 0-KRT
                AS path: 34 666 420 11537 668 1455 I
                Localpref: 100
                Router ID: 84.10.109.1
. . .
```

The display confirms many active BGP routes at Yeast. The highlights call out key route attributes such as the AS path, the origin of the route, the forwarding next hop, and local/remote ASNs. This example shows that a default route is advertised, and the AS path, by virtue of the single entry for 34, confirms that this route originates within AS 34. In contrast, the route to 6.1/16 indicates an origin in AS 1455, and subsequent transversal of ASs 668, 11537, 420, 666, and 34 (Botnet), before arriving at Beer-Co. Note that these routes have an *assumed* local preference of 100 as per BGP standards. A local preference value attribute is not attached to any of these routes because this attribute is not supported on EBGP links.

The announcement bits for the 0/0 BGP route indicate that it is being redistributed into OSPF. Because only active routes are subject to export policy, this implies that the BGP version of the default route must be preferred over the generated one. This is easily confirmed:

```
lab@Yeast> show route 0.0.0.0/0

inet.0: 818 destinations, 801 routes (818 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both
```

```
0.0.0.0/0          *[BGP/170] 00:26:28, localpref 100
                      AS path: 34 I
                    > to 84.10.109.7 via fe-0/0/0.3233
                    [Aggregate/175] 16:56:59
                    > via t1-0/0/2.0
```

The display shows that the BGP default is active with a preference of 170, and the highlights show that traffic matching this default route will be forwarded over the high-speed BGP peering link. Should the BGP session malfunction, Yeast will lose the BGP version of the default and fall back to the generated copy, which in turn forwards traffic over the secondary T1 link.

To confirm what routes are being received, or sent, to a specific BGP peer, use the show route-advertising protocol or show route receive-protocol command:

```
lab@Yeast> show route receive-protocol bgp 84.10.109.7

inet.0: 818 destinations, 801 routes (818 active, 0 holddown, 0 hidden)
  Prefix          Nexthop       MED   Lclpref  AS path
* 0.0.0.0/0       84.10.109.7                  34 I
* 129.1.0.0/16    84.10.109.7                  34 11537 3112 3112 I
* 129.2.0.0/16    84.10.109.7                  34 11537 10886 27 I
* 129.7.0.0/16    84.10.109.7                  34 11537 4557 7276 I
* 129.7.0.0/17    84.10.109.7                  34 11537 4557 7276 I
* 129.7.128.0/19  84.10.109.7                  34 11537 4557 7276 I
* 129.7.160.0/19  84.10.109.7                  34 11537 4557 7276 I
* 129.7.192.0/19  84.10.109.7                  34 11537 4557 7276 I
* 129.7.224.0/19  84.10.109.7                  34 11537 4557 7276 I
* 129.8.0.0/16    84.10.109.7                  34 11537 2153 2152
11422 2150 I
---(more)---[abort]

lab@Yeast> show route advertising-protocol bgp 84.10.109.7

lab@Yeast>
```

The show route receive-protocol bgp 84.10.109.7 command confirms the receipt of prefixes from neighbor 84.10.109.7. You can add the detail or extensive switch to see additional information. In contrast, the show route advertising-protocol bgp 84.10.109.7 command confirms that no routing information is being sent back to Botnet. This is expected, given that recent JUNOS software releases no longer echo received BGP routes back to their source, and because the default BGP export policy is to advertise active BGP routes. Here, all the active BGP routes were learned from neighbor 84.10.109.7; hence, there is nothing for Yeast to advertise back.

Readers familiar with the IOS display format for BGP routes may appreciate the terse switch:

```
lab@Yeast> show route protocol bgp terse

inet.0: 818 destinations, 801 routes (818 active, 0 holddown, 0 hidden)
```

```
+ = Active Route, - = Last Active, * = Both

A Destination     P Prf Metric 1  Metric 2  Next hop      AS path
* 0.0.0.0/0       B 170      100           >84.10.109.7   34 I
* 129.1.0.0/16    B 170      100           >84.10.109.7   34 11537 3112 3112 I
* 129.2.0.0/16    B 170      100           >84.10.109.7   34 11537 10886 27 I
* 129.7.0.0/16    B 170      100           >84.10.109.7   34 11537 4557 7276 I
* 129.7.0.0/17    B 170      100           >84.10.109.7   34 11537 4557 7276 I
* 129.7.128.0/19  B 170      100           >84.10.109.7   34 11537 4557 7276 I
* 129.7.160.0/19  B 170      100           >84.10.109.7   34 11537 4557 7276 I
* 129.7.192.0/19  B 170      100           >84.10.109.7   34 11537 4557 7276 I
* 129.7.224.0/19  B 170      100           >84.10.109.7   34 11537 4557 7276 I
* 129.8.0.0/16    B 170      100           >84.10.109.7   34 11537 2153 2152 11422
2150 I
* 129.10.0.0/16   B 170      100           >84.10.109.7   34 11537 10578 156 I
* 129.11.0.0/16   B 170      100           >84.10.109.7   34 11537 20965 786 I
. . .
```

In the preceding display, the local preference is shown under the Metric 1 column. Before moving on, you gauge the effects of running BGP by again analyzing resource utilization at Yeast:

```
lab@Yeast> show task memory summary
Memory InUse: 3289 kB [2%] Max: 3383 kB [2%]

lab@Yeast> show chassis routing-engine
Routing Engine status:
    Temperature            56 degrees C / 132 degrees F
    CPU temperature        55 degrees C / 131 degrees F
    DRAM                  256 MB
    Memory utilization     89 percent
    CPU utilization:
      User                  0 percent
      Real-time threads    10 percent
      Kernel                1 percent
      Idle                 89 percent
    Model                     RE-J.1
    Serial ID                 AA06500394
    Start time                2007-08-07 07:04:45 UTC
    Uptime                    21 days, 18 hours, 44 minutes, 58 seconds
    Load averages:            1 minute   5 minute  15 minute
                                  0.01       0.04       0.04
```

The output confirms very little change to resource consumption. However, we must stress that you are dealing with a very small number of peers (1) and a very limited set of routes (800 or so), and that these routes are stable, resulting in very little ongoing BGP process churn.

Configure Initial BGP Policy

The initial BGP peering session is confirmed operational. To complete this task, you now create and apply both BGP import and export policy. The former is to reject all received BGP routes except a default route that originates in AS 34. The latter needs to advertise a single 10/8 aggregate to represent the internal connectivity of Beer-Co. An import policy is created and displayed at `Yeast`:

```
[edit]
lab@Yeast# show policy-options policy-statement as_34_import
term 1 {
    from {
        protocol bgp;
        as-path 34_originate;
        route-filter 0.0.0.0/0 exact;
    }
    then accept;
}
term 2 {
    from protocol bgp;
    then reject;
}

[edit]
lab@Yeast# show policy-options as-path 34_originate
"^34$";

[edit]
lab@Yeast# show protocols bgp group as_34 import
import as_34_import;
```

The `as_34_import` policy matches on a specific route (0/0) and route source (BGP), and forces the associated AS path to match the AS regular expressions defined in `34_originate`. The AS path regular expression functions to guarantee that only a default route that originates in AS 34 will be accepted—all routes originating within AS 34 will have an AS path list that starts and ends with 34; the associated regex uses the ^ and $, respectively, to force AS 34 to be the first and last AS number in the list. The `as_34_import` policy is applied to the `as_34` BGP group at import, and the results are confirmed.

```
[edit]
lab@Yeast: run show route protocol bgp
inet.0: 818 destinations, 819 routes (18 active, 0 holddown, 800 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[BGP/170] 02:34:36, localpref 100
                      AS path: 34 I
                    > to 84.10.109.7 via fe-0/0/0.3233
```

The output confirms that only the default route is accepted and installed into the route table, resulting in some 800 routes being hidden.

Generally speaking, the output of the show route receive-protocol command displays routing information as received, before import policy is applied. The exception to this rule is route filtering, which occurs *before* the show route receive-protocol command output is compiled. This means that if your import policy is set to remove a given community, you can expect to see the community (that is to be removed) in the show route receive-protocol output, but not when the route is installed into the route table, because your import policy will have taken effect and will have removed the specified community. In contrast, if your import policy uses route-filter syntax to reject routes, these routes will not be observed in either the route table or the output of a show route receive-protocol command. This condition is demonstrated here, where only the 0/0 default that is accepted by import policy route filtering is displayed:

```
lab@Yeast> show route receive-protocol bgp 84.10.109.7


inet.0: 818 destinations, 819 routes (18 active, 0 holddown,
800 hidden)
  Prefix                  Nexthop              MED
Lclpref    AS path
* 0.0.0.0/0               84.10.109.7                  34 I
```

Add the hidden keyword to display received routes that are hidden, perhaps due to route filtering actions.

Your export policy requires that you define a 10/8 aggregate, and then advertise this aggregate into BGP. At this time, it's assumed that Botnet is routing back into your AS using its static route that points to the slow-speed T1 interface, making this a critical step for proper operation. In theory, it has configured its network to prefer a BGP learned version of the 10/8 route, which results in use of the high-speed link for inbound traffic once you advertise the route through BGP. Here are the aggregate route definition and BGP export policy:

```
[edit]
lab@Yeast# show routing-options aggregate
route 10.0.0.0/8;

[edit]
lab@Yeast# show policy-options policy-statement as_34_export
term 1 {
    from {
        protocol aggregate;
        route-filter 10.0.0.0/8 exact;
    }
    then accept;
}

[edit]
```

```
lab@Yeast# show protocols bgp group as_34 export
export as_34_export;
```

After committing the change, the aggregate route is confirmed active and advertised to Botnet via EBGP:

```
lab@Yeast> show route protocol aggregate

inet.0: 801 destinations, 451 routes (18 active, 0 holddown, 432 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          [Aggregate/175] 17:57:54
                   > via t1-0/0/2.0
10.0.0.0/8        *[Aggregate/130] 00:00:13
                     Reject

lab@Yeast> show route advertising-protocol bgp 84.10.109.7

inet.0: 801 destinations, 451 routes (18 active, 0 holddown, 432 hidden)
  Prefix                 Nexthop          MED     Lclpref    AS path
* 10.0.0.0/8             Self                                I
```

The 10/8 aggregate route is active, which is good given that only active routes can be redistributed through policy. Note that unlike the generated route, the aggregate route has a nonforwarding next hop, which happens to be the default reject-style next hop in this case. Traffic routed into Beer-Co should normally match a more specific route (OSPF or direct) and be forwarded toward that destination. If not, the traffic is shunted to reject, and an ICMP error message is generated reporting an unreachable destination. The show route advertising-protocol command confirms that a single route, the 10/8 aggregate, is advertised to Botnet.

For final verification, the previous traceroute is repeated at PBR:

```
lab@PBR> traceroute 192.168.34.1 no-resolve
traceroute to 192.168.34.1 (192.168.34.1), 30 hops max, 40 byte packets
 1  10.20.129.1  53.267 ms  13.506 ms  10.634 ms
 2  10.20.131.1  9.955 ms  9.985 ms  9.996 ms
 3  10.10.8.2  9.977 ms  10.042 ms  10.034 ms
 4  84.10.109.7  15.349 ms !N  24.503 ms !N  19.968 ms !N
```

The traceroute again succeeds, but this time the final hop is 84.10.109.7; this confirms that the high-speed primary interface is now used to forward traffic into AS 34. This completes the initial BGP peering scenario.

Use BGP for Asymmetric Load Balancing

While congratulating you on the fine work, the CIO of Beer-Co respectfully suggests that you find a way to use the secondary link also. After all, 1.544 Mbps is nothing to sneeze at, and paying for a backup circuit that will never see any use except during a primary outage can be painful.

The most direct solution to this problem is to bring up a second EBGP session to Botnet and simply enable BGP multipath. The multipath option removes the tiebreakers from the active route decision process, thereby allowing otherwise equal-cost BGP routes learned from multiple sources to be installed into the forwarding table. Once multiple next hops are installed in the forwarding table, a specific forwarding next hop is selected by the default JUNOS software per-prefix load-balancing algorithm. This process hashes against a packet's source and destination addresses to deterministically map the prefix paring onto one of the available next hops. Per-prefix mapping works best when the hash function is presented with a large number of prefixes, such as might occur on an Internet peering exchange, and it serves to prevent packet reordering among pairs of communicating nodes.

An enterprise network will normally want to alter the default behavior to evoke a "per-packet" load-balancing algorithm. *Per-packet* is quoted here because its use is a misnomer that stems from the historic behavior of the original Internet Processor ASIC. In reality, current Juniper Networks routers support per-prefix (default) and *per-flow* load balancing. The latter involves hashing against various L3 and L4 headers, including portions of the source address, destination address, transport protocol, incoming interface, and application ports. The effect is that now individual *flows* are hashed to a specific next hop, resulting in a more even distribution across available next hops, especially when routing between fewer source and destination pairs. With per-packet load balancing, packets comprising a communication stream between two endpoints may be resequenced, but packets within individual flows maintain correct sequencing.

Whether you opt for per-prefix or per-packet load balancing, the extreme asymmetry of the Botnet access links presents a technical challenge. Either way, the prefixes/flows that are mapped to the T1 link will exhibit degraded performance when compared to those flows that map to the FE access link, and worse yet, with heavy traffic loads, any attempt at 50/50 load balancing is likely to result in total saturation of the T1 link and session disruption stemming from packet loss.

Fortunately, the Juniper BGP implementation supports the notion of a bandwidth community. This extended community encodes the bandwidth of a given next hop, and when combined with multipath, the load-balancing algorithm will distribute flows across the set of next hops proportional to their relative bandwidths. Put another way, if you have a 10 Mbps and a 1 Mbps next hop, on average nine flows will map to the high-speed next hop for every one that uses the low speed.

> As of this writing, use of BGP bandwidth community is supported only with per-packet load balancing.

The current configuration task is divided onto two parts:

- Configure a second EBGP peering session, enable multipath, and define an import policy to tag routes with a bandwidth community that reflects link speed.
- Enable per-packet (really per-flow) load balancing for optimal distribution of traffic.

You start with the definition of the second EBGP peering session at Yeast. Though not shown here, the generated default route is removed from the configuration because it is no longer needed. Recall that you now expect two default routes, both learned from BGP, with proportionate load balancing when both routes are active:

```
 [edit]
lab@Yeast# show protocols bgp
group as_34 {
    type external;
    import as_34_import;
    export as_34_export;
    peer-as 34;
    neighbor 84.10.109.7;
    neighbor 84.10.113.1;
}
```

The new session shares the same group-level import and export policy, which results in accepting only a default route and the advertisement of only the 10/8 aggregate. After a minute or so, you confirm successful establishment of the second Botnet peering session:

```
[edit]
lab@Yeast# run show bgp summary
Groups: 1 Peers: 2 Down peers: 0
Table  Tot Paths  Act Paths Suppressed    History Damp State  Pending
inet.0      1602          1          0          0          0        0
Peer           AS      InPkt  OutPkt  OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
84.10.109.7    34        824     329     0       0     2:42:55 1/801/0
0/0/0
84.10.113.1    34        462       3     0       0           6 0/801/0
0/0/0
```

The display confirms establishment of the second peering session. Of special interest is the fact that 801 routes have been learned over each session, and only one of these routes is active, for only one of the sessions. Recall that the goal here is to receive an active default route from each peering. For additional details, we display the default route:

```
[edit]
lab@Yeast# run show route protocol bgp detail

inet.0: 818 destinations, 1619 routes (18 active, 0 holddown, 1600
hidden)
0.0.0.0/0 (2 entries, 1 announced)
```

```
        *BGP    Preference: 170/-101
                Next-hop reference count: 802
                Source: 84.10.109.7
                Next hop: 84.10.109.7 via fe-0/0/0.3233, selected
                State: <Active Ext>
                Local AS:  1282 Peer AS:    34
                Age: 2:46:39
                Task: BGP_34.84.10.109.7+179
                Announcement bits (2): 0-KRT 3-OSPFv2
                AS path: 34 I
                Localpref: 100
                Router ID: 84.10.109.1
         BGP    Preference: 170/-101
                Next-hop reference count: 801
                Source: 84.10.113.1
                Next hop: 84.10.113.1 via t1-0/0/2.0, selected
                State: <NotBest Ext>
                Inactive reason: Update source
                Local AS:  1282 Peer AS:    34
                Age: 3:50
                Task: BGP_34.84.10.113.1+179
                AS path: 34 I
                Localpref: 100
                Router ID: 84.10.109.1
```

The display shows that each BGP peer is advertising the 0/0 route, and it confirms that only one version of the route is active. This active route is learned through peer 84.10.109.7, and as such the route shows a single forwarding next hop of fe-0/0/0.3233. There is no hope of any load balancing until both of the next hops for both BGP routes are installed into the forwarding table. The problem here is called out by the update source inactive reason. According to documentation, this indicates that a route was not selected due to characteristics associated with the source, which means either the RID or the BGP peering address. These last two steps in the active route selection process exist to break ties, which is exactly what has happened here. Because both peering sessions terminate on the same router (Hops), the RID is the same, and therefore the route learned from the numerically lowest peering address is selected. To disable the tie-breaking rules and allow use of multiple otherwise equal-cost BGP routes, you must enable multipath:

```
[edit]
lab@Yeast# set protocols bgp group as_34 multipath

[edit]
lab@Yeast# commit
commit complete
```

The change is confirmed by the presence of both the 84.10.109.7 *and* 84.10.113.1 BGP next hops in the show route display:

```
[edit]
lab@Yeast# run show route protocol bgp detail
inet.0: 818 destinations, 1619 routes (18 active, 0 holddown, 1600
hidden) 0.0.0.0/0 (2 entries, 1 announced)
        *BGP    Preference: 170/-101
                Next-hop reference count: 1
                Source: 84.10.109.7
                Next hop: 84.10.109.7 via fe-0/0/0.3233, selected
                Next hop: 84.10.113.1 via t1-0/0/2.0
                State: <Active Ext>
                Local AS:  1282 Peer AS:    34
                Age: 2:54:43
                Task: BGP_34.84.10.109.7+179
                Announcement bits (2): 0-KRT 3-OSPFv2
                AS path: 34 I
                Localpref: 100
                Router ID: 84.10.109.1
         BGP    Preference: 170/-101
                Next-hop reference count: 801
                Source: 84.10.113.1
                Next hop: 84.10.113.1 via t1-0/0/2.0, selected
                State: <NotBest Ext>
                Inactive reason: Update source
                Local AS:  1282 Peer AS:    34
                Age: 11:54
                Task: BGP_34.84.10.113.1+179
                AS path: 34 I
                Localpref: 100
                Router ID: 84.10.109.1
```

The display still shows that only one route is active, but without the tie-breakers in effect, the next hops associated with both routes have been installed for use, thereby enabling load balancing. Your next goal is to adjust the as_34_import policy to tag routes with a bandwidth community, based on the peering from where they are learned. You start by defining the two extended bandwidth communities. The format of this community is bandwidth:asn:bandwidth_value, where the bandwidth is entered in bytes per second. The actual values entered are not as important as having the correct ratio because it is the ratio that actually determines the percentage of flows/prefixes mapped to each next hop:

```
[edit policy-options]
lab@Yeast# show community bw_slow
members bandwidth:1287:193000;

[edit policy-options]
lab@Yeast# show community bw_fast
members bandwidth:1287:12500000;
```

The bw_slow and bw_fast communities are set to reflect the byte-per-second rates of a T1 and Fast Ethernet interface, respectively. The ratio of the two is approximately .01544, meaning that for every 100 prefixes/flows, you expect to see 1.5 of them mapped to the T1. In the Juniper implementation, the flow count is rounded up, giving us an expected spread of 2 flows mapped to the T1 for every 98 mapped to the

Fast Ethernet. The existing as_34_import policy is rewritten, and the modified policy is displayed:

```
[edit]
lab@Yeast# show policy-options policy-statement as_34_import
term slow_peer {
    from {
        protocol bgp;
        neighbor 84.10.113.1;
        as-path 34_originate;
        route-filter 0.0.0.0/0 exact;
    }
    then {
        community add bw_slow;
        accept;
    }
}
term fast_peer {
    from {
        protocol bgp;
        neighbor 84.10.109.7;
        as-path 34_originate;
        route-filter 0.0.0.0/0 exact;
    }
    then {
        community add bw_fast;
        accept;
    }
}
term reject-all {
    then reject;
}
```

The new as_34_import policy makes use of a from neighbor match condition to tag the matching route with the identified bandwidth community. In theory, this can also be done as part of an export policy within Botnet, but this puts reliance on the administration of the remote AS, which may involve delays and the potential for billing and mistakes. Expected operation is verified by once again displaying details about the active BGP route:

```
[edit policy-options]
lab@Yeast# run show route protocol bgp detail

inet.0: 818 destinations, 1619 routes (18 active, 0 holddown, 1600
hidden) 0.0.0.0/0 (2 entries, 1 announced)
      *BGP   Preference: 170/-101
             Next-hop reference count: 1
             Source: 84.10.109.7
             Next hop: 84.10.109.7 via fe-0/0/0.3233 balance 98%
             Next hop: 84.10.113.1 via t1-0/0/2.0 balance 2%, selected
             State: <Active Ext>
             Local AS:  1282 Peer AS:    34
             Age: 3:48:08
```

```
                Task: BGP_34.84.10.109.7+179
                Announcement bits (2): 0-KRT 3-OSPFv2
                AS path: 34 I
                Communities: bandwidth:1287:12500000
                Localpref: 100
                Router ID: 84.10.109.1
          BGP   Preference: 170/-101
                Next-hop reference count: 801
                Source: 84.10.113.1
                Next hop: 84.10.113.1 via t1-0/0/2.0, selected
                State: <NotBest Ext>
                Inactive reason: Update source
                Local AS:  1282 Peer AS:    34
                Age: 1:05:19
                Task: BGP_34.84.10.113.1+179
                AS path: 34 I
                Communities: bandwidth:1287:193000
                Localpref: 100
                Router ID: 84.10.109.1
```

The highlights in the `show route` output confirm that balancing now occurs in proportion to link speed, as required. To complete this task, a per-packet load-balancing policy must be placed into effect at `Yeast`. A policy named `lb_per_packet` is created, and it is applied to the main routing instance's forwarding table:

```
[edit]
lab@Yeast# show policy-options policy-statement lb_per_packet
then {
    load-balance per-packet;
    accept;
}

[edit]
lab@Yeast# show routing-options forwarding-table
export lb_per_packet;
```

The `lb_per_packet` policy matches on all possible routes and effectively converts the system from per-prefix to per-flow load balancing. The effect of your work is confirmed back on router `PBR`, where traceroutes are performed. The test traffic is sourced from various IP addresses owned by `PBR` in an attempt to trigger the per-flow hashing function to use both next hops. Note that by enabling per-flow load balancing, fewer bits are made available for hashing against the source address/destination address pair. The result is that without a wide degree of source address/destination address variance, there is a good chance that all test traffic will hash to the same next hop. To accurately test Juniper per-prefix or per-flow load balancing, a large number of flows should be generated, preferably from a traffic source. Put another way, as the number of flows/prefixes increases, so too does the likelihood of observing ideal balancing among the set of available next hops. Bearing this in mind, the `bw_slow` community is temporarily set to equal `bw_fast` so that we can expect a 50/50 load-balancing split.

This will increase the chances of observing load balancing at play with the limited number of flows available in the lab setup.

```
lab@PBR> traceroute 192.168.34.1 no-resolve source 10.20.129.2
traceroute to 192.168.34.1 (192.168.34.1) from 10.20.129.2, 30 hops
max, 40 byte packets
 1  10.20.129.1  14.553 ms  9.782 ms  8.084 ms
 2  10.20.131.1  21.914 ms  9.935 ms  9.988 ms
 3  10.10.8.2  10.081 ms  19.865 ms  10.002 ms
 4  84.10.113.1  15.697 ms !N  14.286 ms !N  18.954 ms !N
```

The final hop of the traceroute to Brewer Inc.'s 192.168.34.1 route is the 84.10.113.1 address associated with the low-speed Botnet peering link. In this example, test traffic is explicitly sourced from the 10.20.129.2 address on the PBR–Stout link, which happens to be the same IP address that the packet would normally take. Next, a different flow is created by generating an ICMP echo packet from the same source address, but to a different host address (.100), on the 192.168.34.0/24 subnet. The goal here is to try and trigger a different flow hashing result by altering some of the bits used in the flow hashing algorithm. Here, we change both the protocol (ICMP versus UDP), and some of the bits in the addresses's host ID.

```
lab@PBR> ping 192.168.34.100 rapid count 1 source 10.20.129.2
PING 192.168.34.100 (192.168.34.100): 56 data bytes
36 bytes from 84.10.109.7: Destination Net Unreachable
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 0054 5e00   0 0000  3d  01 b186 10.20.129.2  192.168.34.100
.
--- 192.168.34.100 ping statistics ---
1 packets transmitted, 0 packets received, 100% packet loss
```

The destination unreachable error message generated by 84.10.109.7 proves that the ICMP test packet was forwarded over the high-speed Botnet peering link. Satisfied that per-flow load balancing is working, you restore the bw_slow community to its previous value and take a well-deserved break.

```
[edit]
lab@Yeast# rollback 1
load complete

[edit]
lab@Yeast# show | compare
[edit policy-options community bw_slow]
-   members bandwidth:1287:12500000;
+   members bandwidth:1287:193000;

[edit]
lab@Yeast# commit
commit complete
```

Initial BGP Peering Summary

This section showed you an example of how to configure and verify basic EBGP peering using JUNOS software. We also showed the use of routing policy to filter received routes and to control the routes that you advertise, along with the redistribution of a BGP-learned default route into your IGP to provide external reachability for non-BGP speakers within your AS. You also saw how to use a static route with an altered global preference (a concept known as a *floating static route* in IOS speak) to back up a BGP peering, and how the BGP bandwidth community is used to provide asymmetric load balancing based on link speed.

The next section explores typical enterprise applications of BGP routing policy, which in turn prepares you for the increasingly complicated BGP deployment scenarios that follow later in this chapter. Now is a good time to take a break, perhaps to think back over the points covered in this section or just to clear your mind for the outbound and inbound policy discussions in the next section.

Enterprise Routing Policy

You have now been exposed to various applications of JUNOS software routing policy, here and in earlier chapters. We discussed the operational theory of routing policy in detail in Chapter 3. In summary, import routing policy is responsible for placing routes into the route table, possibly with modified attributes, and export policy is responsible for placing copies of routes into outgoing routing protocol updates, again possibly with modified attributes. The complexity of an organization's policy is typically tied directly to the degree of its interconnectivity requirements. An enterprise that is single-homed needs very little policy; in most cases, such an attachment does not even warrant use of BGP!

This section focuses on applying JUNOS software routing policy to meet the needs of an enterprise that is dual-homed to different providers.

Inbound and Outbound Routing Policies

In a majority of cases, a dual-homed enterprise network will have distinctly different inbound and outbound policies. Your inbound policy is intended to control how traffic enters your AS from other networks, whereas your outbound policy dictates how traffic leaves your AS to enter other networks. You use specific instances of export and import policy to facilitate your organization's inbound and outbound policy goals.

Achieving your inbound policy goals can be difficult, or even impossible, given that you do not have direct control over the outbound policies of the networks that you peer with. In the end, each network operator has complete control of its local outbound policy, so at best your inbound policy can influence its policy decisions only within the limits that are permitted by that network's outbound policy. In some cases, achieving your inbound policy goals may require selecting ISPs that are willing to work with your needs—this is a political, not a technical, issue. In contrast, you have complete control over your outbound policy. Simply put, it's your network, and you can configure it to do whatever you want in this regard.

As with most network design considerations, each network must carefully weigh its policy desires against the potential costs, measured in increased administrative/support burdens, potential economic impacts, performance considerations, equipment capabilities, and so on. The network then must decide on a set of policies that best balance all of the factors involved.

Common Policy Design Criteria

Although the specifics always vary, many common elements drive most policy decisions:

Topology-driven

A topology-driven policy is based on the physical connectivity of your network and is typically concerned with locating the lowest-cost (lowest-metric) path for traffic. In many cases, a topology-driven policy will use IGP metrics to locate the best egress point, and in turn will send the IGP metric as the MED in EBGP updates. Recall that MED is like a true metric, in that lower values are preferred. If your peer honors MEDs in their decision process, this should result in traffic entering your AS at the point that is metrically closest to the actual destination. You can set the MED in BGP policy using the `metric` keyword. Support for automatically tracking the IGP metric is also provided.

The topology-driven model is the easiest to implement because in most cases, you leave all attributes unmodified and simply rely on the route selection algorithm to select the best route, which will normally be the shortest path (the fewest number of ASs, best origin, lowest MED, and lowest IGP metric).

Primary/secondary

A primary/secondary policy is based on the preferential use of a primary access link. Motivations for a primary/secondary model tend to be performance-driven, but can also factor economic, reliability, or security concerns. The last factor, security, is often overlooked. Knowing that all your traffic leaves and enters on the same set of links greatly simplifies deployment of stateful firewalls and NAT devices. This is because state instantiated by the transmission of traffic is readily available to match against the return traffic. Sending traffic out of one device, and having the response handled at a different access point by a different device, makes stateful services quite complex.

In a *strict* primary/secondary model, no traffic should use the secondary links unless the primary link becomes unavailable. In contrast, in a *loose* model, some traffic, perhaps based on topology considerations, is allowed to use the secondary, even when the primary is operating. Your design should also factor the desire to revert back to a primary after service is restored. A revertive design switches back to the primary, but this behavior can cause issues when chronic problems plague the primary link. This is because ongoing disruption occurs each time traffic is redirected to and from the bouncing primary circuit. Here, a nonrevertive policy that promotes stability over other factors such as cost, or raw bandwidth, would be preferred.

Using equal capacity links in conjunction with a strict primary/secondary model provides the highest degree of redundancy because either link can handle the offered load with equal performance. With the loose variation, usable bandwidth can be the sum of both link capacities; therefore, the failure of either link reduces overall capacity and may impact performance. This is also true of a strict model that uses asymmetric link speeds to save on bandwidth costs.

Load-sharing

A load-sharing policy attempts to maximize use of all available resources by spreading traffic over the set of available access points. This is typically performed on a per-prefix basis, where some set of routes is mapped to one link while another set is mapped to a different link. In a failure scenario, traffic from affected links is switched to the next most preferred operational link.

A word on outbound/inbound versus export/import policy

Before moving on, it's worth noting that there is somewhat of a reverse relationship between your inbound/outbound policy and the type of JUNOS software routing policy that is applied to your EBGP session. For example, you will normally use *export* policy when you wish to instantiate an *inbound* policy to control how other networks route traffic into your AS. Likewise, you normally use *import* policy to adjust attributes in received routes that in turn affect your *outbound* policy—for example, setting local preference on routes as they are received from an EBGP peer.

If that were not confusing enough, you will likely find that in many cases, you can achieve the same effect using either an import or an export policy. For example, local preference can be set at reception from an EBGP peer using an import policy or when sending the route to other IBGP speakers using an export policy. In fact, you may use an import to set an attribute to some local value, and then use an export to send a modified value to other peers. Wherever possible, you should take a consistent approach to help minimize support burdens and overall network complexity.

Know your ISP's policy

Because your BGP speakers are expected to interact with those under the control of your ISP, it pays to be familiar with your ISP's general policies. For example, many

ISPs set route attributes within their network, based on the receipt of certain communities attached by their customers. As another example, consider that there is no point in advertising a prefix with a /32 network mask if your ISP's policy is not to accept any routes with a prefix length longer than /28.

Most providers use local preference to prefer routes from their customers over those learned from their peers, filter route updates based on prefix lengths, and filter updates received from their customers to ensure that they are not acting as transit peers. Providers often post their policies on public web sites where the information can be used to comparison-shop when seeking service.

Enterprise Policy Summary

This section broke down the seemingly daunting task of BGP and policy into the categories of inbound and outbound policies, which helps to make things more manageable. In most cases, an enterprise will need to be dual-homed to take full advantage of the power of BGP and JUNOS software routing policy. Remembering that you use *export* policy to affect your *inbound* routing goals, and use *import* policy for your *outbound* goals, helps to eliminate a lot of potential confusion.

By default, BGP settles on a topology-based model, but in many cases you will want to alter this behavior based on your organization's needs and desires. You have direct control over your own network's output routing, making that part of the equation straightforward. Effectively establishing a desired inbound policy means you have managed to influence the outbound action of routers in a remote network, which are not under your direct control. That is the mark of a true BGP policy guru.

In the next section, you will begin to apply complex enterprise routing policies, right after you multihome the network by adding a new EBGP peering and deploy a route-reflected IBGP topology within Beer-Co.

Multihome Beer-Co

Beer-Co's initial BGP peering with Botnet in AS 34 is operating successfully, and it's time to bring up a second EBGP session to Borgnet in AS 420. When multihomed to dual providers, the true benefit of BGP and its policy controls can be fully realized. Figure 5-9 provides the new BGP peering topology and illustrates how Borgnet connects to service provider Darknet in AS 666, which is also peered with Botnet. It seems that things could get quite interesting here.

The figure shows key details of each AS. These include the EBGP peering router's name, its loopback address, and the set of routes that originate within that AS and the customer routes associated with that network. The figure calls out three particular customer prefixes within Borgnet, Darknet, and Botnet, which are assigned to customers Cap-co Inc., Bottles Inc., and Brewer Inc., respectively. The 192.168.*xx*/24 prefixes

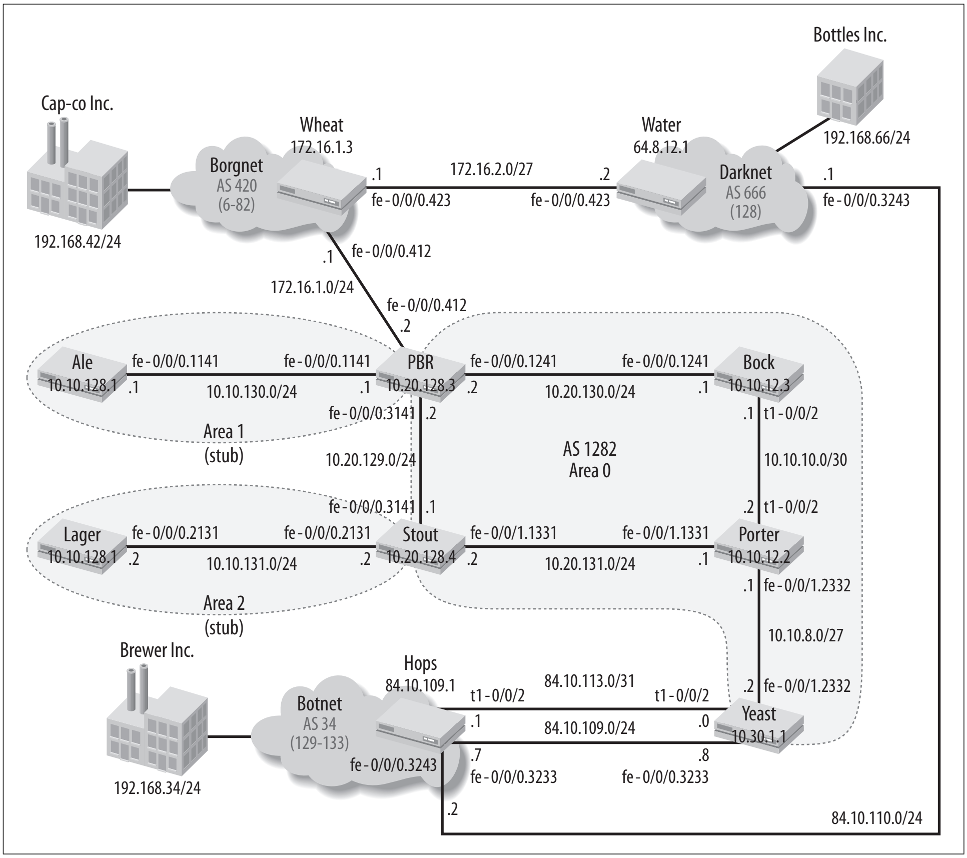


Figure 5-9. Beer-Co goes multihomed with a connection to Borgnet

associated with these extranet partners demonstrate the effects of inbound and outbound policy actions in the following sections.

In this scenario, Beer-Co's IGP consists of an area 0 backbone with two stub areas. Area border routers (ABRs) `PBR` and `Stout` originate an OSPF default route into their respective stub areas.

The design goals for the new BGP peering arrangement are as follows:

- Deploy new import policy at routers `Yeast` and `PBR` to accept only routes that originate in the peering AS, including a default route generated by both providers.
- Establish the new EBGP peering session between `PBR` and `Wheat` and advertise a 10/8 aggregate.
- Configure loopback-based IBGP peering on a minimal set of routers as needed for loop-free transport within Beer-Co.
- Use route reflection to reduce the total number of IBGP sessions and ensure no single point of failure.

- Establish an outbound policy that prefers each peer's customer routes, with all other destinations using the Borgnet link as a revertive primary.

The result of the initial BGP multihoming task is a (default) topology-driven inbound policy and a hybrid outbound policy that combines elements of the topology-driven and primary models. Route filtering and route reflection are used to minimize BGP processing demand on routers with limited memory.

To help put these requirements into a functional perspective, the expected behavior is summarized as follows:

- EBGP speakers accept only peer customer routes (customer routes).
- When sending to customer routes, forward directly to the AS that owns that route when the related peering session is operational.
- When sending to other BGP destinations, all BGP speakers use the default route associated with the primary peering to Borgnet.
- Routers in stub areas use a default to reach the closest ABR, at which point BGP forwarding takes effect.
- The failure of any access link should not sever communications; upon restoration, traffic should again adhere to the loose primary outbound policy.

Implement Beer-Co's Outbound Policy

Configuration begins by creating the import policy at `PBR` that accepts only those routes that originate within Borgnet. The intention is to protect the relatively small access router from the potentially harmful effects associated with the receipt of a full BGP route table from `Wheat`. Similar policy actions will also be performed at `Yeast`. The effect is a topology-driven outbound routing model for the routes owned by each peering AS, and the use of the metrically closest default route for destinations that originate outside of these ASs; for example, the 128/8 and 192.168.66/24 routes that are originated by the nonadjacent AS Darknet.

This type of BGP import policy normally uses an AS path regular expression because it greatly simplifies the matching criteria against the numerous route prefixes that could originate within a given AS. In this example, the routes owned by Borgnet are shown as being in the range of 6–82, making a route filter feasible. However, you also need to consider its internal/direct routes, in this case the 172.16.1.3 loopback address of `Wheat`. When really tight control is needed, you can always combine the effects of route filters and AS path regular expressions. The import policy created for `PBR` uses an AS path regular expression to only accept routes with one or more instances of ASN 420. The regular expression is written in this manner to accommodate the potential of AS path prepending within Borgnet. This way, even if there are 10 instances of ASN 420 in the prefix, the route is still considered to have originated within that specific AS. `PBR`'s import policy is displayed:

```
[edit policy-options]
lab@PBR# show
policy-statement as_420_import {
    term 1 {
        from {
            protocol bgp;
            as-path as_420_originate;
        }
        then accept;
    }
    term 2 {
        then reject;
    }
}
as-path as_420_originate "^420+$";
```

The first term of the as_420_import policy accepts routes from BGP with an AS path matching the named expression as_420_originate. The second term defeats the default BGP import policy, which is to accept all (sane) BGP routes. The AS path regular expression uses the ^ and $ anchors to force a match against the start and end of the AS path attribute, respectively. The + multiplier indicates that the proceeding pattern (420) must appear at least once, but can appear multiple times. The combined effect is a match against any AS path attribute that begins and ends with the value 420, which may contain zero or more repetitions of that same value. The as_34_import policy at Yeast is modified to accept all BGP routes originating in AS 34:

```
[edit]
lab@Yeast# show policy-options policy-statement as_34_import
term slow_peer {
    from {
        protocol bgp;
        neighbor 84.10.113.1;
        as-path 34_originate;
        route-filter 0.0.0.0/0 exact;
    }
    then {
        community add bw_slow;
        accept;
    }
}
term fast_peer {
    from {
        protocol bgp;
        neighbor 84.10.109.7;
        as-path 34_originate;
        route-filter 0.0.0.0/0 exact;
    }
    then {
        community add bw_fast;
        accept;
    }
}
```

```
    term reject-all {
        then reject;
    }
```

The highlights call out sections of the exiting policy that are *removed* to meet the new route filtering criterion. Now, rather than accepting only a default route, Yeast accepts all routes that originate in AS 34.

EBGP Peering to AS 420

With the import policy defined, you need a BGP stanza with which to apply it. The EBGP peering definition at PBR is pretty straightforward:

```
[edit]
lab@PBR# show protocols bgp
group as_420 {
    type external;
    import as_420_import;
    neighbor 172.16.1.1 {
        peer-as 420;
    }
}
```

The newly created as_420_import policy has been applied as import. The commit failure offers a friendly reminder that, for BGP to operate, a local ASN is required. This is quickly remedied:

```
[edit]
lab@PBR# commit
[edit protocols]
  'bgp'
    Error in neighbor 172.16.1.1 of group as_420:
must define local autonomous system when enabling BGP
error: configuration check-out failed

[edit]
lab@PBR# set routing-options autonomous-system 1282

[edit]
lab@PBR# commit
commit complete
```

BGP session status is verified with a show bgp summary command:

```
[edit]
lab@PBR# run show bgp summary
Groups: 1 Peers: 1 Down peers: 0
Table   Tot Paths  Act Paths Suppressed  History Damp State  Pending
inet.0        806        123          0        0          0        0
Peer        AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
172.16.1.1    420    356        257       0       0     2:06:57
123/806/00/0/0
```

The EBGP session to Borgnet is established, as confirmed by the x/x/x field that summarizes active routes, received routes, and damped routes, respectively. This display also begins to validate the as_420_import policy, in that only 123 of the 806 routes received are active. The presence of hidden routes, ostensibly due to filtering, is confirmed:

```
[edit]
lab@PBR# run show route hidden detail

inet.0: 825 destinations, 826 routes (143 active, 0 holddown, 682 hidden)
64.8.12.1/32 (1 entry, 0 announced)
         BGP                 /-101
                Next-hop reference count: 929
                Source: 172.16.1.1
                Next hop: 172.16.1.1 via fe-0/0/0.412, selected
                State: <Hidden Ext>
                Local AS:  1282 Peer AS:   420
                Age: 2:19:43
                Task: BGP_420.172.16.1.1+1530
                AS path: 420 666 I
                Localpref: 100
                Router ID: 172.16.1.3

128.3.0.0/16 (1 entry, 0 announced)
         BGP                 /-101
                Next-hop reference count: 929
                Source: 172.16.1.1
                Next hop: 17^C[abort]
---(more)---
. . .
```

The summary portion of the show route hidden detail command confirms both a large number of hidden routes (682) and that the hidden route displayed has an AS path that *does not* indicate origin in AS 420. This shows that the route is hidden due to your AS path-based import filtering. The CLI's AS path regular expression filter is used for final confirmation:

```
[edit]
lab@PBR# run show route aspath-regex ^420+$ | match path
                      AS path: 420 I
                      AS path: 420 I
                      AS path: 420 I
                      AS path: 420 I
                      AS path: 420 I
. . .
[edit]
lab@PBR# run show route aspath-regex ^420+$ | match path | count
Count: 124 lines
```

The regex-filtered show route display verifies that all matching routes have an AS path consisting of only AS 420. The CLI's count function is then used to confirm that PBR has received a total of 124 routes from Borgnet that pass the as_420_import policy.

One of these should be a default route that is used to reach BGP destinations that do not originate in either AS 34 or AS 420:

```
[edit]
lab@PBR# run show route

inet.0: 825 destinations, 826 routes (143 active, 0 holddown, 682 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/150] 02:24:20, metric 0, tag 0
                    > to 10.20.130.1 via fe-0/0/0.1241
                    [BGP/170] 00:28:13, localpref 100
                      AS path: 420 I
                    > to 172.16.1.1 via fe-0/0/0.412
```

The show route display at PBR confirms the receipt of a BGP default route but shows a potential problem as well; PBR also receives the default route redistributed into OSPF by Yeast, and it prefers the OSPF version due to global preference (known as administrative distance in IOS land).

The goal of your hybrid topological/primary outbound routing policy is to have routers forward to peer customer routes using a topology model that hands traffic directly to the AS that owns those routes, while a default route is used to reach filtered BGP destinations over the primary Borgnet peering. To meet the requirements, this default route should always direct traffic over the Borgnet link when it is operational. Therefore, in normal operation, all routers must prefer the default route advertised by PBR over any copy advertised by Yeast.

In the current setup, a BGP learned default route from AS 34 is being redistributed into OSPF at router Yeast. Recall that this was necessary because up until now, Yeast was the only BGP speaker in Beer-Co. Given that you are now, or soon will be, deploying IBGP among a set of Beer-Co's internal routers, the need to redistribute the default into OSPF can be revisited. The stub area routers already rely on an OSPF default generated by each area's ABR, so this discussion centers on what is done for routers PBR, Bock, Stout, Porter, and Yeast. Figure 5-10 details the plan of action for IBGP deployment on Beer-Co's backbone.

Figure 5-10 shows that all OSPF area 0 routers will be configured to run IBGP. Recall from an earlier discussion that deciding which routers need to run IBGP is a function of whether your import policy accepts only a default, and whether intermediate routers are in the forwarding path between EBGP speakers. Also recall that an EBGP speaker should always be enabled for IBGP unless there is only one BGP speaker in your network. Because your EBGP speakers are accepting only specific prefixes, IBGP should be enabled on any router that can forward traffic between the speakers. In this example, that means Stout, Bock, and Porter must support IBGP. Because the backbone routers will run BGP, they can learn the default route through BGP; this means that redistribution of the BGP default into OSPF is no longer necessary. With this understanding, the ospf_default export policy is removed at Yeast.

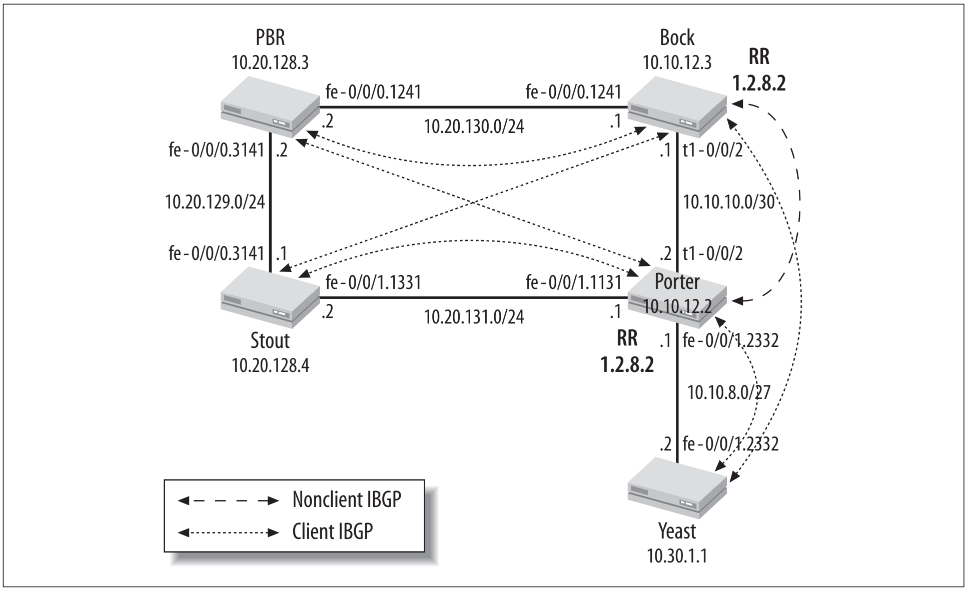


Figure 5-10. Beer-Co IBGP deployment details

```
[edit]
lab@Yeast# delete policy-options policy-statement ospf_default

[edit]
lab@Yeast# delete protocols ospf export
```

The effect of this change is confirmed at PBR, where now only the BGP version of the default route is present and is therefore made active:

```
[edit]
lab@PBR# run show route

inet.0: 827 destinations, 827 routes (145 active, 0 holddown, 682 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[BGP/170] 17:26:08, localpref 100
                      AS path: 420 I
                    > to 172.16.1.1 via fe-0/0/0.412
```

Export Beer-Co Aggregate to Borgnet

The requirements state that PBR should advertise a single 10/8 aggregate to its EBGP peers representing Beer-Co's internal connectivity. The same approach used at Yeast is brought to bear here. Specifically, an aggregate route is defined and policy is created to export it to Wheat in AS 420:

```
[edit]
lab@PBR# show routing-options aggregate
route 10.0.0.0/8;
```

```
lab@PBR# show policy-options policy-statement as_420_export
term 1 {
    from {
        protocol aggregate;
        route-filter 10.0.0.0/8 exact;
    }
    then accept;
}

[edit]
lab@PBR# show protocols bgp group as_420 export
export as_420_export;
```

Validation of the as_420_export policy is straightforward:

```
[edit]
lab@PBR# run show route advertising-protocol bgp 172.16.1.1

inet.0: 827 destinations, 827 routes (145 active, 0 holddown, 682 hidden)
  Prefix                  Nexthop              MED     Lclpref    AS path
* 10.0.0.0/8              Self                                    I
```

Although not shown, a similar state of EBGP learned and advertised routes is also confirmed to exist at router Yeast, except that is has learned the 129–133 and 192.168.34/24 customer routes from AS 34. This completes the EBGP peering and initial import policy phases of the BGP multihoming scenario. It is time to add IBGP to the network.

Monitor system load

Before adding EBGP to Yeast, system resources were analyzed using the show chassis routing-engine and show task memory commands. Now that EBGP has been added, it is a good idea to reexamine resource usage. If the router is having a hard time maintaining its current EBGP load for whatever reason, obviously the addition of IBGP sessions will not help matters. The hidden set task accounting command is used to get a better feel for how much burden BGP itself is adding to the router.

> Hidden commands are hidden because Juniper Networks support engineers feel inappropriate use can cause operational problems. As a general rule, you should never issue hidden commands on a production network router unless a support engineer has instructed you to do so.

This command displays the resource consumption of the various components of the routing daemon (rpd) and is hidden because it requires the router's resources to run, which could make a bad situation worse. Because there is no reason to believe that any of Beer-Co's routers are actually running short on resources, task accounting is enabled (note that there is no CLI auto-completion, hence the term *hidden*). After a few moments, the results are displayed, and task accounting is turned back off. Task accounting should be enabled only when needed, and then only long enough to get the information desired. Also note that set task accounting on is an operational mode command:

```
lab@PBR> set task accounting on
Task accounting enabled.

lab@PBR>
```

After a few moments, the results are displayed:

```
lab@PBR> show task accounting
Task accounting is enabled.

Task                      Started User Time System Time Longest Run
Scheduler                     425     0.004       0.007       0.000
LMP Client                     75     0.001       0.002       0.000
Memory                          6     0.000       0.000       0.000
OSPFv2 I/O./var/run/ppmd_     120     0.001       0.002       0.000
BGP RT Background              32     0.000       0.000       0.000
OSPFv2                        100     0.000       0.001       0.000
BFD I/O./var/run/bfdd_con      29     0.000       0.000       0.000
BGP_420.172.16.1.1+1530        38     0.000       0.001       0.000
KRT                            12     0.000       0.000       0.000
Redirect                        2     0.000       0.000       0.000
MGMT_Listen./var/run/rpd_       2     0.000       0.000       0.000
SNMP Subagent./var/run/sn       3     0.000       0.000       0.000
```

The output indicates that the EBGP peering at PBR is not consuming appreciable system resources. Note that instability and resulting route flaps (repeated route withdrawals and readvertisement) could change this situation. BGP route damping is used to buffer the effects of flapping routes when needed. In operation, once an unstable prefix is damped, subsequent updates/withdrawals are ignored for a specified period to preserve the local router's control plane resources.

Task accounting is again disabled to prevent unnecessary resource usage:

```
lab@PBR> set task accounting off
Task accounting disabled.
```

IBGP Peering Within AS 1282

Referring back to Figure 5-10 and the scenario's design requirements, it's obvious that you need to configure IBGP on the backbone routers. Route reflection is used to minimize the total number of IBGP sessions required. Dual route reflectors are deployed for redundancy, in this case using the same cluster ID. The use of loopback-based IBGP peering means that the potential for session disruption to one reflector, but not the other, is virtually nonexistent, making the lack of cluster 1.2.8.2 updates over the route reflector–route reflector IBGP session a nonissue. Using the same cluster ID on both reflectors reduces the BGP routing information base (RIB) size on the reflectors because they filter updates received from each other that contain the shared cluster ID. Note that the two route reflectors peer to each other as nonclients. The same cluster ID value is configured on both reflectors. In this example, the cluster ID is based on Beer-Co's ASN 1282.

Configuration of route reflection begins with creation of the route reflector–route reflector IBGP peering session on Porter:

```
[edit]
lab@Porter# set routing-options autonomous-system 1282

[edit]
lab@Porter# edit protocols bgp group 1282_rr

[edit protocols bgp group 1282_rr]
lab@Porter# set type internal neighbor 10.10.12.3

[edit protocols bgp group 1282_rr]
lab@Porter# set local-address 10.20.12.2

[edit protocols bgp group 1282_rr]
lab@Porter# top show routing-options
autonomous-system 1282;

[edit protocols bgp group 1282_rr]
lab@Porter# show
type internal;
local-address 10.20.12.2;
neighbor 10.10.12.3;
```

With definition of the local system's ASN under the `routing-options` stanza complete, you create a BGP group called `1282_rr`; this group is designated as an `internal` group, making the configuration of a `peer-as` unnecessary. The highlights show how a loopback-based peering session is defined through specification of the neighbor's loopback address in conjunction with a `local-address` statement representing the local loopback address. The use of the `local-address` statement is crucial for proper loopback peering. Omitting the `local-address`, which is known as `update-source` in IOS, results in a session that is sourced from whatever interface the session is routed over. Because the remote router is configured to peer with a loopback address, the incoming session, which is now sourced from a physical interface's IP, appears unexpected, and peering is refused. Generally speaking, you can omit the `local-address` from one end, as both ends try to form a connection by default, but best practices for loopback peering call for both ends to be configured symmetrically.

A similar configuration is added to Bock:

```
[edit protocols bgp group 1282_rr]
lab@Bock# show
type internal;
local-address 10.10.12.3;
neighbor 10.10.12.2;
```

After a minute or two, the reflector-to-reflector IBGP session status is verified:

```
[edit]
lab@Porter# run show bgp summary
Groups: 1 Peers: 1 Down peers: 1
Table   Tot Paths  Act Paths Suppressed  History Damp State   Pending
inet.0          0          0          0        0          0         0
Peer        AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
10.10.12.3   1282       0       0       0       0        4:35 Idle
```

Things do not look good at Porter. The Idle state implies that the BGP session cannot even be routed, let alone established. A glance at Bock shows an Active state, meaning that the router is at least able to route its TCP session toward its peer and is therefore actively trying to establish a TCP connection:

```
[edit protocols bgp group 1282_rr]
lab@Bock# run show bgp summary
Groups: 1 Peers: 1 Down peers: 1
Table   Tot Paths  Act Paths Suppressed  History Damp State  Pending
inet.0          0          0          0          0        0        0
Peer        AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
10.10.12.2   1282       0          8       0       0     2:33 Active
```

Troubleshoot an IBGP peering problem

Attention is focused at Porter because its BGP session status is the lesser/worse of the two. Because loopback-based peering requires an IGP to resolve the forwarding next hop used to reach the session's target loopback address, it's reasonable to begin fault isolation with the IGP infrastructure. The first step is to confirm whether Porter has a route to Bock's loopback address:

```
[edit]
lab@Porter# run show route 10.10.12.3

inet.0: 20 destinations, 21 routes (20 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.12.3/32      *[OSPF/10] 02:24:59, metric 3
                    > to 10.20.131.2 via fe-0/0/1.1331
```

The output confirms that Porter has an OSPF learned route to Bock's loopback address. A traceroute is performed *between* the IBGP peering addresses. This is achieved by sourcing the traceroute from Porter's loopback address, as highlighted:

```
[edit]
lab@Porter# run traceroute 10.10.12.3 source 10.10.12.2
traceroute to 10.10.12.3 (10.10.12.3) from 10.10.12.2, 30 hops max,
40 byte packets
 1  10.20.131.2 (10.20.131.2)  12.790 ms  14.714 ms  5.128 ms
 2  10.20.129.2 (10.20.129.2)  24.976 ms  9.342 ms  9.845 ms
 3  10.10.12.3 (10.10.12.3)  10.103 ms  27.564 ms  31.800 ms
```

The traceroute succeeds, and in so doing vindicates the IGP as the source of the IBGP peering problem. From a loopback-based IBGP perspective, all that is required of the IGP is a route between loopback addresses, and clearly that part is working here. The next step is to add BGP protocol tracing to see whether that sheds any light. Tracing is added to `Porter`, and the trace file is monitored in real time using the `monitor start` command:

```
[edit protocols bgp]
lab@Porter# show traceoptions
file bgp_trace;
flag open detail;

[edit protocols bgp]
lab@Porter# commit
commit complete

[edit protocols bgp]
lab@Porter# run monitor start bgp_trace
```

BGP trace output is observed after a minute or so; use the `clear bgp neighbor` *<peer address>* command to help expedite activity when you are impatient:

```
*** bgp_trace ***
Sep  1 01:49:02.088247
Sep  1 01:49:02.088247 BGP RECV 10.10.12.3+1601 -> 10.10.12.2+179
Sep  1 01:49:02.088335 BGP RECV message type 1 (Open) length 45
Sep  1 01:49:02.088423 BGP RECV version 4 as 1282 holdtime 90 id
10.10.12.3 parmlen 16
Sep  1 01:49:02.088447 BGP RECV MP capability AFI=1, SAFI=1
Sep  1 01:49:02.088460 BGP RECV Refresh capability, code=128
Sep  1 01:49:02.088469 BGP RECV Refresh capability, code=2
Sep  1 01:49:02.088508
Sep  1 01:49:02.088508 BGP SEND 10.10.12.2+179 -> 10.10.12.3+1601
Sep  1 01:49:02.088537 BGP SEND message type 1 (Open) length 29
Sep  1 01:49:02.088552 BGP SEND version 4 as 1282 holdtime 90 id
10.10.12.2 parmlen 0
Sep  1 01:49:02.088566
Sep  1 01:49:02.088566 BGP SEND 10.10.12.2+179 -> 10.10.12.3+1601
Sep  1 01:49:02.088583 BGP SEND message type 3 (Notification) length 21
Sep  1 01:49:02.088689 BGP SEND Notification code 2 (Open Message
Error) subcode 5 (authentication failure)
Sep  1 01:49:02.089581 bgp_pp_recv: NOTIFICATION sent to 10.10.12.3+1601
proto): code 2 (Opelist
monitor start "bgp_trace" (Last changed Sep  1 01:49:02)
(Message Error) subcode 5 (authentication failure), Reason: no group
for 10.10.12.3+1601 (proto) from AS 1282 found (peer idled), dropping
him
```

The highlights call out key aspects of the trace. Things begin when `Porter` receives a BGP session open from `Bock`. Note that this session is correctly sourced between the loopback addresses associated with routers `Bock` and `Porter`. `Porter` responds with a notification message that reports an authentication failure. In the BGP context, this type of message means that an unknown peer has tried to establish a peering session. BGP normally communicates only with explicitly configured peers (unless you add the allow *<prefix>* keyword). The last highlight is telling—the local system reports that this peer does not belong to any configured groups. The lack of Porter-initiated BGP session requests is expected here; recall that its connection is in the idle state, which means that it cannot begin to form a session, so there would be nothing to trace.

The IBGP configuration is examined with extra scrutiny, because you are sure that Porter has peer 10.10.12.3 configured in the 1282_rr group:

```
[edit protocols bgp]
lab@Porter#
*** monitor and syslog output disabled, press ESC-Q to enable ***

[edit protocols bgp]
lab@Porter# show
traceoptions {
    file bgp_trace;
    flag open detail;
}
group 1282_rr {
    type internal;
    local-address 10.20.12.2;
    neighbor 10.10.12.3;
}
```

The IBGP configuration problem at Porter jumps out and slaps you in the head, emitting a d'oh-like sound that echoes between your ears. The local-address statement incorrectly specifies a nonexistent address. This accounts for the local state of idle because the router cannot create a packet with a spoofed address! This effectively puts the 1282_rr group into an idle state, which in turn leads to the authentication failure for the session initiated by Bock. The tracing configuration is removed, the mistake is corrected, and session status is confirmed to be operational a short time later:

```
[edit protocols bgp]
lab@Porter# delete traceoptions

[edit protocols bgp]
lab@Porter# set group 1282_rr local-address 10.10.12.2

[edit protocols bgp]
lab@Porter# run show bgp summary
Groups: 1 Peers: 1 Down peers: 0
Table  Tot Paths  Act Paths Suppressed    History Damp State    Pending
inet.0         0          0          0          0          0          0
Peer          AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
10.10.12.3  1282          5          6       0       0       1:52 0/0/0
0/0/0
```

Configure route reflection

The configuration for cluster 1.2.8.2 is now added to each reflector. Here is Bock's 1282_clients group:

```
[edit protocols bgp group 1282_clients]
lab@Bock# show
type internal;
local-address 10.10.12.3;
##
## Warning: requires 'bgp-reflection' license
##
cluster 1.2.8.2;
neighbor 10.20.128.3;
neighbor 10.20.128.4;
neighbor 10.30.1.1
```

The 1282_rr_clients group is similar to the previously created 1282_rr group, except for the inclusion of a cluster ID, which makes the local router a route reflector for all peers in that group. All three client loopback addresses are configured, making them clients for cluster 1.2.8.2. The nag warning in the display reminds you that, for the J-series, BGP route reflection is considered to be a value-added service that requires separate licensing. The J-series soft license model means you can expect the feature to work properly, even when unlicensed, but you can also expect a lack of Juniper Networks support and ongoing nags at each commit. You normally obtain feature licenses from the distributor that sold you the router. You make a note to get a license, and for now move on with configuration. A similar configuration is added to Porter.

> A note on next-hop self and route reflectors is in order here. It is common to have an IBGP export policy on EBGP speakers that sets the advertised next hop to the IBGP speaker's peering address to eliminate issues with other routes not being able to resolve the EBGP next hop originally advertised by the remote AS. Applying such a policy for routes that are reflected among clients can easily result in suboptimal forwarding, as traffic will be forced to transit the reflector. In most cases, you want the reflection topology to be independent of the forwarding topology, and leaving the next hop unchanged on reflected routes achieves this goal.

IBGP configuration at routers PBR, Stout, and Yeast is similar. Each router gets an IBGP group that defines loopback peering to each reflector. The use of redundant route refection doubles the total number of IBGP sessions needed for this network, bringing the total to 13. This is still far fewer than the 20 sessions needed to form a full mesh among five routers if reflection were not used. Here is the configuration of client Stout:

```
[edit protocols bgp group 1282_clients]
lab@stout# top show routing-options
```

```
autonomous-system 1282;

[edit protocols bgp group 1282_clients]
lab@stout# show
type internal;
local-address 10.20.128.4;
neighbor 10.10.12.3;
neighbor 10.10.12.2;
```

After the new `1282_clients` peer group is added to client routers `PBR`, `Stout`, and `Yeast`, IBGP session status is confirmed at client `Stout`:

```
[edit protocols bgp group 1282_clients]
lab@stout# run show bgp summary
Groups: 1 Peers: 2 Down peers: 0
Table  Tot Paths  Act Paths Suppressed  History Damp State    Pending
inet.0        0          0          0        0          0          0
Peer           AS      InPkt     OutPkt  OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
10.10.12.2   1282   13  14       0       0      6:19 0/0/0   0/0/0
10.10.12.3   1282   20  22       0       0      9:57 0/0/0   0/0/0

[edit protocols bgp group 1282_clients]
lab@stout# run show route protocol bgp

inet.0: 20 destinations, 20 routes (20 active, 0 holddown, 0 hidden)
```

The output is a bit of a mixed bag of results. On the one hand, both IBGP sessions are established to the reflectors; on the other hand, no routes are being learned over either session. Oddly, a `show route advertising-protocol bgp` command at `PBR` confirms that it is readvertising its EBGP learned routes to reflector `Bock`:

```
[edit protocols bgp group 1282_clients]
lab@PBR# run show route advertising-protocol bgp 10.10.12.2

inet.0: 827 destinations, 827 routes (145 active, 0 holddown, 682 hidden)
  Prefix              Nexthop             MED     Lclpref    AS path
* 0.0.0.0/0           172.16.1.1                  100        420 I
* 6.1.0.0/16          172.16.1.1                  100        420 I
* 6.2.0.0/22          172.16.1.1                  100        420 I
. . . .
```

If `PBR` is advertising routes to the reflector, why are these routes not being reflected to the cluster's clients?

Troubleshoot BGP next hop reachability

Attention shifts to the reflectors, given that the missing routes were last observed being sent to them, while nothing is seen coming back from them. The `show route receive-protocol bgp` command output on reflector `Bock` implies that *no* routes are being received, which is not possible, given that `PBR`'s output shows it advertised routes to `Bock`, and the underlying TCP transport guarantees delivery!

```
[edit protocols bgp group 1282_clients]
lab@Bock# run show route receive-protocol bgp 10.20.128.3

inet.0: 825 destinations, 950 routes (19 active, 0 holddown, 930 hidden)
```

The presence of hidden routes is noted, so you investigate by adding the hidden switch:

```
[edit protocols bgp group 1282_clients]
lab@Bock# run show route receive-protocol bgp 10.20.128.3 hidden

inet.0: 825 destinations, 950 routes (19 active, 0 holddown, 930 hidden)
  Prefix              Nexthop              MED     Lclpref    AS path
  0.0.0.0/0           172.16.1.1                   100        420 I
6.1.0.0/16          172.16.1.1                   100        420 I
. . .
```

The output confirms that the BGP routes advertised by PBR are in fact hidden at Bock. This explains the lack of reflection to other clients, because active routes only are subject to advertisement. The extensive switch is added to get as much detail as possible, but the output does not contain any additional information:

```
[edit protocols bgp group 1282_clients]
lab@Bock# ...protocol bgp 10.20.128.3 hidden extensive

inet.0: 825 destinations, 950 routes (19 active, 0 holddown, 930 hidden)
  0.0.0.0/0 (2 entries, 0 announced)
     Nexthop: 172.16.1.1
     Localpref: 100
     AS path: 420 I
. . .
```

The limited set of information displayed does include the route's associated BGP next hop, which here represents the address assigned to Wheat for use on its EBGP peering to PBR. Recalling that the BGP route selection process begins with a decision as to whether the next hop is reachable, you display the route to 172.16.1.1 at Bock:

```
[edit protocols bgp group 1282_clients]
lab@Bock# run show route 172.16.1.1
```

The output, or more correctly the lack thereof, confirms that the issue is one of BGP next hop reachability. The show route resolution unresolved detail command is used to confirm this fact:

```
[edit protocols bgp group 1282_clients]
lab@Bock# run show route resolution unresolved detail
Tree Index 1
133.3.0.0/16
        Protocol Nexthop: 84.10.109.7
        Indirect nexthop: 0 -
132.252.0.0/16
        Protocol Nexthop: 84.10.109.7
        Indirect nexthop: 0 –
. . . .
```

The display confirms that route reflector Bock is unable to resolve the EBGP next hop attached to the routes it learns from Yeast. There are several common solutions to this classic problem. Recall that by default, the BGP next hop is updated only on EBGP links. You could alter this behavior with a next-hop self policy on the EBGP speakers, which is then applied as an IBGP *export* policy to update the next hop of each route as it is readvertised to other IBGP speakers.

Never apply a next-hop self policy as import for an EBGP session because the resulting routes appear to be looped and are hidden.

Another way to fix the unreachable next hop is to advertise the EBGP peering subnet into your IGP. You should do this by running a passive IGP instance on your EBGP peering links. The passive mode guarantees that an adjacency cannot form to the remote AS, which could be very, very bad (IGPs lack policy controls for interdomain routing, and combining two large IGPs into a single, larger one may push routers beyond their limits).

An IBGP export to affect next-hop self behavior solves the problem. The changes made to PBR's configuration are also placed into effect at Yeast:

```
[edit]
lab@PBR# show policy-options policy-statement next_hop_self
term 1 {
    from protocol bgp;
    then {
        next-hop self;
    }
}

[edit]
lab@PBR# show protocols bgp group 1282_clients export
export next_hop_self;
```

The BGP summary display back at Stout confirms that route reflection is working:

```
[edit protocols bgp group 1282_clients]
lab@stout# run show bgp summary
Groups: 1 Peers: 2 Down peers: 0
Table  Tot Paths  Act Paths Suppressed  History Damp State  Pending
inet.0      1612        806          0        0          0        0
Peer            AS   InPkt    OutPkt   OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
10.10.12.2   1282     163        84      0       0     41:18 806/806/0
0/0/0
10.10.12.3   1282     259         92      0       0     44:56 0/806/0
0/0/0
```

The highlights show that Stout is receiving the same number of BGP routes from both reflectors, which is expected. Recall that BGP tie-breaking rules prefer routes learned from the router with the lowest RID, which is Porter in this case. You could enable multipath for IBGP to install both copies of the routes into the forwarding table. However, in this example, it does not buy anything, given that both copies point to the same forwarding next hop address. We will rely on the IGP to perform load balancing if there are multiple equal cost paths. Details for the customer route to Brewer Inc. are displayed to confirm various attributes for the route, including why the copy learned from Porter is preferred:

```
[edit protocols bgp group 1282_clients]
lab@stout# run show route 192.168.34.0 detail

inet.0: 826 destinations, 1632 routes (826 active, 0 holddown, 0 hidden)
192.168.34.0/24 (2 entries, 1 announced)
        *BGP    Preference: 170/-121
                Next-hop reference count: 2732
                Source: 10.10.12.2
                Next hop: 10.20.131.1 via fe-0/0/1.1331, selected
                Protocol next hop: 10.30.1.1
                Indirect next hop: 8791128 262144
                State: <Active Int Ext>
                Local AS:  1282 Peer AS:  1282
                Age: 30         Metric2: 2
                Task: BGP_1282.10.10.12.2+179
                Announcement bits (2): 0-KRT 4-Resolve tree 1
                AS path: 34 I (Originator) Cluster list:  1.2.8.2
                AS path:  Originator ID: 10.30.1.1
                Communities: bandwidth:1287:12500000
                Localpref: 120
                Router ID: 10.10.12.2
         BGP    Preference: 170/-121
                Next-hop reference count: 2732
                Source: 10.10.12.3
                Next hop: 10.20.131.1 via fe-0/0/1.1331, selected
                Protocol next hop: 10.30.1.1
                Indirect next hop: 8791128 262144
                State: <NotBest Int Ext>
                Inactive reason: Router ID
                Local AS:  1282 Peer AS:  1282
                Age: 4:29       Metric2: 2
                Task: BGP_1282.10.10.12.3+179
                AS path: 34 I (Originator) Cluster list:  1.2.8.2
                AS path:  Originator ID: 10.30.1.1
                Communities: bandwidth:1287:12500000
                Localpref: 120
                Router ID: 10.10.12.3
```

Confirm Outbound Policy Operation

The EBGP and IBGP peering is established within your network, and route reflection is confirmed operational. The verification of your output policy is performed at IBGP speaker Stout. Recall that Ale and Lager use the OSPF default to forward packets to their respective ABRs, which in turn now have BGP routing state and are expected to make the correct outbound forwarding decision.

Things start with traceroutes to customer networks in peering ASs Borgnet and Botnet:

```
lab@stout> traceroute 192.168.42.1
traceroute to 192.168.42.1 (192.168.42.1), 30 hops max, 40 byte packets
 1  10.20.129.2 (10.20.129.2)  6.360 ms  59.843 ms  15.233 ms
 2  172.16.1.1 (172.16.1.1)  10.191 ms !N  8.985 ms !N  10.114 ms !N

lab@stout> traceroute 192.168.34.1
traceroute to 192.168.34.1 (192.168.34.1), 30 hops max, 40 byte packets
 1  10.20.131.1 (10.20.131.1)  40.976 ms  34.719 ms  2.141 ms
 2  10.10.8.2 (10.10.8.2)  10.009 ms  18.695 ms  8.191 ms
 3  84.10.109.7 (84.10.109.7)  32.183 ms !N  19.530 ms !N  19.790 ms !N
```

The results match the topological aspects of Beer-Co's outbound policy—Stout is using the specific routes it has learned from the EBGP peering routers to forward directly to the peer AS that owns the customer route. The point being stressed here is that this aspect of outbound policy is a side effect of the route filtering performed at the EBGP-speaking routers. Yeast, for example, filters the copy of Cap-Co's 192.168.42/24 route when it is readvertised from Botnet because that route did not originate within AS 34. This means that although there are two copies of customer route 192.168.42/24, both copies identify the *same* BGP next hop, which is PBR in this example. There are two copies of this route because of the redundant route reflector design. Refer back to the previous show route display for full details. The following (filtered) display calls out that both copies of the 192.168.42/24 route point to the same BGP egress point, despite being learned from two different reflectors:

```
lab@stout> show route 192.168.42.0 detail | match next
                Next-hop reference count: 496
                Next hop: 10.20.129.2 via fe-0/0/0.3141, selected
                Protocol next hop: 10.20.128.3
                Indirect next hop: 8791000 262142
                Next-hop reference count: 496
                Next hop: 10.20.129.2 via fe-0/0/0.3141, selected
                Protocol next hop: 10.20.128.3
                Indirect next hop: 8791000 262142
```

Things are not so perfect when it comes to destinations that are filtered by both EBGP speakers—for example, the 192.168.66/24 Bottle Inc. route. Because the BGP speakers are relying on a learned default route, which has equal specificity for all such filtered destinations, special steps are required to meet the stated outbound policy to avoid a tie-breaker situation between the otherwise equal-cost versions of the default route. Recall that in this example, all IBGP speakers should prefer the default route learned through PBR and use the one learned from Yeast only when the PBR session is disrupted.

The route to Bottle Inc. is shown at Stout:

```
lab@stout> show route 192.168.66.0 detail

inet.0: 577 destinations, 1134 routes (577 active, 0 holddown, 0 hidden)
0.0.0.0/0 (2 entries, 1 announced)
        *BGP    Preference: 170/-101
                Next-hop reference count: 499
                Source: 10.10.12.3
                Next hop: 10.20.129.2 via fe-0/0/0.3141, selected
                Protocol next hop: 10.20.128.3
                Indirect next hop: 8791000 262142
                State: <Active Int Ext>
                Local AS:  1282 Peer AS:  1282
                Age: 1:15       Metric2: 1
                Task: BGP_1282.10.10.12.3+179
                Announcement bits (2): 0-KRT 4-Resolve tree 1
                AS path: 420 I (Originator) Cluster list:  1.2.8.2
                AS path:  Originator ID: 10.20.128.3
                Localpref: 100
                Router ID: 10.10.12.3
         BGP    Preference: 170/-101
                Next-hop reference count: 1729
                Source: 10.10.12.2
                Next hop: 10.20.131.1 via fe-0/0/1.1331, selected
                Protocol next hop: 10.30.1.1
                Indirect next hop: 8791128 262144
                State: <Int Ext>
                Inactive reason: IGP metric
                Local AS:  1282 Peer AS:  1282
                Age: 1:15       Metric2: 2
                Task: BGP_1282.10.10.12.2+179
                AS path: 34 I (Originator) Cluster list:  1.2.8.2
                AS path:  Originator ID: 10.30.1.1
                Communities: bandwidth:1287:12500000
                Localpref: 100
                Router ID: 10.10.12.2
```

The output confirms that Stout relies on a BGP learned default to reach destinations in nonadjacent ASs. The highlights show that Stout has learned of two copies of the default, one reflected by Bock that originates at PBR and the other via Porter, which originated at Yeast. In this example, the failure to adjust BGP attributes has left route selection to the default algorithm, which here selects the lowest metric IGP path, given that all other factors up to that decision step are the same. Your goal is to ensure that all IBGP speakers prefer the default advertised by PBR—this is not the case, so additional policy action is needed to meet the design requirements. The most direct way to alter which BGP routes are preferred by IBGP speakers is to adjust local preference:

```
lab@PBR# show protocols bgp group 1282_clients export
export [ next_hop_self prefer_Borgnet_transit ];

[edit]
lab@PBR# show policy-options policy-statement prefer_Borgnet_transit
term 1 {
    from {
        protocol bgp;
        route-filter 0.0.0.0/0 exact;
    }
    then {
        local-preference 110;
    }
}
```

After committing the change, the result is confirmed back at Stout:

```
lab@stout> show route 192.168.66.0

inet.0: 577 destinations, 1134 routes (577 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0        *[BGP/170] 00:02:47, localpref 110, from 10.10.12.2
                    AS path: 420 I
                  > to 10.20.129.2 via fe-0/0/0.3141
                  [BGP/170] 00:02:47, localpref 110, from 10.10.12.3
                    AS path: 420 I
                  > to 10.20.129.2 via fe-0/0/0.3141
```

Why Only Two Copies of the Default?

You may be wondering why a router such as Stout is not receiving four copies of the BGP default route. Given that it receives two copies of the 192.168.42/24 route that is advertised *only* by PBR, you might expect twice as many copies for a route that is sent by *both* PBR and Yeast. The answer lies in the active route selection process performed by the reflectors. Each reflector readvertises only routes that are locally active. Because each reflector learns of route 192.168.42/24 from a single source (PBR), each reflector installs the route as active and both reflect it to their clients. In contrast, the default route is learned by each reflector from both PBR and Yeast, and each reflector chooses the copy it considers best, reflecting only that copy to its clients.

As a result, if the current network were to lose one of its EBGP speakers, there would *still* be two copies of the default route at each client. The difference is that now both copies will be the same route, as advertised by the remaining EBGP speaker. The same result occurs if the local preference of one default route is altered, causing it to be preferred by both reflectors.

There are still two copies of the default route, one learned from each reflector, but now both copies identify PBR as the protocol next hop. Therefore, using either version results in a forwarding path that directs traffic to nonadjacent ASs over the Borgnet peering. Both reflectors now prefer the route advertised by PBR because of its higher preference value. A traceroute is performed to confirm a normal forwarding path, and then the EBGP session at PBR is cleared to confirm fallback to Botnet:

```
lab@stout> traceroute 192.168.66.1
traceroute to 192.168.66.1 (192.168.66.1), 30 hops max, 40 byte packets
 1  10.20.129.2 (10.20.129.2)  9.087 ms  8.966 ms  29.973 ms
 2  172.16.1.1 (172.16.1.1)  9.289 ms  9.886 ms  9.868 ms
 3  172.16.2.2 (172.16.2.2)  30.022 ms !N  15.394 ms !N  23.853 ms !N
```

The EBGP session is clear at PBR:

```
[edit]
lab@PBR# run clear bgp neighbor 172.16.1.1
Cleared 1 connections
```

And now the traceroute takes the secondary path via Botnet:

```
lab@stout> traceroute 192.168.66.1
traceroute to 192.168.66.1 (192.168.66.1), 30 hops max, 40 byte packets
 1  10.20.131.1 (10.20.131.1)  39.481 ms  18.973 ms  20.043 ms
 2  10.10.8.2 (10.10.8.2)  159.897 ms  199.206 ms  10.097 ms
 3  84.10.109.7 (84.10.109.7)  39.908 ms  19.261 ms  13.438 ms
 4  84.10.110.1 (84.10.110.1)  16.441 ms !N  44.843 ms !N  34.459 ms !N
```

After a few minutes, PBR's EBGP session should be reestablished, making its default once again preferred, causing transit traffic to switch back (revertive behavior) to the Borgnet peering:

```
lab@stout> traceroute 192.168.66.1
traceroute to 192.168.66.1 (192.168.66.1), 30 hops max, 40 byte packets
 1  10.20.129.2 (10.20.129.2)  9.980 ms  8.803 ms  9.848 ms
 2  172.16.1.1 (172.16.1.1)  20.031 ms  29.300 ms  19.929 ms
 3  172.16.2.2 (172.16.2.2)  9.851 ms !N  9.394 ms !N  29.928 ms !N
```

The final verification is performed at stub router Lager, which has no BGP routes and uses the stub area default to reach its ABR:

```
lab@Lager> show route protocol bgp

inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
```

No BGP routes are present because Lager is not running BGP:

```
lab@Lager> show route 192.168.66.0

inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/10] 05:19:25, metric 11
                    > to 10.10.131.2 via fe-0/0/0.2131

lab@Lager> show route 192.168.34.0

inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both
```

```
0.0.0.0/0          *[OSPF/10] 05:19:30, metric 11
                    > to 10.10.131.2 via fe-0/0/0.2131
```

Lager uses the OSPF default to reach all AS external destinations:

```
lab@Lager> traceroute 192.168.34.1
traceroute to 192.168.34.1 (192.168.34.1), 30 hops max, 40 byte packets
 1  10.10.131.2 (10.10.131.2)  10.507 ms  10.555 ms  9.706 ms
 2  10.20.131.1 (10.20.131.1)  17.896 ms  21.192 ms  20.007 ms
 3  10.10.8.2 (10.10.8.2)  39.897 ms  19.354 ms  20.043 ms
 4  84.10.109.7 (84.10.109.7)  19.780 ms !N  19.619 ms !N  19.887 ms !N

lab@Lager> traceroute 192.168.42.1
traceroute to 192.168.42.1 (192.168.42.1), 30 hops max, 40 byte packets
 1  10.10.131.2 (10.10.131.2)  8.841 ms  8.663 ms  9.940 ms
 2  10.20.129.2 (10.20.129.2)  19.825 ms  9.554 ms  9.726 ms
 3  172.16.1.1 (172.16.1.1)  9.979 ms !N  9.345 ms !N  10.121 ms !N

lab@Lager> traceroute 192.168.66.1
traceroute to 192.168.66.1 (192.168.66.1), 30 hops max, 40 byte packets
 1  10.10.131.2 (10.10.131.2)  8.731 ms  8.681 ms  10.097 ms
 2  10.20.129.2 (10.20.129.2)  19.732 ms  9.801 ms  9.650 ms
 3  172.16.1.1 (172.16.1.1)  9.872 ms  9.606 ms  9.856 ms
 4  172.16.2.2 (172.16.2.2)  39.847 ms !N  19.351 ms !N  29.992 ms !N
```

Lager forwards all external traffic to its ABR. The ABR (PBR in this case) then uses its BGP knowledge to make an optimal forwarding decision that adheres to Beer-Co's outbound routing policy. This completes the multihomed outbound routing policy scenario.

Dual-Homing and Outbound Policy Summary

In this section, you added a second EBGP peering and deployed IBGP on the necessary subset of routers within the Beer-Co network. A redundant route reflection topology was used to minimize the number of IBGP peerings while eliminating single points of failure.

With multihoming in place, you implemented an outbound policy that was a hybrid of the topology driven and strict primary/secondary models. This was achieved via an import policy that accepted only a subset of the routes advertised by your external BGP peers. This filtering allows an optimal routing decision for the specific routes that are accepted, while significantly reducing hardware requirements associated with handling full BGP feeds. The use of local preference ensured that a specific BGP learned default route is used for all other destinations, which in turn provided the strict primary/secondary (with revertive behavior) aspect of the sample outbound policy.

The next section builds upon this foundation by delving into the mechanics of implementing a typical inbound policy by manipulating BGP path attributes through the use of BGP export policy.

Inbound Policy

Referring back to Figure 5-9, it strikes you that the Beer-Co network has come a long way in recent weeks. The network has migrated from being single-homed to one provider to being multihomed to multiple providers, and you have successfully implemented a hybrid outbound policy based on a topology-driven model for peers and a primary/secondary model for transit. With these aspects of BGP operation in check, attention is focused on your company's inbound policy goals.

The use of stateful firewalls and NAT at the EBGP egress points greatly benefits from symmetric routing. By this, we mean that if a packet is routed to Destination X out of router `PBR`, ideally the response traffic will return along the same path to ingress back on router `PBR`. The symmetric routing paths tend to produce symmetric performance, which can be reason enough when asymmetric peering links are present, but the real goal here is to ensure that response traffic correctly matches against the dynamic state created when the outbound request was processed by the border router's stateful firewall.

The design goals for inbound policy indicate they should mirror your outbound policy—namely, that peers should route directly into your AS while transit traffic should arrive via the peering with Borgnet when available. In the previous section, local preference made steering traffic toward the desired EBGP speaker/egress point a straightforward matter. But as previously stated it's generally quite easy to control how traffic flows within your *own* network. The real art and finesse of BGP policy comes to bear when the goal is to influence traffic flow in a remote network that is not under your direct control. The Beer-Co inbound policy should provide the following behavior:

- Topological policy for peers, which should route directly into Beer-Co when the peering session is up
- Revertive primary/secondary traffic for nonadjacent ASs, which should ingress at `PBR` when that peering session is up

Table 5-2 summarizes the BGP attributes that can impact the policy/routing actions of a remote network. As a rule, attributes that are evaluated sooner in the path selection process are more likely to have an impact than those that are evaluated later. For example, altering local preference, which is evaluated at step 2 of 10, is likely to have some impact, whereas changing origin code, which is evaluated at step 4 of 10, is less likely to change a peer's forwarding behavior. The table uses parentheses to identify at which step of the 10-step decision process a given attribute is evaluated. Refer back to "BGP Path Selection" for details on these steps.

Table 5-2. BGP attributes that influence speakers in other networks

Attribute	Mechanism	Scope/caveat
AS path	AS path prepending impacts AS path selection criteria (step 3 of 10).	Global, in that once added, ASNs cannot be removed from the AS path list.
Origin	Altering origin impacts path selection criteria (step 4 of 10).	Global, but can be overwritten by intervening networks.
MED	Altering MED impacts MED selection criteria (step 5 of 10).	Adjacent AS only; MEDs are nontransitive. Generally, useful only for influencing link selection when all links terminate at the same adjacent AS.
Communities	Tagged routes are treated to some pre-agreed action, such as altered local preference.	Generally adjacent AS only. Many network operators strip all community tags upon ingress to their network, and again at egress.

It warrants restating that in all cases, the receiving ASs' policy can thwart even the most skilled attempts at controlling their outbound routing. For example, they can set a higher local preference, which means that AS path length is never even considered, which in turn negates any AS path prepending action you may perform in the hope of altering their path selection. This is why a detailed understanding of each peer AS's policies, and a good working relationship with their administrators, is always beneficial.

The most difficult aspect of the desired inbound policy is the need to influence the routing actions of Darknet, which does not peer directly with your AS. The goal is to make Darknet prefer the 10/8 aggregate it learns through Borgnet such that it uses the advertisement learned from Botnet only when the former is unavailable.

Using MED is out of the question here because the MED, being nontransitive, does not transit the networks you peer with. Also, `PBR` has a single attachment to Borgnet, so there is no use for MED there. MED could be used on the `Yeast`/Botnet peering to help steer ingress traffic over the high-speed link, but this is not the current focus. Communities are likely not an option because you are not a Darknet customer, and it's quite likely that they do not take action on communities attached to noncustomer routes; besides, communities may be stripped when the routes are exchanged between Borgnet and Darknet.

Before settling on a solution, it's noted that both of Beer-Co's BGP peers have a published policy regarding the use of customer routes with specific community tags. This policy results in a modified local preference setting within that peer's network. Table 5-3 provides the community-to-local preference mappings.

Table 5-3. Peer AS community-to-local preference mappings

Community value	Modified local preference
ASN:110	110
ASN:100	100

Table 5-3. Peer AS community-to-local preference mappings (continued)

Community value	Modified local preference
ASN:90	90
ASN:80	80

After careful consideration, it appears that the main problem in achieving the desired inbound behavior lies with the route selection algorithm in nonadjacent AS Darknet. Because you do not peer directly with this AS, the use of MED, and likely communities, is out. This narrows your choice to AS path prepending as the primary mechanism for influencing path selection within AS 666.

Figure 5-11 shows the state of affairs with regard to path selection for the 10/8 prefix in router Darknet.

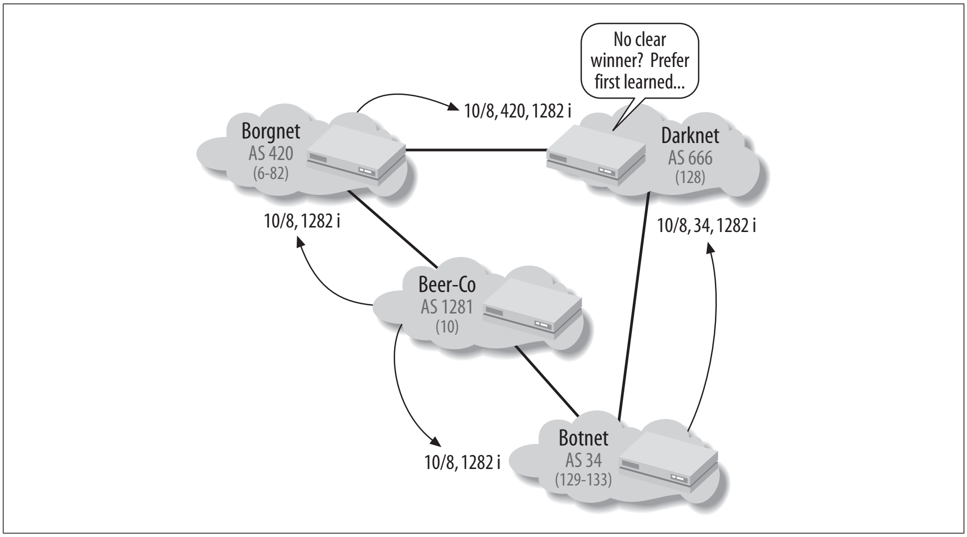


Figure 5-11. 10/8 route selection in Darknet

The figure shows that Darknet receives BGP updates for Beer-Co's 10/8 aggregate from both AS 420 and AS 34. Because all attributes are equal in this example, including the AS path length, the active path selected at Water is determined by which advertisement is learned first. To demonstrate, the 10/8 route is displayed at Water:

```
[edit]
lab@Water# run show route 10/8 detail

inet.0: 812 destinations, 1324 routes (812 active, 0 holddown, 0 hidden)
10.0.0.0/8 (2 entries, 1 announced)
        *BGP    Preference: 170/-101
                Next-hop reference count: 946
                Source: 84.10.110.2
                Next hop: 84.10.110.2 via fe-0/0/0.3243, selected
                State: <Active Ext>
                Local AS:   666 Peer AS:    34
                Age: 41:35
                Task: BGP_34.84.10.110.2+4664
                Announcement bits (2): 0-KRT 1-BGP RT Background
                AS path: 34 1282 I Aggregator: 1282 10.30.1.1
                Localpref: 100
                Router ID: 84.10.109.1
         BGP    Preference: 170/-101
                Next-hop reference count: 682
                Source: 172.16.2.1
                Next hop: 172.16.2.1 via fe-0/0/0.423, selected
                State: <Ext>
                Inactive reason: Active preferred
                Local AS:   666 Peer AS:   420
                Age: 39:41
                Task: BGP_420.172.16.2.1+179
                AS path: 420 1282 I Aggregator: 1282 10.20.128.3
                Localpref: 100
                Router ID: 172.16.1.3
```

The output shows that Water installed the path through AS 34 as the active path, and that the desired primary path is currently not preferred, simply because it was not learned first. Recall that for an EBGP learned route, step 9 of the active route selection process, which normally prefers the lower RID, is not performed due to MED oscillation issues. Instead, EBGP learned routes eliminate steps 9 and 10 to simply prefer the route that is learned first. Because this condition is timing-dependent, if something happens to the 10/8 advertisement from Botnet, the situation is reversed:

```
[edit]
lab@hops# run clear bgp neighbor 84.10.110.1
Cleared 1 connections
```

After waiting for the Botnet/Darknet EBGP peering to reform, the path to 10/8 is again displayed at Water:

```
[edit]
lab@Water# run show route 10/8

inet.0: 812 destinations, 1370 routes (812 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.0.0.0/8         *[BGP/170] 00:43:43, localpref 100
                      AS path: 420 1282 I
                    > to 172.16.2.1 via fe-0/0/0.423
                    [BGP/170] 00:00:29, localpref 100
                      AS path: 34 1282 I
                    > to 84.10.110.2 via fe-0/0/0.3243
```

The display confirms that the tie-breaking action of prefer first-learned is not going to reliably produce the desired inbound policy; nor would relying on the RID/peering address tiebreakers for that matter. This looks like a classic example of how AS path prepending can help to steer path selection by remote networks—in this case, one that you do not even peer with. If the export policy at Yeast is altered to add an extra instance of the local AS number, the AS path length selection criterion should result in the path through AS 420 always being preferred by Darknet routers when available.

AS Path Prepend to Influence Nonadjacent AS Path Selection

Previous analysis of the policy showed that increasing the AS path length for the 10/8 prefix that Darknet learns from Botnet should result in the desired behavior of nonadjacent ASs routing to your network using Botnet as the primary transit AS.

The existing as_34_export policy is displayed at Yeast:

```
[edit]
lab@Yeast# show policy-options policy-statement as_34_export
term 1 {
    from {
        protocol aggregate;
        route-filter 10.0.0.0/8 exact;
    }
    then accept;
}
```

The as_34_export policy is modified to add *two* extra instances of ASN 1282 to the 10/8 update—based on Figure 5-11, it appears that only one instance is required, but extra padding should help to ensure that Darknet prefers the path through Borgnet and provides an additional safety margin to accommodate the potential for topology changes between Borgnet and Darknet. Such a routing change might result in transit through additional ASs and a corresponding increase in the AS path length over the preferred path.

```
[edit policy-options policy-statement as_34_export]
lab@Yeast# show
term 1 {
    from {
        protocol aggregate;
        route-filter 10.0.0.0/8 exact;
    }
    then {
        as-path-prepend "1282 1282";
        accept;
    }
}
```

The effects are examined from the perspective of router Water in the Darknet AS:

```
[edit]
lab@Water# run show route 10/8 detail

inet.0: 812 destinations, 1370 routes (812 active, 0 holddown, 0 hidden)
```

```
10.0.0.0/8 (2 entries, 1 announced)
    *BGP    Preference: 170/-101
            Next-hop reference count: 684
            Source: 172.16.2.1
            Next hop: 172.16.2.1 via fe-0/0/0.423, selected
            State: <Active Ext>
            Local AS:   666 Peer AS:   420
            Age: 53:05
            Task: BGP_420.172.16.2.1+179
            Announcement bits (2): 0-KRT 1-BGP RT Background
            AS path: 420 1282 I Aggregator: 1282 10.20.128.3
            Localpref: 100
            Router ID: 172.16.1.3
     BGP    Preference: 170/-101
            Next-hop reference count: 990
            Source: 84.10.110.2
            Next hop: 84.10.110.2 via fe-0/0/0.3243, selected
            State: <Ext>
            Inactive reason: AS path
            Local AS:   666 Peer AS:    34
            Age: 59
            Task: BGP_34.84.10.110.2+4730
            AS path: 34 1282 1282 I Aggregator: 1282 10.30.1.1
            Localpref: 100
            Router ID: 84.10.109.1
```

The output confirms that chance has been removed from the path selection process for the 10/8 prefix at Water. The longer AS path in the 10/8 prefix learned from the Botnet AS ensures that AS 666 always prefers to route through Borgnet to reach Beer-Co, unless that path is withdrawn (due to problems with the PBR–Wheat peering), at which point it falls back to the Botnet path.

To the casual observer, Beer-Co has met its inbound policy goals, all with a single-line addition to an existing export policy to affect AS path prepending. BGP policy is not really that hard, it would seem. Before heading out the door, you decide to confirm failover behavior. This begins by deactivating the secondary EBGP session to confirm that all traffic arrives at the Borgnet peering:

```
 [edit]
lab@Yeast# deactivate protocols bgp group as_34

[edit]
lab@Yeast# commit
```

Traceroutes are now performed from routers *within* the adjacent and nonadjacent ASs. In most cases, you will need to inspect each AS's routing view, perhaps through a looking glass service, to confirm their forwarding paths.

All routers in the test network advertise their loopbacks (or an encompassing aggregate route) into BGP. All traceroutes are conducted between loopback addresses because full connectivity is expected among the prefixes used for loopback addressing.

What Is a Looking Glass?

A looking glass is basically a publicly accessible route server that allows you to view Internet routing, from the perspective of that particular route server. You use a looking glass to see the effects of that network's import policy and active route selection process, by displaying which BGP paths it has installed as active. You can also gauge the relative stability of a prefix, from the view of that looking glass, by examining how long a route has been known. The following example makes use of an AT&T looking glass, as listed at *http://www.nanog.org/lookingglass.html*, to display its view of the route to Juniper Networks:

```
------------- route-server.ip.att.net ---------------

User Access Verification

Username: rviews
route-server>sho ip rou juniper.net
Routing entry for 207.17.136.0/22, supernet
  Known via "bgp 65000", distance 20, metric 0
  Tag 7018, type external
  Last update from 12.123.1.236 2w3d ago
  Routing Descriptor Blocks:
  * 12.123.1.236, from 12.123.1.236, 2w3d ago
      Route metric is 0, traffic share count is 1
      AS Hops 3
      Route tag 7018

route-server>sho ip bgp 207.17.136.0/22
BGP routing table entry for 207.17.136.0/22, version 181930
Paths: (18 available, best #13, table Default-IP-Routing-Table)
  Not advertised to any peer
  7018 2914 14203, (received & used)
    12.123.29.249 from 12.123.29.249 (12.123.29.249)
      Origin IGP, localpref 100, valid, external
      Community: 7018:5000 7018:33051
. . .
```

The output suggests that AT&T has learned this route from 18 different speakers, that the prefix is stable (given that the last update was more than two weeks ago), and that the AS path to reach this prefix from within AT&T is 7018 (AT&T WorldNet), 2914 (Verio), and finally, 14203 (Juniper Networks itself).

```
[edit]
lab@Wheat# run traceroute 10.10.12.2 source 172.16.1.3
traceroute to 10.10.12.2 (10.10.12.2), 30 hops max, 40 byte packets
 1  172.16.1.2 (172.16.1.2)  17.316 ms  10.118 ms  21.751 ms
 2  10.20.129.1 (10.20.129.1)  12.798 ms  9.507 ms  9.711 ms
 3  10.10.12.2 (10.10.12.2)  16.981 ms  22.462 ms  19.689 ms
```

The traceroute to Porter's loopback address succeeds from within AS 420:

```
[edit]
lab@Water# run traceroute 10.10.12.2 source 64.8.12.1
traceroute to 10.10.12.2 (10.10.12.2), 30 hops max, 40 byte packets
 1  172.16.2.1 (172.16.2.1)  106.100 ms  17.772 ms  10.472 ms
 2  172.16.1.2 (172.16.1.2)  9.423 ms  9.373 ms  9.842 ms
 3  10.20.129.1 (10.20.129.1)  20.042 ms  39.411 ms  19.786 ms
 4  10.10.12.2 (10.10.12.2)  10.109 ms  9.390 ms  94.337 ms
```

The traceroute to Porter's loopback address succeeds from within AS 66:

```
[edit]
lab@hops# run traceroute 10.10.12.2 source 84.10.109.1
traceroute to 10.10.12.2 (10.10.12.2) from 84.10.109.1, 30 hops max, 40 byte packets
 1  84.10.110.1  45.013 ms  125.144 ms  25.062 ms
 2  172.16.2.1  8.442 ms  19.978 ms  9.940 ms
 3  172.16.1.2  30.019 ms  9.885 ms  9.849 ms
 4  10.20.129.1  16.135 ms  10.130 ms  13.433 ms
 5  10.10.12.2  15.628 ms  24.492 ms  16.888 ms
```

And finally, the traceroute to Porter's loopback address succeeds from within AS 34. So far so good, so the EBGP peering session to AS 34 is reactivated. After waiting for the EBGP session to Botnet to re-form, the traceroutes are repeated:

```
[edit]
lab@Wheat# run traceroute 10.10.12.2 source 172.16.1.3
traceroute to 10.10.12.2 (10.10.12.2), 30 hops max, 40 byte packets
 1  172.16.1.2 (172.16.1.2)  9.914 ms  8.950 ms  9.571 ms
 2  10.20.129.1 (10.20.129.1)  19.977 ms  19.534 ms  19.824 ms
 3  10.10.12.2 (10.10.12.2)  9.886 ms  9.498 ms  9.848 ms

lab@Water> traceroute 10.10.12.2 source 64.8.12.1
traceroute to 10.10.12.2 (10.10.12.2), 30 hops max, 40 byte packets
 1  172.16.2.1 (172.16.2.1)  19.317 ms  12.022 ms  16.594 ms
 2  172.16.1.2 (172.16.1.2)  9.889 ms  9.364 ms  10.281 ms
 3  10.20.129.1 (10.20.129.1)  19.596 ms  19.528 ms  7.891 ms
 4  10.10.12.2 (10.10.12.2)  21.967 ms  49.523 ms  9.720 ms
```

The results from Borgnet and Darknet are as before, and both are as expected. Things are not ideal from the perspective for Botnet, however:

```
[edit]
lab@hops# run traceroute 10.10.12.2 source 84.10.109.1
traceroute to 10.10.12.2 (10.10.12.2) from 84.10.109.1, 30 hops max, 40 byte packets
 1  84.10.110.1 (84.10.110.1)  8.589 ms  8.666 ms  10.118 ms
 2  172.16.2.1 (172.16.2.1)  29.935 ms  19.230 ms  20.005 ms
 3  172.16.1.2 (172.16.1.2)  20.021 ms  19.588 ms  19.710 ms
 4  10.20.129.1 (10.20.129.1)  9.916 ms  9.298 ms  10.128 ms
 5  10.10.12.2 (10.10.12.2)  21.422 ms  17.796 ms  14.098 ms
```

The traceroute from Botnet clearly shows that the traffic is failing to arrive at the peering exchange for that AS, resulting in extra AS hops as the traffic is directed over the primary path. This is a violation of the desired inbound policy. Displaying the route to 10/8 at Botnet confirms the problem and sheds lights on its cause:

```
[edit]
lab@hops# run show route 10/8 detail

inet.0: 817 destinations, 1069 routes (817 active, 0 holddown, 0 hidden)
10.0.0.0/8 (3 entries, 1 announced)
        *BGP    Preference: 170/-101
                Next-hop reference count: 750
                Source: 84.10.110.1
                Next hop: 84.10.110.1 via fe-0/0/0.3243, selected
                State: <Active Ext>
                Local AS:    34 Peer AS:   666
                Age: 43:41
                Task: BGP_666.84.10.110.1+179
                Announcement bits (2): 0-KRT 2-BGP RT Background
                AS path: 666 420 1282 I Aggregator: 1282 10.20.128.3
                Localpref: 100
                Router ID: 64.8.12.1
         BGP    Preference: 170/-101
                Next-hop reference count: 126
                Source: 84.10.109.8
                Next hop: 84.10.109.8 via fe-0/0/0.3233, selected
                State: <Ext>
                Inactive reason: Active preferred
                Local AS:    34 Peer AS:  1282
                Age: 4:36
                Task: BGP_1282.84.10.109.8+2957
                AS path: 1282 1282 1282 I Aggregator: 1282 10.30.1.1
                Localpref: 100
                Router ID: 10.30.1.1
         BGP    Preference: 170/-101
                Next-hop reference count: 126
                Source: 84.10.113.0
                Next hop: 84.10.113.0 via t1-0/0/2.0, selected
                State: <NotBest Ext>
                Inactive reason: Not Best in its group
                Local AS:    34 Peer AS:  1282
                Age: 4:32
                Task: BGP_1282.84.10.113.0+3127
                AS path: 1282 1282 1282 I Aggregator: 1282 10.30.1.1
                Localpref: 100
                Router ID: 10.30.1.1
```

IP internetworks are complicated systems, and with any such systems, making a change in one place can have unexpected consequences somewhere else. Before you added AS path prepending, both peer ASs had no problems preferring Beer-Co's 10/8 aggregate as learned directly from Beer-Co. This was because an AS path length of 1 is very hard to beat. The use of AS path prepending, in an attempt to make Darknet prefer the path through the Borgnet AS, has inadvertently altered the path selection in peer AS 34.

Even worse is that this situation results in path selection that is tied to the order in which routes are learned. Timing-related route selection issues are difficult to troubleshoot because administrative actions on one front—say, attribute modification—may trigger a change in the order that routes are learned. This can easily lead to an incorrect belief that policy changes are behind the altered path selection, when in reality things may change back at the next outage. Fortunately, there is a straightforward solution to this problem: community tags.

Use Communities to Influence Peer AS

Referring back to Table 5-3, notice that you can affect the local preference value within your peer ASs by attaching a specific community to your route updates. Because local preference is evaluated before AS path length, altering the local preference of the 10/8 route within AS 34 should be just the ticket. This change ensures that AS 34 always prefers the 10/8 learned directly from the Beer-Co peering regardless of the related AS path length.

Your changes begin with the definition of named communities. In this example, you need to set the 10/8 local preference to a value higher than 100, which is the default. Here, multiple communities are defined, but only the 110 community definition is required and used:

```
[edit]
lab@Yeast# show policy-options
. . .
community 100 members 1282:100;
community 110 members 1282:110;
community 70 members 1282:70;
community 80 members 1282:80;
community 90 members 1282:90;
community bw_fast members bandwidth:1287:12500000;
community bw_slow members bandwidth:1287:193000;
as-path 34_originate "^34$";
as-path 34_trans "^34.+$";
```

The existing `as_34_export` policy is altered to add the appropriate community, which is `110` in this example:

```
[edit policy-options policy-statement as_34_export]
lab@Yeast# show
term 1 {
    from {
        protocol aggregate;
        route-filter 10.0.0.0/8 exact;
    }
    then {
        community add 110;
        as-path-prepend "1282 1282";
        accept;
    }
}
```

The results are confirmed at router Hops in AS 34:

```
[edit]
lab@hops# run show route 10/8 detail

inet.0: 817 destinations, 1069 routes (817 active, 0 holddown, 0 hidden)
10.0.0.0/8 (3 entries, 1 announced)
        *BGP    Preference: 170/-111
                Next-hop reference count: 2
                Source: 84.10.109.8
                Next hop: 84.10.109.8 via fe-0/0/0.3233
                Next hop: 84.10.113.0 via t1-0/0/2.0, selected
                State: <Active Ext>
                Local AS:    34 Peer AS:  1282
                Age: 12
                Task: BGP_1282.84.10.109.8+2957
                Announcement bits (2): 0-KRT 2-BGP RT Background
                AS path: 1282 1282 1282 I Aggregator: 1282 10.30.1.1
                Communities: 1282:110
                Localpref: 110
                Router ID: 10.30.1.1
         BGP    Preference: 170/-111
                Next-hop reference count: 126
                Source: 84.10.113.0
                Next hop: 84.10.113.0 via t1-0/0/2.0, selected
                State: <NotBest Ext>
                Inactive reason: Update source
                Local AS:    34 Peer AS:  1282
                Age: 12
                Task: BGP_1282.84.10.113.0+3127
                AS path: 1282 1282 1282 I Aggregator: 1282 10.30.1.1
                Communities: 1282:110
                Localpref: 110
                Router ID: 10.30.1.1
         BGP    Preference: 170/-101
                Next-hop reference count: 749
                Source: 84.10.110.1
                Next hop: 84.10.110.1 via fe-0/0/0.3243, selected
                State: <Ext>
                Inactive reason: Local Preference
                Local AS:    34 Peer AS:   666
                Age: 1:11:39
                Task: BGP_666.84.10.110.1+179
                AS path: 666 420 1282 I Aggregator: 1282 10.20.128.3
                Localpref: 100
                Router ID: 64.8.12.1
```

Excellent! AS 34 now prefers the route learned directly from Beer-Co, and it still has a valid alternate path in the event of BGP session disruption to Beer-Co. The primary peering link is now deactivated to verify failover to the secondary and reversion back to the primary upon restoration:

```
[edit]
lab@PBR# deactivate protocols bgp group as_420
```

Traceroutes are now performed from adjacent and nonadjacent ASs:

```
[edit]
lab@Wheat# run traceroute 10.10.12.2 source 172.16.1.3
traceroute to 10.10.12.2 (10.10.12.2) from 172.16.1.3, 30 hops max, 40 byte packets
 1  172.16.2.2 (172.16.2.2)  8.411 ms  8.980 ms  9.840 ms
 2  84.10.110.2 (84.10.110.2)  20.057 ms  29.367 ms  9.886 ms
 3  84.10.113.0 (84.10.113.0)  19.999 ms  39.343 ms  20.021 ms
 4  10.10.12.2 (10.10.12.2)  13.796 ms  15.536 ms  19.873 ms

lab@Water> traceroute 10.10.12.2 source 64.8.12.1
traceroute to 10.10.12.2 (10.10.12.2) from 64.8.12.1, 30 hops max, 40 byte packets
 1  84.10.110.2 (84.10.110.2)  30.620 ms  21.427 ms  19.623 ms
 2  84.10.113.0 (84.10.113.0)  30.052 ms  16.285 ms  12.970 ms
 3  10.10.12.2 (10.10.12.2)  20.066 ms  35.912 ms  13.312 ms

[edit]
lab@hops# run traceroute 10.10.12.2 source 84.10.109.1
traceroute to 10.10.12.2 (10.10.12.2) from 84.10.109.1, 30 hops max, 40 byte packets
 1  84.10.113.0 (84.10.113.0)  8.924 ms  28.830 ms  9.856 ms
 2  10.10.12.2 (10.10.12.2)  9.846 ms  9.697 ms  9.795 ms
```

The results prove continued connectivity for both adjacent and nonadjacent ASs, with all traffic now arriving at the only functional peering exchange. The desired failover behavior is working. The Borgnet peering session is now reactivated to test the revertive behavior:

```
[edit]
lab@PBR# rollback 1
load complete
```

After session establishment, traceroutes are again performed to verify revertive primary behavior. Recall that the goal is to have peers route directly into AS 1282 while nonadjacent ASs route toward the Borgnet peering to ingress at PBR:

```
[edit]
lab@Wheat# run traceroute 10.10.12.2 source 172.16.1.3
traceroute to 10.10.12.2 (10.10.12.2) from 172.16.1.3, 30 hops max, 40 byte packets
 1  172.16.1.2 (172.16.1.2)  19.252 ms  12.858 ms  16.050 ms
 2  10.20.129.1 (10.20.129.1)  9.900 ms  9.498 ms  9.686 ms
 3  10.10.12.2 (10.10.12.2)  19.985 ms  19.611 ms  19.615 ms

lab@Water> traceroute 10.10.12.2 source 64.8.12.1
traceroute to 10.10.12.2 (10.10.12.2) from 64.8.12.1, 30 hops max, 40 byte packets
 1  172.16.2.1 (172.16.2.1)  9.220 ms  8.755 ms  29.928 ms
 2  172.16.1.2 (172.16.1.2)  9.844 ms  9.609 ms  9.873 ms
 3  10.20.129.1 (10.20.129.1)  29.962 ms  19.311 ms  20.003 ms
 4  10.10.12.2 (10.10.12.2)  9.862 ms  29.366 ms  29.967 ms

[edit]
lab@hops# run traceroute 10.10.12.2 source 84.10.109.1
traceroute to 10.10.12.2 (10.10.12.2) from 84.10.109.1, 30 hops max, 40 byte packets
 1  84.10.113.0 (84.10.113.0)  9.691 ms  8.756 ms  9.864 ms
 2  10.10.12.2 (10.10.12.2)  19.969 ms  29.445 ms  9.859 ms
```

The results confirm desired inbound policy behavior, thereby concluding the EBGP multihomed enterprise routing scenario. For completeness, the complete protocols and policy stanzas for EBGP routers PBR and Yeast, reflector Porter, and client Stout are shown.

Here is router PBR's configuration:

```
[edit]
lab@PBR# show policy-options | no-more
policy-statement as_420_export {
    term 1 {
        from {
            protocol aggregate;
            route-filter 10.0.0.0/8 exact;
        }
        then accept;
    }
}
policy-statement as_420_import {
    term 1 {
        from {
            protocol bgp;
            as-path as_420_originate;
        }
        then accept;
    }
    term 2 {
        then reject;
    }
}
policy-statement next_hop_self {
    term 1 {
        from protocol bgp;
        then {
            next-hop self;
        }
    }
}
policy-statement prefer_Borgnet_transit {
    term 1 {
        from {
            protocol bgp;
            route-filter 0.0.0.0/0 exact;
        }
        then {
            local-preference 110;
        }
    }
}
as-path as_420_originate "^420+$";

[edit]
lab@PBR# show protocols
```

```
bgp {
    group as_420 {
        type external;
        import as_420_import;
        export as_420_export;
        neighbor 172.16.1.1 {
            peer-as 420;
        }
    }
    group 1282_clients {
        type internal;
        local-address 10.20.128.3;
        export [ next_hop_self prefer_Borgnet_transit ];
        neighbor 10.10.12.3;
        neighbor 10.10.12.2;
    }
}
ospf {
    area 0.0.0.0 {
        interface fe-0/0/0.3141;
        interface fe-0/0/0.1241;
    }
    area 0.0.0.1 {
        stub default-metric 10;
        interface fe-0/0/0.1141;
    }
}
```

Here is router Yeast's configuration:

```
[edit]
lab@Yeast# show policy-options | no-more
policy-statement as_34_export {
    term 1 {
        from {
            protocol aggregate;
            route-filter 10.0.0.0/8 exact;
        }
        then {
            community add 110;
            as-path-prepend "1282 1282";
            accept;
        }
    }
}
policy-statement as_34_import {
    term slow_peer {
        from {
            protocol bgp;
            neighbor 84.10.113.1;
        }
        then {
            community add bw_slow;
        }
    }
    term fast_peer {
        from {
            protocol bgp;
            neighbor 84.10.109.7;
        }
        then {
            community add bw_fast;
        }
    }
}
policy-statement as_34_originate {
    term 1 {
        from {
            protocol bgp;
            as-path 34_originate;
        }
        then accept;
    }
    term 2 {
        then reject;
    }
}
policy-statement lb_per_packet {
    then {
        load-balance per-packet;
        accept;
    }
}
policy-statement next_hop_self {
    term 1 {
        from protocol bgp;
        then {
            next-hop self;
        }
    }
}
community 100 members 1282:100;
community 110 members 1282:110;
community 70 members 1282:70;
community 80 members 1282:80;
community 90 members 1282:90;
community bw_fast members bandwidth:1287:12500000;
community bw_slow members bandwidth:1287:193000;
as-path 34_originate "^34$";
as-path 34_trans "^34.+$";

[edit]
lab@Yeast# show protocols | no-more
bgp {
    group as_34 {
        type external;
        import [ as_34_import as_34_originate ];
        export as_34_export;
        peer-as 34;
        multipath;
        neighbor 84.10.109.7;
        neighbor 84.10.113.1;
    }
    group 1282_clients {
        type internal;
        local-address 10.30.1.1;
        export next_hop_self;
        neighbor 10.10.12.3;
        neighbor 10.10.12.2;
    }
}
ospf {
    area 0.0.0.0 {
        interface fe-0/0/1.2332;
    }
}
```

Here is route reflector Porter's configuration:

```
[edit]
lab@Porter# show policy-options

[edit]
lab@Porter# show protocols | no-more
bgp {
    group 1282_rr {
        type internal;
        local-address 10.10.12.2;
        neighbor 10.10.12.3;
    }
    group 1282_clients {
        type internal;
        local-address 10.10.12.2;
        ##
        ## Warning: requires 'bgp-reflection' license
        ##
        cluster 1.2.8.2;
        neighbor 10.20.128.4;
        neighbor 10.20.128.3;
        neighbor 10.30.1.1;
    }
}
ospf {
    area 0.0.0.0 {
        interface fe-0/0/1.1331;
        interface fe-0/0/1.2332;
        interface t1-0/0/2.0;
    }
}
```

Here is client Stout's configuration:

```
[edit]
lab@stout# show policy-options
```

```
[edit]
lab@stout# show protocols | no-more
bgp {
    group 1282_clients {
        type internal;
        local-address 10.20.128.4;
        neighbor 10.10.12.3;
        neighbor 10.10.12.2;
    }
}
ospf {
    area 0.0.0.0 {
        interface fe-0/0/0.3141;
        interface fe-0/0/1.1331;
    }
    area 0.0.0.2 {
        stub default-metric 10;
        interface fe-0/0/0.2131;
    }
}
```

BGP Inbound Policy Summary

This section demonstrated ways in which a dual-homed enterprise can manipulate BGP path attributes to achieve a desired inbound policy goal. The example demonstrated the need for both AS path manipulation and the use of BGP communities, which worked together to influence the routing decisions of both adjacent and non-adjacent ASs.

Conclusion

BGP can have a dramatic impact on the operation of an enterprise network when the network is multihomed, and even more so when it is multihomed to multiple providers. BGP itself is not a very complex protocol, but the myriad ways in which its attributes are acted upon, and the cascading effects of advertising only what the local speaker considers the best route, often lead to an unanticipated result. To the uninitiated, this often leads to confusion and what might seem to be unpredictable behavior. JUNOS software provides a complete set of diagnostic tools, from the CLI's operational mode displays to the extensive protocol tracing, which makes most BGP problems easy to diagnose. For example, the way the software displays *why* a given BGP path was not selected makes changing the results for that BGP decision step a straightforward matter, that is, whatever attribute caused the route to lose should be modified.

EBGP and IBGP are similar, but they have key differences in the way they are typically configured and in how they operate. This chapter detailed those differences and demonstrated typical EBGP physical peering and IBGP loopback-based peering.

Because IBGP does not rewrite the next hop, you will often need a next hop self-policy or some other method of advertising the external EBGP peering address into your IGP.

Bringing up BGP peerings is really just the start of the process. BGP is all about policy and administrative control over route exchanges, and therefore forwarding paths. Outbound policy controls how your network chooses to reach destinations and is relatively easy to implement as you control all aspects of your own network's operation. Inbound policy is far trickier, because here you are attempting to impact decisions made in remote ASs, over which you have no direct control. A detailed understanding of the BGP attributes that reach into, and beyond, other networks increases the probability that remote networks will bend to your will, resulting in ingress traffic patterns that optimize those factors that matter most within your organization.

The large size of BGP tables means that careful consideration should be leveled as to which routers need to run the protocol and on the import policy that determines which prefixes are accepted. The careful application of policy can easily reduce a BGP table from more than 230,000 routes to a more manageable set that can be distributed among lower-end routers. A partial table can be used to make intelligent routing decisions that optimize network resources and performance. When a full BGP table is not feasible, some form of a default route is used to balance the remaining prefixes or to direct the network traffic to a primary egress point as local policy dictates.

Route reflection is often used to reduce the burden of maintaining a full IBGP mess among a network's IBGP speakers, and when combined with route filtering, it allows the deployment of BGP on even the smallest of enterprise routers.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- Explain the use of BGP.
- Differentiate between IBGP and EBGP sessions.
- Policies to control route advertisement.
- Miscellaneous BGP configuration options.
- Load-balancing BGP routes.
- ISP multihoming scenarios.
- Configure an IBGP route reflection topology.
- Configure EBGP sessions.
- Identify BGP attributes that can be modified using policies.
- Implement a BGP policy for routing traffic over multiple ISP connections.

Chapter Review Questions

1. What BGP attribute guards against loops?
    a. MED
    b. Barring an IBGP speaker from resending IBGP updates
    c. Cluster ID
    d. AS path
2. What BGP attribute is most likely to influence egress from your AS?
    a. AS path
    b. Local preference
    c. MED
    d. Cluster length
    e. None of the above
3. What BGP attribute is mostly likely to influence a remote AS that you do not peer with?
    a. This is not possible given the local scope of BGP
    b. AS path
    c. MED
    d. Local preference
4. Which of the following correctly describes how IBGP differs from EBGP?
    a. IBGP peers to the interface address while EBGP peers to loopbacks
    b. IBGP updates do not alter the next hop attribute
    c. EBGP updates do not alter the next hop
    d. EBGP requires a full mesh
5. When export policy is specified at the global, group, and neighbor levels, which policy is executed?
    a. Only the least specific, which is global export
    b. Only the most specific, which is neighbor-level export
    c. All three are chained, and the global, group, and neighbor policies are executed
    d. None of the above; export can be defined only at the group level
6. When you issue a `show bgp summary` command, what is indicated by the Active state?
    a. The router is actively trying to form the BGP session; you should wait
    b. The session is established and active; you are done

c. The router is unable to even route the session; you should suspect a routing problem

d. At least one route has been received and made active

7. What command displays the routes you are receiving from a BGP peer?

a. `show route advertising-protocol bgp`

b. `show route receive-protocol bgp`

c. `show route protocol bgp`

d. `show ip route bgp`

8. Which type of JUNOS software policy is normally applied at an EBGP speaker to achieve an organization's *outbound* policy?

a. Export policy

b. Import policy

c. Inbound policy

d. Outbound policy

9. When implementing loopback-based peering, what is the purpose of the `local-address` statement?

a. It ensures that the router sources the connection from its loopback address

b. It ensures that the router sources the connection from the interface closest to the session target

c. It eliminates the need for recursive route lookup in EBGP peering

d. It eliminates the need for recursive route lookup in IBGP peering

10. Which of the following is/are true regarding route reflection on a J-series router?

a. A license is required for support, not operation

b. A single command is needed on the reflector

c. New attributes are needed to prevent route looping

d. Reflectors can hide parts of the topology because they reflect only their choice of best route

e. All of the above

11. When configuring BGP in JUNOS software, where is the local router's AS defined?

a. At the `[edit protocols bgp]` hierarchy

b. At the `[edit routing-options]` hierarchy

c. At the `[edit protocols bgp group]` hierarchy

d. At the `[edit protocols bgp group` *`<group name>`* `neighbor]` hierarchy

12. In the following display, why is the route learned from 84.10.109.8 not active?

```
inet.0: 817 destinations, 1069 routes (817 active, 0 holddown, 0 hidden)
10.0.0.0/8 (3 entries, 1 announced)
```

```
        *BGP    Preference: 170/-101
                Next-hop reference count: 750
                Source: 84.10.110.1
                Next hop: 84.10.110.1 via fe-0/0/0.3243, selected
                State: <Active Ext>
                Local AS:    34 Peer AS:   666
                Age: 43:41
                Task: BGP_666.84.10.110.1+179
                Announcement bits (2): 0-KRT 2-BGP RT Background
                AS path: 666 420 1282 I Aggregator: 1282 10.20.128.3
                Localpref: 100
                Router ID: 64.8.12.1
         BGP    Preference: 170/-101
                Next-hop reference count: 126
                Source: 84.10.109.8
                Next hop: 84.10.109.8 via fe-0/0/0.3233, selected
                State: <Ext>
                Inactive reason: Active preferred
                Local AS:    34 Peer AS:  1282
                Age: 4:36
                Task: BGP_1282.84.10.109.8+2957
                AS path: 1282 1282 1282 I Aggregator: 1282 10.30.1.1
                Localpref: 100
                Router ID: 10.30.1.1
         BGP    Preference: 170/-101
                Next-hop reference count: 126
                Source: 84.10.113.0
                Next hop: 84.10.113.0 via t1-0/0/2.0, selected
                State: <NotBest Ext>
                Inactive reason: Not Best in its group
                Local AS:    34 Peer AS:  1282
                Age: 4:32
                Task: BGP_1282.84.10.113.0+3127
                AS path: 1282 1282 1282 I Aggregator: 1282 10.30.1.1
                Localpref: 100
                Router ID: 10.30.1.1
```

a. When all else is equal, an EBGP speaker prefers the first route learned

b. When all else is equal, an IBGP speaker prefers the first route learned

c. When all else is equal, the router prefers the route with best preference

d. The AS path is shorter

Chapter Review Answers

1. Answer: D. The AS path attribute records each AS that a route update has passed through, and is updated on EBGP links. A BGP speaker discards received updates that contain the local ASN in the AS path.
2. Answer: B. The local preference attribute is evaluated early in the BGP decision process, before AS path, MED, origin, and so on.

3. Answer: B. The AS path attribute has global significance; once a value has been added, no other speaker can remove that ASN from the list because this would break BGP's loop prevention. The AS path is considered early in the selection process, and so has a good chance of impacting forwarding decisions in remote ASs. MED does not transit the peer AS, local preference is not supported on EBGP links, and communities can be stripped.
4. Answer: B. The next hop is unchanged on IBGP updates, but it is rewritten on EBGP links. EBGP does not require a full mesh, because the AS path is updated on EBGP links.
5. Answer: B. JUNOS software applies only the most specific policy applications, and a neighbor level is more specific than a group level, which is more specific than a global level. If you need a particular neighbor to execute what you consider a global, group, and neighbor policy, all three must be changed at the neighbor level.
6. Answer: A. The Idle state indicates an inability to route the session, and an established session is displayed with an `x/x/x`, for active, received, and damped routes, respectively.
7. Answer: B. The `show route protocol bgp` command shows all routes learned via BGP, not those from a given neighbor.
8. Answer: B. By filtering and setting attributes in received routes, you most directly impact how your network in turn sends to external destinations. Export policy is normally used to influence peers in the remote AS to affect your inbound policy goals.
9. Answer: A. Loopback-based peering requires that the router source the connection from its loopback interface to match the definition at the remote peer. A recursive route lookup is always required for a loopback-based peering because the remote router's loopback address can never be direct, and therefore must be resolved to a direct forwarding next hop via an IGP, to include a static route.
10. Answer: E. All of the options listed are true.
11. Answer: B. The local router's autonomous number is configured under routing options. The peer AS number is configured at the group or neighbor level for EBGP groups.
12. Answer: A. The RID and peering address tie breakers are replaced by first-learned for EBGP learned routes only. In this example, all three routes have the same local preference, global preference, and AS path length.

CHAPTER 6
Access Security

This chapter discusses the techniques of securing the router via different types of access security. *Access security* is a broad term that includes the creation of users with various authorization levels or allowing access to particular services or networks. Also included in *access security* is verifying that the router has not been compromised and is performing as you expected. The topics covered include:

- Security concepts
- Securing access to the router
- Firewall filters and policers
- Spoof prevention
- Router monitoring

Security Concepts

Everybody wants to have a secure network, but providing that security is often a very complex and difficult process due to the multiple levels that need to be examined. For example, it does not do much good if you provide very detailed filters and access privileges on a router, when the physical access is an unlocked door in a wiring closet at a remote location. Security must not be an afterthought; it must be designed literally from the ground up, from physical access to the network to filters that allow only certain types of traffic. When implementing security at any layer, design toward the security concepts that are displayed in Figure 6-1: integrity, availability, and confidentiality. These concepts will help to build the network's circle of trust.

The first concept of security design is to ensure the *integrity* of the data. In other words, the data should not be altered in any way without purpose. This includes data that could be modified by unauthorized personnel, but does not exclude data manipulation by authorized personnel. Many network breaches are sourced from an "insider," someone who either works or did work for the company. This could be a disgruntled employee who decides to wreak havoc on the network because he never

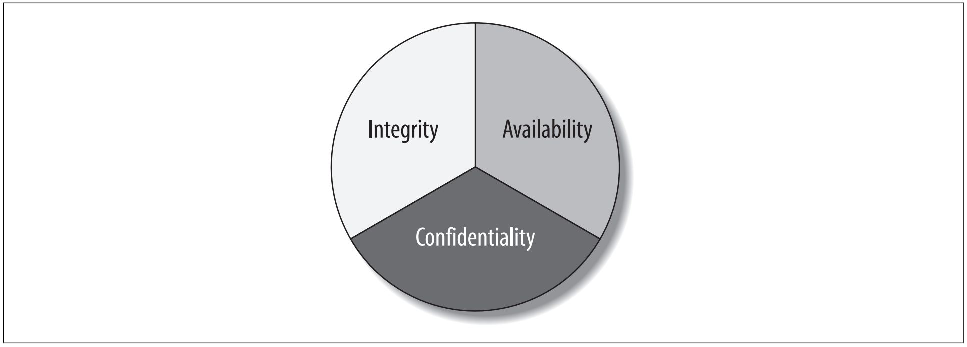


Figure 6-1. Security circle of trust

received his new office stapler! Also, data integrity implies that the data is consistent across internal and external access—that is, a user should not have the experience of making changes to a device from home only to discover that those changes were never propagated to the network.

The next concept is *availability*, which is *access* to reliable and consistent data. You can divide availability into two parts: data that needs to be accessible and the network elements to reach that system. This requires elements such as system redundancy, along with Out-of-Band (OoB) network access to routers and switches. For example, a router that is under a denial of service (DoS) attack may prevent remote access from one location to fail; however, is there another way to reach the router to thwart the attack? Design your network with the correct security tools; and most important, and often overlooked, make sure the tools actually work before disaster strikes. In other words, what good does it do to have protection in place if you cannot log in to the system to implement your tools or monitor and troubleshoot the devices? In recent years, horrible events such as terrorist attacks, earthquakes, and tsunamis have reopened many people's eyes to the importance of availability and redundancy.

Lastly is the *confidentiality* of the data; this means ensuring that unauthorized disclosure has not been unintentionally or intentionally given. In the modern age of thumb drives, BlackBerry devices, Treos, and PCs, the ability to access information has never been greater, and so are the security vulnerabilities. How many times have users left themselves logged in to a cybercafé somewhere? It takes just a few seconds for an evil network engineer lurking in the shadows to notice the open PC, log in to a router session that has been left open, delete the configuration, and walk away, ecstatic.

Are you getting scared yet? We hope so. A security expert without any fear is a very naïve one! Security must take a multiphase and dynamic approach; you will make mistakes, but the objective is to learn from those mistakes, use the tools available to you, and make the necessary corrections so that you avoid those mistakes later.

Always remember: security is a process and not an event! As Homer said, "Even a fool may be wise after the event." As we examine each topic in the remaining chapters, remember to think of the security circle of trust and where each feature fits and enables your security to be a circle without holes.

Summary of Security Concepts

Most people find the security concepts presented here to be somewhat common sense. The issue is that humans are inherently lazy, and security by its very definition tends to get in the way of our need to access information. The need for connectivity often overshadows the need to secure those communications, until the damage is done and it is too late to plug the holes. Always keep these security principles in mind when designing a new network or hardening an existing one.

The next section details ways to secure access to the router itself, which is a critical aspect of an overall security plan.

Securing Access to the Router

The goal of this chapter is to secure the network in Figure 6-2, which consists of three routers—`Ale`, `PBR`, and `Bock`—that are running Open Shortest Path First (OSPF) as the Interior Gateway Protocol (IGP). `PBR` connects to multiple Internet service providers (ISPs) via the Border Gateway Protocol (BGP). Various types of traffic are sent and received from the two ISPs, including web browsing, email, and a variety of remote accounting and engineering applications. The first step will be to secure access to `Ale`, `PBR`, and `Bock` so that only authorized users have access to each router.

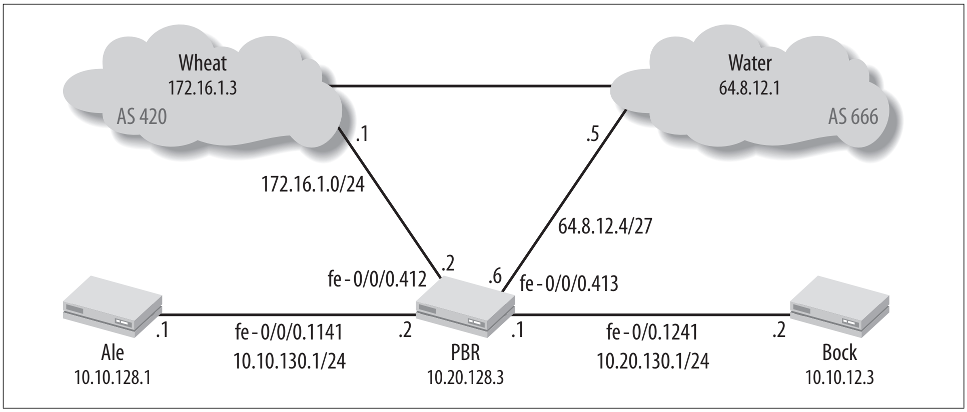


Figure 6-2. Network topology

User Authentication

There are two types of users on a Juniper Networks router—a nonroot user and a root user, both of which must be secured. Recall that user root is the only user who is predefined by default, accessible only via the console port without any default password. You must set a root password before the router will allow you to commit the configuration. To set up a root password, issue to the user the `root-authentication` keyword under the `[edit system]` level:

```
lab@Bock# set system root-authentication ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration
                       data
+ apply-groups-except  Don't inherit configuration data from these
                       groups
  encrypted-password   Encrypted password string
  load-key-file        File (URL) containing one or more ssh keys
  plain-text-password  Prompt for plain text password (autoencrypted)
> ssh-dsa              Secure shell (ssh) DSA public key string
> ssh-rsa              Secure shell (ssh) RSA public key string
```

> Remember that user `root` is very powerful. When logged in as `root`, you are placed directly into the kernel in the form of a BSD shell! As a result, `root` can log in only via the console port, by default. You can enable Secure Shell (SSH) by using the `set system services ssh root-login allow` command.

The password can either be a plain-text password that will be encrypted automatically in the configuration, an SSH key, or an encrypted string for copying and pasting to other routers. In this case, a password of `Bia&abi55a` is supplied:

```
lab@Bock# set system root-authentication plain-text-password
New password:
Retype new password:
```

> When issuing a plain text password, JUNOS has some default requirements for password length and content. The password must be between six and 128 characters and must contain one change of case or special character. You can modify these defaults under `[edit system password]`.

Once the password is set on `Bock`, it automatically becomes encrypted:

```
lab@Bock# show system root-authentication
encrypted-password "$1$iOLTVCdC$2jViYwTCG.kET399/uF/yO";
## SECRET-DATA
```

The encrypted string is now copied to other routers (`PBR` and `Ale`) without needing knowledge of the actual password:

```
lab@PBR# load merge terminal relative
[Type ^D at a new line to end input]
encrypted-password "$1$iOLTVCdC$2jViYwTCG.kET399/uF/yO";
## SECRET-DATA
load complete

[edit system root-authentication]
lab@PBR# show
encrypted-password "$1$iOLTVCdC$2jViYwTCG.kET399/uF/yO";
## SECRET-DATA
```

Next, nonroot users are configured. These users can be defined with local user passwords and permissions, or an external server such as RADIUS or TACACS could be used. In either case, three items need to be configured for the user:

- Username
- Permissions
- Password

A user or user template must always be configured on the router, but the permissions and password could be configured on an external server. To illustrate the possible options, this scenario has the following six requirements:

1. Define two local users, `doug` and `harry`, and provide them with maximum access.
2. A group will be created for the NOC group consisting of 15 engineers. Each NOC engineer will have his own username, but will share the same permissions of read-only commands and maintenance commands for troubleshooting.
3. A group will be created for the design engineer group, consisting of three engineers. This group will have full access to all command-line interface (CLI) commands, except for the `restart` and `request` commands.
4. All users will be authenticated using a RADIUS server with a shared secret of "brianbosworth."
5. Authorization is defined on the local router.
6. If the RADIUS server is down, only `harry` and `doug` may log in to the router.

> One user that is not explored in this case study is the remote user. This is a user that could be created for use on the router if the authenticated user does not exist on the local router or if the authenticated user's record in the authentication server specifies a local user. You can think of this as a default fallback account.

Each user defined must be associated with a login class, which assigns the permissions for a user. The login class can be one of the four default classes listed in Table 6-1, or a custom-defined class.

Table 6-1. Predefined JUNOS user classes

Class	Permissions
`superuser` or `super-user`	All
`read-only`	View
`operator`	Clear, Network, Reset, Trace, View
`unauthorized`	None

Users harry and doug require maximum access, so it makes sense to use a predefined JUNOS software class called super-user. Here we show the step-by-step process for harry only, as user doug has identical steps:

```
lab@Ale# set system login user harry class super-user authentication
plain-text-password
New password:
Retype new password:

[edit]
lab@Ale# show system login
user harry {
    class super-user;
    authentication {
        encrypted-password "$1$oOspqmHP$jlxUulOcAgPq3j88/7WQP/";
        ## SECRET-DATA
    }
}
```

For brevity and sanity, the configuration examples show one router, but the reader should assume that the configuration is copied to all routers in the network.

Next, a group of 15 NOC engineers are defined. Since configuring 15 local users will be a pain to manage and tiresome to type, we will use a *user template*. A user template allows multiple users defined on the RADIUS server with unique passwords to be grouped to a single local Juniper user. Since a predefined class will not satisfy the authorization level for the NOC engineers of read-only and maintenance commands, we will define a custom class:

```
[edit system login]
lab@Ale# set class ops permissions [view maintenance trace]
```

Refer to the access-privilege technical documentation to see each command that is allowed for every permission setting.

Next, we assign the user ops the new class, also called ops:

```
[edit system login]
lab@Ale# set user ops class ops

[edit system login]
lab@Ale# show class ops
permissions [ trace view maintenance ];
lab@Ale# show user ops
uid 2000;
class ops;
```

The RADIUS server will then have 15 users defined that all map to the same Juniper-local user of ops. For example, the configuration for 2 of the 15 users using a RADIUS server would be similar to the following:

```
bruiser   Auth-Type = Local, Password = "iamaDog"
        Service-Type = Login-User,
        Juniper-Local-User-Name = "ops"

josh     Auth-Type = Local, Password = "plumper1"
        Service-Type = Login-User,
        Juniper-Local-User-Name = "ops"
```

The design engineer group requirement will also use a template but will make use of special allow and deny commands that we can also define in a class. If the permission bits that are set are too broad, we can deny individual commands within the permission settings. (And vice versa; if we need an additional command or set of commands that go beyond the permission setting, we can allow them.) These allow and deny statements could be a single command or a group of commands using regular expressions. They are also separated in allow or deny operational mode commands or configuration mode:

```
[edit system login]
lab@Ale# set class design ?
Possible completions:
  allow-commands       Regular expression for commands to allow explicitly
  allow-configuration  Regular expression for configure to allow explicitly
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  deny-commands        Regular expression for commands to deny explicitly
  deny-configuration   Regular expression for configure to deny explicitly
  idle-timeout         Maximum idle time before logout (minutes)
  login-alarms         Display system alarms when logging in
  login-tip            Display tip when logging in
+ permissions          Set of permitted operation categories
```

The design engineer's class will have the permission bits set to all, and all commands that start with *r* (request and restart) will be disallowed:

```
[edit system login]
lab@Ale# set class design permissions all
```

```
[edit system login]
lab@Ale# set class design deny-commands "^r.*$"

lab@Ale# set user design class design
```

> Regular expressions are beyond the scope of the book, but here is a list of common operators:
>
> - . (any character)
> - * (zero or more characters)
> - ^ (start of string to which the regex is applied)
> - $ (end of string to which the regex is applied)
> - ? (zero or one character)

As mentioned, we can define users locally on the router or on an external server such as RADIUS or TACACS. In this chapter's case study, we specified a RADIUS server earlier, in requirement 4. The RADIUS server's IP address and secret password are configured:

```
[edit system]
design@Ale# set radius-server 10.20.130.5 secret brianbosworth
```

For the system to use the RADIUS server, we must configure the `authentication-order` statement. This indicates which order of authentication method should be used, with the default being the local router database only. In this section of our case study, we must decide between the following configuration choices:

1. `authentication-order [radius password]`
2. `authentication-order [radius]`

In either configuration, the local database will be consulted if the RADIUS server is down, so the difference between the two options is evident when the RADIUS server returns a reject. This reject could be caused by a mistyped password or a username that is not defined in the RADIUS server. In option 1, the RADIUS server returns the reject and the local database will be consulted. Option 2 consults the local database only if the RADIUS server is unresponsive; processing stops if the server returns a `reject` message. The requirements state that the RADIUS server should always be used when available (as specified in option 1). If the RADIUS server is not available, users `doug` and `harry` will be allowed to log in using the local database since they are the only users with locally defined passwords on the router. These users are also defined on the RADIUS server:

```
doug    Auth-Type = Local, Password = "superbowlshuffle5"
        Service-Type = Login-User
```

Here is a complete system login configuration that meets all six of the criteria specified earlier:

```
[edit system]
design@Ale# show
host-name Ale;
authentication-order radius password;
ports {
    console type vt100;
}
root-authentication {
    encrypted-password "$1$85xXcov4$fLHtgMlqxRSg24zO8Kbe81"; ##
    SECRET-DATA
}
radius-server {
    10.20.130.5 secret "$9$KdgW87db24aUcydsg4Dj69AORSWLN24ZNd.5TFAt";
    ## SECRET-DATA
}
login {
    class design {
        permissions all;
        deny-commands "^r.*$";
    }
    class ops {
        permissions [ trace view maintenance ];
    }
    user design {
        uid 2004;
        class design;

    user harry {
        uid 2001;
        class super-user;
        authentication {
            encrypted-password "$1$oOspqmHP$jlxUulOcAgPq3j88/7WQP/";
            ## SECRET-DATA
        }
    }
    user doug {
        uid 2003;
        class superuser;
        authentication {
            encrypted-password "$1$ocs3AXkS$JdlQW7z4ZIJblfFZD.fqH/";
            ## SECRET-DATA
        }
    }
    user ops {
        uid 2000;
        class ops;
    }
}
services {
    ftp;
    ssh;
    telnet;
}
syslog {
    user * {
        any emergency;
    }
    file messages {
        any notice;
        authorization info;
    }
    file config-changes {
        change-log any;
    }
}
```

Lastly, to verify that the user has the correct permissions, log in to the router and issue a show cli authorization command:

```
design@Ale> show cli authorization
Current user: 'design      ' class 'design'
Permissions:
    admin       -- Can view user accounts
    admin-control-- Can modify user accounts
    clear       -- Can clear learned network information
    configure   -- Can enter configuration mode
    control     -- Can modify any configuration
    edit        -- Can edit full files
    field       -- Special for field (debug) support
    floppy      -- Can read and write from the floppy
    interface   -- Can view interface configuration
    interface-control-- Can modify interface configuration
    network     -- Can access the network
    reset       -- Can reset/restart interfaces and daemons
    routing     -- Can view routing configuration
    routing-control-- Can modify routing configuration
    shell       -- Can start a local shell
    snmp        -- Can view SNMP configuration
    snmp-control-- Can modify SNMP configuration
    system      -- Can view system configuration
    system-control-- Can modify system configuration
    trace       -- Can view trace file settings
    trace-control-- Can modify trace file settings
    view        -- Can view current values and statistics
    maintenance -- Can become the super-user
    firewall    -- Can view firewall configuration
    firewall-control-- Can modify firewall configuration
    secret      -- Can view secret configuration
    secret-control-- Can modify secret configuration
    rollback    -- Can rollback to previous configurations
    security    -- Can view security configuration
    security-control-- Can modify security configuration
    access      -- Can view access configuration
    access-control-- Can modify access configuration
```

```
        view-configuration-- Can view all configuration (not including
        secrets)
    Individual command authorization:
        Allow regular expression: none
        Deny regular expression: ^r.*$
        Allow configuration regular expression: none
        Deny configuration regular expression: none
```

Remote Access

After the users are configured on the router, we must decide what kind of remote access will be provided to the router, as all methods are disabled by default. Here are the possible options:

Dynamic Host Configuration Protocol (DHCP)

Provides dynamic IP assignment from a pool of addresses to clients attached to the interface on a J-series router only. This option is most often used for the auto-installation feature.

Finger

A protocol to get information about a user logged in to the router. This protocol is no longer used on a large scale and should never be enabled on the router:

```
% finger lab@10.20.128.3
[10.20.128.3]
Login: lab                          Name:
Directory: /var/home/lab            Shell: /usr/sbin/cli
On since Mon Sep 24 00:31 (UTC) on ttyd0, idle 0:01
No Mail.
No Plan.
%
```

FTP

Provides file transfer services. Although FTP is a widely used protocol, it transfers files in plain text, which can lead to security issues. When possible, you should use secure copy (SCP).

Rlogin

The Remote login protocol, which allows remote login to the CLI. This Unix utility has several security flaws and was used only in private environments. This utility is enabled by a hidden command on the router and should never be enabled on the router.

A *hidden command* is a command that does not show up when you use ? in the CLI and does not autocomplete with the Space bar. One of the most famous hidden commands in JUNOS software is `show version and haiku`. Try it yourself if you want to read some really bad poetry!

SSH

Allows for two devices to communicate over an encrypted tunnel. This ensures not only availability, but also data integrity and confidentiality. When SSH is enabled, this automatically enables SCP.

Telnet

A common protocol to remotely manage a system developed in 1969. Telnet transits all data in clear text, so you should use SSH when possible.

Web management

Enables the use of the jweb web GUI on the router for management and configuration. These can be either encrypted or unencrypted Hypertext Transfer Protocol (HTTP) connections.

JUNOScript server

Enables the router to receive commands from a JUNOScript server via clear text or Secure Sockets Layer (SSL) connections.

Netconf

The Network Configuration protocol, which is defined in RFC 4741 and uses XML for configuration and messages. Netconf is the Internet Engineering Task Force (IETF) standard created as a replacement for the Simple Network Management Protocol (SNMP) and is based on JUNOScript.

The most secure methods of remote access on the router will be SSH and transferring files using SCP. To enable any service, simply set it under the `[edit system services]` directory:

```
[edit system services]
lab@Ale# set ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration
                       data
+ apply-groups-except  Don't inherit configuration data from these
                       groups
> dhcp                 Configure DHCP server
> finger               Allow finger requests from remote systems
> ftp                  Allow FTP file transfers
> netconf              Allow NETCONF connections
> service-deployment   Configuration for Service Deployment (SDXD)
                       management application
> ssh                  Allow ssh access
> telnet               Allow telnet login
> web-management       Web management configuration
> xnm-clear-text       Allow clear text-based JUNOScript connections
> xnm-ssl              Allow SSL-based JUNOScript connections
```

Each service will have a variety of options, such as setting a maximum number of connections, rate-limiting the inbound connections, and choosing a certain protocol version.

XML Tags

JUNOScript is a tool you can use to configure and manage the router. Every JUNOS output and configuration contains XML tags that can be referenced by a JUNOScript client. Here is an example of a configuration and an operational command that displays the XML tags for each field:

```
lab@PBR> show system users | display xml
<rpc-reply xmlns:junos="http://xml.juniper.net/junos/8.0R2/junos">
    <system-users-information xmlns="http://xml.juniper.net/junos/
    8.0R2/junos">
        <uptime-information>
            <date-time junos:seconds="1190796857">8:54AM</date-time>
            <up-time junos:seconds="207372">2 days,  9:36</up-time>
            <active-user-count junos:format="1 user">1</active-user-
            count>
            <load-average-1>0.06</load-average-1>
            <load-average-5>0.02</load-average-5>
            <load-average-15>0.00</load-average-15>
            <user-table>
                <user-entry>
                    <user>lab</user>
                    <tty>d0</tty>
                    <from>-</from>
                    <login-time junos:seconds="1190593874">Mon12AM</login-time>
                    <idle-time junos:seconds="0">-</idle-time>
                    <command>-cli (cli)</command>
                </user-entry>
            </user-table>
        </uptime-information>
    </system-users-information>
    <cli>
        <banner></banner>
    </cli>
</rpc-reply>

lab@PBR> show configuration routing-options | display xml
<rpc-reply xmlns:junos="http://xml.juniper.net/junos/8.0R2/junos">
    <configuration>
            <routing-options>
                <static>
            <route>
                        <name>10.10.128.1/32</name>
                        <next-hop>10.10.111.1</next-hop>
                    </route>
                </static>
            </routing-options>
    </configuration>
    <cli>
        <banner></banner>
    </cli>
```

```
lab@Ale# set system services ssh ?
Possible completions:
  <[Enter]>            Execute this command
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  connection-limit     Maximum number of allowed connections (1..250)
+ protocol-version     Specify ssh protocol versions supported
  rate-limit           Maximum number of connections per minute
                      (1..250)
  root-login           Configure root access via ssh
  |                    Pipe through a command
```

In this case, SSH is enabled on the router using the default parameters of 150 connection attempts and 75 active sessions per minute:

```
[edit]
lab@Ale# set system services ssh
```

Bock then initiates a session to Ale. The first connection will need to establish the RSA fingerprint for authentication:

```
lab@Bock> ssh 10.10.128.1
The authenticity of host '10.10.128.1 (10.10.128.1)' can't be
established.
RSA key fingerprint is 5d:f5:51:91:51:0e:ff:54:0c:f4:0a:07:51:3b:70:3a.
Are you sure you want to continue connecting (yes/no)? yes
Warning: Permanently added '10.10.128.1' (RSA) to the list of known
hosts.
lab@10.10.128.1's password:
--- JUNOS 8.0R2.8 built 2006-09-29 09:22:36 UTC
lab@Ale> exit

Connection to 10.10.128.1 closed.
```

However, once Ale is added to the list of known hosts, future sessions do not require reverification:

```
lab@Bock> ssh 10.10.128.1
lab@10.10.128.1's password:
--- JUNOS 8.0R2.8 built 2006-09-29 09:22:36 UTC
lab@Ale>
```

When SSH is enabled on the router, it also automatically enables SCP to initiate secure file exchanges. You can upload or download files using variations of the `file copy` command. In this case, PBR transfers a file called *test* to Ale. PBR must add Ale into its good hosts file:

```
lab@PBR> file copy test lab@10.10.128.1:test.txt
The authenticity of host '10.10.128.1 (10.10.128.1)' can't be
established.
RSA key fingerprint is 5d:f5:51:91:51:0e:ff:54:0c:f4:0a:07:51:3b:70:3a.
Are you sure you want to continue connecting (yes/no)? yes
Warning: Permanently added '10.10.128.1' (RSA) to the list of
known hosts.
```

```
lab@10.10.128.1's password:
test                                  100% 9480     9.3KB/s   00:00
```

After Ale is learned as a host, future transfers will pass the authentication check because both Ale and PBR know each other as trusted hosts:

```
lab@PBR> file copy test2 lab@10.10.128.1:test2.txt
lab@10.10.128.1's password:
test                                  100% 9480     9.3KB/s   00:00
```

Summary of Access Security

Routers are the very fabric of any IP-based network, making it critical that access be limited to only those users that are authorized to access the system, and only for those tasks they are authorized to perform. JUNOS software provides a variety of tools, ranging from local and remote authentication and authorization to secure access and file transfer protocols, which make it easy to secure the router from unauthorized access and many forms of DoS attacks.

The next section details packet-based (stateless) firewall filtering and policing capabilities, which are another critical aspect of a total security solution.

Firewall Filters

To protect the router, you can deploy packet filters to allow only certain traffic into the router's control plane (Routing Engine [RE]). These filters have different names on each router OS, but they still operate in the same stateless manner. On a Cisco device, these filters are called *access lists*, and on a Juniper router, they are called *firewall filters*. These filters look similar to the policy we discussed in Chapter 3; however, filters operate on the actual data-forwarding plane. Table 6-2 provides a comparison of the two features.

Table 6-2. Firewall filters versus routing policies

Feature	Firewall filter	Routing policy
Operates in…	Forwarding plane	Control plane
Match keyword	from	from
Action keyword	then	then
Match attributes	Packet fields	Route attributes
Default action	Discard	Depends on default policy
Applied to…	Interfaces	Routing protocols/tables
Named terms required	Yes	No
Chains allowed	Yes	Yes
Absence of from statement	Match all	Match all

Firewall filter syntax takes a human-friendly, intuitive form:

```
firewall {
    family inet {
        filter filter-1 {
            term term-1 {
                from {
                    protocol tcp;
                    destination-port telnet;
                }
                then {
                    accept;
                }
            }
        }
    }
}
```

This filter matches on Telnet traffic and accepts the packets. As observed, the syntax is very similar to a routing policy with the match conditions in the `from` term and the actions specified in a `then` term.

Filter Processing

Similar to a policy, a filter is made up of multiple terms, and each term is examined in the order listed. If there is a match in a term and there is a terminating action, no other term is examined (see Figure 6-3). Terminating actions are:

`accept`
: Allows the packet through the filter

`discard`
: Silently discards the packet

`reject`
: Discards the packet with an Internet Control Message Protocol (ICMP) error message (the default is administratively prohibited)

Action modifier
: Any action modifier, such as `log`, `count`, `syslog`, and so on

> The presence of an action modifier such as `count` without an explicit `accept`, `discard`, or `reject` will result in a default action of `accept`. If the desired action is to discard or reject the packet, it must be explicitly configured.

If the packet does not match any terms in the filter it is discarded.

You also can apply multiple filters to the interface, and in this case it operates in the same fashion down the filter list until there is a terminating action. If no match occurred in the filter list, the packet is discarded (see Figure 6-4).

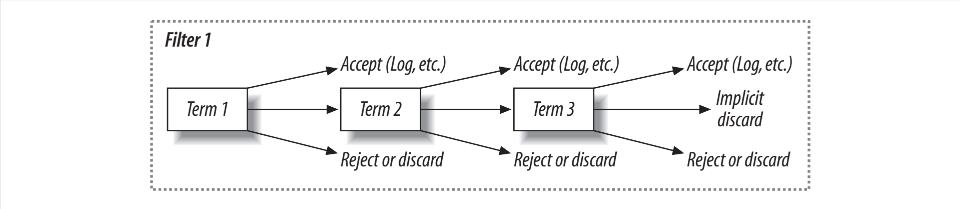


Figure 6-3. Filter processing

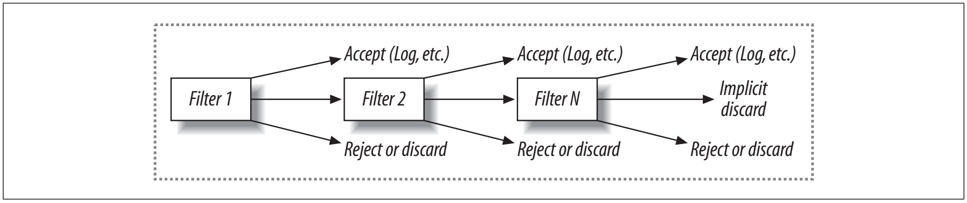


Figure 6-4. Filter chaining

Filter Match Conditions

When examining the possible match conditions, the general rule of thumb is that if it is a field in the IP, Transmission Control Protocol (TCP), User Datagram Protocol (UDP), or ICMP header, it is probably a potential match:

```
lab@PBR# set firewall family inet filter foo term 1 from ?
Possible completions:
> address              Match IP source or destination address
+ apply-groups         Groups from which to inherit configuration
                       data
+ apply-groups-except  Don't inherit configuration data from these
                       groups
> destination-address  Match IP destination address
+ destination-port     Match TCP/UDP destination port
+ destination-port-except  Do not match TCP/UDP destination port
  destination-prefix-list  Match IP destination prefixes in named
                            list
+ dscp                 Match Differentiated Services (DiffServ) code
                       point
+ dscp-except          Do not match Differentiated Services (DiffServ)
                       code point
+ esp-spi              Match IPSec ESP SPI value
+ esp-spi-except       Do not match IPSec ESP SPI value
  first-fragment       Match if packet is the first fragment
+ forwarding-class     Match forwarding class
+ forwarding-class-except  Do not match forwarding class
  fragment-flags       Match fragment flags
+ fragment-offset      Match fragment offset
+ fragment-offset-except  Do not match fragment offset
+ icmp-code            Match ICMP message code
+ icmp-code-except     Do not match ICMP message code
+ icmp-type            Match ICMP message type
+ icmp-type-except     Do not match ICMP message type
> interface            Match interface name
+ interface-group      Match interface group
+ interface-group-except  Do not match interface group
> interface-set        Match interface in set
+ ip-options           Match IP options
+ ip-options-except    Do not match IP options
  is-fragment          Match if packet is a fragment
+ packet-length        Match packet length
+ packet-length-except  Do not match packet length
+ port                 Match TCP/UDP source or destination port
+ port-except          Do not match TCP/UDP source or destination
                       port
+ precedence           Match IP precedence value
+ precedence-except    Do not match IP precedence value
> prefix-list          Match IP source or destination prefixes in
                       named list
+ protocol             Match IP protocol type
+ protocol-except      Do not match IP protocol type
> source-address       Match IP source address
+ source-port          Match TCP/UDP source port
+ source-port-except   Do not match TCP/UDP source port
> source-prefix-list   Match IP source prefixes in named list
  tcp-established      Match packet of an established TCP connection
  tcp-flags            Match TCP flags
  tcp-initial          Match initial packet of a TCP connection
+ ttl                  Match IP ttl type
+ ttl-except           Do not match IP ttl type
```

The match conditions fall into three general categories: numeric, address, and bit field matches (see Table 6-3).

Table 6-3. General match conditions

Numeric matches	Address matches	Bit fields
Protocol fields	Source address	IP options
Port numbers	Destination address	TCP flags
Class of service (CoS) fields	Source-prefix lists	IP fragmentation
ICMP type codes	Destination-prefix lists	Time to Live (TTL)

A term can have zero or many match conditions specified. The absence of a `from` statement creates a match all condition, whereas multiple match conditions are treated as a logical AND or OR depending on common versus uncommon match conditions. A common match is treated as a logical OR, which the router will group together in square brackets. The filter example matches on TCP or UDP packets:

```
filter example {
    term common {
        from {
            protocol [ tcp udp ];
        }
    }
}
```

An uncommon match is treated as a logical AND. You can combine these logical ANDs and ORs in the same term with limitless possibilities. Adding to the example, the following filter matches on TCP or UDP packets and port 123:

```
filter example {
    term common {
        from {
            protocol [ tcp udp ];
            port 123;
        }
    }
}
```

Also, numeric matches such as port or protocol values can either take the numeric match or the more user-friendly keywords. For example, the first term and second term of the filter called same are equivalent, but the second term is written in a more efficient and user-friendly method:

```
firewall {
    filter same {
        term numbers {
            from {
                protocol 6;
                port 23;
            }
            then accept;
        }
        term user-friendly {
            from {
                protocol tcp;
                port telnet;
            }
            then accept;
        }
    }
}
```

Bit field matching such as IP options and TCP flags also support numeric values or more user-friendly terms. In these cases, the numeric support must be written in hex format, so a TCP flag match for SYN packets could be written with the keyword syn or the value 0x2. No reason to break out the hex converter—make life easy and use the keywords!

Can your mother read this?

When writing a filter, always try to adhere to the KISS (Keep It Short and Simple) method. An individual security element may not be that difficult, but when combined with other security functions as a whole, it can contribute to a large web of complexity.

In other words, try to create a filter that the average network engineer can understand without compromising any security. A great start to reach this goal is to use the alpha names for protocol, port numbers, and bit fields instead of the actual numerical values. Additionally, JUNOS has even more to offer using text synonyms to map common bit mappings. These allow the casual reader to quickly understand a filter at a glance and avoid panicked and hysterical research to find what service maps to a numerical value (see Table 6-4).

Table 6-4. Text synonyms

Text synonym	Match equivalent	Common use
`first-fragment`	Offset = 0, MF = 1.	Match on the first fragment of a packet for counting and logging.
`is-fragment`	Offset does not equal zero.	Protect from fragmented DoS attacks.
`tcp-established`	ACK or RST.	Allow only established TCP sessions over an interface. This option does not implicitly check that the protocol is TCP. Use the TCP match condition.
`tcp-initial`	SYN and not ACK.	Allow sessions to be initiated either inbound or outbound.

Filter Actions

Besides the terminating actions that we already discussed (`accept`, `discard`, and `reject`), other action modifiers are commonly used. These include:

`count` *`<counter name>`*
: Counts the total number of packets and bytes that match a term. You can view counters with the `show firewall` command.

`log`
: Records the packet header information and stores the information in memory on the router, which limits the size to approximately 400 entries and clears upon a router reboot. To view the log, issue a `show firewall log` command.

`syslog`
: Records the packet header information and stores the log into a file or sends it to a syslog server. The syslog facility of the firewall will allow any local file to be created for this information.

`policer`
: Rate-limits traffic based on bandwidth and burst size limits (discussed later in this chapter).

`forwarding-class`
: Sends packets to a forwarding class, which maps to a queue.

`sample`
: Creates cflowd export records.

`next term`

Allows packets to match a term and then move on to the next term listed. Since the presence of any action modifier implies an `accept`, this action allows packets to pass through to the next term. This is often deployed when all packets need to be counted before being rejected farther in the chain.

Applying a Filter

The final step after writing the filter is to actually apply it to the interface. You can apply filters to either transit or nontransit traffic. To apply a filter to transit traffic, apply the filter to any Packet Forwarding Engine (PFE) interface as either an input or an output filter or as part of a list of filters. Filters are applied on a logical unit basis:

```
lab@hops# set interfaces fe-0/0/0 unit 0 family inet filter ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  group                Group to which interface belongs
  input                Name of filter applied to received packets
+ input-list           List of filter modules applied to received packets
  output               Name of filter applied to transmitted packets
+ output-list          List of filter modules applied to transmitted packets
```

You can apply a single filter with the `input` or `output` command, or a list with `input-list` or `output-list`, so why the option for both? Historically in JUNOS, only a single filter could be applied per direction per unit, but in later code the concept of a list was created. It is recommended that even if just a single filter is being applied to an interface, to use the `list` command. This adds flexibility in adding more filters to the chain at a later time.

To protect traffic to the router itself (local traffic), you can apply a filter of filter-list to the loopback interface (see Figure 6-5). Local traffic is any packet that is destined to the router itself, such as routing protocols, ICMP, SSH, and other management protocols.

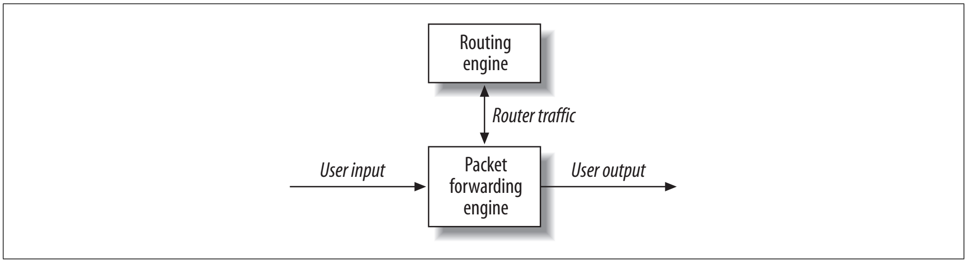


Figure 6-5. Transit versus loopback filters

Case Study: Transit Filters

It is common to see a filter applied to the router's connection to the Internet. Before sitting down to begin typing away on the router, always write down the goals of the filter. In this case study, all outbound traffic from the network to the Internet is allowed while some traffic from the Internet will be filtered. The goals here are as follows:

- TCP connections are only allowed to be initiated outbound to the Internet, except to access a local web server.
- No fragmented ICMP or UDP packets should be allowed.
- TCP fragments are allowed.
- UDP packets should be allowed inbound for traceroutes and return traffic for outbound UDP connections.
- Ping and traceroute are allowed outbound.
- Traceroute is allowed inbound.

First create a prefix list for the internal subnets, which in this case are as follows:

```
10.10.128/22
10.20.128/22
10.10.12/22
[edit]
lab@PBR# set policy-options prefix-list internal-subnets 10.10.128/22

[edit]
lab@PBR# set policy-options prefix-list internal-subnets 10.20.128/22

[edit]
lab@PBR# set policy-options prefix-list internal-subnets 10.20.12/22

lab@PBR# show policy-options prefix-list internal-subnets
10.10.128.0/22;
10.10.12.0/22;
10.20.128.0/22;
```

Now the filter called `internet-in` will be examined with each term explained to match on the five goals stated at the beginning of this case study. First, we define our first term to allow established TCP sessions inbound, which are destined for internal subnets in the first term. The keyword `tcp-established` allows only packets with a TCP flag of `ack` or `rst`. As a result of the implicit deny, all at the end of the filter list, this term will also accomplish task 1, in allowing only outbound TCP sessions. Also, the `fragment-offset` keyword allows for unfragmented packets or first packet fragments to be received as only the first fragmented packet has the headers needed for the check:

```
lab@PBR# show firewall family inet
filter internet-in {
    term allow-established-tcp-sessions {
        from {
            destination-prefix-list {
                internal-subnets;
            }
            fragment-offset 0;
            tcp-established;
            protocol tcp;
        }
        then accept;
    }
```

Next, TCP connections are allowed to the web server at 10.20.12.9 using port numbers https (443) and 8080. Port 80 connections are not allowed toward this web server to add an additional layer of security:

```
        term allow-webserver-connections {
            from {
                destination-address {
                    10.20.12.9/32;
                }
                protocol tcp;
                destination-port [  https 8080 ];
            }
            then accept;
        }
```

UDP and ICMP fragments are denied as these types of packets are normally used in popular DoS attacks. The `fragment-offset` command is matching on all ICMP and UDP fragments, including the first packet. If `is-fragment` and `first-fragment` were used, two terms would have been required:

```
    term deny-udp-icmp-frags {
            from {
                fragment-offset 0-8191;
                protocol [ icmp udp ];
            }
            then {
                discard;
            }
        }
```

TCP fragments are allowed, however. Recall that the `is-fragment` keyword matches on all fragments except the first fragment, which was matched in the first term of the filter:

```
        term allow-tcp-frags {
            from {
                is-fragment;
                protocol tcp;
            }
            then {
                accept;
            }
        }
```

Next, incoming UDP packets are allowed to internal subnets that are not fragments. This is to allow return traffic for outbound UDP sessions as well as inbound traceroute packets that use UDP inbound:

```
    term allow-udp {
        from {
            destination-prefix-list {
                internal-subnets;
            }
            protocol udp;
        }
        then accept;
    }
```

Lastly, ping and traceroute are allowed outbound. Since this is an input filter, the return traffic is actually being allowed in for both ping (echo replies) and traceroute (time exceed messages). Additionally, unreachable messages are allowed in for any possible outbound error responses:

```
    term allow-some-icmp-outbound {
        from {
            destination-prefix-list {
                internal-subnets;
            }
            protocol icmp;
            icmp-type [ echo-reply time-exceeded unreachable ];
        }
        then accept;
    }
}
```

The filter is applied to both WAN interfaces on router PBR as the input list of one to allow for filter additions at a later date:

```
lab@PBR# show interfaces
fe-0/0/0 {
    vlan-tagging;
    unit 412 {
        description PBR-to-Wheat;
        vlan-id 412;
        family inet {
            rpf-check;
            filter {
                input-list internet-in;
            }
            address 172.16.1.2/24;
        }
    }
    unit 413 {
        description PBR-to-Water;
        vlan-id 413;
        family inet {
            rpf-check fail-filter match-spoofs;
            filter {
                input-list internet-in;            }
            address 64.8.12.6/27;
```

Case Study: Loopback Filters

Next, traffic destined to the router itself needs to be secured. The goals of this case study are to allow:

- OSPF traffic
- BGP traffic from configured peers only
- SSH from internal subnets
- Virtual Router Redundancy Protocol (VRRP) packets
- Ping and traceroute
- Domain Name System (DNS) replies
- SNMP and Network Time Protocol (NTP)

First, define a prefix list for the internal subnets in your network:

```
lab@PBR# show policy-options
prefix-list internal-subnets {
    10.10.128.0/22;
    10.10.12.0/22;
    10.20.128.0/22;
}
```

Since BGP traffic should be from configured peers only, the `apply-path` command is used to avoid any IP change issues or neighbor additions that may happen in the future. The `apply-path` allows configuration elements to be matched when the `prefix-list` is applied by using regular expressions. In this case, this will create a list of BGP peers for every BGP group configured due to the match all * regular expression:

```
prefix-list bgp-configured-peers {
    apply-path "protocols bgp group <*> neighbor <*>";
}
```

The `filter protect-router` is created with the first term allowing SSH traffic to *and* from the router due to the `port` command, which matches on either the source or destination port:

```
    filter protect-router {
        term allow-ssh {
            from {
                source-prefix-list {
                    internal-subnets;
                }
                protocol tcp;
                port ssh;
            }
            then accept;
        }
```

Create a term to allow for OSPF packets:

```
term allow-ospf {
    from {
        protocol ospf;
    }
    then accept;
}
```

Then take advantage of the prefix list that was previously created to allow only the configured BGP peer's traffic:

```
term allow-bgp {
    from {
        source-prefix-list {
            bgp-configured-peers;
        }
        protocol tcp;
        port bgp;
    }
   then accept;
}
```

Allow VRRP traffic:

```
term allow-vrrp {
    from {
        protocol vrrp;
    }
    then accept;
}
```

Don't forget about DNS replies. Since these are stateless, filter the return traffic so that DNS resolution is allowed in:

```
term dns-replies {
    from {
        protocol udp;
        source-port 53;
    }
    then accept;
}
```

SNMP is allowed:

```
term snmp {
    from {
        protocol udp;
        port [ snmp snmptrap ];
    }
    then accept;
}
```

Also allowed are UDP packets with a TTL of 1 for traceroute to operate:

```
term traceroute {
    from {
```

```
                protocol udp;
                ttl 1;
            }
            then accept;
        }
```

Allow pings, traceroutes, and error messages:

```
        term allow-icmp {
            from {
                protocol icmp;
                icmp-type [ echo-request echo-reply time-exceeded
                unreachable ];
            }
            then accept;
        }
```

NTP is also allowed:

```
        term allow-ntp {
            from {
                prefix-list {
                    internal-subnets;
                }
                protocol udp;
                port ntp;
            }
            then accept;
        }
```

Lastly, there is a term that denies all other traffic (which is the default) but allows this traffic to be counted as well as logged to a syslog file:

```
        term match-denied {
            then {
                count bad-packets;
                syslog;
                discard;
            }
        }
    }
}
```

The filter is then applied to the loopback interface as an input filter. Even though it is just a single filter, it is added as a list for future expansion:

```
lab@PBR# set interface lo0.0 family inet filter input-list
protect-router
```

This is a good point to dust off the `commit confirmed` to make sure the filter does not break the current network or, worse yet, lock you out of the router:

```
[edit]
lab@PBR# commit confirmed
commit confirmed will be automatically rolled back in 10 minutes unless
confirmed
commit complete
```

```
# commit confirmed will be rolled back in 10 minutes
[edit]
lab@PBR# commit
commit complete
```

Policers

To rate-limit traffic entering an interface, you can deploy a *policer*. The policers that are implemented in the Juniper router are token-based and use the IP packet to limit based on bandwidth and bursts. The bandwidth is measured as the average number of bits in over a one-second interval (see Figure 6-6). The burst size is the number of bytes that can exceed the bandwidth constraints.

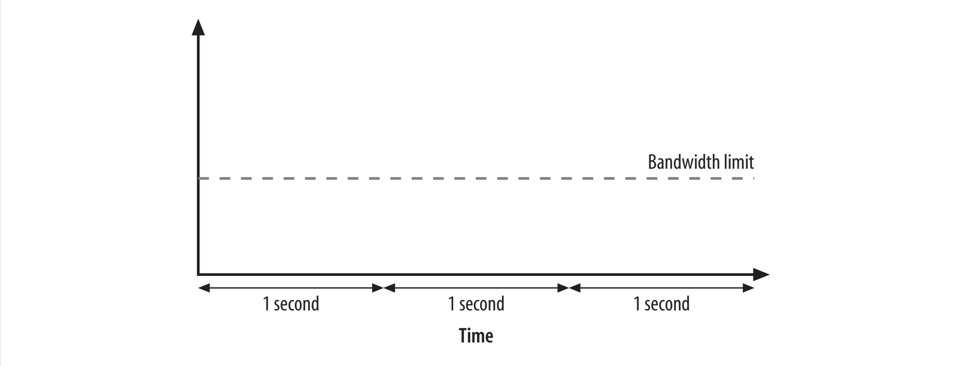


Figure 6-6. Bandwidth limit

The burst size is what implements the policer's "token"-based behavior. The burst size will set the initial and maximum sizes of a bucket in bytes (tokens) that would be accessed each time data needs to be sent. As a packet is sent, the bucket bytes (tokens) are removed from the bucket. If there are not enough tokens to send the packet, the packet will be policed. The bucket is then replenished at the bandwidth rate.

In Figure 6-7, a packet that bursts above the bandwidth limit is nonetheless sent, as there are enough tokens in the bucket. After the packet is sent, the tokens are decreased based on the packet size.

Then, some time later, another packet needs to be sent that is also above the bandwidth limit. Since there are no longer enough tokens left in the bucket, the packet is policed (see Figure 6-8).

As time goes by, the bucket will replenish at a rate equal to the bandwidth limit. When a new packet arrives, it can be sent, as tokens are now available in the bucket. This process continues over a one-second interval, and the result is a rate equal to the bandwidth limit (see Figure 6-9).

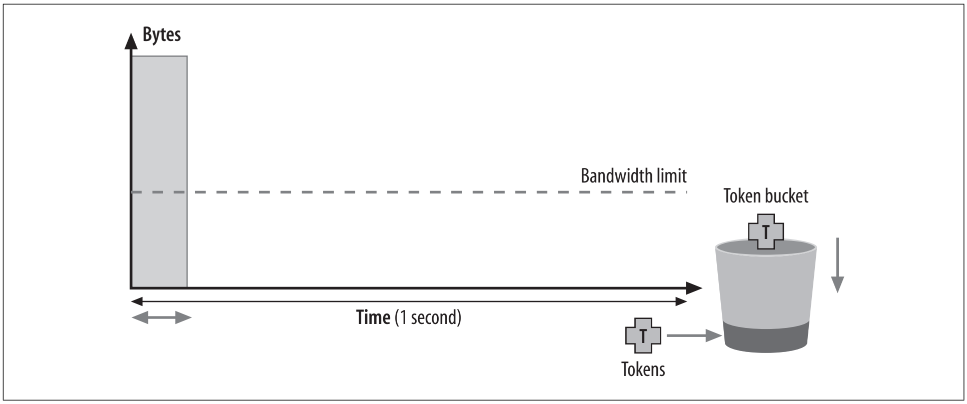


Figure 6-7. Initial burst

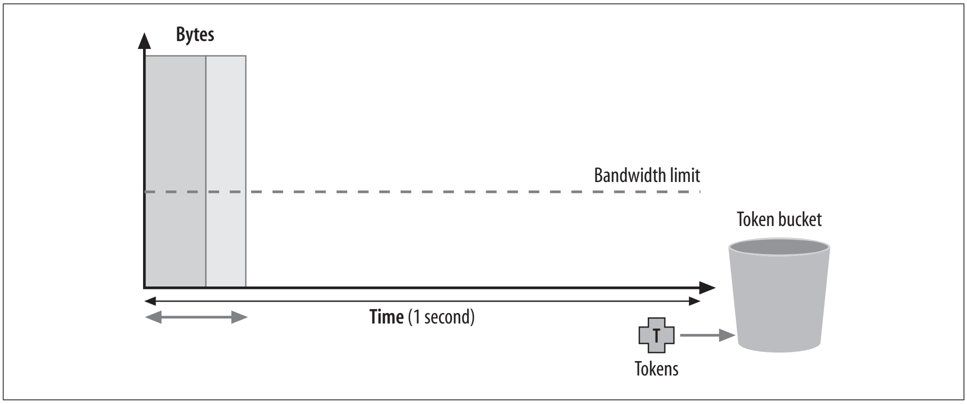


Figure 6-8. Empty token bucket

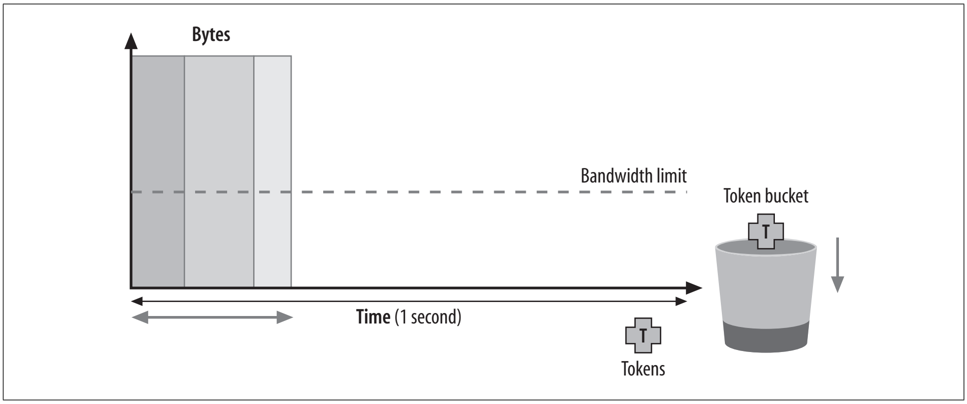


Figure 6-9. Token bucket replenishing

Burst-size limit mystery

The setting of the burst size has always seemed to be a mystery for many operators. Set this value too low, and potentially all packets will be policed. Set the value too high, and no packets will be policed. The rule of thumb is that the burst size should never be lower than 10 times the maximum transmission unit (MTU). The recommended value is to set the amount of traffic that can be sent over the interface in five milliseconds. So, if your interface is a Fast Ethernet interface, the minimum is 15,000 bytes (10 * 1,500), and the recommended value would be 62,500 bytes (12,500 bytes/ms * 5).

Policer actions

Once the policer limits have been configured, you must choose the action taken if a packet exceeds the policer. Two types of policing are available: *soft* policing and *hard* policing. Hard policing specifies that the packet will be dropped if it exceeds the policer's traffic profile. Soft policing simply marks the packet or reclassifies the packet, which could change the probability of the packet being dropped at the egress interface during times of congestion. Soft policing is implemented by either setting the packet loss priority (PLP) setting on the packet or by placing the packet into a different forwarding class. We will examine these concepts further in Chapter 9.

Configuring and applying policers

Policers are configured under the `[edit firewall]` level. The policer will be named and then the burst size will be applied in bytes/second, the bandwidth limit in bits/second, or the percentage of interface bandwidth set along with the policer action. For example:

```
policer simple {
    if-exceeding {
        bandwidth-limit 50m;
        burst-size-limit 15k;
    }
    then discard;
}
```

Once you have configured the policer, you must apply it to an interface. You can do this in one of two ways: either by applying the policer directly underneath the interface or by referencing the policer name in the firewall filter. If you apply the policer directly to the interface, no match conditions can be used. If you reference the policer in a filter, specific types of traffic can be policed as the entire toolkit of filter actions is allowed. You can apply both an interface policer and a policer in a filter at the same time. In this case, a kind of hierarchical policing is used as interface policers are evaluated before input filters and after output filters. Figure 6-10 shows policer processing.

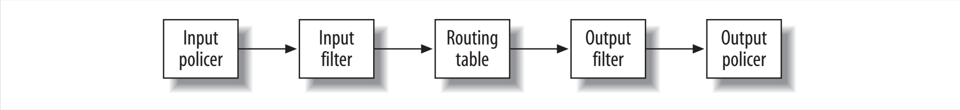


Figure 6-10. Policer processing

Since you can apply the same filter to multiple interfaces, you can apply the same policer to multiple interfaces. In this case, the aggregate bandwidth of all the interfaces is examined before any policing parameters. To avoid this behavior and create a separate instance for each interface, include the `interface-specific` command in the filter. This will create unique policers and counters for each interface to which the filter is applied.

Policer example

In this section, we will examine a very simple two-level policer that:

- Limits virtual LAN (VLAN) 1241 to 1 MB with a burst size of 5,000 bytes
- Limits FTP to 10% of the bandwidth and ICMP to 500,000 bits per second

First, the policers are defined under the firewall level:

```
lab@Bock# show firewall
policer total-int {
    if-exceeding {
        bandwidth-limit 1m;
        burst-size-limit 5k;
    }
    then discard;
}
policer limit-ftp {
    if-exceeding {
        bandwidth-percent 10;
        burst-size-limit 500k;
    }
    then discard;
}
policer police-icmp {
    if-exceeding {
        bandwidth-limit 500k;
        burst-size-limit 500k;
    }
    then discard;
}
```

Then a filter is created to match on FTP and ICMP traffic to limit each application to certain thresholds. The `interface-specific` keyword is used to create a unique instance if the filter if applied to multiple interfaces. This is required if a policer is referenced that uses bandwidth percentage such as the `limit-ftp` policer:

```
firewall {
    family inet {
        filter police-traffic {
            interface-specific;
            term police-ftp {
                from {
                    protocol tcp;
                    port [ ftp ftp-data ];
                }
                then policer limit-ftp;
            }
            term police-icmp {
                from {
                    protocol icmp;
                }
                then policer police-icmp;
            }
            term catch-all {
                then accept;
            }
        }
    }
}
```

Apply the filter and policer to the interface:

```
lab@Bock# show interfaces fe-0/0/0
vlan-tagging;
unit 1241 {
    description Bock-to-PBR;
    vlan-id 1241;
    family inet {
        filter {
            input-list police-traffic;
        }
        policer {
            input total-int;
        }
        address 10.20.130.1/24;
    }
}
```

To verify whether the policer is applied, issue a `show interfaces policers` command:

```
lab@Bock> show interfaces policers
Interface       Admin Link Proto Input Policer       Output Policer
fe-0/0/0        up    up
fe-0/0/0.1241   up    up   inet  total-int-fe-0/0/0.1241-inet-i
gr-0/0/0        up    up
ip-0/0/0        up    up
ls-0/0/0        up    up
lt-0/0/0        up    up
mt-0/0/0        up    up
pd-0/0/0        up    up
pe-0/0/0        up    up
```

```
sp-0/0/0         up    up
sp-0/0/0.16383   up    up   inet
fe-0/0/1         up    up
fe-0/0/1.100     up    up   inet
t1-0/0/2         up    up
t1-0/0/2.0       up    down inet
t1-0/0/3         up    up
dsc              up    up
gre              up    up
ipip             up    up
lo0              up    up
lo0.0            up    up   inet
lo0.16385        up    up   inet
lsi              up    up
mtun             up    up
pimd             up    up
pime             up    up
pp0              up    up
tap              up    up
```

To examine whether packets are exceeding the traffic parameters, view the policer counters. For interface policers, you can see packet counts with the `show policer` command:

```
lab@Bock> show policer total-int-fe-0/0/0.1241-inet-i
Policers:
Name                                                Packets
total-int-fe-0/0/0.1241-inet-i                            5
```

Policers that are referenced in a firewall filter automatically get counters created for them based on the policer name, interface applied, and direction. You can view these in the same command as normal counters for filters, with the `show firewall` command:

```
lab@Bock> show firewall
Filter: fe-0/0/0.1241-i
Policers:
Name                                                Packets
police-icmp-police-icmp-fe-0/0/0.1241-i                   0
limit-ftp-police-ftp-fe-0/0/0.1241-i                      0
Filter: __default_bpdu_filter__
Filter: police-traffic
Policers:
Name                                                Packets
police-icmp-police-icmp                                   0
limit-ftp-police-ftp                                      0
```

A difficulty is determining how much traffic the policer is allowing to ascertain if the exceeding parameters are too large or too small. You can do this using the policer counters, interface statistics, and a little math. First, determine the byte-per-packet size the policer sees by dividing the bytes by the number of packets as seen by the policer counter. Then, multiply the egress rate in packets per second by the per-packet size and 8 bits to get the bytes per second.

For example, say the policer counter claimed 1,406,950 bytes and 18,494 packets exceeded the policer. This would calculate to an average per-packet size of 76 bytes (1,406,950/18,494). Then, via the `show interfaces` command, the interface rate would be determined to be 203 packets per second (pps). So, 203 pps multiplied by 76 bytes divided by a packet time of 8 bits per second will provide a bytes-per-second rate of 123,424, which should be close to the configured bandwidth rate.

Summary of Firewall Filters and Policers

Stateless firewall filters offer the advantage of high-speed processing, which allows you to maintain local control plane and transit security at near-wire-rate speeds. The easy-to-read and intuitive nature of JUNOS filter and policer syntax makes it easy to create, deploy, monitor, and modify filters.

You may also consider the use of stateful firewall filtering, which provides for enhanced packet and application layer processing, using the techniques covered in Chapters 7, 8, and 11. The flexibility of JUNOS software allows you to choose which solution is best for a specific set of needs and, when desired, to use both types of filtering for an optimal security and performance solution.

The next section details ways in which JUNOS can help to prevent the use of bogus source addressing, which is a common occurrence in a distributed DoS (DDoS) attack.

Spoof Prevention (uRPF)

Many distributed DoS attacks take advantage of address "spoofing" by randomly selecting an address in the source field of IP packets. In some attacks, this source address is deterministic to the target network under attack. In other words, this address will be taken out of the network's address block to create attacks on other internal machines generating ICMP error messages or other traffic back to the spoofed addresses. You can protect yourself from these types of attacks by applying ingress filtering at the edge of your network, which denies incoming packets with addresses out of the network's address block. This filtering has traditionally been solved with an inbound packet filter.

Referring back to the topology in Figure 6-2, note that three internal address blocks are assigned to `PBR`, `Ale`, and `Bock`'s network:

10.10.128/22
10.20.128/22
10.10.12/22

So, a simple filter would deny any addresses from those address blocks coming from the WAN connection off `PBR`:

```
[edit firewall]
lab@PBR# show
family inet {
    filter spoof-prevention {
        term my-addresses {
            from {
                source-address {
                    10.10.128.0/22;
                    10.20.128.0/22;
                    10.10.12.0/22;
                }
            }
            then {
                count spoofs;
                log;
                discard;
            }
        }
        term allow-rest {
            then count no-spoof;
        }
    }
}
```

Apply the firewall filter as an input filter on `fe-0/0/0.412` and `fe-0/0/0.413`:

```
lab@PBR# show interfaces fe-0/0/0
vlan-tagging;
unit 412 {
    description PBR-to-Wheat;
    vlan-id 412;
    family inet {
        filter {
            input-list spoof-prevention;
        }
        address 172.16.1.2/24;
    }
}
unit 413 {
    description PBR-to-Water;
    vlan-id 413;
    family inet {
        filter {
            input-list spoof-prevention;
        }
        address 64.8.12.6/27;
    }
}
```

After applying the filter, we can see that spoofed addresses are being properly denied over PBR's `fe-0/00.413` interface, as shown in the firewall log:

```
lab@PBR> show firewall log
Log :
```

```
Time      Filter    Action Interface     Protocol Src Addr       Dest Addr
01:39:18  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:17  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:16  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:15  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:14  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:13  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:12  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:11  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:10  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:09  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
```

The problem with ingress firewall filters is that you must update them manually when an address block or network changes. A more dynamic method that has been developed to prevent spoofing is called *unicast Reverse Path Forwarding* (uRPF). RPF is a mechanism that is used in multicast networks to avoid looping based on the source IP address (the reverse path), not the destination IP address. In essence, the source IP address is compared against the route table to see whether it was learned over that interface. If the packet was received via the incoming interface on which it was learned, it is accepted; if not, the packet will be dropped.

This concept has now been extended to Unicast packets for spoof prevention to create dynamic filters based on the route table. The mechanism will remain the same, in that the source IP address will need to be "verified" for incoming packets. Unicast RPF can operate on one of two modes:

Strict
: The incoming packet must be received on the interface that would be used to forward traffic to the source IP address. Strict mode is the default.

Loose
: The incoming packet's source address must be in the route table.

Strict mode provides a reliable, simple, fast, and cheap filter at the edge of any network. The configuration to enable strict mode is quite simple; just add the `rpf-check` command under the proper interface:

```
lab@PBR# show interfaces fe-0/0/0
vlan-tagging;
unit 412 {
    description PBR-to-Wheat;
    vlan-id 412;
    family inet {
        rpf-check;
        address 172.16.1.2/24;
    }
}
unit 413 {
    description PBR-to-Water;
    vlan-id 413;
    family inet {
        rpf-check;
        address 64.8.12.6/27;
    }
}
```

Verify that uRPF is enabled by looking for the uRPF flag in the interface:

```
[edit]
lab@PBR# run show interfaces fe-0/0/0.413 | match uRPF
      Flags: uRPF
```

The packets that fail the RPF check are automatically counted on the interface:

```
[edit]
lab@PBR# run show interfaces fe-0/0/0.413 extensive | match RPF
      Flags: uRPF
      RPF Failures: Packets: 8, Bytes: 672
```

Strict mode is the preferred solution when possible, but it does run into some problems under certain scenarios. In particular, it assumes symmetrical traffic flows. In the case of a BGP multihoming environment or redundant IGP paths, this may not always be the case.

Remember that the default load balancing for a Juniper router is to choose a single next hop to install in the forwarding table per destination.

PBR is multihomed to two ISPs (see Figure 6-11) and receives the same set of routes from each; however, only the route received from autonomous system (AS) 666 is active.

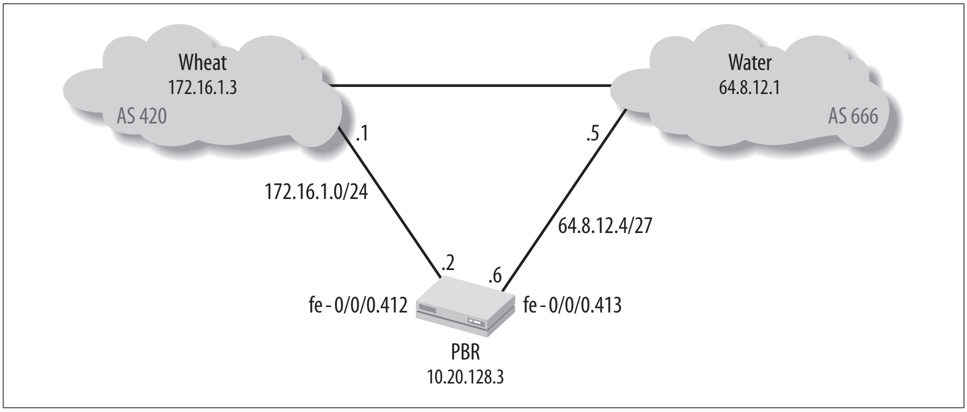


Figure 6-11. Multihoming

```
lab@PBR# run show bgp summary
Groups: 2 Peers: 2 Down peers: 0
Table          Tot Paths  Act Paths Suppressed    History Damp State    Pending
inet.0               497        249          0          0          0          0
Peer               AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn
State|#Active/Received/Damped...
```

```
64.8.12.5        666      1239      1114       0      0     9:15:56 248/248/0
0/0/0
172.16.1.1       420      1354      1238       0      0     9:15:26 0/248/0
0/0/0
```

This means that any traffic received from AS 420 that is an inactive route will fail the RPF check. An example is the 128.3/16 address block:

```
[edit]
lab@PBR# run show route 128.3.3.4

inet.0: 264 destinations, 513 routes (264 active, 0 holddown, 1 hidden)
+ = Active Route, - = Last Active, * = Both

128.3.0.0/16       *[BGP/170] 09:20:20, localpref 100
                      AS path: 666 11537 293 16 I
                    > to 64.8.12.5 via fe-0/0/0.413
                    [BGP/170] 09:19:50, localpref 100
                      AS path: 420 666 11537 293 16 I
                    > to 172.16.1.1 via fe-0/0/0.412
```

Since JUNOS performs uRPF against active paths only, in order to allow for multihoming or asymmetric traffic flows you can configure a feature called *feasible paths*. This knob allows every possible path in the route table to be considered, including active and inactive paths. You enable this global command for the entire router under the [edit routing-options] stanza:

```
lab@PBR# show routing-options
aggregate {
    route 10.10.128.0/22;
    route 10.20.128.0/22;
    route 10.10.12.3/32;
}
autonomous-system 1282;
forwarding-table {
    unicast-reverse-path feasible-paths;
}
```

Loose RPF provides less security, as it verifies only that the route is in the route table and does not check which interface it points to. This is more of a route presence check than an actual verification of the reverse path. The only benefit would be for *route martians*, or packets that are not currently being routed. One such example could be a private RFC 1918 address if only publicly routable addresses are used in the network. Since loose mode sacrifices directionality, it is not a recommended approach to spoof prevention and has limited scope.

Another problem with loose mode occurs when a default route is present in the table. In this case, every packet would pass the check and thus uRPF checks would be negated. Strict mode with a default route will still verify that the packet entered on the interface to which the default route points.

To enable loose mode on an interface, specify the loose command after turning on uRPF:

```
lab@PBR# set interfaces fe-0/0/0.412 family inet rpf-check mode loose
```

Other filters could still be applied to the interface when uRPF mode is enabled; in this case, the input filter is examined first, and the uRPF checks process only the traffic that passes this filter. Due to this processing, it is hard to perform a log action for packets that failed the RPF filter. In this instance, you can configure a *fail* filter. A fail filter is performed after the RPF check and on all traffic that has failed the RPF check (see Figure 6-12).

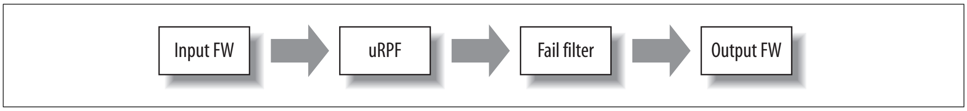


Figure 6-12. Firewall filter and uRPF relationship

You can use a fail filter to:

- Allow traffic that would normally fail an RPF check, such as DHCP on a LAN interface
- Allow traffic that would normally fail an RPF check to be accepted and counted
- Allow failed traffic to be processed by a filter modifier such as counting or logging

An example of the first filter could be DHCP requests that would always fail an RPF check:

```
filter rpf-dhcp {
            term dhcp {
                from {
                    source-address {
                        0.0.0.0/32;
                    }
                    destination-address {
                        255.255.255.255/32;
                    }
                }
                then accept;
            }
        }
    }
```

If traffic that fails the RPF check should be further examined, you also can use a fail filter. The following filter would be able to log all packets that are failing the RPF check:

```
filter match-spoofs {
    term 1 {
        then {
            log;
            discard;
        }
    }
}
```

Apply the fail filter to the interface:

```
    [edit interfaced fe-0/0/0]
    lab@PBR# show
    unit 413 {
        description PBR-to-Water;
        vlan-id 413;
        family inet {
            rpf-check fail-filter match-spoofs;
            address 64.8.12.6/27;
        }
    }
```

View the packets that are failing uRPF by examining the firewall log:

```
    lab@PBR# run show firewall log
    Log :
    Time      Filter    Action Interface     Protocol Src Addr       Dest Addr
    02:23:59  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
    02:23:58  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
    02:23:57  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
    02:23:56  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
    02:23:55  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
    02:23:54  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
    02:23:53  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
    02:23:52  pfe       D      fe-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
```

Summary of Spoof Prevention

Current best practices suggest that all source addresses should be validated as close to the ingress point of traffic as is possible. Historically, the added processing led to poor forwarding performance due to a lack of processing resources. This often resulted in a total lack of address enforcement, and the resulting ease in which DDoS attacks can be successfully launched.

The unique design of JUNOS software allows you to enable spoof prevention features while still maintaining a high level of forwarding performance.

The next section details ways that JUNOS can help monitor the router to actively and proactively determine the presence of attacks.

Monitoring the Router

Once the access configuration is in place, you should monitor the router for health and analysis. The two primary methods of remote monitoring are via SNMP and syslog (system logging). SNMP is a way to gather statistics and other event information off the router, whereas syslog is used to gather various log messages off the router. To validate these types of messages, you should use proper time and date stamping, which is often implemented by using NTP.

Syslog

Syslog was originally developed as a method to send information for the sendmail application in BSD, but it was so useful that it was extended to other applications and operating systems. Essentially, syslog is a standard way to send log messages across an IP network.

Syslog describes the actual transport mechanism used to send these messages and is often used to describe the actual application that is sending them. Originally, it was an "industry" standard and was not attached to an informational RFC until 2001, with RFC 3164, "The BSD Syslog Protocol."

Syslog messages are sent over UDP with a destination port of 514. The IP transport mechanism is defined and not the actual syslog content. It is left to the discretion of the application or system coder to create an informative message to the receiver. The message always contains a message severity level and a facility level. The *facility level* can be defined as the type of message that is being sent, and the *severity level* indicates the message's importance. Table 6-5 defines the severity levels.

Table 6-5. Syslog severity levels

Numerical code	Severity
0	Emergency: system is unusable
1	Alert: action must be taken immediately
2	Critical: critical conditions
3	Error: error conditions
4	Warning: warning conditions
5	Notice: normal but significant condition
6	Informational: informational messages
7	Debug: debug-level messages

Table 6-6 lists the facility levels that are available in JUNOS.

Table 6-6. Syslog facility levels

Facility	Description
Any	All facilities (all messages)
Authorization	Authentication and authorization attempts
Change-Log	Changes to the configuration
Conflict-Log	Specified configuration is invalid on the routing platform type
Daemon	Actions performed or errors encountered by system processes
DFC	Events related to dynamic flow capture
Firewall	Packet filtering actions performed by a firewall filter
FTP	Actions performed or errors encountered by the FTP process
Interactive commands	Commands executed by the user interface
Kernel	Actions performed or errors encountered by the JUNOS kernel
PFE	Actions performed or errors encountered by the Packet Forwarding Engine
User	Actions performed or errors encountered by user-space processes

The default system log is called "messages"; you can view it with the `show log messages` command:

```
lab@PBR> show log messages
Nov 20 06:00:00 PBR newsyslog[2858]: logfile turned over due to size>128K
Nov 21 09:47:59  PBR login: LOGIN_PAM_AUTHENTICATION_ERROR: PAM authentication error
for user lab
Nov 21 09:47:59  PBR login: LOGIN_FAILED: Login failed for user lab from host
Nov 21 09:48:03  PBR login: LOGIN_INFORMATION: User lab logged in from host [unknown]
on device ttyd0
Nov 21 09:48:06  PBR mgd[2978]: UI_DBASE_LOGIN_EVENT: User 'lab' entering
configuration mode
Nov 21 09:54:36  PBR mgd[2978]: UI_DBASE_LOGOUT_EVENT: User 'lab' exiting
configuration mode
Nov 21 09:54:55  PBR mgd[2978]: UI_REBOOT_EVENT: System rebooted by 'lab'
Nov 21 09:55:09  PBR /kernel: KERNEL_MEMORY_CRITICAL: System low on free memory,
notifying init (#1).
Nov 21 09:55:09  PBR rpd[2800]: Received low-memory signal: no job active, 34 free
pages
Nov 21 09:55:09  PBR rpd[2800]: Processing low memory signal
Nov 21 09:55:49  PBR shutdown: reboot by lab:
Nov 21 09:55:49  PBR init: watchdog (PID 2768) terminate signal sent
Nov 21 09:55:49  PBR init: chassis-control (PID 2770) terminate signal sent
Nov 21 09:55:49  PBR init: alarm-control (PID 2771) terminate signal sent
Nov 21 09:55:49  PBR craftd[2772]: craftd_user_conn_shutdown: socket 8, errno = 0
Nov 21 09:55:49  PBR init: craft-control (PID 2772) terminate signal sent
Nov 21 09:55:49  PBR snmpd[2811]: SNMPD_CLOSE_SA_IPC: ipc_free_local: closed IPC
socket /var/run/craft
Nov 21 09:55:49  PBR init: management (PID 2773) terminate signal sent
Nov 21 09:55:49  PBR init: inet-process (PID 2775) terminate signal sent
Nov 21 09:55:49  PBR init: syslogd (PID 2682) terminate signal sent
Nov 21 09:55:49  PBR init: ecc-error-logging (PID 2779) terminate signal sent
Nov 21 09:55:49  PBR init: forwarding (PID 2780) terminate signal sent
Nov 21 09:55:49  PBR init: usb-control (PID 2781) terminate signal sent
Nov 21 09:55:49  PBR init: mib-process (PID 2799) terminate signal sent
Nov 21 09:55:49  PBR snmpd[2811]: SNMPD_CLOSE_SA_IPC: ipc_free_local: closed IPC
socket /var/run/mib2d
Nov 21 09:55:49  PBR init: routing (PID 2800) terminate signal sent
Nov 21 09:55:49  PBR rpd[2800]: RPD_SIGNAL_TERMINATE: first termination signal
received
Nov 21 09:55:49  PBR init: l2-learning (PID 2801) terminate signal sent
Nov 21 09:55:49  PBR init: vrrp (PID 2802) terminate signal sent
Nov 21 09:55:49  PBR snmpd[2811]: SNMPD_CLOSE_SA_IPC: ipc_free_local: closed IPC
socket /var/run/vrrpd
Nov 21 09:55:49  PBR rpd[2800]: RPD_OSPF_NBRDOWN: OSPF neighbor 10.20.130.1 (fe-0/0/
0.1241) state changed from Full to Down due to KillNbr (event reason: interface went
down)
Nov 21 09:55:49  PBR init: sampling (PID 2803) terminate signal sent
Nov 21 09:55:49  PBR init: class-of-service (PID 2804) terminate signal se
```

Many of the syslog messages will have headers specified in uppercase letters that you can input into the help command specifying which facility the message was logged on, the severity level, a description, and a recommended action. Looking at the log entry for November 21, one such header is noted as RPD_OSPF_NBRDOWN:

```
Nov 21 09:55:49  PBR rpd[2800]: RPD_OSPF_NBRDOWN: OSPF neighbor 10.20.130.1 (fe-0/0/
0.1241) state changed from Full to Down due to KillNbr (event reason: interface went
down)
```

You can examine this message using the help syslog command, which indicates that an OSPF neighbor went down due to an event:

```
lab@PBR> help syslog RPD_OSPF_NBRDOWN
Name:          RPD_OSPF_NBRDOWN
Message:       OSPF neighbor <neighbor> (<interface>) state changed from
               <old-state> to <new-state> due to <event> (event reason:
               <event-reason>)
Help:          OSPF neighbor adjacency was terminated
Description:   An OSPF adjacency with the indicated neighboring router was
               terminated. The local router no longer exchanges routing
               information with, or directs traffic to, the neighboring router.
Type:          Event: This message reports an event, not an error
Severity:      notice
```

You can create custom logs by specifying a filename, facility, message facility, and location to send the message. The message can either be stored in a local file, sent to a syslog server, sent to the console, or sent to a user or group of users when logged in to the router.

The factory default configuration enables three system logs: two logs that are sent to a file, and one log that is sent to any user that is logged in. Although the default system log receives all information as specified with the any keyword, you can create other files for easier log parsing:

```
syslog {
    user * {
        any emergency;
    }
    file messages {
        any any;
        authorization info;
    }
    file interactive-commands {
        interactive-commands any;
    }
}
```

Case study: Syslog

To avoid having to specify every syslog option available, let's examine a realistic example with specific goals. The goals are as follows:

- Increase the default size of the *messages* file to 1 MB and the number of archives to 15.
- Send all messages to a syslog server with a domain name of *syslog.underdogssf.com*.
- Ensure that all messages sent to the syslog server are in the same format as the Cisco routers in your network.
- Create a syslog file to log all firewall filter log information.

Each syslog file that is created on a Juniper Networks router is stored in the file directory *var/log* and is given a size of 128 KB on a J-series router and 1 MB on an M-series router. When the file is full, the file is cleared, an archive is created of the old data, and the file is written to again. For example, once 128 KB of data is written into the *messages* file, that file will be cleared and the information will be moved into a *message.0* file. When the *messages* file is filled up again, the old data is archived into *messages.0* and the old *messages.0* now becomes *messages.1*. This will continue for 10 archives until the data is written. In the case study, you should increase the default number of archives to 15 and the file size to 1 MB. You can do this with the following archive configuration:

```
[edit system syslog]
lab@PBR# set file messages archive files 15 size 1M

[edit system syslog]
lab@PBR# show file messages
any notice;
authorization info;
archive size 1m files 15;
```

Next, syslog messages need to be sent to a syslog server:

```
[edit system syslog]
lab@PBR# set host syslog.underdogssf.com any any
```

The default JUNOS message does not send the priority (facility value and severity) of the syslog message, which could cause issues when trying to parse the output at the receiver. Cisco routers by default do send this priority field; to ensure that both vendors send the same message format, configure the `explicit-priority` keyword:

```
[edit system syslog]
lab@PBR# set host syslog.underdogssf.com explicit-priority
```

Lastly, a new syslog file is created to log firewall entries:

```
[edit system syslog]
lab@PBR# set file fw-log firewall info
```

Here is the complete stanza:

```
[edit system syslog]
lab@PBR# show
user * {
    any emergency;
}
host syslog.underdogssf.com {
    any any;
    explicit-priority;
}
file messages {
    any notice;
    authorization info;
    archive size 1m files 15;
}
file interactive-commands {
    interactive-commands any;

}
file fw-log {
    firewall info;
}
```

SNMP

SNMP is a standard protocol used for a network management station to receive information for the router (or agent; see Figure 6-13). The manager can poll the router for router health information such as memory utilization, link status, or firewall filter statistics in the form of a GET command. The router can also send event information to the network manager without polling, in a process called a *TRAP*.

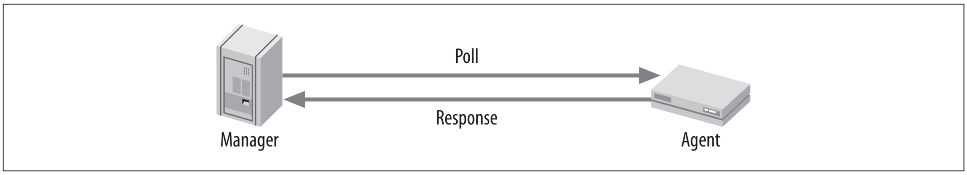


Figure 6-13. SNMP concept

The data structure that is used to carry information is called a Management Information Base (MIB). An MIB has a structure in the format of a tree that defines groups of objects into related sets. These MIBs are identified by an Object Identifier (OID), which names the object. The leaf of the OID contains the actual managed objects. MIBs are defined into two categories: standard and enterprise-specific. Standard MIBs are defined by the IETF in various RFCs, whereas enterprise-specific MIBs are defined by the vendor and must be compiled into the management station. Here is an example of MIB data taken from a network manager:

```
SNMPv2-MIB::sysDescr.0 = STRING: M120 - Okemos, MI
SNMPv2-MIB::sysObjectID.0 = OID: JUNIPER-MIB::jnxProductNameM120
SNMPv2-MIB::sysUpTime.0 = Timeticks: (80461526) 9 days, 7:30:15.26
SNMPv2-MIB::sysContact.0 = STRING: Doug Marschke - x8675309
SNMPv2-MIB::sysName.0 = STRING: PBR-3
SNMPv2-MIB::sysLocation.0 = STRING: Okemis, MI USA - Rack 4
SNMPv2-MIB::sysServices.0 = INTEGER: 4
```

To configure SNMP on a Juniper router, you must specify a community string on the router. This acts as a password to verify incoming SNMP information on the management station:

```
[edit snmp]
lab@PBR# set community sample

[edit snmp]
lab@PBR# show
community sample;
```

Juniper Networks routers support SNMP v1, SNMP v2, and SNMP v3.

With this basic configuration, SNMP GETs can be received on any interface from any management statement. It is recommended that access is restricted to particular interfaces and clients:

```
lab@PBR# show
interface fe-0/0/0.1141;
community sample {
    clients {
        10.10.12.4/32;
        0.0.0.0/0 restrict;
    }
}
```

Also, the router may want to initiate some information in the form of TRAPs. TRAPs are sent to a specified list of targets and are defined by categories. Possible categories include:

Authentication
User login authentication failures

Chassis
Chassis and environmental notifications

Configuration
Notification of configuration changes

Link
Link status changes

Remote operations
Remote operation notifications

Rmon-alarm
Events for RMON alarms

Routing
Routing protocol information such as neighbor status changes

Services
Events for additional JUNOS services such as Network Address Translation (NAT) and stateful firewall

Sonet-alarm
A variety of SONET alarms such as loss of light, BER defects, and so on

Start-up
Warm and cold boots

VRRP events
VRRP events such as mastership changes

In the following example, a TRAP group called `health` is added to the SNMP configuration that sends chassis and link TRAPs to station 10.10.12.4:

```
lab@PBR# show
interface fe-0/0/0.1141;
community sample {
    clients {
        10.10.12.4/32;
        0.0.0.0/0 restrict;
    }
}
trap-group health {
    categories {
        chassis;
        link;
    }
    targets {
        10.10.12.4;
    }
}
```

By default, both SNMP v1 and v2 TRAPs are sent. You can overwrite this by specifying a version under the TRAP group.

It may also be useful to walk down the MIB tree to verify information in the MIB and for troubleshooting purposes. To perform an SNMP walk on the router, issue the `show snmp mib <object>` command. In this case, the system MIB is examined on the router:

```
lab@PBR> show snmp mib walk system
sysDescr.0    = Juniper Networks, Inc. j6300 internet router, kernel JUNOS 8.0R2.8
#0: 2006-09-29 09 Build date: 2006-09-29 08:22:29 UTC Copyright (c) 1996-2006 Juniper
Networks, Inc.
sysObjectID.0 = jnxProductNameJ6300
sysUpTime.0   = 50415199
sysContact.0
sysName.0     = PBR
sysLocation.0
sysServices.0 = 4
```

NTP

When examining logs, it is essential to ensure that the proper date and time are recorded for each event. You can set the time and date manually on each router using the `set date` command:

```
lab@PBR> set date ?
Possible completions:
  <time>  New date and time (YYYYMMDDhhmm.ss)
  ntp     Set system date and time using Network Time Protocol servers
```

However, since many devices are likely to be managed at once, each with slightly different clock speeds and drift, it is virtually impossible to keep all the clocks on every device synchronized. NTP was developed for the purpose of clock synchronization. NTP works in one of three modes:

Client
: A client has a one-way synchronization with a server.

Symmetric active
: There is equal peer synchronization with each other's local clock.

Broadcast
: The server sends periodic broadcast messages on shared media, and clients listen to these messages for synchronization.

NTP uses a concept of *clock strata* to define the distance from the clock reference and the accuracy. A stratum 0 clock is the reference clock (such as an atomic clock), and each level of peering relationship decreases in accuracy and stratum level (see Figure 6-14).

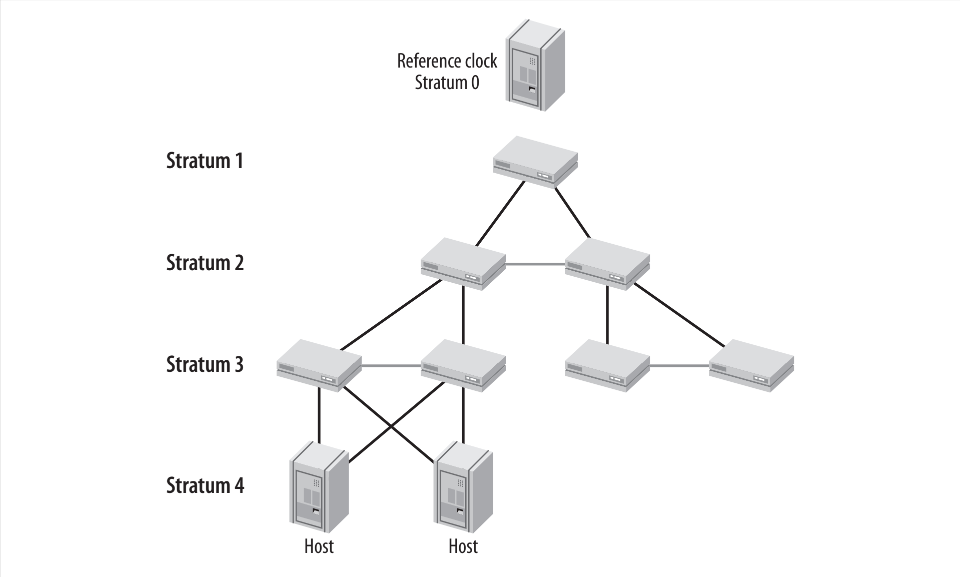


Figure 6-14. NTP stratum levels

All NTP configurations are set under [edit system ntp]. In the following configuration, Bock is configured in client mode with a server of 10.20.130.5. Also, a boot server is configured to allow the initial clock setting to be set at boot time:

```
lab@Bock> show configuration system ntp
boot-server 10.20.130.5;
server 10.20.130.5;
```

If a router is configured for NTP and the clocks are more than 128 seconds apart, the synchronization process will fail. In the past, to recover from that scenario, the operator either rebooted the device with the boot server configuration or set the date manually within 128 seconds. JUNOS software now allows you to synchronize the device by simply issuing the set date ntp command and avoiding a reboot:

```
lab@Bock> set date ntp 10.20.130.5
10 Feb 13:50:21 ntpdate[794]: step time server 10.20.130.5 offset 0.000163 sec
```

To verify that NTP has worked correctly, issue the show ntp associations command and look for the * next to the remote IP:

```
lab@Bock> show ntp associations
     remote     refid  st t when poll reach  delay   offset  jitter
====================================================================
*10.20.130.5  LOCAL(0)  11 u   10   64   17   0.491   12.991  10.140
```

Check the correct time:

```
lab@Bock> show system uptime
Current time: 2007-11-22 03:53:35 UTC
System booted: 2007-11-20 04:58:58 UTC (1d 22:54 ago)
```

```
Protocols started: 2007-11-20 04:59:24 UTC (1d 22:54 ago)
Last configured: 2007-11-22 03:40:02 UTC (00:13:33 ago) by lab
 3:53AM  up 1 day, 22:55, 1 user, load averages: 0.19, 0.10, 0.03
```

You also can change the time zone in the router by issuing a `set system time-zone` command:

```
lab@Bock# set system time-zone ?
Possible completions:
  <time-zone>          Time zone name or POSIX-compliant time zone string
  Africa/Abidjan
  Africa/Accra
  Africa/Addis_Ababa
  Africa/Algiers
  Africa/Asmera
---(more 5%)---[abort]
```

Is NTP REALLY Working?

The `show ntp associations` command is often a source of mass confusion and terror for operators, as there is no distinct "broken field." The synchronization process will be indicated by interpreting the delay and offset fields, as well as by noting the presence or absence of a * character.

Here is an example of an association that has failed. Notice the space in front of the 10.20.130.5 as well as the zeros is the delay and offset fields. This is an indication that no messages have been sent at all!

```
lab@Bock> show ntp associations
    remote       refid   st t when poll reach   delay   offset  jitter
======================================================================
10.20.130.5 0.0.0.0      0 u   12   64    0    0.000    0.000 4000.00
```

In comparison, here is another association that failed; however, notice that there are values in the delay and offset fields. These indicate that NTP messages have been exchanged but synchronization has not been achieved, as no * has been displayed next to the remote peer. The large offset is usually an indication that the clocks are too far apart (above the 128-second threshold):

```
lab@Bock> show ntp associations
    remote    refid  st t when poll reach   delay   offset  jitter
===================================================================
10.20.130.5 LOCAL(0)    11 u   25   64   37  0.492  2542804 4000.00
```

After issuing a `set date ntp` command, the clocks synchronize without having to reboot the router. Note the more sane offset value and the presence of the illustrious star next to the remote peer address:

```
lab@Bock> show ntp associations
     remote      refid  st t when poll reach   delay   offset  jitter
======================================================================
*10.20.130.5  LOCAL(0)    11 u   10   64   17   0.491   12.991  10.140

3:53AM  up 1 day, 22:55, 1 user, load averages: 0.19, 0.10, 0.03
```

> Since NTP uses a step process to synchronize the clocks after issuing the `set date ntp` command, the association could still appear to be broken. This is normal for NTP, so just sit back, enjoy a drink, and after three to five minutes, everything should be working as normal.

Summary of Router Monitoring

Many types of attacks and network abuse leave telltale signs, if the operator only takes the time to look for them. The Unix underpinnings of JUNOS software offer full syslogging capabilities, which when synchronized to other routers via the NTP protocols can provide invaluable forensics when problems are being investigated. Using SNMP to remotely monitor network operations to include the receipt of asynchronous TRAPs reporting anomalous conditions provides an excellent way to adopt a more proactive stance toward securing your network.

Conclusion

When the router is deployed in the network, you must secure it properly to protect your network, investments, and hard work. The first step is to configure the proper users with access privileges. Depending on the number of users, the local router or an external server database may be used to hold this information, or an external server.

Once the users are in place, you need to deploy packet filters to protect the router. These filters may be very elaborate or quite simple depending on your security policies. Also, you may need to rate-limit some applications in your network using policers.

It also does not do much good to have a secure router if you can't gather router health and other statistical information from it. Therefore, you also should deploy standard protocols such as SNMP, syslog, and NTP to achieve these management goals.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- List the various user authentication methods.
- Describe the uses of login classes.
- Describe authentication order.
- Describe system logging.
- Identify the configuration of a stateless packet filter.
- Secure the router by applying packet filters to protect the Routing Engine.
- Evaluate the result of a given stateless packet filter.

- Configure SNMP.
- Customize class templates with varying permissions and commands.
- Configure and operate the Network Time Protocol.

Chapter Review Questions

1. What is the default password on the router?
    a. Juniper
    b. Cisco
    c. There is no password
    d. Enable
2. Which predefined login class allows the user to have access rights to any login command?
    a. Privileged
    b. Super-user
    c. Privileged exec
    d. Power-user
3. What is the default action at the end of a firewall filter chain?
    a. Discard
    b. Reject
    c. Accept
    d. Do nothing
4. Which interface would you apply to a filter to protect the router's local traffic?
    a. `fxp1`
    b. `fxp0`
    c. `manage`
    d. `lo0`
5. Which command is used to view all firewall filter counters, including counters automatically created in policers?
    a. `show counters`
    b. `show policer`
    c. `show interfaces filters counters`
    d. `show firewall`
6. Which two features can you use to protect your network against spoofed IP addresses? (Choose two.)
    a. Firewall filters
    b. Spoof routes

c. Unicast reverse path forwarding

d. Secondary addresses

7. Which three parameters are specified in a policer? (Choose three.)

   a. Bandwidth limit

   b. Policer action

   c. Bucket level

   d. Burst size

   e. Leak rate

8. Choose two possible reasons for using a fail filter using uRPF. (Choose two.)

   a. Allow packets to pass through RPF

   b. Log packets that fail RPF

   c. Implement NAT

   d. Send traffic through a tunnel

9. Which syslog facility logs all CLI commands?

   a. `cli-commands`

   b. `accounting`

   c. `change-log`

   d. `interactive-commands`

10. In which directory are all logfiles stored?

    a. */var/home/user*

    b. */log*

    c. */var/home/log*

    d. */var/log*

    e. */syslog*

11. Which feature of SNMP v2 acts as a password to authenticate SNMP messages?

    a. MIBs

    b. Communities

    c. OID

    d. TRAPs

12. Which command allows NTP synchronization without a router reboot?

    a. `set system ntp`

    b. `request system time update`

    c. `set date ntp`

    d. `set ntp boot-server`

Chapter Review Answers

1. Answer: C. There is no default password on a Juniper router in the factory default configuration. A single user, `root`, will be configured with no password.
2. Answer: B. The class of `superuser` allows users to issue any command that they desire on the router. The other options listed are not supported classes.
3. Answer: A. At the end of a filter chain, if a packet has not matched any other term, it will be discarded. Special care must always be taken when writing a filter to allow traffic that would otherwise be denied by the final implicit discard at the end of the filter.
4. Answer D. If a filter is applied to the loopback interface, any traffic local to the router can be protected, including routing protocol, ICMP, and FTP traffic.
5. Answer: D. You can use the `show firewall` command to view counters defined in any firewall filter. Also, any policer that is referenced in a filter will have a counter automatically created and viewed by this command. The `show policer` command will only show the counter for policers applied directly to the interface.
6. Answer: A, C. Both firewall filters and Unicast RPF will help to avoid packets with spoofed IP addresses. Unicast RPF could provide for more dynamic and automatic filtering.
7. Answer: A, B, D. Policers must specify bandwidth and burst size limit. Also, once a packet hits one of the limits, an action to either hard- or soft-police must be specified.
8. Answer: A, B. A fail filter matches on packets that fail the RPF check. You could use this to accept packets such as DHCP, which would always fail an RPF check, or to count or log packets that have passed an RPF check.
9. Answer: D. The facility `interactive-commands` will log any commands that were typed via any user interface method, including the CLI.
10. Answer: D. This is the directory for all syslog and trace-options files.
11. Answer: B. A community will act as a password for SNMP messages. This community value is sent in clear text on the wire, which could easily be captured. The next version of SNMP corrects this issue.
12. Answer: C. If the NTP server is reachable, `set date ntp` will restart the NTP update process without having to reboot the router, thus eliminating the need for a `boot-server` configuration statement.

CHAPTER 7

Introduction to JUNOS Services

Once the routing aspect of a network has been deployed, you'll want additional services to be added to fit your network requirements. In the past, a separate device would have performed these types of services, but in modern networking these tasks have been moved to the router itself. *Service* is a broad term that can include tasks that are performed at Layer 2 (such as link bonding) or at Layer 3 (such as Network Address Translation [NAT]). We will examine all of these services in this chapter, as well as provide additional detail regarding more specific services throughout the book.

Because many of these services require intensive packet processing on the router, you may have to install additional hardware to avoid any degradation in packet forwarding and throughput. Although this may seem to be a slight nuisance at first, it does solve the problem of increased services causing decreased throughput, as is observed in most other router implementations.

The service topics covered in this chapter include:

- JUNOS services
- Layer 2 services
- Layer 3 services
- Layer 3 service command-line interface (CLI) configuration
- Additional service options

The information covered in this chapter, and in Chapter 8, is based on services that are implemented via ASP on the M7i, or on the J-series through its emulation of ASP functionality. Starting with Release 8.5, Juniper Networks has made available its JUNOS software with enhanced services. The reader should be aware that the primary difference between JUNOS and JUNOS software with enhanced services relates to services. In the JUNOS software with enhanced services release, these services are based on ScreenOS functionality. Along with the improved services comes new configuration syntax.

Readers who are not deploying JUNOS software with enhanced services, or who will deploy both JUNOS software and JUNOS software with enhanced services, will need to know the ASP-based service configuration, as covered here and in Chapter 8. Readers who plan to deploy only JUNOS software with enhanced services should focus on the material covered in Chapter 11. Note that at this writing the Juniper Networks Certified Internet Expert (JNCIE-ER) examination is not based on JUNOS software with enhanced services, so readers interested in passing the JNCIE-ER examination will need to be familiar with ASP-based service definitions.

JUNOS Services

A JUNOS software service consists of a variety of Layer 2 and Layer 3 services, including:

- Multilink Point-to-Point Protocol (MLPPP)
- Multilink Frame Relay (MLFR)
- Compressed Real-Time Transport Protocol (CRTP)
- Multiclass MLPPP
- Stateful firewall
- NAT
- Intrusion detection service (IDS)
- IPSec
- Layer 2 Tunneling Protocol (L2TP)
- Active monitoring (cflowd)
- Tunnel services (Generic Routing Encapsulation [GRE], IP-IP, Physical Interface Module [PIM] register encapsulation)
- Data link switching (DLSw)

In an M-series router, enabling these services will require an additional piece of hardware: a Physical Interface Card (PIC) for packet processing. A J-series router supports most of the features in the preceding list and performs the packet processing within the software, so no additional hardware is necessary. Depending on the type of service required and the size of the service, different PICs can be used. The current offerings include:

Link Services PIC

Provides simultaneous support for three separate capabilities: enhanced multilink bundling, tunneling, and link fragmentation and interleaving (LFI)

Encryption Services PIC

Provides IPSec encryption for IPSec tunnels

Monitoring Services PIC
Provides J-Flow accounting at high speeds and across millions of flows, using standards-based cflowd v5 and v8 records

Tunnel Services PIC
Provides tunnel services such as GRE, IP-IP, IPv6 in IPv4, and multicast tunnels

Adaptive Services PIC (ASP)
Supports all services at Layer 2 and Layer 3

Multiservices PIC
Offers all the same services as ASP with a higher capacity and throughput

Adaptive Services Module (ASM)
Internal module for the M7i only which supports all services at a reduced rate, as well as one of the PICs that supports L2TP LTP Network Server (LNS) functionality

Which PIC to Use?

Deciding which PIC to use is a delicate balance of feature set versus price. For example, if all you require are IPSec tunnels (which can be provided on an Encryption Services PIC[a]), you may not need to use the more expensive Multiservices PIC. However, you should also consider your need for future services. So, if you require NAT, you would have to use a new PIC (an ASP, or a Multiservices PIC); since the Multiservices PIC will do both NAT and IPSec, ideally this should be your first choice.

[a] The Encryption Services PIC has a completely different configuration from a Monitoring Services PIC, ASM, or ASP, and is beyond the scope of this book.

The most common implementation of services will be to use a J-series, an ASM in an M7i, or a Monitoring Services PIC in other M-series routers. Table 7-1 lists the performance and scaling values for these deployments.

Table 7-1. Service scaling number

Feature	Multiservices Type 1	ASP	ASM	J-series
Throughput	920 Mbps	800 Mbps	256 Mbps	Varies
Service sets	2,000	2,000	500	10
Flows	1.6 million	1 million	400,000	8,000–64,000
MLPPP links	2,048	2,044	2,044	128
MLPPP bundles	1,023	255	255	16
IPSec throughput	950 Mbps	640 Mbps	200 Mbps	Varies
IPSec tunnels	5,000	2,048	512	256

In addition to scaling differences in the various PICs and platforms, there are some minor configuration differences when referencing the interface names for Layer 2 service, as shown in Table 7-2.

Table 7-2. Service interface naming

Service interface	ASM	ASP	Multiservice	Multilink service	J-series
Layer 2	`lsq`	`lsq`	`lsq`	`ml`	`ls`
Layer 3	`sp`	`sp`	`sp`	None	`sp`

Most of the configuration captures used in this chapter are from a J-series router, so the `ls` interface will be used. If you are using an M-series router, you still have to substitute the interface name, but the rest of the configuration will be the same.

Layer 2 Services

Layer 2 services are essentially the services that are enabled on a physical interface such as LFI (FRF.12), MLFR (FRF.15), user-to-network interface (UNI) NNI (FRF.16), MLPPP, and multiclass MLPPP.

Multilink PPP

MLPPP (RFC 1490) allows the router to combine multiple links together into one large logical bundle (as shown in Figure 7-1). This was originally created to bond multiple Integrated Services Digital Network (ISDN) bearer signals together, but it is now used for any two systems with multiple links between them. Multilink is negotiated during the initial Link Control Protocol (LCP) option negotiation. When configuring MLPPP on a Juniper router, you can combine into one bundle any eight PPP links of the *same* type on the chassis. To configure MLPPP, first create a logical bundle link (`lsq-x/x/x` on an ASP or `ls-x/x/x` on a J-series).

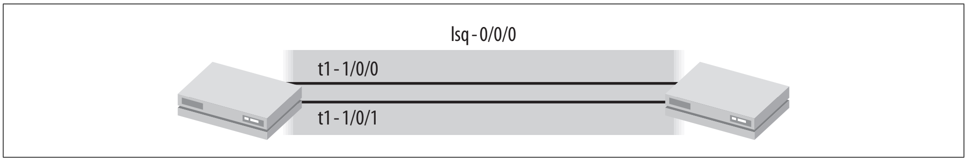


Figure 7-1. MLPPP bundle

```
lsq-0/0/0 {
    unit 0 {
        encapsulation multilink-ppp;
        family inet {
            address 166.8.67.30/30;
        }
    }
}
```

Next, configure the physical interfaces to link the newly created link service interface. In the following example, interfaces `t1-1/0/0` and `t1-1/0/1` are linked to the logical bundle unit 0 on the `lsq-0/0/0` interface:

```
t1-1/0/0 {
    unit 0 {
        family mlppp {
            bundle lsq-0/0/0.0;
        }
    }
}
t1-0/0/1 {
    unit 0 {
        family mlppp {
            bundle lsq-0/0/0.0;
        }
    }
}
```

When there are multiple links in your bundle, packets above the minimum maximum transmission unit/maximum received reconstructed unit (MTU/MRRU) size of all links in the bundle will be fragmented on a packet-by-packet basis across all the physical links. MRRU is similar to an interface MTU except that it applies only to multilink bundles. To avoid out-of-order issues, a sequence number is added to each packet. The receiving end will then reassemble the fragments into the full packet size. The advantage of this approach is that the high-bandwidth flows are able to use the full capacity of all the egress links. The disadvantage of this per-packet approach is that smaller packets may have to "wait" for larger packets to be transmitted.

For example, imagine you have low delay-sensitive data packets traversing with a size of 1,250 bytes and high delay-sensitive voice traffic with a size of 64 bytes. If the data packet arrives first on a link and the voice packet arrives second, the voice packet will have to wait until the data packet is done before it can be sent. On low-speed interfaces with a high serialization delay, this could greatly affect the high delay-sensitive traffic. To solve this problem, you can configure LFI.

The first step is to fragment the larger-size packets to allow the router to balance the fragments across multiple links, thus reducing the time it takes to transmit the packet:

```
root@P1R1# set interfaces ls-0/0/0 unit 0 fragment-threshold ?
Possible completions:
  <fragment-threshold> Fragmentation threshold in 64-byte steps (bytes)
[edit]
root@P1R1# set interfaces ls-0/0/0 unit 0 fragment-threshold  128
```

Now that the larger packets are fragmented, we want to place the nonfragmented packets on the link with the fragmented packets. Otherwise, the voice traffic will have to wait for *all* fragments to transmit before being sent. To turn on this behavior, configure the `interleave-fragments` command underneath the bundle configuration:

```
root@P1R1# set interfaces ls-0/0/0 unit 0 interleave-fragments
```

It is also recommended when LFI is turned on that the member links turn on traffic shaping to reduce jitter. Configure the shaping rate to be equal to the combined physical interface bandwidth for the constituent links. To apply shaping rates to interfaces, you must enable `per-unit scheduling` in the interfaces.

Since each egress link may not have the same delay, the packets that are not fragmented and are part of the same traffic flow may arrive out of order at the far end. To avoid this scenario (which will increase delay and jitter), each flow should take the same egress link.

By default, the JUNOS software chooses a single link for each unfragmented Transmission Control Protocol/User Datagram Protocol (TCP/UDP) flow over MLPPP links using a hash algorithm, based on the source and destination addresses, source and destination port numbers, and protocol field. This default behavior ensures that flows stay on the correct link and arrive in the correct order at the far end.

The final issue to think about is to enable the voice traffic to have a higher priority and thus be transmitted before the data traffic. Although we will discuss class of service (CoS) in a later chapter, we will provide a high-level discussion here.

To ensure that voice traffic is transmitted first, place it into a higher-priority queue. For CRTP traffic, this mapping occurs automatically, whereas for other traffic, it will have to be configured. Note that the J-series and M-series differ on this mapping. In a J-series router, high-priority traffic, including CRTP, should *only* be mapped to queue 2 on an MLPPP link. When the router maps traffic to constituent links, traffic from queue 2 of the bundle interface will be mapped to queue 2 on the constituent links, whereas traffic from all other queues on the bundle interface will be mapped to a default queue of 0 (as shown in Figure 7-2). Traffic that is placed into other queues on the bundle interface and that is mapped into queue 0 on a constituent link will be serviced according to the relative priority. In other words, if traffic on the bundle interface is placed into queue 1 with a medium-high priority and into queue 4 with a medium-low priority, queue 1 will be scheduled first and will be placed into the constituent link's queue 0 first. In an M-series router using multiclass MLPPP, other queues besides queue 0 and queue 2 could be utilized.

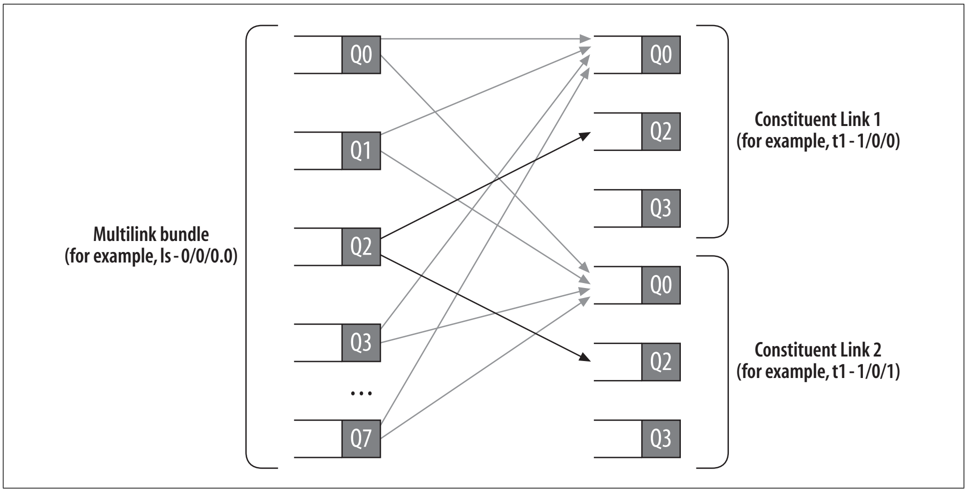

Q0
Q1
Q2
Q3
...
Q7
Multilink bundle
(for example, ls - 0/0/0.0)
Q0
Q2
Q3
Constituent Link 1
(for example, t1 - 1/0/0)
Q0
Q2
Q3
Constituent Link 2
(for example, t1 - 1/0/1)

Figure 7-2. J-series queuing and LFI

Multiclass MLPPP

Sometimes when using LFI, fragments from different classes cannot be interleaved. This means that all fragments from a single packet must be sent before any fragments from another packet can be sent. Using LFI, nonfragmented packets can be interleaved with fragmented packets to reduce the latency of the nonfragmented packets. The nonfragmented packets can also be placed into a different queue to be transmitted first, which basically enables two classes of packets: *fragmented* and *nonfragmented*. This model extends to scenarios in which the delay-sensitive traffic comprises the nonfragmented packets, but fails if there is high-priority fragmented traffic that must take precedence over the nonfragmented traffic. In this case, it would make sense to be able to assign a higher priority for some fragmented traffic over nonfragmented traffic by placing some fragmented traffic into a higher-priority queue. This mapping of fragments to different queues is referred to as Multiclass Multilink PPP (MCML).

MCML is supported only on PICs with link services intelligent queuing (LSQ) interface support—that is, ASPs, ASMs, and Multiservices PICs. It is not supported on a J-series router.

Also, when using classic LFI on MLPPP, packets that are nonfragmented will be balanced across a link on a per-flow basis. This can lead to the *hot link* scenario where a single flow will always take the same link and will not fully utilize the full-bundle bandwidth. MCML can help with this problem by allowing packets that are not fragmented to be load-balanced across multiple links.

Lastly, MCML can be used if you simply need more than two CoSs for either fragmented or nonfragmented packets. In general, MCML needs to be deployed if any of these criteria has to be met:

- Some fragmented traffic needs to be transmitted before nonfragmented traffic.
- Nonfragmented traffic needs to be balanced across multiple links.
- More than two queues (0 and 2) are required.

To configure MCML, you should configure a fragmentation map where a fragmentation threshold is configured and a multilink class is assigned the forwarding class. The other option is to disable fragmentation on a per-forwarding class basis using the `no-fragmentation` command. If the `no-fragmnetation` command is used, the `fragment-threshold` and `multilink-class` statements cannot be configured:

```
[edit class-of-service fragmentation-maps sample forwarding-class
expedited-forwarding]
lab@PBR# set ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration
data
+ apply-groups-except  Don't inherit configuration data from these
groups
  fragment-threshold   Fragmentation threshold (64..9192 bytes)
  multilink-class      Multilink-Class assigned to this FC (0..7)
  no-fragmentation     Don't allow fragmentation
```

Lastly, the fragmentation map must be tied to the bundle interface under the `class-of-service` stanza:

```
class-of-service {
    interfaces {
        lsq-0/3/0 {
            unit 1 {
                fragmentation-map sample;
            }
        }
    }
}
```

CRTP

On lower-speed interfaces, serialization and queuing delay can be a factor for delays of sensitive traffic. *Serialization delay* is the time it takes to move the packet out the network interface, and it depends on the clock rate and the size of the packet. For instance, for a 512-byte packet on a T1, the serialization delay would be:

(512 * 8)bits/1,544,000 bits/sec = 2.65 ms

Queuing delay is the time it takes for the packet to be buffered in the router when other packets are being transmitted. This delay is variable but is related to the serialization delay, as each packet has to wait for the previous packet to be sent before it can be transmitted. So, if the buffer is three packets deep, the delay to transmit the 512-byte packet is not 2.65 ms, but perhaps 8 ms to 19 ms.

The most common type of delay for sensitive traffic is voice traffic, which is often transported using the Real-Time Transport Protocol (RTP). RTP is simply a standard packet format to transport voice or video over an IP network, usually using UDP ports in the range of 384–32,767. It produces a header of 40 bytes—12 bytes for RTP, 8 bytes for UDP, and 20 bytes for IP.

One quick way to reduce serialization and, potentially, queuing delay is to reduce the packet size. When using RTP, you can compress the entire IP/UDP/RTP header to a 2- or 4-byte header. As explained earlier in this chapter, this is referred to as Compressed RTP (CRTP) and is standardized in RFC 2508.

Juniper Networks routers can compress RTP traffic in MLPPP bundles. J-series routers can also compress RTP traffic on standard PPP interfaces.

All CRTP voice traffic is automatically placed into queue 2 on a J-series router.

To enable CRTP on any interface, configure the compression parameters on the link services interface. The router maps which traffic to compress by either matching on a range of UDP port numbers or matching on the queue on which the packet was placed. You can configure both conditions, and the router treats the match as a logical OR. In the following example, a standard PPP interface is using CRTP with a port range of 384–32,767:

```
ls-0/0/0 {
    unit 0 {
        compression {
            rtp {
                port minimum 384 maximum 32767;
            }
        }
        family inet {
            address 10.10.10.1/30;
        }
    }
}
```

You can then map the physical interface to the link services compression interface:

```
t1-0/0/2 {
    description Bock-to-porter;
    unit 0 {
        compression-device ls-0/0/0.0;
    }
}
```

If you are using CRTP with MLPPP, simply add the compression configuration to the existing bundle.

To verify that CRTP is working, use the `show services crtp` command:

```
lab@Bock# run show services crtp ?
Possible completions:
  <[Enter]>            Execute this command
  extensive            Show CRTP extensive output
  flows                Show CRTP flow table entries
  interface            Name of link services interface
  |                    Pipe through a command
```

Use the `show services crtp extensive` command to verify correct configuration as well as track statistics for packets exiting the interface:

```
[edit]
lab@Bock# run show services crtp extensive
Interface: ls-0/0/0.0
  Port minimum: 384, Port maximum: 32767
  Maximum UDP compressed sessions: 256
  CRTP maximum period: 256, CRTP maximum time: 5
  Compression ratio: 0, Decompression ratio: 0, Discards: 0
  CRTP stats                       Receive        Transmit
  Sessions                               0               0
  IP bytes                               0               0
  Compressed bytes                       0               0
  CRTP packets                           0               0
  CUDP/CNTCP packets                     0               0
  Full header packets                    0               0
  Context state packets                  0               0
  IP packets                             0               0
  Compressed packets                     0               0
```

Multilink Frame Relay

Similar to bonding multiple PPP sessions together, a router can also bond multiple Frame Relay circuits together. These will have the same fragmentation and interleaving characteristics as previously discussed with MLPPP. One bonding standard is FRF.15, which allows the router to bind multiple Frame Relay data-link connection identifiers (DLCIs) together into a single logical interface, as shown in Figure 7-3. The DLCIs could be on the same physical interface or on multiple physical interfaces, but the aggregate bandwidth cannot be greater than a DS3. The advantage of FRF.15 is that the provider does not have any knowledge that link bonding has occurred, but the disadvantage is that the each MLFR bundle can communicate with only a single endpoint.

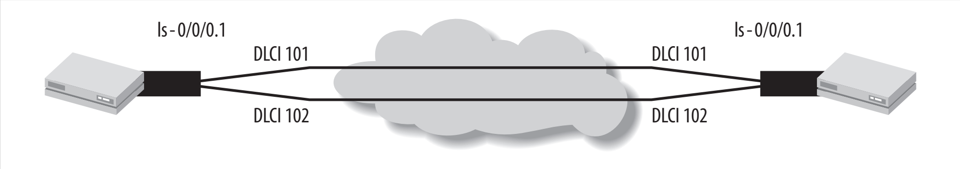


Figure 7-3. FRF.15

FRF.15 on J-series routers is supported only on T1/E1 interfaces, as of JUNOS 8.0R2.

To configure FRF.15, first create a logical unit with the bundle IP address on the link services interface and specify the desire for FRF.15 with `encapsulation multilink-frame-relay-end-to-end`:

```
ls-0/0/0 {
    unit 1 {
        encapsulation multilink-frame-relay-end-to-end;
        family inet {
            address 84.10.113.1/31;
        }
    }
}
```

Then bond the local DLCIs' values together to the newly created bundle interface. In this case, the DLCIs were on the same physical interface but could have also been on different physical interfaces:

```
[edit interfaces t1-0/0/2]
lab@Yeast# show
description Yeast-to-hops2;
encapsulation frame-relay;
unit 101 {
    dlci 101;
    family mlfr-end-to-end {
        bundle ls-0/0/0.1;
    }
}
unit 102 {
    dlci 102;
    family mlfr-end-to-end {
        bundle ls-0/0/0.1;
    }
}
```

Verify that the links are bonded by viewing the bundle interface:

```
lab@hops# run show interfaces ls-0/0/0.1
  Logical interface ls-0/0/0.1 (Index 70) (SNMP ifIndex 37)
    Flags: Point-To-Point SNMP-Traps 0x4000 Encapsulation: Multilink-FR
    Bandwidth: 3072kbps
```

```
Statistics         Frames        fps         Bytes          bps
Bundle:
  Fragments:
    Input :            71          0          5030            0
    Output:             3          0           264            0
  Packets:
    Input :            71          0          4604            0
    Output:             3          0           270            0
Link:
  t1-0/0/2.101
    Input :            36          0          2540            0
    Output:             2          0           176            0
  t1-0/0/2.102
    Input :            35          0          2490            0
    Output:             1          0            88            0
Protocol inet, MTU: 1500
  Flags: None
  Addresses, Flags: Is-Preferred Is-Primary
    Destination: 84.10.113.0/31, Local: 84.10.113.1
```

Another type of Frame Relay bonding is called FRF.16, which allows the router to take multiple physical connections from the provider and tie them into a single logical connection, as shown in Figure 7-4. Once this connection is bonded together, one or more DLCIs could be configured over this single logical connection. This allows for incremental and increased bandwidth Frame Relay connections, while also allowing the provider to combine each bundle into multiple high-speed bundles in the network. The advantage over FRF.15 is that a different endpoint in each bundle is supported, but the disadvantage is that the provider is no longer transparent to bundling.

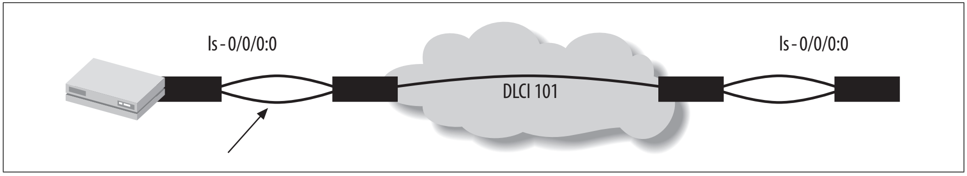


Figure 7-4. FRF.16

To configure FRF.16 on a Juniper router, the link services interface is configured and *channelized*. A channel is designated, but the colon (`:`) represents the FRF.16 logical bundle. You can configure a single DLCI or multiple DLCIs to different endpoints in this bundle.

First, to create a channelized bundle interface, set the `mlfr-unu-nni-bundles` statement under `[edit chassis]`. Channels start counting at zero, so the following configuration will create an `ls-/0/0/0:0`:

```
chassis {
    fpc 0 {
        pic 0 {
            mlfr-uni-nni-bundles 1;
        }
   }
```

Here is a bundle specified as channel 1 with one DLCI specified:

```
ls-0/0/0:0{
    encapsulation multilink-frame-relay-uni-nni;
    unit 0 {
        dlci 101;
        family inet {
            address 101.88.77.1/30;
        }
    }
 }
```

A last point to understand in MLFR is that the physical interfaces, such as those with two Juniper T1s, will need to be bonded together to the logical bundle `ls-0/0/0:0` interface:

```
t1-0/0/2 {
    encapsulation multilink-frame-relay-uni-nni;
    unit 0 {
        family mlfr-uni-nni {
            bundle ls-0/0/0:0
        }
    }
}

t1-0/1/2 {
    encapsulation multilink-frame-relay-uni-nni;
    unit 0 {
        family mlfr-uni-nni {
            bundle ls-0/0/0:0
        }
    }
}
```

GRE

We already examined the configuration for a basic GRE tunnel in Chapter 2:

```
gr-0/0/0 {
    unit 0 {
        tunnel {
            source 10.20.1.38;
            destination 172.66.13.1;
        }
        family inet
    }
}
```

Although various PICs will allow a GRE tunnel to be created on an M-series router, using an ASP, a Multiservices PIC, or a J-series router can enable a few additional features, namely key numbers (ASP, Monitoring Services only), fragmentation, and tunnel MTU.

> Although GRE tunnels are supported on an M-series router using an ASP in Layer 2 or Layer 3 mode, fragmentation and GRE keys are supported only in Layer 3 mode.

The first feature is taken from RFC 2890 and is called "Key and Sequence Number Extensions to GRE." This RFC adds two more optional fields that can be carried in the GRE header: a *key field* and a *sequence number field*. The key field is inserted by the sender and is matched at the receiver to identify fields. If the key fields do not match, the packet is dropped. Currently, only the ASP and Monitoring Services PIC support this feature, and only one key is allowed per source and destination pair. To enable this feature, manually configure a key value under the logical unit:

```
lab@Cider set interfaces gr-0/0/0 unit 0 tunnel key 123
```

A concern when configuring any type of tunnel is making sure the maximum payload is no larger than the MTU across the entire path. By default, the gr interface has an unlimited physical MTU and a protocol MTU that is equivalent to the MTU of the next hop interface toward the tunnel destination. So, when an IP packet arrives at the ingress router, the GRE header is added, with the do-not-fragment bit set, and the IP packet is sent to the egress router. If a transit router had a smaller MTU than the ingress router, the packet would be dropped.

> In JUNOS 8.0R2.8, path MTU is enabled by default. You can disable it for GRE tunnels.

A few tools in the router can solve this issue. For example, use path MTU discovery to determine the MTUs that are along the path. In the current JUNOS release, path discovery is enabled by default. The following example shows that the maximum IP protocol MTU can be 726:

```
 [edit]
lab@Water# run show interfaces gr-0/0/0.0 extensive | match mtu
  Type: GRE, Link-level type: GRE, MTU: Unlimited, Speed: 800mbps
    Protocol inet, MTU: 726, Generation: 141, Route table: 0
```

A problem can arise when traffic is coming into the router with an MTU that is too large and the do-not-fragment bit is set. If you must send traffic with the do-not-fragment bit over the tunnel, you can override the sender's wishes by having the router clear the do-not-fragment bit. In the following example, router Wheat is trying to send traffic over the GRE tunnel that is too large, and Water is sending an Internet Control Message Protocol (ICMP) error message indicating that the packet is being dropped:

```
[edit]
root@Wheat# run ping 5.5.5.5 size 700 do-not-fragment
PING 5.5.5.5 (5.5.5.5): 700 data bytes
36 bytes from 1.1.1.2: frag needed and DF set (MTU 726)
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 02d8 3274   2 0000  40  01 f9a5 1.1.1.1  5.5.5.5

36 bytes from 1.1.1.2: frag needed and DF set (MTU 726)
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 02d8 3275   2 0000  40^C
--- 5.5.5.5 ping statistics ---
2 packets transmitted, 0 packets received, 100% packet loss
```

On a J-series router or with the ASP, ASM, or Monitoring Services PIC, you can enable a `clear-dont-fragment` command, which allows for ingress fragmentation as well as clearing the do-not-fragment bit on all packets that transmit the tunnel. Note, however, that although the original packets have the do-not-fragment bit cleared, the GRE packets still have the `DF` bit set. This command is set on `Water`:

```
[edit]
lab@Water# set interfaces gr-0/0/0 unit 0 clear-dont-fragment-bit

[edit]
lab@Water# commit
[edit interfaces gr-0/0/0]
  'unit 0'
    gr-0/0/0.0: Must configure INET family MTU
error: configuration check-out failed
```

To use this command, you must also set the MTU value so that the ingress router knows which size packets to begin fragmenting. This MTU value should be the smallest value along the entire path of the GRE tunnel.

```
lab@Water# set interfaces gr-0/0/0 unit 0 family inet mtu 726
```

Verify correct operation by reissuing the `ping` command from router `Wheat`:

```
[edit]
root@Wheat# run ping 5.5.5.5 size 1400 do-not-fragment
PING 5.5.5.5 (5.5.5.5): 700 data bytes
1408 bytes from 5.5.5.5: icmp_seq=0 ttl=63 time=18.449 ms
1408 bytes from 5.5.5.5: icmp_seq=1 ttl=63 time=120.600 ms
1408 bytes from 5.5.5.5: icmp_seq=2 ttl=63 time=30.325 ms
^C
```

Layer 2 Services Summary

This section examined many of the services that you can enable, such as multilink bonding compression and GRE features. The rest of the chapter examines the Layer 3 services that you can also deploy in your network. You may consider taking a brief break before diving into the next section, as it moves a layer up in the protocol stack—because this one layer is Layer 3, the network layer, it will be a large jump!

Layer 3 Services

The JUNOS software services are not limited to just Layer 2 services, but can also include Layer 3 services. These services include stateful firewall, NAT, IDS, and IPSec tunnels. We will give an overview of these services here and will provide a detailed discussion of them in Chapter 8.

> On the ASP or Multiservices-100 PIC, you must choose to enable *either* Layer 2 *or* Layer 3 services; the ASM on the M7i and the J-series router support *both* Layer 2 and Layer 3 concurrently.

Stateful Firewall

Usually when certain traffic needs to be blocked on a router, a simple stateless packet filter is applied to an interface. On a Juniper router, these are called *firewall filters* (other vendors call these *access lists*). Regardless of the name, all stateless filters function in the same manner—they look at a packet and operate on a series of match rules. If the packet matches a rule, it can be either accepted or discarded.

The important point about a packet filter is that it works on a packet-by-packet basis and does not associate a packet with a traffic flow or stream. In other words, it does not maintain any connection state. This type of filter will work in many situations when applications are using well-known port numbers or TCP applications, where the initiator is always in the same direction. Stateless packet filters become more difficult when the application uses random port numbers—TCP initiators are not always the same—or when UDP input and output flows need to be associated with each other. For example, if a Domain Name System (DNS) server was located outside your network, you could easily write a packet filter that allows outbound access to UDP port 53, but you would need to write a rule for the inbound packet as well. The source port would be port 53, but the destination port could be any port from 1024–65534, depending on which random port the host chose. Allowing this large of a UDP port opens up a large hole in your network.

A stateful firewall will track *flows* of traffic for a given application such as DNS, which will provide for much stronger security. This means that if a packet hits the firewall rule and is accepted based on the match conditions, the system will calculate the return packet, so no reverse rule will have to be created. A flow is usually defined by parameters such as source and destination addresses, source and destination port numbers, and protocol values. A bidirectional flow between the source and destination devices is often called a *session* or a *conversation*. Once a session or conversation is created, it is stored in memory, so the firewall rules do not need to process any additional packets that are part of that flow. These conversations will be stored until a period of inactivity occurs, which is 30 seconds by default for most protocols. You can modify this globally under the service interface:

```
lab@hops# set interfaces sp-0/0/0 services-options inactivity-timeout ?
Possible completions:
  <inactivity-timeout>  Inactivity timeout period for established sessions
```

A flow is removed from the table under the following conditions:

- If a TCP RESET or FIN packet is received. The flow is marked for deletion and is removed in approximately five seconds.
- If the TCP flow appears to be idle (no traffic). In this case, the router implements a TCP tickle by sending an ACK message with the last seen sequence number, minus one numeral, to the end host. This verifies whether the ports are open. If no response is received, the flow is marked for deletion in approximately five seconds.
- If the forward flow of the UDP conversation reaches the inactivity timeout period. Since the reverse flow will be created based on the forward flow, this flow will not be tracked for inactivity.

The stateful firewall will also add a layer of protection by checking to make sure there are no strange protocol anomalies that could indicate a denial of service (DoS) attack. Some examples of protocol anomalies that are checked include the following:

- The Time to Live (TTL) in the IP packet equals 0.
- The source IP address equals the destination IP address.
- An IP fragment is missed.
- The TCP or UDP port is set to 0.
- TCP flags are set to an invalid combination.
- A SYN packet is received without a SYN-ACK response.
- The first flow packet is not a SYN packet.
- ICMP unreachable errors occur for SYN or UDP packets.

This is a small list of the possible anomalies; please consult the Juniper Technical Documentation for a more complete list.

Application Layer Gateways

Most of the time, the stateful firewall will easily be able to predict the packets that will be required for the return flow of a conversation by simply reversing the source and destination port numbers, addresses, and so forth. However, some applications, such as FTP, H.323, RTSP used by RealAudio, and SIP, are more difficult to predict because the application may initiate separate connections for data and control flows or may generate new protocol flows based on an open connection. In this case, special care must be taken to analyze the packets and allow the new connections to be established. Each application may have a unique set of parameters that must be examined, which are implemented as Application Later Gateways (ALGs).

The classic example of why an ALG is needed is when you look at an application such as an active outgoing FTP, which uses both a control and a data channel. First, the TCP three-way handshake is established between the client (84.10.113.0) and the server (84.10.113.1) using a destination port of 20:

```
02:21:00.500569  In IP 84.10.113.0.4290 > 84.10.113.1.20: Syn
02:21:00.500627 Out IP 84.10.113.1.20 > 84.10.113.0.4290: Syn Ack
02:21:00.510683  In IP 84.10.113.0.4290 > 84.10.113.1.20: .   Ack
```

Then the server initiates a new connection for the data transfer using a new source port of 21 and a destination port that the client gives to the server in the initial connection using a PORT command (56958, in this case):

```
02:26:28.024058 Out IP 84.10.113.1.21 > 84.10.113.0.56958: Syn
02:26:28.032298  In IP 84.10.113.0.56958 > 84.10.113.1.21: Syn Ack
02:26:28.032362 Out IP 84.10.113.1.21 > 84.10.113.0.56958: . Ack
```

So, the problem with the active mode FTP application and standard firewall rules is that the connections are initiated by both the server and the client, and the connection initiated by the server to the client is using an unpredictable port number.

The ALG solves this problem by looking deep into the packets during the initial connection phase for the PORT command, indicating which port number the client will be expecting from the server during the data phase and allowing the firewall to create a predictable pinhole for the server-to-client connection.

If passive FTP is used, all connections are initiated from the client to the server, but the ALG must still monitor the PORT command from the server to open the data connection.

Another example in which ALG is needed is when you're using H.323, the umbrella specification for a family of protocols for transporting voice and video over data networks. H.323 involves protocols that open control and data channels similar to our FTP example. In a common setup and data flow, these steps occur:

1. First, an H.225 connection is created for call signaling, the media (audio and video), the stream packetization, the media stream synchronization, and the control message formats.
2. During the H.225 connection, information is exchanged to also establish an H.245 connection.
3. An H.245 connection is established to convey control information for the media flow, such as encryption and flow control as well as port information for RTP/RTCP flows.
4. RTP/RTCP data traffic flows begin.

The ALG that is used for H.323 is more complex than in the FTP example, but the general idea of watching one conversation to open more flows is the same. The ALG watches the H.225 connection for information to open the H.245 connection and then watches this connection to open the media connections.

Since these ALGs can be very complex, most of them are already created in the Juniper Networks router for you, although you can create custom ALGs. You can view all the Juniper-defined ALGs by issuing the `show groups junos-defaults applications` command from configuration mode. All default system applications will begin with the `junos` keyword.

Network Address Translation

NAT is simply the changing of the IP address (source, destination, or both) of the packet as it traverses the router. These translations are stored in a table to allow for traffic flows from the source to the destination systems. Additionally, port numbers could also be translated (often referred to as Network Address Port Translation [NAPT] or Port Address Translation [PAT]). Traditionally, NAT was used to hide private addresses behind a public network or to try to conserve address space by mapping multiple port numbers to a single IP address. When NAT is configured, you must answer the following questions:

- Which IP address is going to be translated: the source IP (source-NAT), the destination IP (destination-NAT), or both (bidirectional NAT)?
- Does port translation need to occur?
- Does the mapping need to be the same (static) or can a pool of addresses and ports be used (dynamic)?

Next, you must examine the type of NAT that must be configured. The NAT types available on a Juniper router include the following:

Static source NAT
: Maps a pool of private IP addresses to a pool of public addresses on a one-to-one basis. This means traffic from a private address, such as 192.168.2.1, will always be mapped to the same public address, such as 207.12.18.2.

Dynamic source NAT
: Maps a pool of private IP addresses to a pool of public addresses. This mapping is dynamic, so 192.168.2.1 could be translated to the configured public address pool.

Source NAT with port translation
: Maps a pool of private IP addresses to a single address or pool of public addresses, while also translating the port numbers. This allows for one-to-many NAT, when many private IP addresses are translated to a single public address.

Destination NAT
: Behaves the same as source NAT, except it operates on the incoming flow of the destination address. Destination NAT will translate an incoming public address

to one or many private addresses. One use of this is to allow the Internet to use a public address to contact a server on the internal network that is configured with a private IP address.

Bidirectional NAT
A combination of a source NAT and destination NAT in which Host A can initiate a session with Host B and Host B can also initiate a session with Host A. This is common when an email server is onsite.

Twice NAT
Defined in RFC 2663 and similar to bidirectional NAT. The major difference is that in twice NAT, the source and destination addresses are translated within the same flow, whereas bidirectional NAT would use different flows.

You can configure NAT on a Juniper Networks router as a standalone service or combine it with another service, such as stateful firewall.

Intrusion Detection Services

Intrusion detection monitors traffic flows and looks for hostile patterns. If such a pattern exists, the event can be logged. Intrusion detection and prevention (IDP) takes this one step further by stopping an attack once a hostile pattern is recognized. The Juniper Networks router is limited in its IDP implementation, as it does not match on any higher-layer signature attacks. Essentially, the IDP implantation can aid in protecting your network from attacks such as the following:

Port scanning
When a hostile machine probes the network for open ports to attack.

SYN flood attacks
When a high number of SYN packets are received in an attempt to flood the network.

IP fragmentation attacks
Protects against packets with the `more fragments` flag set, such as attacks like Teardrop and Boink. Teardrop attacks exploit the reassembly of fragmented IP packets by offsetting the options in the IP header. When the sum of the offset and size of one fragmented packet differ from that of the next fragmented packet, the packets overlap, and the server attempting to reassemble the packet can crash.

ICMP floods
When ICMP echo requests overload its victim with so many requests that all its resources respond until it can no longer process valid network traffic.

When any of these attacks occur, events are logged and are sent to a collector for analysis, or in the case of flood attacks, are rate-limited. You also can prevent SYN floods by configuring SYN cookie protection that will cause the router to operate as a *SYN proxy*. We will discuss this further in Chapter 8.

IPSec VPN

When securing data over a public network, often a tunnel is configured between the two networks. A tunnel simply encapsulates your data into another packet or frame to transport it across the public network. For instance, you can create a tunnel to connect Remote Office A to Corporate Office B over the public Internet, as shown in Figure 7-5, to create a virtual private network (VPN).

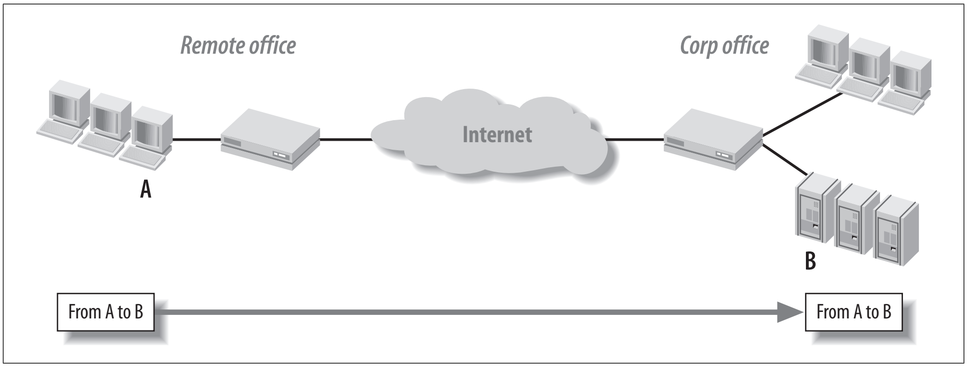


Figure 7-5. Connecting a remote office to the corporate office

The purpose of this book is not to teach IPSec theory; a number of books do that well, such as *IPSec: The New Security Standard for the Internet, Intranets, and Virtual Private Networks* (Prentice Hall).

You can use many tunneling protocols for this connection, but one of the most widely deployed protocols for transporting IP traffic is IPSec. IPSec can provide the following security functions:

Source authentication

Ensures that the data is from the expected sender. This is accomplished by the ingress router of the IPSec tunnel, creating a one-way hash value of certain parameters of the packet as well as a password (preshared key) that is known by both endpoints. It will insert this hash value into the packet so that when the receiving endpoint examines the packet, it can compare this value with the hash that will be locally computed. If they are the same, the authentication passes; if they are different, the authentication fails. Common algorithms to accomplish this are Message Digest 5 (MD5) and the Secure Hash Algorithm (SHA-1).

A *hash function* is a predictable mathematical calculation that takes some variable-size input and produces a fixed-size string called a *hash*. A key attribute of a hash is that it is one-way operation—so, the hash value can be created based on the input but the input cannot be recreated based on the hash value. Hash functions are used in both authentication and data integrity.

Data integrity

Ensures that the data was not altered during packet transmission. A hash value is computed and is placed into the packet based on packet fields. The receiving router will compute a hash based on the same fields of the packet and then compare the computed hash value with the received hash value. If they are not equivalent, the data was altered and the packet will be dropped. The hash algorithm that is used is normally MD5 or SHA-1.

Confidentiality

Ensures that the data cannot be read over the public infrastructure. IPSec provides confidentiality by encrypting the traffic using the Data Encryption Standard (DES), Triple DES (3DES), or Advanced Encryption Standard (AES) algorithm.

Replay protection

Even though data can be encrypted, a hostile device can intercept a packet, recreate it, and send a flood of that packet to the endpoint to try to create a DoS attack. To protect against this, sequence numbers are verified to avoid packet duplication.

When an IPSec tunnel is made, the tunnel endpoints create a security association (SA) with each VPN. An SA is a list of the protocols, algorithms, and protected networks upon which both endpoints have agreed. These SAs can be created manually on each side, or dynamically with the use of the Internet Key Exchange (IKE) protocol. IKE consists of two phases: Phase 1 establishes the protocols and shared secrets needed to create a secure channel; and Phase 2 uses this secure channel to exchange the protocols, algorithms, and other parameters that will be used for the data exchange, thus creating the SAs. When Phase 2 has completed, data can flow securely between the two endpoints, as shown in Figure 7-6.

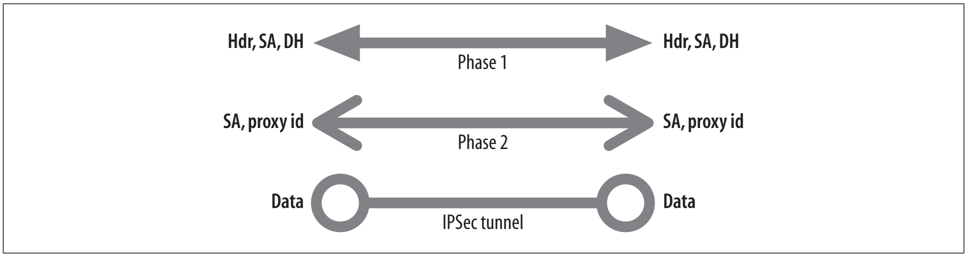


Figure 7-6. IPSec VPN dynamic tunnel establishment

Layer 3 Services Summary

This section examined many Layer 3 services, including NAT, stateful firewall, IDP, and IPSec-based VPNs. In the next section, we will put this theory into practice as we configure and operationally verify various network layer services.

Layer 3 Services Configuration

The first step when configuring Layer 3 services on your router is to enable the hardware for those services. If the ASP or Multiservices PIC is used, you must specify the layer of service as either Layer 2 or Layer 3:

```
lab@sake# set chassis fpc 1 pic 2 adaptive-services service-package ?
Possible completions:
  layer-2              Layer 2 service package
  layer-3              Layer 3 service package
[edit]

lab@sake# show chassis hardware
Hardware inventory:
Item           Version Part number Serial number Description
Chassis                            A1609         M7i
Midplane        REV 04 710-008761  CR6773        M7i Midplane
Power Supply 1 Rev 06 740-008537  6039089       AC Power Supply
Routing Engine REV 01 740-011202  1000618737    RE-850
CFEB            REV 08 750-010464  CR5380        Internet Processor II
FPC 0                                            E-FPC
  PIC 0         REV 11 750-002992  CT2202        4x F/E, 100 BASE-TX
  PIC 2         REV 08 750-005724  CR1650        2x OC-3 ATM-II IQ, MM
FPC 1                                            E-FPC
  PIC 2         REV 07 750-009487  CP5197        ASP - Integrated
  PIC 3         REV 10 750-009098  CR4858        2x F/E, 100 BASE-TX
```

The ASM and J-series routers do not contain this limitation and can support *both* types of services concurrently. The main building block when configuring JUNOS software services is called a *service set*, which is a list of service interfaces, service types, and service rules applied to either an interface or a routing next hop. A service set can contain one type of Layer 3 service or a grouping of services such as NAT, IDS, and stateful firewall. If an IPSec VPN is required, you must place it in its own unique service set.

To match which packet will be processed by each service set, you must write a set of rules with a match condition and an action. These rules have a similar format to JUNOS software policies and stateless firewall filter rules, containing a `from` statement for the match portion and a `then` statement for the action. But a major difference is that service rules are always processed in a stateful manner, so the match clauses do not need to account for return traffic. The match clauses will have a variety of options depending on the service configured, and the actions will define which service to apply. You also can combine the rules for each service to form a rule set, as shown in Figure 7-7.

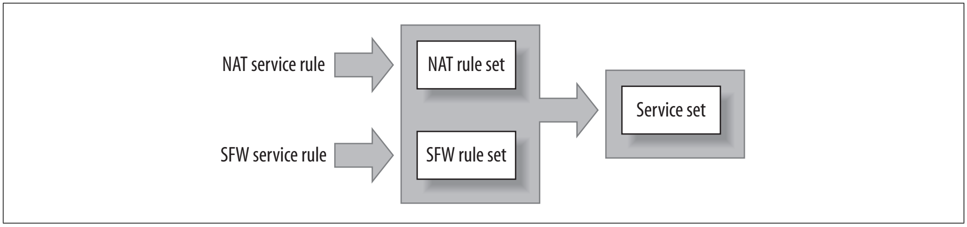


Figure 7-7. CLI rule, rule set, and service set relationship

When you create your service set, you'll need to decide whether it should be applied as an interface or a next hop. An interface-style service set is applied directly to the interface affecting traffic as it leaves and enters the interface.

> An interface-style service set tracks session on a per-service-set basis. This means that the same service set could be applied to multiple physical interfaces to design around asymmetrical traffic flows.

A next hop-style service set makes use of two logical service interfaces, called the *inside* and *outside* interfaces. Traffic is mapped to these interfaces as a result of a routing next hop lookup. The traffic can enter or exit *either* the inside or the outside interface depending on the configuration, which depends primarily on the routing configuration and stateful-firewall rules.

Both types of service styles use the service interface, named sp-, in the definition of the service set. This interface is the software interface that the router will send traffic to if a Layer 3 service is required. The interface-style service set requires a single logical unit to be configured with IPv4 support enabled:

```
lab@Porter# set interfaces sp-0/0/0 unit 0 family inet

lab@Porter# show interfaces
sp-0/0/0 {
    unit 0 {
        family inet;
```

> When configuring the sp- interface, the system generally reserves unit 0 for service logging and other communication from the service PIC; however, you can use it for an interface-style service set not used in a virtual router. Next hop service sets cannot use unit 0.

The next hop service set requires the service interface to be logically divided into an inside and outside interface:

```
[edit]
lab@Porter# set interfaces sp-0/0/0 unit 1 service-domain inside family inet
```

```
[edit]
lab@Porter# set interfaces sp-0/0/0 unit 2 service-domain outside family inet

[edit]
lab@Porter# show interfaces sp-0/0/0
unit 0 {
    family inet;
}
unit 1 {
    family inet;
    service-domain inside;
}
unit 2 {
    family inet;
    service-domain outside;
}
```

After creating the service interfaces, you'll need to create the service rules and the service sets. When creating the service rules, one item you must configure is a direction of either *input* or *output*, as shown in Figure 7-8. The direction that is recorded for a packet must match for the service rule to match. This direction is straightforward for an interface-style service set, as input is for incoming traffic to the physical interface, and output is for traffic leaving the physical interface.

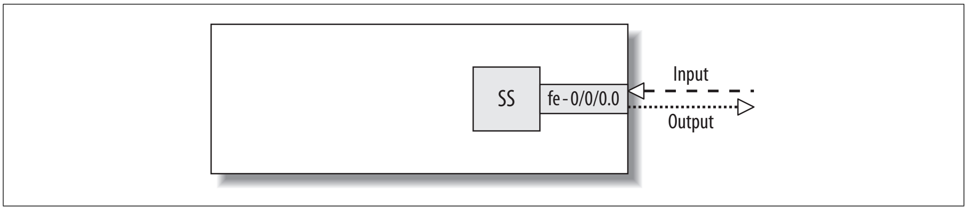


Figure 7-8. Directions for interface-style service sets

But when you look at a next hop-style service set, the direction is a bit more complex because now the next hop could point to two possible logical interfaces. If the next hop points to the inside interface, the direction is *input*, and if the next hop points to the outside interface, the direction is *output*. The direction for next hop-style service sets is often misconfigured, which causes traffic to be serviced incorrectly. Figure 7-9 shows the proper directions that you should use when creating service rules.

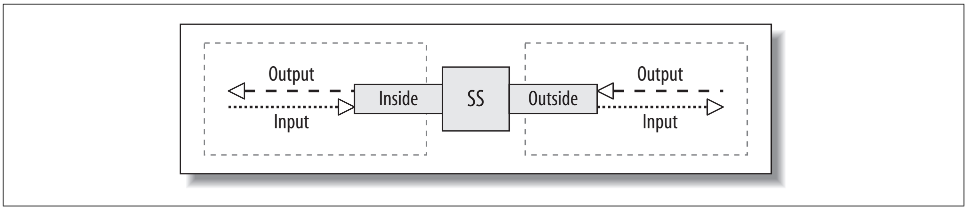


Figure 7-9. Directions for next hop-style service sets

When configuring service rules for next hop-style service sets, you should consider traffic flow from the perspective of the inside interface. Traffic that the router routes to the inside interface is considered input traffic on the inside interface and is considered input traffic by the router when it evaluates service rules. Traffic that the router receives on the outside interface, processes, and then transmits out the inside interface is considered output traffic on the outside interface and is considered output traffic by the router when it evaluates service rules. In general, it may be much less confusing to point traffic to the inside interface when possible, as the directions seem to be as expected, while the outside interface appears to be opposite from what is expected. Although traffic mapping to an inside interface may make more sense in the human mind, the router makes no logical distinction, so mapping to either the inside or the outside configuration will work.

Since next hop-style service sets are a little more complex, it seems as though interface-style service sets would be preferred. Each service set, however, has its own advantages and disadvantages, as detailed in Table 7-3.

For instance, an interface-style service set has the following limitations:

- It cannot support multicast traffic matched through the service set (including IPSec tunnels).
- It cannot have overlapping address spaces (such as RFC 1918) that need to be NATed.
- It cannot run routing protocols over the service sets, such as IPSec tunnels.
- Locally generated traffic will not match the rules.

So, to solve any of those four general limitations, you *must* use a next hop service set.

Interface-style service sets do have their place, though; they are much easier to configure for simple tasks, and they are easier to apply to multiple interfaces. If the same service needs to be applied to multiple interfaces with separate route tables for individual customers, a next hop service set would require multiple service sets, whereas an interface-style service set might require only a single service set. Also, an interface-style service set allows for the use of an external interface address for certain NAT circumstances that a next hop service set cannot accomplish. Therefore, you should choose a service set based on which features need to be supported. Table 7-3 can assist you as a general guideline for choosing your service style.

Table 7-3. Summary of service-style feature support

Service style	General configuration complexity	Multicast support	Routing protocols over IPSec	Overlapping NAT addresses	PAT with external interface in the NAT pool	Treat IPSec tunnels as a link	Number of security zones supported
Interface	Easy	No	No	No	Yes	No	One

Table 7-3. Summary of service-style feature support (continued)

Service style	General configuration complexity	Multicast support	Routing protocols over IPSec	Overlapping NAT addresses	PAT with external interface in the NAT pool	Treat IPSec tunnels as a link	Number of security zones supported
Next hop	Hard	Yes	Yes	Yes	No	Yes	Many

You will have to apply the service set for it to take effect. You can apply it directly to the interface unit (interface style) or reference the service interface (next hop).

First, here is an example of a service set applied directly to interface `t1-0/0/2`:

```
lab@Porter# show interfaces t1-0/0/2
description Porter-to-Bock;
unit 0 {
    family inet {
        service {
            input {
                service-set test-rule;
            }
            output {
                service-set test-rule;
            }
        }
        address 10.10.10.2/30;
    }
}
```

The service set `test-rule` is applied to the interface at the logical unit level and is applied for `family inet` (IPv4) traffic. The strange piece of this configuration is the fact that the service set must be applied as *both* an input and an output service, and it *must* be the same service set. This means direction is never inferred when applying a service set to an interface. Recall that the direction of a rule is decided in the service rule and not in the direction in which the service set is applied to the interface!

> Applying the service set to both the input and the output of an interface has no real purpose in the current implementation; it was created as part of the original specification outline. There was a thought that asymmetrical traffic with different service sets would be supported, but it was decided later not to implement that function in JUNOS software.

If a next hop service type is used, simply configure the router to forward packets to either the inside or the outside service interface. This is usually done by creating a static route that points to the service interface, which in turn creates another route table to point traffic to the service interface or runs a routing protocol over the service interface. This example sends all 5.5.0/19 traffic to the sp-0/0/0.1 (inside) interface:

```
[edit]
lab@Porter# show routing-options
static {
    route 5.5.0.0/19 next-hop sp-0/0/0.1;
}
```

This verifies that the route is active:

```
[edit]
lab@Porter# run show route protocol static

inet.0: 10 destinations, 10 routes (10 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

5.5.0.0/19         *[Static/5] 00:00:08
                    > via sp-0/0/0.1
```

Simple Interface-Style Service Set

We will discuss Layer 3 services in more detail in the next chapter, but here let's examine a simple example of a stateful-firewall rule to illustrate how the CLI pieces fit together using the topology shown in Figure 7-10. A stateful firewall is going to be applied on Porter's t1-0/0/2 interface for traffic from Bock to Yeast's loopback address of 10.30.1.1.

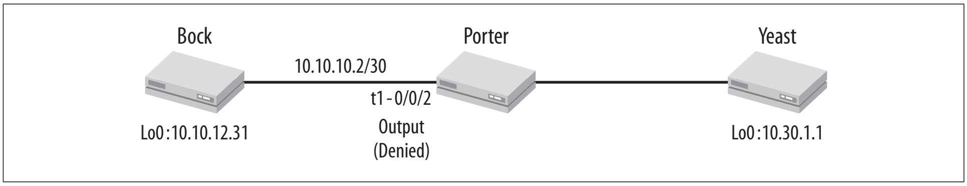


Figure 7-10. Topology for a simple interface-style stateful firewall

This firewall will allow traffic to be initiated from the Bock loopback to Yeast's loopback, but not initiated from Yeast to Bock. To configure, first create a logical unit on the sp- interface with IPv4 support on Porter:

```
lab@Porter#  show interfaces
sp-0/0/0 {
    unit 0 {
        family inet;
    }
```

Then configure a stateful rule to allow traffic from Bock to Yeast's loopback address. Since this is going to be applied on Porter's t1-0/0/2 interface for traffic received from Bock, the direction should be input:

```
[edit services]
lab@Porter# show
```

```
stateful-firewall {
    rule simple-rule {
        match-direction input;
        term 1 {
            from {
                destination-address {
                    10.30.1.1/32;
                }
            }
            then {
                accept;
            }
        }
    }
}
```

Now create an interface-style service set and apply the rule and service interface:

```
[edit services]
lab@Porter# show service-set test-rule
stateful-firewall-rules simple-rule;
interface-service {
    service-interface sp-0/0/0.0;
}
```

Apply the service set to the `t1-0/0/2` interface as both an input and an output:

```
[edit services]
lab@Porter# top show interfaces t1-0/0/2
description Porter-to-Bock;
unit 0 {
    family inet {
        service {
            input {
                service-set test-rule;
            }
            output {
                service-set test-rule;
            }
        }
        address 10.10.10.2/30;
    }
}
```

The last step is to test the stateful firewall on `Porter`, so a ping is issued from `Bock` to `Yeast` to test connectivity; this example shows that it succeeds:

```
[edit]
lab@Bock# run ping 10.30.1.1 count 100 rapid size 700
PING 10.30.1.1 (10.30.1.1): 700 data bytes
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!
--- 10.30.1.1 ping statistics ---
100 packets transmitted, 100 packets received, 0% packet loss
round-trip min/avg/max/stddev = 17.787/23.982/125.399/14.994 ms
```

To verify that the packets are traversing the stateful firewall, several `show services state-firewall` commands are issued. The first command is `show services stateful-firewall flows`, which displays the active flows that are transiting the system. In this case, the ping from `Bock` to `Yeast` is observed with 100 packets (`Frm count`) sent in both directions:

```
[edit services]
lab@Porter# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: test-rule
Flow                                   State    Dir       Frm count
ICMP    10.30.1.1:8471  -> 10.10.10.1  Watch    O             100
ICMP   10.10.10.1:8471  ->  10.30.1.1  Watch    I             100
```

When there is a related flow from input to output and output to input, it is called a *conversation*, and you can view it with the `show services stateful-firewall conversations` command. A flow must exist in each direction to be stored as a conversation that is *not* traffic-dependent, as the router will always create the return flow after the initial communication is initiated. Once again, the test ping traffic is observed:

```
[edit services]
lab@Porter# run show services stateful-firewall conversations
Interface: sp-0/0/0, Service set: test-rule

Conversation: ALG protocol: icmp
  Number of initiators: 1, Number of responders: 1
Flow                                   State    Dir       Frm count
ICMP   10.10.10.1:8471  ->  10.30.1.1   Watch    I             100
ICMP    10.30.1.1:8471  -> 10.10.10.1   Watch    O             100
```

Every flow is given a state of either Forward, Drop, or Watch. A Forward flow forwards without looking at the payload, a Drop discards, and a Watch looks at the payload of the packet to determine whether the packet should be forwarded. If a flow is part of an ALG, it will always remain in the Watch state, but if it is part of a predicted flow, it may transition to the Forward state.

A final, useful command, `show services stateful-firewall statistics`, is used to view the statistics for a given service set rule. Notice in the following example that 200 packets have been accepted: 100 for the ICMP echo, and 100 for the ICMP reply, created when we issued the `ping` command on `Bock`:

```
[edit services]
lab@Porter# run show services stateful-firewall statistics
Interface   Service set      Accept    Discard    Reject     Errors
sp-0/0/0    test-rule           200          0         0          0
```

Lastly, verify that the stateful firewall is blocking traffic initiated from `Yeast` to `Bock` by pinging the loopback of `Bock` and sourcing from `Yeast`'s loopback address:

```
lab@Yeast# run ping 10.10.12.3 source 10.30.1.1 rapid count 100
PING 10.10.12.3 (10.10.12.3): 56 data bytes
```

```
.....................................................................
..............
--- 10.10.12.3 ping statistics ---
100 packets transmitted, 0 packets received, 100% packet loss
```

All packets are being lost, and you can verify this on `Porter` by looking at the flow and the drop states, as well as by viewing the stateful-firewall statistics and noting that the `Discard` counter is increasing:

```
[edit services]
lab@Porter# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: test-rule
Flow                                     State    Dir       Frm count
ICMP     10.30.1.1:36119 ->  10.10.12.3   Drop     O              3

[edit services]
lab@Porter# run show services stateful-firewall statistics
Interface   Service set     Accept   Discard     Reject    Errors
sp-0/0/0    test-rule          200       100          0         0
```

Service Filters and Post-Service Filters

You can configure some additional configuration options on the interface where the service set is applied. For instance, you can apply multiple service sets to a single logical interface:

```
t1-0/0/2 {
    description Porter-to-Bock;
    unit 0 {
        family inet {
            service {
                input {
                    service-set new-service-set;
                    service-set test-rule;
                }
                output {
                    service-set new-service-set
                    service-set test-rule;
                }
            }
            address 10.10.10.2/30;
        }
    }
}
```

However, if multiple service sets are applied to a single logical interface, traffic must be mapped to one service set or another. You can accomplish this with service filters, as indicated when trying to issue a `commit` with the preceding configuration:

```
lab@Porter# commit
[edit interfaces t1-0/0/2 unit 0 family inet service input]
  'service-set new-service-set'
    Service will never be used without service filter on previous service-set
```

```
[edit]
  'interfaces'
    error parsing interfaces object
error: configuration check-out failed
```

A service filter is configured under the [edit firewall] level and has very similar match conditions as a standard JUNOS firewall filter. A major difference is that it must be configured under [edit firewall family inet].

In this example, the goal will be to have traffic destined for 10.30.1.1 serviced by set new-service-set, and all other traffic serviced by test-rule.

The service filter choose-service-set matches on all packets except for those with a destination IP of 10.30.1.1. So, any packet besides 10.30.1.1 will be serviced, and a packet with the destination address 10.30.1.1 will be skipped:

```
family inet {
    service-filter choose-service-set {
        term 1 {
            from {
                destination-address {
                    0.0.0.0/0;
                    10.30.1.1/32 except;
                }
            }
            then service;
        }
    }
```

Remember that the default behavior within a service filter is then skip. If no service filter is applied, the default behavior is then service.

The router processes the service sets in the order of the list under the family inet service hierarchy. In our example, test-rule is examined followed by and then new-service-set. Therefore, traffic with any destination IP address other than 10.30.1.1 will be serviced by the test-rule service set, and traffic destined for 10.30.1.1 will be processed by new-service-set, since it is the service set listed next in the unit's [family inet service input] stanza. All seems well, and the service filter is applied to the logical interface:

```
t1-0/0/2 {
    description Porter-to-Bock;
    unit 0 {
        family inet {
            service {
                input {
                    service-set test-rule service-filter choose-service-set;
                    service-set new-service-set;
                }
                output {
                    service-set test-rule;
                    service-set new-service-set;
```

After issuing a commit, however, the router reports an error:

```
[edit interfaces t1-0/0/2]
lab@Porter# commit
[edit interfaces t1-0/0/2 unit 0 family inet service output]
  'service-set new-service-set'
    Service will never be used without service filter on previous service-set
[edit interfaces t1-0/0/2 unit 0 family inet]
  'service'
    Both input and output services must be configured
[edit]
  'interfaces'
    error parsing interfaces object
error: configuration check-out failed
```

You will also need to look at traffic in the return direction; otherwise, it will be serviced only by the first service set in the output list. So, a second service filter will skip the traffic from 10.30.1.1 and will service all other traffic:

```
    service-filter rest-of-traffic {
        term 1 {
            from {
                source-address {
                    10.30.1.1/32;
                }
            }
            then skip;
        }
        term 2 {
            then service;
        }
    }
}
```

Finally, the service filter is applied to the service sets under the logical interface. This configuration will cause all packets with the destination address 10.30.1.1 to be serviced by the new-service-set service set, and all other traffic to be serviced by the test-rule service set:

```
t1-0/0/2 {
    description Porter-to-Bock;
    unit 0 {
        family inet {
            service {
                input {
                    service-set test-rule service-filter choose-service-set;
                    service-set new-service-set;
                }
                output {
                    service-set test-rule service-filter rest-of-traffic;
                    service-set new-service-set;                }
            }
```

```
                address 10.10.10.2/30;
            }
        }
    }
```

Pings are issued to verify that the proper flows are serviced by the correct service set:

```
lab@Porter# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: new-service-set
Flow                                       State   Dir  Frm count
ICMP      10.20.131.2:27176 ->    10.30.1.1   Watch   I        13
ICMP        10.30.1.1:27176 ->  10.20.131.2   Watch   O        13

Interface: sp-0/0/0, Service set: test-rule
Flow                                       State   Dir  Frm count
ICMP      10.20.131.2:27432 ->    10.10.8.2   Watch   I         6
ICMP        10.10.8.2:27432 ->  10.20.131.2   Watch   O         6
```

You also can use a service filter to exclude traffic from being serviced through all service sets applied to an interface. Simply use the skip action to exclude certain traffic:

```
lab@Porter# set firewall family inet service-filter example term 1 then ?
Possible completions:
+ apply-groups        Groups from which to inherit configuration data
+ apply-groups-except Don't inherit configuration data from these groups
  count               Count the packet in the named counter
  log                 Log the packet
  port-mirror         Port-mirror the packet
  sample              Sample the packet
  service             Forward packets to service processing
  skip                Skip service processing
```

You can apply one last type of filter to a service set: post-service-filter. This is a stateless packet filter that is evaluated after the service set has processed the packet. This type of filter is available only on input, and it applies only to non-IPSec-VPN packets. Lastly, and most importantly, it will apply only to packets that have been processed by the service set, and it is applied after they have been processed (so, if addresses have been changed by NAT rules, you would match on the post-NAT addresses).

In the following code snippet, a post-service filter called test is applied to the t1-0/0/2.0 interface:

```
t1-0/0/2 {
    description Porter-to-Bock;
    unit 0 {
        family inet {
            service {
                input {
                    service-set test-rule service-filter choose-service-set;
                    service-set new-service-set;
                    post-service-filter test;

                }
```

```
                    output {
                        service-set test-rule service-filter rest-of-traffic;
                        service-set new-service-set;                }
                }
                address 10.10.10.2/30;
            }
        }
    }
```

Simple Next Hop-Style Service Set

In this section, we will again create a stateful firewall, but this time using a next hop-style service set. The topology is slightly different, as shown in Figure 7-11, because PBR would like to limit all Telnet traffic coming from Water with a source IP subnet of 64.8.12.0/27 and destined for the loopback of router Bock.

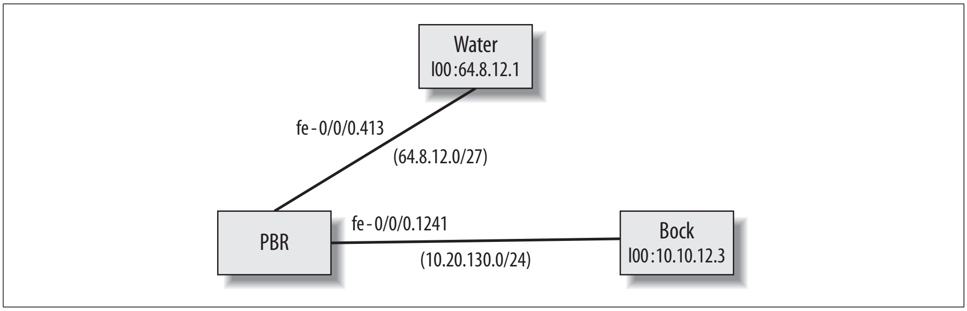


Figure 7-11. Simple next hop service set topology

First, create an inside and outside interface on the service interface using any unit except for unit 0:

```
lab@PBR# show interfaces sp-0/0/0
unit 1 {
    family inet;
    service-domain inside;
}
unit 2 {
    family inet;
    service-domain outside;
}
```

Then create the stateful-firewall rule to allow the Telnet traffic through PBR using an application of junos-telnet, since this is the only traffic currently allowed in. The match direction in this case is specified at input, as traffic is going to be directed into the inside interface.

```
stateful-firewall {
    rule restricted-telnet {
        match-direction input;
        term 1 {
            from {
                source-address {
                    64.8.12.0/27;
                }
                destination-address {
                    10.10.12.3/32;
                }
                applications junos-telnet;
            }
            then {
                accept;
            }
        }
    }
}
```

This rule is very restrictive to illustrate an example. All routing protocols, ICMP traffic, and so on would also be blocked by this stateful firewall, so in everyday practice, the rule would be more complex.

Next, create the service set and link the rule and service interfaces together:

```
service-set telnet-set {
    stateful-firewall-rules restricted-telnet;
    next-hop-service {
        inside-service-interface sp-0/0/0.1;
        outside-service-interface sp-0/0/0.2;
    }
}
```

The last piece is to map the traffic to the service set. You can do this in a variety of ways, but in this case we will create a static route that maps the 10.10.12.3 traffic to the service interface:

```
lab@PBR# set routing-options static route 10.10.12.3 next-hop sp-0/0/0.1
```

After applying the configuration, however, a telnet from `Water` fails:

```
lab@Water> telnet 10.10.12.3
Trying 10.10.12.3...
^C
```

Examining the flow, it appears that traffic is matching the rule and is traversing the router in the input direction, but no return traffic is being counted despite the creation of the correct return flow:

```
lab@PBR# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: telnet-set
Flow                                         State    Dir  Frm count
TCP     64.8.12.5:3827  -> 10.10.12.3:23    Forward  I          8
TCP    10.10.12.3:23    ->  64.8.12.5:3827  Forward  O          0

lab@PBR# run show services stateful-firewall conversations
Conversation: ALG protocol: tcp
```

```
  Number of initiators: 1, Number of responders: 1
Flow                                 State    Dir  Frm count
TCP     64.8.12.5:3827  -> 10.10.12.3:23    Forward  I         8
TCP    10.10.12.3:23    ->  64.8.12.5:3827  Forward  O         0
```

Examine the stateful-firewall statistics and identify whether any errors are incrementing. In this case, it appears that they are:

```
[edit]
lab@PBR# run show services stateful-firewall statistics
Interface   Service set    Accept    Discard    Reject    Errors
sp-0/0/0    telnet-set         48          6         0        59
```

When examined further, these errors seem to be SYN errors—multiple SYN packets are being seen from the same flows:

```
lab@PBR# runs show services statful-firewall statistics extensive | find "TCP Errors"
    TCP errors:
      TCP header length inconsistencies: 0
      Source or destination port number is zero: 0
      Illegal sequence number and flags combinations: 0
      SYN attack (multiple SYN messages seen for the same flow): 132
      First packet not a SYN message: 13
      TCP port scan (TCP handshake, RST seen from server for SYN): 0
      Bad SYN cookie response: 0
    UDP errors:
```

Lastly, examine the log (we will discuss logs later in the section “Logging and Tracing”) to ensure that the rule created is indeed matching and correct. The first two log entries indicate that there is no issue with the stateful-firewall rule, but the next entries indicate a SYN attack:

```
Aug 10 02:57:01  (FPC Slot 0, PIC Slot 0) {telnet-set}[FWNAT]: ASP_SFW_RULE_ACCEPT:
proto 6 (TCP) application: any, fe-0/0/0.413:64.8.12.5:2250 -> 10.10.12.3:23, Match
SFW accept rule-set: , rule: restricted-telnet, term: 1
Aug 10 02:57:01  (FPC Slot 0, PIC Slot 0) {telnet-set}[FWNAT]: ASP_SFW_CREATE_ACCEPT_
FLOW: proto 6 (TCP) application: any, fe-0/0/0.413:64.8.12.5:2250 -> 10.10.12.3:23,
creating forward or watch flow
Aug 10 02:57:01  (FPC Slot 0, PIC Slot 0) {telnet-set}[FWNAT]: ASP_IDS_TCP_SYN_
ATTACK: proto 6 (TCP), sp-0/0/0.2:64.8.12.5:2250 -> 10.10.12.3:23, TCP SYN flood
attack
Aug 10 02:57:01  (FPC Slot 0, PIC Slot 0) {telnet-set}[FWNAT]: ASP_IDS_TCP_SYN_
ATTACK: proto 6 (TCP), sp-0/0/0.2:64.8.12.5:2250 -> 10.10.12.3:23, TCP SYN flood
attack
Aug 10 02:57:01  (FPC Slot 0, PIC Slot 0) {telnet-set}[FWNAT]: ASP_IDS_TCP_SYN_
ATTACK: proto 6 (TCP), sp-0/0/0.2:64.8.12.5:2250 -> 10.10.12.3:23, TCP SYN flood
attack
Aug 10 02:57:01  (FPC Slot 0, PIC Slot 0) {telnet-set}[FWNAT]: ASP_IDS_TCP_SYN_
ATTACK: proto 6 (TCP), sp-0/0/0.2:64.8.12.5:2250 -> 10.10.12.3:23, TCP SYN flood
attack
Aug 10 02:57:01  (FPC Slot 0, PIC Slot 0) {telnet-set}[FWNAT]: ASP_IDS_TCP_SYN_
ATTACK: proto 6 (TCP), sp-0/0/0.2:64.8.12.5:2250 -> 10.10.12.3:23, TCP SYN flood
attack
```

```
Aug 10 02:57:01  (FPC Slot 0, PIC Slot 0) {telnet-set}[FWNAT]: ASP_IDS_TCP_SYN_
ATTACK: proto 6 (TCP), sp-0/0/0.2:64.8.12.5:2250 -> 10.10.12.3:23, TCP SYN flood
attack
Aug 10 02:57:01  (FPC Slot 0, PIC Slot 0) {telnet-set}[FWNAT]: ASP_IDS_TCP_SYN_
ATTACK: proto 6 (TCP), sp-0/0/0.2:64.8.12.5:2250 -> 1
```

The stateful firewall believes there is a SYN attack because of the two-service interface concept of a next hop service set. Recall that traffic is sent from one service interface to another. In this case, traffic is arriving into PBR's physical interface fe-0/0/0.413, and a route table lookup is performed:

```
lab@PBR> show route 10.10.12.3

inet.0: 18 destinations, 18 routes (18 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.12.3/32      *[Static/5] 00:24:47
                    > via sp-0/0/0.1
```

This route points to the inside interface, so traffic is sent to be serviced. The problem is that after traffic is serviced, it exits the outside interface and performs another route lookup. This route lookup points back to the inside interface, and a service loop is created, as shown in Figure 7-12.

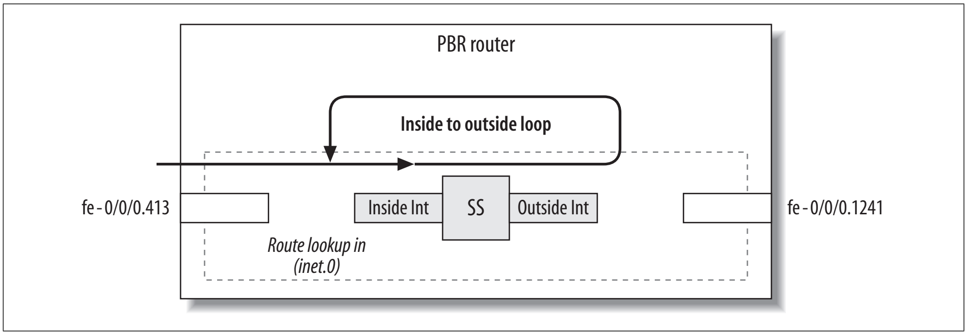


Figure 7-12. Next hop service set loop with single route table

You could also see this loop by viewing the service interface with a show interfaces sp-0/0/0.1 command and noticing the ttl-exceeded flag. This flag indicates that it is OK to receive a packet with an expired TTL, which the router would normally not do. Although this does not actually indicate a loop, since there is no internal TTL method, it should throw a red flag. Remember that no loop actually occurred because the router determined the loop was a SYN attack and dropped the packets:

```
Logical interface sp-0/0/0.1 (Index 64) (SNMP ifIndex 41)
    Flags: Point-To-Point SNMP-Traps Encapsulation: Adaptive-Services
    Input packets : 7
    Output packets: 0
    Protocol inet, MTU: 9192
      Flags: Receive-options, Receive-TTL-Exceeded
```

There are multiple ways to fix the loop, but typically each method will try to achieve the same goal: when the packets are serviced and the second lookup is performed, the packet must point to a different route in a different route table. One way to create a new route table is to create a virtual router (VR). With a VR, it is easy in JUNOS to create a different route table and a forwarding table and then add routes in those tables. In a VR, you can specify interfaces, create static routes, and even run routing protocols in their own instances. So, any packet that arrives on an interface that is configured in the VR will perform a route lookup in the VR's route table. In this way, traffic can be easily mapped to a new table without the need for filters or policies. Let's create a VR to allow for the two lookups in two tables with the inside interface in the main instance and the outside interface in the newly created VR, as shown in Figure 7-13.

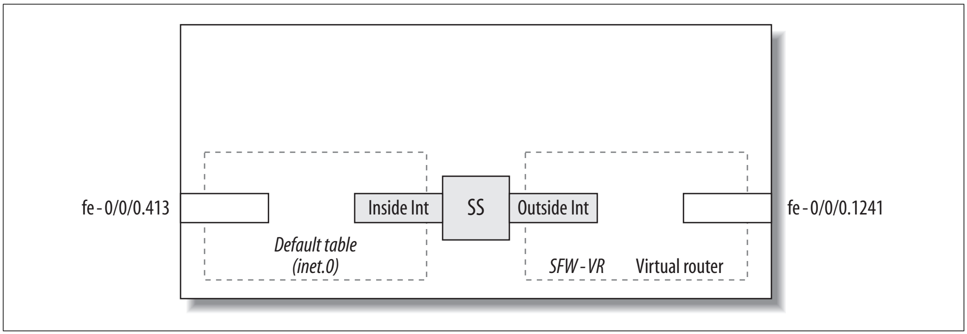


Figure 7-13. VR setup

First, create a VR by naming the routing instance and specifying the instance type:

```
lab@PBR# set routing-instances SFW-VR instance-type virtual-router
```

Next, add the interfaces that should be linked to the VR. One interface will be the outgoing interface on PBR toward Bock, and the other interface will be the outside service interface. Adding the outside service interface allows the VR's table to be used for the second lookup:

```
lab@PBR# set routing-instances SFW-VR interface sp-0/0/0.2

[edit]
lab@PBR# set routing-instances SFW-VR interface fe-0/0/0.1241
```

Lastly, you need to configure routing for the return flow to succeed. When traffic is received on interface fe-0/0/0.1241, it should be directed to the outside interface, serviced, and sent out the inside interface. Finally, a route table lookup should be performed in the main inet.0 table. You can accomplish this just like you did before by creating a static route, but this time pointing it to the outside interface:

```
lab@PBR# set routing-instances SFW-VR routing options static route
0.0.0.0/0 next-hop sp-0/0/0.2
```

Here is the entire routing instance, with Open Shortest Path First (OSPF) also configured between PBR and Bock for internal connectivity:

```
lab@PBR# show routing-instances
SFW-VR {
    instance-type virtual-router;
    interface sp-0/0/0.2;
    interface fe-0/0/0.1241;
    routing-options {
        static {
            route 0.0.0.0/0 next-hop sp-0/0/0.2;
        }
    }
    protocols {
        ospf {
            area 0.0.0.0 {
                interface fe-0/0/0.1241;
            }
        }
    }
}
```

A route table is automatically created with the form *<routing-instance-name>*.inet.0. Notice the static route that was configured and the direct route that represents the links on the fe-0/0/0.1241 interface:

```
[edit]
lab@PBR# run show route table SFW-VR

SFW-VR.inet.0: 7 destinations, 7 routes (7 active, 0 holddown, 0
hidden) + = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[Static/5] 03:27:05
                    > via sp-0/0/0.2
10.10.10.0/30      *[OSPF/10] 03:24:23, metric 66
                    > to 10.20.130.1 via fe-0/0/0.1241
10.10.12.2/32      *[OSPF/10] 03:24:23, metric 66
                    > to 10.20.130.1 via fe-0/0/0.1241
10.10.12.3/32      *[OSPF/10] 03:24:23, metric 1
                    > to 10.20.130.1 via fe-0/0/0.1241
10.20.130.0/24     *[Direct/0] 03:27:05
                    > via fe-0/0/0.1241
10.20.130.2/32     *[Local/0] 03:27:05
                      Local via fe-0/0/0.1241
224.0.0.5/32       *[OSPF/10] 03:24:43, metric 1
                      MultiRecv
```

After committing the changes on PBR, the telnet now succeeds on Water:

```
lab@Water> telnet 10.10.12.3
Trying 10.10.12.3...
Connected to 10.10.12.3.
Escape character is '^]'.
```

```
Bock (ttyp1)

login:
```

The conversation is now complete, as shown in the session table on PBR:

```
lab@PBR# run show services stateful-firewall conversations
Interface: sp-0/0/0, Service set: telnet-set

Conversation: ALG protocol: tcp
  Number of initiators: 1, Number of responders: 1
Flow                                       State    Dir   Frm count
TCP    64.8.12.5:1874  ->  10.10.12.3:23    Forward  I          9
TCP   10.10.12.3:23    ->   64.8.12.5:1874  Forward  O          7
```

Logging and Tracing

Since you can configure system logging and tracing in a variety of places in the configuration file, it can be confusing which statement is actually doing the logging. The rule in JUNOS software is that the more specific configuration will always override the more global configuration. The levels of logging possible, in order of global to specific, are as follows:

Interface logging

```
lab@PBR# set sp-0/0/0 services-options syslog host 1.1.1.1 services ?
Possible completions:
  <[Enter]>          Execute this command
  alert              Conditions that should be corrected immediately
  any                All levels
  critical           Critical conditions
  emergency          Panic conditions
  error              Error conditions
  info               Informational messages
  none               No messages
  notice             Conditions that should be handled specially
  warning            Warning messages
  |                  Pipe through a command
```

Service set logging

```
lab@PBR# set services service-set telnet-set syslog host 1.1.1.1 services ?
Possible completions:
  <[Enter]>          Execute this command
  alert              Conditions that should be corrected immediately
  any                All levels
  critical           Critical conditions
  emergency          Panic conditions
  error              Error conditions
  info               Informational messages
  none               No messages
  notice             Conditions that should be handled specially
  warning            Warning messages
  |                  Pipe through a command
```

Feature rule (stateful firewall, IPSec, etc.) logging

```
set stateful-firewall rule restricted-telnet term 1 then syslog
```

So, if logging was enabled at the service interface level and three service sets were configured, all three service sets would inherit the service-level logging settings. If a single service set also enabled logging, those settings would override the service-level logging for that service set. The remaining service sets would inherit the service interface logging settings.

There are also different types of logging: standard syslog and traceoptions. Syslog will send a system log message to a syslog server or the local router, and traceoptions will only send information to the local router. When you are viewing services, traceoptions usually gives you a view of the actual software operations on the Routing Engine (RE) and not the service PIC itself.

You can send syslog information to a remote syslog server by indicating a host, or send it to the local router by specifying the keyword `local`:

```
sp-0/0/0 {
    services-options {
        syslog {
            host local {
                services any;
            }
        }
    }
```

If you specify that the syslog messages should be sent to the local router, you can send the messages to the default system log of *messages* or to another designated file. Also, for those messages to actually appear, you will have to configure the router to accept messages for the `local2` facility. To place these syslog entries in the *messages* file, you can use this configuration:

```
[edit]
lab@PBR# set system syslog file messages local2 any
```

An example of the types of syslog messages is messages that show which rules have been matched and created. Here, router `PBR` is monitoring the *messages* file in real time, and you can see that a stateful-firewall rule was matched and a flow was created based on that match:

```
[edit]
lab@PBR# run monitor start messages

*** messages ***
Aug 10 06:45:50  (FPC Slot 0, PIC Slot 0) {telnet-set}[FWNAT]: ASP_SFW
_RULE_ACCEPT: proto 6 (TCP) application: any, fe-0/0/0.413:64.8.12.5:
10.10.12.3:23, Match SFW accept rule-set: , rule: restricted-telnet,
term: 1
Aug 10 06:45:50  (FPC Slot 0, PIC Slot 0) {telnet-set}[FWNAT]: ASP_SFW_CREATE_ACCEPT_
FLOW: proto 6 (TCP) application: any, fe-0/0/0.413:64.8.12.5:3225 -> 10.10.12.3:23,
creating forward or watch
flow
```

If you need to examine the service's software operation, you can configure traceoptions at the PIC level. If no file is specified, the information will be placed into a file called *spd*:

```
lab@PBR# set services adaptive-services-pics traceoptions flag ?
Possible completions:
  all                  Trace everything
  configuration        Trace configuration events
  kernel-object        Trace kernel object management
  routing-protocol     Trace routing protocol events
  routing-socket       Trace routing socket events
  snmp                 Trace SNMP operations
```

Here is an example of the types of messages you would see in *spd*. In this code snippet, software sockets have been created and resources have been assigned when services were configured:

```
lab@PBR# run show log spd
Aug 10 07:13:27 spd process starting, pid 12555
Aug 10 07:13:27 rpd session connected
Aug 10 07:13:27 registered async opaque handler for traps
Aug 10 07:13:27 Added sp-0/0/0 snmpindex 21 fpc_slot 0 pic_slot 0 to database
Aug 10 07:13:27 Loading initial state from kernel...
Aug 10 07:13:27 Processed ASP_CFG_GLOBAL_OPTIONS config object
Aug 10 07:13:27 Adding blob to set: id = 1, type = 16, size = 92, pic = sp-0/0/0 (0)
Aug 10 07:13:27 Blob id = 1, type = 16, size = 92 is new, adding
Aug 10 07:13:27 Imported config object (type 16, id 1)
Aug 10 07:13:27 Adding blob to set: id = 1, type = 16, size = 92, pic = sp-0/0/0 (0)
Aug 10 07:13:27 State initialization from kernel complete
Aug 10 07:13:27 ------ Finished with RTSOCK initialization ------
Aug 10 07:13:28 get_pic_index sp-0/0/0.1 pic index 0
Aug 10 07:13:28 get_pic_index sp-0/0/0.1 pic index 0
Aug 10 07:13:28 Adding blob to set: id = 2, type = 12, size = 912, pic = sp-0/0/0 (0)
Aug 10 07:13:28 get_pic_index sp-0/0/0 pic index 0
Aug 10 07:13:28 Adding blob to set: id = 1, type = 16, size = 92, pic = sp-0/0/0 (0)
Aug 10 07:13:28 Blob id = 1 is not changed, skipping
Aug 10 07:13:28 Blob id = 2, type = 12, size = 912 is new, adding
Aug 10 07:13:28 Added service set telnet-set (id 2, pic sp-0/0/0 (0))
Aug 10 07:13:28 Adding blob to set: id = 2, type = 12, size = 912, pic = sp-0/0/0 (0)
Aug 10 07:13:28 rpd session established
```

Layer 3 Services Configuration Summary

This section described the various Layer 3 service offerings as well as the CLI configuration steps that were needed. We also discussed the option of interface-style or next hop-style service sets. In addition, we covered some basic examples to illustrate the CLI options. We will cover more complex examples in the next chapter.

Now is a good time to take a break, perhaps to think about the points we covered in this section. The next section will examine some additional features that are less common but could be deployed in your own network.

Additional Service Options

You can enable many other services that are not as common but could play a large role in your network. We will briefly discuss these services here, but you should consult the router or PIC documentation at *http://www.juniper.net/techpubs* for more detailed configuration information.

Layer 2 Tunneling Protocol (L2TP)

L2TP is a tunneling protocol that tunnels PPP packets across a network, acting like a Layer 2 data link tunneling protocol. L2TP headers and payload are actually sent in a UDP datagram, so maybe people claim it to be a Layer 5 or Layer 4.5 protocol. Each endpoint of the tunnel has its own designation, one being an LNS and the other an LT2P Access Concentrator (LAC). A Juniper Networks router can act as an LNS.

Only M7i, M10i, and M120 routers support LT2P.

Real-Time Performance Monitoring (RPM)

RPM is a feature for tracking and monitoring your network by sending network *probes* to other devices. These probes could be ICMP, UDP, or TCP,[*] depending on the configuration. You can use these probes to measure packet round-trip times, jitter, delay, and packet (probe) loss. You also can use RPM to verify the path toward Border Gateway Protocol (BGP) neighbors.

RPM does not require an ASP or Multiservices PIC, unless you are configuring RPM timestamping, which was released in JUNOS 8.1 for the sender and in JUNOS 8.3 for the responder.

You can configure probes with a variety of parameters, such as the type or contents of the probe. Also, you can set thresholds to trigger syslog messages and Simple Network Management Protocol (SNMP) TRAPs. In the following example, router `PBR` has a probe to send an ICMP ping to `Porter` at 10.10.12.2. Seven probes should be sent every three seconds:

```
[edit services rpm]
lab@PBR# show
probe foo {
    test Porter {
        probe-type icmp-ping;
```

[*] UDP and TCP probes require a Juniper server.

```
        target address 10.10.12.2;
        probe-count 7;
        probe-interval 3;
    }
}
```

To verify that probes are being sent and data is being received, you can examine SNMP Management Information Bases (MIBs) or use the local router sending the probes by issuing show services rpm commands. The first command, history-results, should show the time at which the probes are sent and the round-trip length of the probe:

```
lab@PBR# run show services rpm history-results
    Owner, Test         Probe received              Round trip time
    foo, Porter         Wed Aug  8 07:02:54 2007         46097 usec
    foo, Porter         Wed Aug  8 07:07:41 2007         33662 usec
    foo, Porter         Wed Aug  8 07:07:44 2007         20133 usec
    foo, Porter         Wed Aug  8 07:07:47 2007         20112 usec
    foo, Porter         Wed Aug  8 07:07:50 2007         20112 usec
    foo, Porter         Wed Aug  8 07:07:53 2007         20104 usec
    foo, Porter         Wed Aug  8 07:07:56 2007         20092 usec
    foo, Porter         Wed Aug  8 07:07:59 2007         20104 usec
```

Verify the actual probe results by issuing a show services rpm probe-results command:

```
[edit services rpm]
lab@PBR# run show services rpm probe-results
   Owner: foo, Test: Porter
   Target address: 10.10.12.2, Probe type: icmp-ping, Test size: 7 probes
   Probe results:
     Response received, Wed Aug  8 07:07:59 2007
     Rtt: 20104 usec
   Results over current test:
     Probes sent: 7, Probes received: 7, Loss percentage: 0
     Measurement: Round trip time
       Minimum: 20092 usec, Maximum: 33662 usec, Average: 22046 usec,
       Jitter: 13570 usec, Stddev: 4742 usec
   Results over last test:
     Probes sent: 7, Probes received: 7, Loss percentage: 0
     Test completed on Wed Aug  8 07:07:59 2007
     Measurement: Round trip time
       Minimum: 20092 usec, Maximum: 33662 usec, Average: 22046 usec,
       Jitter: 13570 usec, Stddev: 4742 usec
   Results over all tests:
     Probes sent: 7, Probes received: 7, Loss percentage: 0
     Measurement: Round trip time
       Minimum: 20092 usec, Maximum: 33662 usec, Average: 22046 usec,
       Jitter: 13570 usec, Stddev: 4742 usec
```

You also can examine the paths to configured BGP peers by sending probes to configured peers. Once RPM is configured, probes will be sent to neighbors configured for BGP automatically. In this example, router PBR has one BGP neighbor to router

`Porter`. The probes will be ICMP pings with five probes sent at an interval of one second. They will be 255 bytes with ICMP data of hex 0123456789. The test will run every 60 seconds:

```
[edit services rpm]
lab@PBR# show
bgp {
    probe-type icmp-ping;
    probe-count 5;
    probe-interval 1;
    test-interval 60;
    history-size 10;
    data-size 255;
    data-fill 0123456789;
}
```

As previously mentioned, you can retrieve the results via `show services rpm` commands or via SNMP in MIBs such as the following:

- `pingResultsTable`
- `jnxPingResultsTable`
- `jnxPingProbeHistoryTable`
- `pingProbeHistoryTable`

The following, final example details the `show services rpm probe-results` for `PBR`'s BGP peer:

```
[edit services rpm]
lab@PBR# run show services rpm probe-results
   Owner: Rpm-Bgp-Owner, Test: Rpm-Bgp-Test-0
   Target address: 10.10.12.2, Source address: 10.20.128.3,
   Probe type: icmp-ping, Test size: 5 probes
   Probe results:
     Response received, Wed Aug  8 07:20:37 2007
     Rtt: 20135 usec
   Results over current test:
     Probes sent: 5, Probes received: 5, Loss percentage: 0
     Measurement: Round trip time
       Minimum: 20102 usec, Maximum: 69744 usec, Average: 30049 usec,
       Jitter: 49642 usec, Stddev: 19847 usec
   Results over last test:
     Probes sent: 5, Probes received: 5, Loss percentage: 0
     Test completed on Wed Aug  8 07:20:37 2007
     Measurement: Round trip time
       Minimum: 20102 usec, Maximum: 69744 usec, Average: 30049 usec,
       Jitter: 49642 usec, Stddev: 19847 usec
   Results over all tests:
     Probes sent: 10, Probes received: 10, Loss percentage: 0
     Measurement: Round trip time
       Minimum: 20102 usec, Maximum: 69744 usec, Average: 25119 usec,
       Jitter: 49642 usec, Stddev: 14875 usec
```

Data Link Switching (DLSw)

DLSw is a protocol that offers IP routing support for unroutable, legacy protocols such as System Network Architecture (SNA) and NETBUI/NetBIOS. Once configured, the routers set up connections with their local end systems, as well as with other peer routers, and the traffic flow from one end system to another is transparent, meaning the presence of the routed IP network is not known to the end stations. When DLSw is configured, TCP sessions are established between peer routers and capabilities are negotiated. Then a circuit is established between the end system and the router.

DLSw is supported only on J-series routers.

For example, in the SNA example shown in Figure 7-14, the sequence would be as follows:

1. An SNA device sends out an explorer frame looking for Mainframe 1.
2. The router receives this frame and sends a `canureach` frame to its peer DLSw routers.
3. The remote routers forward the `canureach` message to their attached Mainframes.
4. Mainframe 1 sends an `icanreach` response to its local router, which in turn forwards the frame toward the DLSw peers.
5. After the frames have been exchanged, a circuit is established between the SNA devices and the local routers, as well as between the peer routers.

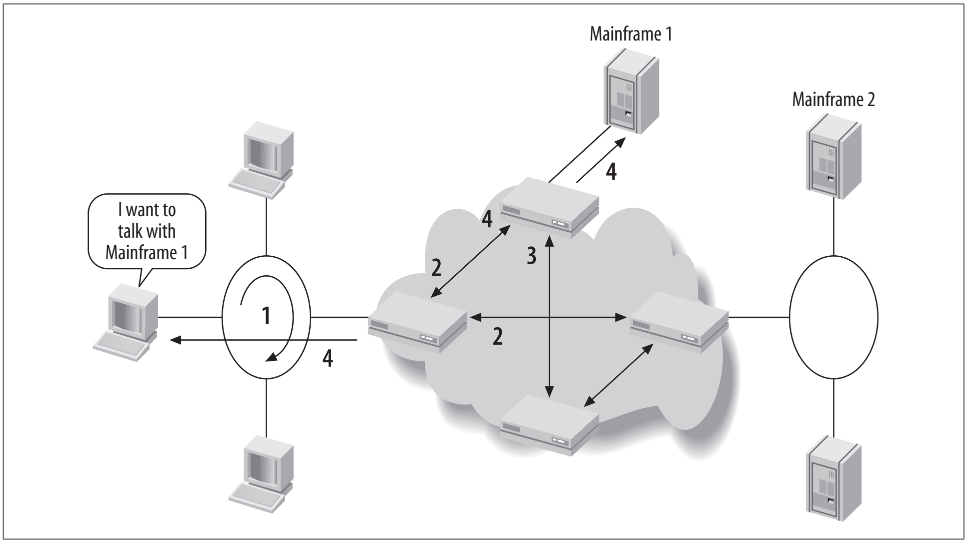


Figure 7-14. DLSw example flow

Flow Monitoring

Juniper Networks routers give you the ability to take monitored traffic flows and export this data in cflowd format or direct the flows in their native format to different packet analyzers. You can also encrypt the flows when sending them.

One common type of monitoring that you can perform is called *active monitoring*, whereby the router takes the inbound traffic, extracts the flow into a cflowd format, and sends the cflowd record of the matched traffic to a flow collector device, as shown in Figure 7-15. The original packet is usually forwarded toward the destination, but other options do exist, including *discard accounting*, whereby the cflowd record is sent to the flow collector and the original packet is discarded, or *port mirroring*, whereby the entire packet is copied and sent to an additional interface and the original packet is forwarded on to its intended destination.

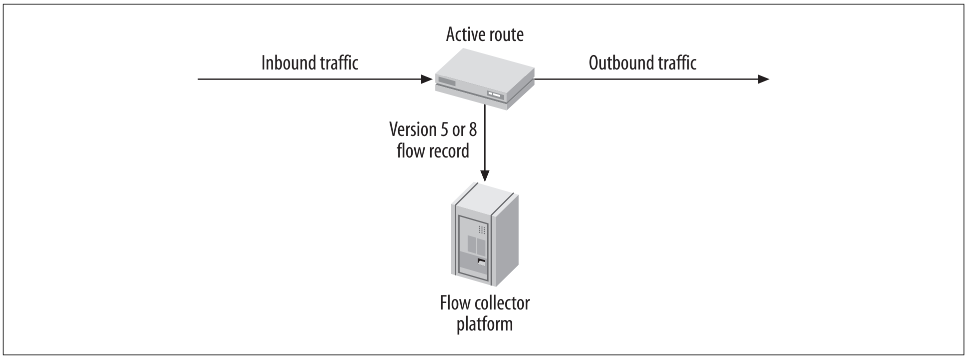


Figure 7-15. Active flow monitoring

There are some restrictions on how many actions can be performed on a network flow in the router:

- Sampling (cflowd) to a collector *or* port mirroring at one time
- Forwarding the original packet *or* discard accounting at one time

And only certain combinations of configurations are allowed on the *same* set of traffic:

- Port mirroring and forwarding
- Port mirroring and discard accounting
- Sampling and forwarding
- Sampling and discard accounting

Sampling (cflowd) and port mirroring can be performed at the same time only if they are on different sets of traffic.

Tunnel Services

We have already discussed a variety of different tunnels, and even more can be configured. You can use these tunnels for external connections or for connections with the same router. Any tunnel that is created will get an internal interface created for it. These interfaces are as follows:

`ip`
: For configuring an IP-IP tunnel that encapsulates one IP packet inside another. This type of tunnel is often seen in mobile environments where the endpoint address changes, and is migrated to different networks. This could also be useful in tunneling IPv6 packets over an IPv4 network.

`lt`
: Creates internal tunnel connections between different logical routers or VRs in the same chassis. In a J-series router, you also can use this interface to implement CoS on DLSw and RPM.

`mt`
: Used to create multicast tunnels. These tunnels are automatically created when running multicast in a Layer 3 BGP/Multiprotocol Label Switching (MPLS) VPN.

`pd`
: Used to de-encapsulate PIM register messages sent from a designated router to a rendezvous point (RP) in a multicast network.

`pe`
: Used to encapsulate PIM register messages sent from a designated router to an RP in a multicast network.

`vt`
: Used to loop a packet through the Packet Forwarding Engine (PFE) as an additional instance. This is normally used in a VPN environment to concurrently perform both an MPLS lookup and an IP lookup. This is supported only on M/T-series routers and not on J-series routers.

Conclusion

JUNOS software offers a vast number of both Layer 2 and Layer 3 services that you can run on your network. Not all of these services will likely be running on your network at the same time, but often you'll use them for the features and security they offer. This chapter examined the basic building blocks of those services, and how to deploy them on a single-service feature basis. The next chapter examines more complex scenarios with multiple services running concurrently.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- Configure MLPPP.
- Configure Layer 2 services to optimize voice traffic.
- Configure and apply an interface-style service set.
- Configure a next hop-style service set.
- Identify the match direction given a network diagram.
- Understand and implement various types of service sets.
- Describe the differences between stateful firewalls and stateless packet filters.
- Describe NAT and PAT.
- Describe the functions of ALGs.
- Configure a stateful firewall via the CLI.
- Monitor a stateful firewall.
- Explain the uses of IPSec VPNs.
- Intrusion detection and prevention (IDP).
- Virtual routers to segment secure services.

Chapter Review Questions

1. Which type of service allows for multiple physical interfaces running Frame Relay to be bonded together into a single logical bundle?
   a. MLPPP
   b. FRF.15
   c. FRF.12
   d. FRF.16
2. Which type of service set would you choose if you wanted to service multicast traffic?
   a. Interface-style
   b. Next hop-style
3. True or False: All Layer 2 services will always use the `ls-` interface.
4. Which CLI command displays a session for a stateful firewall?
   a. `show services stateful-firewall conversations`
   b. `show services stateful-firewall packets`
   c. `show services stateful-firewall session`
   d. `show services stateful-firewall flows bidirectional`

5. Which feature of an IPSec VPN allows for confidentiality of data?
    a. IKE
    b. MD5 hashes
    c. AES encryption
    d. Sequence numbers
6. What type of load balancing is used across MLPPP links for fragmented traffic?
    a. Per packet
    b. Per flow
    c. Per fragment
    d. Per port
7. If fragmentation is turned on for MLPPP, what type of load balancing would occur for unfragmented packets?
    a. Per packet
    b. Per flow
    c. Per fragment
    d. Per port
8. Which feature will help to lower latency of voice traffic on a point-to-point link?
    a. CHAP
    b. Codecs
    c. RTP
    d. CRTP
9. If traffic was arriving on the outside interface of a service set, for which direction would the rule be configured?
    a. `input`
    b. `output`
    c. `bi-directional`
    d. `no-direction`
10. Which feature would allow traffic to be skipped in a service set?
    a. Post-service filter
    b. Firewall filter
    c. Service filter
    d. Service skipping
11. Which type of service PIC can be integrated on an M7i?
    a. ASM
    b. ASP

    c. Monitoring Services
    d. Hardware acceleration

12. How is traffic chosen to be compressed when configuring CRTP? (Choose two.)
    a. IP address
    b. Port numbers
    c. Packet size
    d. Queue

Chapter Review Answers

1. Answer: D. FRF.16 allows bonding of physical interfaces together, whereas FRF.15 bonds multiple DLCIs together.
2. Answer: B. The only way to service multicast traffic is to use a next hop service set. Interface-style service sets ignore multicast traffic.
3. Answer: False. Some PICs will use an `lsq` interface, and others will use an `ls` interface. `lsq` allows for more CoS features than `ls`.
4. Answer: A. In JUNOS software, a session is referred to as a conversation, which is a flow in each direction.
5. Answer: C. To achieve data confidentiality, you should encrypt the traffic. One algorithm you can use to encrypt traffic is AES.
6. Answer: C. When MLPPP is enabled, packets will be sent down each link on a per-fragment basis. Since each packet fragment will have an MLPPP header with a sequence number, order will be maintained by the end device.
7. Answer: B. If fragmentation does not occur on an MLPPP link, the packets are balanced over a flow (source IP, destination IP, protocol, etc.). Since nonfragmented packets will not contain an MLPPP header, per flow is the only way to maintain packet order.
8. Answer: D. Compressed RTP decreases the header size to a few bytes, which reduces serialization and queuing delay.
9. Answer: B. Traffic arriving on the outside service interface will be in the output direction. Traffic arriving on the inside service interface will be in the input direction.
10. Answer: C. You can apply a service filter to an interface with an action of `skip` to allow traffic to pass any service rules.
11. Answer: A. You can integrate ASM into an M7i router only. For other M-series routers, you must install a physical PIC into a slot.
12. Answer: B, D. Traffic can be classified for RTP compressed based on port numbers or based on which queue a packet was placed into. If both match conditions are configured, a packet will be compressed if either condition is met.

CHAPTER 8

Advanced JUNOS Services

We discussed the framework for JUNOS services in Chapter 7. This chapter will dive into more advanced scenarios and configurations. Often, you will need to use many Layer 3 services simultaneously, such as Network Address Translation (NAT), stateful firewall, and IPSec virtual private networks (VPNs), so you must plan properly to create transparent service additions.

The topics we will cover in this chapter include:

- Route tables and next hop service sets
- IPSec VPNs
- NAT
- Combined Layer 3 services
- Packet flow

This chapter assumes that the reader grasps the concepts discussed in the preceding chapter; specifically, the types of service sets and command-line interface (CLI) configurations. If these concepts are unfamiliar, please review the preceding chapter.

Route Tables and Next Hop Service Sets

When using a next hop service set, remember that the packet must go through the "two-legged table" of the inside and outside interfaces. Regardless of which interface the packet enters, two route table lookups will always be performed. To avoid a routing loop, the pre- and post-service lookups must return different next hop values. You can accomplish this in a few ways:

- Implement virtual routers (VRs)
- Use filter-based forwarding (FBF)
- Perform destination NAT to change the destination address

VRs are the most preferred method, followed by FBF and destination NAT. VRs and FBF solve the double next hop issue by using multiple route tables, whereas destination NAT attempts to use a single route table.

With destination NAT, the forward direction can be fairly cut and dried, as Figure 8-1 demonstrates; simply perform a lookup on the original destination address, which causes the packet to be serviced, and then change the destination address and perform a second lookup on the new destination address to be used for forwarding. Issues arise in the reverse direction, where the destination address would normally stay the same. In this case, you would have to use a method such as FBF to solve this problem.

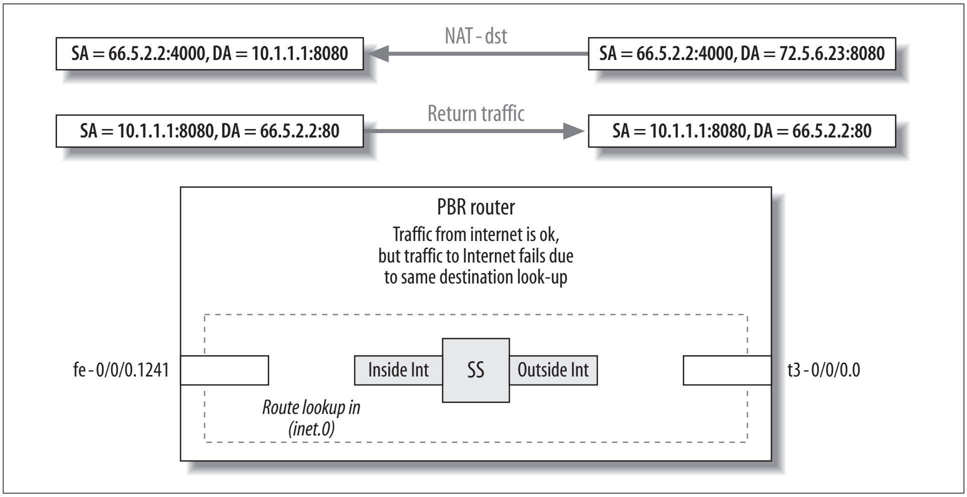

NAT - dst
SA = 66.5.2.2:4000, DA = 10.1.1.1:8080
SA = 66.5.2.2:4000, DA = 72.5.6.23:8080
Return traffic
SA = 10.1.1.1:8080, DA = 66.5.2.2:80
SA = 10.1.1.1:8080, DA = 66.5.2.2:80
PBR router
Traffic from internet is ok,
but traffic to Internet fails due
to same destination look-up
fe - 0/0/0.1241
Inside Int
SS
Outside Int
t3 - 0/0/0.0
Route lookup in
(inet.0)

Figure 8-1. Destination NAT

FBF uses JUNOS software packet filters to redirect traffic to a new route table. These filters are applied to a physical interface to match traffic that should be serviced. This traffic is then sent to a new route table containing a route, which causes the traffic to be serviced (see Figure 8-2). The problem with FBF is that the configuration can be complex and not as scalable or secure as VRs.

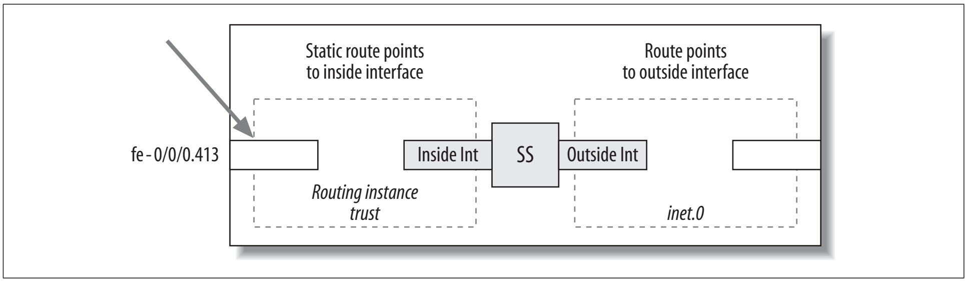


Figure 8-2. FBF

The first step when using FBF is to create a *routing instance*. A routing instance is simply a way to create a new route table. The properties of the route table will depend on the instance type (forwarding, nonforwarding, Virtual Route and Forwarding [VRF], VR, etc.). Instance types include:

Forwarding
: Used for FBF applications when a route table and forwarding table are required.

l2vpn
: Used to create Kompella-based Border Gateway Protocol/Multiprotocol Label Switching (BGP/MPLS) VPNs.

Nonforwarding
: Used when a separation of routing information is required. Sometimes it is used to monitor certain prefixes by an NMS system.

VR
: Used to create a local VPN, with local interfaces and protocols.

VRF
: Used to create Layer 3 BGP/MPLS VPNs.

The instance is named, which creates the name of the route table with the format `<instance name>.inet.0`. In this case, we create a forwarding instance of type `forwarding`, which creates a route and a forwarding table for the instance:

```
lab@PBR# set routing-instances example instance-type forwarding
```

Next, create the filter to match which traffic should be serviced and sent to the new table. In this case, external traffic destined for 128.3.3/24 will be sent to the instance example. It is vital not to forget about the default behavior of a filter, which is to deny all traffic at the end of processing. This could cause major problems on the interface for internal transit traffic, so make sure you always have additional terms that allow this traffic. The `filter match-outbound term 2` allows all other traffic through the interface for route lookups in the default route table, `inet.0`:

```
lab@PBR# show firewall
family inet {
    filter match-outbound {
        term 1 {
            from {
                destination-address {
                    128.3.3.0/24;
                }
            }
            then routing-instance example;
        }
        term 2 {
            then accept;
        }
    }
```

Apply the filter to the interface where incoming traffic needs to be matched, such as a LAN interface:

```
lab@PBR# show interfaces fe-0/0/0 unit 1241
description PBR_to_Bock;
vlan-id 1241;
family inet {
    filter {
        input-list match-outbound;
    }
    address 10.20.130.2/24;
}
```

So far, we've covered the easy part, but now things get a bit trickier as we enable routing. When traffic enters the new `example.inet.0` table, it should be sent to an `sp-` service interface to be serviced. To do this, you should add static routes to the routing instance. This could be in the form of a series of static routes or a default, as needed:

```
[edit routing-instances example]
lab@PBR# show
instance-type forwarding;
routing-options {
  static {
    route 0.0.0.0/0 next-hop sp-0/0/0.1;
  }
}
```

If only the required configuration would end there—but it continues. For any static route to be active in a route table, the next hop value must be reachable in that route table. Since the route points to the service interface `sp-0/0/0.1`, we must ensure that the interface is in the `example.inet.0` route table. To accomplish this, we must copy the route from the `inet.0` table to the `example.inet.0` table, which is implemented in a concept called *rib-groups*.

> Over the years, many network engineers have struggled with the rib-group concept. Rib-groups are often difficult to understand. They are even harder to explain even if you think you actually understand the concept. In current JUNOS code, there are many ways to avoid the use of rib-groups, such as using VRs, which is one of the reasons FBF is not the preferred approach.

The first rule for a rib-group is the local logical grouping definition that defines which tables will be able to share routes. These definitions are spelled out in the `[edit routing-options]` stanza. The rib-group will be named, as it will need to be referenced later. In this case study, we define a rib-group called `test` to share the `sp-0/0/0.1` interface in `inet.0` and `example.inet.0`. Here is the result:

```
[edit routing-options]
lab@PBR# show
rib-groups {
  test {
      import-rib [ inet.0 example.inet.0 ];
  }
}
```

After the rib-group is defined, we must configure which information is actually placed into the rib-group. In other words, we must decide whether Open Shortest Path First (OSPF), BGP, static routes, interface routes, and so on are going to be shared. To have the sp- interface shared, we need to apply interface routes to the test rib-group:

```
[edit routing-options]
lab@PBR# set interface-routes rib-group inet test
```

The issue that arises with this command is that *all* interface routes in inet.0 will be placed into example.inet.0 when only the sp- interface is required. To allow only that interface to be copied from inet.0, we must configure a policy and apply it to the rib-group. The policy should send the sp-0/0/0.1 interface to the correct table and deny all other routes from being moved:

```
}
policy-statement inside-interface {
    term service {
        from interface sp-0/0/0.1;
        to rib example.inet.0;
        then accept;
    }
    term reject {
        then reject;
    }
}
```

Once we apply the policy to the rib-groups, the route table will contain one default route that points to the service interface. Here is the final result after the policy is applied:

```
[edit routing-options]
lab@PBR# show
interface-routes {
  rib-group inet test;
}
rib-groups {
  test {
      import-policy inside-interface;
      import-rib [ inet.0 example.inet.0 ];
  }
}
```

Using rib-groups and FBF usually results in a maximum use of brain-cell capacity. To reduce the number of brain cells being used and reserve them to concentrate on other things, try the preferred method for next hop service sets: VRs. VRs provide the cleanest, easiest, most scalable, and more secure solution. By using VRs, you can align with the *security zone* concept, in which interfaces are placed within certain logical zones (we will outline this zone concept in more detail in Chapter 11). In the case of a router, a zone is actually a new route table, so when a packet hits an interface in a zone (VR), a table lookup is performed in that VR. The most basic case would be two VRs—a trust VR for LAN interfaces and an untrust VR for WAN interfaces (see Figure 8-3).

Every router always contains one default VR called the *default VR*. In JUNOS software, this is represented by the route table `inet.0`. When creating two VRs, you can either create two new "trust" or "untrust" VRs or use the default VR as one of the VRs.

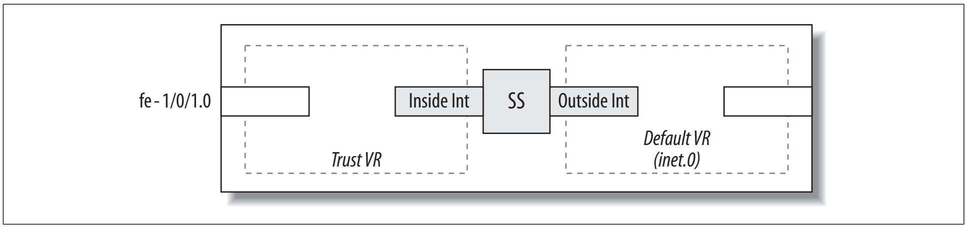


Figure 8-3. The VR concept

The VR concept can extend to as many VRs as needed. For example, some external servers may have special services applied to them that don't fall into a trust or untrust category. This third category is often referred to as the *demilitarized zone* (DMZ). Figure 8-4 illustrates the three-category setup.

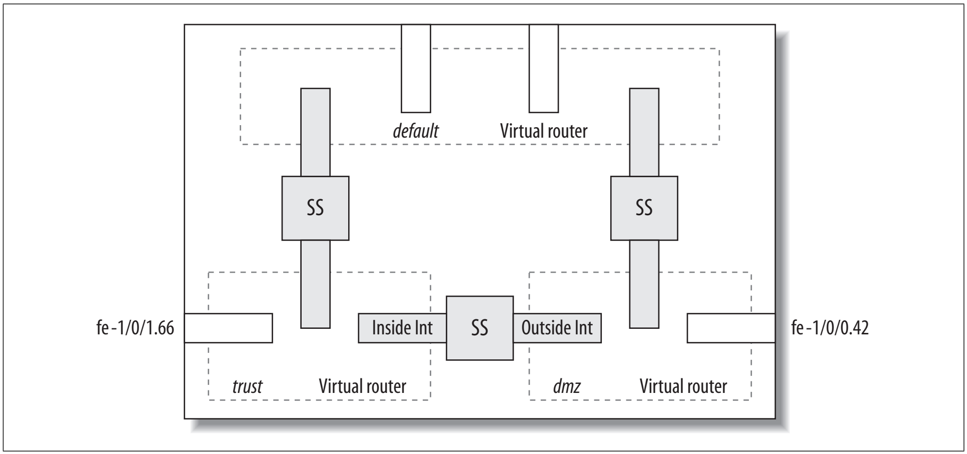


Figure 8-4. Three-zone VRs

A large advantage of a VR is the fact that rib-groups and firewall filters are avoided since interfaces are now tied to the routing instance and are placed in the instance's route table. As a result, traffic arriving over the applied interface automatically has a route lookup performed in the instance's route table. VRs also allow routing protocols to be configured to automatically populate the route table. This actually creates a new process or instance of that protocol, so the standard `show` commands must be followed by the instance switch. More to the point, if a VR called trust was configured with OSPF, a show ospf neighbor instance trust would be issued in order to view the OSPF neighbors. As in Figure 8-3, a VR trust is going to be configured with LAN interface fe-1/0/1 and inside service interfaces of sp-0/0/0.1 and lo0.1:

```
routing-instances {
   trust {
      instance-type virtual router
      interface sp-0/0/0.1;
      interface fe-1/0/1.0;
      interface lo0.1;

}
```

The lo0.1 interface is created for routing protocol use in a VR. When a new logical interface is configured on the loopback interface, it must be applied to a routing instance to avoid commit failures.

Next, routing is configured to send traffic to the service interface for servicing (the stateful firewall, NAT, intrusion detection service [IDS], etc.). Similar to FBF, a static default route is used with a next hop value of the service interface. Also, OSPF is enabled on the LAN Fast Ethernet interface. Here is the result of the entire VR configuration:

```
routing-instances {
   trust {
      instance-type virtual router
      interface sp-0/0/0.1;
      interface fe-1/0/1.0;
      interface lo0.1;
      routing-options {
         static {
            route 0.0.0.0/0 next-hop sp-0/0/0.1;
         }
      }
      protocols {
         ospf {
            area 0.0.0.0 {
               interface fe-1/0/1.0;
            }
         }
      }
   }
```

The FBF and Virtual Router example shows traffic in only one direction. Additional routes for return traffic may need to be created to the outside interface depending on the type of service.

Compared to FBF, the VR configuration should let you sleep much easier at night due to its simplicity. The next hop service set examples that follow utilize the preferred VR solution.

Summary of Route Tables and Next Hop-Style Service Sets

When using the flexible next hop-style service set, you must consider multiple route table lookups. Due to the multiple lookup requirement, a unique result must be present in each lookup iteration. You can accomplish this by using destination NAT, FBF, or VRs. The recommended method, and the foundation for the remaining chapters, is to use VRs.

In the next section, we will look at one of the common services used in enterprise networks today: IPSec VPNs.

IPSec VPNs

IPSec VPNs, as discussed in Chapter 7, tunnel IP traffic across an IP network to provide security features such as data privacy and integrity. When building an IPSec tunnel, you must decide on a few parameters:

- Protocol (Encapsulating Security Payload [ESP], authentication header [AH], or Bundle)
- Encryption algorithm (Advanced Encryption Standard [AES], Data Encryption Standard [DES], Triple DES [3DES], or none)
- Authentication algorithm (Message Digest 5 [MD5], Secure Hash Algorithm [SHA-1])
- Perfect forward secrecy (on/off)
- Anti-replay (on/off)

Together, these parameters form a *proposal*. The proposal must be equivalent on each side of the tunnel for the tunnel to become established. These proposals can be statically configured or dynamically negotiated using the Internet Key Exchange (IKE) protocol. Static proposals are rarely used, as they are cumbersome to manage, prone to error, and difficult to change on the fly. IKE uses a method of key exchanges to exchange parameters in a secure manner over two phases. Phase 1 establishes the parameters needed to exchange information to form a secure IPSec tunnel. Phase 2 establishes the actual security parameters for that IPSec tunnel. When viewing commands on the router, Phase 1 is seen as an IKE security association, and Phase 2 is seen as an IPSec security association.

Since multiple tunnels can be established between two peers, there has to be some way to identify which packets belong to each tunnel. To do this, a database is created with entries called security associations (SAs) for each tunnel. An SA identifies each tunnel by the following parameters:

- Destination IP address
- Security protocol and parameters (protocol, encryption, and authentication)
- Security Parameter Index (SPI)
- Secret keys

> IPSec theory is beyond the scope of this book; we focus instead on network implementation and design. Please consult O'Reilly dedicated IPSec books for more information on the specifics of ESP, AH, encryption, and IKE.

Minimum IPSec Tunnel Configuration

When configuring an IPSec tunnel, as with all Layer 3 services, you will need a service set. These service sets contain the rules for matching traffic that should transit the IPSec tunnel. The rules can include policies that link the various proposals that the tunnel will use (see Figure 8-5). There can be separate policies and proposals for the Phase 1 (IKE) and Phase 2 (IPSec) SAs.

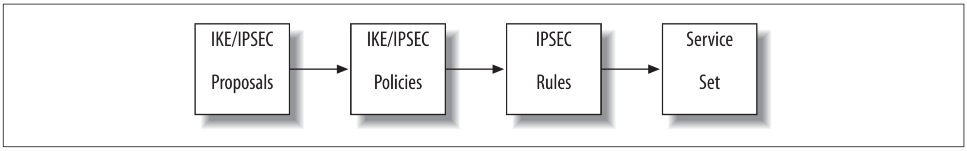


Figure 8-5. IPSec rule, policy, and proposal relationships

`PBR` is going to form an IPSec tunnel with the extranet `Cans` for traffic to a 128.3.3/24 address block to secure traffic (see Figure 8-6). The remote endpoint of the tunnel is 128.3.3.4 and the local address on `PBR` is 172.16.1.2. `PBR` is learning the 123.3.3/24 subnet via BGP with `Wheat`.

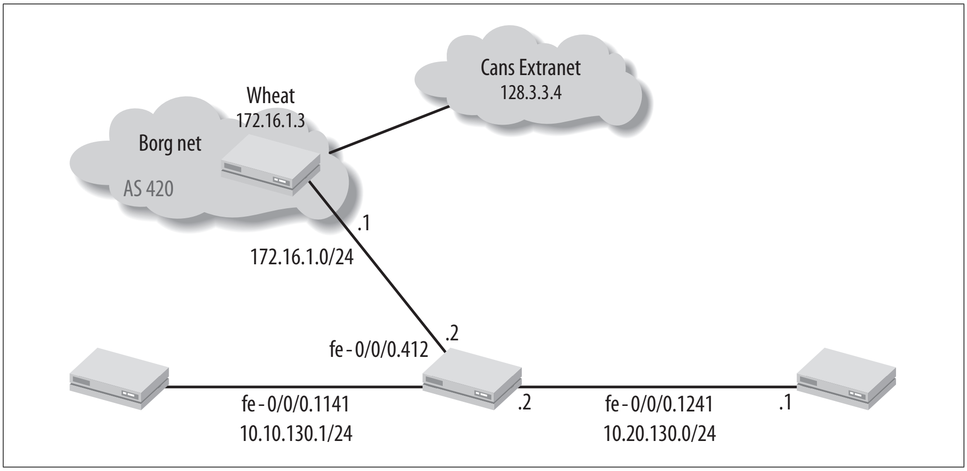


Figure 8-6. Sample topology

The tunnel will be set up with the default parameters shown in Table 8-1.

Table 8-1. Default parameters for tunnel

	IKE	IPSec
Mode	Main	N/A
Protocol	N/A	ESP
Encryption	3DES-CBC (cipher block chaining)	3DES-CBC
Authentication	SHA-1	Hashed Message Authentication Code (HMAC)-SHA-1-96
Lifetime	3,600 seconds	28,800 seconds
Additional options	N/A	Antireplay, no Perfect Forward Secrecy (PFS) protocol

Interface-style service set

First we will implement the tunnel as an interface-style service set and then as a next hop service set. Begin by creating the service interface to use for the interface-style service set:

```
[edit interfaces]
lab@PBR# set sp-0/0/0 unit 0 family inet
```

Now create the rule to match traffic sent to the tunnel and, minimally, an IKE policy to be applied. An IKE policy referencing either a preshared key or a certificate is required, and IPSec policies are optional. With this configuration, the tunnel will inherit the default parameters listed in Table 8-1:

```
[edit services ipsec-vpn]

ike {
        policy min-policy {
            pre-shared-key ascii-text "$9$BSJ1RSdVYJUH8XGDHkPfIEh";
## SECRET-DATA
        }
    }
```

Create the IPSec VPN rule to match on the required traffic and send it through the tunnel toward the endpoint. The IKE policy will also need to be applied, along with a direction in which to *encrypt* traffic:

```
lab@PBRt# show services
ipsec-vpn {
   rule secure-extranet {
      term 1 {
        from {
           destination-address {
             128.3.3.0/24;
           }
        }
        then {
          remote-gateway 128.3.3.4;
          dynamic {
            ike-policy min-policy;
         }
      }
   }
   match-direction output;
}
   }
```

The router automatically created bidirectional SAs, so when specifying traffic to be secured in the outbound direction, the router automatically secures the inbound direction. This means that when specifying an interface-style service set, the output direction is generally used, whereas a next hop-style service set will use the input direction.

Next, we need to create the service set that maps the IPSec rule and the service interface. Additionally, we need to configure the local gateway for the IPSec tunnel. This will be the address used to source all IPSec packets as well as the address to which the remote tunnels will connect. You can have only a single gateway address in a service set, but you can configure multiple remote gateways in the IPSec rules.

```
[edit services]
lab@PBR# show service-set basic-vpn
interface-service {
    service-interface sp-0/0/0.0;
}
ipsec-vpn-options {
    local-gateway 172.16.1.2;
}
ipsec-vpn-rules secure-extranet;
```

Apply the service set to the tunnel's outbound interface:

```
lab@PBR# top show interfaces fe-0/0/0 unit 412
description PBR-to-Wheat;
vlan-id 412;
family inet {
    service {
        input {
            service-set basic-vpn;
        }
        output {
            service-set basic-vpn;
        }
    }
    address 172.16.1.2/24;
```

After committing the configuration, you can view the tunnel status with the `show service ipsec` command. In this case, the tunnel appears to be down, as no Phase 2 SAs appear:

```
lab@PBR# run show services ipsec-vpn ipsec security-associations
Service set: basic-vpn
```

```
    Rule: secure-extranet, Term: 1, Tunnel index: 1
    Local gateway: 172.16.1.2, Remote gateway: 128.3.3.4
    Tunnel MTU: 1500

    --- No IPSec SA information available ---
```

Issuing a ping to the remote gateway address of 128.3.3.4 on PBR indicates the problem:

```
lab@PBR# ping 128.3.3.4
PING 128.3.3.4 (128.3.3.4): 56 data bytes
ping: sendto: No route to host
ping: sendto: No route to host
ping: sendto: No route to host
ping: sendto: No route to host
^C
--- 128.3.3.4 ping statistics ---
4 packets transmitted, 0 packets received, 100% packet loss
n
```

Recall that the 128.3.3/24 network was learned via BGP. When viewing the BGP neighbor status toward Wheat, the session appears to be down, as seen by the connect state:

```
lab@PBR# run show bgp summary
Groups: 1 Peers: 1 Down peers: 1
Table   Tot Paths  Act Paths Suppressed  History Damp State  Pending
inet.0          0          0          0        0          0        0
Peer          AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
172.16.1.1    420     198       184     0      7        6:30 Connect
```

The BGP session is down because the service set is applied to the session's interface. Remember that once a service set is applied to an interface, any traffic that does not match the term is serviced by default. To avoid this problem, you should apply a service filter to skip the procession of BGP traffic. The default action of a service filter is skip, so make sure other traffic is serviced accordingly:

```
[edit firewall]
lab@PBR# show
family inet {
    service-filter allow-bgp {
        term 1 {
            from {
                protocol tcp;
                port bgp;
            }
            then skip;
        }
    }
        term 2 {
            then service;
        }

}
```

Apply the service filter to the interface in both directions:

```
lab@PBR# top show interfaces fe-0/0/0 unit 412
description PBR-to-Wheat;
vlan-id 412;
family inet {
    service {
        input {
            service-set basic-vpn service-filter allow-bgp;
        }
        output {
            service-set basic-vpn service-filter allow-bgp;
        }
    }
    address 172.16.1.2/24;
```

After the service filter has been applied, the BGP session and the IPSec tunnel will become established. Verify the tunnel using the `show services ipsec` command. First, verify Phase 1, ensuring that the state is matured:

```
[edit firewall family inet service-filter allow-bgp]
lab@PBR# run show services ipsec-vpn ike security-associations
Remote Address  State         Initiator cookie  Responder cookie
Exchange type
128.3.3.4       Matured       773036d8a2d22e7b  ef23082150245a03
Main
```

Often, an operator will view the IKE SA, and when nothing appears, the operator will assume that the IPSec tunnel is down. This is not always the case, as IKE associations appear only on an "as needed" basis. So, if the IPSec SA has been established, the IKE SA may time out. Using default parameters, the lifetime of an IKE SA is 3,600 seconds and the lifetime of IPSec is 28,800 seconds, which means that a stable network may not have an active IKE SA for up to 7 hours! Make sure that if any changes occur that could prevent two-way IKE communication between the remote peers, the IPSec SA is cleared to force a renegotiation of the IKE SA. Otherwise, a filter-blocking IKE message may not been seen for several hours before the IPSec SA reaches its lifetime.

Now verify that Phase 2 has an inbound and outbound SA for bidirectional traffic flows:

```
[edit firewall family inet service-filter allow-bgp]
lab@PBR# run show services ipsec-vpn ipsec security-associations
Service set: basic-vpn

  Rule: secure-extranet, Term: 1, Tunnel index: 1
  Local gateway: 172.16.1.2, Remote gateway: 128.3.3.4
  Tunnel MTU: 1500
    Direction SPI         AUX-SPI     Mode       Type     Protocol
    inbound   2579118494  0           tunnel     dynamic  ESP
    outbound  247425684   0           tunnel     dynamic  ESP
```

> By default, the establishment of an IPSec tunnel is data-driven. This means that the tunnel is not established until a packet matches a rule that requires the tunnel. If you want to change this behavior, use the `establish-tunnels immediately` command.

When IPSec is deployed on the router, the router must know how to direct traffic to the service Physical Interface Card (PIC) or service module to authenticate, de-encrypt, and de-encapsulate the packet. The router accomplishes this by creating forwarding table entries based on the source IP address, destination IP address, and protocol tuple. These entries will be seen as /72s in the forwarding table with a next hop of service:

```
[edit firewall family inet service-filter allow-bgp]
lab@PBR# run show route forwarding-table | find /72
172.16.1.2.128.3.3.4.50/72
                   user    0             service   324    3
172.16.1.2.128.3.3.4.51/72
                   user  0            service   324   3
172.16.1.3/32      user  0 172.16.1.1    ucst   332   5 fe-0/0/0.412
172.16.1.255/32    dest  0 172.16.1.255  bcst   320   1 fe-0/0/0.412
224.0.0.0/4        perm  1               mdsc    13   1
224.0.0.1/32       perm  0 224.0.0.1     mcst     9   3
224.0.0.5/32       user  1 224.0.0.5     mcst     9   3
255.255.255.255/32 perm  0               bcst    10   1

Routing table: __juniper_private1__.inet
Internet:
Destination        Type RtRef Next hop      Type Index NhRef Netif
default            perm     0               rjct    62     1
10.0.0.1/32        intf     1 10.0.0.1      locl   321     2
10.0.0.16/32       intf     0 10.0.0.16     locl   322     1
224.0.0.0/4        perm     0               mdsc    61     1
224.0.0.1/32       perm     0 224.0.0.1     mcst    57     1
255.255.255.255/32 perm     0               bcst    58     1
```

The consequence of these entries, if you are using an interface-style service set, is that traffic received on any interface, regardless of where the service set is applied, will be serviced.

Next hop-style service set

The same IPSec VPN is now implemented using a next hop-style service set. As with every next hop-style service set, you must configure the two “legs” of the inside and outside service sets:

```
sp-0/0/0 {
    unit 0 {
        family inet;
    }
    unit 1 {
        family inet;
        service-domain inside;
    }
    unit 2 {
        family inet;
        service-domain outside;
    }
}
```

Then you need to create the IPSec rules. These rules will look the same as they did in the previous example using interface-style service sets, with one notable exception: *rule direction*. Since traffic is going to be mapped to the inside interface for encryption, a match-direction of input should be used:

```
ipsec-vpn {
    rule secure-extranet {
        term 1 {
            from {
                destination-address {
                    128.3.3.0/24;
                }
            }
            then {
                remote-gateway 128.3.3.4;
                dynamic {
                    ike-policy min-policy;
                }
            }
        }
        match-direction input;
    }
```

Now traffic is mapped to the inside service interface to be encrypted in the IPSec tunnel. You can accomplish this mapping in a variety of ways; the simplest is with a static route:

```
lan@PBR set routing-options static route 128.3.3/24 next-hop sp-0/0/0.1
```

After committing the configuration and sending traffic from Bock to the extranet 128.3.3/24 subnet, the IKE and IPSec SAs are created:

```
[edit]
lab@PBR# run show services ipsec-vpn ike security-associations
Remote AddressState   Initiator cookie Responder cookie Exchange type
128.3.3.4      Matured 833d31c69f915b75 4326d4b9c69e624f Main


lab@PBR# run show services ipsec-vpn ipsec security-associations
Service set: basic-vpn

  Rule: secure-extranet, Term: 1, Tunnel index: 1
  Local gateway: 172.16.1.2, Remote gateway: 128.3.3.4
  IPSec inside interface: sp-0/0/0.1, Tunnel MTU: 1500
    Direction SPI         AUX-SPI     Mode       Type     Protocol
```

```
        inbound   612210302   0          tunnel     dynamic  ESP
        outbound  1652494959  0          tunnel     dynamic  ESP
```

Also verify that the traffic from `Bock` to the extranet is actually being encrypted *and* decrypted by viewing the IPSec statistics:

```
lab@PBR# run show services stateful-firewall ipsec-vpn ipsec statistics
PIC: sp-0/0/0, Service set: basic-vpn

ESP Statistics:
  Encrypted bytes:            4400
  Decrypted bytes:            5336
  Encrypted packets:            50
  Decrypted packets:            63
AH Statistics:
  Input bytes:                   0
  Output bytes:                  0
  Input packets:                 0
  Output packets:                0
Errors:
  AH authentication failures: 0, Replay errors: 0
  ESP authentication failures: 0, ESP decryption failures: 0
  Bad headers: 0, Bad trailers: 0
```

The interface-style service set requires a service filter to allow the external BGP session to be established; however, these filters do not exist in next hop-style service sets, nor are they required. Simply ensure that only traffic that should be serviced is mapped to the service interface.

Besides the usual `show` command to troubleshoot IPSec tunnels, you also can configure IKE traceoptions via `set services ipsec-vpn traceoptions flag ike`. These messages are automatically placed into a file called *kmd*.

Unique Proposals

You can create a variety of different proposals for both the IKE and IPSec negotiations. You can change these values from the default values based on security constraints and objectives, or simply for interoperability with other vendors. Recall from the beginning of the chapter that we mentioned the link between proposals and policies: proposals link to policies, which link to IPSec rules. When viewing the default parameters, the keen observer will notice that not all of the strongest authentication, encryption, and keys are being used. There are two reasons for this: interoperability and memory usage. It makes sense to create default parameters that most vendors and systems can support. Also, as the algorithms become more complex and the keys larger, the memory and CPU required also increase. This creates a very delicate balance between desired algorithms and performance. We must examine the memory usage when creating an IPSec tunnel with very minimal traffic flow:

```
[edit services ipsec-vpn]
lab@PBR# run show services service-sets memory-usage
Interface   Service Set                              Bytes Used
sp-0/0/0    basic-vpn                                      4310

[edit services ipsec-vpn]
lab@PBR# run show services service-sets summary
             Service sets                            CPU
Interface  configured       Bytes used Policy bytes used  utilization
sp-0/0/0             1 4392 ( 0.03 %)    1764 ( 0.00 %)       0.00 %
```

Now create unique IKE and IPSec policies and see how they affect memory usage. The IKE proposal is going to use the strongest values and the largest keys possible:

```
[edit services ipsec-vpn
lab@PBR# show ike
proposal unique-ike {
    authentication-method pre-shared-keys;
    dh-group group2;
    authentication-algorithm sha-256;
    encryption-algorithm aes-256-cbc;
}
```

Then the proposal is linked to the policy, and a preshared key is configured:

```
[edit services]
lab@PBR show ike | find policy
    policy unique-ike-policy {
        proposals unique-ike;
        pre-shared-key ascii-text "$9$Tz9peK8N-wO17VbsJZz36ApBEclKWLREVw"; ## SECRET-
DATA
    }
}
```

An IPSec proposal is also created with the strongest algorithms possible:

```
[edit services]
lab@PBR# show | find ipsec
ipsec {
    proposal unique-ipsec {
        authentication-algorithm hmac-sha1-96;
        encryption-algorithm aes-256-cbc;
    }
```

Then the proposals are linked to an IPSec policy. This policy also enables PFS:

```
    policy unique-ipsec-policy {
        perfect-forward-secrecy {
            keys group2;
        }
        proposals unique-ipsec;
    }
}
```

> PFS is a method that creates new keys that are not mathematically related to each other. This creates an additional level of security in case a security key is compromised.

Apply the new policies to an IPSec rule in the action statement:

```
lab@PBR# show rule secure-extranet
term 1 {
    from {
        destination-address {
            128.3.3.0/24;
        }
    }
    then {
        remote-gateway 128.3.3.4;
        dynamic {
            ike-policy unique-ike-policy;
            ipsec-policy unique-ipsec-policy;
        }
    }
}
match-direction input;
```

Once the tunnel is up, you can view the parameters when using the detailed or extensive switch on the SA commands:

```
[edit services ipsec-vpn]
lab@PBR# run show services ipsec-vpn ike security-associations detail
IKE peer 128.3.3.4
  Role: Initiator, State: Matured
  Initiator cookie: 38d4aa648ce7b6b5, Responder cookie: e39275d71141441d
  Exchange type: Main, Authentication method: Pre-shared-keys
  Local: 172.16.1.2:500, Remote: 128.3.3.4:500
  Lifetime: Expires in 3587 seconds
  Algorithms:
   Authentication        : sha256
   Encryption            : aes-cbc (256 bits)
   Pseudo random function: hmac-sha256
  Traffic statistics:
   Input  bytes  :                772
   Output bytes  :                872
   Input  packets:                  4
   Output packets:                  5
  Flags: Caller notification sent
  IPSec security associations: 1 created, 0 deleted
  Phase 2 negotiations in progress: 1

    Negotiation type: Quick mode, Role: Initiator, Message ID: 533813962
    Local: 172.16.1.2:500, Remote: 128.3.3.4:500
    Local identity: ipv4_subnet(any:0,0.0.0.0/0)
    Remote identity: ipv4_subnet(any:0,[0..7]=128.3.3.0/24)
    Flags: Caller notification sent, Waiting for done
```

```
[edit services ipsec-vpn]
lab@PBR# run sh services ipsec-vpn ipsec security-associations
 extensive Service set: basic-vpn

   Rule: secure-extranet, Term: 1, Tunnel index: 1
   Local gateway: 172.16.1.2, Remote gateway: 128.3.3.4
   IPSec inside interface: sp-0/0/0.1, Tunnel MTU: 1500
   Local identity: ipv4_subnet(any:0,0.0.0.0/0)
   Remote identity: ipv4_subnet(any:0,[0..7]=128.3.3.0/24)

     Direction: inbound, SPI: 1138084291, AUX-SPI: 0
     Mode: tunnel, Type: dynamic, State: Installed
     Protocol: ESP, Authentication: hmac-sha1-96, Encryption: aes-cbc (256 bits)
     Soft lifetime: Expires in 28640 seconds
     Hard lifetime: Expires in 28775 seconds
     Anti-replay service: Enabled, Replay window size: 64

     Direction: outbound, SPI: 795324419, AUX-SPI: 0
     Mode: tunnel, Type: dynamic, State: Installed
     Protocol: ESP, Authentication: hmac-sha1-96, Encryption: aes-cbc (256 bits)
     Soft lifetime: Expires in 28640 seconds
     Hard lifetime: Expires in 28775 seconds
     Anti-replay service: Enabled, Replay window size: 64
```

How much additional processing was actually used? Viewing the memory usage after the more labor-intensive proposals were created shows a 4% increase from the default case. Adding a higher volume of traffic again increases these values:

```
lab@PBR# run show services service-sets memory-usage
Interface   Service Set                           Bytes Used
sp-0/0/0    basic-vpn                                   4454

[edit services ipsec-vpn]
lab@PBR# run show services service-sets summary
           Service sets                                CPU
Interface  configured       Bytes used Policy bytes used utilization
sp-0/0/0             1 4536 ( 0.03 %)    1764 ( 0.00 %)      0.00 %
```

Backup Tunnels

One application of an IPSec tunnel is for redundancy, if physical redundancy does not exist. You can establish a tunnel over another private network or over a public network, such as the Internet. In the case study shown in Figure 8-7, PBR, which is the WAN router for Internet connectivity, there is a single link to Stout. If that link fails, an IPSec tunnel will be used between PBR and Stout. This tunnel will actually be established over the path from the Water Internet service provider (ISP) to Hops.

First, you must configure the tunnel endpoints. They could be physical or loopback interfaces. For the purposes of this example, the tunnel from PBR to Stout is going to be established from PBR's WAN interface to Water (64.7.12.6) to Stout's loopback interface (10.20.128.4). PBR's physical interface was chosen for optimal path redundancy (i.e., to avoid the tunnel establishment via ISP Wheat). A simple IPSec VPN is

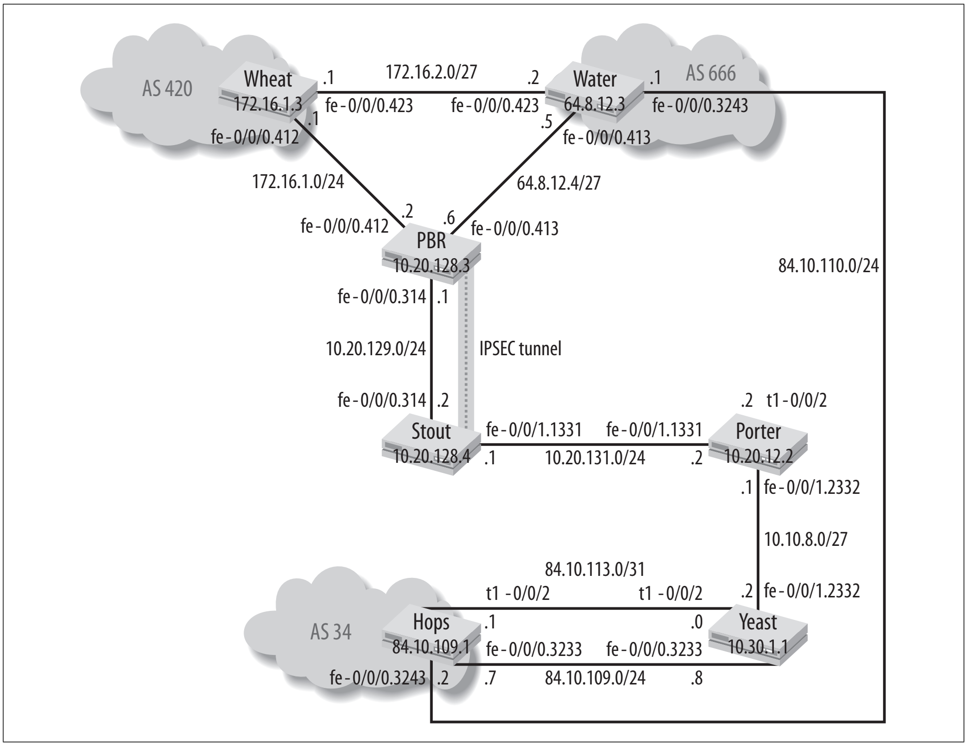


Figure 8-7. Backup tunnel

created using JUNOS default parameters on Stout. You must use a next hop-style service set since OSPF will be running over the IPSec tunnel:

```
lab@stout> show configuration services
service-set Basic-ipsec {
    next-hop-service {
        inside-service-interface sp-0/0/0.2;
        outside-service-interface sp-0/0/0.1;
    }
    ipsec-vpn-options {
        local-gateway 10.20.128.4;
    }
    ipsec-vpn-rules simple-rule;
}
ipsec-vpn {
    rule simple-rule {
        term 1 {
            from {
                source-address {
                    0.0.0.0/0;
                }
                destination-address {
                    0.0.0.0/0;
                }
            }
            then {
                remote-gateway 64.8.12.6;
                dynamic {
                    ike-policy basic-ike;
                }
            }
        }
        match-direction input;
    }
    ike {
        policy basic-ike {
            pre-shared-key ascii-text "$9$iqPQ/CuEclFnclKMN-Hqm";
## SECRET-DATA
        }
    }
    establish-tunnels immediately;
}

}
lab@stout> show configuration interfaces sp-0/0/0
unit 1 {
    family inet;
    service-domain outside;
}
unit 2 {
    family inet;
    service-domain inside;
}
```

The configuration is mirrored on router PBR with only the local gateway and remote gateway address-swapping. Notice two differences from previous examples. One is the open IPSec rule set of any address configured, as well as the `establish-tunnels immediately` keyword. These are used to speed up the failover process and avoid having to wait for the IPSec tunnel establishment.

```
lab@PBR# show services
service-set Basic-ipsec {
    next-hop-service {
        inside-service-interface sp-0/0/0.2;
        outside-service-interface sp-0/0/0.1;
    }
    ipsec-vpn-options {
        local-gateway 64.8.12.6;
    }
    ipsec-vpn-rules simple-rule;
}
ipsec-vpn {
    rule simple-rule {
        term 1 {
            from {
                source-address {
                    0.0.0.0/0;
                }
                destination-address {
                    0.0.0.0/0;
                }
            }
            then {
                remote-gateway 10.20.128.4;
                dynamic {
                    ike-policy basic-ike;
                }
            }
        }
        match-direction input;
    }
    ike {
        policy basic-ike {
            pre-shared-key ascii-text "$9$iqPQ/CuEclFnclKMN-Hqm";
## SECRET-DATA
        }
    }
    establish-tunnels immediately;
```

Also configure OSPF over the inside interface on Stout and PBR, in order to run OSPF over the IPSec tunnel:

```
[edit]
lab@stout# set protocols ospf area 0 interface sp-0/0/0.2

[edit]
lab@stout# commit
commit complete
```

Verify that OSPF is running over the tunnel. The tunnel is treated as a standard point-to-point interface in OSPF:

```
lab@stout# run show ospf neighbor
  Address          Interface       State    ID               Pri  Dead
10.20.129.2      fe-0/0/0.3141     Full    10.20.128.3      128    38
10.20.131.1      fe-0/0/1.1331     Full    10.10.12.2       128    31
10.20.128.3      sp-0/0/0.2        Full    10.20.128.3      128    32
```

Since the tunnel should be treated as a backup and not as an equal cost, increase the metric in the sp-0/0/0.2 interface to 1,000 on both Stout and PBR:

```
[edit]
lab@stout# set protocols ospf area 0 interface sp-0/0/0.2 metric 1000
```

Routing and verification for IPSec tunnels

Before you can test the IPSec tunnel, the proper routing has to be in place. First, the loopback address of Stout on PBR must point over ISP Water to be used during a failover. Also, you must create an aggregate route for the internal network and advertise it via BGP. Lastly, generate a default into OSPF if the link to Water is up.

```
[edit]
lab@PBR# show routing-options
static {
    route 10.20.128.4/32 next-hop 64.8.12.5;
}
aggregate {
    route 10.0.0.0/8;
}
generate {
    route 0.0.0.0/0 policy isp-routers;
}
autonomous-system 1282
```

Setting routes to the loopback of Bock may seem strange, so as an alternative you could configure an additional loopback address (nonprimary) for tunnel establishment and failover.

For completeness, the policy for the default generated route, the policy to export the generated route into OSPF, and the policy to advertise the internal autonomous system (AS) 1282 address block (10/8) are shown:

```
lab@PBR# show policy-options
policy-statement default-ospf {
    term 1 {
        from {
            protocol aggregate;
            route-filter 0.0.0.0/0 exact accept;
        }
    }
}
policy-statement isp-routers {
    term 1 {
        from {
            protocol bgp;
            neighbor 64.8.12.5;
        }
        then accept;
    }
    term 2 {
        then reject;
    }
}
policy-statement send-agg {
    from {
        route-filter 10.0.0.0/8 exact accept;
    }
    then accept;
}
```

Verify that the internal subnet is being advertised to Water via BGP:

```
[edit]
lab@PBR# run show route advertising-protocol bgp 64.8.12.5
```

```
inet.0: 701 destinations, 1389 routes (701 active, 0 holddown, 0
hidden)
  Prefix                  Nexthop     MED     Lclpref    AS path
* 10.0.0.0/8              Self                           I
```

When the physical Ethernet interface is up, all the OSPF routes point to the `fe-0/0/0.3141` interface since the IPSec tunnel is eliminated in the Shortest Path First (SPF) calculation.

```
lab#PBR> show route protocol ospf
inet.0: 701 destinations, 1389 routes (701 active, 0 holddown, 0
hidden)
+ = Active Route, - = Last Active, * = Both

10.10.8.0/27       *[OSPF/10] 00:12:32, metric 3
                    > to 10.20.129.1 via fe-0/0/0.3141
10.10.12.2/32      *[OSPF/10] 00:12:32, metric 2
                    > to 10.20.129.1 via fe-0/0/0.3141
10.10.128.1/32     *[OSPF/10] 01:59:30, metric 1
                    > to 10.10.130.1 via fe-0/0/0.1141
10.20.128.4/32      [OSPF/10] 00:12:32, metric 1
                    > to 10.20.129.1 via fe-0/0/0.3141
10.20.131.0/24     *[OSPF/10] 00:12:32, metric 2
                    > to 10.20.129.1 via fe-0/0/0.3141
10.30.1.1/32       *[OSPF/10] 00:12:32, metric 3
                    > to 10.20.129.1 via fe-0/0/0.3141
64.8.12.6/32        [OSPF/150] 00:12:32, metric 0, tag 0
                    > to 10.20.129.1 via fe-0/0/0.3141
224.0.0.5/32       *[OSPF/10] 23:30:31, metric 1
                      MultiRecv

__juniper_private1__.inet.0: 2 destinations, 2 routes (2 active, 0
holddown, 0 hidden)
```

As shown in Figure 8-7, router `Yeast` is connected to an ISP called `Hops`. `Yeast` is not running BGP, and instead relies on static routes due to its single-homed nature. To reach the WAN interface of `PBR` (64.8.12.6), you need to configure a static route pointing each T1 link toward the ISP:

```
lab@Yeast# show
static {
    route 64.8.12.6/32 next-hop [ 84.10.113.1 84.10.109.7 ];
}
autonomous-system 1282;
```

The problem is that if traffic is sourced from `PBR`'s WAN IP address of 64.8.12.6, it resolves over the default route redistributed in OSPF by `PBR`:

```
lab@stout# run show route 64.8.12.6

inet.0: 18 destinations, 18 routes (18 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/150] 00:21:45, metric 0, tag 0
                    > to 10.20.129.2 via fe-0/0/0.3141
```

This is OK when the physical link between PBR and Stout is up, but if the link goes down, Stout has no way to send traffic back to PBR for tunnel establishment. There are multiple ways to solve this issue, but we decided to redistribute the static route on Yeast into OSPF (policy send-static) instead of creating a static route on Stout and Porter. We did this to try to avoid a blackhole issue and have some dynamism by sending the 64.8.12.6 when a link from Yeast to Hops is in the "up" state.

```
lab@Yeast# top show protocols ospf
export send-static;
area 0.0.0.0 {
    interface fe-0/0/1.2332;
[edit]
```

After this change, Stout has a specific /32 route pointing toward Porter:

```
[edit]
lab@stout# run show route 64.8.12.6

inet.0: 18 destinations, 18 routes (18 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

64.8.12.6/32       *[OSPF/150] 00:26:58, metric 0, tag 0
                    > to 10.20.131.1 via fe-0/0/1.1331
```

Finally, verify that the correct routing is in place by sending some traceroutes from PBR. First verify that PBR can reach Stout's loopback via ISP routing:

```
[edit]
lab@PBR# run traceroute 10.20.128.4
traceroute to 10.20.128.4 (10.20.128.4), 30 hops max, 40 byte packets
 1  64.8.12.5 (64.8.12.5)  14.087 ms  9.459 ms  8.301 ms
 2  84.10.110.2 (84.10.110.2)  41.429 ms  29.842 ms  30.051 ms
 3  84.10.113.0 (84.10.113.0)  9.856 ms  9.521 ms  10.061 ms
 4  10.10.8.1 (10.10.8.1)  9.863 ms  12.269 ms  18.228 ms
 5  10.20.128.4 (10.20.128.4)  39.245 ms  99.785 ms  130.072 ms
```

Ensure that the traffic to other internal networks—in this case, Porter's loopback—takes the correct and shortest path through the internal network:

```
[edit]
lab@PBR# run traceroute 10.10.12.2
traceroute to 10.10.12.2 (10.10.12.2), 30 hops max, 40 byte packets
 1  10.20.129.1 (10.20.129.1)  14.160 ms  17.784 ms  11.653 ms
 2  10.10.12.2 (10.10.12.2)  29.985 ms  29.766 ms  9.955 ms
```

In summary, you must meet these criteria for failover to work properly:

- PBR must have a route to Stout's loopback over the ISP networks.
- PBR must advertise its internal network subnet to the ISP.
- Yeast must have a route to PBR's WAN address.
- Stout must have a route to PBR's WAN address not pointing directly to PBR.
- A default route must be generated by PBR as it is the preferred exit point for all Internet traffic.

Physical interface goes down!

Here is the big moment: interface failure on PBR and Stout. Was all the hard work and design worth it or was it a fruitless effort? First, verify that OSPF is still enabled over the IPSec tunnel:

```
[edit]
lab@PBR# run show ospf neighbor
  Address          Interface        State      ID            Pri  Dead
10.10.130.1      fe-0/0/0.1141    Full      10.10.128.1   128    31
10.20.128.4      sp-0/0/0.2       Full      10.20.128.4   128    36

[edit]
lab@PBR#
```

Next, verify that Stout has Internet connectivity by issuing a show route command on Water's link address to PBR. Notice that Stout is learning a default route over the IPSec tunnel. All appears good so far!

```
[edit]
lab@stout# run show route 64.8.12.5

inet.0: 16 destinations, 16 routes (16 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/150] 00:04:49, metric 0, tag 0
                    > via sp-0/0/0.2
```

Test internal connectivity from PBR by seeing whether Porter's loopback address is reached via the tunnel:

```
[edit]
lab@PBR> ping 10.0.12.2
PING 10.0.15.2 (10.0.15.2): 56 data bytes
64 bytes from 10.0.12.2: icmp_seq=0 ttl=64 time=0.221 ms
64 bytes from 10.0.12.2: icmp_seq=1 ttl=64 time=0.165 ms
^C
--- 10.0.15.2 ping statistics ---
2 packets transmitted, 2 packets received, 0% packet loss
round-trip min/avg/max/stddev = 0.165/0.193/0.221/0.028 ms
```

Lastly, verify that encrypted traffic is being sent and received over the IPSec tunnel:

```
lab@PBR# run show services ipsec-vpn ipsec statistics

PIC: sp-0/0/0, Service set: Basic-ipsec

ESP Statistics:
  Encrypted bytes:          144400
  Decrypted bytes:          127520
  Encrypted packets:          1850
  Decrypted packets:          1621
AH Statistics:
  Input bytes:                   0
  Output bytes:                  0
```

```
      Input packets:                 0
      Output packets:                0
    Errors:
      AH authentication failures: 0, Replay errors: 0
      ESP authentication failures: 0, ESP decryption failures: 0
      Bad headers: 0, Bad trailers: 0
```

Pat yourself on the back; the failover worked to perfection! Time to grab a beer (PBR me ASAP) and celebrate!

Dynamic IPSec Tunnels

So far, every IPSec tunnel used in this chapter has had static IP addresses on each side. What happens if the router is receiving requests from systems that have dynamic IPs? One such example would be a remote site with a cable modem receiving an address from the ISP via the Dynamic Host Configuration Protocol (DHCP). In this case, you could configure dynamic IPSec endpoints on the router with the static IP address (local router). The amazing thing about these dynamic tunnels is that there seems to be a magic man behind the curtain: the local router will automatically create the proper IPSec rules and static routes based on the incoming proxy information from the remote peer. The process is as follows:

1. The remote site (dynamic IP) initiates a connection with the local site (static IP).
2. The local router checks the incoming connection against the default proposals (see Table 8-2) or a list of custom proposals for Phase 1 on the connection process.
3. Phase 2 begins, and the local router verifies that the proxy ID (protected networks) of the remote system matches the allowed list. The default (0.0.0.0/0) matches any proxy ID sent.
4. After Phase 2 is completed, the `kmd` router process creates dynamic rules for encrypting traffic based on the received proxy ID. These rules are created for inside service interfaces so that they will always have a match direction of input.
5. Reverse Route Insertion (RRI) is performed. These are static routes for the remote protected networks and are automatically created to point to the inside interface. These routes are created only if the proxy ID is nondefault (0.0.0.0/0).

Table 8-2. Default IKE and IPSec proposals

Statement	Values
IKE	
Authentication method	Preshared keys
DH Group	Group 1 or Group 2
Authentication algorithm	SHA-1, SHA-256, MD5
Encryption algorithm	3DES-CBC, DES-CBC, AES-128, AES-192, AES-256
Lifetime	3,600 seconds

Table 8-2. Default IKE and IPSec proposals (continued)

Statement	Values
IPSec	
Protocol	ESP, AH, or Bundle
Authentication algorithm	HMAC-SHA-1-96, HMAC-MD5-96
Encryption algorithm	3DES-CBC, DES-CBC, AES-128, AES-192, AES-256
Lifetime	8 hours

To allow connection from dynamic peers, you need to configure an access profile and reference it in a service set. In the profile-specific client address, ranges are allowed, as are particular proxy IDs, proposals, and authentication using either preshared keys or RSA certificates. You also must configure the interface identifier, which will be used to map the remote router to a logical service interface. In the following example, PBR is configured to allow connections from any client (the * wildcard) using a preshared key for authentication and a proxy ID of 10/8 for local networks and 77.7.7/24 for remote networks. Since no proposals are specified, the default values are used. Lastly, an interface ID name of single-interface-id is tied to the profile.

```
[edit]
lab@PBR# show access
profile dynamic-peer {
    client * {
        ike {
            allowed-proxy-pair local 10.0.0.0/8 remote 77.7.7.0/24;
            pre-shared-key ascii-text "$9$Tz9peK8N-wO17VbsJZz36ApBEclKWLREVw"; ##
SECRET-DATA
            interface-id single-interface-id;
        }
    }
}
```

As with any other next hop service set, you will need to configure an inside and outside interface; however, an additional inside interface will also be used for the remote peer. This is the interface that the router will tie to each remote client. This logical interface could either be shared by multiple tunnels or dedicated per tunnel. In this case, unit 3 is defined for use with dynamic peers with the profile matching single-interface-id. This logical interface can be used by only a single tunnel due to the dedicated knob:

```
[edit]
lab@PBR# show interfaces sp-0/0/0
unit 0 {
    family inet;
}
unit 1 {
    family inet;
    service-domain inside;
}
unit 2 {
    family inet;
    service-domain outside;
}
unit 3 {
    dial-options {
        IPSec-interface-id single-interface-id;
        dedicated;
    }
    family inet;
    service-domain inside;
}
```

Lastly, a next hop-style service set is created that references an inside and outside interface, a local gateway, and the access profile. Note that no rules are applied to the service set since they are dynamically created after Phase 2 of IPSec is completed:

```
[edit]
lab@PBR# show services
service-set basic-vpn {
    next-hop-service {
        inside-service-interface sp-0/0/0.1;
        outside-service-interface sp-0/0/0.2;
    }
    ipsec-vpn-options {
        local-gateway 172.16.1.2;
        ike-access-profile dynamic-peer;
    }
}
```

A remote connection is initiated to PBR with the correct proposals and preshared key:

```
lab@PBR# run show services ipsec-vpn ike security-associations
detail
IKE peer 128.3.3.4
  Role: Responder, State: Matured
  Initiator cookie: 5f5d01b859c5500c, Responder cookie:
cbf493d41825e544
  Exchange type: Main, Authentication method: Pre-shared-keys
  Local: 172.16.1.2:500, Remote: 128.3.3.4:500
  Lifetime: Expires in 3130 seconds
  Algorithms:
   Authentication        : sha256
   Encryption            : aes-cbc (256 bits)
   Pseudo random function: hmac-sha256
  Traffic statistics:
   Input  bytes  :                 1312
   Output bytes  :                 1320
   Input  packets:                    7
   Output packets:                    7
  Flags: Caller notification sent
  IPSec security associations: 2 created, 0 deleted
  Phase 2 negotiations in progress: 0
```

After Phase 2, the proxy ID is verified, which is protecting the PBR local network of 10/8 and a remote network of 77.7.7/24. The _junos_ rule was automatically created for logical interface sp-0/0/0.3:

```
lab@PBR# show service ipsec-vpn ipsec security-associations extensive
Service set: basic-vpn

  Rule: _junos_, Term: tunnel1, Tunnel index: 1
  Local gateway: 172.16.1.2, Remote gateway: 128.3.3.4
  IPSec inside interface: sp-0/0/0.3, Tunnel MTU: 1500
  Local identity: ipv4_subnet(any:0,[0..7]=10.0.0.0/8)
  Remote identity: ipv4_subnet(any:0,[0..7]=77.7.7.0/24)

    Direction: inbound, SPI: 3948527911, AUX-SPI: 0
    Mode: tunnel, Type: dynamic, State: Installed
    Protocol: ESP, Authentication: hmac-sha1-96, Encryption: aes-cbc
(256 bits)
    Soft lifetime: Expires in 28411 seconds
    Hard lifetime: Expires in 28501 seconds
    Anti-replay service: Enabled, Replay window size: 64

    Direction: outbound, SPI: 1740456130, AUX-SPI: 0
    Mode: tunnel, Type: dynamic, State: Installed
    Protocol: ESP, Authentication: hmac-sha1-96, Encryption: aes-cbc
(256 bits)
    Soft lifetime: Expires in 28411 seconds
    Hard lifetime: Expires in 28501 seconds
    Anti-replay service: Enabled, Replay window size: 64
```

Also, reverse routes are automatically created to the remote networks using the logical interface to the next hop with the dialer applied. These static routes will have a preference of 1 to avoid any contention with other routes on the system:

```
inet.0: 32 destinations, 37 routes (31 active, 0 holddown, 3 hidden)
+ = Active Route, - = Last Active, * = Both

77.7.7.0/24        *[Static/1] 00:05:44
                    > via sp-0/0/0.3

__juniper_private1__.inet.0: 2 destinations, 2 routes (2 active, 0
holddown, 0 hidden)
```

IPSec over GRE

Sometimes the names for network features seem to be created out of thin air, with no rhyme or reason. This is the case with an IPSec over GRE tunnel. The name does not accurately describe the feature, as it actually is a Generic Routing Encapsulation (GRE) tunnel that is secured with IPSec. A better name would be GRE over IPSec, but as we all know, network engineering can't be that logical. The most common usage of IPSec over GRE tunnels is to interoperate with older Cisco IOS codes that do not support routing over IPSec tunnels. In these cases, routing is configured over

GRE and then IPSec is added. In JUNOS, routing over IPSec tunnels is accomplished by using next hop-style service sets. However, when implementing IPSec over GRE, you can use either service set type, with one exception. If the GRE endpoints are the same as the IPSec tunnel endpoints, you should use interface-style service sets.

> You could use a next hop-style service set if the tunnel endpoints are the same and FBF was used to map the GRE packets to the IPSec tunnel, but this adds an additional level of complexity that you should avoid if possible.

As in Figure 8-6, an IPSec over GRE tunnel will be configured between PBR and the Cans extranet. First, an unnumbered GRE interface is created from PBR to Cans:

```
lab@PBR# show interfaces gr-0/0/0
unit 0 {
    tunnel {
        source 172.16.1.2;
        destination 128.3.3.4;
    }
    family inet;
}
```

> To aid in troubleshooting, you could add an IP address to the GRE tunnel, but it is not necessary.

Traffic to the extranet is mapped via a static route that points to the gr-0/0/0.0 interface:

```
[edit]
lab@PBR# show routing-options static route 128.3.3.0/24
next-hop gr-0/0/0.0;
```

Next, you need to configure unique proposals that map to Cisco defaults (for more information on custom proposals, see “Unique Proposals,” earlier in this chapter):

```
    ipsec {
        proposal cisco-interop {
            protocol esp;
            authentication-algorithm hmac-md5-96;
            encryption-algorithm des-cbc;
        }
        policy ipsecgre {
            perfect-forward-secrecy {
                keys group1;
            }
            proposals cisco-interop;
        }
    }
    ike {
        proposal cisco-interop-ike {
            authentication-method pre-shared-keys;
            dh-group group1;
            authentication-algorithm md5;
            encryption-algorithm des-cbc;
        }
        policy main_ike {
            proposals cisco-interop-ike;
            pre-shared-key ascii-text "$9$JhUi.QF/OBEP5BEcyW8ZUjHP5z
36AuO"; ## SECRET-DATA
        }
    }
```

Then, you need to create the rule to map the GRE packets to the IPSec tunnel. You can do this by matching on the source IP address and destination IP address of the GRE tunnel, as well as by mapping the Cisco interoperable proposals to the IPSec tunnels:

```
lab@PBR# show services | find ipsec-vpn
ipsec-vpn {
    rule map-gre {
        term 1 {
            from {
                source-address {
                    172.16.1.2/32;
                }
                destination-address {
                    128.3.3.4/32;
                }
            }
            then {
                remote-gateway 128.3.3.4;
                dynamic {
                    ike-policy main_ike;
                    ipsec-policy ipsecgre;
                }
            }
        }
        match-direction output;
    }
```

A service set is then created and applied to the interface between PBR and Wheat:

```
lab@PBR# show services
service-set ipsec-gre {
    interface-service {
        service-interface sp-0/0/0.0;
    }
    ipsec-vpn-options {
        local-gateway 172.16.1.2;
    }
    ipsec-vpn-rules map-gre;
}
```

```
lab@PBR# show interfaces
fe-0/0/0 {
    vlan-tagging;
    unit 412 {
        description PBR-to-Wheat;
        vlan-id 412;
        family inet {
            service {
                input {
                    service-set ipsec-gre                }
                output {
                    service-set ipsec-gre
                }
            }
            address 172.16.1.2/24;
        }
    }
```

Two additional pieces of configuration should probably be added: IKE traceoptions and automatic tunnel establishment. IKE traceoptions will be used to help troubleshoot if the IPSec tunnel does not come up, and automatic tunnel establishment will be used to avoid lost packets that could result when GRE packets are sent before the IPSec tunnel is fully established:

```
[edit]
lab@PBR# set services ipsec-vpn establish-tunnels immediately

[edit]
lab@PBR# set services ipsec-vpn traceoptions flag ike traceoptions {
```

After the configuration is committed, the tunnel is established:

```
[edit]
lab@PBR# run show services ipsec-vpn ipsec security-associations
Service set: ipsec-gre

  Rule: map-gre, Term: 1, Tunnel index: 1
  Local gateway: 172.16.1.2, Remote gateway: 128.3.3.4
  Tunnel MTU: 1500
    Direction SPI         AUX-SPI     Mode       Type     Protocol
    inbound   4232427354  0           tunnel     dynamic  ESP
    outbound  83055442    0           tunnel     dynamic  ESP
```

However, traffic does not flow across the tunnel, and the BGP session to Wheat is down. The solution to this problem screams service filter!

```
[edit]
lab@PBR# run show bgp summary
Groups: 1 Peers: 1 Down peers: 1
Table   Tot Paths  Act Paths Suppressed  History Damp State  Pending
inet.0          0          0          0        0          0        0
Peer               AS      InPkt     OutPkt    OutQ   Flaps Last
Up/Dwn State|#Active/Received/Damped...
172.16.1.1   420   11892    10737       0       4       11:53 Active
```

It is obvious that we need to build a service filter to skip the BGP traffic from being serviced, while also ensuring that the GRE traffic gets sent down the IPSec tunnel. What might not be so obvious is that we need a service filter in *both* directions, because when GRE packets are encapsulated inside the system and the packets are circulated, the input interface becomes the next hop outgoing interface, as shown here and later in Figure 8-14 (we will examine this in detail in “The Life of a Packet,” later in this chapter):

```
lab@PBR> show configuration firewall
family inet {
    service-filter match-vpn-input {
        term service {
            from {
                source-address {
                    128.3.3.4/32;
                }
                destination-address {
                    172.16.1.2/32;
                }
            }
            then service;
        }
        term skip {
            then skip;
        }
    }
    service-filter match-vpn-output {
        term service {
            from {
                source-address {
                    172.16.1.2/32;
                }
                destination-address {
                    128.3.3.4/32;
                }
            }
            then service;
        }
        term skip {
            then skip;
        }
    }
}
```

Apply the service filters to the WAN interface on PBR:

```
lab@PBR> show configuration interfaces fe-0/0/0 unit 412
description PBR-to-Wheat;
vlan-id 412;
family inet {
    service {
        input {
            service-set ipsec-gre service-filter match-vpn-input;
        }
        output {
            service-set ipsec-gre service-filter match-vpn-output;
        }
    }
    address 172.16.1.2/24;
```

Generate some test traffic to the extranet on the internal router Bock:

```
lab@Bock> ping 128.3.3.3 rapid count 100
PING 128.3.3.3 (128.3.3.3): 56 data bytes
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
--- 128.3.3.3 ping statistics ---
100 packets transmitted, 100 packets received, 0% packet loss
round-trip min/avg/max/stddev = 9.666/18.435/40.117/9.181 ms
```

Verify that the packets are both encrypted and decrypted to and from the Cans extranet:

```
lab@PBR# run show services ipsec-vpn ipsec statistics

PIC: sp-0/0/0, Service set: ipsec-gre

ESP Statistics:
  Encrypted bytes:            11200
  Decrypted bytes:            11200
  Encrypted packets:            100
  Decrypted packets:            100
AH Statistics:
  Input bytes:                    0
  Output bytes:                   0
  Input packets:                  0
  Output packets:                 0
Errors:
  AH authentication failures: 0, Replay errors: 0
  ESP authentication failures: 0, ESP decryption failures: 0
  Bad headers: 0, Bad trailers: 0
```

For reference purposes only, here is an example of what the configuration may look like on the Cisco side in the extranet:

```
crypto isakmp policy 1
 hash md5
 authentication pre-share
crypto isakmp key test address 172.16.1.2
crypto isakmp keepalive 10 2 periodic

!
!
crypto ipsec transform-set esp_des_set esp-des esp-md5-hmac
!
!
crypto map gre-to-ipsec 1 ipsec-isakmp
 set peer 172.16.1.2
 set transform-set esp_des_set
 set pfs group1
 match address 110


access-list 110 permit ip host 128.3.3.4 host 172.16.1.2

interface tunnel1
 tunnel mode gre ip
 tunnel destination 172.16.1.2
 tunnel source 128.3.3.4

interface fast0
 crypto map gre-to-ipsec
```

Summary of IPSec VPNs

IPSec VPNs provide a secure method for protecting data over a private or public network. These could be VPNs with default proposals or VPNs with very specific authentication and encryption methods. Also, you can use these VPNs for a variety of applications, including securing access to an extranet, providing remote office connectivity, or providing a backup link for your internal network. Some of these VPNs may have dynamic endpoints or require GRE tunnels for interoperability with other vendors. You can accomplish all of this using JUNOS software and services.

The next section details another service that is offered: NAT.

NAT

NAT is simply a way to change the source or destination IP address of a packet due to public address exhaustion or a security mechanism to protect internal hosts. The internal hosts can be mapped to their own individual public addresses, or a pool of addresses could be used. Also, many addresses could be mapped to a single address utilizing different Transmission Control Protocol/User Datagram Protocol (TCP/UDP) port numbers for the flow, referred to as Port Address Translation (PAT). The most common NAT scenarios are listed here (and shown in Figure 8-8):

Destination NAT without port mapping
: The incoming public address is mapped to a private address. This is usually used to hide an internal server's address from the outside world.

Destination NAT with port mapping
: The incoming destination address and port are mapped to a private address. This allows for many services to be tied to the same destination address differentiated by port numbers. This is normally used when only a single external address is given that must map to multiple private connections.

NAT source without port translation
: The outgoing private source IP address is mapped to a public IP address. This is used when inside hosts want to reach external networks and the host information wants to remain hidden.

NAT source with port translation
: The outgoing private IP address is mapped to a public IP and the port number is also changed. This is used when multiple sources are mapped to a few public IP addresses.

Twice NAT
: This is used when both the source IP and the destination IP need to be changed. This could be a mail server that needs both inbound and outbound connections.

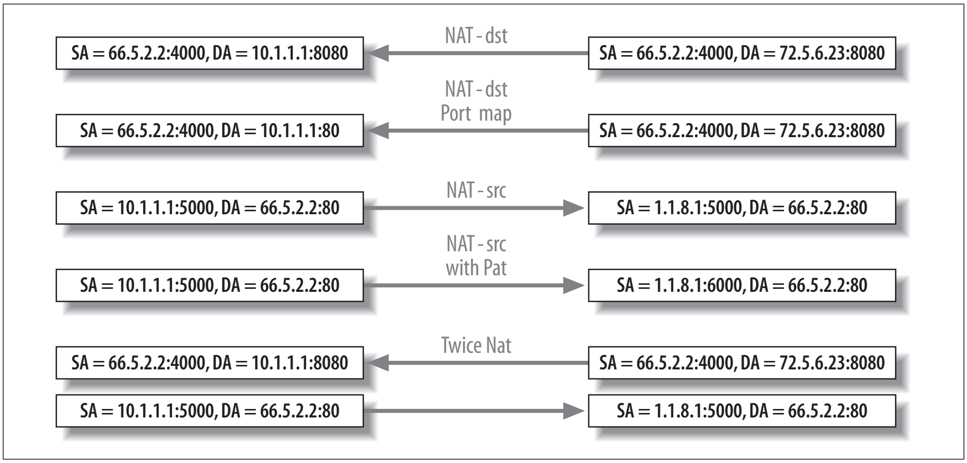

NAT - dst
SA = 66.5.2.2:4000, DA = 10.1.1.1:8080
SA = 66.5.2.2:4000, DA = 72.5.6.23:8080
NAT - dst Port map
SA = 66.5.2.2:4000, DA = 10.1.1.1:80
SA = 66.5.2.2:4000, DA = 72.5.6.23:8080
NAT - src
SA = 10.1.1.1:5000, DA = 66.5.2.2:80
SA = 1.1.8.1:5000, DA = 66.5.2.2:80
NAT - src with Pat
SA = 10.1.1.1:5000, DA = 66.5.2.2:80
SA = 1.1.8.1:6000, DA = 66.5.2.2:80
Twice Nat
SA = 66.5.2.2:4000, DA = 10.1.1.1:8080
SA = 66.5.2.2:4000, DA = 72.5.6.23:8080
SA = 10.1.1.1:5000, DA = 66.5.2.2:80
SA = 1.1.8.1:5000, DA = 66.5.2.2:80

Figure 8-8. Common NAT deployments

The translated address can be either specified in the NAT rule or created as a pool of addresses. If PAT is required, you must use a pool. You can reuse a pool in multiple NAT rules. In the pool, you can specify a single address, a prefix, or a range of addresses. You also can enable port translation in the pool to select a range of port values or have the system automatically choose a value.

```
lab@PBR# set services nat pool example ?
Possible completions:
> address               Address or address prefix for NAT
> address-range         Range of addresses for NAT
+ apply-groups          Groups from which to inherit configuration
data
+ apply-groups-except   Don't inherit configuration data from these
groups
> port                  Specify ports for NAT
[edit]
```

The pool is then applied as a source or destination pool in the NAT rule.

You also can configure an *overload pool* if the primary pool becomes exhausted.

In addition, you can apply a prefix without using a pool of addresses:

```
[edit]
lab@PBR# set services nat rule example term 1 then translated ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  destination-pool     NAT pool for destination translation
  destination-prefix   NAT prefix for destination translation
  overload-pool        NAT pool to be used when source pool is overloaded
  overload-prefix      NAT prefix to be used when source pool is overloaded
  source-pool          NAT pool for source translation
  source-prefix        NAT prefix for source translation
> translation-type     Type of translation to perform
```

When deciding how to configure NAT, several questions drive the correct solutions:

- Is the source IP address and/or destination IP address going to be translated?
- Is port translation going to occur?
- Are the addresses going to be statically mapped or dynamically mapped?
- Should an address pool be used?

We will examine a few common scenarios in the following sections.

Source NAT with No PAT

A simple source NAT for all private addresses to an external address pool of 55.55.5/27 is implemented on PBR using the preferred solution of a next hop service set, as shown in Figure 8-9.

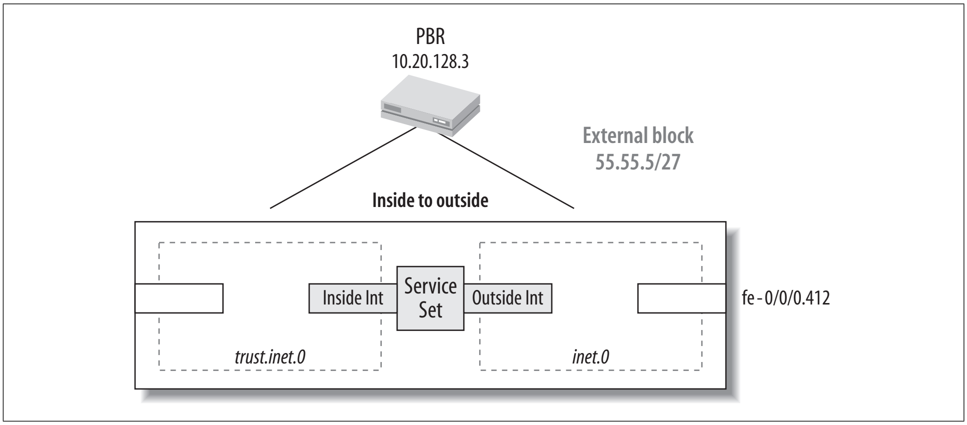


Figure 8-9. Source NAT example

First, an address pool called ext-block is created without port translation. An address block is not necessary but is used for future scalability:

```
lab@PBR# show services
nat {
    pool ext-block {
        address 55.55.5.0/27;
    }
```

Then a rule is created to translate all source addresses using this address block. This must be a dynamic translation since there is no matching source subnet:

```
    rule basic-source {
        match-direction input;
        term 1 {
            then {
                translated {
                    source-pool ext-block;
                    translation-type source dynamic;
                }
            }
        }
    }
}
```

A next hop service set is created to map the NAT rule:

```
service-set Trust-Untrust {
    nat-rules basic-source;
    next-hop-service {
        inside-service-interface sp-0/0/0.1;
        outside-service-interface sp-0/0/0.2;
    }
}
```

The external address block must be reachable by the outside world. Since PBR already has a hazy BGP relationship with AS 420, this address block is sent via BGP:

```
[edit]
lab@PBR# show protocols bgp
export [ send-agg send-ext-block ];
group as_420 {
    type external;
    neighbor 172.16.1.1 {
        peer-as 420;
    }
}
lab@PBR# run show bgp summary
Groups: 1 Peers: 1 Down peers: 0
Table   Tot Paths  Act Paths Suppressed History Damp State  Pending
inet.0          7          5          0       0          0        0
Peer        AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
172.16.1.1        420       7852       7077       0       2  2d
7:07:42 5/7/0 0/0/0

^
unknown command.
lab@PBR# run show route advertising-protocol bgp 172.16.1.1 55/8
```

```
inet.0: 21 destinations, 26 routes (20 active, 0 holddown, 5 hidden)
  Prefix                  Nexthop      MED     Lclpref    AS path
* 55.55.5.0/27            Self                            I
```

Next, we create a VR to represent the internal trust (internal) portion of the network. The LAN interface of PBR is added, as well as the inside service interface. Also, the OSPF configuration is moved over the VR. This includes a policy called send-default (not shown) that sends a default route into OSPF for Internet connectivity. Also, a loopback is added for use in OSPF. Lastly, a default route is created to send all noninternal traffic to the inside service interface:

```
[edit]
lab@PBR# show routing-instances
trust {
    instance-type virtual-router;
    interface fe-0/0/0.1241;
    interface sp-0/0/0.1;
    interface lo0.0;
    routing-options {
        static {
            route 0.0.0.0/0 next-hop sp-0/0/0.1;
        }
    }
    protocols {
        ospf {
            export send-default;
            area 0.0.0.0 {
                interface fe-0/0/0.1241;
                interface lo0.1;
            }
        }
    }
}
```

For completeness, the policies on PBR are shown here. Please refer to Chapter 3 for a policy discussion.

```
[edit]
lab@PBR# show policy-options
prefix-list internal-subnets {
    10.10.12.0/22;
    10.10.128.0/22;
    10.20.128.0/22;
}
policy-statement send-agg {
    from protocol aggregate;
    then accept;
}
policy-statement send-default {
    from {
        route-filter 0.0.0.0/0 exact accept;
    }
}
policy-statement send-ext-block {
    from {
        route-filter 55.55.5.0/27 exact accept;
    }
}
```

Verify that all the static routes are active on the router in both the routing instance trust and the main route table. The 55.55.5/27 static route in the main instance was automatically created due to the NAT rule with a very low preference of 1, which points to the outside interface for return NAT traffic. The default route was manually created during the VR configuration:

```
lab@PBR# run show route protocol static

inet.0: 21 destinations, 26 routes (20 active, 0 holddown, 5 hidden)
+ = Active Route, - = Last Active, * = Both

55.55.5.0/27       *[Static/1] 00:14:38
                    > via sp-0/0/0.2

__juniper_private1__.inet.0: 2 destinations, 2 routes (2 active, 0 holddown, 0
hidden)

trust.inet.0: 16 destinations, 16 routes (16 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[Static/5] 00:19:31
                    > via sp-0/0/0.1
```

Also, verify that all the internal routes are received via OSPF in the VR's route table, trust.inet.0:

```
[edit]
lab@PBR# run show route table trust

trust.inet.0: 16 destinations, 16 routes (16 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[Static/5] 00:19:59
                    > via sp-0/0/0.1
10.10.8.0/27       *[OSPF/10] 00:13:32, metric 67
                    > to 10.20.130.1 via fe-0/0/0.1241
10.10.10.0/30      *[OSPF/10] 00:19:50, metric 66
                    > to 10.20.130.1 via fe-0/0/0.1241
10.10.11.0/24      *[OSPF/10] 00:19:50, metric 2
                    > to 10.20.130.1 via fe-0/0/0.1241
10.10.12.1/32      *[OSPF/10] 00:13:32, metric 2
                    > to 10.20.130.1 via fe-0/0/0.1241
10.10.12.2/32      *[OSPF/10] 00:13:32, metric 66
                    > to 10.20.130.1 via fe-0/0/0.1241
10.10.12.3/32      *[OSPF/10] 00:19:50, metric 1
                    > to 10.20.130.1 via fe-0/0/0.1241
10.20.128.4/32     *[OSPF/10] 00:13:32, metric 67
                    > to 10.20.130.1 via fe-0/0/0.1241
10.20.128.128/32   *[Direct/0] 00:19:59
                    > via lo0.1
```

```
10.20.129.0/24     *[OSPF/10] 00:13:32, metric 68
                    > to 10.20.130.1 via fe-0/0/0.1241
10.20.130.0/24     *[Direct/0] 00:19:59
                    > via fe-0/0/0.1241
10.20.130.2/32     *[Local/0] 00:19:59
                      Local via fe-0/0/0.1241
10.20.131.0/24     *[OSPF/10] 00:13:32, metric 67
                    > to 10.20.130.1 via fe-0/0/0.1241
10.30.1.1/32       *[OSPF/10] 00:13:32, metric 67
                    > to 10.20.130.1 via fe-0/0/0.1241
64.8.12.6/32       *[OSPF/150] 00:13:32, metric 0, tag 0
                    > to 10.20.130.1 via fe-0/0/0.1241
224.0.0.5/32       *[OSPF/10] 00:20:00, metric 1
                      MultiRecv
```

Now verify that the OSPF network is running correctly in the VR. Don't forget the `instance` switch!

```
[edit]
lab@PBR# run show ospf database instance trust

    OSPF link state database, Area 0.0.0.0
 Type       ID            Adv Rtr       Seq    Age  Opt  Cksum  Len
Router   10.10.12.1    10.10.12.1    0x8000016d 817  0x22 0x30df  48
Router   10.10.12.2    10.10.12.2    0x8000022a 817  0x22 0x7889  84
Router   10.10.12.3    10.10.12.3    0x8000017b 739  0x22 0x3575  84
Router   10.20.128.4   10.20.128.4   0x800004fc 818  0x22 0xa79b  60
Router  *10.20.128.128 10.20.128.128 0x8000000c 160  0x22 0x5f14  48
Router   10.30.1.1     10.30.1.1     0x80000227 818  0x22 0x4ef0  48
Network  10.10.8.1     10.10.12.2    0x800000a1 817  0x22 0x45e7  32
Network  10.10.11.1    10.10.12.3    0x80000003 816  0x22 0xbef1  32
Network *10.20.130.2   10.20.128.128 0x80000004   9  0x22 0x1320  32
Network  10.20.131.2   10.20.128.4   0x8000020b 818  0x22 0xf32f  32
    OSPF AS SCOPE link state database
 Type       ID           Adv Rtr        Seq    Age  Opt  Cksum  Len
Extern  *0.0.0.0       10.20.128.128 0x80000001 562  0x22 0x7f14  36
Extern   64.8.12.6     10.30.1.1     0x8000009b 818  0x22 0xf84   36
```

Traffic is sent to the Internet and verified by looking at the `show services stateful-firewall flows` output. When a NAT service set is applied, a stateful firewall that accepts all traffic is actually also applied. Notice that the source is being translated from 10.20.120.1 to 55.55.5.1 with no port translation, and the return flow is automatically created. Also, the state is `watch` because an ICMP Application Later Gateway (ALG) is being used:

```
[edit]
lab@PBR# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: Trust-Untrust
Flow                                State    Dir       Frm count
ICMP        128.3.3.27:62239 ->      55.55.5.1      Watch    O   188
    NAT dest         55.55.5.1:62239   ->     10.20.130.1:0
ICMP       10.20.130.1:62239 ->     128.3.3.27      Watch    I   196
    NAT source     10.20.130.1:62239   ->      55.55.5.1:62239
```

You also can view the ALG by looking at the output of the conversations command, which is JUNOS terminology for the transit and receive flow:

```
lab@PBR# run show services stateful-firewall conversations extensive
Interface: sp-0/0/0, Service set: Trust-Untrust

Conversation: ALG protocol: icmp
  Number of initiators: 1, Number of responders: 1
Flow                                    State    Dir       Frm count
ICMP       10.20.130.1:62239 ->     128.3.3.27      Watch    I   211
    NAT source     10.20.130.1:62239   ->       55.55.5.1:62239
  Byte count: 17724
  Flow role: Master, Timeout: 30, Protocol detail: echo request
ICMP        128.3.3.27:62239 ->      55.55.5.1      Watch    O   203
    NAT dest         55.55.5.1:62239   ->     10.20.130.1:0
  Byte count: 17052
  Flow role: Responder, Timeout: 30, Protocol detail: echo reply
```

The NAT pool is also examined, and although a /27 is configured in the pool, only 30 addresses have been allocated, excluding the 55.55.5.0 and 55.55.5.31 addresses:

```
lab@PBR# run show services nat pool
Interface: sp-0/0/0, Service set: Trust-Untrust
NAT pool          Type    Address               Port      Ports used
ext-block         dynamic         55.55.5.1-55.55.5.30
```

Source NAT with PAT

Now we will add port translation; refer back to "Source NAT with No PAT" to see the VR, rules, service setup, and so on. To enable PAT, simply add the port command in the address pool definition:

```
[edit]
lab@PBR# set services nat pool ext-block port automatic
```

After the change is committed, it still appears that the flows are not performing any port translation:

```
[edit]
lab@PBR# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: Trust-Untrust
Flow                                 State    Dir       Frm count
ICMP        128.3.3.27:62239 ->      55.55.5.1      Watch    O   188
    NAT dest         55.55.5.1:62239   ->     10.20.130.1:0
ICMP       10.20.130.1:62239 ->     128.3.3.27      Watch    I   196
    NAT source     10.20.130.1:62239   ->       55.55.5.1:62239
```

You can verify this by looking at the NAT pool and seeing that no ports have been assigned:

```
lab@PBR# run show services nat pool
Interface: sp-0/0/0, Service set: Trust-Untrust
NAT pool          Type    Address             Port        Ports used
ext-block         dynamic            55.55.5.1-55.55.5.30
```

The port translation is not occurring because the change was done on the fly and the session had not timed out. To create a new session in the flow table, you must first clear the flows:

```
lab@PBR# run clear services stateful-firewall flows
Interface   Service set                            Conv removed
sp-0/0/0    Trust-Untrust                                     1
```

Now the port number is being changed from 62239 to 1024, as expected:

```
[edit services nat pool ext-block]
lab@PBR# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: Trust-Untrust
Flow                                 State    Dir       Frm count
ICMP        128.3.3.27:1024  ->      55.55.5.1      Watch    O   8
    NAT dest         55.55.5.1:1024    ->     10.20.130.1:62239
ICMP       10.20.130.1:62239 ->     128.3.3.27      Watch    I   8
    NAT source     10.20.130.1:62239   ->       55.55.5.1:1024
```

You can verify this by viewing the port range allowed (512–65535), and by the fact that a single port is shown to be in use out of the pool:

```
[edit services nat pool ext-block]
lab@PBR# run show services nat pool
Interface: sp-0/0/0, Service set: Trust-Untrust
NAT pool          Type    Address             Port       Ports used
ext-block         dynamic      55.55.5.1-55.55.5.30  512-65535    1
```

Destination NAT

Another common application is to change the incoming public IP address to a private IP address inside the network. Often, this is done to open a particular service from the WAN interface, frequently referred to as a *pinhole* for its hopefully diminutive access. In this case study, a custom application called *slingbox* is running over TCP and is using a port range of 4000–4050. This will be coming into public IP address 55.55.5.27 and will be mapped to internal address 10.10.12.3. Destination NAT must always be of type static, so the incoming public address range must map to the outgoing private address range.

Since a unique application must be used for this pinhole, first you must define an application that will later be referenced in the NAT rule. This application is called `custom-app`:

```
lab@PBR# show | find applications
applications {
    application custom-app {
        protocol tcp;
        destination-port 4000-4050;
    }
}
```

Create the NAT rule by referencing the incoming public destination address 55.55.5.27 and the custom-app, and by translating this address to 10.10.12.3. Use a destination-prefix instead of a destination-pool as this is a single address mapping. Since this is a destination NAT that is added to the previously created next hop service set, specify a direction of output because traffic will be received and directed to the outside interface by the already created 55.55.5/27 static route:

```
[edit services nat]
lab@PBR# show | find rule

        rule pin-hole {
            match-direction output;
            term 1 {
                from {
                    destination-address {
                        55.55.5.27/32;
                    }
                    applications custom-app;
                }
                then {
                    translated {
                        destination-prefix 10.10.12.3/32;
                        translation-type destination static;
                    }
                }
            }
        }
    }
```

Then add the rule to the previously created service set:

```
    service-set Trust-Untrust {
        nat-rules basic-source;
        nat-rules pin-hole;
        next-hop-service {
            inside-service-interface sp-0/0/0.1;
            outside-service-interface sp-0/0/0.2;
        }
    }
}
```

Remember that you can combine multiple rules into a rule set if desired.

Traffic is incoming to PBR's WAN interface and the destination NAT is verified. This flow happens to have an incoming port number of 4020, which does fall into the custom application range:

```
lab@PBR# run show services stateful-firewall conversations
Interface: sp-0/0/0, Service set: Trust-Untrust
```

```
Conversation: ALG protocol: tcp
  Number of initiators: 1, Number of responders: 1
Flow                               State    Dir       Frm count
TCP         172.16.1.1:4216  ->    55.55.5.27:4020  Forward  O   1
    NAT dest        55.55.5.27:4020    ->      10.10.12.3:4020
TCP         10.10.12.3:4020  ->    172.16.1.1:4216  Forward  I   1
    NAT source      10.10.12.3:4020    ->      55.55.5.27:4020
```

NAT and the stateful firewall

By default, when NAT rules are exclusively applied in a service set, a stateful firewall is implicitly applied. This default stateful firewall matches on all traffic with an action of accept and is created in *both* directions. If a stateful-firewall rule is created later and applied to the service set, the default stateful-firewall rules are removed. This means that to allow for NAT traffic, you may need to create new stateful-firewall rules if a stateful-firewall rule is later applied to the service set. In a simple example, a stateful-firewall rule is created to allow all JUNOS ALGs and other traffic outbound from the internal network to the Internet:

```
stateful-firewall {
    rule allow-outbound {
        match-direction input;
        term 1 {
            from {
                application-sets junos-algs-outbound;
            }
            then {
                accept;
            }
        }
        term 2 {
            then {
                accept;
            }
        }
    }
}
```

Apply this stateful-firewall rule to the service set that already contains the NAT rules:

```
service-set Trust-Untrust {
    stateful-firewall-rules allow-outbound;
    nat-rules basic-source;
    nat-rules pin-hole;
    next-hop-service {
        inside-service-interface sp-0/0/0.1;
        outside-service-interface sp-0/0/0.2;
    }
}
```

Verify the source NAT and that all works as expected since the stateful firewall is allowing all outbound flows:

```
[edit]
lab@PBR# run show services stateful-firewall conversations
Interface: sp-0/0/0, Service set: Trust-Untrust

Conversation: ALG protocol: icmp
  Number of initiators: 1, Number of responders: 1
Flow                                State    Dir       Frm count
ICMP       10.20.130.1:11552 ->     128.3.3.27      Watch    I  31
    NAT source     10.20.130.1:11552   ->       55.55.5.1:1024
ICMP        128.3.3.27:1024  ->      55.55.5.1      Watch    O   31
    NAT dest         55.55.5.1:1024    ->     10.20.130.1:11552
```

Note that when test traffic is sent from ISP router Wheat to PBR for incoming destination NAT, the traffic is dropped by the newly applied stateful firewall that allows only outbound flows to be initiated, not inbound flows:

```
lab@Wheat> telnet 55.55.5.27 port 4020
Trying 55.55.5.27...

lab@PBR# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: Trust-Untrust
Flow                                State    Dir       Frm count
TCP         172.16.1.1:3469  ->     55.55.5.27:4020  Drop     0   0
```

So, to allow incoming NAT processing to occur in the output interface, the packet must be allowed through the stateful firewall. The incoming service flow when multiple service rules are applied is:

Stateful firewall → NAT

You cannot set this order at this point, which means that the stateful firewall must match on the static NAT address:

```
[edit servisce stateful-firewall]
lab@PBR# show | find rule allow-pin-hole

rule allow-pin-hole {
    match-direction output;
    term 1 {
        from {
            destination-address {
                55.55.5.27/32;
            }
        }
        then {
            accept;
        }
    }
}
```

Apply the new rule to the service set:

```
lab@PBR# show services service-set Trust-Untrust
stateful-firewall-rules allow-outbound;
stateful-firewall-rules allow-pin-hole;
```

```
nat-rules basic-source;
nat-rules pin-hole;
next-hop-service {
    inside-service-interface sp-0/0/0.1;
    outside-service-interface sp-0/0/0.2;
}
```

Now destination NAT works as expected, and TV can sling around the world with our special application:

```
lab@PBR# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: Trust-Untrust
Flow                             State    Dir       Frm count
TCP        10.10.12.3:4020  ->     172.16.1.1:1059  Forward  I   1
    NAT source      10.10.12.3:4020    ->      55.55.5.27:4020
TCP        172.16.1.1:1059  ->     =55.55.5.27:4020  Forward  O   1
    NAT dest        55.55.5.27:4020    ->      10.10.12.3:4020

[edit]
```

Since multiple stateful-firewall rules are applied, this may be another place where a rule set could be helpful:

```
service-set Trust-Untrust {
    stateful-firewall-rule-sets in-out;
    nat-rules basic-source;
    nat-rules pin-hole;
    next-hop-service {
        inside-service-interface sp-0/0/0.1;
        outside-service-interface sp-0/0/0.2;
    }
}
rule-set in-out {
    rule allow-outbound;
    rule allow-pin-hole;
}
```

Twice NAT

Lastly, you can configure twice NAT on the router, which involves changing the source IP address for outbound flows and the destination address for inbound flows (see Figure 8-10). This is really no different from the scenarios we've already discussed, except that you must configure a source and a destination address, as well as a source prefix or pool and a destination prefix or pool. In the example that follows, traffic that matches 10.58.254.24 or 10.58.254.35 will be source-NAT'd using a static pool called `src-pool`.

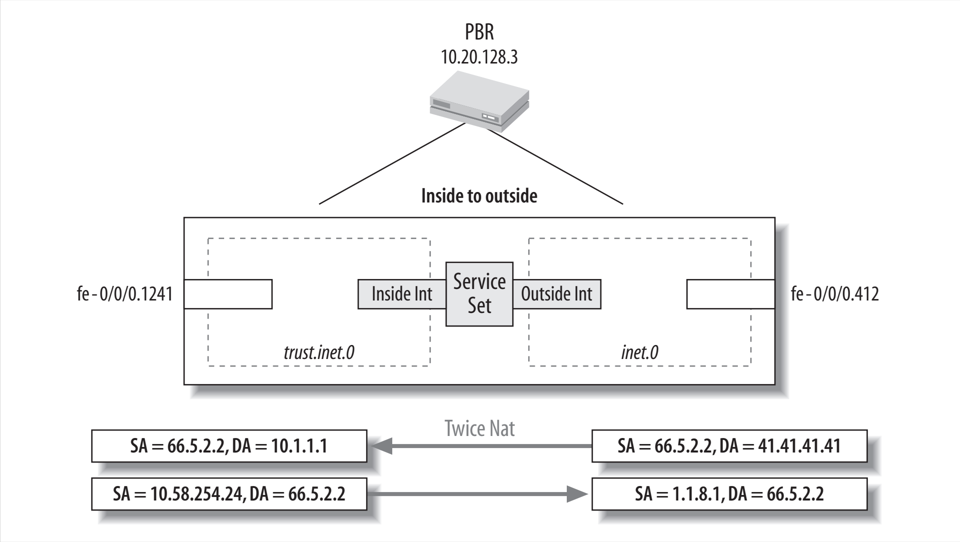

PBR
10.20.128.3
Inside to outside
fe-0/0/0.1241
Inside Int
Service Set
Outside Int
fe-0/0/0.412
trust.inet.0
inet.0
Twice Nat
SA = 66.5.2.2, DA = 10.1.1.1
SA = 66.5.2.2, DA = 41.41.41.41
SA = 10.58.254.24, DA = 66.5.2.2
SA = 1.1.8.1, DA = 66.5.2.2

Figure 8-10. Twice NAT example

Traffic destined for 41.41.41.41/32 will be destination-NAT'd using a NAT pool called dst_pool:

```
[edit services nat]]
lab@Bock# show
rule twice-nat {
    match-direction input;
    term my-term1 {
        from {
            destination-address {
                41.41.41.41/32;
            }
            source-address-range {
                low 10.58.254.34 high 10.58.254.35;
            }
        }
        then {
            translated {
                source-pool src-pool;
                destination-pool dst_pool;
                translation-type source static destination static;
            }
        }
    }
}
```

At the time of this writing, you cannot configure ALGs when twice NAT is configured.

Summary of NAT

NAT has become a common language and requirement for networks in every facet of the world due to the exhaustion of IPv4 addresses as well as a way to protect internal resources. Various types of NAT are defined, including source IP translation, destination IP translation, and port translation. Which method you choose should depend on a variety of factors, such as the number of public IPs that are assigned to the network, the number of incoming Internet connections allowed, and the level of invisibility required. In fact, you can combine many of these concepts into a newer standard called twice NAT.

The next section explains how to configure multiple services at the same time, and the configuration processing that will occur during deployment.

IDS

JUNOS services support a limited set of IDSs to help detect attacks such as port scanning and anomalies in traffic patterns. It also supports some attack prevention by limiting the number of flows, sessions, and rates. In addition, it protects against SYN attacks by implementing a SYN cookie mechanism. Since the intrusion detection and prevention (IDP) service does not support higher-layer application signatures, we must examine another solution.

The IDP solution is really more of a monitoring tool than an actual prevention tool. So, how does Juniper make the IDP claim? One response is that protection against a SYN attack can be configured. To prevent a SYN attack, the router will operate as a type of SYN "proxy" and will utilize cookie values. Essentially, when this feature is turned on, the router will respond to the initial SYN packet with a SYN-ACK packet that contains a unique cookie value in the sequence number field. If the initiator responds with the same cookie in the sequence field, the TCP flow is accepted; if the responder does not respond or if it responds with the wrong cookie, the flow is dropped. To kick off this defense, we must configure a SYN cookie threshold.

To enable the SYN cookie defense, an IDS rule action must contain a threshold that indicates when the feature should be enabled and an MSS value to avoid having the router manage segmented fragments when acting as a SYN proxy:

```
[edit]
lab@PBR# set services ids rule simple-ids term 1 then syn-cookie ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these
groups
  mss                  MSS value for TCP delayed binding (128..8192)
  threshold            Threshold above which SYN cookies are enabled
[edit]
```

You would then apply this rule to a service set as you would any other service previously discussed.

> Since IDP and stateful firewalls are processed in parallel, you should configure a stateful-firewall rule alongside the IDS rule. If you forget a rule, the default stateful firewall of `allow all` will be used.

Along with SYN cookie protection, the IDS is used to detect attacks and gather information to create rules to stop these attacks. When looking at the possible IDS rule actions for detection of attacks, you can:

- Set up thresholds to monitor certain sources, destinations, or source and destination pairs
- Force "good" entries to the IDS table for tracking purposes
- Log packets when they hit a certain threshold:

```
lab@PBR# set services ids rule all term 1 then ?
Possible completions:
> aggregation          Define aggregation parameters
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  force-entry          Force entries in IDS tables for matching traffic
  ignore-entry         Ignore IDS events for matching traffic
> logging              Define system logging parameters
> session-limit        Define IDS session limit parameters
> syn-cookie           Define SYN cookie parameters
```

For example, here is a rule that logs packets as soon as an event happens (threshold 1), enables SYN cookie protection at five SYN packets per second, and forces all entries to be recorded:

```
[edit]
lab@PBR# show services
ids {
    rule all {
        match-direction input;
        term 1 {
            then {
                force-entry;
                logging {
                    threshold 1;
                    syslog;
                }
                syn-cookie {
                    threshold 5;
                    mss 1500;
                }
            }
        }
    }
}
```

```
service-set Trust-Untrust {
    ids-rules all;
    next-hop-service {
        inside-service-interface sp-0/0/0.1;
        outside-service-interface sp-0/0/0.2;
    }
}
```

The IDS tables can then be matched by source, destination, or pair:

```
[edit]
lab@PBR# run show services ids ?
Possible completions:
  destination-table    Show attack destination address table
  pair-table           Show attack source and destination address pair table
  source-table         Show attack source address table
```

Here is some output (not from this example) that shows some of the different types of anomalies that can be tracked:

```
user@underdogs> show services ids destination-table extensive
Interface: sp-1/3/0, Service set: null-sfw
Sorting order: Packets
Source address       Dest address   Time    Flags        Application

any            ->   10.58.255.146   35m52s SYN cookie
  Bytes:   34.0 m, Packets:  798.0 k, Flows:  266.0 k, Anomalies: 2251.0 k
    Anomalies                           Count   Rate(eps) Elapsed
    First packet of TCP session not SYN     160.0 k       0       14s
    TCP source or destination port zero     634.0 k   154.6     3m37s
    UDP source or destination port zero     633.0 k   170.0     3m37s
    ICMP header length check failed         2875     0.9     3m37s
    IP fragment assembly timeout            820.0 k    12.8     3m18s
    UDP header length check failed           385     0.5     3m53s
    TCP header length check failed           383     0.5     3m53s

Total IDS table entries:
87
Total failed IDS table entry insertions
0
Total number of
```

Combining Services

When combining multiple services, the general path must be remembered in the forward and reverse directions (see Figure 8-11). This is especially true when NAT is deployed to determine whether the pre- or post-NAT address should be used to match a rule. In the forward path from a LAN interface to a WAN interface, IDS and stateful firewall are performed first, then NAT, and finally IPSec. This means that the stateful firewall must match on a pre-NAT address whereas the IPSec tunnel would match on the post-NAT address.

In the return path, the IPSec packet will be processed first, then NAT, and finally the stateful firewall. This still allows IPSec to match a public address and the stateful firewall to match on a private address.

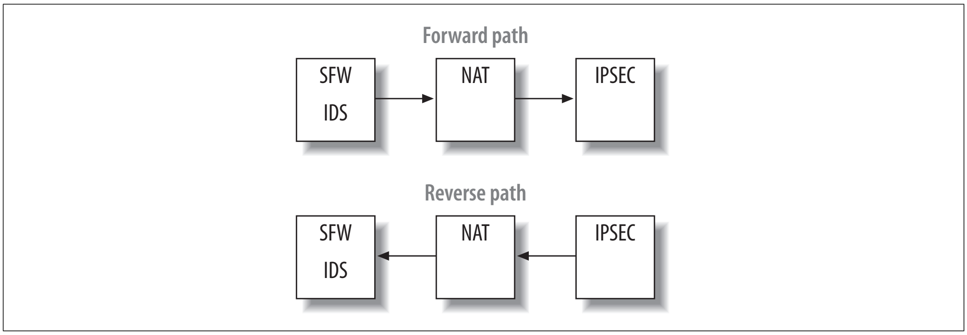


Figure 8-11. Service path

Everything becomes much more complicated when IPSec over GRE is implemented in the router with other services turned on. This is because JUNOS treats GRE packets in a very peculiar fashion after GRE encapsulation. After a packet is encapsulated in a GRE packet, it is marked with an input interface as the next hop outgoing interface. This causes GRE packets to be blocked if any input filters or input services are allowed that do not allow for this service.

In Figure 8-12, an IP packet comes into the `fe-1/0/0.42` interface and a route lookup is performed that directs the packet into a GRE tunnel, which has an egress interface of `se-1/0/0`. After the GRE encapsulation, the input interface changes to the output interface. So, at the final stage, any stateful-firewall processing or stateless filters are going to see the packet coming into interface `se-1/0/0` and out of interface `se-1/0/0`, which is unexpected!

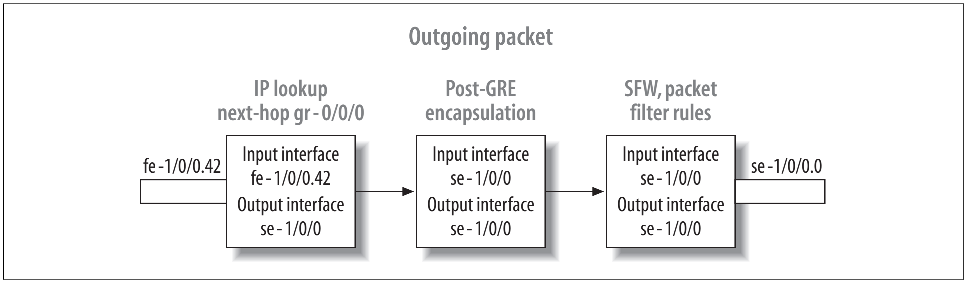


Figure 8-12. GRE processing with services

Stateful Firewall, NAT, and IPSec over GRE Together

To illustrate the uniqueness of GRE encapsulation, we will again examine the IPSec over GRE tunnel. This is the same tunnel we configured in "IPSec over GRE," earlier in this chapter. Just to recap, here is the complete IPSec over GRE configuration rule set that is applied as an interface-style service set:

```
service-set ipsec-gre {
    interface-service {
        service-interface sp-0/0/0.0;
    }
    ipsec-vpn-options {
        local-gateway 172.16.1.2;
    }
    ipsec-vpn-rules map-gre;
}
ipsec-vpn {
    rule map-gre {
        term 1 {
            from {
                source-address {
                    172.16.1.2/32;
                }
                destination-address {
                    128.3.3.4/32;
                }
            }
            then {
                remote-gateway 128.3.3.4;
                dynamic {
                    ike-policy main_ike;
                    ipsec-policy ipsecgre;
                }
            }
        }
        match-direction output;
    }
    ipsec {
        proposal cisco-interop {
            protocol esp;
            authentication-algorithm hmac-md5-96;
            encryption-algorithm des-cbc;
        }
        policy ipsecgre {
            perfect-forward-secrecy {
                keys group1;
            }
            proposals cisco-interop;
        }
    }
    ike {
        proposal cisco-interop-ike {
            authentication-method pre-shared-keys;
            dh-group group1;
            authentication-algorithm md5;
            encryption-algorithm des-cbc;
        }
        policy main_ike {
            proposals cisco-interop-ike;
            pre-shared-key ascii-text "$9$JhUi.QF/0BEP5BEcyW8ZUjHP5z
36Au0"; ## SECRET-DATA
        }
    }
    traceoptions {
        flag ike;
    }
    establish-tunnels immediately;
}
```

Stateful-firewall and NAT rules are to be configured from the LAN side of router PBR to the WAN side of the router for all internally sourced traffic. Since IPSec requires its own service set, a new service set called trust-untrust will be created that references the same service interface and a single NAT and stateful-firewall rule:

```
[edit services]

service-set trust-untrust {
    stateful-firewall-rules allow-outbound;
    nat-rules basic-source;
    interface-service {
        service-interface sp-0/0/0.0;
    }
}
```

A stateful-firewall rule is created to match on traffic that is sourced from the internal network. Notice that only ALGs are allowed from the internal subnet, whereas the second term contains no condition. The second term does not contain this condition in order to allow some management traffic and BGP traffic to flow between the 172.16.1/24 network between PBR and Wheat (see Figure 8-6):

```
stateful-firewall {
    rule allow-outbound {
        match-direction output;
        term alg {
            from {
                source-address {
                    10.0.0.0/8;
                }
                application-sets junos-algs-outbound;
            }
            then {
                accept;
            }
        }
        term other {
            then {
                accept;
            }
        }
    }
}
```

Also, a source NAT rule is applied for all internal traffic using port translation:

```
nat {
    pool ext-block {
        address 55.55.5.0/27;
        port automatic;
    }
    rule basic-source {
        match-direction output;
        term 1 {
            from {
                source-address {
                    10.0.0.0/8;
                }
            }
            then {
                translated {
                    source-pool ext-block;
                    translation-type source dynamic;
                }
            }
        }
    }
}
```

The new service set is applied to the WAN interface on PBR. Take a look at the previous example to view the service filters match-vpn-input and match-vpn-output:

```
[edit interfaces fe-0/0/0 unit 412]
lab@PBR# show
description PBR-to-Wheat;
vlan-id 412;
family inet {
    service {
        input {
            service-set ipsec-gre service-filter match-vpn-input;
            service-set trust-untrust;
        }
        output {
            service-set ipsec-gre service-filter match-vpn-output;
            service-set trust-untrust;
        }
    }
    address 172.16.1.2/24;
```

After the configuration is committed, observe the flows through the stateful firewall. GRE packets are being dropped that were destined to 128.3.3.4. Notice that the direction is input, since after GRE encapsulation, the packet appears to be coming into the outgoing WAN interface. Because the stateful-firewall rules are now written to allow incoming GRE packets, the packets are dropped:

```
[edit services stateful-firewall rule allow-outbound]

lab@PBR# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: trust-untrust
Flow                                        State    Dir   Frm count
TCP    172.16.1.1:179   ->  172.16.1.2:2439  Forward  I         11
TCP    172.16.1.2:2439  ->  172.16.1.1:179   Forward  O         12
GRE    172.16.1.2:0     ->   128.3.3.4:0     Drop     I          0
```

Since the packets are being dropped by the stateful firewall, they are not even reaching the IPSec tunnel. You can see this by observing the 0 packet counts on the IPSec statistics:

```
[edit services service-set trust-untrust]
lab@PBR# run show services ipsec-vpn ipsec statistics

PIC: sp-0/0/0, Service set: ipsec-gre

ESP Statistics:
  Encrypted bytes:              0
  Decrypted bytes:              0
  Encrypted packets:            0
  Decrypted packets:            0
AH Statistics:
  Input bytes:                  0
  Output bytes:                 0
  Input packets:                0
  Output packets:               0
Errors:
  AH authentication failures: 0, Replay errors: 0
  ESP authentication failures: 0, ESP decryption failures: 0
  Bad headers: 0, Bad trailers: 0
```

We must now create a service filter to allow the GRE packets to bypass the stateful firewall and be encapsulated into the IPSec packet. This service filter must match on the source and destination IP addresses of the tunnel, as seen from the discard flows. Don’t forget to service all other packets besides the GRE packets:

```
 [edit firewall]
lab@PBR# show | find allow-gre
    service-filter allow-gre {
        term gre {
            from {
                source-address {
                    172.16.1.2/32;
                }
                destination-address {
                    128.3.3.4/32;
                }
            }
            then skip;
        }
        term all {
            then service;
        }
    }
}
```

Apply the service filter as an input service filter for the stateful firewall containing the service set:

```
[edit interfaces fe-0/0/0 unit 412]
lab@PBR# set family inet input service-set trust-untrust service-
filter allow-gre

[edit interfaces fe-0/0/0 unit 412]
lab@PBR# show
description PBR-to-Wheat;
vlan-id 412;
family inet {
    service {
        input {
            service-set ipsec-gre service-filter match-vpn-input;
            service-set trust-untrust service-filter allow-gre;
        }
        output {
            service-set ipsec-gre service-filter match-vpn-output;
            service-set trust-untrust;
        }
    }
    address 172.16.1.2/24;
}
```

After the filter has been applied, the service filter packets are encrypted and decrypted in the IPSec tunnel:

```
lab@PBR> show services ipsec-vpn ipsec statistics

PIC: sp-0/0/0, Service set: ipsec-gre

ESP Statistics:
  Encrypted bytes:            51408
  Decrypted bytes:            51408
  Encrypted packets:            459
  Decrypted packets:            459
AH Statistics:
  Input bytes:                    0
  Output bytes:                   0
  Input packets:                  0
  Output packets:                 0
Errors:
  AH authentication failures: 0, Replay errors: 0
  ESP authentication failures: 0, ESP decryption failures: 0
  Bad headers: 0, Bad trailers: 0
```

In addition, other internal flows are source-NAT'd as expected:

```
lab@PBR> show services stateful-firewall conversations
Interface: sp-0/0/0, Service set: trust-untrust

Conversation: ALG protocol: icmp
  Number of initiators: 1, Number of responders: 1
Flow                                    State    Dir       Frm count
IC   10.20.130.1:30242 ->  77.7.7.7       Watch    O              3
    NAT source     10.20.130.1:30242   ->       55.55.5.1:1033
ICMP 77.7.7.7:1033  ->      55.55.5.1     Watch    I              3
    NAT dest        55.55.5.1:1033    ->     10.20.130.1:30242

Conversation: ALG protocol: tcp
  Number of initiators: 1, Number of responders: 1
Flow                                        State    Dir  Frm count
TCP     172.16.1.2:1075  ->  172.16.1.1:179   Forward  O         77
TCP     172.16.1.1:179   ->  172.16.1.2:1075  Forward  I         76
```

The Life of a Packet

When you've decided which services you need in your network, implementing them can seem like a daunting task. Which configuration do you apply first? Which addresses do you apply to a given service when applying a rule? How about if you have a class of service (CoS) applied? Where do packet filters fit into the packet flow?

Figures 8-13 and 8-14 should help you sort through this mystery and decide where configuration processes occur. These diagrams are not meant to represent every possible scenario, but rather to give you a general feel for the complex processing that could be involved. The exact processing will depend on whether a next hop- or an interface-style service set is applied (for more on CoS concepts, refer to Chapter 9).

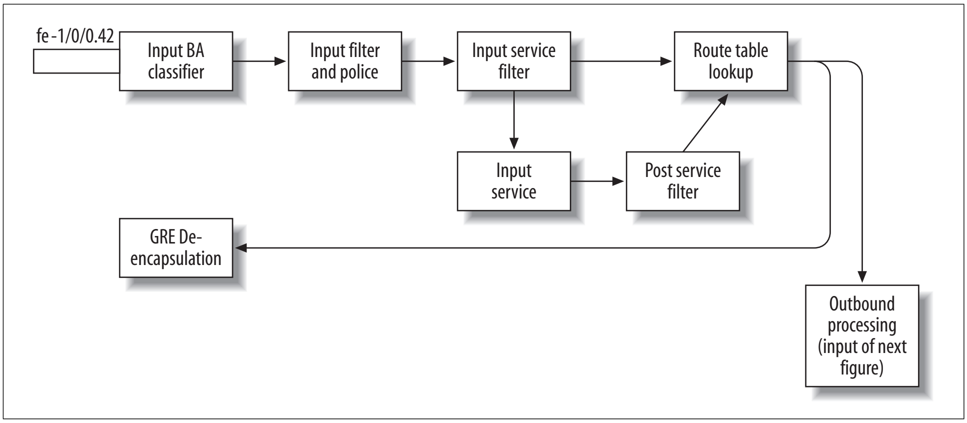


Figure 8-13. Incoming packet processing

The steps outlined in Figure 8-13 are as follows:

1. The packet enters the incoming interface.
2. The packet is classified by a behavior aggregate (BA) classifier.
3. The packet is processed by an input filter and policer (and may be reclassified).
4. The packet enters a service filter, and it is either serviced or skipped; if it is skipped, jump to step 7.
5. The input service is performed.
6. A post-service filter is applied.
7. The route lookup occurs.
8. If the result of the route lookup is a GRE packet, go to step 9; if not, send on for output processing.
9. De-encapsulate the GRE packet and go back to step 1.

After the packet is done with the input processing, it moves toward output processing (see Figure 8-14).

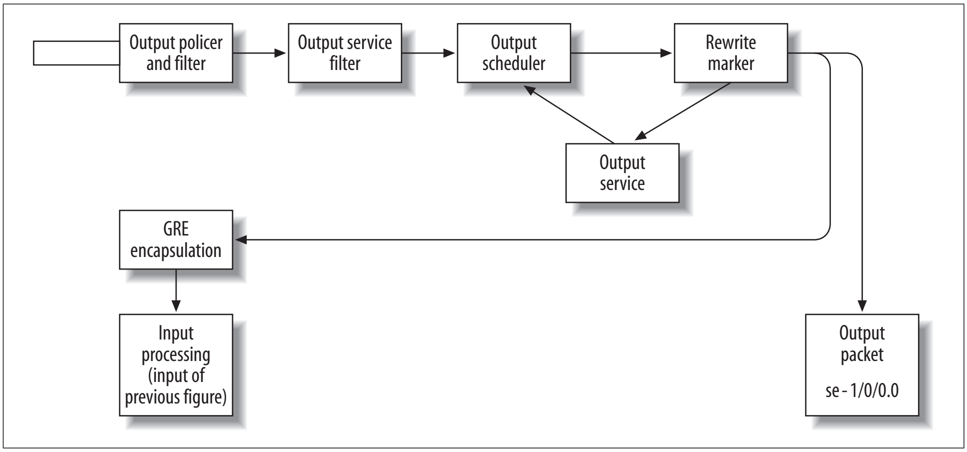


Figure 8-14. Outbound packet processing

The steps outlined in Figure 8-14 are as follows:

1. The packet is received from input processing and enters the output policer or filter.
2. The packet then goes through an output service filter to determine whether the packet will be marked for service. If the packet matches the service filter, the output interface is set to the service interface; if there is no match, the output interface is the outgoing physical interface.
3. The packet is sent to an output scheduler.
4. A write of the Type of Service (ToS) byte could occur. If the output interface is a service interface, go back to step 3; otherwise, go to step 5.

5. If the packet needs to be GRE-encapsulated, go to step 6; otherwise, go to step 7.
6. GRE encapsulation occurs, and the packet is sent back to the input processing stage where it is sent to step 1 of Figure 8-13 (input filters); after the GRE encapsulation, the input interface is the next hop outgoing interface of the GRE tunnel.
7. The packet is sent out the physical output interface.

Considerations Regarding Order of Operations

The packet processing order just discussed can be practically applied when designing the branch office connectivity for your network (see Figure 8-15). If connectivity is provided via IPSec VPNs and CoS is applied, where should the packet be classified? If an IPSec packet enters a router, the packet can be classified by setting the CoS value in the outer IP header using a BA classifier. However, after the packet is de-encapsulated, it enters the input filtering stage and is not sent through another BA classifier. That means that if packet classification is required on the de-encapsulated packet, you must use a multifield classifier (a firewall filter).

In comparison, if remote connectivity is provided by GRE tunnels, similar to IPSec tunnels, the incoming GRE packet could be classified using a BA classifier. The difference, however, is that once the GRE packet is de-encapsulated, it sends the inner packet through another BA classifier. This means you should apply the same classifier to the incoming interface and the `gr-` interface to avoid reclassification. Also, don't forget that when a GRE packet is encapsulated, it is reprocessed through all input filters and services on the output interface.

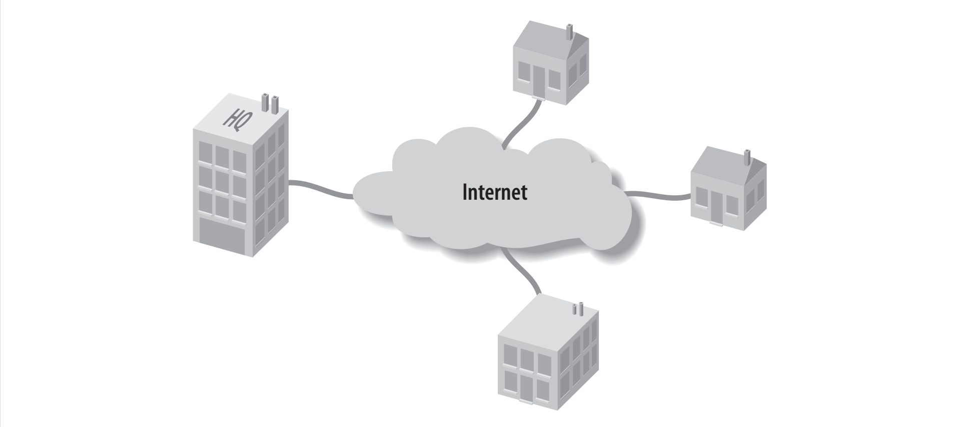


Figure 8-15. Branch office connectivity

The possible scenarios could fill an entire book, so be sure to consult Figures 8-13 and 8-14 for application to your network.

Conclusion

IP networks have changed drastically since they were first deployed 25 years ago, when addresses were plentiful and simple filters sufficed. In today's modern data networks, the concepts of yesteryear won't float for long. Packet filters will always have their place, but without tracking state, they will always have limitations; thus, the need for stateful firewalls. With IPv4 exhaustion coming to fruition, NAT has taken a front seat in network design and is now almost a requirement.

You can deploy these services individually or as a combined security design. When combining these services, be sure to verify each step along the way to avoid a broken configuration that is a bear to troubleshoot.

Although configuration may seem a bit daunting at first, the power and scalability of JUNOS are evident in the services code. For additional service examples to accompany this chapter, please consult *http://www.cubednetworks.com*.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- Configure and apply an interface-style service set.
- Configure a next hop-style service set.
- Identify the match direction given a network diagram.
- Understand and implement various types of service sets.
- Describe NAT and PAT.
- Configure a stateful firewall via the CLI.
- Monitor a stateful firewall.
- Configure NAT and PAT via the CLI.
- Monitor NAT and PAT via the CLI.
- Explain IPSec VPN processing on M-series and J-series routers.
- Configure an IPSec VPN via the CLI.
- Configure a route-based GRE tunnel (over IPSec) via the CLI.
- Monitor IPSec VPNs.
- IPSec tunnels as backup links.
- Routing over an IPSec or GRE tunnel.

Chapter Review Questions

1. Why are VRs the preferred implementation choice when deploying next hop-style service sets? (Choose two.)
   a. Added security benefits
   b. More features can be implemented
   c. Simplicity in configuration
   d. Automatic rules
2. Which match direction should be specified when creating an IPSec tunnel?
   a. De-encapsulation direction
   b. Both directions
   c. Encapsulation direction
   d. No direction
3. True or False: A single proposal can be applied to an IPSec tunnel.
4. Which type of service set would allow for OSPF routing over an IPSec tunnel?
   a. Next hop
   b. Interface
   c. Virtual router
   d. Route set
5. After an IP packet is encapsulated by a GRE header, what is the incoming interface of the packet set to?
   a. `service interface`
   b. `gre interface`
   c. `outgoing interface`
   d. `loopback interface`
6. Which type of NAT would be used to hide all local PCs' addresses as they connect to the Internet?
   a. Destination
   b. Half-Cone
   c. Twice NAT
   d. Source NAT
7. The following source NAT rule is applied to a next hop service set but doesn't seem to be working:

```
rule basic-source {
        match-direction output;
        term 1 {
            then {
                translated {
                    source-pool ext-block;
                    translation-type source dynamic;
                }
            }
        }
    }
}
```

What is the possible issue?

a. Missing a `from` statement

b. Can't use dynamic translation for source NAT

c. The match direction is incorrect

d. Missing the `accept` action

8. True or False: IPSec VPNs must have their own service set.

9. If packets need to be skipped in an interface-style service set, what should be configured?

   a. A service rule allowing traffic to be skipped

   b. A post-service filter allowing traffic to be skipped

   c. A service filter allowing traffic to be skipped

   d. A firewall filter allowing traffic to be skipped

10. Which NAT type is *not* supported on a Juniper router?

    a. Dynamic source

    b. Static source

    c. Dynamic destination

    d. Static destination

11. What are the advantages of using a NAT pool? (Choose two.)

    a. Can reuse pool in other rules

    b. Can implement discontinuous addresses

    c. Doesn't have to reference in a rule

    d. Can enable port translation

12. Why might there not be an active IKE SA for a configured and operational VPN?

    a. SA is no longer needed

    b. VPN has yet to time out

    c. IKE SA was never established

    d. GRE tunnel was used instead

Chapter Review Answers

1. Answer: A, C. VRs add a security benefit over other solutions since the interfaces and route tables are separated from the main table. Also, VRs avoid the complexity of rib-groups that plague other solutions.
2. Answer: C. The direction that encapsulates the packet into the IPSec tunnel should be used. In an interface-style service set, this is normally set to `output` whereas a next hop service set usually uses `input`.
3. Answer: False. You can apply multiple proposals to the IPSec tunnel; only one proposal has to match on each side for tunnel establishment.
4. Answer: A. You must use a next hop-style service set to support routing protocols.
5. Answer: C. Strangely enough, after a packet gets GRE encapsulation, the incoming interface is set to the next hop outgoing interface. This causes the GRE packet to be subject to input filters and services on the outgoing interface.
6. Answer: D. If a PC wants to be hidden from the outside world, you should deploy source NAT. This changes the "private" source IP to one or more "public" IP addresses.
7. Answer: C. One of the most common configuration errors when making service rules is not specifying the correct direction, especially when using next hop-style service sets, and match directions often seem backward when compared to interface-style service sets. Remember that traffic mapped to the inside interface is input traffic and traffic mapped to the outside interface is output traffic.
8. Answer: True. At the time of this writing, IPSec VPNs are always a unique service set, and no other service rules can be combined in the set. If you need to implement other services on top of IPSec, they must have their own unique service set.
9. Answer: C. Service filters allow for some traffic to be skipped through a service set. They also allow certain services to be selected.
10. Answer: C. At the time of this writing, dynamic destination NAT is not supported. All destination NAT must be statically mapped to the same IP address.
11. Answer: A, D. NAT pools provide greater scalability, as they can be reused in multiple terms and in multiple rules. Also, a pool is required if port translation needs to be enabled.
12. Answer: A. The IKE SA is needed only during the initial tunnel establishment to negotiate the IPSec tunnel parameters. After the IPSec tunnel is established, the IKE SA will time out and will reestablish only on an as-needed basis.

CHAPTER 9
Class of Service

This chapter details M7i and J-series class of service (CoS) capabilities while also demonstrating typical CoS configuration and verification steps under JUNOS software. A detailed comparison between the ASIC-based M7i and the software-based J-series platform is provided to clarify their operational differences, which is a common source of confusion given that they have so many similarities. The topics covered include:

- What IP CoS is and why it is needed
- IP differentiated services primer
- M7i and J-series CoS capabilities
- DiffServ-based CoS deployment and verification
- J-series virtual channels

Juniper Networks routers offer extensive support for IP CoS. As of this writing, the list of supported standards includes:

- RFC 2474, “Definition of the Differentiated Services Field in the IPv4 and IPv6 Headers”
- RFC 2597, “Assured Forwarding PHB Group”
- RFC 2598, “An Expedited Forwarding PHB”
- RFC 2698, “A Two Rate Three Color Marker”

What Is IP CoS, and Why Do I Need It?

Simply put, CoS provides a mechanism by which certain packets are afforded preferred treatment in an effort to provide the associated application with a level of performance required for proper operation. Although the preceding sentence seems simple enough, it implies support for several capabilities that must work together within each node—and in a *consistent* manner network-wide—for an IP CoS deployment to be successful.

Why IP Networks Need CoS

IP networks are based on the principal of statistical multiplexing (stat MUX), which is a resource-sharing technique that allocates resources on an as-needed basis. A stat MUX provides efficiency gains by playing the odds that a given application or user will not be active at its peak rate 100% of the time. By allocating bandwidth resources only when needed, a large number of bursty applications can be supported over a network with an aggregate capacity that is significantly less than the potential aggregate rate of its user base.

To make all this work, some degree of buffering is needed to accommodate the occasional synchronized bursts. Because no network has infinite buffers, flow control (typically supported by a virtual circuit [VC] technology) or simple discard in the case of datagram operation (connectionless) is needed during chronic periods of congestion. Throwing more buffers at the problem only changes the symptom from one of discard to one of delay and delay variance, which is known as *jitter*. Although non-real-time applications such as an order-entry system can tolerate loss and lengthy/variable delays, the user will generally have a degraded experience and productivity can suffer. More demanding real-time applications such as Voice over IP rapidly become unusable when loss and delay/jitter are not kept within relatively stringent bounds.

IP networks are based on statistical multiplexing, and there is an increasing trend to converge all communications, be it data, voice, video, real-time simulation, and so on over a single IP infrastructure to maximize return on investment and economy of scale. Put differently, a single network is far less expensive to deploy and maintain, and much to the chagrin of Integrated Services Digital Network (ISDN) and Asynchronous Transfer Mode (ATM), that single network technology is shaping up to be IP. Saving money always looks good on paper, but these gains quickly disappear if the result is unproductive, angered workers who can no longer perform their jobs due to intermittent application performance.

Historically, network technologies were circuit-based and were designed to support toll-quality voice. Although there is little to find sexy in “toll-quality voice,” these telephone network architects did not realize what they were dealing with: what would become the panacea of IP network quality of service (QoS)—namely, a service that provides (once connected) minimal and *fixed* delays, freedom from congestion, guaranteed bandwidth, in-sequence delivery, and low loss. Legacy circuit-switched networks are not without their drawbacks, and all indications are that the future of voice, data, and video transport will be packet- rather than circuit-based.

Overbuilding an IP network with excess bandwidth is a viable way to ensure that all applications work properly, even during periods of peak usage or network outages. The fact that costs associated with bandwidth are constantly dropping, and new ways are always being found to drive existing fiber to increasingly higher rates allows the “overbuild it and they will be happy” network design philosophy to pass the giggle test, which is to say that there are cases where adding bandwidth is more expedient, and potentially less costly, than deploying an IP CoS solution. This is especially true if existing IP infrastructure requires hardware upgrades to support CoS, which is often the case with legacy gear that may already be struggling in the basic IP routing role and that simply does not have the capability or resources to provide additional CoS processing.

When simply throwing bandwidth at the problem is not seen as feasible, due to either economic impact or equipment limitations, deploying IP CoS is the key to successfully converging services and applications onto an IP-based infrastructure.

Although there are CoS processing variances across the product line, all current Juniper Networks routing platforms provide IP CoS capabilities that you can deploy in a production network without negatively impacting basic IP packet forwarding performance.

Circuit-switching inefficiencies

Although legacy circuit-switched networks offered some mighty fine CoS, circuit-switched technologies are inefficient or poorly suited as a convergent technology in numerous areas. The root cause of this inefficiency is the lack of statistical multiplexing in circuit-switched networks, which prevents the sharing of resources during naturally occurring idle periods in communication streams. The issues with circuit switching and network efficiency are outlined in the following list, and they hold true whether using an analog or newer digital (ISDN) type of circuit switch:

Blocking during congestion
: Establishment of new circuits is blocked when the network reaches capacity through a call admission control (CAC) function (fast busy). This behavior helps to preserve the CoS of existing users, but lack of priority/preemption capabilities means that routine calls can lock out new users, even when their communication needs are high priority.

Dedicated resources
: Allocating guaranteed bandwidth in fixed chunks (64 Kbps DSO) is inefficient, even for voice, given that most communication is bursty—the simple fact that voice communication is inherently bursty, that it is half-duplex, and that speech waveforms are predictable and consist of idle periods is behind most speech compression algorithms.

Fixed bandwidth allocation
: The fixed allocation of bandwidth can be too coarse, given that it is based on multiples of a 3 KHz voice band coded into a 64 Kbps channel with standard Pulse Code Modulation (PCM). For some applications, this is too much bandwidth, and for others, it is not enough. Bonding multiple voice channels together

to form a higher-speed link is possible, but you are still forced to deal with complete channels—one channel may not be enough and two might be too much.

Poor survivability

In most cases, the failure of any link or node along a circuit-switched connection's path results in the loss of that connection. The user normally has to reestablish his connection to resume communications, which can take time. Furthermore, due to blocking, perhaps due to diminished capacity after equipment failure, the call may not succeed.

To date, most IP networks are not CoS-enabled. This is simply because the historic application of IP as an internetworking protocol for LAN and WAN interconnection simply did not warrant the added complexity, both in equipment design and in the network-wide configuration needed for a working CoS solution. In fact, with some early (non-Juniper) router architectures, enabling CoS services consumed so many resources that forwarding performance was actually *better* with CoS disabled.

In other cases, when some level of performance was actually required, engineers simply overbuilt the network from a capacity and bandwidth perspective. When all is said and done, the simple truth is that all of the world's most sophisticated CoS processing does no good for a packet that encounters a router with relatively empty queues anyway; CoS matters only when link utilization begins to exceed 80%; otherwise, packets are dispatched virtually as soon as they arrive, as there is no appreciable queue fill in such conditions. Put differently, enabling CoS on an underutilized network is akin to buying a low-emissions vehicle just so that you can use a carpool lane, and then finding your commute hours occur at 2:00 a.m. when the roadways are empty anyway.

Even though bandwidth prices continue to trend downward while the raw forwarding rates of routers continue to rise, there are practical limits to the "overbuild and they will be happy" philosophy of network design. In addition, the increasing trend toward the use of IP as a mission-critical infrastructure supporting many, if not all, of an enterprise's data, voice, and automation/manufacturing needs makes the prioritization of critical traffic a prudent decision. In the most basic sense, consider the outbreak of a fire that significantly reduces your network's capacity. With the "overbuild it" safeguard now up in smoke (pun intended), you reach for the last unmelted IP phone handset to summon emergency help. This is not the time that you should have to ask yourself whether you feel lucky; with IP CoS, you *know* that your critical voice signaling and related media packets will be the first to be routed, assuming, of course, that any routing is still possible.

The use of IP-based statistical multiplexing combined with a sound CoS deployment provides the best of all worlds—the efficiency gains of statistical multiplexing and easily extended IP-based signaling protocols that provide CAC (RFC 2205 RSVP) and/or preemption and priority (draft-ietf-tsvwg-mlpp-that-works), combined with the ability to support virtually all known application types over a single, future-proof network infrastructure.*

CoS Terms and Concepts

This section defines common IP network CoS terms and operational concepts in the context of JUNOS software, and the terminology used in the Internet QoS working group's survey titled "Network QoS Needs of Advanced Internet Applications." The reader is encouraged to consult this document for a detailed description of application-specific characteristics and typical CoS needs; the focus here is strictly on those QoS parameters and concepts associated with IP layer network operation and packet handling.

It should also be noted that the actual measurement of IP performance, including the effects of CoS, is defined in RFC 2544, "Benchmarking Methodology for Network Interconnect Devices."

This section explores the following terms and concepts:

- Network QoS parameters
- Classification
- Packet marking
- Forwarding classes, queues, and schedulers
- Congestion management
- Policing and shaping
- Typical CoS processing stages in a Juniper router

Network QoS parameters

In common vernacular, the terms *CoS* and *QoS* are used interchangeably. To help keep things clear, this chapter reserves the term *QoS* for individual network parameters such as delay or loss probability, and uses *CoS* to describe the combined effect of applying specific QoS parameters to a packet stream, which should result in a service differentiation among the supported traffic classes in your network.

By way of analogy, consider commercial aviation and the typical coach versus first-class traveling experience. First, if there were no differences between these service classes, the airline would have a hard time charging so much more for a first-class seat.

* Although the future of IP may well rest with IPv6, version 4 has shown a remarkable degree of resiliency and has quietly supported the world's internetworking needs while rival after rival has come and gone, leaving only obsolete certifications in their wake. There are numerous migration strategies to move from IPv4 to IPv6, and the CoS models are the same, which allows direct application of this material to an IPv6 infrastructure when needed.

It can be said that the service associated with these classes of travel is in turn a function of various QoS parameters, such as the maximum time to get a drink after being seated (delay), the likelihood of having your luggage make it to your destination (loss), and being treated to proper flatware and real food, as opposed to the experience of using a plastic spork (a combined spoon/fork) to choke down a bag lunch. The combined effects of these airline-based QoS parameters yield a particular CoS, and each such service class is differentiated so as to leave little ambiguity as to which class one happens to be traveling in at any given time.

To get maximum benefit of network QoS, the user's application should be QoS-aware so that it can request the appropriate resources during CAC (when supported) and correctly mark its traffic to ensure that it maps to the desired service class or classes.

The primary network QoS parameters are defined as follows:

Bandwidth
: Bandwidth is a measure of each link's information-carrying capacity. It is limited by the lesser of the bandwidth supported by each link crossed between two endpoints.

Delay
: Delay is a measure of the time taken to move a packet from one point to another. End-to-end delay is a cumulative function of serialization delays, propagation delays, and any queuing delays (buffering) that the packet may experience.

Delay variation (jitter)
: Delay variation, often called jitter, is a measure of the variance in transfer delays between packets that make up a stream. Jitter is significant to real-time applications because the receiver must dimension its jitter buffer based on maximum jitter, which adds delays for all packets and causes eventual loss when jitter values exceed buffer capacity.

Loss
: Loss measures the percentage of packets not delivered. Loss can stem from transmission errors or discard stemming from congestion in packet-based networks.

Loss pattern
: The loss pattern defines the nature of a loss event as either bursty (short duration) or chronic, which is sometimes called a *dribble error*.

Classification

Classification is the act of associating received packets with a defined forwarding class, which in turn maps to a queue. Classification is a critical aspect of IP CoS, given that the underlying principle of CoS is to enforce different forwarding behavior on one packet versus another, based on the associated set of QoS parameters defined for each forwarding class. Errors in classification result in incorrect handling of the associated packet stream, which may negate CoS benefits by treating all traffic the same or by causing congestion in one or more forwarding classes, which in turn leads to loss and delay-related problems for that forwarding class. Figure 9-1 shows how incoming packets are subjected to a classifier function that in turn maps each packet to a defined forwarding class.

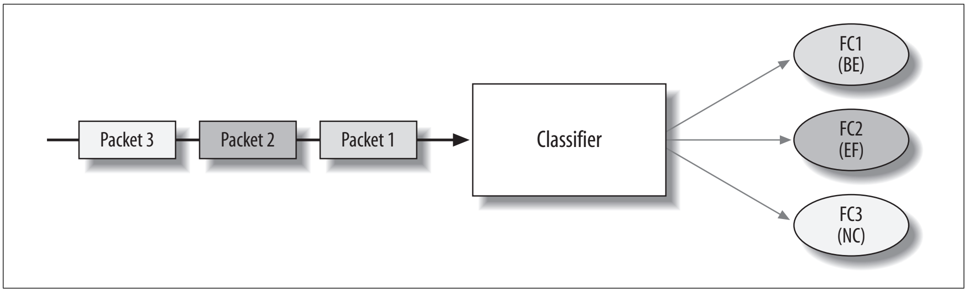


Figure 9-1. Classification

At egress, the forwarding class is used to link the packet to the correct output queue/scheduler profile. Classification can be a resource drain on a router, because it adds processing steps to each received packet. Modern IP routers support two types of classification to help mitigate resource consumption concerns:

Multifield classification
: Multifield classifiers are the most flexible and therefore the most computationally burdensome type of classifier. As the name suggests, a multifield classifier is based on matches against multiple fields with the IP packet, including source and destination addresses, protocol type, ports, and so on.

Behavior aggregate (BA)
: A BA classifier uses a fixed field in the packet header to make classification decisions. This is highly efficient because of the fixed position, length, and meaning of the bits used in the BA classification field. Classifications based on IP precedence or Differentiated Services code points (DSCPs) are examples of BA classification.

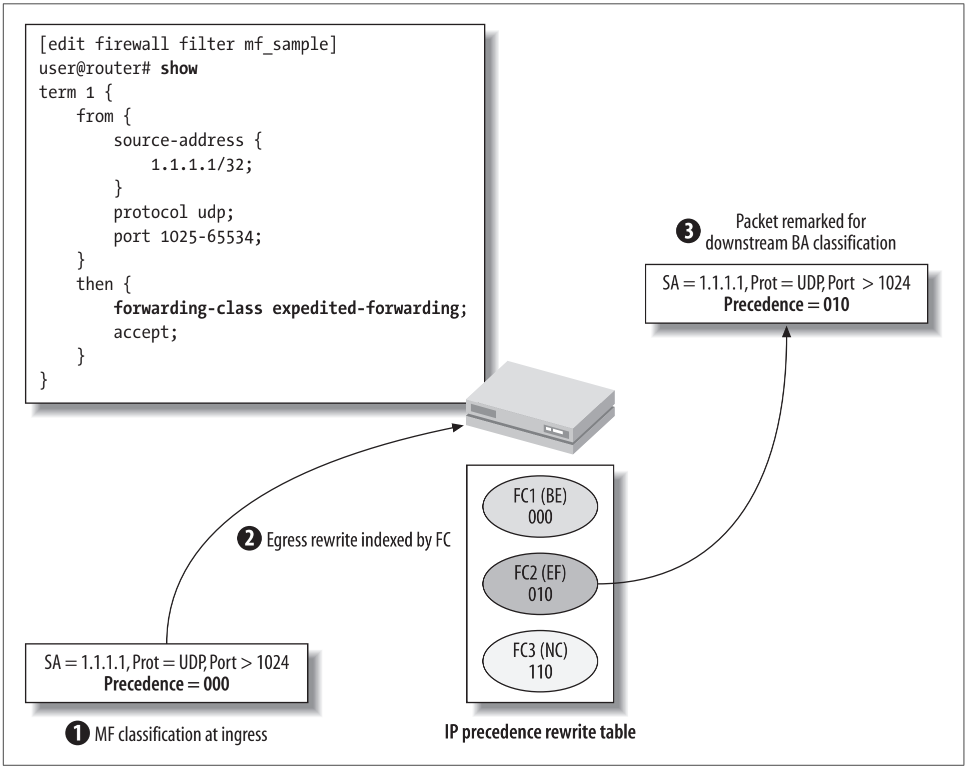
Normally you deploy multifield classifiers at the network's edges, as close to the traffic source as possible—that is, in the access layer. Once correctly classified, the packets are typically remarked to permit the more efficient BA type of classification in the aggregation and core layers. Juniper routers use firewall filters to perform multifield classification and support various types of BA classifiers, as detailed in "BA classification capabilities," later in this chapter. The highly efficient manner in which JUNOS software firewall filters are compiled and optimized allows large-scale use of multifield classification without incurring a significant reduction in forwarding capacity. With that said, you should use BA type classification wherever possible to keep things streamlined.

Loss priority. Many CoS models expect that loss will be lower in some classes than in others, or that loss will be lower for traffic within a class when it conforms to the class's associated rate limit, versus a higher loss probability for nonconformant traffic. Technologies such as ATM and Frame Relay achieve this functionality with the cell loss priority (CLP) and discard-eligible (DE) bits, respectively.

The IP packet header does not have a mechanism for signaling a packet's loss priority. As a result, the loss priority status for an IP packet is an internal flag that is set based on classification or policing actions. Once a packet is flagged at ingress as having a low or high loss priority, other nodes are expected to make the same determination—policing is done at the edge, and the resultant loss status should not be altered once set. This is normally accomplished by rewriting the BA field. Downstream nodes then use the altered BA value during classification to determine that packet's loss priority.

Packet marking/rewriting

Once mapped to a forwarding class, a packet can be subjected to one or more rewrite rules. Rewrite rules are used to mark the packet to facilitate BA classification in downstream nodes. Figure 9-2 shows packet marking in action.



```
[edit firewall filter mf_sample]
user@router# show
term 1 {
    from {
        source-address {
            1.1.1.1/32;
        }
        protocol udp;
        port 1025-65534;
    }
    then {
        forwarding-class expedited-forwarding;
        accept;
    }
}
```

3 Packet remarked for downstream BA classification
SA = 1.1.1.1, Prot = UDP, Port > 1024
Precedence = 010
2 Egress rewrite indexed by FC
FC1 (BE)
000
FC2 (EF)
010
FC3 (NC)
110
SA = 1.1.1.1, Prot = UDP, Port > 1024
Precedence = 000
1 MF classification at ingress
IP precedence rewrite table

Figure 9-2. Packet marking

Step 1 of Figure 9-2 shows an incoming packet with a default IP precedence field that is subjected to a multifield classifier. In this example, the packet matches against the source address, protocol, and port range criteria associated with the Expedited Forwarding (EF) class, which results in a mapping to forwarding class 2. At egress, the packet is subjected to an IP precedence rewrite rule that is indexed according to each packet's assigned forwarding class and drop priority. In this example, packets belonging to forwarding class 2 (EF) have their IP precedence field rewritten to a binary 010—the altered IP precedence field can now be used for BA-based classification in downstream nodes (steps 2 and 3, respectively). Though not shown, the packet's local packet loss priority (PLP) can also be factored into a rewrite pattern that enabled downstream nodes, which typically do not perfom policing actions, to make the same discard priority determination.

Generally speaking, you cannot rely upon user applications to correctly mark the BA fields of their traffic streams; doing so can easily lead to service abuse by savvy users who know how to alter their operating system's protocol stack to alter the default marking of their packets. The current best practice is to perform multifield classification and re-marking to the appropriate forwarding class at the networked edges to ensure that BA tags used in the core meet your organization's acceptable use CoS policy. If desired, you can rewrite the BA field to a default value at network egress, perhaps to meet the receiving application's expectations or simply to hide the markings used for classification in the core.

Forwarding classes, queues, and schedulers

It's been established that packet classification results in the mapping of each packet to a forwarding class. So, what is a forwarding class? In Juniper parlance, a forwarding class essentially maps to a queue. Typically, there is a one-to-one mapping of forwarding class to queue number, but a many-to-one mapping is also possible. For example, the default CoS configuration defines only two forwarding classes—Best Effort (BE) and Network Control (NC)—and the default IP precedence classifier maps the eight possible precedence values into these two forwarding classes (queues) in a 6:1 and 2:1 ratio, respectively. Forwarding classes are referenced by symbolic names, which you can redefine if desired. Table 9-1 shows the default mappings.

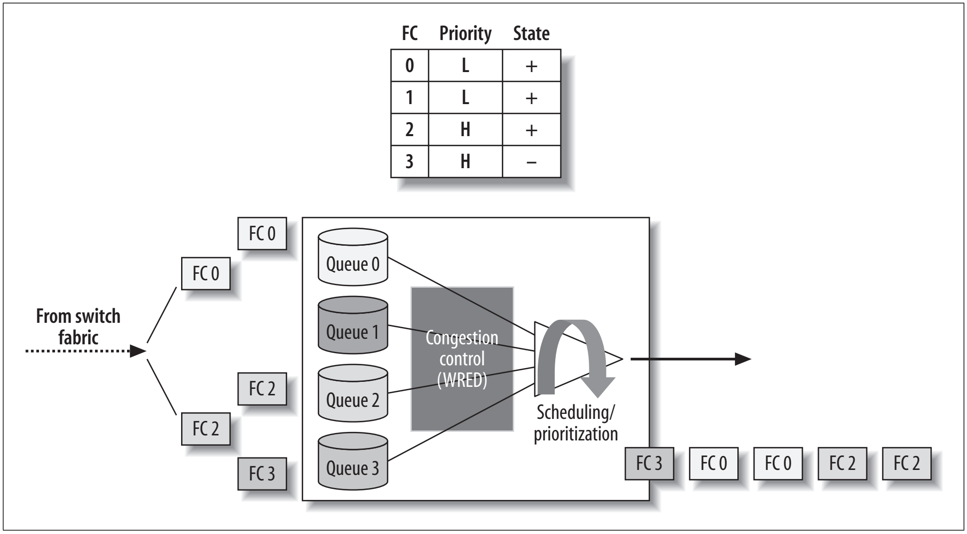
Table 9-1. Default forwarding class names and queue mappings

Forwarding class	Symbolic name	Queue number
0	Best-effort	0
1	Expedited-forwarding	1
2	Assured-forwarding	2
3	Network-control	3

In IP DiffServ terminology, a forwarding class maps to a *DS behavior aggregate*, or in the newer terminology, an *ordered aggregate*. The term *ordered* here refers to the fact that packets classified as part of the same micro flow should not be resequenced, and therefore the associated BA is expected to preserve sequencing. These terms describe the externally visible behavior of a DiffServ-compliant node for a given BA, which is a stream of packets with the same DSCP marking crossing a link in a particular direction. Stating this differently, and in English, a forwarding class is a stream of packets that, as a result of classification, are placed into the same egress queue and are therefore serviced by a common set of dequeuing parameters, resulting in consistent, and therefore predictable, handling of packets within that node.

Schedulers. Packets placed into an egress queue are serviced by a scheduler. The scheduler algorithm determines how often a queue is serviced, and in which order, based on an associated priority and transmit rate percentage. Packet scheduling combined with rate limiting and policing are an important aspect of IP CoS because together they provide the necessary isolation between forwarding classes. This isolation ensures that one misbehaving or nonconformant forwarding class does not degrade the service of other (compliant) forwarding classes.

The scheduler essentially controls how packets are dequeued for transmission, and it is therefore a critical component of the JUNOS software CoS model. Figure 9-3 illustrates the high-level operation of a scheduler.



FC	Priority	State
0	L	+
1	L	+
2	H	+
3	H	–

Figure 9-3. Scheduler operation

Figure 9-3 shows how packet notifications arriving from the switch fabric are placed into notification queues, based on their ingress classification. Recall that in the Juniper architecture, the packets themselves are placed into shared memory once, and only a notification that points to the packet's shared memory address is actually queued on the egress Flexible PIC Concentrator/Physical Interface Card (FPC/PIC).

The scheduler selects the next packet to dequeue based on a function on transmission credit and associated priority.

The basic algorithm (for M-series routers) is to service all high-priority queues with positive credit before moving on to service low-priority queues with positive credit. When no queues with positive credit remain, the scheduler divides any remaining bandwidth among those nonempty queues, typically using a simple round-robin algorithm (this can vary by platform, as detailed in "Scheduling and queuing" later in this chapter). The net result is that all queues are guaranteed to receive at least their configured transmission rate, and high-priority queues will exhibit less delay because the associated queue is serviced before low-priority queues as long as it remains within its configured transmit rate.

Figure 9-3 shows the scheduler state for each forwarding class as either positive (+) or negative (–) and also indicates the associated priority setting. In this example, queue 3 is set to high priority, but it is currently in negative credit—this means the queue has sent more traffic than its configured transmit percentage and must now wait to accumulate credit to go positive again. Queue 1 has no packets pending, so it is skipped—a work-conserving scheduler does not service empty queues. The result is that the high-priority queue (#2) with positive credit is serviced first, which results in the dequeuing of its two packets. Because there are no remaining high-priority queues with positive credit and pending notifications, the low-priority queues can be serviced, and queue 0, having pending traffic and positive credit, is serviced next.

Queue 0 is emptied after its two packets are serviced, leaving only queue 3 with traffic pending. Unless this queue is rate-limited, it will be serviced, despite its negative credit status, as long as no positive credit queues become active. However, servicing a queue with negative credit results in an increase in the queue's negative credit, up to some maximum value, which, while allowing a queue to send more than its configured transmit weight, ensures that other queues will be the first to be serviced as soon as they have a notification pending.

Congestion management

Statistically multiplexed networks are subject to congestion. This can be chronic as a function of design or transient due to equipment or circuit failures or because of synchronized bursts from users. In any of these events, a method is needed to deal with congestion gracefully, and in a manner that is fair to all users. Because datagram networks do not support flow control, discard is the only mechanism a router has to prevent total buffer meltdown during a congestion event.

Modern IP routers implement some form of Active Queue Management (AQM), which is intended to optimize discard actions to obtain maximum benefit and to ensure fairness. AQM for IP networks is defined in RFC 2309, "Recommendations on Queue Management and Congestion Avoidance in the Internet."

Put simply, when a queue is filling faster than it can be emptied, a router has two choices as to where to drop. It can wait until the queue can hold no more, and then simply drop all packets as they arrive (which is called *tail dropping*). Or it can detect incipient congestion and *proactively* begin to drop packets based on a probability function that is in turn tied to average queue depth. The latter technique is known as random early detection (RED) and has many advantages over simple tail dropping.

Tail dropping can allow hyperactive applications to lock out less busy users, and it tends to result in queues operating at near capacity. A queue is really useful only when it is able to absorb packet burst, and any queue, no matter how large, that is near its fill capacity becomes useless for absorbing burst (it's already full), and therefore serves only to add delay. RED acts before the queue is full, and works on the principle that Transmission Control Protocol (TCP) sources assume that lost segments stem from congestion, and lower their window advertisements as a result. This ultimately results in less traffic from the related TCP source.

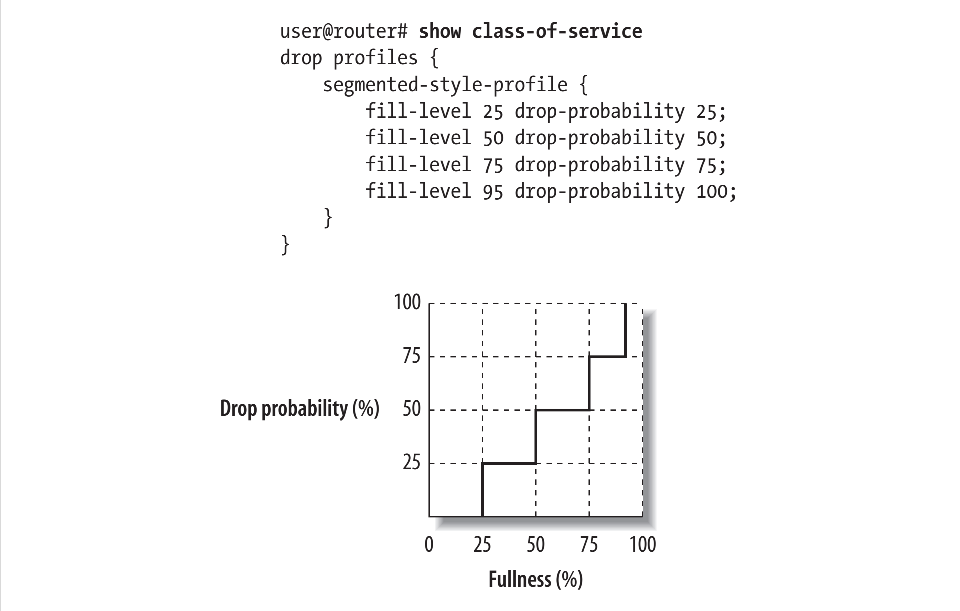
RED seeks to maintain an average queue fill by taking more aggressive drop actions as the queue fill increases. Using the queue's average fill level allows tolerance for receiving packet burst, because discards are probable only when the *average* queue level rises above configured thresholds. RED begins to perform tail drops once the queue reaches 100% full, in which case no new notifications can be queued and they are dropped upon receipt. The random nature of RED discards avoids the potential of queue lockout of certain users, as can occur with simple tail drops. In fact, because RED makes a discard decision upon receipt of each packet, the busiest users experience the most RED-induced drops, which is more than fair.

Figure 9-4 shows a sample RED configuration block and a graphical depiction of the resultant profile.

Weighted RED. Weighted RED (WRED) is simply a RED algorithm that maintains different drop probability profiles based upon traffic type. In the Juniper implementation, you can index one of as many as four RED profiles, based on traffic type of TCP versus User Datagram Protocol (UDP) with a loss priority of high or low. The result is a weighting of RED drop actions, based on traffic type.

Policing and shaping

Packet-based networks are capable of interconnecting devices and links that operate at variable speeds. Packet buffers are critical when supporting mixed-link speeds because they provide an elastic coupling between the high- and low-speed links. As noted previously, a packet buffer is most useful when it operates at a low fill level. Any packet network that constantly operates near buffer capacity should be redesigned, because a full buffer has lost its ability to provide additional buffering and leads only to increased delays.



```
user@router# show class-of-service
drop profiles {
    segmented-style-profile {
        fill-level 25 drop-probability 25;
        fill-level 50 drop-probability 50;
        fill-level 75 drop-probability 75;
        fill-level 95 drop-probability 100;
    }
}
```

Figure 9-4. RED configuration and profile

The inherent support of mismatched device and link speeds, combined with the many-to-one nature of datagram networks, can result in a chronic condition in which more traffic arrives at a device than can be transmitted downstream. If left unchecked, this condition can lead to indiscriminate tail dropping—WRED tends to have little effect on UDP-based applications, so cannot be relied on to prevent congestion.

To resolve this type of problem, a mechanism is needed to limit, or *cap*, the amount of traffic that a device is able to send. Such a mechanism is called *policing* or *rate limiting*, and serves to limit the overall amount of traffic that can be sent over a given unit of time by placing limits on maximum packet rate and burst size.

Isolation is needed to preserve CoS. Isolation between forwarding classes is a critical aspect of IP CoS. Class-based isolation is provided by the scheduler via its priority and transmit weight settings. However, isolation between classes is not sufficient to ensure fair service for users that share the same class. Although policing can be used on a forwarding class basis, it's commonly used at the individual device, or even at a micro-flow level, to limit the amount of traffic that is accepted into the network. Policing provides the necessary isolation between users or applications in the same forwarding class to prevent one user from dominating the resources associated with that class.

Policing versus shaping. Users are often confused about the differences between policing and shaping. Figure 9-5 shows the operational differences.

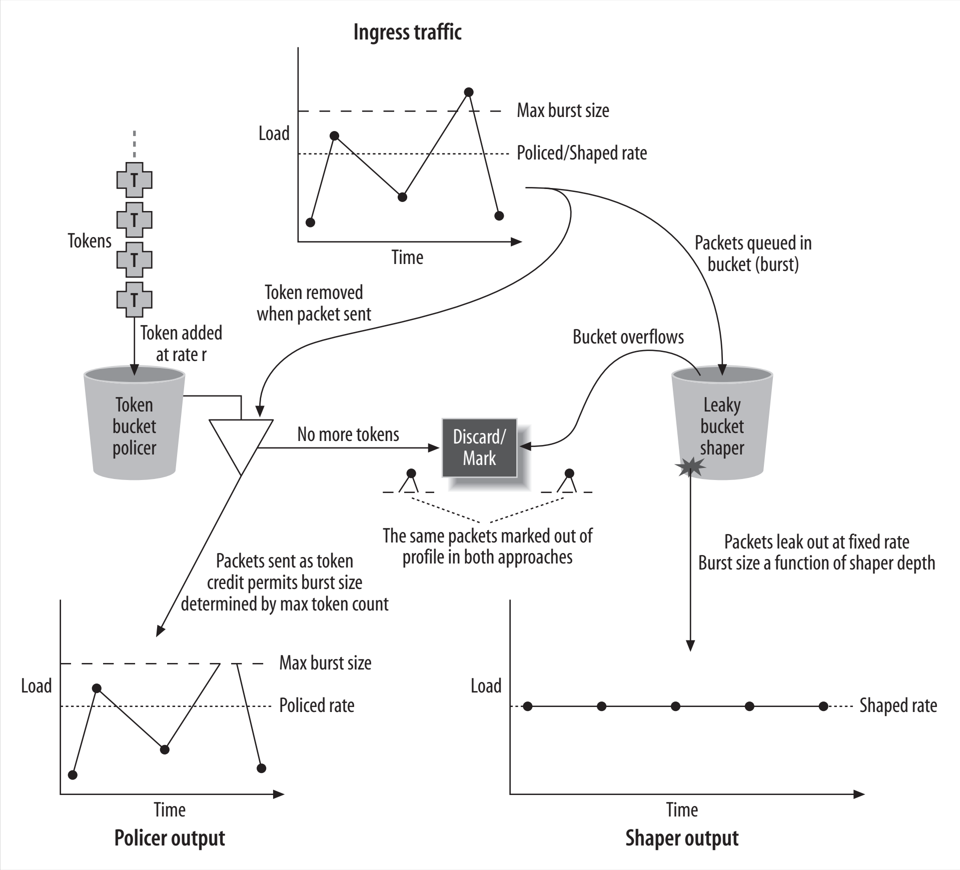


Figure 9-5. Policing versus shaping

The lefthand side of Figure 9-5 shows a typical token-rate-based policer. The size of the token bucket limits the total number of tokens that can accumulate, which in turn limits the maximum burst size. The rate at which new tokens are added limits the average transmission rate. Policers do not smooth traffic bursts, and they either mark or discard traffic that exceeds the configured burst size or average rate of token accumulation. A policer does not buffer the actual user traffic, and therefore does not add appreciable delays.

On the righthand side of the figure, the same input traffic is subjected to a leaky bucket-based shaper. The shaper buffers the actual user data (not tokens, as in the case of a policer), and the related output is spread over time to eliminate bursts—the shaper smoothes the peaks and valleys by buffering traffic and letting it leak out at a specified rate. The upside to shaping is that packet-buffering requirements are reduced in downstream nodes, given the lack of bursting. The downside is the need for buffering within the shaper, which adds delay and cost.

Generally speaking, on a macro level there is no difference in the amount of traffic transmitted (or marked/discarded) by a policer versus a shaper when they are configured with compatible parameters. At increasingly smaller time scales, the difference is manifest by the absence, or presence, of clumped packets (bursts) that instantaneously exceed the configured average rate. As long as downstream devices are not operating near buffer capacity, policing is generally preferred to shaping, given that it is less complex and less costly (buffers are not free), and does not induce any additional buffering delays. Stated differently, you perform shaping at an upstream device to *condition* traffic only when needed to meet the requirements of an attached device with limited buffering capabilities. If the downstream device is not buffer/capacity-challenged, it's far more efficient to quickly move traffic from point A to point B by sending bursts rather than artificially delaying each subsequent packet to eliminate clumping (bursts).

Summary of CoS processing steps

Figure 9-6 provides a big-picture view of the CoS processing stages associated with Juniper M- and J-series routers. Although useful in its own right, due to its detailed depiction of JUNOS CoS capabilities, the intent here is to tie the various terms and concepts discussed in this section into a single example to show how the various CoS process stages work together.

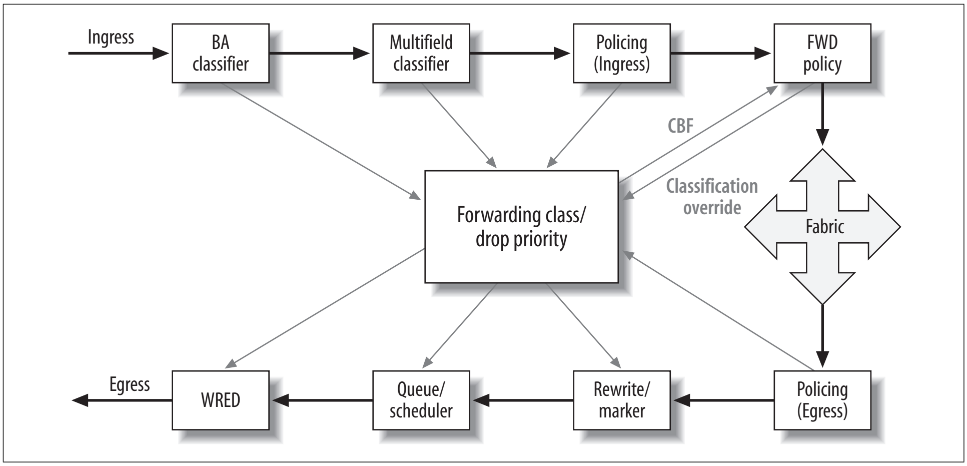


Figure 9-6. Big-picture CoS walkthrough

The discussion begins with a packet arriving at the ingress interface. The operation and general capabilities of each CoS stage encountered as a packet travels from ingress to egress are described as follows:

Ingress CoS processing

BA classification

Packets arriving at the router are first subjected to the BA classification stage. This stage sets the forwarding class and packet loss priority (PLP) using any of the supported BA classifier types, including IP precedence, Diff-Serv DSCP, IEEE 802.1P, and so on.

Multifield classification

The next processing stage is multifield classification. Here a firewall filter can be defined to match against numerous packet fields, incoming interfaces, and so on, in order to set the forwarding class or PLP or to override the values set during previous BA classification.

Ingress policing

When desired, a firewall or interface-level policer can be applied to limit matching traffic, by discard, by reclassification, or by marking excess traffic with a loss priority of high. This means that in the event of congestion, a RED profile can be used to more aggressively drop PLP high traffic.

Forwarding policy

The last ingress processing stage is forwarding policy. This policy can alter the existing forwarding class or PLP setting, and it can be used to select a forwarding next hop based on a forwarding class, a feature called *Class-Based Forwarding* (CBF).

Egress CoS processing

Egress policing

After encountering the switching fabric, a packet begins its journey toward the selected egress interface. The first egress CoS processing state is output policing, which is again based on either a firewall or an interface-level policer. Once again, excess traffic can be discarded or marked with a loss priority for later discard in the event of congestion.

Rewrite marker

The rewrite marker stage allows you to alter one, or in some cases multiple packet fields, as the packet is transmitted to downstream nodes. Normally, you rewrite packet fields to accommodate downstream BA-based classification. Rewrite markers are indexed by protocol family and by forwarding class—for example, writing a 001 pattern into the precedence field of all `family inet` packets that are classified as BE.

Queuing and scheduling

The queuing stage involves placing packet notifications into the corresponding forwarding class queue, where they are serviced by a scheduler that factors priority and configured weight to determine when a packet should be dequeued from a given queue.

RED/congestion control

The final CoS processing stage involves a WRED drop decision, based on protocol, loss priority, and average queue fill level. Recall that RED tends to operate at the head of the queue, and a RED decision is made against each packet selected for transmission by the scheduler stage.

At this stage, it should be clear that Juniper Networks enterprise routers offer a rich set of IP CoS capabilities that provide numerous points where a packet can be touched for CoS actions or manipulations. In most cases, a single router would not be configured to use all of these capabilities at the same time, but the Juniper design means that all CoS features can be deployed with minimal impact to the control and forwarding planes. As a point of fact, the default out-of-the-box configuration includes IP CoS, albeit in a relatively simplified manner. Details regarding the default CoS configuration are provided in "JUNOS Software CoS Defaults," later in this chapter.

A scalable CoS design strives to distribute the load—for example, by placing the relatively computationally intensive multifield classification function at the edges of the access layer only. Once classified, packets can be re-marked to accommodate streamlined BA-based classification in the core and distribution layers, where packet rates tend to be higher and more cycles need to be dedicated to forwarding traffic, rather than on complex classification tasks.

Figure 9-7 illustrates the CoS divide and conquer approach. It shows the CoS-enabled subset of the Beer-Co network, which has been divided into access and distribution/core layers. Generally speaking, CoS functionality is most complex at the edges of your network. This is because the network's edge has to deal with individual devices/micro-flows, whereas the core acts on traffic aggregates. Core devices are normally not burdened with CPU-intensive operations such as multifield classification, thus allowing these devices to focus their actions on actual packet forwarding. By policing at the network's edge, you throttle each user/application at ingress, making additional policing within the distribution and core layers unnecessary. Policing aggregate stream rates in the core is possible, but it has the serious drawback of allowing one or more hyperactive users to dominate the resources of that forwarding class. By performing rate limiting and related discard at the edges, as traffic initially ingresses the network, you can fairly limit all users to their assigned rate; when combined with a properly dimensioned core, additional policing actions are unnecessary.

The core CoS functionality of classification and resulting queuing/congestion control is performed by all nodes in the network to provide the consistent node-by-node, and therefore end-to-end, packet-handling behavior needed for a successful IP CoS deployment.

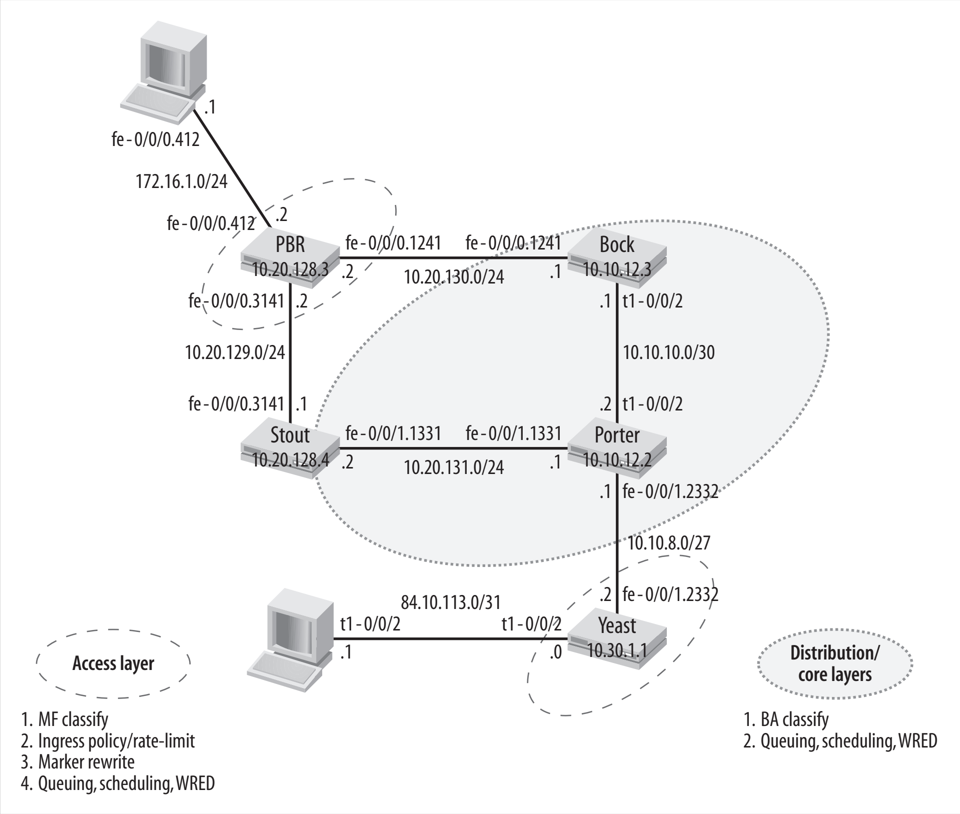


Figure 9-7. The CoS divide and conquer approach

IP CoS Summary

This section described IP CoS and why it's becoming increasingly important with the trends toward IP convergence. We defined basic network CoS/QoS terminology, and we walked through the typical CoS processing stages of a modern IP router.

Although likely not too earth shattering, there was a fair bit of information to digest here. You might consider taking a brief break before diving into the next section, which provides a primer on IP Differentiated Services (DiffServ).

IP Differentiated Services

Over the years, there have been several false starts to a standardized IP CoS solution. This section summarizes the history of IP CoS, and it provides a primer on the current solution known as IP Differentiated Services (DiffServ).

The original use of IP networks was to support robust communications in the face of battlefield conditions, an application to which datagram (connectionless) operation is well suited. This discussion is tempered with the knowledge that the concept of integrating services over IP internetworks was not considered by the protocol's architects, and wide-scale adoption of IP CoS has yet to occur. However, recent advancements in router platforms have enabled the high-bandwidth forwarding rates required to make IP-based convergence a commercial reality. With high-capacity forwarding in place, the final piece of the IP CoS puzzle is the intelligent handling of packets to effectively prioritize certain packets during times of reduced capacity or link congestion.

IP ToS

RFC 791 is the original RFC specification of the Internet Protocol (IP) and was published in 1981. The RFC defined an 8-bit field in the IP header as a Type of Service (ToS) field. Figure 9-8 shows the IP header and details the structure of the ToS field itself.

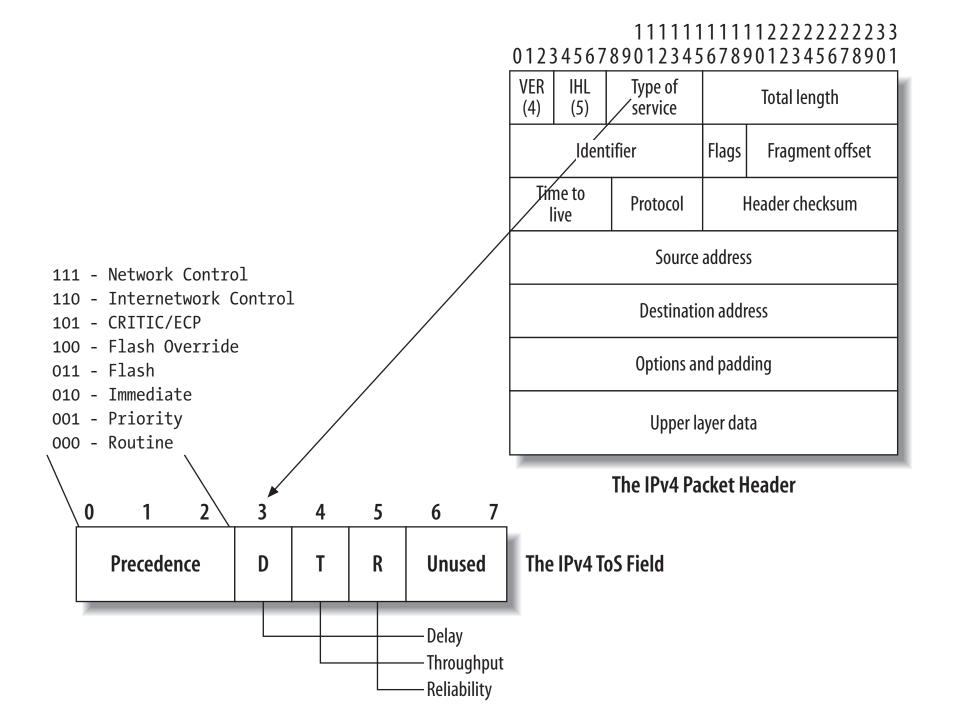


Figure 9-8. The IP ToS byte

The original IP ToS field is structured into a 3-bit precedence field, a 3-bit ToS indication field, and two reserved bits. The ToS bits were intended to provide a clue to the router as to which type of link metric (e.g., delay, throughput, or reliability) should be considered when handling the packet. This capability presumes a ToS-capable routing protocol, one that builds a routing information base (RIB) based on specific link metrics. Such a protocol has never seen use in commercial networks (Open Shortest Path First [OSPF] has this capability, but it never saw actual deployment).

Lack of ToS-capable Interior Gateway Protocols (IGPs) meant that the ToS bits have gone historically unused by routers. Many applications set these bits; for example, Telnet often sets the D bit to indicate low delay, but routers generally take no specific action upon any ToS combinations.

With bits 6 and 7 reserved, this left only the precedence field, which at 3 bits in length is able to code eight possible precedence levels (2^3). IP precedence is supposed to influence packet loss—generally speaking, each increase from the default value, which is 0, was expected to result in a reduced probability for discard. Unlike the ToS bits, IP precedence processing has been supported in routers for some time, but usually in a rather coarse, binary manner that results in two discard probabilities—a low probability for precedence values 6 and 7, which are associated with NC, and a higher probability for all other levels. In the Juniper implementation, the default behavior results in a maximum of four drop probabilities, two for non-NC classes and two for the NC class, based on a WRED profile set to act differently on high- versus low-loss probability traffic.

Most routing protocol stacks do in fact set the precedence bits of their control packets, as shown in the following `monitor traffic` sample, which explains how JUNOS software transmits an OSPF packet:

```
[edit]
lab@Bock# run monitor traffic interface fe-0/0/1.100 detail
Listening on fe-0/0/1.100, capture size 96 bytes
. . .
02:12:44.430326 Out IP (tos 0xc0, ttl   1, id 3867, offset 0, flags
[none], proto: OSPF (89), length: 68) 10.10.11.3 > 224.0.0.5: OSPFv2,=
Hello, length: 48
        Router-ID: 10.10.12.1, Backbone Area, Authentication Type:
none (0)
        Options: [External] [|ospf]
```

The hexadecimal value shown for the ToS field (*0xc0*) breaks down to a binary 1100 0000, which in turn codes IP precedence level 6 with the D, T, and R ToS bits cleared (not set). The default Juniper behavior is to classify based on IP precedence, such that NC messages are placed into queue 3, which is the default queue for the NC class, as shown here:

```
lab@PBR> show class-of-service classifiers type precedence name ipprec-compatibility
| match network-control
  110              network-control                    low
111              network-control                    high
```

A breakdown of IP precedence to binary, along with the decimal equivalent, is provided. This can be useful when testing CoS using utilities such as ping or traceroute, because when you include the tos switch, the resultant values are specified in *decimal*, not binary or hexadecimal. Note that only IP ToS bits are supported with the CLI tos switch—you cannot specify a DSCP value. Table 9-2 provides a complete breakdown of IP precedence to binary and the resultant decimal equivalents.

Table 9-2. IP ToS to binary and decimal equivalents

Precedence	Binary	Powers of 10	Decimal
Precedence 7	1110 00xx	128+64+32+0+0+0+x+x	224
Precedence 6	1100 00xx	128+64+0+0+0+0+x+x	192
Precedence 5	1010 00xx	128+0+32+0+0+0+x+x	160
Precedence 4	1000 00xx	128+0+0+0+0+0+x+x	128
Precedence 3	0110 00xx	0+64+32+0+0+0+x+x	96
Precedence 2	0100 00xx	0+64+0+0+0+0+x+x	64
Precedence 1	0010 00xx	0+0+32+0+0+0+x+x	32
Precedence 0	0000 00xx	0+0+0+0+0+0+x+x	0

Enter IP Integrated Services

Recognizing an increasing need for functional IP CoS, the Internet Engineering Task Force (IETF) began work on an Integrated Services (IS, or IntServ) model that was first published in 1994 in RFC 1633, “Integrated Services in the Internet Architecture: An Overview.” The authors felt that simple packet classification and scheduling was not enough to guarantee real-time services over the Internet, and specifically felt that some form of admission control and resultant resource reservation was needed. Figure 9-9 shows the IntServ concept.

The added functionality needed to support IntServ is shown in the upper-right portion of the router’s control plane in Figure 9-9—specifically, the addition of the CAC and the reservation control entities, along with the related resource reservation database and related hooks into the router’s management plane.

Put simply, the IntServ plan was to include the Resource Reservation Protocol (RSVP), as defined in RFC 2205, to routers and hosts, adding what amounts to a *call establishment* phase (for non-BE traffic). Here, the user specifically requests resources from the network, while also characterizing the nature of the related traffic with parameters such as average and peak rates, maximum transmission unit (MTU), and so on.

Each network node then either accepts or rejects the reservation request based on its local CAC function, which is run against that node’s current resource availability, as shown at the bottom of the figure. When all nodes along the path accept the reservation, soft state is established for the duration of the reservation and is used to create

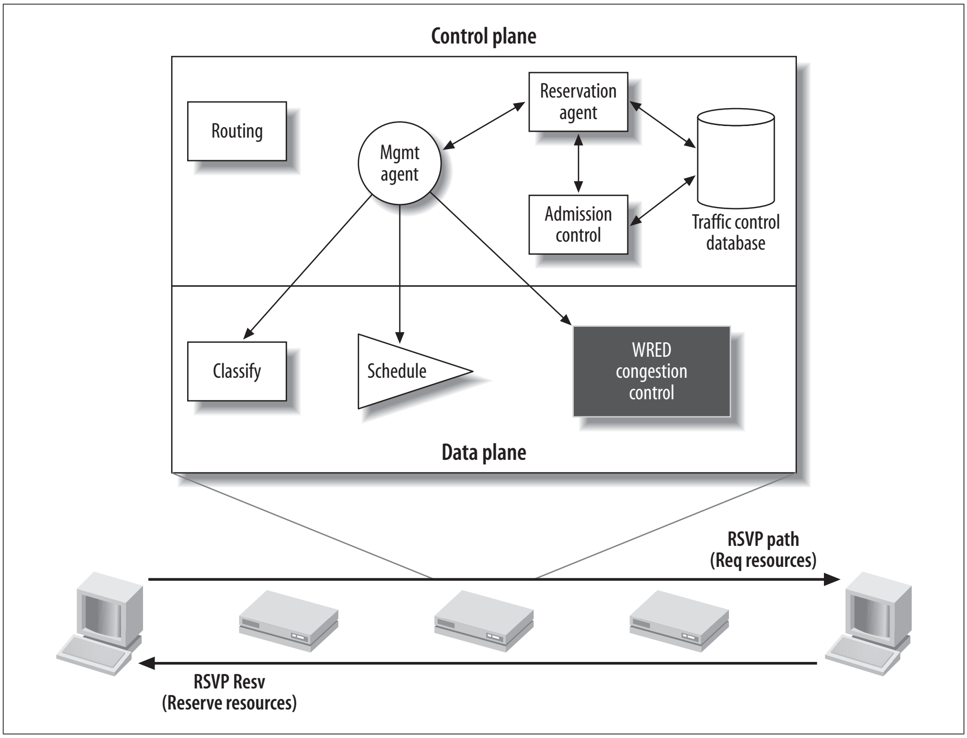


Figure 9-9. IP Integrated Services

the data plane state needed to support the new reservations. Specifically, a classifier is instantiated to match traffic belonging to that reservation using the details contained in the RSVP filter spec object. The reservation is torn down when it is no longer needed. This results in removal of the related data plane state and the freeing of allocated resources to accommodate the next reservation request. When a node is encountered that cannot meet the reservation's requirements, the session fails with the appropriate reason given—in theory, the user application will either keep trying, give up, or reduce its resource request to improve its chances of success.

Although all this sounds great, many practical issues resulted in little to no real deployment of IntServ. Ironically, the RSVP signaling protocol has seen significant commercial success as a Multiprotocol Label Switching (MPLS) signaling protocol within service provider networks, rather than in its original QoS signaling role.

The biggest nail in the IntServ coffin was the need to establish and maintain control plane state for every non-BE flow in the network. Even today the development of a large-scale, flow-based router remains a daunting task, at least at the scale needed for a modern Internet core router. Perhaps when the plan was IP at the edge supported by an ATM circuit-switched core, such a model could fly, but IntServ simply cannot scale to today's Internet needs. It is noted that RFC 3175, "Aggregation of RSVP for

IPv4 and IPv6 Reservations," offers a scalable model in which individual RSVP micro-flows can be aggregated into fewer, larger flows. Although promising, as of this writing, neither Juniper nor Cisco offers support for Aggregated RSVP in its shipping products.

IntServ results in network blocking when the network approaches capacity, meaning that no new reservations can be placed. Although not a problem for those users lucky enough to already hold a reservation, the total absence of (integrated) service for the remaining users was seen by many as a serious violation of the historical Internet paradigm of providing the same level of (degraded) service to all users in the same class. With IntServ, users at the *same* service level can be locked out by existing reservations, and the real rub is that this is true even when those existing reservations are not transporting traffic due to bursty sources. Many still have a hostile view toward the idea of blocking users in the control plane (putting aside the scaling issues of a control plane that has to interact on an end-user micro-flow basis), when at that very moment the data plane may well be idle, leading to wasted resources.

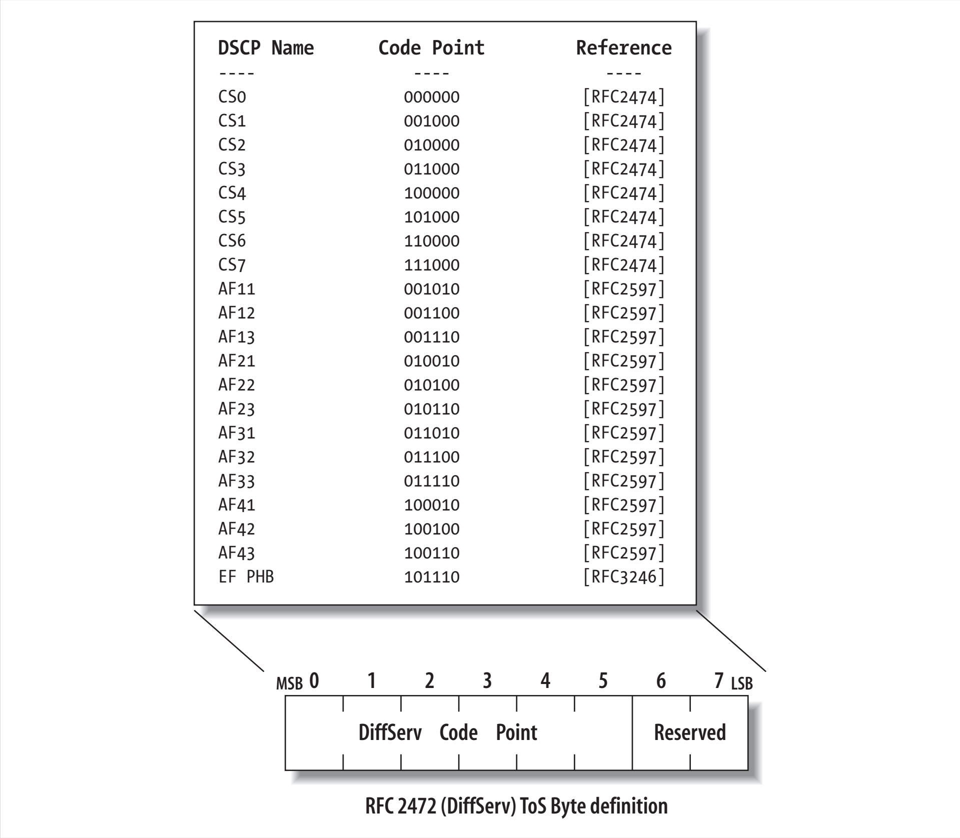
The commercial failure of IntServ prompted the development of a data-plane-only solution known as Differentiated Services.

IP Differentiated Services

IP Differentiated Services (DiffServ) was originally defined in RFCs 2474 and 2475 in 1998. Since that time, several RFCs have updated the original definition of the DSCP. RFC 3168 added explicit congestion notification (ECN) support, and RFC 3260 clarified the terminology to support MPLS traffic engineering, but the essence of the original DiffServ architecture remains.

DiffServ is scalable because it is a data-plane-only solution; there is no signaling component to DiffServ. DiffServ redefines the original IP ToS byte to support a 6-bit field, which, as noted previously, is called the DiffServ code point (DSCP). This provides for up to 64 levels of BA classification. Figure 9-10 shows the DiffServ definition of the IP ToS field. Related RFCs define the current set of per-hop behaviors (PHBs), which are described later, and essentially define the externally visible handling characteristics associated with a given forwarding class, or BA in DiffServ terminology.

Figure 9-10 also shows a table of the recommended DSCP mappings, most of which have yet to be defined. The Class Selector (CS) code points are designed to mimic the functionality of IP precedence, and they provide backward compatibility for non-DiffServ-aware routers, assuming any still exist. All of the CS code points have zeros where the original ToS definition placed the Delay, Throughput, and Reliability (DTR) flags. The 6-bit DSCP field leaves the original two least-significant bits (LSBs) of the original IP ToS field untouched, where they can be used for ECN signaling as per RFC 3168, "The Addition of Explicit Congestion Notification (ECN) to IP."



DSCP Name	Code Point	Reference
----	----	----
CS0	000000	[RFC2474]
CS1	001000	[RFC2474]
CS2	010000	[RFC2474]
CS3	011000	[RFC2474]
CS4	100000	[RFC2474]
CS5	101000	[RFC2474]
CS6	110000	[RFC2474]
CS7	111000	[RFC2474]
AF11	001010	[RFC2597]
AF12	001100	[RFC2597]
AF13	001110	[RFC2597]
AF21	010010	[RFC2597]
AF22	010100	[RFC2597]
AF23	010110	[RFC2597]
AF31	011010	[RFC2597]
AF32	011100	[RFC2597]
AF33	011110	[RFC2597]
AF41	100010	[RFC2597]
AF42	100100	[RFC2597]
AF43	100110	[RFC2597]
EF PHB	101110	[RFC3246]

RFC 2472 (DiffServ) ToS Byte definition

Figure 9-10. The DiffServ code point

DiffServ Terminology

This section defines key DiffServ terms and operational concepts. Refer to Figure 9-11 to match the terms to their functional location in a DiffServ network.

BA
: This is a classification based on DSCP packets with a common DSCP belonging to the same BA.

DiffServ field
: This is the original IPv4 ToS byte. DSCPs occupy the six most significant bits of the DS field.

PHB
: This is the externally visible forwarding treatment associated with a given BA. Within a DiffServ domain, the set of PHBs should be consistent across all nodes, resulting in a consistent end-to-end handling of traffic.

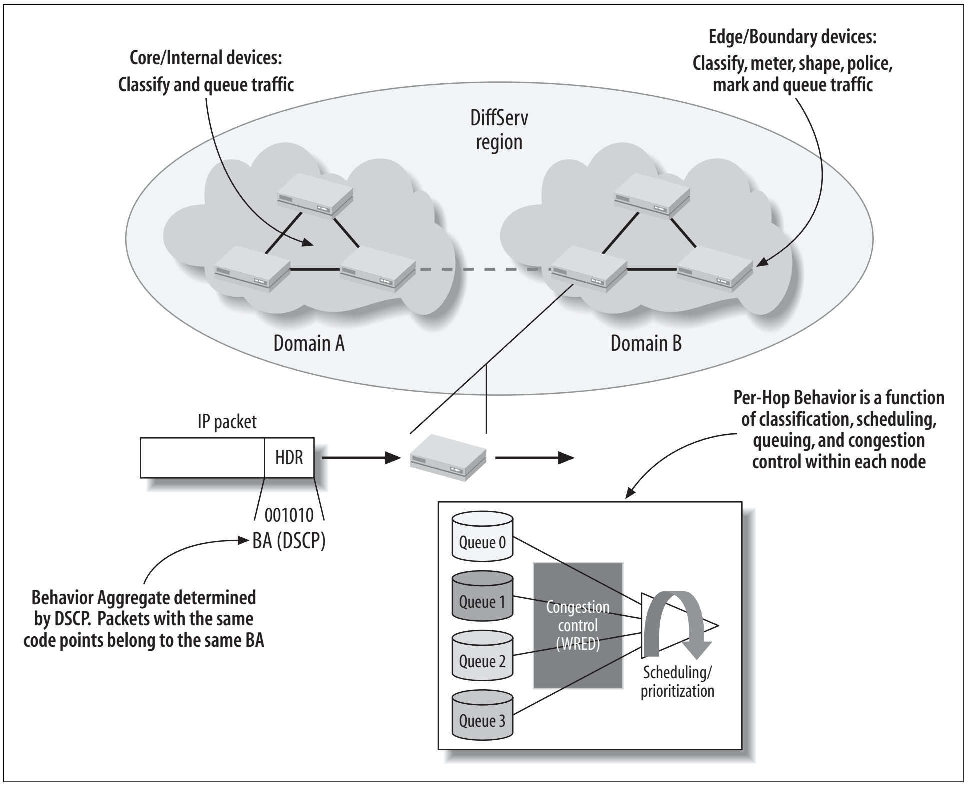

Core/Internal devices:
Classify and queue traffic
Edge/Boundary devices:
Classify, meter, shape, police, mark and queue traffic
DiffServ region
Domain A
Domain B
IP packet
HDR
001010
BA (DSCP)
Behavior Aggregate determined by DSCP. Packets with the same code points belong to the same BA
Per-Hop Behavior is a function of classification, scheduling, queuing, and congestion control within each node
Queue 0
Queue 1
Queue 2
Queue 3
Congestion control (WRED)
Scheduling/ prioritization

Figure 9-11. DiffServ terminology and concepts

PHB group
This is a set of one or more PHBs that can only be meaningfully specified and implemented simultaneously, due to a common constraint applying to all PHBs in the set, such as a queue servicing or queue management policy. Currently, the only standardized group behavior relates to the Assured Forwarding (AF) PHB.

DiffServ domain
This is a contiguous collection of nodes under a common policy with a common set of PHBs:

- Edge/boundary devices classify, meter, shape, police, mark, and queue traffic.
- Core devices classify and queue traffic.

DiffServ region
This is a contiguous set of interconnected DiffServ domains.

DiffServ PHBs

Currently, four PHBs are standardized within DiffServ: the default PHB and the CS, EF, and AF groups:

The default PHB

The default PHB must be present in each DiffServ-compliant node, and it defines a BE delivery service. Any packets that are not explicitly classified into one of the other PHBs are considered to belong to the default group. Although the default group should not be starved, BE is generally serviced only after all other active PHBs have been given their share of bandwidth.

The CS PHB

The CS PHB is designed to subsume the historic drop behavior associated with the original IP precedence field definition. The PHB behavior set for the CS PHB is left somewhat vague, in keeping with the fact that IP precedence was used only to control drop probability and not to provide any delay, delay jitter, or minimum through guarantees. To be compliant, a DiffServ node supporting the CS PHB must demonstrate at least two different forwarding behaviors, and a packet with a CS value of 000xxx should be dropped in preference of a packet with a CS code point of 111xxx. Put simply, there are no throughput or delay guarantees in the CS PHB, and at a minimum, a node is expected to favor CS code points mapping to IP precedence 6 and 7 over all other CS values from a drop perspective.

The EF PHB

The EF PHB is associated with a low-latency, low-jitter, low-loss, end-to-end service. This type of service is suitable for circuit emulation, or the support of voice, video, or other real-time services. EF support is not mandated, but when offered, the EF PHB requires two independent functions: that each node is configured with a minimum departure rate that is independent of the activity levels of other PHBs within that node; and that the EF BA be conditioned through policing or shaping to ensure that the EF arrival rate at any node is always less than that node's configured minimum departure rate. The first behavior is defined within the EF PHB itself, and the second is a function of general traffic conditioning.

The AF PHB

The AF PHB is a family of PHBs, called a *PHB group*, which is used to classify packets into various drop precedence levels. The drop precedence assigned to a packet determines the relative importance of a packet within the AF class and generally also indicates whether that packet was within, or above, some guaranteed rate. Packets within the associated AF PHB group's minimum rate have the lowest drop probability and are expected to be delivered, whereas packets above the minimum rate have an increasing probability of loss.

The AF PHB can be used to implement a multitiered model consisting of three classes—bronze, silver, and gold—and is associated with loss-sensitive, nonrealtime applications. A minimal AF PHB implementation is required to recognize all three drop priorities within each supported AF group, but it has to offer only a minimum two-drop precedence within each AF group.

Recommended/default DHCPs. Each administrator of a DiffServ region is free to choose the specific DSCPs that map to supported PHBs. It's critical that any such mapping be consistent across all nodes in the DiffServ domain/region. Packet re-marking can be used to map between two regions that are part of the same domain, but this process is prone to error. The various IETF documents describing DiffServ PHBs provide recommended DSCP mappings, which were shown in Figure 9-10.

DiffServ Summary

This section provided a brief history of IP CoS, from the original ToS definition to the not-quite-successful IntServ model on up to the current approach known as IP Differentiated Services. The data-plane-centric approach defined in DiffServ provides a scalable solution that is known to work.

DiffServ is based on the principle of isolation between forwarding classes (BAs) and a consistent classification and resultant per-hop behavior across the routers in a DiffServ domain, such that predictable end-to-end CoS can be provided.

The next section provides a detailed description of M7i and J-series CoS capabilities and their differences. There is a lot to cover, so perhaps another break is in order before you dive back in.

M7i and J-Series CoS Capabilities

With a thorough grounding of IP CoS concepts and terminology now under your belt, it's time to get down to the particular CoS capabilities of Juniper's enterprise routing products, specifically the M7i and J-series service routers.

Although both the M7i and the J-series run pretty much the same JUNOS software, the ASIC-based HW design of the M7i versus the software-based J-series does lead to some operational differences and capabilities. Fortunately, the vast majority of CoS functionality is shared between the two platforms, and this section is structured accordingly—the common capabilities are covered first, followed by details regarding any specific exceptions or differences.

The discussion of CoS capabilities and default settings is presented in the context of the CoS packet processing steps available for transit traffic. This is done to provide structure and to reinforce your understanding of CoS processing stages within a Juniper router. You should refer back to Figure 9-6 as each CoS processing stage is discussed.

You configure CoS at the `[edit class-of-service]` hierarchy, which has quite a few options under it. The primary CoS configuration options are displayed:

```
[edit]
lab@Bock# edit class-of-service
```

```
[edit class-of-service]
lab@Bock# set ?
Possible completions:
> adaptive-shapers     Define the list of trigger types and associated rates
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
> classifiers          Classify incoming packets based on code point value
> code-point-aliases   Mapping of code point aliases to bit strings
> drop-profiles        Random Early Drop (RED) data point map
> forwarding-classes   One or more mappings of forwarding class to queue number
> forwarding-policy    Class-of-service forwarding policy
> fragmentation-maps   Mapping of forwarding class to fragmentation options
> interfaces           Apply class-of-service options to interfaces
> loss-priority-maps   Map loss priority of incoming packets based on code point
value
> rewrite-rules        Write code point value of outgoing packets
> scheduler-maps       Mapping of forwarding classes to packet schedulers
> schedulers           Packet schedulers
> traceoptions         Trace options for class-of-service process
> virtual-channel-groups  Define list of virtual channel groups
> virtual-channels     Define the list of virtual channels
```

Input Processing

Input processing stages include BA classification, multifield classification, policing, and forwarding policy actions. Each is discussed separately.

BA classification capabilities

The BA classification stage supports classification based on the following Layer 3 and Layer 2 fields:

- DSCP (Layer 3, 64 levels in updated ToS byte)
- IP precedence (Layer 3, eight levels in ToS byte)
- MPLS EXP (Layer 2, four levels via experimental [EXP] bits in MPLS tag)
- IEEE 802.1p (Layer 2, eight priority levels in 802.1Q virtual LAN [VLAN] tag)

If you apply an IEEE 802.1p to a logical interface, you cannot apply any other classifier types to other logical interfaces on the same PIC port unless you are configuring an intelligent queuing (IQ)/IQ2 PIC (J-series routers emulate IQ/IQ2 PIC functionality). Some combinations of BA classifiers simply make no sense and are mutually exclusive; for example, you cannot apply both an IP precedence and a DSCP classifier to the same logical interface at the same time. You configure a BA classifier at the `[edit class-of-service classifiers]` hierarchy:

```
[edit class-of-service classifiers]
lab@Bock# set ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
```

```
> dscp                 Differentiated Services code point classifier
> dscp-ipv6            Differentiated Services code point classifier IPv6
> exp                  MPLS EXP classifier
> ieee-802.1           IEEE-802.1 classifier
> inet-precedence      IPv4 precedence classifier
```

The following example shows a user-defined IP precedence type classifier named test, with a defined code point that maps to the BE forwarding class with a low-loss priority:

```
[edit class-of-service classifiers inet-precedence test]
lab@Bock# show
forwarding-class best-effort {
    loss-priority low code-points 000;
}
```

When desired, you can populate a classifier table with default values, which is useful when your goal is to modify only some code points. The best practice is to always have complete classification tables, even when all possible code point values are not expected. Even though unmatched code points map to the BE class by default, explicitly stating this with a complete code point mapping can reduce confusion down the road.

```
[edit class-of-service classifiers inet-precedence test]
lab@Bock# set import ?
Possible completions:
  <import>             Include this classifier in this definition
  default              Default classifier for this code point type
  test
[edit class-of-service classifiers inet-precedence test]
lab@Bock# set import default

[edit class-of-service classifiers inet-precedence ]
lab@Bock# show
import default;
forwarding-class best-effort {
    loss-priority low code-points 000;
```

The BA classifier is placed into service when you apply it to one or more logical interfaces:

```
[edit class-of-service interfaces]
lab@Bock# set fe-0/0/0 unit 0 classifiers inet-precedence test

[edit class-of-service interfaces]
lab@Bock# show
fe-0/0/0 {
    unit 0 {
        classifiers {
            inet-precedence test;
        }
    }
}
```

> Note that a BA classifier is applied to an interface at the [edit class-of-service interfaces *<interface-name>* unit *<unit-number>*] hierarchy, whereas multifield classifiers are applied to an interface at the [edit interfaces *<interface-name>* unit *<unit-number>*] hierarchy. Keep this distinction in mind to avoid confusion down the road.

Multifield classification

In the Juniper architecture, multifield classification is implemented via firewall filters, using a variety of Layer 2 or Layer 3 match criteria. We discuss general firewall filter configuration and capabilities in Chapter 6.

Suffice it to say that you use a filter to perform multifield classification by associating a set of match criteria to a then forwarding-class action. To activate multifield classification, the filter is applied as an input filter on an ingress interface. Because BA classification is always performed first, you can always apply a multifield classifier in combination with any BA classifier. In case of conflict, the forwarding class associated with the BA match is overwritten by the multifield classifier's choice of forwarding class.

This example shows a simple multifield classifier that classifies a specific UDP protocol and port combination to the BE class with high-loss priority, while all other traffic is classified as BE with the default low-loss priority:

```
[edit firewall filter mf_class]
lab@Bock# show
term udp_port_5555 {
    from {
        protocol udp;
        port 5555;
    }
    then {
        loss-priority high;
        forwarding-class best-effort;
        accept;
    }
}
term default {
    then {
        loss-priority low;
        forwarding-class best-effort;
        accept;
    }
}
```

Policing

Policers are generally considered to be part of the JUNOS software firewall architecture, in that you normally link to a policer as a result of a multifield classification match. Juniper also supports policers that are applied directly to protocol families, on a per-logical-interface basis. From a CoS perspective, interface-level policers are really useful only when you classify based on the incoming interface—that is, all traffic received on interface *<name>* is forwarding class *x*, which is a somewhat corner case, given that most interfaces are assumed to carry a mix of forwarding classes.

Ingress policing is a key component of the traffic conditioning that is needed in the DiffServ model to ensure independence between forwarding classes and the associated PHBs, and between users in the same class. You should deploy policing on the network's edges, as close to the traffic sources as possible. The goal is to limit the aggregate rate of all non-BE traffic to constrain it to a value less than the aggregate rate of the transmission resources associated with all non-BE classes. This ensures that the non-BE PHBs can be met locally and by subsequent core nodes, which generally are not burdened by any CoS-related policing.

Where possible, you should police on a per-class basis for *each* user—JUNOS software features such as highly scalable firewall filters, combined with ease-of-use features such as per-prefix counting and policing, generally make such a fine-grained level of policing practical. This policing ensures that a few dominant users are not able to monopolize all the resources of a given forwarding class by providing per-user isolation within the same class.

Traffic that exceeds the policer's profile can be discarded, reclassified into a different class, or marked for increased discard probability by altering the internal PLP. The latter approach provides a minimum level of service with the potential for increased delivery during periods of low network utilization. In contrast, immediate discard caps the user at ingress, which helps to prevent network congestion from occurring in the first place.

Here is an example of a firewall filter that both classifies and polices on a per-forwarding class basis:

```
[edit firewall]
lab@Bock# show
policer EF_policer {
    if-exceeding {
        bandwidth-limit 128k;
        burst-size-limit 2k;
    }
    then discard;
}
filter mf_class_and_police {
    interface-specific;
    term EF_classify {
        from {
            protocol udp;
            port 6000-6100;
        }
        then {
            policer EF_policer;
            forwarding-class expedited-forwarding;
        }
    }
    term other {
        then forwarding-class best-effort;
    }
}
```

In this example, UDP packets with a matching port range (either source or destination ports) are directed to a policer named `EF_policer`. Traffic within the policer profile is handed back to the calling term, where it's classified as EF and accepted. In this case, any excess traffic is summarily dropped. The final term in the filter classifies all remaining traffic as BE, which is not policed in this example.

It may seem odd that the EF class is policed—with a rather Draconian discard action, no less—while the BE class, which appears to be less important, is left to run unchecked. The reason for this seemingly backward policer application is due to the related scheduling priority, which for the EF class is often strict, or strict-high, and can lead to the starvation of lower-priority forwarding classes when there is an abundance of this traffic. Ingress policing with associated discard ensures an aggregate limit on the EF class, which prevents this problem. Ironically, it's relatively safe to accept all the BE traffic users care to generate, because BE is generally assigned a low priority (other classes cannot be starved) and a low transmit percentage (so that it does not significantly impact other classes), thus excess BE is sent only when one or more of the other forwarding classes are not using their full bandwidth allocation anyway.

The addition of the `interface-specific` statement allows the same filter to be applied to multiple interfaces, with each such application resulting in instantiation of a unique policer instance. The end result is that each interface to which this filter is applied will be limited to a maximum average EF rate of 128 Kbps. The aggregate EF class rate becomes a simple function of policer rate multiplied by the number of interfaces to which the filter is applied. Note that omitting the `interface-specific` statement and applying the same filter to multiple interfaces results in a shared policer, which in this example would cap the aggregate EF class rate to 128 Kbps.

CoS policy

CoS policy is used in one of two ways: to provide CBF or to perform classification override. CBF allows you to specify one or more next hops based on a packet CoS classification. CBF is not demonstrated in this chapter, but a good configuration example is provided in the user manual, located at *http://www.juniper.net/techpubs/software/junos/junos80/swconfig80-cos/html/cos-based-forwarding4.html#1171479*.

Classification override does just what its name implies. This capability can be useful when performing CoS-related testing, or it can mitigate negative impacts that can result from an upstream device that is suspected of generating improperly marked traffic. The configuration example performs an override of any previous classification including overriding any loss-priority setting, and it resets all matching traffic to the BE class:

```
[edit]
lab@Bock# show policy-options
policy-statement AF_override {
    term 1 {
        from interface fe-0/0/0.0;
        then class reset_to_be;
    }
    term 2 {
        then accept;
    }
}
```

The AF_override policy is used to identify what traffic is subjected to classification override; in this example, all traffic received over interface fe-0/0/0 is marked as belonging to a CoS-related policy class named reset_to_be:

```
[edit]
lab@Bock# show class-of-service
forwarding-policy {
    class reset_to_be {
        classification-override {
            forwarding-class best-effort;
        }
    }
}
[edit]
lab@Bock# show routing-options forwarding-table
export AF_override;
```

A forwarding-policy is created at the [edit class-of-service] hierarchy that identifies the policy class that is subject to classification override. In this example, packets marked as belonging to the reset_to_be policy class have their initial classification, whatever that might be, reset to the BE class. The forwarding policy must be applied at the [edit routing-options forwarding-table export] hierarchy to take effect. Such a policy configuration might temporarily work around issues with an upstream device that incorrectly marks all traffic as EF, resulting in EF class congestion and violation of the related service level agreements (SLAs). The group managing the upstream device will quickly find the motivation needed to correct the configuration error when its users begin to complain about poor performance stemming from suddenly getting nothing but BE treatment.

Output Processing

Output CoS processing stages include egress policing, rewrite marking, queuing/ scheduling, and active queue management through RED-based congestion control.

Egress policing

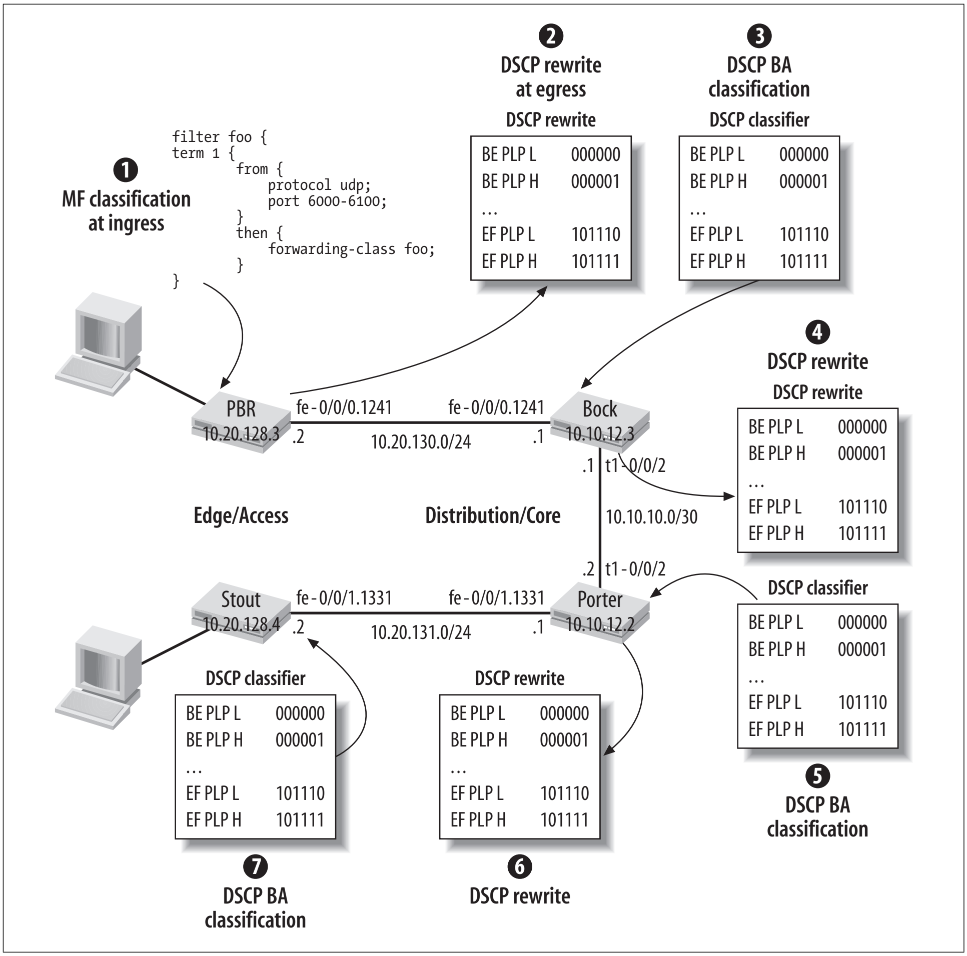
Policers are, well, policers, and there is really nothing unique about an output policer versus an input one, other than the simple fact that the policing action now occurs after the route lookup, rather than before. To an external observer, there is no difference between the use of input versus output policers. Consider an input policer, unless you must police based on the result of route lookup—that is, based on the forwarding next hop.

Rewrite marking

The rewrite marking stage is a critical component of a scalable CoS design because it's one-half of the BA classification story. For scalability, multifield classification should be used only at the network's access layer, where the function can be distributed among the largest set of routers with the smallest average packet forwarding requirements. Packet rates near the core typically dictate the more efficient BA type classification; Juniper routers are capable of wire-rate BA classification in all scenarios, whereas heavy use of firewall filters can degrade forwarding performance.

You should think of your input BA classifiers as a mirror image of the corresponding rewrite marker. This is to say that for each entry in a given BA table, there should be a corresponding entry in the associated rewrite marker table, and that entry is normally set to the same value—this ensures that the node downstream makes the same classification decision as did the local node. The consistent classification at each node between endpoints is a critical component of the DiffServ model, which presumes a consistent PHB among all nodes in a DS region. Figure 9-12 shows the interaction between multifield classification, marker rewrite, and resultant BA classification.

The sequence numbers in Figure 9-12 take you from initial ingress processing (where a multifield classification is used at step 1), on to step 2 (where the ingress node uses a DSCP rewrite table to write a specific DSCP pattern, based on its ingress classification). In this example, we assume EF with low PLP, so the packet's DSCP field is written to binary 101110. At step 3, the downstream node (which is in the distribution or core layer) performs *only* DSCP-based BA classification. Note that `Bock`'s DSCP classifier entry for the EF class with low PLP matches the same value as that used in `PBR`'s DSCP rewrite table. The result, shown in steps 4–7, is a consistent classification, and therefore there is a resulting consistency in the PHB across each node in the path.



```
filter foo {
term 1 {
        from {
            protocol udp;
            port 6000-6100;
        }
        then {
            forwarding-class foo;
        }
}
```

Figure 9-12. Multifield at the edge, BA in the core

The configuration example shown creates an IP precedence rewrite marker table that matches the example provided in the section "BA classification capabilities," earlier in this chapter.

```
[edit class-of-service rewrite-rules inet-precedence test]
lab@Bock# show
import default;
forwarding-class best-effort {
    loss-priority low code-point 000;
}
```

As in the case of BA classifiers, a rewrite table can be fully populated by importing any entries not explicitly defined by the user from the default set associated with that classifier type.

Scheduling and queuing

The scheduling stage determines when a given queue is serviced, in which order, and how much traffic can be drained at each servicing. Schedulers and queues are closely linked in the Juniper architecture. When you configure a scheduler, you can also control certain queue parameters such as maximum queue depth, and you also link that queue to one or more WRED profiles. You typically alter a queue's default size, which is based on the associated transmit weight, to control delay—larger buffer sizes favor less loss at the cost of increased latency.

Scheduling discipline. Both the M7i and J-series platforms implement a modified deficit round-robin (MDRR) scheduler. Because different transmit weights can be assigned to each queue, the algorithm is technically a modified weighted deficit round-robin (MWDRR) approach.

Scheduling is one area where the M-series and J-series implementation significantly differs. The M-series scheduling behavior is described here, along with general scheduling capabilities and concepts. "Differences Between J-Series and M7i CoS," later in this chapter, specifically calls out where the two platforms differ in scheduling behavior.

MDRR extends the basic deficit round-robin (DRR) mechanism by adding support for a priority queue that exhibits minimal delay. The deficit part of the algorithm's name stems from the allowance of a small amount of negative credit in an attempt to keep queues empty. The resultant negative balance from one servicing interval is carried over to the next quantum's credit allocation, keeping the average dequeuing rate near the configured transmit value.

An MDRR scheduler is defined by four variables:

Buffer size
: This is the delay buffer for the queue that allows it to accommodate traffic bursts. You can configure a buffer size as a percentage of the output interface's total buffer capacity or as a temporal value from 1–200,000 microseconds, which simply represents buffer size as a function of delay, rather than bytes.

The quantum
: The quantum is the number of credits added to a queue every unit of time and is a function of the queue's transmit weighting. In Juniper's implementation, a quantum is added 5,000 times per second (or once every 200 microseconds). The queue's transmit rate specifies the amount of bandwidth allocated to the queue and can be set based on bits per second or as a percentage of egress interface bandwidth. By default, a queue can be serviced when in negative credit, as long as no other queues have traffic pending. When desired, you can rate-limit a queue to its configured transmit rate with inclusion of the `exact` keyword.

Priority

The priority can be low, high, or strict-high, and it determines the sequence in which queues are serviced. The scheduler services high-priority queues with positive credit before it addresses any low-priority queues.

A strict-high priority queue is a special case of high priority, where the effective transmit weight is set to equal egress interface capacity. This means that a strict-high queue can never go negative, and therefore is serviced before any low-priority queue anytime it has traffic waiting. The result is a type of low-latency queuing (LLQ). Care should be used when a queue is set to strict-high to ensure that the queue does not starve low-priority traffic; a strict-high queue does not support shaping via the `exact` keyword. Normally, though, ingress policing/rate limiting is used to control the aggregate rate of traffic that can be placed into the strict-high queue. When you have two or more queues set to high priority (two high, or one high and one strict-high), the MDRR scheduler simply round-robins between them until they both go negative, or until the queue is empty in the case of strict-high, at which time the low-priority queues can be serviced.

Deficit counter

MDRR uses the deficit counter to determine whether a queue has enough credits to transmit a packet. It is initialized to the queue's quantum, which is a function of its transmit rate, and it is the number of credits that are added to the queue every quantum.

The Juniper implementation of MDRR scheduling on the M-series supports a basic deficit weighted round-robin (DWRR) scheduling discipline, or a combination of strict-priority queuing (SPQ) and DWRR scheduling when a high-priority queue is configured.

Scheduler configuration. You configure the scheduling and queuing stage by first defining a scheduler for each forwarding class used in your network. Schedulers are defined at the `[edit class-of-service schedulers]` hierarchy, and they indicate a forwarding class's priority, transmit weight, and buffer size.

```
[edit class-of-service]
lab@Bock# show schedulers
be_sched {
    transmit-rate percent 30;
    priority low;
    drop-profile-map loss-priority high protocol any drop-profile be_high_drop;
    drop-profile-map loss-priority low protocol any drop-profile be_low_drop;
}
ef_sched {
    buffer-size temporal 50k;
    transmit-rate percent 60 exact;
    priority high;
    drop-profile-map loss-priority high protocol any drop-profile ef_high_drop;
    drop-profile-map loss-priority low protocol any drop-profile ef_low_drop;
}
```

```
nc_sched {
    transmit-rate percent 10;
    priority low;
    drop-profile-map loss-priority high protocol any drop-profile nc_high_drop;
    drop-profile-map loss-priority low protocol any drop-profile nc_low_drop;
}
```

This example supports three forwarding classes—BE, EF, and NC—and each forwarding class's scheduler block is associated with a priority and a transmit rate. Priority support varies by platform and takes the form of strict-high, high, and low, with the J-series also supporting medium-high and medium-low priorities.

> The differences in scheduler priorities and behavior between M-series and J-series routers are discussed in "Differences Between J-Series and M7i CoS," later in this chapter. For example, although both platforms support a `strict-priority` scheduler setting, the effect is platform-dependent and significantly different.

The transmit rate can be entered as a percentage of interface bandwidth or as an absolute value. You can rate-limit (sometimes called *shape*) a queue with the `exact` keyword, which prevents a queue from getting any unused bandwidth, effectively capping the queue at its configured rate.

In this example, the EF scheduler is set to high priority and is rate-limited to 60% of the interface speed, even when all other schedulers are idle, through the addition of the `exact` keyword. Using `exact` is a common method of providing the necessary forwarding class isolation when a high-priority queue is defined, because it caps the total amount of EF that can leave each interface to which the scheduler is applied. Rate-limiting helps to ensure that the aggregate rate of EF traffic arriving at downstream nodes is not excessive, whereas ingress policing should limit the arriving EF to an aggregate rate that is less than the EF scheduler's transmit rate to ensure that the local node meets the associated PHB.

With the configuration shown, each of the three forwarding classes are guaranteed to get at least their configured transmit percentage. The EF class is limited to no more than 60%, while during idle periods both the BE and NC classes can use 100% of egress bandwidth. When it has traffic pending, the high-priority EF queue is serviced as soon as possible—that is, as soon as the BE or NC packet currently being serviced has been completely dequeued.

Assuming a somewhat worst-case T1 link speed (1.544 Mbps) and a default MTU of 1,504 bytes, the longest time the EF queue should have to wait to be serviced is only about 7.7 milliseconds (1/1.544^6 * (1504 * 8)). With higher speeds (or smaller packets), the servicing delay becomes increasingly smaller. Given that the typical rule of thumb for the one-way delay budget of a Voice over IP application is 150 milliseconds, this PHB can accommodate numerous hops before voice quality begins to suffer.

Delay Buffer Size

Notifications for packets pending transmission are stored in a delay bandwidth buffer that is sized according to the interface's speed and the platform's maximum delay buffer time. Both the M7i and J-series routers support at least 100,000 microseconds (or 100 milliseconds) of delay buffer time.

> When using low-speed interfaces, such as DSOs within a channelized T1/E1, you may want to enable IQ/IQ2 PIC large buffer support. With the `q-pic-large-buffer` knob in conjunction with supported IQ/IQ2 PIC hardware on the M7i, or with the channelized E1/T1 Physical Interface Modules (PIMs) for the J-series, you can increase delay buffer time to as much as 4 million microseconds (four seconds). The larger delay buffer can be useful on slow-speed interfaces due to the resultant increase in serialization delay, which is a function of link speed and MTU.

In this example, the delay buffer size for the BE and NC classes is left at the default `remainder` setting. This means that each is allocated a percentage of the 100-millisecond delay buffer based on its configured transmit weighting, and is allowed to grow into any unallocated buffer space, such as can occur when the sum of configured weights does not add up to 100%.

The formula to compute the actual delay buffer size is:

interface speed (bps) * delay buffer size (microseconds) = delay buffer size (bytes)

If we assume a J-series platform with a 100 Mbps Fast Ethernet interface in this example, the total scheduler delay buffer size is $100^{6} * 100^{-3}$ = 1.25 MB. By default, the BE and NC classes are assigned 30% and 10% of the scheduler's delay buffer, respectively.

In contrast, the EF queue has its buffer set to permit no more than 50,000 microseconds (50 milliseconds). When using a temporal setting, the maximum delay buffer size is computed by multiplying the interface speed by the configured temporal value.

Because the EF class has been assigned 60% of the transmit bandwidth, the default behavior would allocate 60% (60,000 microseconds) of delay buffer; by reducing the size of the delay buffer, as shown in the case of the EF class, you keep the higher transmit percentage while forcing a smaller buffer size. Setting a delay buffer that is smaller than the default results in a trade-off between the resultant increased probabilities of congestion-related loss versus a reduction in maximum delay and delay variance (jitter).

The scheduler block for each forwarding class also references WRED drop profiles, which provide active queue management to control congestion. Generally, you will have a different WRED profile for each forwarding class—for example, one aggressive profile that begins to drop at a lower fill, with a greater drop probability for the BE class, and another that waits until a higher queue fill before less-aggressive drops begin for the NC class. We will discuss drop profiles in "Congestion control," later in this chapter.

Scheduler Maps

Once you have defined your schedulers, you must link them to one or more egress interfaces using a `scheduler-map`. Scheduler maps are defined at the `[edit class-of-service scheduler-maps]` hierarchy.

```
[edit class-of-service]
lab@Bock# show scheduler-maps
three_FC_sched {
    forwarding-class best-effort scheduler be_sched;
    forwarding-class expedited-forwarding scheduler ef_sched;
    forwarding-class network-control scheduler nc_sched;
}
```

Applying a `scheduler-map` to an interface places the related set of schedulers and drop profiles into effect:

```
[edit class-of-service]
lab@Bock# show interfaces
fe-0/0/0 {
    scheduler-map three_FC_sched;
}
```

Defining scheduler blocks that are based on a transmit percentage rather than an absolute value, such as in this example, makes it possible to apply the same `scheduler-map` to all interfaces without worrying whether the sum of the transmit rates exceeds interface capacity, which results in a committed, but effectively ignored, CoS configuration that can be a real pleasure to debug. An example of this condition is shown for `Bock`, whose T1 interface cannot handle the 100 Mbps required when the rate is substituted for the same numeric value, but in Mbps!

```
lab@Bock# show class-of-service schedulers ef_sched
transmit-rate 35m exact;
buffer-size temporal 30k;
priority high;

[edit]
lab@Bock# run monitor list
monitor start "messages" (Last changed Oct 29 05:21:00)

[edit]
lab@Bock# commit
Oct 30 05:39:11  Bock mgd[2982]: UI_COMMIT: User 'lab' performed commit: no comment
Oct 30 05:39:15  Bock /kernel: RT_COS: COS IPC op 5 (SCHED POLICY DEF) failed, err 5
(Invalid)
Oct 30 05:39:15  Bock /kernel: RT_COS: COS IPC op 5 (SCHED POLICY DEF) failed, err 5
(Invalid)
```

```
Oct 30 05:39:15  Bock fwdd[2791]: COSMAN: queue 0 got tx_rate = 50000 kbps which is
too high for t1-0/0/2
Oct 30 05:39:15  Bock fwdd[2791]: COSMAN: policy update failed
Oct 30 05:39:15  Bock fwdd[2791]: COSMAN: queue 0 got tx_rate = 50000 kbps which is
too high for t1-0/0/2
Oct 30 05:39:15  Bock fwdd[2791]: COSMAN: policy update failed
. . .
```

A word on per-unit scheduling

By default, when you apply a scheduler to an interface, it takes effect at the port, or interface device (`ifd`) level. This is fine when the port in question is configured with a single logical interface (`ifl`), such as would be the case when running Cisco High-Level Data Link Control (HDLC) or the Point-to-Point Protocol (PPP). However, when the interface is partitioned into multiple logical units—for example, as the result of adding VLAN tagging—you need to apply a per-unit scheduler. A per-unit scheduler provides fine-grained queuing by creating a set of queues and an associated scheduler for each logical interface. M-series platforms require special IQ/IQ2 PIC hardware to support per-unit scheduling whereas the J-series achieves this via software, with no specific hardware needs.

You configure per-unit scheduling by adding the `per-unit-scheduler` statement at the interface level. Because some hardware combinations do not support fine-grained queuing, you should monitor the *messages* log when committing a per-unit scheduling configuration to make sure the configuration is compatible with installed hardware.

```
[edit interfaces fe-0/0/0]
lab@Bock# show
per-unit-scheduler;
vlan-tagging;
unit 0 {
    vlan-id 1241;
    family inet {
        address 10.20.130.1/30;
    }
}
```

Congestion control

The final CoS processing stage in the output direction is the WRED congestion control function. We described the reasoning behind active queue management previously—we'll reiterate that the general goal is to avoid the indiscriminate tail drops that occur when a queue reaches capacity, by sensing a queue that is beginning to fill and then randomly discarding packets from the head of the queue. The chance of actual discard rises from the first fill level and discard probability point until it reaches 100% at 100% fill. Configuring a discard profile with a fill/discard probability of 100/100 effectively disables RED on that queue. This is the default setting.

Configure WRED drop profiles

You configure a WRED drop profile at the [edit class-of-service drop-profiles] hierarchy. RED drop profiles are placed into effect on an egress interface via application of a scheduler-map. Recall that, as shown earlier, the scheduler-map references a set of schedulers, and each scheduler definition links to one or more drop profiles. It is an indirect process, to be sure, but it quickly begins to make sense once you have seen it in action.

Here are some examples of drop profiles, as referenced in the preceding scheduler-map example:

```
[edit class-of-service drop-profiles]
lab@Bock# show
be_high_drop {
    fill-level 40 drop-probability 0;
    fill-level 50 drop-probability 10;
    fill-level 70 drop-probability 20;
}
be_low_drop {
    fill-level 70 drop-probability 0;
    fill-level 80 drop-probability 10;
}
ef_high_drop {
    fill-level 80 drop-probability 0;
    fill-level 85 drop-probability 10;
}
ef_low_drop {
    fill-level 90 drop-probability 0;
    fill-level 95 drop-probability 30;
}
nc_high_drop {
    fill-level 40 drop-probability 0;
    fill-level 50 drop-probability 10;
    fill-level 70 drop-probability 20;
}
nc_low_drop {
    fill-level 70 drop-probability 0;
    fill-level 80 drop-probability 10;
}
```

In this example, the drop profiles for the BE and NC classes are configured the same, so technically a single-drop profile could be shared between these two classes. It's a best practice to have per-class profiles because ongoing CoS tuning may determine that a particular class will perform better with a slightly tweaked RED threshold setting.

Both the BE and NC queues begin to drop 10% of high-loss priority packets once the respective queues average a 50% fill level. You can specify as many as 64 discrete points between the 0% and 100% loss points, or use the interpolate option to have all 64 points automatically calculated around any user-supplied thresholds. In this example, only three points are specified. At 50% fill, 10% of PLP 1 BE and NC traffic is dropped; when the queue fill crosses 70%, the next discard threshold is activated and 20% of the packets are discarded. The 20% discard rate is maintained during an average queue fill of 70% to 99%. At 100% fill, tail drop begins, as the queue can no longer hold incoming notifications. The weighted aspect of the RED algorithm is shown with the configuration of a less-aggressive drop profile for BE/NC traffic with a low-loss priority.

A similar approach is taken for the EF class, except it uses a less aggressive profile for both loss priorities, with discards starting at 80% and 90% fill for high- and low-loss priorities, respectively. Some CoS deployments disable RED (100/100) for real-time classes such as EF because these sources are normally UDP-based and do not react to loss in the same way that TCP-based applications do. M-series platforms support WRED profiles based on TCP versus UDP, in addition to loss priority, which allows you to adopt a less aggressive RED profile for those application types that do not react to RED drop anyway. J-series platforms support WRED indexing based on loss priority only, but the J-series supports four drop priorities, so you can still index up to four RE profiles per queue. The examples shown are from a J-series, which forces the protocol to any.

Here's the be_high drop profile:

```
[edit]
lab@Bock# run show class-of-service drop-profile be_high_drop
Drop profile: be_high_drop, Type: discrete, Index: 27549
  Fill level    Drop probability
          40                   0
          50                  10
          70                  20
```

To provide contrast, the be_high profile is altered to use interpolate, which fills in all 64 points between 0% and 100% loss, as constrained by any user-specified fill/drop probability points:

```
edit]
lab@Bock# show class-of-service drop-profiles be_high_drop
interpolate {
    fill-level [ 40 50 70 ];
    drop-probability [ 0 10 20 ];
}
[edit]
lab@Bock# run show class-of-service drop-profile be_high_drop
Drop profile: be_high_drop, Type: interpolated, Index: 27549
  Fill level    Drop probability
           0                   0
           1                   0
           2                   0
           4                   0
           5                   0
              . . .
```

```
 38                  0
 40                  0
 42                  2
 44                  4
 45                  5
 46                  6
 48                  8
 49                  9
 51                 10
 52                 11
 54                 12
     . . .
 78                 41
 80                 46
 82                 52
 84                 57
 85                 60
     . . .
 99                 97
100                100
```

Differences Between J-Series and M7i CoS

The preceding section detailed the general CoS capabilities of the M7i and J-series routers, which for the most part are supported across all JUNOS-based routing platforms. This section calls out areas where the CoS capabilities differ. With so many similarities, the differences are easy to lose track of, but no matter how similar, they can have a pronounced operational impact if you do not understand and design for them.

Table 9-3 summarizes the differences between M7i and J-series CoS behavior.

Table 9-3. M7i versus J-series CoS behavior and capabilities

M7i	J-series
Per-unit scheduling only with IQ/IQ2 PIC hardware.	Per-unit scheduling on all interfaces.
DWRR scheduling to provide at least configured weight. Leftover bandwidth shared using priority-based round-robin. No scheduler-based shaping.	Strict priority scheduling with DWRR among queues of the same priority. Leftover bandwidth shared according to priority, and within a priority according to transmit weight. Supports scheduler-based shapers.
Two scheduling priorities: high and low. No support for LLQ.	Five scheduling priorities: strict-high, high, medium-high, medium-low, and low. LLQ support via strict-high (in 8.1).
Hierarchical shaping and shared schedulers with supported IQ/IQ2 PICs.	No hierarchical shaping. Shared scheduler via virtual channel construct.
No support for virtual channel CoS construct or adaptive shaping.	Supports scheduling into virtual channel, group to share a scheduler among a set of data-link connection identifier (DLCI)-based logical interfaces. Adaptive shaping based on forward explicit congestion notification (FECN).

Table 9-3. M7i versus J-series CoS behavior and capabilities (continued)

M7i	J-series
WRED based on TCP, UDP, and PLP. Head-drop-based, acts on packets as they are dequeued.	WRED based on PLP only—no TCP versus UDP indexes. Tail-drop-based, acts on packets as they are enqueued.
Sixteen WRED drop profiles per Enhanced FPC (E-FPC), two with original FPC.	Thirty-two WRED drop profiles per PIM.
Supports four queues.	Supports eight queues on all interfaces.
PLP based on classification/policer action only, no mapping of DE to PLP.	PLP based on classification, policer action, or in response to Frame Relay DE mapping.
Two loss priorities: high and low.	Four loss priorities: high, medium-high, medium-low, and low.
Maximum number of rewrite markers is not specified.	A total of 64 rewrite markers can be defined per PIM.

Table 9-3 makes it clear that there are quite a few operational differences between the ASIC-based M7i and the software-based J-series product line. We will examine the functional differences in detail in the following sections.

Per-unit scheduling

M-series platforms do not support per-unit scheduling unless the platform is equipped with an IQ-style PIC, in which case the actual queuing is moved from the chassis level onto to the PIC itself when you enable per-unit scheduling.

J-series platforms support fine-grained, per-unit scheduling on all interfaces through emulation of the on-PIC queuing capabilities of a Q-PIC.

In addition to logical unit-based queuing, per-unit scheduling also enables use of the `shaping-rate` command at the logical unit level to shape output traffic on all interfaces.

Weight- versus priority-based scheduling

One of the most pronounced differences between the M-series and J-series CoS functionality is the way in which the MDRR algorithm is implemented. The differences are so pronounced that you will typically find that an existing M-series scheduler configuration cannot be copied over and applied to a J-series, at least not if you expect similar CoS behavior!

The M-series weight-based scheduler. On M-series routers, the MDRR scheduler is based on guaranteed transmit weight with any leftover (unused) bandwidth divided on a prioritized, round-robin basis, which empties high-priority queues in negative credit before moving on to low-priority queues with negative credit. Figure 9-13 illustrates the operational characteristics of the M-series scheduler implementation.

Figure 9-13 shows a scheduler configuration supporting two priorities and three forwarding classes/queues. The scheduler first services all high-priority queues with positive credit, and then moves on to service low-priority queues with positive credit.

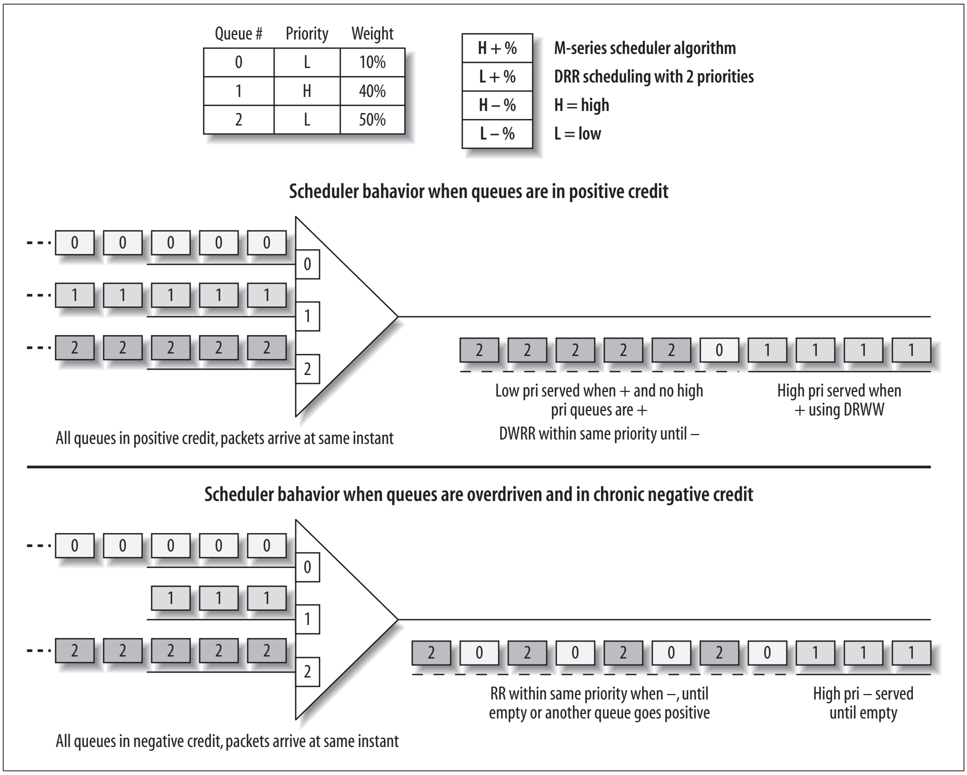

Queue #
Priority
Weight
0
L
10%
1
H
40%
2
L
50%
H + %
L + %
H – %
L – %
M-series scheduler algorithm
DRR scheduling with 2 priorities
H = high
L = low
Scheduler bahavior when queues are in positive credit
Low pri served when + and no high pri queues are +
DWRR within same priority until –
High pri served when + using DRWW
All queues in positive credit, packets arrive at same instant
Scheduler bahavior when queues are overdriven and in chronic negative credit
RR within same priority when –, until empty or another queue goes positive
High pri – served until empty
All queues in negative credit, packets arrive at same instant

Figure 9-13. The M-series scheduler

Once all queues have been given at least their assigned weights, the queues go negative and the scheduler begins to allocate unused bandwidth. Because the dispatch of unused bandwidth is affected by numerous factors, including the number of priorities, number of queues, and average packet size, it is safe to say that the M-series algorithm for the allocation of unused bandwidth among negative credit queues is, practically speaking, nondeterministic. This does not mean the process is random, just that it is extremely difficult to predict how much extra bandwidth a given queue will end up getting.

The top half of the figure shows the scheduler's DWRR operation when queues are in positive credit. The scheduler services the high-priority queue until its transmit weight is satisfied, resulting in four forwarding class 2 packets, or 40% utilization in this example. Once the priority queue is in negative credit, the scheduler moves on to the low-priority level, which has two queues in this example. The scheduler services both of the low-priority queues according to their weight, resulting in one FC0 and five FC2 packets being transmitted.

The lower half of Figure 9-13 continues the example by showing M-series scheduler behavior among queues with negative credit. The leftover bandwidth is not allocated according to configured weight, but rather using a priority-based round-robin approach that empties one packet per queue, first emptying all high-priority queues and then moving on to round-robin between negative low-priority queues.

This approach can lead to some unexpected results, especially when queues are chronically overdriven and therefore tend to remain in negative credit, and when the average packet size differs within each queue. The lack of granularity in the per-packet round-robin handling of negative queues tends to favor the queue with the larger packet size. This can be most pronounced when that queue is also given the lowest weight, because it will be able to send the same number of packets as other negative queues at the same priority level. When combined with a larger packet size, such a queue winds up getting a larger percentage of the leftover bandwidth than you might first assume.

The M7i supports two priority levels: high and low. On the M-series, the `strict-high` priority is the same as high priority—the `strict-high` setting simply provides that queue with a 100% transmit weight, thus ensuring that it is always in positive credit and able to send. You cannot rate-limit a `strict-high` queue with the `exact` keyword because it always gets 100% of the interface transmit weight, and you can include only one `strict-high` queue in a given `scheduler-map`.

The J-series priority scheduler. The J-series scheduler is based on strict priority. In this context, the word *strict* means that each priority level at value *n* is considered a higher priority than level *n* – 1, and that the scheduler always services higher-priority queues before lower-priority queues, even if the higher-priority queue is negative while the lower-priority queue is in positive credit. This is a critical point, so it's restated differently, a few times:

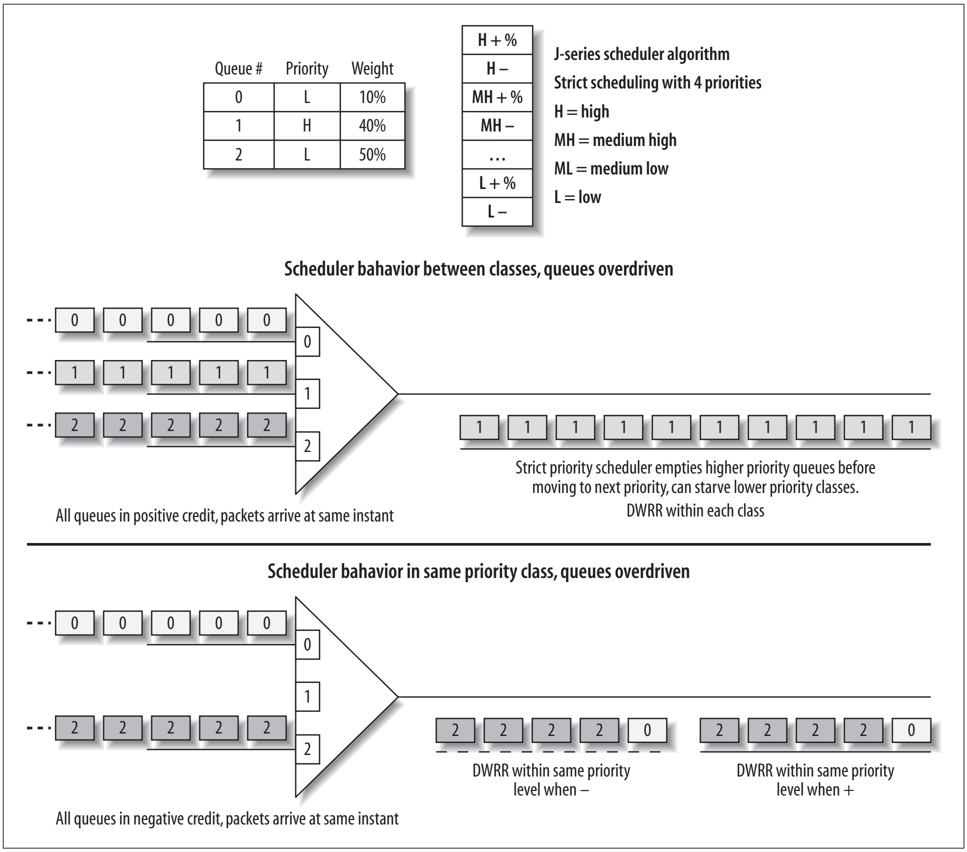
- On the J-series, WRR/configured weight is honored only for queues at the same priority level.
- On the J-series, a high-priority queue can starve all other priorities unless it is rate-limited. The same goes for medium-high and medium, medium-low and low, and so on down the priority chain.

On a J-series, the `strict-high` setting is an actual priority level, making it, pardon the pun, *higher* than high. The `strict-high` setting is specifically offered to back up the LLQ feature, which is an 8.1 feature specific to the J-series.

A J-series `strict-high` queue cannot be rate-limited with the `exact` keyword. Instead, a policer is used to mark traffic above a configured limit as excess. Excess LLQ traffic is permitted only when all other queues have been emptied, meaning there is no interface congestion. The result is a queue that is always serviced as soon as possible, whenever it has traffic pending (the highest of all priorities, and only one `strict-high` queue is permitted per scheduler map), with a guarantee of at least the configured rate, while still permitting excess LLQ traffic when no other queues are congested.

If these differences were not enough to confuse the innocent, the J-series scheduler differs from the M-series by honoring configured weight when servicing negative credit queues at the same priority. As a side effect, you can configure shaping within a J-series scheduler. This `shaping-rate` can be less than the default 100%, but more than the configured transmit rate, which shapes the queue's output to the specified value while allowing limited used of unused bandwidth, as determined by the differences between the transmit and shaping rates.

Figure 9-14 shows the J-series scheduler behavior.



Queue # Priority Weight
0 L 10%
1 H 40%
2 L 50%
H + %
H –
MH + %
MH –
…
L + %
L –
J-series scheduler algorithm
Strict scheduling with 4 priorities
H = high
MH = medium high
ML = medium low
L = low
Scheduler bahavior between classes, queues overdriven
Strict priority scheduler empties higher priority queues before moving to next priority, can starve lower priority classes.
DWRR within each class
All queues in positive credit, packets arrive at same instant
Scheduler bahavior in same priority class, queues overdriven
DWRR within same priority level when –
DWRR within same priority level when +
All queues in negative credit, packets arrive at same instant

Figure 9-14. The J-series scheduler

The upper portion of Figure 9-14 shows the priority-based scheduling behavior, which results in the complete emptying of all queues at priority *n* before it moves to the next set of queues at priority *n* – 1. On the J-series, the configured transmit rate is significant only between classes at the *same* priority level. In this case, the higher-priority traffic associated with queue 1 is shown starving the two lower-priority queues.

To resolve this issue, you need to either rate-limit the high-priority traffic or assign all queues to the same priority level.

The lower half of Figure 9-14 shows how the J-series scheduler honors weight among negative credit queues at the same priority. Since no additional priority packets are pending in this example, the scheduler continues to serve the low-priority queues according to their weight, rather than using a simple round-robin scheme, as is the case with the M-series.

Although it's likely obvious, we are nonetheless explicitly stating here that, because of the differences in scheduler behavior, you cannot simply copy an existing M-series CoS configuration over to a J-series and just expect it to work the same way. Successful translation between the two scheduler models requires a complete understanding of the operational differences. The upcoming lab scenario provides an example of both an M-series and J-series scheduler that meet the same requirements, and therefore provide similar operational behavior.

Scheduler-based shaping to limit excess bandwidth usage

M-series routers do not support the `shaping-rate` statement under a scheduler. The only way to cap a forwarding class's usage of excess bandwidth is to use `exact`, which allows no excess bandwidth, or to use a policer to control the total rate of traffic in that class, which indirectly controls how much extra bandwidth it will use. In contrast, the J-series scheduler supports shaping above the configured transmit weight but below the line rate, which provides a guarantee of a minimum weight and a cap on some amount of excess bandwidth. By default, all schedulers are allowed to use all excess bandwidth, up to the line rate, unless limited by `shaping-rate` (J-series) or `exact`.

Scheduler priority levels

The M7i supports two scheduler priority levels: high and low. The `strict-high` setting on the M-series is no different from high, from a priority perspective. If you configure both a `strict-high` and a `high` priority queue, the scheduler serves each in round-robin manner until one or both go negative. The `strict-high` setting here simply prevents that queue from ever going negative by internally setting its transmit rate to 100%. As of this writing, the options for medium-high and medium-low are hidden in the M7i command-line interface (CLI), but you can configure and commit such a setting without any warnings. Note that even though the CLI displays the associated scheduler as having medium priority, in reality there are only two priority levels, with low and medium-low treated the same, as are medium-high, high, and strict-high.

In contrast, the J-series supports five distinct priority levels, with `strict-high` being an actual priority, not just an assumption of 100% transmit rate, as is the case with the M-series. On the J-series, you can define strict-high, high, medium-high, medium-low, and low priority values.

Hierarchical shaping and shared scheduling

M-series platforms with supported IQ-PICs (GE IQ2 PICs) can support both hierarchical shaping and shared scheduling resources. A hierarchical shaper is normally associated with the support of oversubscription and involves applying a shaper via the `input-shaping-map` statement at both the port and logical interface levels. The result is the ability to limit the input port rate to a value less than the port speed, and at the same time shape the individual logical interfaces based on transmit weights that are oversubscribed with respect to the (shaped) port speed.

A shared scheduler (or shaper) is a set of scheduling resources that is shared among multiple logical interfaces. This feature is designed to scale the platform by supporting large numbers of subscribers, on a per-VLAN basis, with a limited set of resources.

J-series platforms do not emulate IQ2 functionality, and therefore do not offer hierarchical shaping and scheduling in the same way as the M-series with an IQ2. Instead, the J-series use a virtual channel construct, which provides a close approximation of a shared scheduler or shaper. We describe J-series virtual channels in the next section.

J-series virtual channels

J-series routers support the notion of a virtual channel, which in the context of CoS is not a logical connection such as an ATM permanent virtual circuit (PVC), but instead a grouping of logical channels that share a common scheduler. We provide a virtual channel configuration example in the section “Virtual Channels,” later in this chapter, so a detailed discussion is held until that time. For now, it is sufficient to say that virtual channels are designed to accommodate Frame Relay hub and spoke topologies by allowing a central site with a high-speed attachment the ability to schedule traffic into each DLCI based on some maximum rate, which is typically matched to the remote site’s access rate.

RED behavioral differences

The M7i WRED implementation is head-of-line-based, which is to say that a RED decision is made at the time of packet servicing. This approach has the advantage of notifying senders of congestion sooner, but comes at the cost of allocating queue resources for a packet that is ultimately doomed. The M-series platform supports RED profiles that are indexed via protocol (TCP versus UDP) and loss status, for a total of four possible WRED profiles per queue.

The M7i can support up to 16 WRED profiles per enhanced (current) FPC.

The J-series WRED algorithm operates at the tail of the queue, as the notifications arrive rather than as the scheduler visits the next notification at the head of each queue. From a practical perspective, there is little operational impact to the different WRED approaches—we mention them here largely for the sake of completeness. As of this writing, J-series platforms support only a packet-loss-priority-based WRED index, supporting as many as four WRED profiles per queue. The trade-off in simplicity comes at the cost of not allowing a more aggressive drop profile for TCP-based traffic, which is sometimes desired as this type of traffic reacts best to implicit congestion notification, is normally not real-time-based, and has retransmission to recover from the loss, so no one is the wiser.

The J-series supports up to 32 WRED profiles per PIM.

Number of queues/forwarding classes

The M7i supports a maximum of four queues per logical interface. Note that on the M320 and T-series platforms, you can configure up to eight queues with certain IQ-type PICs.

J-series routers support eight queues on all interfaces. This obviously accommodates a finer-grained queuing model, but given the strict priority scheduler you will sometimes want to allocate additional queues to hold overflow traffic from other queues at various priority levels. These overflow queues are typically set to the same (low) priority level, and packets that wind up in one of these overflow queues are serviced according to the queue's assigned weight, but only when all higher-priority queues are empty.

PLP and adaptive shaping

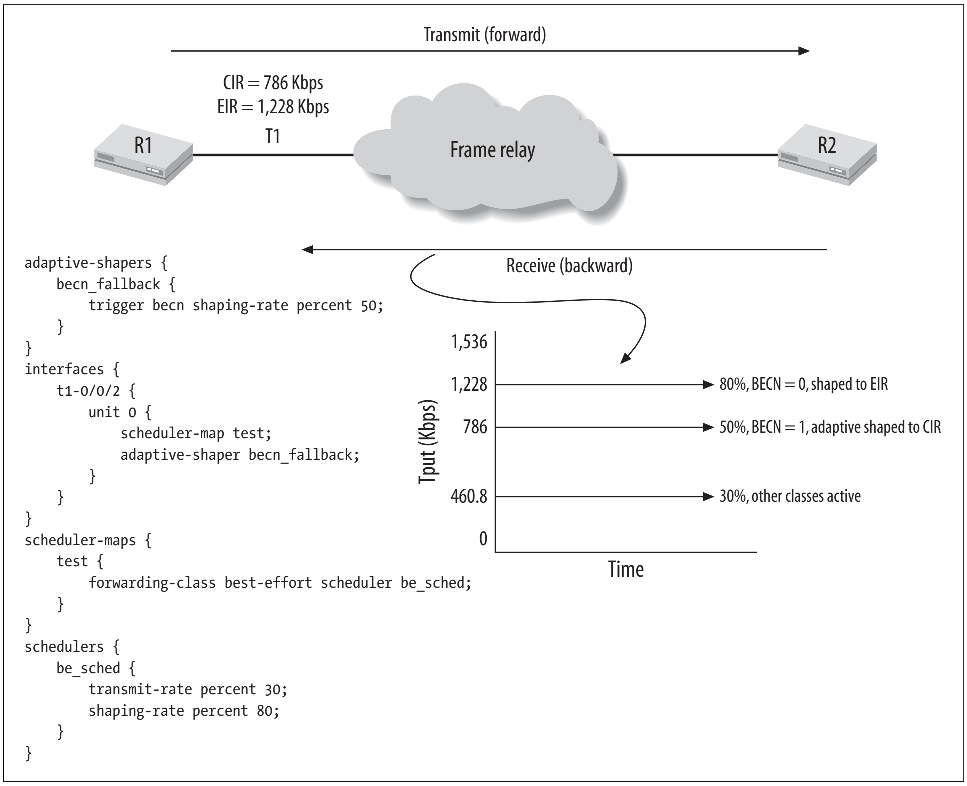
M-series platforms support two PLPs: high and low. You can set the PLP using a policer, a multifield classifier, or a BA classifier. Adaptive shaping based on Frame Relay congestion notification is not supported, nor is setting the local PLP based on received DE bit status.

J-series routers support four PLP levels: high, medium-high, medium-low, and low. PLP can be set using a policer, a filter action, or a BA classifier as in the case of the M-series. J-series boxes can also map received Frame Relay DE indication into a loss priority using a `loss-priority-maps` statement. The following example shows a custom `frame-relay-de` map that happens to match the default, which is to say that received frames with DE = 1 are classified as having high PLP:

```
[edit class-of-service]
lab@PBR# show loss-priority-maps
frame-relay-de map_de_to_plp {
    loss-priority high code-points 1;
    loss-priority low code-points 0;
}
```

You can also apply a BA classifier to further classify traffic. The BA classifier occurs after any loss priority map and can overwrite the PLP, but only to a *higher*-loss priority value. The priority map supports only the high- and low-loss priorities, whereas the subsequent BA classifier stage supports all four priorities.

Adaptive shaping. Adaptive shaping is a J-series-specific feature that allows the use of two output shapers, based on the current congestion state of a Frame Relay network. Figure 9-15 shows the adaptive shaping feature in action.



```
adaptive-shapers {
    becn_fallback {
        trigger becn shaping-rate percent 50;
    }
}
interfaces {
    t1-0/0/2 {
        unit 0 {
            scheduler-map test;
            adaptive-shaper becn_fallback;
        }
    }
}
scheduler-maps {
    test {
        forwarding-class best-effort scheduler be_sched;
    }
}
schedulers {
    be_sched {
        transmit-rate percent 30;
        shaping-rate percent 80;
    }
}
```

Figure 9-15. Adaptive shaping in response to network congestion

Figure 9-15 shows a pair of routers connected via Frame Relay. R1 is attached via a T1 interface and has a committed information rate (CIR) of 50% of T1 capacity, or 778 Kbps. The Frame service offers an extended burst through the excess information rate (EIR). EIR is not guaranteed, especially when the network experiences congestion, which is indicated in the forward direction by the receipt of frames with a set FECN bit, and in the backward direction with a set backward explicit congestion notification (BECN) bit.

The shaper for the BE class is set to 30% of the interface bandwidth. It is guaranteed only 30% of capacity, which equates to the 460.8 Kbps of throughput in this case. When other classes are not active, the BE class can burst to its shaped rate of 80%. The shaped rate matches the EIR parameter, which is good, because traffic in excess of the EIR can be discarded upon ingress by the network—the shaping configuration prevents immediate discard by limiting how much unused bandwidth the BE class can use. The maximum (EIR) rate is shown in the top throughput line and represents 80% of a T1's usable throughput.

An adaptive shaper is also configured and applied to the T1 interface. The adaptive shaper takes effect when the last frame received (assuming there is transmit traffic from R2 to R1) has a set BECN bit. When activated, the adaptive shaper enforces the CIR to prevent congestion-related discards within the network. When a frame is received with a cleared BECN bit, the adaptive shaper is removed and R1 is again able to send at the EIR, assuming that no other classes are active.

Number of rewrite markers

M-series platforms with E-FPCs do not have a known limit on the number of rewrite marker tables that can be defined.

J-series platforms are limited to 64 rewrite markers per PIM.

JUNOS Software CoS Defaults

JUNOS software comes with a set of default CoS settings that are designed to ensure that both transit and control plane traffic is properly classified and forwarded. The default CoS setting supports two forwarding classes (BE and NC) and implements an IP precedence-style BA classifier that maps network control into queue 3 while all other traffic is placed into queue 0 as BE. A scheduler is placed into effect on all interfaces that allocates 95% of the bandwidth to queue 0 and the remaining 5% to queue 3. Both of the queues are low priority, which guarantees no starvation in either platform.

A default WRED profile with a single loss point is placed into effect. The 100% drop at 100% fill setting effectively disables WRED.

No IP packet rewrite is performed with a default CoS configuration. Packets are sent with the same markers as when they were received.

Four forwarding classes, but only two queues

The default CoS configuration defines four forwarding classes: BE, EF, AF, and NC, which are mapped to queues 0, 1, 2, and 3, respectively. However, as noted earlier, there is no default IP classification that will result in any traffic being mapped to either the AF or the EF class. This is good, because as also noted earlier, no scheduling resources are allocated to queue 1 or 2 in a default CoS configuration. It's worth noting that the default MPLS EXP classifier table is capable of directing traffic into all four queues, but MPLS is not being deployed in this lab. Some very interesting and difficult-to-solve problems occur if you begin to classify AF or EF traffic without first defining and applying schedulers for those classes. Doing so typically results in intermittent communications (some small trickle credit is given to 0% queues to prevent total starvation) for the AF/EF classes; this intermittency is tied to the loading levels of the BE and NC queues, given that when there is no BE or NC traffic, more AF/EF can be sent, despite the 0% default weighting.

BA and rewrite marker templates

JUNOS creates a complete set of BA classifier and rewrite marker tables for each supported protocol family and type, but most of these tables are not used in a default CoS configuration. For example, there is both a default IP precedence (two actually) and a default DSCP classifier and rewrite table. You can view default and custom tables with the `show class-of-service classifier` or `show class-of-service rewrite-rule` command.

The default values in the various BA classifier and rewrite tables are chosen to represent the most common/standardized usage. In many cases, you will be able to simply apply the default tables. Because you cannot alter the default tables, it is suggested that you always create custom tables, even if they end up containing the same values as the default table. This does not involve much work, given that you can copy the contents of the default tables into a customer table, and in the future, you will be able to alter the customer tables as requirements change.

In a default configuration, input BA classification is performed by the `ipprec-compatibility` table and IP rewrite is in effect, meaning the ToS marking of packets at egress match those at ingress. The only rewrite table in effect in a default configuration is for MPLS using the `exp-default` table.

M-Series and J-Series CoS Summary

This section detailed the many common CoS capabilities of the M7i and J-series platforms, and it highlighted the few areas where their operation or capabilities differ. For example, the J-series has built-in per-unit scheduling capabilities, for which the M-series platforms require special IQ PICs. Also, the J-series scheduler is priority-based, which can be a common source of confusion for technicians who are familiar with the M-series scheduler behavior. Despite these differences, the use of a common code base and CLI, combined with relatively consistent CoS handling, means that the same set of commands are used to configure and monitor CoS operation.

The next section applies the knowledge gained thus far in a practical CoS deployment and verification scenario. Despite the fact that the lab sections are such fun, you should consider taking another break to think about the material covered to this point and to review any areas with which you are not comfortable.

DiffServ CoS Deployment and Verification

It was a long time getting here, but you have arrived, and you are now ready to rush headlong into a JUNOS software-based CoS configuration and verification lab. Figure 9-16 provides the network topology for the IP DiffServ CoS deployment scenario.

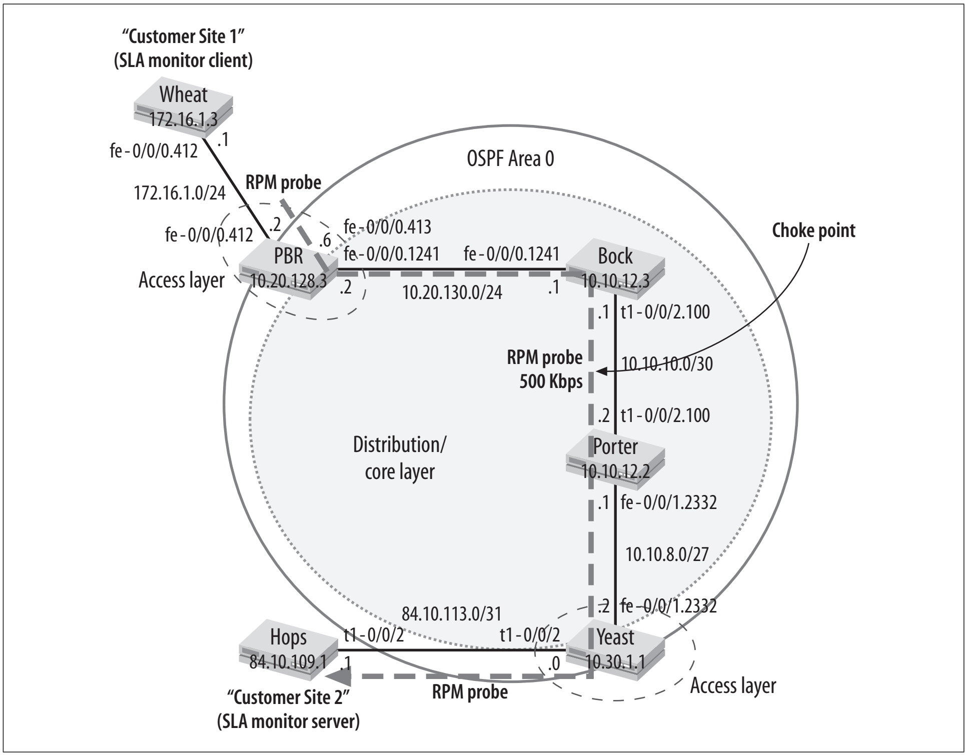


Figure 9-16. DiffServ CoS deployment topology

There are a few things to note in Figure 9-16. The test topology is somewhat simplified, and the test bed lacks the external test equipment needed to accurately measure and verify data plane performance. The first issue is not really a problem, because a workable CoS configuration is somewhat repetitive, basically involving the need to put the same configuration bits, consistently, in lots of places. As such, any network with a clearly marked edge and distribution/core devices services as a workable model with which to demonstrate CoS configuration and operational verification.

The subset of routers selected for the CoS topology was chosen in large part because of the (relatively) low-speed T1 interface interconnecting Bock and Porter. We noted previously that CoS matters only when link utilization begins to approach 80%. Obviously, with a given offered load, a slower link will exhibit higher utilization than a faster one—considering the lack of external traffic generators, it will be hard enough to congest a T1 link, let alone a 100 Mbps Fast Ethernet. In fact, to help stack the odds against a successful CoS demonstration, the T1 link between Bock and Porter is shaped to 500 Kbps. Although considerably less than the full T1 rate of 1536 Kbps, the shaped rate still qualifies as a broadband connection, which maintains a fair degree of realism.

Why Not Test CoS with Control-Plane-Generated Traffic?

The only true way to measure the impact of any CoS configuration is through data plane stimulation using a *reputable* external traffic generator. We stress the term *reputable* here because any device that is used to diagnose problems that might relate to a few extra milliseconds of queuing delay has to be spot-on accurate and believable; otherwise, you are likely to find that folks blame unexpected results on the test methodology and tools rather than on the router's CoS performance. Software-based traffic generators exist, and they are certainly better than trying to generate test traffic from a router's control plane, but a real router tester, one that is hardware-based, can easily cost tens of thousands of dollars.

The Juniper Networks architecture separates the control and data planes, and various rate-limiting and prioritization functions within the PFE and routing engine conspire against any attempt to generate either large volumes of traffic or test traffic with a high degree of time-based accuracy. To expand, internal RE-based rate limits control how much traffic the RE can generate using rapid or flood pings. The PFE also has a rate limit as to how many such Internet Control Message Protocol (ICMP) echo request packets it will even try to pass up to the host RE. If that were not enough, handling ICMP messages is considered a low priority within JUNOS software. Given the choice of replying to a ping or processing a Border Gateway Protocol (BGP) route update, a Juniper router always chooses the latter. This is not to say that the router will not reply to the ping; quite the opposite—it most certainly will reply, but only when it's good and ready. Although exceedingly reasonable, this behavior results in significant variance in ping response, even in a network that is largely idle in the control plane and is transporting very little data.

Putting issues with time-based inaccuracies aside for the moment, the JUNOS software control plane simply does not generate enough traffic to congest most modern network links. With no congestion, there is no way to consistently demonstrate any benefit to a CoS configuration.

Consider the output taken between PBR and Bock, when the *only* traffic in the network is periodic OSPF hellos and the ICMP test traffic itself:

```
[edit]
lab@PBR# run traceroute 10.10.12.3
traceroute to 10.10.12.3 (10.10.12.3), 30 hops max, 40 byte packets
 1  10.10.12.3 (10.10.12.3)  24.981 ms  6.937 ms  32.217 ms
```

The traceroute confirms that the direct 100 Mbps link is used between PBR and Bock, yet notice the large variance in ping response times, which is normal and expected given the Juniper design:

```
[edit]
lab@PBR# run ping 10.10.12.3 count 20
PING 10.10.12.3 (10.10.12.3): 56 data bytes
64 bytes from 10.10.12.3: icmp_seq=0 ttl=64 time=26.263 ms
64 bytes from 10.10.12.3: icmp_seq=1 ttl=64 time=10.116 ms
64 bytes from 10.10.12.3: icmp_seq=2 ttl=64 time=20.121 ms
64 bytes from 10.10.12.3: icmp_seq=3 ttl=64 time=10.126 ms
64 bytes from 10.10.12.3: icmp_seq=4 ttl=64 time=10.130 ms
64 bytes from 10.10.12.3: icmp_seq=5 ttl=64 time=44.755 ms
. . .
64 bytes from 10.10.12.3: icmp_seq=15 ttl=64 time=69.799 ms
64 bytes from 10.10.12.3: icmp_seq=16 ttl=64 time=10.124 ms
64 bytes from 10.10.12.3: icmp_seq=17 ttl=64 time=10.129 ms
64 bytes from 10.10.12.3: icmp_seq=18 ttl=64 time=10.162 ms
64 bytes from 10.10.12.3: icmp_seq=19 ttl=64 time=9.868 ms

--- 10.10.12.3 ping statistics ---
20 packets transmitted, 20 packets received, 0% packet loss
round-trip min/avg/max/stddev = 9.868/16.122/69.799/14.835 ms
```

The highlighted entries show the degree of response time variance considered par for the course in the Juniper design. Clearly, trying to validate CoS using rapid pings is simply not workable in JUNOS software, because you will not be able to generate enough traffic to reliably congest most links. Also, the test results will be all over the map, whether or not your CoS configuration is working, simply because the endpoints generating the test traffic treat it as a low-priority process, thereby breaking the CoS chain at its first link.

Cannot control classification of locally generated traffic

Generally speaking, unless you are running JUNOS software Release 9.0 or later, you have virtually no control over what egress queue locally generated traffic is placed into. The basic issue here is that when the RE injects traffic into the PFE, it bypasses ingress multifield and BA classification and simply does what it feels is best.

For example, a BGP transmission is normally placed into the BE queue (0), unless it is a retransmission, in which case it goes into the NC queue (3). As another example, you can generate a ping with any arbitrary ToS pattern, but this ping will be locally classified as BE and placed into queue 0. Downstream nodes can be expected to correctly recognize the packet's ToS field, because they see the traffic as transit.

The inability to apply your transit CoS actions to locally generated traffic is yet another reason why you cannot test a local nodes PHB with traffic sourced or received by that same node.

Enter resource performance monitoring

Juniper routers support an SLA monitoring feature that uses Real-Time Performance Monitoring (RPM) probes to measure performance, and if desired, to generate Simple Network Management Protocol (SNMP) alarms when performance falls below a configurable threshold. In the initial implementation, the RPM daemon ran as a user process in the RE—unfortunately, this resulted in inaccuracies when the RE CPU happened to be busy doing something else. Starting with Release 8.3, J-series routers can move the timestamp function into the real-time thread for significantly improved accuracy. Similar hardware timestamping functionality on the M-series requires use of the M7i's built-in services interface or an Adaptive Services PIC (ASP) on the M10i. The use of hardware timestamps does not cause the actual generation or processing of the RPM probes to be any more accurate, as the RE will still schedule the processing as it sees fit, but when the RE does get around to looking at the probe, the timestamp, already added at the hardware layer, allows for accurate performance measurements.

Although not nearly as definitive as a *real* traffic generator, the RPM service automatically tracks loss and summarizes one-way and round-trip delays, including jitter measurements, which beats the heck out of using pings and a pad of paper. Also, because the RPM service is instantiated on a pair of routers that are *external* to the CoS test bed, maximum accuracy can be expected. By *external*, we mean that `Wheat` and `Hops` simulate attached CE devices and are not taxed with any packet forwarding (other than the locally generated RP probes themselves) or any other processing task that could lead to large variances in RPM test probe results—these routers are not running *any* other services, are not running any routing protocols, and are not involved in the FTP transfer used to produce congestion. In this lab topology, `Wheat` and `Hops` function strictly as SLA monitoring devices—which is actually a realistic scenario, as some service providers deploy J-series routers in just such a capacity.

Configure DiffServ-Based CoS

Refer back to Figure 9-16 for the topology details of the IP DiffServ CoS scenario. You can assume that the network infrastructure is already configured with the interface addressing and single-area OSPF topology shown. A passive OSPF instance is enabled on the customer-facing interfaces at `PBR` and `Yeast` in order to provide reachability between their respective interface addresses. Your goal is to enable CoS in accordance with these criteria:

1. Perform the following multifield classification:
    - Classify ICMP timestamp messages received over customer-facing interfaces as EF to support RPM-based SLA monitoring for the EF class.
    - Classify Telnet traffic received over customer-facing interfaces as bronze (BR).
    - Classify OSPF in the core as NC.
    - Classify all other traffic as BE.
2. Perform DSCP-based BA classification at all other nodes, supporting the following forwarding classes and queue assignments:
    - BE, mapped to queue 0
    - EF, mapped to queue 1
    - BR, mapped to queue 2
    - NC, mapped to queue 3
3. Shape traffic on the Frame Relay link to 500 Kbps, in accordance with a 0 CIR service terminating in a 500 Kbps switch port.
4. Define and apply the following scheduler policy:
    - Provide BE at least 50% and allow use of excess bandwidth. Configure a PLP = 0 RED profile with 5% drop probability at 50%, and 20% drop probability at 80%, and a PLP = 1 RED profile with 20% drop probability at 50%, and 70% drop probability at 80%.
    - Limit BR to 10%; accept up to 1 Mbps/200 KB burst of BR from customers. Excess traffic must be treated as BE with high PLP by all nodes.
    - Provide EF at least 35% and ensure that it's serviced quickly to support low-latency applications. Traffic must not experience more than 30 milliseconds of buffering per hop.
    - Provide NC with at least 5% and ensure that it cannot be starved. The NC class must be able to use excess bandwidth.

At first glance, the long list of CoS requirements may seem daunting, but when tackled in small parts, the overall task becomes much easier to manage. CoS-related configurations tend to have a lot of common elements, which allows you to save time by configuring one node and then using that configuration as a template to bootstrap the configuration of the remaining routers.

Because the default CoS configuration offers scheduling support for the BE and NC classes only, it's a good idea to get as much of the CoS infrastructure up and running before you apply any classification that could result in traffic being mapped into queues other than 0 and 3. This avoids potential disruption resulting from traffic being assigned to a queue with no scheduling resources assigned.

This scenario calls for the use of DSCP classification. Previous sections detailed how the original IP precedence functionality is subsumed by the CS code point grouping. The default DSCP rewrite and classifier tables support the CS DSCPs. This means you can use the default IP precedence classifier at the network's edges while the rest of CoS is configured, including the DSCP BA classification and rewrite in the distribution and core layers. Stated differently, the goal is to enable CoS for all four forwarding classes, while maintaining the pre-CoS classification of only two forwarding classes in an attempt to minimize disruptions stemming from a network with partial CoS configuration. When all nodes are CoS-aware, MF classification is activated at the edge to enable use of all four forwarding classes.

Multifield classification and policing (task 1)

The first set of CoS functions to be configured are the multifield classifiers used at the edges to perform initial classification actions on the traffic received from customers. This is accomplished with firewall filters, which also provide a hook into the policing needed for the EF class in this example. Because the customer devices do not run any routing protocol, there is no need to support NC classification at ingress. If NC support is needed, it's a good idea to define explicit multifield classifier support, because the results of ingress BA classification can be overwritten by a multifield classifier, which could lead to NC being placed into the BE queue.

A multifield classifier and associated policer meeting the requirements of this example are configured at PBR:

```
lab@PBR# show
policer police_bronze {
    if-exceeding {
        bandwidth-limit 1m;
        burst-size-limit 200k;
    }
    then {
        loss-priority high;
        forwarding-class best-effort;
    }
}
filter mf_classify {
    term classify_ef {
        from {
            protocol icmp;
            icmp-type [ timestamp timestamp-reply ];
        }
        then {
            count ef_in;
            forwarding-class expedited-forwarding;
            accept;
        }
    }
    term classify_bronze {
        from {
            protocol tcp;
            port telnet;
        }
        then {
            policer police_bronze;
            count bronze_in;
            forwarding-class bronze;
        }
    }
    term else_be {
        then {
            forwarding-class best-effort;
            accept;
        }
    }
}
```

The classify_ef term matches on ICMP timestamp-related messages, which are then classified as EF. This term supports the ICMP-based RPM probe request that is generated at Wheat, along with the probe replies generated at Hops. The classify_bronze term performs a similar function for matching Telnet traffic, except it also evokes a policer to limit traffic in this class. The associated bronze_policer is set with a traffic profile in accordance with the provided criteria for rate and burst size. Conforming traffic is handed back to the calling classify_bronze term, where it is classified as BR, while out-of-profile traffic is classified as BE with a high-loss priority. Both the EF- and BR-related terms evoke a counter action that can be used later when confirming that CoS handling and classification are working as expected. The final term matches on everything else for classification into the BE bin.

Although not shown, the same multifield classifier and policer configuration is also added to Yeast. Also, for reasons cited earlier, the multifield classifier is not yet placed into effect given that resources have not yet been defined for the EF or BR class.

BA classification and rewriting (task 2)

With multifield classification ready to be placed into effect, you move on to create the DSCP-based BA tables used by distribution and core layer devices for efficient packet classification. This example creates custom tables that are then populated with the defaults. This ensures full table population, which is a good housekeeping practice, given the required behavior of dispatching unmatched traffic into the BE queue. Note that unlike the default IP precedence classifier (which is actually in effect by default), the default DSCP tables support four forwarding classes: BE, AF, EF, and NC. This example replaces the AF class with a custom-defined class called bronze (BR). Once you define a forwarding class called BR and map it to queue 2, the classification and rewrite tables automatically associate any code point mapping to that queue as belonging to the BR class.

The default DSCP table entries do not support a high- and low-loss priority for BE traffic. To convey an ingress setting of PLP to other nodes, as required in this case study, you need to define an entry for BE traffic with high-loss priority. It is customary to use the least significant bit of a given BA field to denote loss priority, which is the approach taken here, such that the binary pattern 000000 is interpreted as BE with a low-loss priority, and binary 000001 indicates BE with a high-loss priority. Note how each entry in a BA classification should have a matching entry in the related rewrite table for consistent handling in downstream nodes.

The custom forwarding class definition and BA classification/rewrite configuration is shown at Bock:

```
[edit class-of-service]
lab@Bock# show forwarding-classes
queue 2 bronze;

[edit class-of-service]
lab@PBR# show classifiers
dscp dscp_classify {
    import default;
    forwarding-class best-effort {
        loss-priority high code-points 000001;
    }
}

[edit class-of-service]
lab@PBR# show rewrite-rules
dscp dscp_rewrite {
    import default;
    forwarding-class best-effort {
        loss-priority high code-point 000001;
    }
}
```

The forwarding-classes statement is used to define a new forwarding class alias called bronze, and to bind that alias to a queue number. In this case, only one nondefault forwarding class alias is needed, and it is correctly mapped to queue 2; in a default configuration, this queue number is associated with the AF alias.

The user-defined DSCP BA classifier and rewrite tables are assigned names that denote their function and are initially populated with the code point defaults. A single modified entry is added to support the conveyance of loss priority for the BE class to downstream nodes.

The custom forwarding class definition and DSCP classification/rewrite tables are placed into effect on all noncustomer-facing interfaces at all nodes. There is no harm in applying these tables to the customer-facing interfaces; but there isn't much gain either. The multifield classification that will be used at the edge makes any BA classifier superfluous, given that the mf_classify filter is written to classify *all* traffic that is received and overrides the results of any BA classification anyway. A rewrite marker at the customer edge is generally used only when you wish to reset packet markings to some agreed upon default, or to help obfuscate the markings that are significant in the core, which could be used as ammunition in a CoS-centered denial of service (DoS) attack. In this example, packets are handed to the egress customer device, with whatever marking they were received with on the core-facing interface.

Here is the application of the user-defined DSCP classifier and rewrite tables, again at Bock:

```
[edit class-of-service]
lab@Bock# show interfaces
fe-0/0/0 {
    unit 1241 {
        classifiers {
            dscp dscp_classify;
        }
        rewrite-rules {
            dscp dscp_rewrite;
        }
    }
}
t1-0/0/2 {
    unit 0 {
        classifiers {
            dscp dscp_classify;
        }
        rewrite-rules {
            dscp dscp_rewrite;
        }
    }
}
```

At this stage, the custom forwarding class definition and DSCP BA configuration is replicated to all nodes. The DSCP classifier and rewrite tables are then applied on all interfaces in the CoS topology, with the exception of the customer-facing interfaces, which do not use a BA classifier or rewrite table.

Completing the aforementioned steps at all routers has accomplished a large portion of the needed CoS configuration. To recap, you now have a multifield classifier with policing on the network's edges (not yet activated, however), you have defined a custom forwarding class call bronze, and you created and applied custom DSCP classifiers and rewrite rules to support loss priority for the BE class on all noncustomer-facing interfaces.

The DSCP tables currently use default values for any entry not explicitly specified by the user because the import default statement is included. The default code points inherently support the IP precedence-based classification that is still in effect at the network's edges. The use of the default IP precedence classifier, combined with the inherent compatibility of IP precedence via the CS DSCPs, results in all traffic being classified into either the BE or the NC class at ingress, just as it was before you began the CoS configuration. Importantly, the ingress classification is maintained end to end even though downstream devices classify based on DSCP. It's noted again that the default scheduler configuration, which is still in effect, allocates resources only to the BE and NC classes, meaning that actions to this point should have had no operational effect on the network. It could be said that for the average core node, the only changes are a newly defined but still unused forwarding class and the use of DSCP rather than default IP precedence ingress classification. However, the compatibility between the precedence and DSCP tables means that the packets are classified into BE or NC with both the original and modified configurations.

CoS shaping (task 3)

Shaping, which reduces the maximum speed of an interface to some lesser value, is useful for a variety of reasons. You can rate-limit an interface using a policer, but this is problematic from a CoS perspective because the CoS components do not see the policed rate, but rather the rate of the interface itself. As a result, policing a 100 Mbps interface to 1 Mbps, and then configuring a scheduler with a 10% transmit rate, leads the scheduler to allocate 10% of 100 Mbps, not the policed rate of 1 Mbps. Shaping performed at the `[edit class-of-service]` hierarchy works around this issue, but is supported on only M-series routers when using IQ/IQ2 PICs. J-series routers support shaping on all interfaces because of their built-in support for per-unit scheduling.

> It is fortunate that we used shaping in this example. During testing, it was determined that a bug affecting buffer allocation (PR 236548) for IXP-based T1/E1 interfaces resulted in minimal benefit to CoS over the T1 interface, just where it was needed the most. The presence of the `shaping` statement corrects the buffer allocation issue, even when set to 95% of the line rate, and is a reasonable workaround for users on affected code. In addition to fixing bugs, Juniper is constantly enhancing the CoS capabilities of the J-series platform. Where possible, users should upgrade to 8.5 or later to get maximum CoS performance.

In this example, `Bock` and `Porter` are interconnected via a Frame Relay service provisioned with a 0 CIR, which terminates in a 500 Kbps port. Traffic sent in excess of the port speed results in immediate discard, so the T1 interfaces at `Bock` and `Porter` are shaped to a 500 Kbps rate. Later, when you apply a scheduler to these interfaces, the scheduler will allocate resources based on the *shaped* rate of 500 Kbps rather than the 1.536 Mbps physical rate. What follows are the Frame Relay interface configuration and related CoS shaping settings for `Bock`:

```
[edit]
lab@Bock# show interfaces t1-0/0/2
description Bock-to-porter;
per-unit-scheduler;
dce;
encapsulation frame-relay;
unit 100 {
    dlci 100;
    family inet {
        address 10.10.10.1/30;
    }
}

[edit]
lab@Bock# show class-of-service interfaces t1-0/0/2
unit 100 {
    shaping-rate 500k;
    classifiers {
        dscp dscp_classify;
    }
    rewrite-rules {
        dscp dscp_rewrite;
    }
}
```

The code highlights show the per-unit-scheduler statement, which is specified at the interface device level to back up the shaping-rate configuration at the [edit class-of-service interfaces interface-name unit unit-number] hierarchy. Also highlighted is the related Frame Relay configuration; in this case, Bock is set to a data circuit-terminating equipment (DCE) device to enable use of ANSI Annex D link integrity (keepalive) and PVC status polling from (default) data terminal equipment (DTE) Porter.

With shaping in place, the only CoS functionality yet to be configured is the scheduler definition and application to CoS-enabled interfaces.

Scheduler definition and application (task 4)

Up until this stage, the CoS configuration examples and steps shown are the same whether you are dealing with an M7i (equipped with IQ PICs) or a J-series platform. The differences in scheduler behavior between these platforms demand careful consideration—you will generally need different scheduler configurations for a J-series versus an M-series to produce similar scheduling effects.

The scheduling requirements of this scenario were decided upon in equal parts because they are typical, and because they help to demonstrate the differences in scheduling behavior. Table 9-4 summarizes the scheduling requirements.

Table 9-4. Summary of scheduling behavior for the DiffServ scenario

Class	Guaranteed rate	Priority; AQM; buffer	Excess bandwidth
BE	50%	Low; WRED based on PLP; N/A	Yes
BR	10%	Low; N/A; N/A	No/Yes, ingress policing sets excess as BE with PLP = 1
EF	35%	High; N/A; 30 msec	No
NC	5%	High; N/A; N/A	Yes

M-series scheduler definition. Table 9-4 shows that two priority levels are required to help expedite EF and NC traffic over BR and BE, and also details each queue's settings with regard to transmit weight, AQM (WRED)-enabled, buffer size restriction, and ability to use leftover bandwidth above its configured weight.

The following output shows an M-series scheduler definition that meets all of the specified requirements:

```
[edit class-of-service]
lab@M-Series# show schedulers
be_sched {
    transmit-rate percent 50;
    priority low;
}
ef_sched {
    transmit-rate percent 35 exact;
    priority high;
    buffer-size temporal 30k;
}
nc_sched {
    transmit-rate percent 5;
    priority high;
}
bronze_sched {
    transmit-rate percent 10 exact;
    priority low;
}
```

The EF class does not require use of excess bandwidth and is rate-limited through the use of the exact keyword. This limits EF traffic to its configured weight, which helps to ensure that the class is not oversubscribed in downstream nodes. Because both the EF and NC classes are set to high priority, you can guarantee that neither can starve the other. By not specifying strict-high, you also ensure that no starvation among low-priority queues should the nonpoliced NC class become overactive. This is because the M-series scheduler round-robins between high-priority queues until their transmit weight has been satisfied, and then moves on to service low-priority queues with positive credit.

The EF scheduler has its buffer depth manually set to 30 milliseconds of delay bandwidth (30,000 microseconds). This queue's relative high transmit weight combined with its high priority means it should maintain a low fill level anyway. The reduced buffer size and rate limiting leads to drops in the EF queue during periods of excessive EF traffic, even when all other classes are idle. In most cases, trying to accept overflow EF traffic—for example, by reclassifying the excess into another class or by configuring ever-larger buffer depths—results in more harm than good. This is because although you may reduce the overall number of EF drops, the resultant increase in delay and delay variance is often more disruptive to a real-time application than the outright loss such actions aimed to prevent. Worse yet, troubleshooting this type of problem is difficult when compared to the relatively straightforward task of correlating service complaints to excessive EF queue drops.

You cannot use the exact keyword for NC scheduling due to the requirement that it be able to use any excess bandwidth. Without some form of policing/rate limiting, it is possible that excess NC traffic could capitalize on all unused bandwidth, preventing both the BE and BR classes from being able to send traffic above their configured weights. Although it's easy enough to police NC traffic, this is seen as unnecessary here because:

- There is no requirement that the BE and BR classes must actually get excess bandwidth, just that they should be able to use it when it's available. Because M-series scheduling is not strict-priority-based, you need to worry about having high-priority queues affecting a low-priority queue's ability to get at least its configured weight.
- You are not accepting any NC traffic from customer/end devices, which means the only source of NC traffic is within the network, and you trust your network not to launch an NC-based DoS attack. The only source of NC in this network is OSPF, which unlike a full BGP table feed, does not generate appreciable volumes of NC. This is especially true for a small- to medium-scale network that is mostly stable.

The BR scheduler is also shaped to its transmit rate via the exact keyword; recall that ingress policing classifies excess BR as BE, so the BR class gets its excess bandwidth indirectly via the BE class.

J-series scheduler definition. Here is an example of a J-series scheduler that closely approximates the M-series example just described:

```
be_sched {
    transmit-rate percent 50;
    priority low;
}
ef_sched {
    transmit-rate percent 35 exact;
    priority high;
    buffer-size temporal 30k;
}
nc_sched {
    transmit-rate percent 5;
    shaping-rate percent 20;
    priority high;
}
bronze_sched {
    transmit-rate percent 10 exact;
    priority medium-high;
}
```

Because of the strict priority nature of a J-series scheduler, your first concern should be how to ensure that higher-priority classes do not prevent lower-priority classes from at least getting their configured weight. This is accomplished in a number of ways.

First the EF and NC classes are set to the same priority, which is the highest priority configured. This ensures that the EF and NC classes cannot be starved, and that they cannot starve each other. The EF class is again capped to its configured weight using `exact`. In this example, the NC class is *shaped*, rather than rate-limited, allowing it to use up to 20% of interface bandwidth.

Although not able to send at line rate, technically this meets the requirement given because the NC class is able to use excess bandwidth beyond its configured weight. This behavior differs from the M-series scheduler example, where the NC class could use up to 100% of available bandwidth when no other classes are active, but again, the behavior still meets all criteria specified.

Second, the shaped rate of 20% for the NC class, combined with the maximum 35% rate for the EF class, accounts for only 55% of transmit bandwidth. This leaves a guarantee that at least 45% of the bandwidth remains for use by the BE and BR classes. The BR class is serviced after the high-priority queues have reached their limits, but before the BE class due to its higher priority setting. Because the BR class is limited to a maximum of 10%, you can guarantee that the BE class will get at least 35% of interface bandwidth, using the following formula:

BE avail% = 100 – (EF max + NC max + BR max)
BE avail% = 100 – (35 + 20 + 10)
BE avail% = 100 – 65

The net result of all this interaction is that the BE class is *actually* guaranteed to get 35% of transmit bandwidth, despite its configured 50% weight. However, this reduction in BE capacity occurs *only* during periods of excessive NC activity, an event that should be both rare and transient. Besides, any negative impacts of the design are relegated to the BE class where folks are used to being treated poorly, so who will complain?

> This book is written to the 8.0 code base. Starting with Release 8.1, J-series platforms offer support for an LLQ feature that offers a fifth priority level called `strict-high`. You can define only one `strict-high` queue (well, technically, only the first one defined is actually considered `strict-high`). The `exact` command does not apply because a `strict-high` scheduler is automatically given 100% transmit. To prevent starvation when using the `strict-high` priority, you must define a policer (or as many as two) that limits how much traffic is guaranteed, that is dropped only when the egress interface is congested, or that is dropped regardless of egress congestion.
>
> Refer to the JUNOS software documentation for Release 8.1 and later for additional details on the LLQ feature.

An Alternative J-Series Scheduler Approach

Although not demonstrated here, you can more closely approximate M-series scheduler behavior by defining additional forwarding classes that are used to support overflow traffic from higher-priority classes, and that are serviced only when no other *real* class has traffic pending. This approach is quite workable on the J-series, given the support of eight queues/forwarding classes.

Here is an example of the alternative scheduler approach:

```
be_sched {
    transmit-rate percent 49;
    priority low;
}
ef_sched {
    transmit-rate percent 35 exact;
    priority high;
    buffer-size temporal 30k;
}
nc_sched {
    transmit-rate percent 5 exact;
    priority high;
}
bronze_sched {
    transmit-rate percent 10 exact;
    priority medium-high;
}

nc_overflow_sched {
    transmit-rate percent 1;
    priority low;
}
```

Note that the scheduler now supports five classes. The new forwarding class is defined as `nc_overflow`, and the related scheduler is assigned a low priority, as well as a minimal transmit rate designed to minimize impact on the BE class. The NC scheduler is now configured with an exact transmit rate of 5%. The support of excess NC is now backed up by a policer (not shown) that limits NC to 5% of the interface speed, which for Fast Ethernet would be 5 Mbps.

> To configure a policer that is based on a percentage of interface bandwidth, you must add the `interface-specific` keyword to the firewall filter that calls the policer.

Traffic exceeding the policer profile is classified as `nc_overflow`. Because the `nc-overflow` and BE classes are assigned the same priority, you ensure that excessive amounts of BE traffic cannot starve the NC overflow queue. This is a matter of choice here, as the requirements do not mandate that the NC class *always* be able to send more than its weight, just that it be able to when excess bandwidth is available.

With the alternative configuration, the NC class gets a guaranteed 5% as NC, and an additional 1% BE transmit rate, and can burst up to 100% when no other classes are active (95% of which will be treated as BE). At the same time, the BE class is now guaranteed to get at least 49% when all other classes are active and can burst to line rate when they are not. This configuration meets all requirements, and offers the additional benefit of allowing the NC scheduler to operate at 100% when other classes are idle.

Define RED Profiles

To complete the definition of the BE scheduler, you must define two drop profiles—one for PLP 0 and another for PLP 1 traffic—and link them to the be_sched scheduler. The drop profiles are shown, and the BE scheduler is updated to incorporate them. The same WRED configuration applies to both M- and J-series routers because the requirements do not expect drop behavior that is tied to TCP versus UDP, which is not supported on the J-series anyway. This is an example of WRED because two drop profiles are defined; in this case, the weighting is toward the internal loss-priority status of each packet in the BE queue.

```
[edit class-of-service]
lab@PBR# show drop-profiles
be_low_plp {
    fill-level 50 drop-probability 5;
    fill-level 80 drop-probability 50;
}
be_high_plp {
    fill-level 50 drop-probability 50;
    fill-level 80 drop-probability 70;
}

[edit class-of-service]
lab@PBR# show schedulers be_sched
transmit-rate percent 50;
priority low;
drop-profile-map loss-priority low protocol any drop-profile be_low_plp;
drop-profile-map loss-priority high protocol any drop-profile be_high_plp;
```

The remaining forwarding classes use the default RED profile, which effectively disables RED given that the only drop point specified is 100% drop at 100% fill.

Scheduler application

The J-series version of the scheduler definition is used in this example, in keeping with the J-series makeup of the enterprise routing lab. You apply a scheduler to an interface through a scheduler-map statement. Here is a working scheduler map and its application to all CoS-enabled interfaces, shown at node PBR:

```
[edit class-of-service]
lab@PBR# show scheduler-maps
```

```
er_cos_scheduler {
    forwarding-class best-effort scheduler be_sched;
    forwarding-class expedited-forwarding scheduler ef_sched;
    forwarding-class network-control scheduler nc_sched;
    forwarding-class bronze scheduler bronze_sched;
}

[edit class-of-service]
lab@PBR# show interfaces
fe-0/0/0 {
    unit 412 {
        scheduler-map er_cos_scheduler;
    }
    unit 1241 {
        scheduler-map er_cos_scheduler;
        classifiers {
            dscp dscp_classify;
        }
        rewrite-rules {
            dscp dscp_rewrite;
        }
    }
}
```

The `scheduler-map` links each defined forwarding class to a scheduling policy. When applied to an interface, a scheduler is instantiated according to the combined policy of the statements in the `scheduler-map`. Note that in this example the use of VLAN tagging warrants the need for per-unit scheduling, which enables scheduling at the logical interface—that is, at the VLAN level. By default, a per-unit scheduler assumes the full physical interface bandwidth, unless it is shaped to a lesser value. The scheduler map shown will fail to commit unless `per-unit-scheduling` is also set at the `[edit interfaces interface-name]` hierarchy, as shown:

```
[edit]
lab@PBR# show interfaces fe-0/0/0
per-unit-scheduler;
vlan-tagging;
unit 412 {
    description PBR-to-Wheat;
    vlan-id 412;
    family inet {
        address 172.16.1.2/24;
    }
}
unit 1241 {
    description PBR-to-Bock;
    vlan-id 1241;
    family inet {
        address 10.20.130.2/24;
    }
}
```

Activate multifield classification

Now that all forwarding classes have been defined with scheduling resources and you have a consistent BA classification scheme deployed throughout the network, it is safe to activate the previously defined multifield classification filter at edge nodes PBR and Yeast. The filter and related policer were defined in a previous step; all that is left now is to apply the filter in the input direction on all customer-facing interfaces:

```
[edit]
lab@PBR# show interfaces fe-0/0/0 unit 412
description PBR-to-Bock;
vlan-id 412;
family inet {
    filter {
        input mf_classify;
    }
    address 172.16.1.2/24;
}
```

The complete configuration

The various parts of the CoS configuration have been shown and discussed individually. Here is the complete CoS configuration at ingress node PBR, to give you a better perspective of the big picture:

```
[edit]
lab@PBR# show class-of-service | no-more
classifiers {
    dscp dscp_classify {
        import default;
    }
}
drop-profiles {
    be_low_plp {
        fill-level 50 drop-probability 5;
        fill-level 80 drop-probability 50;
    }
    be_high_plp {
        fill-level 50 drop-probability 50;
        fill-level 80 drop-probability 70;
    }
}
forwarding-classes {
    queue 2 bronze;
}
interfaces {
    fe-0/0/0 {
        unit 412 {
            scheduler-map er_cos_scheduler;
        }
        unit 1241 {
            scheduler-map er_cos_scheduler;
            classifiers {
                dscp dscp_classify;
            }
            rewrite-rules {
                dscp dscp_rewrite;
            }
        }
    }
}
rewrite-rules {
    dscp dscp_rewrite {
        import default;
    }
}
scheduler-maps {
    er_cos_scheduler {
        forwarding-class best-effort scheduler be_sched;
        forwarding-class expedited-forwarding scheduler ef_sched;
        forwarding-class network-control scheduler nc_sched;
        forwarding-class bronze scheduler bronze_sched;
    }
}
schedulers {
    be_sched {
        transmit-rate percent 50;
        priority low;
        drop-profile-map loss-priority low protocol any drop-profile be_low_plp;
        drop-profile-map loss-priority high protocol any drop-profile be_high_plp;
    }
    ef_sched {
        transmit-rate percent 35 exact;
        buffer-size temporal 30k;
        priority high;
    }
    nc_sched {
        transmit-rate percent 5;
        shaping-rate percent 20;
        priority high;
    }
    bronze_sched {
        transmit-rate percent 10 exact;
        priority medium-high;
    }
}

[edit]
lab@PBR# show interfaces fe-0/0/0
per-unit-scheduler;
vlan-tagging;
unit 412 {
    description PBR-to-Wheat;
    vlan-id 412;
    family inet {
        filter {
            input mf_classify;
        }
        address 172.16.1.2/24;
    }
}
unit 1241 {
    description PBR-to-Bock;
    vlan-id 1241;
    family inet {
        address 10.20.130.2/24;
    }
}

[edit]
lab@PBR# show firewall
policer police_bronze {
    if-exceeding {
        bandwidth-limit 1m;
        burst-size-limit 200k;
    }
    then {
        loss-priority high;
        forwarding-class best-effort;
    }
}
filter mf_classify {
    term classify_ef {
        from {
            protocol icmp;
            icmp-type [ timestamp timestamp-reply ];
        }
        then {
            count ef_in;
            forwarding-class expedited-forwarding;
            accept;
        }
    }
    term classify_bronze {
        from {
            protocol tcp;
            port telnet;
        }
        then {
            policer police_bronze;
            count bronze_in;
            forwarding-class bronze;
        }
    }
    term else_be {
        then {
            forwarding-class best-effort;
            accept;
        }
    }
}
```

Most of the CoS configuration is common to all nodes, with the exception of interface names and the presence of multifield versus BA classification at customer-facing interfaces. Recall that T1 interface shaping is also in effect at nodes Bock and Porter. The t1-0/0/2 CoS configuration is displayed to show the shaping configuration, and the interface is set for DSCP-based BA classification and DSCP rewrite:

```
[edit]
lab@Bock# show class-of-service interfaces t1-0/0/2
unit 100 {
    scheduler-map er_cos_scheduler;
    shaping-rate 500k;
    classifiers {
        dscp dscp_classify;
    }
    rewrite-rules {
        dscp dscp_rewrite;
    }
}
```

Verify DiffServ-Based CoS

With the routers configured, it's time to verify that all this CoS mumbo jumbo actually amounts to a hill of beans, and better yet, happy end users.

> Whenever you feel that a CoS-related configuration is not doing what you expected, it is a good idea to monitor the system's messages and cosd logfiles while you perform a commit. Some misconfigurations, or a configuration that requires some bit of missing hardware to function correctly, often pass the commit check while generating a log message, indicating that some aspect of the configuration is being ignored and for what reason.

A number of operational mode commands display CoS configuration, and more important, operational status. Most you can access with the show class-of-service command:

```
lab@PBR> show class-of-service ?
Possible completions:
  <[Enter]>            Execute this command
  adaptive-shaper      Show trigger types and associated rate for adaptive shaper
  classifier           Show mapping of code point to forwarding class/loss priority
  code-point-aliases   Show mapping of symbolic name to code point bit pattern
  drop-profile         Show interpolated data points of named drop profile
  forwarding-class     Show mapping of forwarding class names to queue numbers
  forwarding-table     Show forwarding table information
  fragmentation-map    Show mapping of forwarding classes to fragmentation options
  interface            Show mapping of CoS objects to interfaces
  loss-priority-map    Show mapping of code point to loss priority
  rewrite-rule         Show mapping of forwarding class/loss priority to code point
  scheduler-map        Show mapping of forwarding classes to schedulers
```

```
    traffic-control-profile  Show traffic control profiles
    virtual-channel      Show virtual channel names
  virtual-channel-group  Show virtual channel group information
```

To save space, we will call upon the various commands when actually needed to verify CoS in the test network; we will cover the virtual channel and adaptive shaper-related commands in the next section.

You will also find that general firewall and the show interface queue commands come in particularly handy when checking CoS behavior—the former because firewall filters are used for multifield classification and to help debug CoS through match and count operations, and the latter because the resultant per-queue packet and drop counts provide critical information needed to verify classification-general queuing behavior. To display the queue statistics with show interface queue, you need an M-series platform equipped with an E-FPC, or any J-series platform.

Also note that you have the relative luxury of a test bed that, aside from OSPF, is completely quiescent unless stimulated in some way by user traffic, which is under your control. This makes it quite easy to confirm packet classification and general queuing behavior and to test the overall effects of CoS. This luxury is rarely afforded on a production network, and it is why it is always a good idea to stage a new CoS rollout in a proof-of-concept test bed where it is easy to validate and debug the results.

Confirm general CoS configuration

Things start at edge node PBR, where confirmation of the required forwarding classes is performed:

```
lab@PBR> show class-of-service forwarding-class
Forwarding class                     ID               Queue
  best-effort                         0                   0
  expedited-forwarding                1                   1
  bronze                              2                   2
  network-control                     3                   3
```

All four forwarding classes are present, including the custom bronze class. Good. You next verify CoS-related interface parameters for the core-facing Fast Ethernet interface at PBR with the show class-of-service interface command:

```
lab@PBR> show class-of-service interface fe-0/0/0.1241
  Logical interface: fe-0/0/0.1241, Index: 70
    Object              Name                 Type         Index
    Scheduler-map       er_cos_scheduler     Output       21207
    Rewrite             dscp_rewrite         dscp         26780
    Classifier          dscp_classify        dscp         25819
```

The output confirms that the er_cos_scheduler map is in effect, and shows that the custom dscp_classify classifier and dscp_rewrite rewrite tables have been applied. The index numbers are used internally when referencing the various tables or scheduler map instances. The makeup of the er_cos_scheduler is now confirmed:

```
lab@PBR> show class-of-service scheduler-map er_cos_scheduler
Scheduler map: er_cos_scheduler, Index: 21207

  Scheduler: be_sched, Forwarding class: best-effort, Index: 54989
    Transmit rate: 50 percent, Rate Limit: none, Buffer size: remainder,
    Priority: low
    Drop profiles:
      Loss priority   Protocol    Index    Name
      Low             any         45889    be_low_plp
      Medium low      any             1    <default-drop-profile>
      Medium high     any             1    <default-drop-profile>
      High            any         14464    be_high_plp

  Scheduler: ef_sched, Forwarding class: expedited-forwarding, Index: 5877
    Transmit rate: 35 percent, Rate Limit: exact, Buffer size: 30000 us,
    Priority: high
    Drop profiles:
      Loss priority   Protocol    Index    Name
      Low             any             1    <default-drop-profile>
      Medium low      any             1    <default-drop-profile>
      Medium high     any             1    <default-drop-profile>
      High            any             1    <default-drop-profile>

  Scheduler: bronze_sched, Forwarding class: bronze, Index: 26824
    Transmit rate: 10 percent, Rate Limit: exact, Buffer size: remainder,
    Priority: medium-high
    Drop profiles:
      Loss priority   Protocol    Index    Name
      Low             any             1    <default-drop-profile>
      Medium low      any             1    <default-drop-profile>
      Medium high     any             1    <default-drop-profile>
      High            any             1    <default-drop-profile>

  Scheduler: nc_sched, Forwarding class: network-control, Index: 22188
    Transmit rate: 5 percent, Rate Limit: none, Buffer size: remainder,
    Priority: high, Shaping rate: 20 percent,
    Drop profiles:
      Loss priority   Protocol    Index    Name
      Low             any             1    <default-drop-profile>
      Medium low      any             1    <default-drop-profile>
      Medium high     any             1    <default-drop-profile>
      High            any             1    <default-drop-profile>
```

The output of the show class-of-service scheduler-map command contains a lot of gold. The various highlights call out key differences in the scheduler behavior for each forwarding class. For example, the BE class is associated with the two RED drop profiles that are indexed against packet loss priority. All other forwarding classes link to the default RED profile. The EF scheduler's high priority is called out, as is the time-based constraint on its buffer size.

The BR scheduler is called out for its `medium-high` priority, and its rate-limiting through use of `exact`. Excess traffic in this BR class is reclassified as high-loss BE, affording this class an indirect way of getting unused bandwidth. The NC scheduler has a 20% shaping rate, which caps that queue at 20% of the transmit bandwidth, even when all other forwarding classes are idle.

It's critical to note that in this example, the only mechanism that prevents higher-priority schedulers from starving lower-priority schedulers is the rate limiting achieved through use of either the `exact` or the `shaping-rate` keyword. As an alternative, you could also use a firewall-based policer to provide the isolation needed between traffic classes for a successful DiffServ deployment.

The RED profiles associated with the BE class are displayed:

```
ab@PBR> show class-of-service drop-profile
Drop profile: <default-drop-profile>, Type: discrete, Index: 1
  Fill level    Drop probability
        100                  100
Drop profile: be_high_plp, Type: discrete, Index: 14464
  Fill level    Drop probability
         50                   50
         80                   70
Drop profile: be_low_plp, Type: discrete, Index: 45889
  Fill level    Drop probability
         50                    5
         80                   50
```

The output confirms the 100%/100% setting for the default drop profile, and the two custom RED profiles reflect the required drop points, which differ for high versus low-loss priority BE traffic. You now confirm the DSCP BA and rewrite tables. For brevity's sake, we show only a portion of the classification table:

```
lab@PBR> show class-of-service classifier type dscp name dscp_classify
Classifier: dscp_classify, Code point type: dscp, Index: 25819
  Code point         Forwarding class                  Loss priority
  000000             best-effort                       low
  000001             best-effort                       high
  000010             best-effort                       low
  000011             best-effort                       low
. . .
```

The highlighted code calls out the custom portion of the table, which defines a high-loss priority BE class code point. With the basic components of CoS configuration confirmed, it's time to move on to confirm data plane behavior.

Confirm classification and queuing

Displayed here for reference is the RPM-related configuration for the SLA monitoring client `Wheat`. We will display and analyze the actual RPM probe status later in this section.

Verifying Control and Data Plane Consistency

Most of the operational-mode CoS commands shown in this chapter have a forwarding table counterpart. Generally speaking, the output of control plane versus data plane forwarding table-related commands should agree. In some cases, a configuration may be rejected, and as a result the changes are not pushed into the forwarding table. When troubleshooting a CoS problem, it's always a good idea to look for CoS-related log messages when you commit, and to confirm that the forwarding table state matches the configuration and related control plane displays. The following code sample taken from PBR shows that the forwarding table's view of the DSCP rewrite function does in fact match the configuration:

```
[edit]
lab@PBR# run show class-of-service forwarding-table rewrite-rule
Rewrite table index: 26780, # entries: 4, Table type: DSCP
FC#  Low bits  State    High bits  State    Medium    State    Medium     State
                                          Low bits           High bits
0   000000   Enabled   000001    Enabled
1   101110   Enabled   101110    Enabled
2   001010   Enabled   001100    Enabled
3   110000   Enabled   111000    Enabled
```

The output confirms that packets placed into queue 0, the BE queue, will have their DSCP rewritten to binary 000000 when classified as low loss, or 000001 when classified as high loss. The default DSCP classifier supports loss priority for the AF (now called bronze) and NC classes. User customization was required for BE loss priority support. The default settings for queue 1 (EF) result in the same marker regardless of PLP status.

```
[edit]
lab@Wheat# show services
rpm {
    probe test_cos {
        test icmp_timestamp_cos {
            probe-type icmp-ping-timestamp;
            target address 84.10.109.7;
            probe-count 2;
            probe-interval 1;
            test-interval 1;
            history-size 15;
            data-size 574;
            hardware-timestamp;
        }
    }
    probe-limit 100;
}
```

The RPM configuration defines a test called icmp_timestamp_cos that is owned by the test_cos entity. The target address specifies Hops's fe-0/0/0.3233 interface address.

Various other parameters are specified to control probe frequency, test count, and test repetition rate. In this case, we expect to see one probe generated each second, with two such probes constituting a test group and a new test beginning one second later. The service is configured to retain 15 history samples, which given these settings, represents approximately 15 seconds' worth of performance data.

The SLA probe routers are loaded with an 8.3 release to support timestamping within the real-time forwarding thread, which is enabled with the hardware-timestamp keyword. This significantly decouples general control plane activity from the processing of the probe message timestamps, thereby offering significantly improved accuracy.

No specific configuration is needed at the probe server because ICMP messages are replied to by default; the use of a TCP or UDP test probe requires a server configuration to ensure that a matching process is created to listen for incoming probe requests.

Multifield classification. CoS is configured in the test network in a symmetric, bidirectional manner. Still, it sometimes helps to think in a simplex manner when verifying CoS. Once proper behavior is verified in the Wheat-to-Hops direction, you simply perform the same steps, but now in the opposite direction to obtain full confirmation of CoS operation.

You begin confirmation of multifield classification at PBR because Wheat is the source of EF test probes. To ensure a clean slate, you clear all firewall and interface counters at PBR, and the interface counters at all other nodes; here are the commands issued on PBR:

```
lab@PBR> clear firewall all

lab@PBR> clear interfaces statistics all
```

After a few moments, you display the firewall counters associated with the mf_classify filter:

```
lab@PBR> show firewall filter mf_classify
Filter: mf_classify
Counters:
Name                                              Bytes      Packets
ef_in                                             56488           92
bronze_in                                             0            0
Policers:
Name                                            Packets
police_bronze-classify_bronze                         0
```

The firewall counter and related policer output is a good indication that PBR is correctly classifying EF traffic. The presence of ICMP test probes is registering as EF traffic, and the lack of a Telnet session keeps the bronze class at zero. The police_bronze policer, which is called from the classify_bronze term, has a 0 count, indicating that no out-of-profile BR traffic has been reclassified as BE. Given that there is currently no traffic in the BR class, this too is in keeping with expectations.

To test the BR classification, a Telnet session is opened and subsequently closed, between Wheat and Hops:

```
lab@Wheat# run telnet 84.10.109.7
Trying 84.10.109.7...
Connected to 84.10.109.7.
Escape character is '^]'.

hops (ttyp0)

login: lab
Password:

--- JUNOS 8.3R3.2 built 2007-10-13 04:50:17 UTC
lab@hops> exit

Connection closed by foreign host.

[edit]
```

Correct multifield classification for the BR class is confirmed by redisplaying the counters associated with the multifield classifier:

```
lab@PBR> show firewall | match bronze
bronze_in                                       1986             35
police_bronze-classify_bronze                      0
```

The bronze_in counter correctly reflects the generated Telnet traffic, which confirms multifield classification for BR traffic.

BA classification. There is no firewall counter for the BE class in this example. To verify correct BE classification, and for that matter general BA classification among all nodes in the forwarding path between Wheat and Hops, you examine egress queue statistics using the show interfaces queue command. In this example, the command is run on the customer-facing interface of egress node Yeast. Observing the expected queue statistics here goes a long way toward confirming that network-wide BA classification is working correctly.

> The 8.0R1 release used to develop this material was affected by a bug that incorrectly lumps the queue statistics for all locally generated network control traffic (OSPF) into a single logical interface for each physical interface device. Transit network control traffic (e.g., Internal BGP [IBGP]) is not affected. As a result of this issue, no NC count is observed on the core-facing interface at PBR, because the NC count was erroneously tallied against the customer-facing fe-0/0/0.412 interface, which is running a passive OSPF instance and should therefore reflect a 0 count for NC. PR 258580 is tracking this issue.

Before looking at the queue stats, we stimulate the BE class with some regular (not timestamp related) pings from `Wheat` to `Hops`. Recall that except for the background OSPF, this network is otherwise completely idle, which makes it easier to correlate test traffic to queuing statistics:

```
[edit]
lab@Wheat# run ping 84.10.109.7 rapid count 10
PING 84.10.109.7 (84.10.109.7): 56 data bytes
!!!!!!!!!!
--- 84.10.109.7 ping statistics ---
10 packets transmitted, 10 packets received, 0% packet loss
round-trip min/avg/max/stddev = 9.972/20.469/32.392/7.602 ms
```

Here are the egress queuing statistics for the customer-facing interface at router `Yeast`:

```
lab@Yeast# run show interfaces queue fe-0/0/0.3233
  Logical interface fe-0/0/0.3233 (Index 69) (SNMP ifIndex 41)
Forwarding classes: 8 supported, 8 in use
Egress queues: 8 supported, 8 in use
Burst size: 0
Queue: 0, Forwarding classes: best-effort
  Queued:
    Packets              :                    10             0 pps
    Bytes                :                  1020             0 bps
  Transmitted:
    Packets              :                    10             0 pps
    Bytes                :                  1020             0 bps
    Tail-dropped packets :                     0             0 pps
    RED-dropped packets  :                     0             0 pps
     Low                 :                     0             0 pps
     Medium-low          :                     0             0 pps
     Medium-high         :                     0             0 pps
     High                :                     0             0 pps
    RED-dropped bytes    :                     0             0 bps
     Low                 :                     0             0 bps
     Medium-low          :                     0             0 bps
     Medium-high         :                     0             0 bps
     High                :                     0             0 bps
Queue: 1, Forwarding classes: expedited-forwarding
  Queued:
    Packets              :                   130             0 pps
    Bytes                :                 82160          5000 bps
  Transmitted:
    Packets              :                   130             0 pps
    Bytes                :                 82160          5000 bps
    Tail-dropped packets :                     0             0 pps
    RED-dropped packets  :                     0             0 pps
     Low                 :                     0             0 pps
     Medium-low          :                     0             0 pps
     Medium-high         :                     0             0 pps
     High                :                     0             0 pps
    RED-dropped bytes    :                     0             0 bps
     Low                 :                     0             0 bps
```

```
         Medium-low          :                      0             0 bps
         Medium-high         :                      0             0 bps
         High                :                      0             0 bps
    Queue: 2, Forwarding classes: bronze
      Queued:
        Packets              :                     36             0 pps
        Bytes                :                   2686             0 bps
      Transmitted:
        Packets              :                     36             0 pps
        Bytes                :                   2686             0 bps
        Tail-dropped packets :                      0             0 pps
        RED-dropped packets  :                      0             0 pps
         Low                 :                      0             0 pps
         Medium-low          :                      0             0 pps
         Medium-high         :                      0             0 pps
         High                :                      0             0 pps
        RED-dropped bytes    :                      0             0 bps
         Low                 :                      0             0 bps
         Medium-low          :                      0             0 bps
         Medium-high         :                      0             0 bps
         High                :                      0             0 bps
    Queue: 3, Forwarding classes: network-control
      Queued:
        Packets              :                      0             0 pps
        Bytes                :                      0             0 bps
      Transmitted:
        Packets              :                      0             0 pps
        Bytes                :                      0             0 bps
        Tail-dropped packets :                      0             0 pps
        RED-dropped packets  :                      0             0 pps
         Low                 :                      0             0 pps
         Medium-low          :                      0             0 pps
         Medium-high         :                      0             0 pps
         High                :                      0             0 pps
        RED-dropped bytes    :                      0             0 bps
         Low                 :                      0             0 bps
         Medium-low          :                      0             0 bps
         Medium-high         :                      0             0 bps
         High                :                      0             0 bps
```

The display is long, but mostly repetitive in that the same information is repeated for each defined forwarding class. The command output displays the number of bytes/packets queued and transmitted—any differences in these counts indicate some type of drop. Tail and RED-induced drops are each counted, allowing you to determine the nature of any drops that happen to occur.

The sample output shows that no drops have occurred, and reflects that the 10 ordinary ICMP packets (nontimestamp-related) were classified as BE, that ongoing traffic is being tallied as EF (the RPM probes), and that 36 BR packets have been classified (the Telnet session). The NC queue is shown at zero, which is expected given that OSPF is not actively sending hellos on the `Hops`-facing interface. These results show that initial multifield classification at the edge is correctly conveyed among all nodes in the path via BA classification.

Confirm that all this CoS stuff actually does something

To this point the various operational mode commands have returned expected results, which imply that CoS is correctly configured and is up and doing its thing. But how can you really prove the benefit, especially when lacking external packet generation equipment?

The use of highly accurate RPM timestamp probes, combined with the relatively low-speed link (the 500 Kbps [shaped] between Bock and Porter), should allow a repeatable demonstration of IP CoS benefits.

No CoS benchmark

You begin by obtaining a no CoS network baseline. Later, when CoS is reenabled, the before and after results allow you to accurately gauge what effects CoS has in the current test bed. You remove CoS by stripping down the class-of-service stanza at Bock and Porter to leave only the 500 Kbps shaping rate. Remember, a CoS chain is only as strong as the weakest link, so removing CoS-aware packet handling at the 500 Kbps choke point should fatally weaken the entire chain. This actually provides an interesting demonstration of how a consistent PHB in *all nodes* is critical to overall CoS success—a single misconfigured router can ruin CoS performance on an end-to-end basis.

The modified CoS configuration is displayed at Bock:

```
[edit]
lab@Bock# show class-of-service
interfaces {
    t1-0/0/2 {
        unit 100 {
            shaping-rate 500k;
        }
    }
}
```

Meanwhile, back at Wheat, connectivity is confirmed and the RPM service is temporarily deactivated to ensure that a fresh history is created:

```
[edit]
lab@Wheat# run ping 84.10.109.7 rapid count 10
PING 84.10.109.7 (84.10.109.7): 56 data bytes
!!!!!!!!!!
--- 84.10.109.7 ping statistics ---
10 packets transmitted, 10 packets received, 0% packet loss
round-trip min/avg/max/stddev = 9.884/22.581/39.944/9.170 ms

[edit]
lab@Wheat# deactivate services

[edit]
lab@Wheat# commit
```

An FTP transfer is started between Porter and Bock. Once the transfer begins, the RPM service is activated at Wheat:

```
[edit]
lab@Porter# run ftp 10.10.12.3
Connected to 10.10.12.3.
220 Bock FTP server (Version 6.00LS) ready.
Name (10.10.12.3:lab): lab
331 Password required for lab.
Password:
230 User lab logged in.
Remote system type is UNIX.
Using binary mode to transfer files.
ftp> mget ju*
mget junos-jseries-8.0R2.8-domestic.tgz? y
200 PORT command successful.
150 Opening BINARY mode data connection for 'junos-jseries-8.0R2.8-domestic.tgz'
(38563456 bytes).
0%  44888       14:19 ETA
```

With the transfer underway, the RPM service is reactivated:

```
[edit]
lab@Wheat# activate services

[edit]
lab@Wheat# commit
```

The probes are allowed to run for 15–30 seconds to get some statistical accuracy. The RPM history is displayed at Wheat:

```
[edit]
lab@Wheat# run show services rpm history-results
  Owner, Test                 Probe received          Round trip time
  test_cos, icmp_timestamp_cos Mon Oct 29 00:58:53 2007   266417 usec
  test_cos, icmp_timestamp_cos Mon Oct 29 00:58:54 2007   265010 usec
  test_cos, icmp_timestamp_cos Mon Oct 29 00:58:55 2007   237000 usec
  . . .
  test_cos, icmp_timestamp_cos Mon Oct 29 00:59:08 2007   268167 usec
  test_cos, icmp_timestamp_cos Mon Oct 29 00:59:09 2007   171237 usec
```

The display confirms some pretty long round-trip times, some as long as 265 milliseconds. Given that the one-way target delay for Voice over IP is only 150 milliseconds, it's safe to say there is no joy for IP telephony users in the current network.

You can display details about each probe, along with an average for all completed tests, using the show services rpm probe-results command:

```
[edit]
lab@Wheat# run show services rpm probe-results
    Owner: test_cos, Test: icmp_timestamp_cos
    Target address: 84.10.109.7, Probe type: icmp-ping-timestamp,
    Test size: 2 probes
    Probe results:
      Response received, Mon Oct 29 00:59:17 2007,
      Client and server hardware timestamps
      Rtt: 300236 usec, Round trip jitter: 283526 usec,
      Round trip interarrival jitter: 95059 usec
    Results over current test:
      Probes sent: 1, Probes received: 0, Loss percentage: 100
    . . .
    Results over all tests:
      Probes sent: 53, Probes received: 49, Loss percentage: 7
      Measurement: Round trip time
        Samples: 49, Minimum: 16710 usec, Maximum: 300236 usec,
        Average: 199529 usec, Peak to peak: 283526 usec, Stddev: 81768 usec
      Measurement: Positive round trip jitter
        Samples: 25, Minimum: 421 usec, Maximum: 283526 usec,
        Average: 82333 usec, Peak to peak: 283105 usec, Stddev: 75539 usec
      Measurement: Negative round trip jitter
        Samples: 23, Minimum: 1407 usec, Maximum: 280411 usec,
        Average: 88507 usec, Peak to peak: 279004 usec, Stddev: 71908 usec
```

The highlights call out that some probes are being lost, and that the average round-trip delay is more than 199 milliseconds. Note that average one-way jitter is rather large at some 82 milliseconds.

The CoS benchmark

OK, drum roll please.... A lot of work has led up to this point, and now it is time for the CoS rubber to meet the road, as it were. You restore the CoS configuration at Bock and Porter, and again deactivate the RPM service at Wheat to reset for a new test.

A new FTP session is started between Porter and Bock:

```
[edit]
lab@Porter# run ftp 10.10.12.3
Connected to 10.10.12.3.
220 Bock FTP server (Version 6.00LS) ready.
. . .
mget junos-jseries-8.0R2.8-domestic.tgz? y
200 PORT command successful.
150 Opening BINARY mode data connection for 'junos-jseries-8.0R2.8-domestic.tgz'
(38563456 bytes).
  0%  31856       40:12 ETA
```

With the new FTP session underway, the RPM service is again activated at Wheat:

```
[edit]
lab@Wheat# activate services

[edit]
lab@Wheat# commit
```

As before, we again wait 30 seconds or so to allow some RPM statistics to accumulate. After a long 30 seconds, the results are displayed:

```
[edit]
lab@Wheat# run show services rpm history-results
  Owner, Test                 Probe received         Round trip time
  test_cos, icmp_timestamp_cos Mon Oct 29 01:08:52 2007   17236 usec
  test_cos, icmp_timestamp_cos Mon Oct 29 01:08:53 2007   20896 usec
  . . .
  test_cos, icmp_timestamp_cos Mon Oct 29 01:09:06 2007   17769 usec
  test_cos, icmp_timestamp_cos Mon Oct 29 01:09:07 2007   18294 usec
  test_cos, icmp_timestamp_cos Mon Oct 29 01:09:08 2007   19068 usec
```

Well, the history results are far, far better than observed in the no-CoS benchmark. The round-trip delays now average only 18 milliseconds, as opposed to the 200+ result observed with no CoS. Once again, probe details are displayed:

```
[edit]
lab@Wheat# run show services rpm probe-results
    Owner: test_cos, Test: icmp_timestamp_cos
    Target address: 84.10.109.7, Probe type: icmp-ping-timestamp,
    Test size: 2 probes
    Probe results:
      Response received, Mon Oct 29 01:09:12 2007,
      Client and server hardware timestamps
      Rtt: 24557 usec, Round trip jitter: -13326 usec,
      Round trip interarrival jitter: 8125 usec
    Results over current test:
      Probes sent: 2, Probes received: 2, Loss percentage: 0
      Measurement: Round trip time
        Samples: 2, Minimum: 24557 usec, Maximum: 37883 usec,
        Average: 31220 usec, Peak to peak: 13326 usec, Stddev: 6663 usec
    . . .
    Results over all tests:
      Probes sent: 58, Probes received: 58, Loss percentage: 0
      Measurement: Round trip time
        Samples: 58, Minimum: 16455 usec, Maximum: 44654 usec,
        Average: 22455 usec, Peak to peak: 28199 usec, Stddev: 7167 usec
      Measurement: Positive round trip jitter
        Samples: 28, Minimum: 506 usec, Maximum: 26628 usec, Average: 8293 usec,
        Peak to peak: 26122 usec, Stddev: 8134 usec
      Measurement: Negative round trip jitter
        Samples: 29, Minimum: 7 usec, Maximum: 25318 usec, Average: 7781 usec,
        Peak to peak: 25311 usec, Stddev: 6889 usec
```

The probe details confirm that CoS has made a dramatic impact on network performance, at least when congestion is present and you are a member of the EF class! The average round-trip time is 22 milliseconds and the average one-way jitter is now only 8 milliseconds. A quick look at Bock's T1 interface stats confirms that all drops are confined to the BE class, and that the drops stem from the low-loss priority RED profile:

```
lab@Bock# run show interfaces queue t1-0/0/2.100
  Logical interface t1-0/0/2.100 (Index 69) (SNMP ifIndex 39)
Forwarding classes: 8 supported, 8 in use
```

```
Egress queues: 8 supported, 8 in use
Burst size: 0
Queue: 0, Forwarding classes: best-effort
  Queued:
    Packets              :                32519               0 pps
    Bytes                :             48570458               0 bps
  Transmitted:
    Packets              :                30047               0 pps
    Bytes                :             44852756               0 bps
    Tail-dropped packets :                    0               0 pps
    RED-dropped packets  :                 2472               0 pps
     Low                 :                 2472               0 pps
     Medium-low          :                    0               0 pps
     Medium-high         :                    0               0 pps
     High                                     0               0 pps
```

Note that the total queued versus transmitted packet counters for the BE class differ by the same number as displayed under RED drops. This confirms that RED is kicking in when the BE queue begins to fill. The lack of tail drops implies that the TCP-based FTP source correctly sensed the loss as an indication of congestion, and began to slow down the rate of traffic by reducing the window size.

Comparing pre- and post-CoS results leaves little doubt that JUNOS software CoS works. The only question that remains is “Why are you still here, reading this, when you should be adding CoS to your network, *now*?”

DiffServ Deployment Summary

This section demonstrated how Juniper Networks routers are configured to provide end-to-end CoS based on the DiffServ model. This involves the use of multifield classification at the network’s edges, and custom BA classification in the core to convey loss priority for the BE class.

The scenario also demonstrated three different approaches to scheduling, two of which were based on the use of the M-series or J-series platform, and the third simply an alternative J-series approach that made use of an extra queue for handling overflow traffic.

We demonstrated the use of shaping, policing, and rate limiting to preserve class isolation, as well as the operational mode commands that allow you to confirm proper CoS behavior and operation. We proved that the JUNOS software CoS solution works through the use of external LSA monitoring probes that show a clear benefit to the CoS configuration when link congestion occurred.

The next section details specific J-series CoS capabilities that are designed to enhance interworking with Frame Relay. You should make sure you are comfortable with the configuration and confirmation examples used in this section before proceeding.

Displaying J-Series Tail Drops

Currently, the CoS statistics obtained via the CLI show interfaces queue command on a J-series router tally *both* RED and tail drops under the RED-dropped packets counter, which results in a constant 0 value for tail drops. This issue was tracked under PR 230928 and has been fixed, starting with the 8.2R4 release. The only way to view tail drops in previous code releases is to connect to the fwdd daemon to issue the show outq statistics command. The output displays the cumulative tail drops for all enabled interfaces:

```
[edit]
lab@Bock# run start shell
% su
Password:
root@Bock% vty fwdd

BSD platform (Pentium processor, 84MB memory, 8192KB flash)

FWDD(Bock vty)# show outq statistics

Number of packets queued in outq queues:        70412
Number of txdone callbacks:                     176652
Red drops:                      0

    Tail drops:                     0

Error counters:
        Invalid vctable base in packet enqueue:         0
        Bad result buffers:             0
        Queue not ready:                0
        Empty queue schedule:           0
        Transmit errors:                        0
        Result stats increment errors:          0
        Invalid outq ifl index errors:          0
        Invalid txdone callbacks:               0
        Invalid requests for vctable base:              1

Ifl               Pkts In      Bytes In        Pkts Tx      Bytes Tx
---               -------      --------        -------      --------
fe-0/0/0.1241        79672       45260412        79672       45260412
t1-0/0/2.100        96980       45119122        96980       45119122
t1-0/0/2.100            0              0            0              0
```

J-Series Adaptive Shapers and Virtual Channels

This section focuses on J-series-specific CoS capabilities that are designed to work with Frame Relay. The virtual channel and adaptive shaping features help to optimize Frame Relay-based transport. Note that currently you cannot combine the functionality of an adaptive shaper with that of a virtual channel.

Configure Adaptive Shaping

Recall that Bock and Porter are connected via a 0 CIR Frame Relay service terminating in a 500 Kbps port. With the newly added DiffServ-based CoS infrastructure now in place, the idea of a 0 CIR service has been revisited. The result is a decision to pay extra for a guaranteed CIR of 256 Kbps, with the ability to burst to port speed via an EIR of 244 Kbps (CIR + EIR = port speed).

Simply configuring a scheduler or shaper that allows the router to send at maximum speed, all the time, is problematic because during network congestion only the CIR traffic is guaranteed for delivery. Ideally, you want to send at the EIR rate *only* when the network is not congested, and then fall back to the CIR when congestion is detected, in an effort to ensure that congestion-induced discards do not negate your CoS SLAs. This capability is exactly what adaptive shaping on J-series routers provides.

The configurations at Bock and Porter are updated to support adaptive shaping. The modified configuration at Bock is shown:

```
[edit class-of-service]
lab@Bock# show adaptive-shapers
becn_shaper {
    trigger becn shaping-rate 256k;
}

[edit class-of-service]
lab@Bock# show interfaces t1-0/0/2
unit 100 {
    scheduler-map er_cos_scheduler;
    adaptive-shaper becn_shaper;
    shaping-rate 500k;
    classifiers {
        dscp dscp_classify;
    }
    rewrite-rules {
        dscp dscp_rewrite;
    }
}
```

The changes to the configuration are highlighted, and they show the definition of an adaptive shaper called becn_shaper. The adaptive shaper is set to trigger on receipt of a set BECN bit, at which point the scheduler begins to shape to 256 Kbps. This rate matches the service's CIR, which prevents discards and the resulting impact to your CoS SLA. When the last frame received has a cleared BECN, the interface begins to schedule back into the 500 Kbps rate.

Here, use the show class-of-service interface and show class-of-service adaptive-shaper commands to verify adaptive shaping:

```
[edit class-of-service]
lab@Bock# run show class-of-service adaptive-shaper
Adaptive shaper: becn_shaper, Index: 44416
  Trigger type      Shaping rate
        BECN            256000 bps

[edit class-of-service]
lab@Bock# run show class-of-service interface t1-0/0/2.100
  Logical interface: t1-0/0/2.100, Index: 69
    Shaping rate: 500000
    Object                 Name                   Type      Index
    Scheduler-map          er_cos_scheduler       Output    21207
    Adaptive-shaper        becn_shaper                      44416
    Rewrite                dscp_rewrite           dscp      26780
    Classifier             dscp_classify          dscp      25819
```

The displays confirm that the adaptive shaper is correctly programmed and placed into effect on Bock's Frame Relay interface.

Virtual Channels

Virtual channels are used to ensure that a central site with a high bandwidth connection does not overrun remote sites that access the network at slower rates. Figure 9-17 illustrates a typical hub and spoke Frame Relay topology. The headquarters site has a significantly higher access rate when compared to the branch office spokes.

The key point of Figure 9-17 is that the central site terminates at a T1 switch port in the service provider's network, while the remote sites are terminated at significantly lower speeds. In a Frame Relay service, the absolute limit on data transfer rate is the logical port speed, which can be lower than the transmission link's physical bit rate; for example, Site 1 is using a Fractional T1 (FT1) circuit to access the provider, but pays for only 128 Kbps of port speed and can use only 128 Kbps of the T1's capacity. Regardless of CIR rate or the state of network congestion, Site 1 and Site 2 are physically limited to the reception of no more that 128/256 Kbps of traffic, respectively.

The problem, if not already obvious, is that the central site can easily burst to full T1 rates, and if these bursts are of any appreciable duration, there will be massive loss due to buffer overflow in the network. This causes TCP-based sources to sense

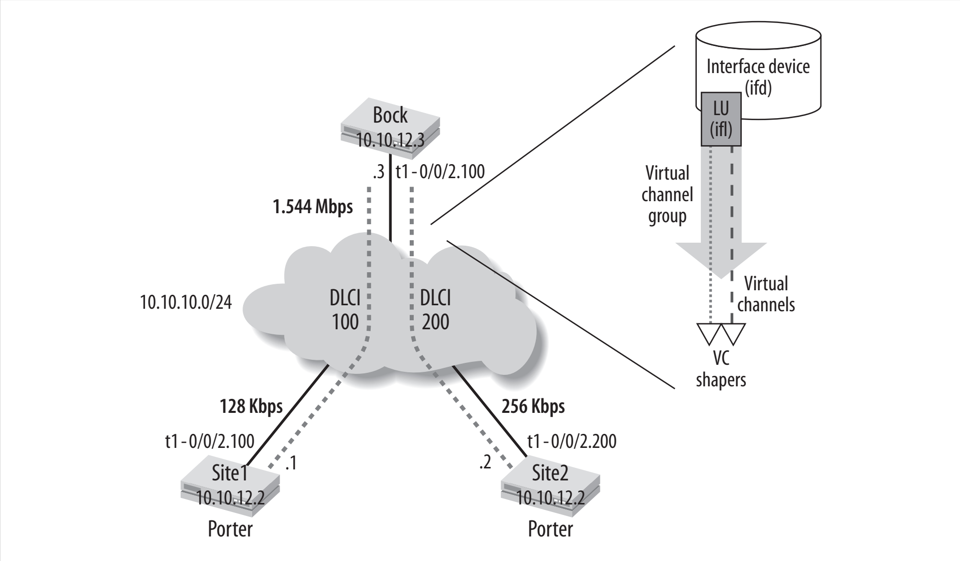


Figure 9-17. J-series virtual channels

congestion and throttle back. If not corrected, this can lead to an ongoing boom/bust cycle as the sources ramp up, sense loss, and then ramp back down, resulting in diminished throughput and higher latency due to buffering within the network. This is more than a simple issue of not knowing each virtual channel's CIR, as the topology shown in Figure 9-17 may well be based on a 0 CIR service. The issue is simply one of mismatched port speed over a network that does offer extensive buffering.

A virtual channel group is a collection of virtual channels that are applied to a logical interface. Each virtual channel within the group has its own queues and `scheduler-map`, and each can be shaped to a rate that is less than the physical interface speed. In some cases, you may choose to shape a virtual channel based on CIR, but in most cases the shaping rate is set to the lesser of the two port speeds. When not shaped, each virtual channel can burst to full interface speed, and when multiple unshaped virtual channels are active, they each get a round-robin fair share of the total physical interface bandwidth. There is no priority scheduling between virtual channels.

Firewall filters are used to direct traffic to the correct virtual channel based on some match condition—for example, the destination address. Unmatched traffic is sent to a default virtual channel. This requires that one virtual channel be designated as the default within each virtual channel group.

Configure virtual channels

The lack of logical router support for the J-series in the 8.0R1 code used in this lab, combined with the lack of Frame Relay switching, results in the need to use `Porter` twice—once as Site 1 using DLCI 100 and again as Site 2 with DLCI 200. This is why Figure 9-17 shows the same lo0 address for both Sites 1 and 2. Because there is no virtual channel configuration at remote sites, this example focuses on Bock, the central site router. In this example, we do not bother with a virtual router (VR) instance for the second connection from Porter to Bock; instead, a new logical unit is added to the t1-0/0/2 interface with a unique host ID, and the original IP address is reassigned under unit 100 to match the addressing shown in Figure 9-17:

```
[edit]
lab@Porter# show interfaces t1-0/0/2
description Porter-to-Bock;
per-unit-scheduler;
encapsulation frame-relay;
unit 100 {
    dlci 100;
    family inet {
        address 10.10.10.1/24;
    }
}
unit 200 {
    dlci 200;
    family inet {
        address 10.10.10.2/24;
    }
}
```

The addressing results in a duplicate subnet shared between units 100 and 200, but this is not a problem here:

```
[edit]
lab@Porter# run show ospf neighbor
  Address          Interface        State     ID              Pri  Dead
10.10.8.2        fe-0/0/1.2332    Full      10.30.1.1       128    31
10.10.10.1       t1-0/0/2.100     Full      10.10.12.3      128    31
10.10.10.1       t1-0/0/2.200     Full      10.10.12.3      128    30

[edit]
lab@Porter# run show route 10.10.10/24

inet.0: 14 destinations, 16 routes (14 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.10.0/24      *[Direct/0] 00:01:46
                    > via t1-0/0/2.200
                    [Direct/0] 00:01:46
                    > via t1-0/0/2.100
                    [OSPF/10] 00:01:45, metric 65
                    > via t1-0/0/2.100
10.10.10.1/32      *[OSPF/10] 00:01:45, metric 65
                    > via t1-0/0/2.200
                      via t1-0/0/2.100
10.10.10.2/32      *[Local/0] 00:01:46
                      Local via t1-0/0/2.100
```

```
10.10.10.3/32      *[Local/0] 00:01:46
                      Local via t1-0/0/2.200
```

The result is OSPF adjacencies over both the 100 and 200 logical units and two equal cost routes to Bock's IP address. Things are more interesting at Bock, where a multipoint Frame Relay interface is defined to create the logical connectivity shown in Figure 9-17:

```
[edit]
lab@Bock# show interfaces t1-0/0/2
description Bock-to-porter;
per-unit-scheduler;
dce;
encapsulation frame-relay;
unit 100 {
    multipoint;
    family inet {
        address 10.10.10.3/24 {
            multipoint-destination 10.10.10.1 dlci 100;
            multipoint-destination 10.10.10.2 dlci 200;
        }
    }
}
```

The modified configuration maps two locally defined DLCIs on the same logical interface to each associated IP address; DLCI 100 leads to Site 1's 10.10.10.1 address and DLCI 200 maps to the address of Site 2 and the 10.10.10.2 address. Per-unit scheduling must be enabled on the physical interface to support scheduling into each virtual channel.

At first glance, the show route command at Bock indicates that all traffic for the 10.10.10/24 subnet will use the same link, as indicated by the absence of logical unit 200:

```
[edit]
lab@Bock# run show route 10.10.10.2

inet.0: 12 destinations, 13 routes (12 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.10.0/24      *[Direct/0] 00:13:24
                    > via t1-0/0/2.100
                    [OSPF/10] 00:13:12, metric 130
                    > to 10.10.10.2 via t1-0/0/2.100
```

The route to 10.10.10.2 seems to indicate that Bock plans to use the wrong DLCI, given that DLCI 200 maps to Site 2, not Site 3. The forwarding table, however, correctly reflects the correct IP-to-DLCI mapping as configured under the multipoint Frame Relay interface:

```
[edit]
lab@Bock# run show route forwarding-table destination 10.10.10.1
Routing table: inet
Internet:
```

```
Destination     Type RtRef Next hop     Type Index NhRef Netif
10.10.10.1/32   dest     0 dlci: 100    ucst   334    5 t1-0/0/2.100

[edit]
lab@Bock# run show route forwarding-table destination 10.10.10.2
Routing table: inet
Internet:
Destination     Type RtRef Next hop     Type Index NhRef Netif
10.10.10.2/32    dest     0 dlci: 200   ucst   336     1 t1-0/0/2.100
```

With the Frame Relay aspects confirmed, you move on to the virtual channel configuration:

```
[edit class-of-service]
lab@Bock# show virtual-channels
site1_default;
site2;
```

Two virtual channels are defined, one for each remote site. Here, Site 1 is set as the default virtual channel. Traffic that is routed out the logical interface to which the virtual channel group is applied will default to the virtual channel for Site 1, unless directed via a firewall filter to Site 2. The virtual channel group configuration is displayed:

```
[edit class-of-service]
lab@Bock# show virtual-channel-groups
er_vc_group {
    site1_default {
        scheduler-map er_cos_scheduler;
        shaping-rate 128k;
        default;
    }
    site2 {
        scheduler-map er_cos_scheduler;
        shaping-rate 256k;
    }
}
```

A virtual channel group configuration links multiple virtual channel definitions together for application to a logical interface. Here, the `er_vc_group` configuration links the `site1` and `site2` definitions, much like a `scheduler-map` links multiple scheduler policies. When applied to a logical interface, eight queues are created for each virtual channel associated with the group, and a `scheduler-map` is used to control scheduling into each set of per-virtual-channel queues. This example shapes each virtual channel to the remote site's port speed, but if desired, some virtual channels can be left unshaped to allow bursting up to physical interface speed.

The virtual channel group is applied to an interface, at the logical unit level. You will not be able to commit the configuration unless you remove any adaptive shaping, shaping, or `scheduler-map` configuration on the same logical unit:

```
[edit class-of-service]
lab@Bock# show interfaces t1-0/0/2
```

```
unit 100 {
    virtual-channel-group er_vc_group;
    classifiers {
        dscp dscp_classify;
    }
    rewrite-rules {
        dscp dscp_rewrite;
    }
}
```

The final step in the virtual channel configuration is the definition of the filter that directs traffic to the correct virtual channel, where it is in turn shaped according to the remote site's port speed. Recall that one virtual channel in each group must be designated the default virtual channel, which means it's used when no explicit virtual channel mapping is found. A working virtual channel mapping filter is shown at Bock:

```
[edit]
lab@Bock# show firewall
filter er_vc_select {
    term select_site2 {
        from {
            destination-address {
                10.10.10.2/32;
            }
        }
        then {
            virtual-channel site2;
            accept;
        }
    }
    term default_to_site1 {
        then {
            virtual-channel site1_default;
            accept;
        }
    }
}
```

The er_vc_select filter matches on packets addressed to Site 2 and directs them to the scheduler/shaper associated with the site2 virtual channel. Any traffic not matched by the select_site2 term is matched by the default_to_site1 term, which results in a mapping to the default virtual channel. The er_vc_select filter is placed into service in the output direction:

```
[edit]
lab@Bock# show interfaces t1-0/0/2 unit 100 family inet filter
output er_vc_select;
```

To confirm that your virtual channel configuration is active on a given interface, use the show class-of-service interface command:

```
[edit]
lab@Bock# run show class-of-service interface t1-0/0/2.100
```

```
  Logical interface: t1-0/0/2.100, Index: 70
    Object                 Name                   Type      Index
    Virtual-channel-group  er_vc_group                      55210
    Rewrite                dscp_rewrite           dscp      26780
    Classifier             dscp_classify          dscp      25819
```

The show class-of-service virtual-channel-group command confirms the details of er_vc_group:

```
[edit]
lab@Bock# run show class-of-service virtual-channel-group
Virtual channel group: er_vc_group, Index: 55210
        Virtual channel: site1_default
                Scheduler map: er_cos_scheduler
                Shaping rate : 128000 bps
        Virtual channel: site2
                Scheduler map: er_cos_scheduler
                Shaping rate : 256000 bps
```

Currently, you cannot obtain per-virtual-channel queuing statistics from the CLI. The output of the show interfaces queue t1-0/0/2.100 command displays the aggregate packet counts for all virtual channels in effect on the interface.

J-Series Adaptive Shaping and Virtual Channel Summary

This section demonstrated the configuration and operational analysis of the J-series-specific adaptive shaper and virtual channel features. The former allows dynamic switching between two shapers, one based on the service's CIR and another on the EIR, based on the congestion state of the network, as signaled by received BECN bits. By sending at or below the CIR during periods of network congestion, you avoid loss, and when the congestion clears, you are able to send at the EIR rate with a high probability of delivery, given the lack of congestion.

The virtual channel feature is designed to allow a central site route with a high-speed attachment to shape into individual virtual channels, with each such virtual channel dimensioned according to the remote site's port speed (or CIR). The goal of this feature is to prevent buffer overrun and loss that can occur when a site with a high-speed access rate sends to a remote site that is attached at a much slower speed.

Conclusion

IP CoS is an enabling factor for many value-added services, or a cost-effective convergence onto a single network infrastructure. Even though bandwidth may be relatively cheap and links always seem to get faster, you can still deploy CoS to ensure that you get the most of whatever bandwidth your network has to work with. All Juniper Networks routers support a robust and practical set of CoS capabilities that, given the general design of Juniper products, can be enabled in any production network without concerns of performance degradation or unpredictable behavior.

The future is IP-based, and more and more services are being adapted to IP transport each day. By deploying an effective CoS solution early, you gain a competitive advantage, now and in the future, because you will find you can confidently roll out new and ever-more-demanding applications, knowing that your network will make the most of its resources to deliver the goods that matter most.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- Describe the uses of CoS.
- Explain CoS processing on M-series and J-series routers.
- Identify the ways traffic can be classified.
- Explain the purpose of BAs.
- Explain the use of policers.
- Describe how traffic is mapped to queues.
- Configure the mapping of forwarding classes to queues.
- Explain the role of a scheduler and how M-series versus J-series behavior differs.
- Configure a scheduler to service queues based on a CoS design.
- Monitor a CoS implementation.
- Configure BA and multifield classification.
- Congestion management and avoidance.
- Code point rewriting.
- Rate-limiting with shaping, policing, or both.
- J-series adaptive shapers and virtual channels.

Chapter Review Questions

1. Which IP CoS approach requires signaling to reserve resources?
    a. IP ToS
    b. IntServ
    c. DiffServ
    d. ATM
2. In the DiffServ architecture, what is a BA?
    a. A sequence of packets with a shared marking, crossing a given link
    b. The collective behavior of all nodes in the domain
    c. The act of aggregating multiple reservations into a single, larger one, for scalability
    d. None of the above

3. With regard to J-series versus M-series CoS capabilities, which is true?
    a. The M-series can support only four queues; the J-series supports eight
    b. The M-series does not support per-unit scheduling
    c. The J-series WRED cannot be protocol-based, whereas the M-series WRED can be
    d. The M-series offers LLQ support, whereas the J-series does not
4. How do you convey packet loss priority to a downstream node?
    a. By implementing the same multifield classifiers as used originally at the ingress
    b. This is not possible because the IP header does not support a loss-priority flag
    c. You must reclassify all packets with high loss priority into a forwarding class reserved for that purpose
    d. Use a BA rewrite table with a matching BA classifier
5. What is the actual scheduling priority when used on an M7i?

    ```
    lab@PBR# show schedulers
    . . .
    bronze_sched {
        transmit-rate 10m exact;
        priority medium-high;
    }
    ```

    a. Low
    b. High
    c. Strict-high
    d. This will not commit because the M7i supports only two priority levels
6. Which of the following is true?
    a. On the J-series, strict-high and high are the same priority
    b. On the M-series, strict-high is a separate priority
    c. You must use the exact option with a strict-high queue to prevent starvation
    d. Policing should be used when strict-high is set, especially on the J-series
7. What is the purpose of the shaping-rate statement in the following code snippet?

    ```
       test_sched {
            transmit-rate percent 5;
            shaping-rate percent 20;
            priority high;
        }
    ```

    a. It ensures that this queue cannot starve other queues of their configured weight

   b. It limits how much traffic this queue can send, even when all other queues are idle

   c. It shapes the traffic allowed by the transmit rate so that at least 20% of the packets are not clumped

   d. This is used in adaptive shaping, in order to set the maximum transmit rate when the network is not congested

8. When committing a CoS configuration, you notice the following log message. What does it mean?

```
Nov  3 00:25:25  PBR /kernel: RT_COS: COS IPC op 5 (SCHED POLICY DEF) failed, err
5 (Invalid)
Nov  3 00:25:25  PBR fwdd[2780]: COSMAN_FWDD: Wrr underflow, for fe-0/0/0
Nov  3 00:25:25  PBR fwdd[2780]: COSMAN: policy update failed
```

   a. There is a problem in the configuration and the default settings are in effect

   b. There is a problem in the configuration, causing it to fail commit

   c. There is a problem in the configuration; the software adapts the configuration to meet the underlying capability

   d. The error indicates that the sum of the assigned weights in the `scheduler-map` did not equal 100%

9. Consider the CoS configuration at `PBR` in the DiffServ scenario, as shown in Figure 9-16, and select the best option:

   a. Each logical interface on `fe-0/0/0` can send up to 100 Mbps

   b. When both logical interfaces are active, each gets only 50 Mbps

   c. Both A and B

   d. None of the above

10. Refer to the output provided and select the best answer:

```
[edit class-of-service drop-profiles test]
lab@PBR# show
fill-level 50 drop-probability 0;
fill-level 70 drop-probability 10;
fill-level 80 drop-probability 20;
fill-level 90 drop-probability 30;
```

   a. Between 70% and 80% fill, there is 10% drop probability

   b. Between 75% and 80% fill, there is 15% drop probability

   c. Between 70% and 80% fill, there is 10% drop probability for PLP = 1

   d. Between 70% and 80% fill, there is 10% drop probability for PLP = 0

11. Which of the following is true?

   a. BA overrides multifield classification

   b. Multifield overrides BA classification

    c. You cannot combine BA and multifield classification; a packet is classified only once
    d. You should perform BA and multifield classification on all nodes for consistency

12. How can the PLP status be set?
    a. With multifield classification
    b. With BA classification
    c. With a policer
    d. Using policy
    e. All of the above

Chapter Review Answers

1. Answer: B. Only the Integrated Services (IntServ) model made use of control plane signaling for resource allocation.
2. Answer: A. In the DiffServ model, a BA is a collection of packets with a shared code point. It is expected that each node will have the same PHB for a given BA, and therefore end-to-end performance can be modeled.
3. Answer: C. J-series WRED has four drop priority levels, but no TCP/UDP index. The M-series can support eight queues and per-unit scheduling with IQ PICs. Only the J-series offers true LLQ.
4. Answer D. Although you could use multifield classification everywhere, this approach does not scale. Use a BA classifier and associated rewrite to convey PLP status between nodes.
5. Answer: B. The M7i has two hardware priority levels, and medium-high, high, and strict-high all map to the same value, which is high.
6. Answer: D. Because strict-high is given 100% of transmit weight, it should be used with a policer to ensure that other classes are not starved, especially on the J-series, where strict-high is an actual priority. You cannot use `exact` with a strict-high queue, but on the J-series you can use the shaping rate to cap total usage. However, a policer is preferred, as this allows excess bandwidth only when other queues are empty.
7. Answer: B. Supported on the J-series only, the `shaping-rate` limits the total amount of bandwidth available to the queue, regardless of activity in other queues. This in itself does not prevent starvation of lesser-priority queues, but it can help.
8. Answer: A. Many CoS configuration errors allow a commit, but they generate a log warning indicating that the configured values can be programmed. This means the default values are in effect.

9. Answer: C. Unless you shape at the logical interface level, each IFL can send up to line rate, and when multiple IFLs are active, they share available bandwidth. This is another benefit to using schedulers based on transmit percentage, rather than absolute values. The latter would result in one IFL getting 100 Mbps while the other receives a default scheduler configuration with 95%/5% assigned to queue 0 and 3, respectively.
10. Answer: A. The profile defines a 10% drop probability for fill levels between 70% and 80%. You cannot tell from the drop profile itself whether it affects PLP 0 or 1 (or UDP versus TCP), because the function of WRED against some criteria is performed via a `scheduler-map`, which was not shown.
11. Answer: B. Multifield overrides BA classification and generally is used only at network edges.
12. Answer: E. All of the methods listed can impact the PLP status of a given packet.

CHAPTER 10
IP Multicast in the Enterprise

This chapter explores typical enterprise deployment scenarios for IPv4 multicast. Focus is placed on the design and configuration of a scalable, fault-tolerant, multicast infrastructure using JUNOS software. Operational analysis and fault isolation are also demonstrated. The topics covered include:

- Multicast terminology and concepts
- Multicast protocols: group management and routing
- Protocol Independent Multicast (PIM) sparse mode using static rendezvous points (RPs)
- PIM sparse mode with bootstrap-based RP election
- PIM and Multicast Source Discovery Protocol (MSDP)-based Anycast-RP

Juniper Networks routers offer extensive support for IPv4 multicast. Consult the multicast overview in the JUNOS software documentation to confirm the list of supported RFC and drafts for your software release.

What Is Multicast?

Multicast defines the concept of a one-to-many communications stream. To a casual observer, multicast is similar to broadcast in that a single copy of a packet can be received by multiple nodes—however, multicast is not dependent on an underlying multiaccess medium. It can operate network-wide (unlike broadcast traffic that is not forwarded by routers), and is associated with protocols that attempt to automatically tune the network to eliminate unnecessary transport and delivery of multicast traffic.

Routers use multicast routing protocols to control the forwarding of multicast traffic to prevent loops and avoid inefficiencies associated with having multiple copies of a given packet transmitted over the same link multiple times. Multicast group membership protocols are used by hosts to express interest in one or more multicast groups—multicast traffic is not forwarded over an interface with attached hosts unless at least one host has explicitly requested the receipt of multicast traffic.

When all goes to plan, the presence of multicast traffic is noted only by those nodes that have expressed interest in that particular stream, which is in marked contrast to a link-level broadcast that forces reception of the packet by all nodes on that link. In summary, broadcast is one-to-all with a link-level scope, whereas multicast is one-to-many, network-wide, but only when there is express interest in receiving multicast.

The sources and destinations of multicast content are generally hosts, not routers. The role of a multicast router entails locating multicast sources, replicating packets for transmission over multiple interfaces, preventing routing loops, and connecting interested destinations with the proper source, all while keeping the flow of unwanted packets to a minimum.

Multicast Applications

There are numerous applications for IP multicast. In many cases, a given application is capable of operating in either unicast or multicast mode, depending on user settings and overall scaling needs. Network applications that can function with unicast but are better suited for multicast include collaborative groupware, teleconferencing, and distributed applications such as multiplayer gaming or virtual reality. Any IP network concerned with reducing network resource consumption for one-to-many or many-to-many applications, to include multimedia streams with multiple receivers such as IP-TV, benefits from multicast.

Multicast-enabled networks and applications provide significant scaling benefits. When unicast is employed by an Internet radio or news ticker service, for example, each recipient requires a *separate* traffic session. The processing load at the server and network bandwidth consumed increase linearly as each new receiver attaches to the server. This is extremely inefficient, whether dealing with the global scale of the Internet or a modest enterprise-scale network.

In a broadcast model, the source needs to generate only a single stream using a broadcast destination address. Ignoring for the moment that the link-level scope of broadcast makes this model unusable in a routed network, a broadcast model is extremely inefficient because it consumes maximum bandwidth and places the burden of packet rejection on each host.

Multicast provides the most efficient and effective solution for most one-to-many or many-to-many applications, with none of the drawbacks and all of the advantages of the unicast or broadcast model. With multicast, a single multicast packet stream finds its way to every interested receiver, and replication is performed in a distributed manner within each router as needed, allowing large-scale deployment because no one device is forced to replicate or handle all traffic associated with the application. With IP multicast, a sending host generates a single IP packet stream, whether there is one receiver or 1 million receivers, and links that connect to subnets consisting of entirely uninterested receivers carry no multicast traffic at all.

Locating content

Once you have enabled multicast in your network, the first question becomes “What new services and applications can I enable with it, and how will users know?” In other words, for maximum benefit, there needs to be a TV Guide-like function available to the end user. The *Session Directory tool* (known as SDR) is an end-user application that uses multicast protocols to locate and list available sessions in the network. Figure 10-1 shows the user interface for the SDR application.

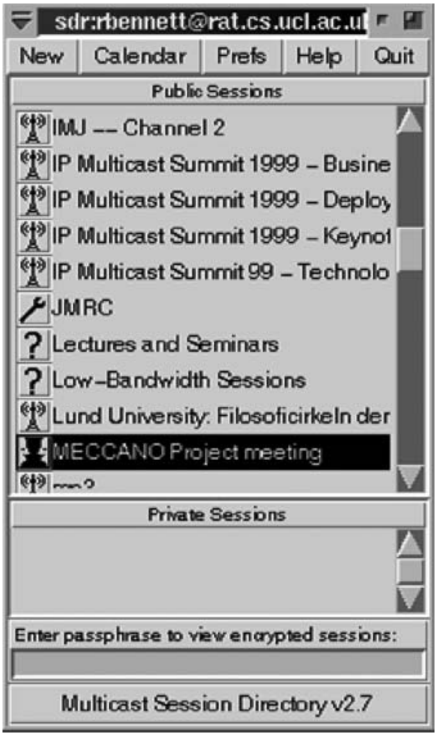

sdr:rbennett@rat.cs.ucl.ac.u
New
Calendar
Prefs
Help
Quit
Public Sessions
IMJ -- Channel 2
IP Multicast Summit 1999 - Busine
IP Multicast Summit 1999 - Deploy
IP Multicast Summit 1999 - Keynot
IP Multicast Summit 99 - Technolo
JMRC
Lectures and Seminars
Low-Bandwidth Sessions
Lund University: Filosoficirkeln der
MECCANO Project meeting
Private Sessions
Enter passphrase to view encrypted sessions:
Multicast Session Directory v2.7

Figure 10-1. The Session Directory tool

The transport protocol used by the Session Directory tool is the Session Announcement Protocol (SAP). SAP messages are transmitted to the well-known multicast group address of 224.2.127.254, and they contain descriptions of currently available sessions formatted using the Session Description Protocol (SDP). You can download the SDR application and get additional information at *http://www-mice.cs.ucl.ac.uk/multimedia/software/sdr/*.

Multicast Terminology and Concepts

To the uninitiated, multicast can seem to be a jumble of confusing terms and concepts. It helps to keep in mind that multicast is largely state-driven, which is to say that things may or may not happen, based on the presence or absence or some other event. For example, a join message is generated when a router wishes to receive multicast traffic for a given group. As a result of this join, a multicast distribution tree is instantiated, or modified, which adds the interface on which the join was received in the outgoing interface list (OIL) for that group. After some period of time, lack of continued join activity results in this state timing out, the removal of the interface from the OIL, and the cessation of multicast forwarding for that group over that interface. This "now you see it, now you don't" aspect of multicast often leads to confusion, at least when compared to the more or less steady-state nature of unicast routing protocols. In Open Shortest Path First (OSPF), the absence or presence of a route is not a function of an actual desire or need to use the route. In contrast, a multicast "route" is actually a dynamic entry that is based on the presence of an active sender and, to some degree, the presence of at least one interested receiver.

Routing turned upside down

If the dynamic state of multicast is not reason enough for confusion, consider that multicast forwarding is actually a type of reverse routing. Unicast routing is based on longest-matching against the packet's destination address, with the overall goal being the forwarding of a packet toward its destination. In contrast, multicast forwarding is performed based on the *source* address, with the goal being the forwarding of the packet *away* from the source, as opposed to toward any particular destination. This behavior is known as reverse path forwarding (RPF) and is detailed in a later section.

Multicast terms

The reader should be familiar with the following terms and concepts before delving any further into multicast. Refer to Figure 10-2 to see how the terms relate to an IP multicast network.

Figure 10-2 looks complicated, so let's tackle each part individually:

Multicast sources

The multicast sources for groups 1 and 2 are shown at the top of Figure 10-2. A multicast source is the entity that generates a stream of packets addressed to one or more multicast groups. The set of addresses from 224.0.0.0–239.255.255.255 (224/4) are reserved for IP multicast use. Any device that sends one or more packets to a destination address in this range is a multicast sender. No multicast-specific routing or group management protocol is required by a multicast sender; in fact, the sender does not even need to be able to receive multicast traffic. The sender is the root of a shortest-path tree (SPT).

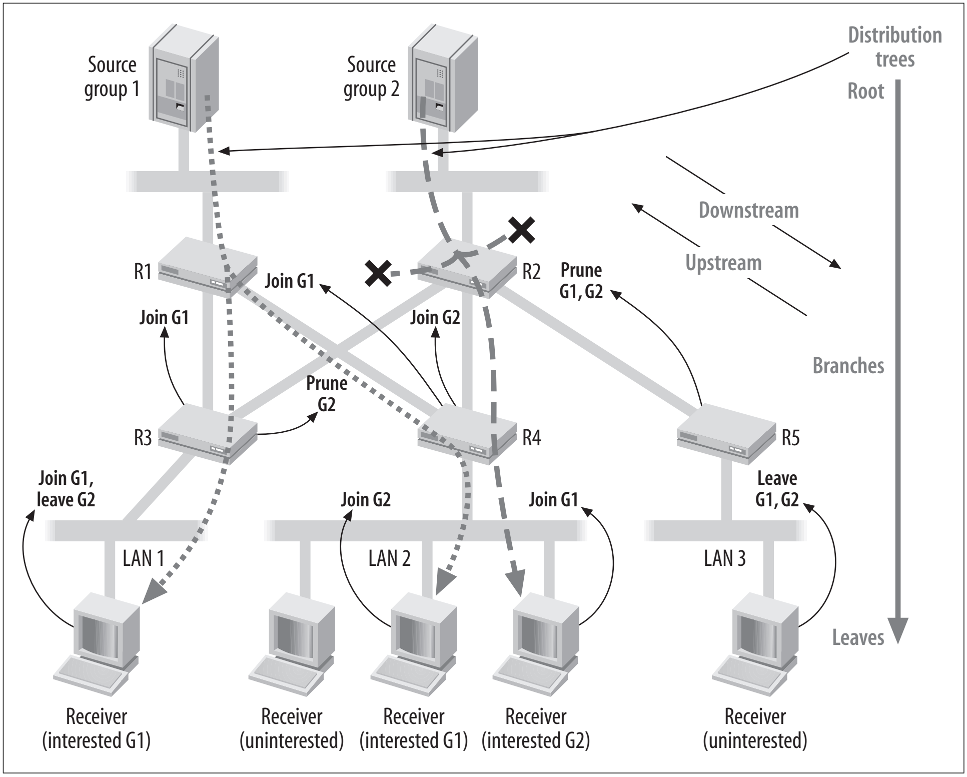


Figure 10-2. Multicast terms

Multicast receivers

Several multicast receivers are shown at the bottom of Figure 10-2. The receivers form the leaves of a multicast distribution tree. Multicast receivers run the Internet Group Management Protocol (IGMP), to inform attached routers what multicast groups they are interested in. A node becomes a leaf on the distribution tree when it joins a given group. A branch is pruned from the multicast tree when no interested hosts remain; that is, when all of its leaves have fallen off. This condition is shown for LAN 3, where the sole receiver has indicated a desire to leave both multicast groups. Note how the group management protocol's leaves become a multicast routing protocol prune message, assuming that the first hop router has no other interested receivers (leaves) for the related branch.

Multicast protocols

Multicast protocols control the flow of multicast traffic between sources and receivers. For now, it's sufficient to note that receivers use a group management protocol to inform their routers which groups they are interested in; receivers are not aware of the actual multicast topology. Routers run a group management protocol to communicate with attached receivers, and a multicast routing protocol when communicating with other multicast-aware routers. A multicast routing protocol such as PIM is significantly more complex than the group management protocols used by receivers, and it is responsible for ensuring loop-free forwarding and management of the distribution tree based on the absence or presence of interested receivers.

Upstream/downstream

Many operations in multicast are directionally oriented. The multicast tree is rooted at each source and terminates at the various leaves. Traffic flows downstream, along the distribution tree, from the source to each receiver. In contrast, control messages that establish a prune/join state are sent upstream, in the direction of the receiver to the source. Figure 10-2 shows the multicast traffic from groups 1 and 2 flowing downstream toward interested receivers while the related control messages flow upstream.

Distribution trees, branches, and leaves (oh, my)

A distribution tree is the interconnection of nodes that lie between a sender and interested receivers. Figure 10-2 shows two senders, and each is associated with its own distribution tree. The tree is rooted at the sender in an SPT, or at the RP in a shared tree. The example in the figure consists of two SPTs. Traffic flows downstream on the tree while control messages flow upstream to influence multicast flow. Between the root and each leaf lies one or more branches. A router must replicate packets to each branch that leads to a leaf, noting, however, that the same effort is required whether there is one or 1,000 leaves on that branch. A leaf is a multicast receiver with interest in a given group. A branch is pruned from the tree when it has no remaining leaves. The figure shows R3 and R5 pruning branches from the tree in response to the receipt of leave messages that indicate no remaining leaves.

Dense and sparse modes

There are two primary strategies when it comes to forming the initial distribution tree. There is the *flood first, prune later* philosophy known as dense mode, and there is the *prune first and flood only when asked for* method known as sparse mode. Stated differently, dense mode is like a push model that assumes that all receivers want all multicast, and sparse mode functions in a client pull manner, where it is assumed that most receivers do not want any multicast. In both methods, the distribution tree is ultimately pruned of any leafless branches, but in the former, the expiration of state results in resumed dense mode flooding, whereas in the latter, an expiration of join state results in a return to the default pruned mode. Generally speaking, older multicast routing protocols such as the Distance Vector Multicast Routing Protocol (DVMRP) support only dense mode, whereas newer protocols such as PIM support both modes. In some cases, the same protocol can operate in a *sparse-dense* mode, whereby certain groups are handled in dense fashion while others are treated as sparse. Dense mode operation is best suited for use over LANs because its flood-first nature tends to consume more bandwidth. On the upside, dense mode does not require the complexities of an RP. Recall that in dense mode, any active source results in flooding down all branches, which are then pruned if not needed; this means that routers have no problems learning about active sources and groups. In contrast, sparse mode operation creates somewhat of a chicken-before-the-egg problem, in that a router must send an explicit join before it can receive traffic for a given group, but before it can send the join it has to know which groups and sources are active! This problem is resolved with the introduction of a shared tree and an RP, which we will detail in a subsequent section.

Additional multicast building blocks

This section discusses IP multicast concepts that are independent of any specific multicast routing protocol or mode of operation. Understanding these concepts prepares the reader for the upcoming IP multicast configuration and operational mode analysis examples.

Multicast addressing. Multicast uses the Class D IP address range, from 224.0.0.0–239.255.255.255. In modern vernacular, the concept of classful addresses has lost favor, so addresses in this range are commonly referred to as simply *multicast addresses*. A multicast address can be used only as the destination address of an IP packet—the source address must always be of the unicast form. A multicast address normally has a /32 prefix length, although other prefix lengths are allowed. Recall that a multicast address represents a logical grouping of devices rather than a physical collection of devices. Multicast addresses can still be described in terms of prefix length using traditional notation. For example, the entire multicast address range can be written as 224/8. The base address 224.0.0.0 is reserved and cannot be assigned to any group, addresses in the 224.0.0.1–224.0.0.255 range are reserved for local wire use, and the 239.0.0.0–239.255.255.255 range is reserved for administratively scoped addresses.

Internet numbering authorities normally do not allocate multicast addresses to their customers. This is because multicast addresses are concerned more with content than with a given physical device. Receivers do not require a multicast address, but they need to know the multicast address associated with the multicast content they are interested in. Multicast sources need an assigned multicast address only to produce the content, not to identify their place in the network. Every source, receiver, and numbered router interface still needs an ordinary, unicast IP address.

Many applications have been assigned a range of multicast addresses, either by the Internet Engineering Task Force (IETF) or by the applications' developers. Although statically assigned multicast addressing is certainly possible, in most cases you can simply use the application's defaults. Table 10-1 shows some application-to-multicast address mappings, as defined by the Internet Assigned Numbers Authority (IANA) at *http://www.iana.org/assignments/multicast-addresses*.

Table 10-1. IANA application-to-multicast address mappings (select examples)

Address	Application
224.2.0.0–224.2.127.253	Multimedia conference calls
224.4.0.0–224.4.0.254	London Stock Exchange
224.0.1.141	Dynamic Host Configuration Protocol (DHCP) servers
224.0.1.39	cisco-rp-announce

Mapping IP Multicast to Link Layer Multicast

On multiaccess networks such as LANs, using the broadcast address to forward IP multicast results in disruption to all nodes on that LAN segment, whether they are interested in multicast or not. Using a unicast address negates the one-to-many efficiency benefit of multicast. The solution is to map a Layer 3 IP multicast address, which is 32 bits in length, into a corresponding 48-bit media access control (MAC) layer multicast address. Figure 10-3 shows a sample of this mapping.

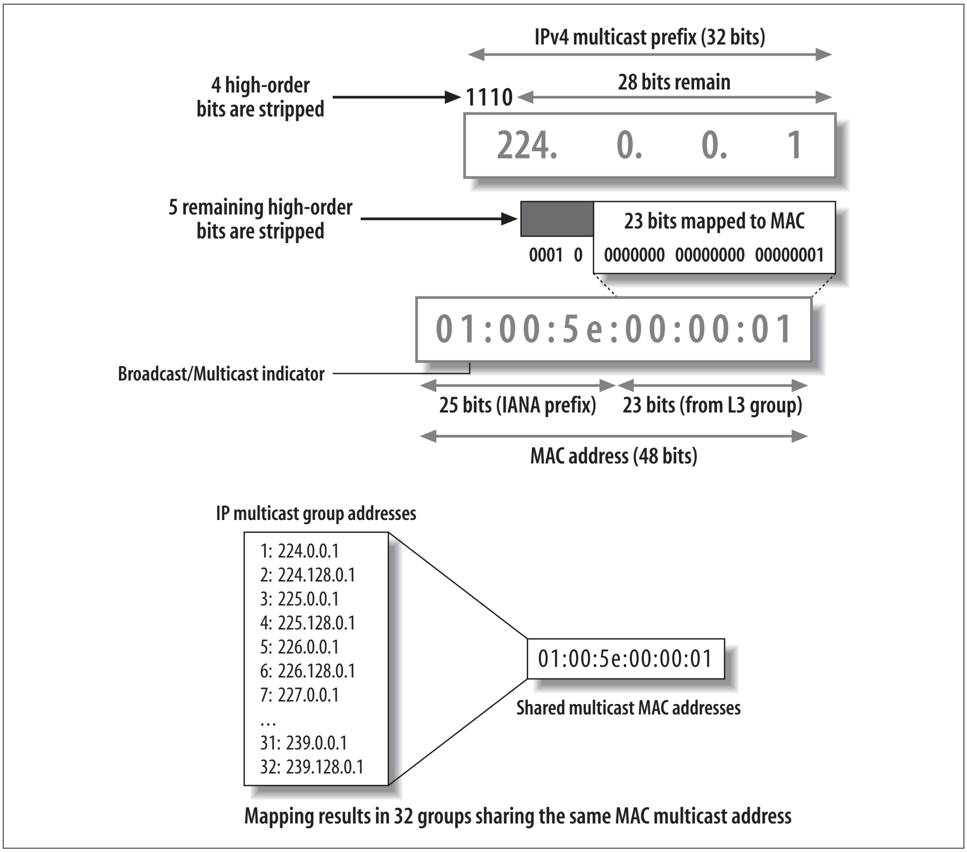


Figure 10-3. Layer 3 to Layer 2 multicast mapping

Given the different address lengths, a direct 1:1 mapping between Layer 2 and Layer 3 addresses is not possible. One-half of the IANA-owned block of Ethernet MAC addresses, the first 24 bits starting with 0x 01:00:5E, are reserved for multicast, yielding the usable range of 0100.5e00.0000–0100.5e7f.ffff inclusive. This allocation results in a 24-bit field, but because the first bit is always set to 0, only 23 bits remain to be populated with the IP multicast address. The mapping process strips the 4-bit class D identifier as well as the 5 high-order bits from the group ID, which leaves 23 bits remaining to be mapped into the multicast MAC address. Because 5 high-order bits are stripped from the group ID, there is a resulting loss of granularity in the Layer 3 to Layer 2 address mapping resulting in 32(2^5) different group addresses mapping to the same multicast MAC address, as shown at the bottom of Figure 10-3.

In a Layer 2 network, the sharing of a MAC address among as many as 32 IP multicast groups results in a loss of efficiency, because traffic sent to one multicast group will be received by all hosts using the same shared MAC layer multicast address, even though they do not subscribe to that particular group. Wherever possible, you should be careful when selecting IP multicast addresses to ensure that they map to a unique MAC layer multicast address; otherwise, host systems will have to expend cycles receiving, and then discarding, multicast traffic for groups that have no local applications listening.

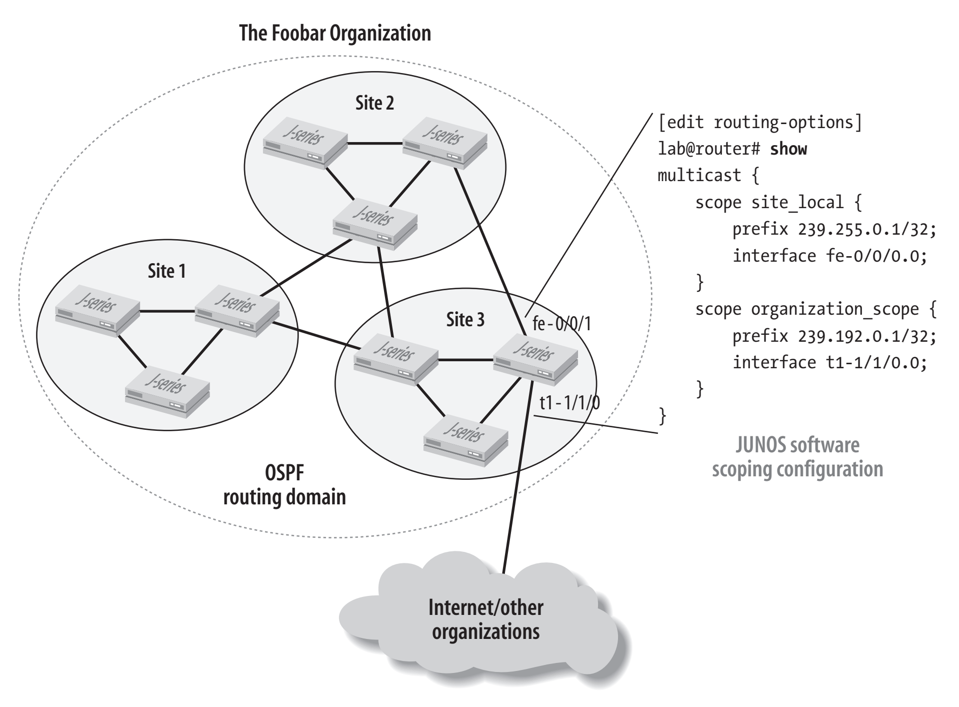
Multicast addressing and administrative scoping

Multicast addresses are categorized according to their scope. Scoping is designed to limit the extent to which a multicast packet can travel. Scoping is used for both performance and administrative reasons. Table 10-2 details currently defined IPv4 multicast address scopes.

Table 10-2. IPv4 multicast address scopes

Address	Scope	Comment
224.0.0.0/24	Link local	Confined to a single link, often used for unicast routing protocols; allows same multicast address on each link
239.0.0.0–239.255.255.255	Administratively scoped	Further subdivided into site-local (239.255.0.0/16) and organizational (239.192.0.0/14) scopes
224.0.1.0–238.255.255.255	Global	Addresses with global scope, of which several static assignments exist: • 224.1.0.0–224.1.255.255: shared tree multicast groups • 224.2.0.0–224.2.127.253: multimedia conference calls • 224.2.127.254: SAPv1 announcements • 224.2.127.255: SAPv0 announcements • 224.2.128.0–224.2.255.255: SAP dynamic assignments • 224.252.0.0–224.255.255.255: DIS transient groups • 232.0.0.0–232.255.255.255: VMTP transient groups

Modern IP networks use address-based scoping rather than IP Time to Live (TTL)-based scoping. This is because TTL-based techniques are prone to problems in terms of being able to accurately predict TTL values network-wide, especially in the face of changes in forwarding topology during failover scenarios. Addresses in the link-local scope cannot be forwarded beyond the boundaries of a single link. These addresses tend to be used by unicast routing protocols such as Routing Information Protocol version 2 (RIPv2) and OSPF. The administratively scoped address range is broken into site-local and organizational boundaries. An enterprise might consist of a single site, the exact definition of which is left to the administrators of the routing domain, or it may consist of multiple sites. Generally, the organizational scope is defined as the extent of a routing domain. Administrators configure site or global scoping on the appropriate interfaces to block related traffic from leaving that interface. Figure 10-4 illustrates a scoping example.



```
[edit routing-options]
lab@router# show
multicast {
    scope site_local {
        prefix 239.255.0.1/32;
        interface fe-0/0/0.0;
    }
    scope organization_scope {
        prefix 239.192.0.1/32;
        interface t1-1/1/0.0;
    }
}
```

Figure 10-4. Multicast scoping

The approach shown in Figure 10-4 is address-based, but JUNOS software also supports scoping based on a `scope-policy`. Unlike address scoping, which is applied per interface, a `scope-policy` applies to all interfaces, and you cannot use it in conjunction with interface-level scoping. You confirm address scoping using the `show multicast scope` command. The remaining IP multicast address space is considered to have a global scope. Some addresses within the global range are statically assigned by the IANA, as shown in Table 10-2.

It is common to see scoping used to block the multicast addresses associated with the auto-RP discovery mechanism (224.0.1.39 and 224.0.1.40) at administrative boundaries to prevent the use of the local domain's RP by routers outside of local administrative control.

> You cannot use scoping to block RP discovery via the bootstrap protocol because the bootstrap mechanism operates hop by hop and uses the 224.0.0.13 ALL-PIM-Routers multicast address, which, if scoped, would break other aspects of PIM operation. Normally, bootstrap messages are "scoped" by configuring interdomain interfaces to run PIMv1, which does not support bootstrap, or through definition of bootstrap import/export policy that blocks reception or transmission of bootstrap router (BSR) messages, respectively.

Interface lists

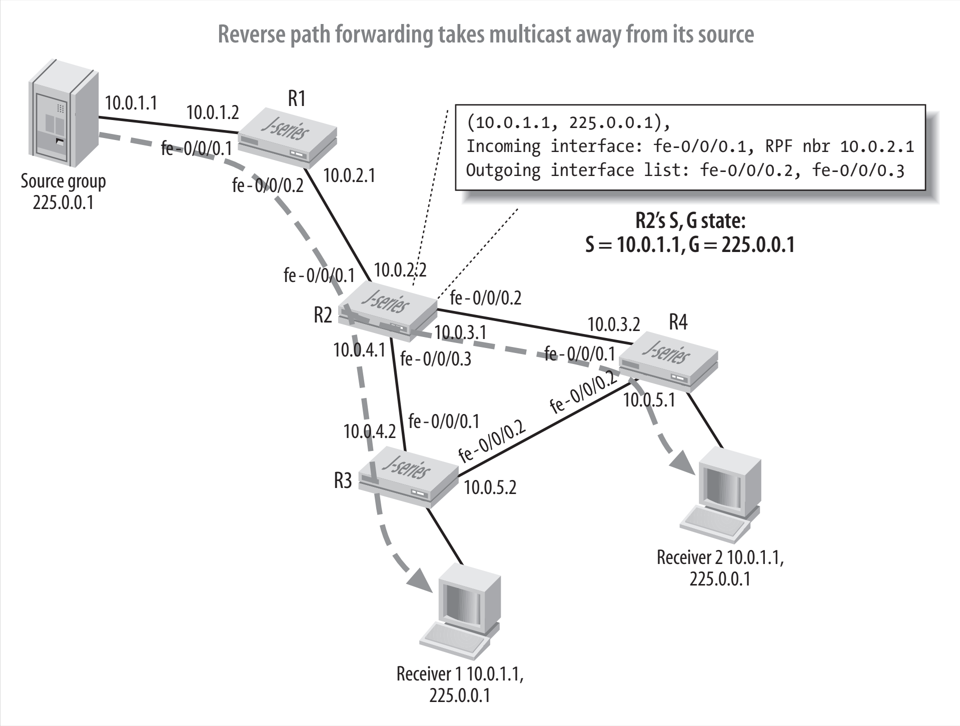
Multicast routers maintain state to determine which multicast packets should be forwarded, and over which interfaces copies of a packet should be sent. Part of this state is in the form of incoming and outgoing interface lists (IILs/OILs) for each active multicast source in the network. Maintaining accurate interface lists is critical for loop avoidance.

> Loops in any IP network are a bad thing. A multicast loop can be particularly nasty given the replication action of routers, which serves to provide an amplification effect for any looping packets.

The interface that lies on the shortest path *back* to the source is the upstream (incoming) interface, and packets are never allowed to be forwarded *toward* the multicast source. All remaining interfaces could become a downstream (outgoing) interface, depending upon join state.

A router with multicast forwarding state for a particular multicast group is "switched on" for that group's content. Interfaces on the router's outgoing interface list send copies of the group's packets received on the IIL for that group. Figure 10-5 shows this condition.

The router state that controls multicast forwarding is referred to as (S,G) or (*,G). In (S,G), the *S* refers to the unicast IP address of the source for the multicast traffic, and the *G* refers to the particular multicast group IP address for which S is the source. All multicast packets sent from this source have S as the source address and G as the destination address. The asterisk (*) in the (*,G) notation is a wildcard indicating that the state applies to any multicast source sending to group G. So, if two sources are originating content for multicast group 224.1.1.2, a router could use (*, 224.1.1.2) to



```
(10.0.1.1, 225.0.0.1),
Incoming interface: fe-0/0/0.1, RPF nbr 10.0.2.1
Outgoing interface list: fe-0/0/0.2, fe-0/0/0.3
```

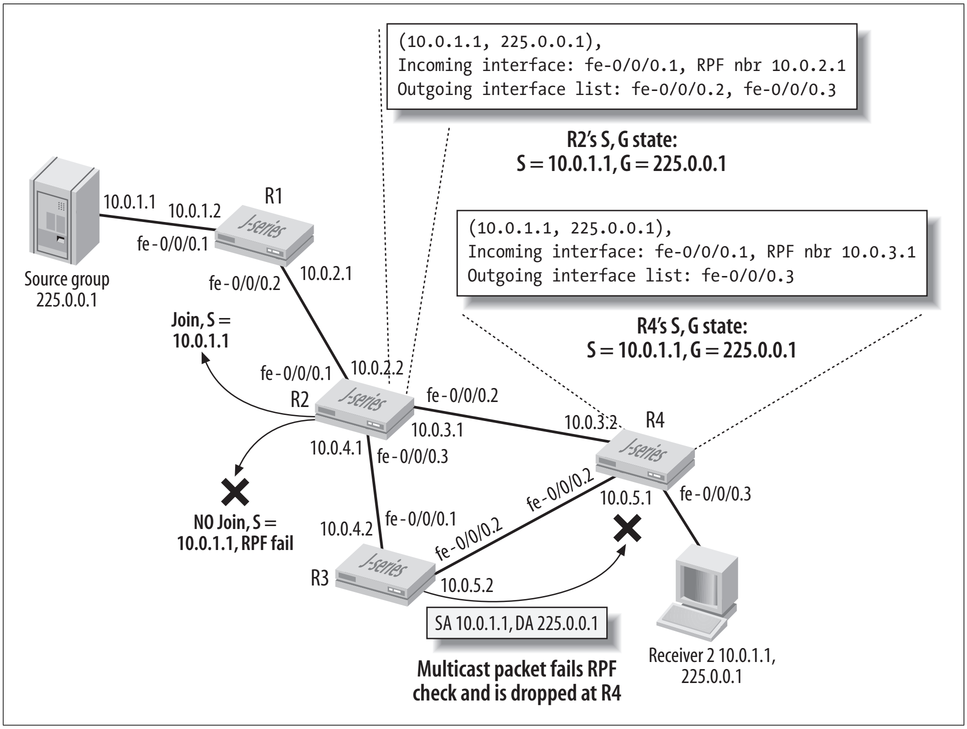
Figure 10-5. Interface lists

represent the state of a router forwarding traffic from both sources to members of that group, as is done in the case of a shared tree.

An incoming and outgoing interface list is maintained for each active source to group tuple. When you consider that group membership is itself often dynamic, and that this volatility leads to a need for ongoing maintenance of the related interface list, it becomes clear that a router handling large numbers of multicast groups can consume significant control plane resources maintaining multicast forwarding state. All Juniper Networks router architectures are well suited to hardware/real-time thread-based multicast replication and can forward multicast at the same (near-line-rate) performance level as unicast. A typical control plane scaling guideline for a router with 1 GB of memory is no more than 120,000 PIM entries [sum of (*,G) and (S,G)], 1,000 PIM neighbors, and 1,000 dynamic IGMP groups per interface.

Reverse path forwarding

Conventional routing is based on a longest match against the destination address of a packet. The unicast route table is maintained by unicast routing protocols such as the Routing Information Protocol (RIP) and OSPF, and it is used when forwarding unicast packets toward their destinations. As noted previously, multicast is like routing turned upside down, in that now the router actually forwards packets *away* from the source, based on the source rather than the destination address. A multicast router's forwarding state is thus organized based on a *reverse path* paradigm. As noted earlier, this process is known as reverse path forwarding (RPF) and is shown in Figure 10-6.



```
(10.0.1.1, 225.0.0.1),
Incoming interface: fe-0/0/0.1, RPF nbr 10.0.2.1
Outgoing interface list: fe-0/0/0.2, fe-0/0/0.3
```

```
(10.0.1.1, 225.0.0.1),
Incoming interface: fe-0/0/0.1, RPF nbr 10.0.3.1
Outgoing interface list: fe-0/0/0.3
```

Figure 10-6. The multicast RPF check

An RPF check simply makes sure that a packet arrives on the same interface that would be used for egress by the local router when routing *back* to that multicast source using the Interior Gateway Protocol's (IGP's) shortest path—in effect, a multicast packet is routed twice, once based on the source address and, if that passes, again based on the group address, this time against the OIL for that group. It's important to note that RPF checks occur both in the control plane when processing joins, and in the data plane when deciding whether a packet should be forwarded. Multicast packets that fail the RPF check are dropped because the incoming interface is not on the shortest path back to the source. Figure 10-6 shows how router R4 drops a multicast packet from source 10.0.1.1 when it is received on an interface that would not be used when routing a unicast packet to address 10.0.1.1. The figure also shows that routers generate joins over the RPF interface back to the source.

In some cases, the multicast routing protocol maintains its own RPF table, which is used specifically for the purpose of forwarding multicast. DVMRP is an example of such a protocol. PIM, on the other hand, makes use of the existing unicast route table to perform its RPF checks. This capability is why PIM is considered to be *protocol-independent*; it can use any route source for its RPF checks, including static, IGP, and even Border Gateway Protocol (BGP) routes. JUNOS software supports extensions to unicast routing protocols to accommodate the building of a separate RPF table. Examples include the Multiprotocol Border Gateway Protocol (MBGP) and multi-topology routing in Intermediate System-to-Intermediate System (IS-IS), or M-IS-IS.

Using the main unicast route table for RPF checks provides simplicity; using a dedicated route table for RPF checks allows a network administrator to set up separate paths and routing policies for unicast and multicast traffic. This allows the multicast network to function more independently of the unicast network.

Distribution trees

Previous discussions have indicated that multicast traffic is distributed via a tree that is rooted at the source and branches as needed to pick up all interested leaves. Several different types of distribution trees exist, and in many cases multiple tree types are used (over time) for the same multicast stream.

SPT. SPT is a distribution tree that is rooted at the source. This is sometimes called a *source tree*. An SPT is formed by sending the appropriate join messages over the RPF path to the desired source. Figure 10-7 shows this process.

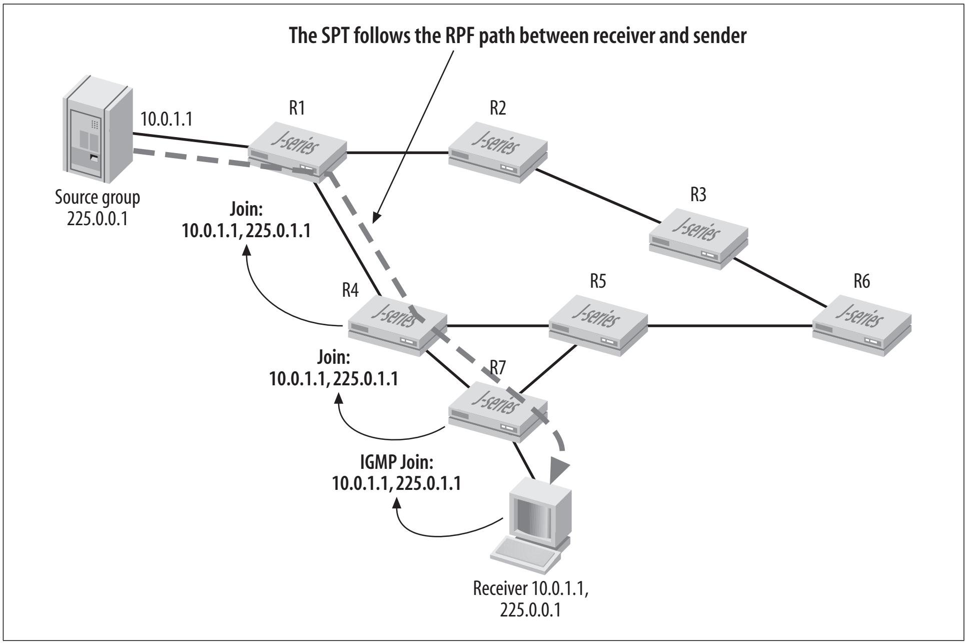


Figure 10-7. An SPT

Things begin when the receiver sends an IGMP join for source 10.0.1.1 and group 225.0.0.1. R7, the first hop (and, in this case, designated) router, generates the appropriate join message out the RPF interface for that source. This is referred to as an (S,G) join, because in this case both S and G are known. Router R4 receives the (S,G) join, which triggers the addition of the receiving interface to its OIL for the 10.0.1.1, 225.0.0.1 tuple. R4 now performs its own RPF check on the source address, and as a result R4 sends its (S,G) join message out its RPF interface for 10.0.1.1, causing reception of the (S,G) join at R1. The process stops when the join message reaches the router directly connected to the source or when it reaches a router that already has multicast forwarding state for this (S,G) tuple. The key point is that RPF handling of (S,G) join messages results in an SPT.

Shared trees and RPs. A shared multicast tree is rooted at an intermediate router, rather than at a specific source. The use of a shared tree can offer the benefit of less overall state, in that a single (*,G) entry can now represent state for numerous sources that may be sending to this group. In the most common multicast protocol in use today, PIM, the shared tree is short-lived and used only to make initial contact between senders and receivers, however. Once this initial contact is made, an SPT is established and the shared tree is no longer used for that (S,G) tuple. In PIM, the root of the shared tree is the RP, which functions to support sparse mode operation. Recall that in sparse mode, multicast is forwarded only as a result of an explicit join for the related group. Without prior knowledge of which senders are active for what groups, a router cannot generate an (S,G) join toward the source, because the source is not yet known.

> Source-specific multicast (SSM) describes a condition in which the receiver has preexisting knowledge of what source it wishes to join. This allows the generation of an SPT without the need for an RP. The use of receiver joins that do not specify a particular source is known as Any Source Multicast (ASM).

In a sparse mode Any Source Multicast (ASM) operation, the router generates an (*,G) join toward the RP, which results in joining a tree that is shared among all senders associated with that group. Figure 10-8 shows this process.

In the example in Figure 10-8, the receiver generates an IGMP join for group 225.0.0.1 that does not specify a particular source; hence, the *any* in the term Any Source Multicast and the use of a wildcard metacharacter to represent the resulting state (*,G). The last hop router, which functions as a designated router, performs an RPF check for the RP that handles this group, and the join is sent toward the RP rather than toward any particular source.

Figure 10-8 calls out how the source generates native multicast to the first hop router, R1 (which also functions as a designated router), which in turn encapsulates

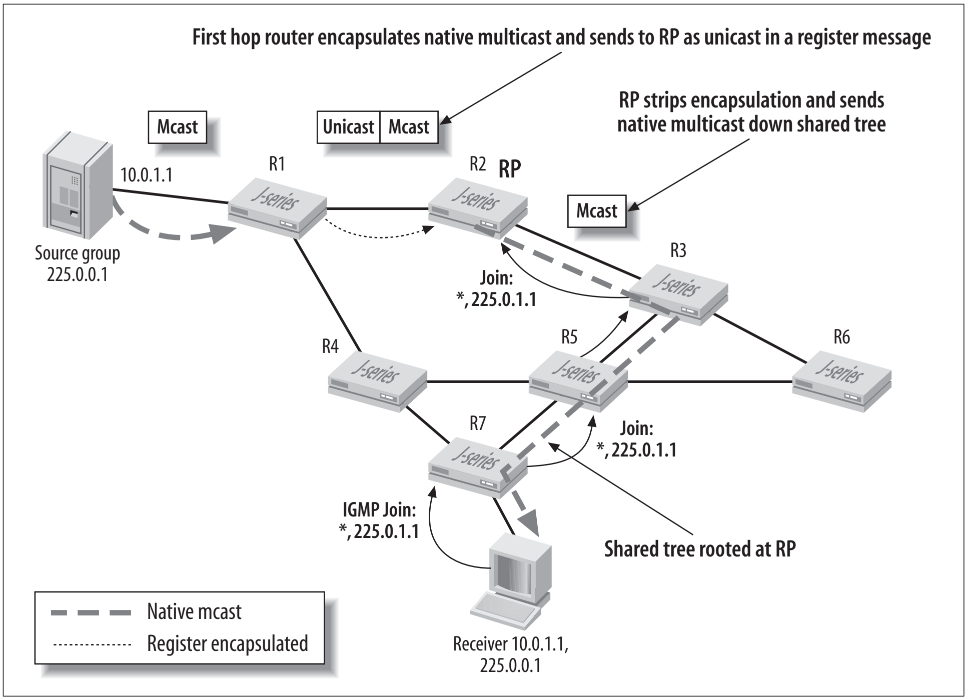


Figure 10-8. An RP tree

the traffic into a unicast datagram addressed to the RP. Upon receipt, the RP strips the register message encapsulation and sends the now native multicast down the shared tree associated with that group.

The purpose of register encapsulation is to eliminate the need for multicast-enabled routers between sources and the RP. The downside is that the first hop routers (those attached directly to multicast sources) and the RP require tunneling hardware/software support. On M-series platforms, this normally requires the presence of a Tunnel Services PIC—note that the M7i has a built-in Tunnel Services PIC whereas the M10i does not. J-series platforms perform multicast register message encapsulation in software, using the internal services interface, making additional hardware unnecessary.

Switching from a shared tree to an SPT. In PIM sparse mode operation, the shared RP tree (RPT) is used only for discovery of active sources. The receipt of traffic on the RPT initiates a switchover to an SPT by the last hop router (the router attached to the receiver), for each active source that is discovered. Once the SPT is formed, the last hop router begins to receive native multicast directly from the source, so an (S,G) prune is sent up the shared tree, toward the RP, to prevent reception of traffic over both the SPT and the RPT for that source. In some PIM implementations, a user-configurable threshold can be set to control when the switch to an SPT is instigated.

This capability is designed to prevent cutover to an SPT for short-lived sessions, where the traffic may no longer even be present by the time the SPT is established. In the JUNOS software PIM implementation, you can alter the default behavior of immediately switching to an SPT in favor of *never* switching to an SPT. You can do this with the `spt-threshold infinity` statement, in conjunction with a policy that specifies one or more (S,G) pairs that are subject to the modified behavior. The last hop router will never attempt to switch from the RPT to an SPT for matching (S,G) traffic. This behavior is desired for applications that send very low levels of multicast traffic, where the default behavior could result in undesired oscillation between SPT establishment, a timeout, and a resultant switch back to the RPT.

> PIM sparse mode operation requires tunnel services hardware (or software emulation) to perform the register encapsulation and decapsulation functions. J-series platforms can use the internal services interface for this functionality, as can the M7i with its built-in ASM hardware. The M10i requires the installation of tunnel services hardware to support register encapsulation. If your router lacks tunnel services, you can still commit a PIM sparse mode configuration, but things will simply not work if that router is the first hop attached to a source or when it functions as a (remote) RP, as both of these roles require processing of register messages. A Tunnel Services PIC is not required for dense or SSM modes of operation. You can also eliminate the need for register encapsulation and related tunnel PICs with the corner-case scenario of always having the first hop router also function as the RP.

Multicast Terminology Summary

This section defined the key terms and concepts associated with IP multicast. The next section explores multicast routing and group management protocols.

Multicast Protocols

This section describes the operation of group management and multicast routing protocols. We will focus on PIM sparse mode because it's the predominate form of multicast routing protocol in modern IP multicast networks. Simply stated, group management protocols are run by hosts to inform local routers of a host's interest, or lack thereof, in a particular multicast group. Multicast routing protocols are run only on routers and are concerned with RPF checks and the establishment and maintenance of (*,G) and (S,G) forwarding state.

Group Management Protocols

IGMP performs multicast group management and is run on hosts and on routers that attach to host segments. IGMP versions 1, 2, and 3 are currently defined in RFCs 1112, 2236, and 3376, respectively. The basic mechanics of IGMP operation center on hosts generating report messages to inform attached routers what groups the host is interested in, and to inform routers generating query messages to determine whether any active listeners still remain for a particular group.

There are three versions of IGMP—Juniper routers default to version 2, but you can configure them for version 1 or version 3 as needed. Although the various versions of IGMP are backward-compatible, this compatibility is achieved at the cost of having to drop back to the lowest common denominator. For example, if one host is running IGMPv1, any router attached to the LAN running IGMPv2 drops back to IGMPv1 operation, effectively eliminating the advantages of IGMPv2. Where possible, you should ensure that all multicast receivers run the highest version of IGMP that is supported and configured on the routers serving that network segment.

Table 10-3 identifies the key differences among IGMP versions.

Table 10-3. ICMP version comparison

Version	Characteristics	Comment
IGMPv1	Periodic generation of queries to the all-routers multicast address (224.0.0.1); hosts reply with list of interested groups; querier function performed by routing protocol	Join and leave latency stemming from periodic (60-second) nature of queries
IGMPv2	Lowest IP becomes querier for LAN; group-specific query and leave-group message	Routing protocol no longer performs the querier function; improved join/leave latency
IGMPv3	Support for group-source report messages	Supports SSM by allowing receivers to specify (S,G) tuples

Figure 10-9 details key aspects of IGMPv2 report and query behavior.

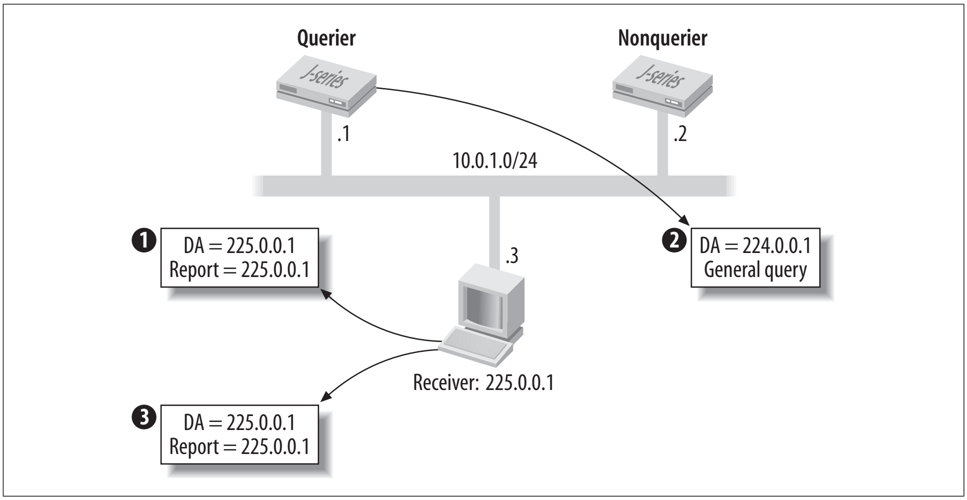


Figure 10-9. IGMPv2 operation

Things begin in Figure 10-9 when the receiver generates an IGMPv2 report, expressing interest in becoming a member of the 225.0.0.1 group. Note that the report is sent to the multicast address equating to the group being joined. Both multicast routers see this report. The router with the lowest IP address is elected the querier and periodically generates general queries to update its knowledge of host-to-group bindings on this LAN, as shown in step 2. All multicast-capable hosts receive the general query, and after a randomized delay, one of the interested hosts will reaffirm the group binding by generating a corresponding report message, which is shown in step 3. Other interested hosts suppress their reports upon seeing a matching report sent by any other node on the segment—the same level of multicast replication and forwarding is needed, be there one or 1,000 interested hosts on a given segment—therefore, only one report is needed to keep the group binding active.

Figure 10-10 goes on to show an IGMPv2 leave process.

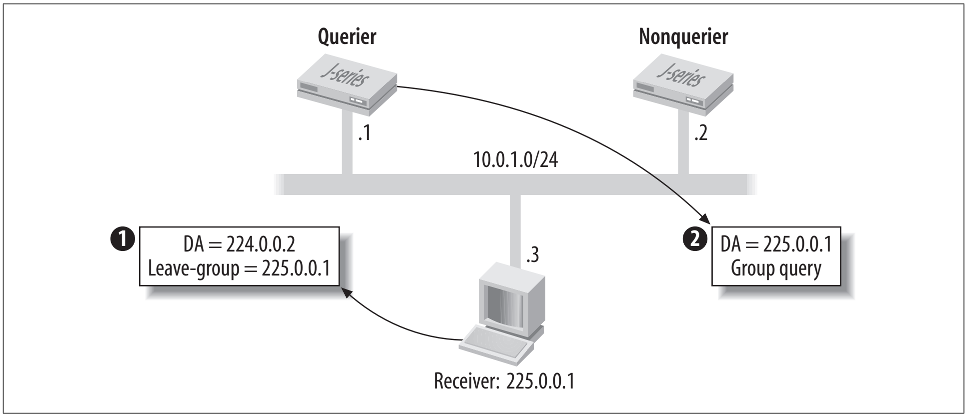
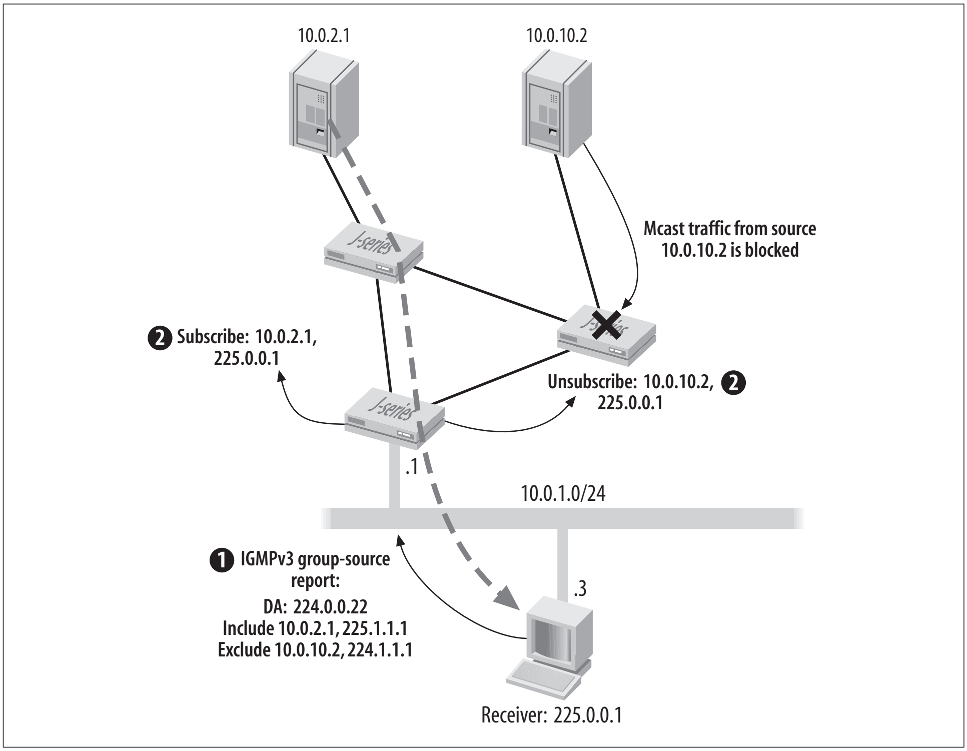


Figure 10-10. IGMPv2 leave process

Later on, the receiving host no longer desires content from group 225.0.0.1. It generates an IGMPv2 group-leave message, which is addressed to 224.0.0.2, the all-routers multicast address. The querier router now generates a group-specific query, which is addressed to the multicast address of the related group, in order to determine whether any interested listeners remain. If so, one will be the first to generate a group report, which keeps the binding active. Otherwise, after a small delay, the group join state is removed from the associated interface. The support of group leaves and general queries can greatly reduce join and leave latency. For example, in IGMPv1, the routing protocol must generate three queries before removing join state—with the default 60-second timer, this equates to 180 seconds of continued multicast delivery after the last interested host has left the group.

IGMPv3

IGMPv3 adds the concept of a source-specific join, which in turn enables SSM. The new capability allows a host to filter multicast content by group, as well as by source. With IGMPv1 or IGMPv2, a host simply has no way to express interest in a particular source, and therefore has to receive traffic from all active senders to that group. Because a source-specific join explicitly identifies the desired source, an SPT can be instantiated without the services of an RP. Figure 10-11 shows IGMPv3 SSM operation.



10.0.2.1
10.0.10.2
Mcast traffic from source 10.0.10.2 is blocked
J-series
J-series
J-series
2 Subscribe: 10.0.2.1, 225.0.0.1
Unsubscribe: 10.0.10.2, 225.0.0.1 2
.1
10.0.1.0/24
1 IGMPv3 group-source report:
DA: 224.0.0.22
Include 10.0.2.1, 225.1.1.1
Exclude 10.0.10.2, 224.1.1.1
.3
Receiver: 225.0.0.1

Figure 10-11. IGMPv3 SSM operation

In Figure 10-11, our trusty receiver (which is now IGMPv3-enabled) is told by its multicast application to *subscribe* to the multicast *channel* identified by the tuple 10.0.2.1,225.0.0.1. At the same time, the application instructs the machine to unsubscribe from the 10.0.10.2.225.0.0.1 channel. SSM uses the term *channel* in a manner analogous to the word *group* in ASM. Similarly, the terms *subscribe* and *unsubscribe* describe what in ASM is called *join* and *leave*. Note that the same protocol fields and values are used; the modified terminology simply helps to disambiguate which mode is being discussed, and more correctly describes ASM operation. Subscribing to an (S,G) is somewhat like tuning into a specific media channel when compared to IGMPv2's behavior of drawing traffic from all sources in the group.

Note that IGMPv3 group report messages are sent to all IGMPv3-capable multicast routers with a multicast address of 224.0.0.22, rather than to the multicast address of the group specified in the group address of the report message itself, as is done in versions 1 and 2.

The result, shown at step 1, is the receiver generating an IGMPv3 report that specifically lists the sources (and groups) for which content is desired. The same message can also be used to remove any previously subscribed-to sources. The LAN's designated router translates the IGMP report into the appropriate PIM join and prune messages, which in this context are referred to as subscribe and unsubscribe, respectively.

PIM

Several multicast routing protocols are still in use, but by far the most widely deployed is PIM. PIM was designed to avoid the dense-mode scaling issues of DVMRP and the potential performance problems of Core-Based Tree (CBT) at the same time. PIM supports dense mode, sparse mode, and sparse-dense modes of operation, and it has been in production use for several years.

PIM is a rapidly evolving Internet specification. PIM has seen two major revisions to its protocol operation (and packet structure)—PIM version 1 and PIM version 2—three major RFCs (RFC 4601 obsoleted RFC 2362, which in turn obsoleted RFC 2117), and numerous drafts describing major components of PIM. Work continues on PIM in a number of areas, such as bidirectional trees, and the rapid pace of development generates numerous PIM-related Internet drafts.

PIM versions

PIMv1 and PIMv2 can coexist on the same router, but not on the same interface. The main difference between PIMv1 and PIMv2 is the packet format. PIMv1 messages use IGMP packets, whereas PIMv2 has its own IP protocol number (103) and packet structure. All routers connecting to a shared IP subnet must use the same PIM version. Because the difference between PIMv1 and PIMv2 simply involves the message format, not the semantics or message processing rules, a router can easily support a mix of PIMv1- and PIMv2-enabled interfaces.

In this chapter, we are focusing on PIMv2 operating in sparse mode because this represents the most common usage of PIM in modern IP internetworks.

PIM components

The components needed to run PIM vary depending on operational mode. PIM dense mode requires only multicast sources and receivers and a series of interconnected PIM dense mode routers to allow receivers to obtain multicast content.

PIM sparse mode is more complicated because it requires the services of an RP in the network core. The RP is the root of a shared tree and is the point where upstream join messages from interested receivers meet downstream traffic from multicast sources. If there is only one RP in a routing domain, the RP and adjacent links might become congested and form a single point of failure for all multicast traffic. As a result, it is common to see multiple RPs deployed within a multicast network, for both performance and reliability reasons.

You can view PIM SSM as a subset of a special case of PIM sparse mode, and it requires no specialized equipment other than that used for PIM sparse mode (and IGMP version 3). When a host sends an IGMPv3 join for (S,G) the receiving designated router initiates creation of the SPT by sending an (S,G) join to its RPF neighbor for that source.

RP discovery. Having one or more routers configured as RPs is one thing, but how do the various sources and receivers come to learn which routers are acting as RPs, and for which multicast groups? You can take several approaches to propagate knowledge of the routing domain's RPs to client routers. They include:

Static

The simplest RP discovery mechanism is a static definition of the RP's address and group ranges on each client. This approach does not require any dynamic discovery protocols, but it is prone to reliability issues in the event that the statically defined RP fails, unless Anycast-RP is being used. PIM versions 1 and 2 support static RP assignments.

Auto-RP

The auto-RP mechanism is a nonstandard approach (developed by Cisco Systems) for the dissemination of RP information. Despite the lack of standards, auto-RP is supported in JUNOS software. The main drawback to auto-RP, aside from its nonstandard status, is the need for dense-mode handling of the two group addresses associated with auto-RP itself. This requirement forces sparse-dense mode operation on the network. The two auto-RP groups are 224.0.1.39 (announce), which is used to learn which routers in the network are possible candidate RPs, and 224.0.1.40 (discovery), which allows PIM routers to learn about the active group-to-RP mapping information. In operation, one or more routers are configured to perform the mapping function, which takes as input the set of candidate RPs learned in discovery messages and generates as output the chosen RP-to-group mappings that all routers should use. Auto-RP does support failover to backup RPs, but auto-RP does not support the ability to load-balance among multiple RPs for the same group range. Auto-RP is supported in PIM versions 1 and 2.

Bootstrap

The BSR mechanism is the standardized way to dynamically communicate a domain's RP to group address bindings. Unlike auto-RP, BSR does not require any dense-mode flooding. This is because bootstrap messages are propagated hop by hop rather than flooded via multicast, which thereby eliminates the cart-before-the-horse issues of auto-RP needing a working dense-mode multicast infrastructure before an RP can be communicated. The bootstrap mechanism is supported in PIM version 2 only. You can configure multiple candidate BSRs for redundancy—it is common to have the same routers configured as candidate RPs to be set as candidate BSRs also.

Once the BSR is elected (the router with the highest BSR priority), each candidate RP advertises its configured group ranges. The BSR processes the received advertisements, based in part on factors such as local policy, group range specificity, configured RP priority, and so on. The resulting RP set is communicated to all PIM routers, at which point each router is required to run its own hash to determine the RP for a given group. It is important to note that the hash algorithm ensures that all routers select the same RP-to-group mappings from the information in the domain's RP set, and when multiple candidate RPs are present, the algorithm automatically load-balances between those RPs. Stated differently, if two RPs both announce the default 224/4 range, bootstrap operation results in each RP handling one-half of the active groups. The failure of one RP results in all groups being shifted to the remaining RP—however, at no one time can multiple RPs be active for the same group when using bootstrap.

Anycast-RP

PIM supports the notion of Anycast-RPs, which bypasses the restriction of having one active RP per multicast group. With Anycast-RP, you can deploy multiple RPs for the same group range. Anycast-RP provides redundancy and load balancing, but unlike bootstrap, Anycast-RP can balance traffic from sources within the *same* group. With Anycast-RP, the various RPs share a common unicast IP address, such that clients simply choose the metrically closest route to the shared RP address. In the event of RP failure, the IGP simply reroutes to the next best path to the shared IP address, thus preserving connectivity. For proper operation, is it critical that each Anycast-RP be aware of active sources using other Anycast-RPs. This RP-to-RP communication can be performed using MSDP, as defined in RFC 3446, or using the newer, PIM-only approach defined in RFC 4610. Both methods are supported in JUNOS software.

PIM modes

PIM can operate in dense, sparse, sparse-dense, or SSM mode. Although in this chapter we are emphasizing PIM sparse mode in support of ASM, for completeness we will expand on the various modes here.

Dense mode. PIM dense mode is useful for multicast LAN applications, the main environment for all dense mode protocols. PIM dense mode uses the same flood first, prune later approach associated with DVMRP. The main difference between

DVMRP and PIM dense mode is that PIM provides protocol independence and can use the route table populated by any underlying unicast routing protocol to perform RPF checks. PIM dense mode supports the ASM model.

Sparse mode. PIM sparse mode is the most common way to deploy PIM. Sparse mode operation is considerably more complex than dense mode, but sparse mode offers the benefit of bandwidth conservation, which often more than justifies the added complexity. The various configuration examples shown in this chapter are based on PIM sparse mode. The key aspect of sparse mode operation is the need for an RP to serve as a liaison between active senders and any receivers that wish to obtain their content.

A PIM sparse mode router joins the RP-based shared tree upon receipt of an IGMP join from attached receivers. This is known as an (*,G) join because it matches any source sending to that group. If any sources are active for that group, their packets are sent down the shared tree until they reach the last hop router (the router directly attached to the receiver) and are delivered to the receiver(s) on that network segment. Receipt of traffic over the shared tree allows the last hop router to learn the address of active sources, at which point it initiates an SPT by sending an (S,G) over the RPF path toward each source. Once the SPT is established, the last hop router prunes that source from the shared tree by sending an (S,G) prune. This transitional aspect of PIM sparse mode from shared to source-based tree is one of the major attractions of PIM. This feature prevents overloading the RP or surrounding core links, which was the Achilles' heel of the CBT approach—which has yet to see commercial deployment.

PIM sparse mode supports the ASM and SSM models.

Source-specific multicast. The original multicast RFCs specify both many-to-many and one-to-many models. These modes are now known as ASM because ASM supports one or many sources for a multicast group's traffic. However, ASM operation requires that receivers be able to determine the locations of *all* sources for a particular multicast group, no matter where the sources might be located in the network. In ASM, *source discovery* is a critical and complex function within the network.

ASM makes sense in a highly dynamic environment where sources often come and go, as, for example, in a videoconferencing service. However, several promising multicast applications, such as IP-based television, are being brought to commercial realization quickly and efficiently through an assumption that there is a longer-lived single source for some particular content. PIM SSM is simpler than PIM sparse mode because only the one-to-many model is supported. PIM SSM therefore forms a subset of PIM sparse mode. It builds only SPTs, and an RP is no longer necessary, given that the user specifies the source address as part of his IGMPv3 report message.

PIM SSM can coexist with ASM by confining the SSM model to a subset of the IP multicast group address range. The IANA has reserved the address range 232.0.0.0–232.255.255.255 for SSM operation. JUNOS software allows SSM configuration for the entire range of IP multicast addresses (224.0.0.0–239.255.255.255). When a custom SSM range is defined, legacy IP multicast applications cannot receive any traffic for groups in that SSM range, unless the application is modified to support SSM (S,G) channel subscription.

PIM messages

PIM uses a variety of message types to do its job. The reader is encouraged to consult the appropriate RFC for an exhaustive description of each field found in the various PIM messages. Our purpose here is to describe *how* these PIM messages operate to establish SSM operation:

Join/prune

PIM state is established and withdrawn using join/prune messages. An individual message may contain both join and prune information, join information (a join message) only, or prune information (a prune message) only. A single join/prune message can list multiple senders/groups to join or prune.

Register

Routers connected to a multicast source encapsulate the multicast data stream into unicast packets that are addressed to the RP that serves that group range. A PIM register message contains an encapsulated multicast packet, which can be sent to the RP without the need for multicast transport between the sender and the RP. Once received by the RP, the register encapsulation is stripped and the RP forwards native multicast packets down the shared RPT.

Register stop

The RP may wish to stop receiving the encapsulated multicast traffic from the first hop router, and the register-stop message is used to accomplish this goal. An RP may wish to stop receiving register-encapsulated messages for several reasons:

- The RP has no join state for the group address of the traffic (there are no interested listeners on the RPT).
- The RP may have received a prune message from the network for a group being forwarded along the RPT, perhaps as the result of SPT establishment leaving no interested receivers.
- The RP itself might be receiving the multicast traffic natively from the network along an SPT.

The designated router

PIM defines specific functions for the first and last hop routers, which are known as designated routers. The designated router sends register and join/prune messages on behalf of directly connected senders and receivers, respectively. The designated router may or may not be the same router as the IGMP querier.

On multiaccess networks, a designated router is elected to ensure that packets and PIM control state are not duplicated. In operation, PIM neighbors on a shared LAN periodically send PIM Hello messages to each other. The sender with the highest IP address becomes the designated router for that LAN segment.

PIM assert. PIM supports an assert mechanism that prevents ongoing packet duplication, which can occur when there are parallel paths to a source or the RP. Figure 10-12 shows the PIM assert process in action.

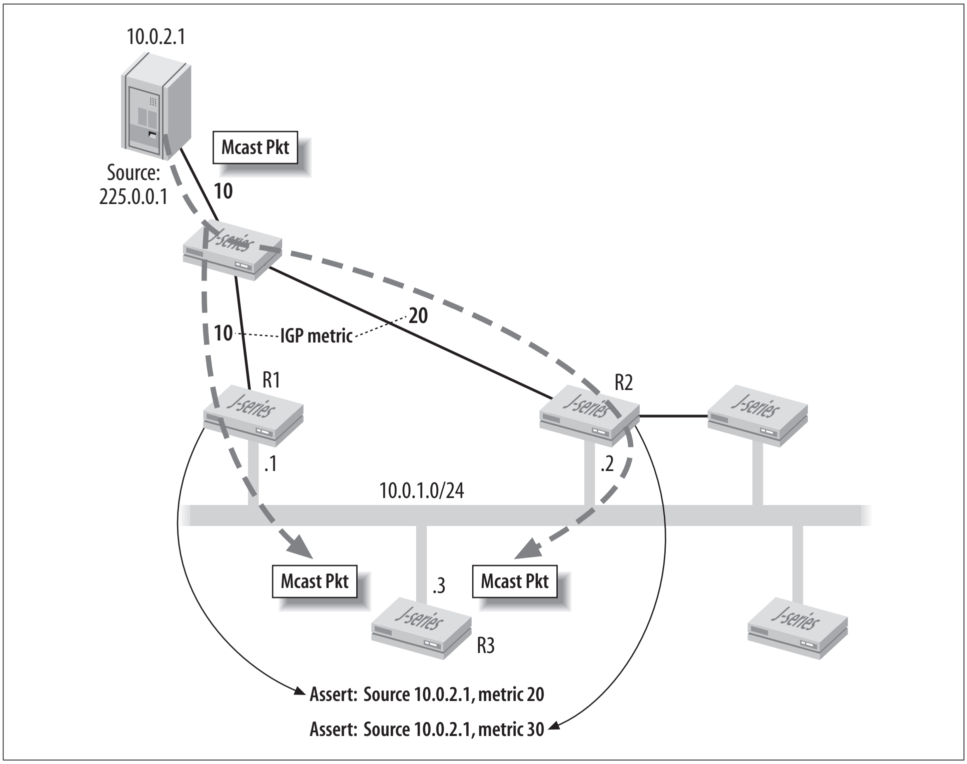


Figure 10-12. The PIM assert process

The figure shows three routers, R1–R3, connected to a shared LAN, along with an RP and a source for group 225.0.0.1. The figure also shows the IGP metrics to reach the source, as seen by routers R1 and R2. In this example, both R1 and R2 have added the multicast source to their OIL for their LAN attached interface. As a result, a packet sent from the source is replicated and forwarded by both R1 and R2, resulting in an extra copy of the packet on the LAN segment. To prevent ongoing occurrences, the PIM assert process is started, by which the upstream PIM routers assert their right to be the designated forwarder by sending assert messages to the 224.0.0.13 (ALL-PIM-ROUTERS) group multicast address. Each router places its IGP preference and corresponding metric to the source in its assert message. The router with the best preference, or lowest metric, wins (metrics are compared only in the event of a preference tie). In the event of a tie, the router with the highest IP address wins. Figure 10-12 also shows that R1 has a better metric and therefore becomes the forwarder for the LAN segment. Meanwhile, downstream router R3 has eavesdropped on the assert battle and takes note of the victor because this is the router to which R3 will subsequently send joins for that source.

PIM asserts are also needed for (*,G) entries. This is because the RPT and SPT for a given group may transit a shared media link such as a LAN. In these cases, the assert mechanism determines which of the two trees will carry the packet on the shared links, again to avoid unneeded packet duplication. According to the specifications, an SPT is always preferred over an RPT. When there are multiple paths to the RP through the LAN, the designated router may lose the (*,G) assert process to another router on the LAN. As a result, that router ceases to be the designated router for local receivers on that LAN, and the victor becomes the last hop router and is therefore responsible for sending (*,G) join messages to the RP.

Multicast Protocol Summary

This section detailed the function of group management protocols, which allow routers to determine which interfaces have attached listeners, and allow multicast routing protocols that provide for RPF checking and manage join and prune states.

We also discussed the use of shared and source-specific trees, as well as the role of the RP in supporting ASM and SSM.

In the next section, we will put multicast theory to the test with a PIM sparse mode deployment scenario using a static RP.

PIM Sparse Mode: Static RP

At this stage, you should have an extensive grounding in IP multicast theory in general, and in PIM sparse mode operation in particular. This knowledge is soon to bear fruit as you configure and validate the operation of PIM sparse mode using a statically defined RP with Juniper Networks' routers.

The initial PIM sparse mode deployment goals are as follows:

- Configure router `PBR` as an RP for the entire multicast address range.
- Configure all other routers to use `PBR` as the domain's RP without using BSR or auto-RP.
- Configure `Cider` to function as a multicast receiver for group 225.1.1.1.

- Use Ale as a multicast source to generate traffic to group 225.1.1.1.
- Verify RPT join and subsequent traffic-driven switches to SPT.

Figure 10-13 details the portion of Beer-Co's network that is to be enabled for multicast support. The figure also highlights key aspects of the IGP routing infrastructure now in place.

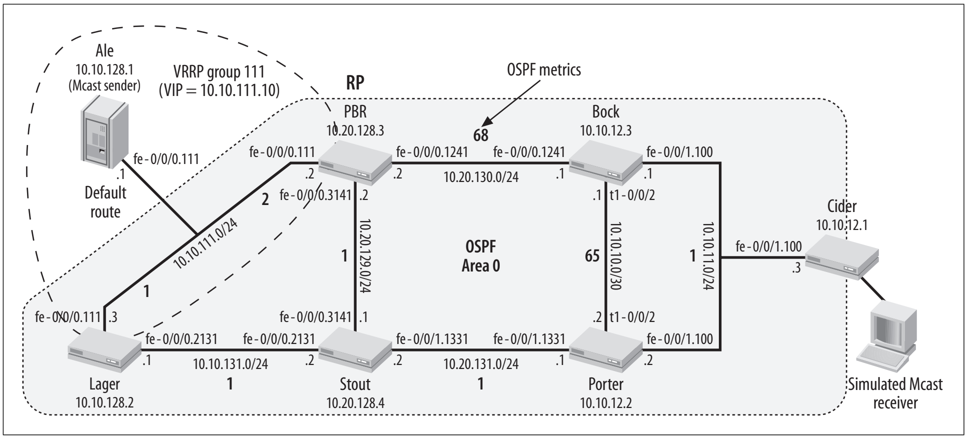


Figure 10-13. Beer-Co's multicast topology

Details to note in Figure 10-13 include the following:

- The default OSPF bandwidth scaling factor is in effect with the exception of PBR's end of the PBR–Lager link (asymmetric) and the PBR–Bock link. The metric for these links has been altered in an effort to favor the Lager–Stout–Porter path for communications between Ale and Cider.
- Router Ale is configured to emulate a host sending to a multicast group. Ale uses a default route pointing to the virtual IP (VIP) address associated with the PBR–Lager Virtual Router Redundancy Protocol (VRRP) group. No routing or multicast protocols are enabled at Ale.
- Cider is used to simulate a PIM-enabled router with a directly attached multicast receiver.

Validate the Baseline IGP Forwarding Path

Before starting any multicast configuration, a quick confirmation of IGP connectivity and the resulting forwarding paths through the network is performed. The use of a default route is confirmed at Ale, as is the use of the Lager, Stout, and Porter forwarding paths for communications between Ale and Cider:

```
[edit]
lab@Ale# run show route 10.10.12.1
```

```
inet.0: 4 destinations, 4 routes (4 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

  0.0.0.0/0          *[Static/5] 00:00:04
                    > to 10.10.111.10 via fe-0/0/0.111
[edit]
lab@Ale# run traceroute 10.10.12.1 no-resolve
traceroute to 10.10.12.1 (10.10.12.1), 30 hops max, 40 byte packets
 1  10.10.111.3  11.837 ms  9.735 ms  10.115 ms
 2  10.10.131.2  19.716 ms  20.203 ms  9.681 ms
 3  10.20.131.1  10.109 ms  10.395 ms  9.298 ms
 4  10.10.12.1  20.214 ms  9.747 ms  19.893 ms
```

Symmetrical forwarding in the return path from Cider to Ale is also confirmed, as is the use of OSPF routing at Cider; recall that unlike Ale, which is running no routing protocols, Cider simulates a PIM/OSPF-enabled router with an attached receiver:

```
[edit]
lab@Cider# run traceroute 10.10.128.1 no-resolve
traceroute to 10.10.128.1 (10.10.128.1), 30 hops max, 40 byte packets
 1  10.10.11.2  9.945 ms  9.711 ms  9.856 ms
 2  10.20.131.2  20.054 ms  39.955 ms  19.863 ms
 3  10.10.131.1  19.854 ms  18.125 ms  31.839 ms
 4  10.10.128.1  19.792 ms  19.949 ms  20.214 ms

[edit]
lab@Cider# run show route 10.10.128.1

inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.128.1/32     *[OSPF/150] 00:20:10, metric 0, tag 0
                    > to 10.10.11.2 via fe-0/0/1.100
```

The OSPF route to the loopback address of Ale is seen as an OSPF external by router Cider. This is because a static route representing Ale's lo0 address is redistributed into OSPF at routers PBR and Lager, which is necessary here given that Ale does not participate in OSPF routing. The 111 VRRP group shared by PBR and Lager is configured to make Lager the VRRP master when its fe-0/0/0.111 interface is operational via the preempt keyword and a priority of 100—the accept-data option is added to permit diagnostic ping testing to the VIP. According to the VRRP RFC, the VIP is allowed to respond only to Address Resolution Protocol (ARP) requests, meaning that unlike Cisco's HSRP, by default you cannot ping the VIP associated with a VRRP group.

Lager's static route, related redistribution policy, and VRRP configuration are shown. PBR has a similar configuration, except that its VRRP priority is set to 50.

```
[edit]
lab@Lager# show routing-options
static {
    route 10.10.128.1/32 next-hop 10.10.111.1;
}

[edit]
lab@Lager# show policy-options
policy-statement Ale_lo0 {
    term 1 {
        from {
            protocol static;
            route-filter 10.10.128.1/32 exact;
        }
        then accept;
    }
}

[edit]
lab@Lager# show interfaces fe-0/0/0 unit 111
description Lager_PBR_Ale;
vlan-id 111;
family inet {
    address 10.10.111.3/24 {
        vrrp-group 69 {
            virtual-address 10.10.111.10;
            priority 100;
            preempt;
            accept-data;
        }
    }
}
```

Configure PIM Sparse Mode with Static RP

With the underlying IGP's operation confirmed, you move on to PIM configuration on the routers making up the multicast test bed. In the JUNOS software implementation, enabling PIM on an interface automatically enables IGMPv2, making explicit configuration of IGMP unnecessary unless you need to modify default settings. IGMP is not required on links that connect only routers—hosts use IGMP to inform routers of their group membership. Leaving IGMP enabled on these links does not lead to appreciable resource consumption and ensures that things will work as expected if hosts are added at a later time.

PIM configuration begins at router PBR because it's been designated as the RP in the initial multicast topology; without an RP, PIM sparse mode cannot begin to operate. PIM is configured at the [edit protocols pim] hierarchy. The configuration options for PIM are displayed:

```
[edit protocols pim]
lab@PBR# set ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  assert-timeout       Set assert timeout (5..210)
```

```
    > dense-groups         Dense mode groups for sparse-dense mode
      disable              Disable PIM
    > graceful-restart     Configure graceful restart attributes
    + import               PIM sparse import join policy
    > interface            PIM interface options
    > mdt                  Configure multicast data tunnel parameters
    > rib-group            Routing table group
    > rp                   Router's rendezvous point properties
    > spt-threshold        Set shortest-path-tree threshold policy
    > traceoptions         Trace options for PIM
    vpn-group-address    Group address for the VPN in provider space
```

The assert-timeout setting determines how often the forwarding router reasserts its right to do so, based on its belief that it has the lowest SPF RPF cost for a given source or RP; the router always generates an assert message when a multicast packet is *received* on an interface that is in the *outgoing* interface list for a given group. Internal rate-limiting of these event-driven assert messages (as with all control plane messaging in JUNOS software) ensures that the network and local processing resources are not overrun in the event of a packet loop or broken multicast forwarding state in an adjacent node.

The dense-groups configuration identifies any groups that are flooded in dense mode over interfaces set for sparse-dense mode operation. This setting is used when you operate in sparse mode but you still want dense mode flooding on a group-by-group basis, and is typically used to support auto-RP's need for dense mode flooding of its announce (224.0.1.39) and discovery (224.0.1.40) messages.

The graceful-restart settings control the graceful restart duration and can be used to specifically disable graceful restart for PIM when graceful restart is globally enabled under the [edit routing-options] stanza. The import keyword links to one or more policies that allow filtering of join messages, which prevents the resulting (*,G) or (S,G) state, therefore blocking the extent of multicast traffic distribution by preventing installation of related forwarding state in the control plane. In contrast, multicast scoping operates in the *data* plane to provide a similar effect. Generally speaking, the use of scoping is preferred over join filtering because the former scales better, and it prevents the transport of multicast traffic that could result from the use of dense mode flooding or a packet generation tool.

The spt-threshold determines whether the local router attempts a switch to an SPT after the first packet (default), or never when set to infinity. The use of multicast distribution tree (MDT) tunnels and routing information base (RIB) groups is beyond the scope of this book. Suffice it to say that MDT tunnels are used to support PIM sparse mode in a Layer 3 virtual private network (VPN) environment, and that use of RIB groups allows a PIM multicast forwarding topology that is independent of the unicast RPF table.

The interface keyword allows specification of which interfaces should run PIM, along with interface-level parameters such as PIM version, hello time, and so on. The options available at the [edit protocols pim interface *interface-name*] hierarchy are:

```
[edit protocols pim]
lab@PBR# set interface fe-0/0/0.111 ?
Possible completions:
  <[Enter]>            Execute this command
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  disable              Disable PIM on this interface
  hello-interval       Hello interval (0..255 seconds)
  mode                 Mode of interface
  priority             Hello option DR priority (0..4294967295)
  version              Force PIM version (1..2)
```

Most interface-level options are self-explanatory. The priority setting specified under an interface controls the router's likelihood of being elected the PIM designated router on that network segment; the default setting is 1, making the router least likely to be the designated router. The mode keyword determines whether the associated PIM interface operates in sparse, dense, or sparse-dense mode. When an interface is in sparse-dense mode, the list of groups specified with the dense-groups keyword is flooded in dense mode, and all other groups are handled as sparse.

You configure a router to be an RP, or to learn about other RPs using either the static, bootstrap, auto-RP or Anycast-RP mechanism under the [edit protocol pim rp] hierarchy. The configuration options available at this hierarchy are:

```
[edit protocols pim]
lab@PBR# set rp ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
> Auto-RP              Set Auto-RP mode (IPv4 only)
> bootstrap            Bootstrap properties
+ bootstrap-export     Bootstrap export policy (IPv4 only)
+ bootstrap-import     Bootstrap import policy (IPv4 only)
  bootstrap-priority   Eligibility to be the bootstrap router (IPv4 only)
+ dr-register-policy   DR policy applied to outgoing register messages
> embedded-rp          Set embedded-RP mode (IPv6 only)
> local                Router's local RP properties
+ rp-register-policy   RP policy applied to incoming register messages
> static               Configure static PIM RPs
```

As you would expect, the properties that control auto-RP-based RP election are configured under the Auto-RP hierarchy. Auto-RP is not demonstrated here because it has lost favor to BSR-based election for reasons that were cited previously. Several bootstrap-related configuration keywords are used in bootstrap-based RP election—we will skip these knobs for now because we will explore them in a subsequent BSR configuration example.

The dr-register-policy and rp-register-policy keywords link to policy statements that filter register messages sent by the designated router or filter register messages received by the RP, respectively. This feature allows you to control the number of sources that a given RP can know about, and that might be used for performance or security-related reasons. The embedded-rp hierarchy controls the number of embedded RPs, as well as groups that can contain an embedded RP address. Embedded RP is used for interdomain IPv6 multicast and is beyond the scope of this book. Note, however, that IPv4 interdomain multicast is normally associated with MSDP.

Static definition of an RP is performed with the static keyword. A statically configured RP eliminates the need for dynamic RP election, but this simplicity can come at the cost of reduced reliability because routers may continue to use an RP that has ceased functioning. However, the use of a statically defined RP, in conjunction with Anycast-RP, alleviates many of these concerns, and we discuss it in detail in "PIM Sparse Mode with Anycast-RP Summary," later in this chapter.

Configure PIM on the RP

Local RP characteristics are defined under the [edit protocols pim local] hierarchy, and are used when the local router functions as an RP. Because PBR is the PIM domain's RP in this example, your configuration begins at PBR with the specification of its local RP properties. The command-line interface's (CLI's) ? function displays the configuration mode set options available at the [edit protocols pim rp local] hierarchy:

```
[edit protocols pim rp local]
lab@PBR# lab@PBR# set ?
Possible completions:
  address              Local RP address (IPv4 only)
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  disable              Disable this RP (IPv4 only)
> family               Local RP address family
> group-ranges         Group address range for which this router can be an RP (IPv4
only)
  hold-time            How long neighbor considers this router to be up, in seconds
(IPv4 only)
priority             Router's priority for becoming an RP (IPv4 only) (0..255)
```

Use the address keyword to define the local RP address for IPv4 operation. Normally, this will be a globally routable address (i.e., a non-127.*x.x.x* address) assigned to the router's lo0 interface for maximum reliability, given that the virtual nature of a loopback interface tends to make it the last to fail. The family keyword is used to configure an IPv6-based RP under the inet6 family. You may wish to divide the multicast address space among multiple RPs using the group-ranges keyword to help spread processing load or to improve overall robustness by eliminating a potential single point of failure for all multicast groups in the domain.

The configured hold-time value is included in candidate RP messages (sent to a domain's bootstrap router when using BSR), and determines how long the BSR includes that RP in the candidate RP set before the entry needs to be refreshed by receipt of a new candidate RP advertisement for that same RP. The priority value is used in the hash function that chooses a particular RP for a given group range from the set of candidate RPs. A numerically smaller priority value is preferred—the range is from 0–255, with 1 being the default. Note that a setting of 0 indicates that the BSR can override the received RP-to-group mappings in the candidate RP set that it advertises.

Because you are configuring a static RP environment, only the address keyword is of concern in the current configuration. "Configure PIM Sparse Mode with Bootstrap RP," later in this chapter, demonstrates BSR-based RP election. PBR is configured to use its globally routable loopback address as the domain's RP:

```
[edit protocols pim rp local]
lab@PBR# set address 10.20.128.3
```

The interfaces that should run PIM are configured next; there is no need or benefit to running PIM on the lo0 interface, so transit interfaces only are enabled for PIM. The completed PIM stanza at PBR is displayed:

```
[edit protocols pim]
lab@PBR# show
rp {
    local {
        address 10.20.128.3;
    }
}
interface fe-0/0/0.3141;
interface fe-0/0/0.1241;
interface fe-0/0/0.111;
```

After committing the changes to the local RP, status is confirmed:

```
lab@PBR# run show pim rps
Instance: PIM.master
Address family INET
RP address       Type       Holdtime Timeout Groups Group prefixes
10.20.128.3      static            0    None      0 224.0.0.0/4
```

The output of the show pim rps command shows that PBR is functioning as a statically defined RP for the entire multicast address 224/4 group range. You next verify that PIM is enabled on all transit interfaces used in the multicast test bed with a show pim interfaces command:

```
[edit protocols pim]
lab@PBR# run show pim interfaces
Instance: PIM.master
```

```
Name                   Stat Mode       IP V State Count DR address
fe-0/0/0.111           Up   Sparse      4 2 DR        0 10.10.111.2
fe-0/0/0.1241          Up   Sparse      4 2 DR        0 10.20.130.2
fe-0/0/0.3141          Up   Sparse      4 2 DR        0 10.20.129.2
pd-0/0/0.32769         Up   Sparse      4 2 P2P       0
```

The command output confirms that PIM is now running on all three of PBR's network interfaces used in the multicast test bed, and that sparse is the default mode of operation. Because PBR is the first, and so far the only, PIM-enabled router, it has won the designated router election on all of its multiaccess interfaces; a designated router is not required on point-to-point interfaces. The 0 count value indicates that no PIM neighbors have been detected, which is expected until other routers are enabled for PIM. The show pim neighbors command returns an empty list at this time (not shown).

The highlighted code in the output calls out that the router has automatically instantiated a PIM decapsulation (pd) interface using the J-series built-in services interface functionality. Recall that in sparse mode, the first hop router encapsulates multicast into a unicast register message (using a PIM encapsulate [pe] interface), which is then decapsulated back to native multicast at the RP for distribution down the shared tree. No explicit configuration is needed for these pd and pe interfaces; they are created automatically when PIM sparse mode is configured and the required tunnel support is present. On some platforms, such as the M10i, you must order and install tunnel hardware to support PIM sparse mode register message encapsulation.

As noted previously, in JUNOS software, enabling PIM automatically enables IGMP on that interface. The output of the show igmp interface command confirms that this is the case:

```
lab@PBR# run show igmp interface
Interface: fe-0/0/0.111
    Querier: 10.10.111.2
    State:         Up Timeout:    None Version:  2 Groups:      5
Interface: fe-0/0/0.1241
    Querier: 10.20.130.1
    State:         Up Timeout:     156 Version:  2 Groups:      0
Interface: fe-0/0/0.3141
    Querier: 10.20.129.1
    State:         Up Timeout:     154 Version:  2 Groups:      0

Configured Parameters:
IGMP Query Interval: 125.0
IGMP Query Response Interval: 10.0
IGMP Last Member Query Interval: 1.0
IGMP Robustness Count: 2

Derived Parameters:
IGMP Membership Timeout: 260.0
IGMP Other Querier Present Timeout: 255.
```

Configure PIM on remaining routers

With the domain's RP up and running, you move on to add PIM to the remaining routers. Aside from specifying PIM-enabled interfaces, you must also specify the domain's RP explicitly, given that this is a static RP scenario. The PIM configuration added to Stout is shown. All remaining routers have a similar PIM configuration.

```
[edit protocols pim]
lab@stout# show
rp {
    static {
        address 10.20.128.3;
    }
}
interface fe-0/0/0.2131;
interface fe-0/0/0.3141;
interface fe-0/0/1.1331;
```

The key to this PIM sparse mode configuration is the static definition of the domain's RP, which in this example is PBR's lo0 address. When desired, you can further define a static RP's group range and PIM version:

```
[edit protocols pim]
lab@stout# set rp static address 10.20.128.3 ?
Possible completions:
  <[Enter]>            Execute this command
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
> group-ranges         Group address range of RP
version              PIM version of RP (1..2)
```

In this example, the default version 2 and 224/4 group range are desired, so no further changes are needed. After the changes are committed, you confirm the presence of PIM neighbors at router Stout:

```
[edit protocols pim]
lab@stout# run show pim interfaces
Instance: PIM.master

Name                   Stat Mode       IP V State Count DR address
fe-0/0/0.2131          Up   Sparse      4 2 DR        1 10.10.131.2
fe-0/0/0.3141          Up   Sparse      4 2 NotDR     1 10.20.129.2
fe-0/0/1.1331          Up   Sparse      4 2 DR        1 10.20.131.2
pe-0/0/0.32769         Up   Sparse      4 2 P2P       0
```

The display shows that Stout has detected one PIM neighbor on all but its pe encapsulation interface, which is expected given this setup. The output also shows that the local router is the designated router for two of its three network interfaces. To display neighbor information, issue a show pim neighbors command:

```
lab@stout# run show pim neighbors
Instance: PIM.master
```

```
Interface           IP V Mode        Option      Uptime Neighbor addr
fe-0/0/0.2131        4 2             HPLG      00:18:12 10.10.131.1
fe-0/0/0.3141        4 2             HPLG      00:18:12 10.20.129.2
fe-0/0/1.1331        4 2             HPLG      00:18:12 10.20.131.1
```

The display shows the IP address of each detected PIM neighbor, the associated interface, and the supported IP/PIM version. The Mode column is expected to be empty when configured for PIMv2 because v2 supports dense, sparse, and sparse-dense modes. The Option column displays a coded list of each neighbor's supported PIM options. The codes are interpreted as follows:

B	Bidirectional-capable
H	Hello option hold time
G	Generation identifier
P	Hello option designated router priority
L	Hello option LAN prune delay

Add the `detail` switch to view the specific timers and parameters associated with each neighbor:

```
[edit protocols pim]
lab@stout# run show pim neighbors detail
Instance: PIM.master
Interface: fe-0/0/0.2131

    Address: 10.10.131.1,       IPv4, PIM v2
        Hello Option Holdtime: 105 seconds 95 remaining
        Hello Option DR Priority: 1
        Hello Option Generation ID: 532624463
        Hello Option LAN Prune Delay: delay 500 ms override 2000 ms

    Address: 10.10.131.2,       IPv4, PIM v2, Mode: Sparse
        Hello Option Holdtime: 65535 seconds
        Hello Option DR Priority: 1
        Hello Option Generation ID: 756451044
        Hello Option LAN Prune Delay: delay 500 ms override 2000 ms
```

The PIM neighbor state is as expected at `Stout`. RP information is displayed with the `show pim rps` command:

```
[edit protocols pim]
lab@stout# run show pim rps
Instance: PIM.master
Address family INET
RP address         Type        Holdtime Timeout Groups Group prefixes
10.20.128.3        static             0    None      0 224.0.0.0/4

Address family INET6
```

The output displays the loopback address associated with router `PBR`, which is functioning as the Beer-Co domain's RP. Further, the display confirms that the RP was learned via static configuration (hence, no timeout), and that currently no multicast groups are mapped to this RP, as indicated by the 0 in the Groups column. Given that there are no active groups (or sources, for that matter) in the current network, the lack of any group-to-RP mappings is expected at this time. As further confirmation, PIM join state is displayed at Stout:

```
[edit protocols pim]
lab@stout# run show pim join
Instance: PIM.master Family: INET

Instance: PIM.master Family: INET6
```

The join list is empty, which indicates that no SPT or RPT joins have been instigated by the local router. This display confirms that no groups are currently mapped to the domain's RP. The lack of join state means there should be no multicast forwarding state, which is easily verified with a show multicast route command:

```
[edit protocols pim]
lab@stout# run show multicast route
Family: INET

Family: INET6
```

As expected, there are no active multicast routes, which is in keeping with no RPT or SPT join state. At this stage, the PIM network is awaiting an active source and an interested receiver.

Verify RPF

Before you activate any senders or multicast receivers, the RPF state of the current network is analyzed. Recall that multicast forwarding and control plane operations tend to center on the RPF function. An RPF check is, in essence, nothing more than a route lookup on a packet source, and then verification that the packet arrives on the same interface that would be used when routing packets addressed to that source.

Referring back to Figure 10-13, it is restated that IGP metrics are altered to prefer the lower forwarding path consisting of routers Lager, Stout, and Porter. The network's RPF state should reflect the IGP's preferred forwarding path, which is confirmed with a show multicast rpf command issued at router Bock for the prefix associated with the domain's RP:

```
[edit]
lab@Bock# run show multicast rpf 10.20.128.3
Multicast RPF table: inet.0 , 21 entries

10.20.128.3/32
    Protocol: OSPF
    Interface: fe-0/0/1.100
    Neighbor: 10.10.11.2
```

The output shows that Bock expects to receive packets sent from the 10.20.128.3 loopback address of PBR, via its fe-0/0/1.100 interface. Based on this RPF state, any packets from source 10.20.128.3 received on *any other* interface fail the RPF check, resulting in discard. The OSPF route to 10.20.128.3 is displayed at Bock to confirm that the shortest path route from Bock to PBR's loopback does in fact egress on its fe-0/0/1.100 interface.

```
[edit]
lab@Bock# run show route 10.20.128.3

inet.0: 21 destinations, 22 routes (21 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.20.128.3/32     *[OSPF/10] 01:18:05, metric 4
                    > to 10.10.11.2 via fe-0/0/1.100
```

Configure the simulated receiver

The test bed used to develop this book did not have external multicast senders or receivers. Although unfortunate from an overall reality perspective, the upside is that their absence forces the use of JUNOS software to simulate their functionality, and these little-known techniques often prove useful when troubleshooting multicast issues because they allow you to isolate potential problems with attached hosts and their multicast applications/protocol stack.

A Word on Multicast Client Options

Multicast is a somewhat dry subject, and it is always nice to use some media content, such as a multiplayer game or cool streaming DVD video, to validate multicast operation and performance. If your test bed contains multicast-capable hosts, we suggest that you investigate programs such as VideoLAN, which supports streaming video over unicast or multicast, on a variety of platforms to include Windows and various flavors of Unix. For more information, see the VideoLAN development web site at *http://www.videolan.org*.

Unix platforms can use the *mgen/mrec utilities*, which respectively stand for multi-generator and dynamic-receiver. These utilities are available for download at *http://downloads.pf.itd.nrl.navy.mil/mgen/mgen3/*. The command line used to evoke drec to function as a receiver for group 225.1.1.1 in this scenario is similar to the example shown, but local interface names will vary:

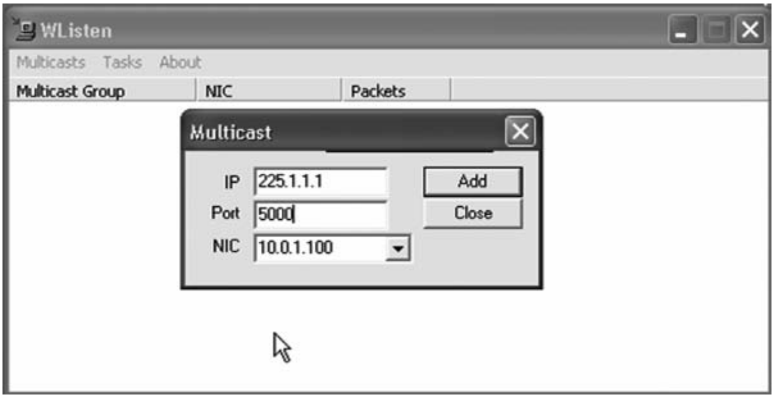
```
%./drec -b 225.1.1.1 -n 1 -p 5000 -i em1 -S NOW /dev/null
DREC: Version 3.1a3
DREC: Loading event queue ...
DREC: Listening for packets ...
      (Hit <CTRL-C> to stop)
```

As for the command-line switches, the -b value specifies the base group address to join, and the -n value determines how many groups, starting at the base, are to be joined. The -p value specifies a User Datagram Protocol (UDP) port (5000 is the default), and the -i switch indicates the local interface that should be joined. The -S value determines test start time; test duration can also be specified. Once drec is launched, you would expect to see a join for the associated group, and would then fire up mgen with compatible settings to generate multicast traffic to that group. The command example uses the -t switch to set the desired TTL and the -r switch to set a rate of 10 packets per second:

```
%./ mgen -b 225.0.0.1:5000 -n 1 -i em1 -p 5000 -t 32 -r 10

MGEN: Version 3.1a3
MGEN: Loading event queue ...
MGEN: Seeding random number generator ...
MGEN: Beginning packet generation ...
      (Hit <CTRL-C> to stop)
```

A number of multicast test utilities are available for Windows platforms, but generally speaking, these tend to be somewhat crude when compared to the myriad options supported on Unix systems. The WSend and WListen utilities are popular options, and an Internet search will likely reveal several download locations; there no longer appears to be an official source for these applications. Figure 10-14 shows how the WListen utility is configured to support the role of the multicast receiver for group 225.1.1.1 in this lab.



IP 225.1.1.1
Port 5000
NIC 10.0.1.100

Figure 10-14. Configuration of the Windows-based WListen utility

Static IGMP membership. The simplest way to simulate an attached multicast receiver in JUNOS software is to configure a static IGMP join. The problem with a simple static join is that the local router does not join the group, and as such it does not receive any test traffic, which means that without an actual external receiver on the associated interface, there can be no hope of replies to generated multicast test traffic. With no such external receiver in this lab, the only way to confirm multicast forwarding is to monitor interface traffic stats on the receiver interface while trying to correlate the received packet count to the generated multicast test traffic. In a quiescent lab setup, this may be workable, but in any type of production network, there will likely be enough background traffic to make accurate matching of transmitted traffic to received multicast packets all but impossible. The syntax for a static IGMP join is shown, but this approach is not used because a different technique is planned for simulating a multicast receiver at router Cider:

```
[edit]
lab@Cider# show protocols igmp
interface fe-0/0/0.0 {
    static {
        group 225.1.1.1;
    }
}
```

Before moving on, it's noted that the lack of multicast hosts means there will be no IGMP activity to monitor in the lab. With the static join in place, you can view IGMP group status to familiarize yourself with the display. Things begin with the clearing of any IGMP membership to ensure that no stale state is displayed:

```
[edit]
lab@Cider# run clear igmp membership
Clearing Group Membership Info for fe-0/0/1.100
Clearing Group Membership Info for fe-0/0/0.0

[edit]
lab@Cider# run show igmp group
Interface: fe-0/0/0.0
    Group: 225.1.1.1
        Source: 0.0.0.0
        Last reported by: Local
        Timeout:       0 Type: Static
Interface: local
    Group: 224.0.0.2
        Source: 0.0.0.0
        Last reported by: Local
        Timeout:       0 Type: Dynamic
    Group: 224.0.0.5
        Source: 0.0.0.0
        Last reported by: Local
        Timeout:       0 Type: Dynamic
    Group: 224.0.0.6
        Source: 0.0.0.0
        Last reported by: Local
        Timeout:       0 Type: Dynamic
    Group: 224.0.0.22
        Source: 0.0.0.0
        Last reported by: Local
        Timeout:       0 Type: Dynamic
```

As noted previously, multicast forwarding is all about dynamic state, and this state can seem to persist for an annoyingly long period of time if it's not cleared out manually. When testing any multicast environment, it is wise to let things cook for at least five minutes in all operational modes to ensure that things are really working the way you expect. Although bogus multicast state will generally not cause any negative impact to the router or network, it can affect communications for several minutes if left to age out using its own means.

The output of the `show igmp membership` command confirms the statically configured membership on interface `fe-0/0/0` for the 225.1.1.1 group. The lack of a specific source address shows that this is an (*,G), or shared tree join. When IGMPv3 is enabled, you can specify a source address when configuring static membership to generate (S,G) state and a resulting SPT. Dynamic entries are associated with a timeout value indicating when the entry will age out if it is not refreshed as a result of a host membership report for that group. The local entries represent multicast addresses associated with local processes that need to listen to multicast traffic. The 225.0.0.5 and 225.0.0.6 addresses represent all OSPF routers and all OSPF designated router groups, 225.0.0.1 is the all hosts group, 225.0.0.2 is the all routers group, and 225.0.0.22 is the multicast group associated with IGMP reports.

Create a listening multicast process

Many multicast applications operate in a simplex fashion, meaning that a reply is not technically needed for the application to work. However, in this lab the goal is to use Internet Control Message Protocol (ICMP) echo packets sent to a multicast group address, with success being determined by the receipt of a unicast reply, because this is the most expedient way to confirm that multicast test traffic is successfully forwarded all the way to the multicast receiver.

You can disable response generation to multicast-targeted pings by including the `no-multicast-echo` statement at the `[edit system]` hierarchy level, in JUNOS software releases 8.1 and later. This does not alter behavior for unicast-targeted pings.

The trick to making a Juniper router initiate a PIM join, while also creating a process that listens to the associated group in contrast to a static IGMP join, is to enable the SAP process on the group in question. SAP always operates on the well-known group address 224.2.127.254, using port 9875, but you can configure SAP to operate on other groups (and ports) as well. This is the approach we're taking for the test bed's 225.1.1.1 group.

> Active multicast sources transmit SDP messages infrequently, often on the order of minutes. This long delay between messages can cause problems in a PIM sparse mode network. The receipt of the SAP message by the RP causes it to examine its current join state for the 224.2.127.254 multicast group. If no state is enabled, the SAP message is not forwarded into the network. The end result is that the SDP message delay makes it extremely hard to get the SDP messages from the multicast source to the interested clients when operating in sparse mode. To reduce this delay, you can configure a SAP process on each router directly attached to receivers. This causes the router to generate a PIM join for the SAP group address of 224.2.127.254. The router refreshes this join state such that the RP maintains a constant forwarding tree for the SAP group. This allows the infrequent SDP messages to be forwarded to the interested clients and to populate the Session Directory tool. Frankly, it's hard to imagine something this good still being legal.

Before altering the configuration at `Cider`, a `show pim join` command is issued to confirm that no join state currently exists:

```
lab@Cider# run show pim join
Instance: PIM.master Family: INET

Instance: PIM.master Family: INET6
```

`Cider`'s configuration is altered to instantiate a SAP process that will listen on 225.1.1.1, port 5000:

```
lab@Cider# show sap
listen 225.1.1.1 port 5000;
```

After the change is committed, PIM join state is again displayed. This time the `extensive` switch is added to view all possible details:

```
[edit protocols]
lab@Cider# run show pim join extensive
Instance: PIM.master Family: INET

Group: 224.2.127.254
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/1.100
    Upstream neighbor: 10.10.11.2
    Upstream state: Join to RP
    Downstream neighbors:
        Interface: Local

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/1.100
    Upstream neighbor: 10.10.11.2
    Upstream state: Join to RP
    Downstream neighbors:
        Interface: Local
```

The output indicates that the newly created SAP process has issued an RPT (shared tree, or [*,G]) join for both the well-known and user-configured SAP groups. The upstream (incoming) interface is the RPF interface leading toward the domain's RP, and the downstream (outgoing) interface list is empty because this join is the result of a local process rather than a received PIM join or IGMP membership report. The presence of a listening UDP process on both SAP-associated ports is now verified. Here the command makes use of CLI matching and logical OR functionality to make quick work of the task:

```
[edit protocols]
lab@Cider# run show system connections | match "(5000|9875)"
udp4       0      0  *.5000                 *.*
udp4       0      0  *.9875                 *.*
```

The output confirms the two expected UDP-based listening processes on the well-known and user-specified SAP ports. The lack of data activity on the 225.1.1.1 group results in no cached forwarding state, as evidenced by the lack of a multicast route for the 225.1.1.1 group at transit node Porter:

```
[edit]
lab@Porter# run show multicast route
Family: INET

Family: INET6
```

Before generating traffic, the network's RPT join state is again analyzed. Recall that PIM joins are sent using RPF toward the source, and that for an (*,G) join, that source is the RP. Given the metric adjustments in effect in the multicast topology, the RPF path from Cider to PBR (the RP) should consist of the path Porter, Stout, PBR. The presumed forwarding path is first confirmed:

```
[edit protocols]
lab@Cider# run traceroute 10.20.128.3
traceroute to 10.20.128.3 (10.20.128.3), 30 hops max, 40 byte packets
 1  10.10.11.2 (10.10.11.2)  9.235 ms  8.720 ms  9.706 ms
 2  10.20.131.2 (10.20.131.2)  10.190 ms  9.147 ms  7.321 ms
 3  10.20.128.3 (10.20.128.3)  12.943 ms  38.945 ms  9.847 ms
```

The traceroute results show that the unicast forwarding path from Cider to PBR's loopback address is as anticipated—therefore, an RPT join initiated at Cider should take this same path. Shared tree join state is displayed at Porter:

```
[edit]
lab@Porter# run show pim join 225.1.1.1
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/1.1331
```

The RPT join state at Porter is as expected, in that the upstream interface is pointing toward Stout. The join state for 225.1.1.1 is displayed at Stout:

```
[edit]
lab@stout# run show pim join 225.1.1.1
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/0.3141
```

As expected, RPF forwarding of the shared tree join at Stout results in an upstream interface of fe-0/0/0.3141, which is the metrically closest way for Stout to reach PBR's 10.20.128.3 address.

The current state of the network correctly represents PIM sparse mode state for a receiver interested in a group with no active senders. In the next section, we will generate multicast traffic and examine the impact on network state.

Generate multicast traffic

With the receiver join state and resulting PIM sparse mode RP-rooted shared tree verified, it is time to shake things up by actually generating some multicast traffic! In this example, a Juniper router is used to simulate a multicast source with the ping command, in conjunction with the bypass-routing, ttl, and interface switches. The bypass-routing switch is needed to avoid the fact that the inet.1 table does not have multicast forwarding state for the 225.0.0.1 group; remember, Ale is a router, not a host. Because there is no routing entry to rely on, you must identify the egress interface for the test traffic using the interface switch. By default, locally generated multicast ping traffic uses a TTL of 1, which is done to limit the scope of the traffic to the local link. This is because in a real-world scenario, *numerous* receivers could be listening to the related group, and this in turn can result in significant packet replication and a resulting avalanche of replies. The test bed has only one receiver for the test traffic, making this a nonissue. A TTL value of at least 5 is recommended to ensure that the test traffic can make it all the way from Ale to Cider.

> A TTL value of 4 results in the test traffic being handed to Cider with a TTL of 1. Although adequate for unicast, in some cases multicast TTL may be decremented upon receipt, which can lead to intermittent replies for packets received with a TTL = 1. By setting the TTL higher than strictly necessary, you guarantee that you will not encounter this issue.

We have spent a lot of effort leading to this point, and several things are about to happen in rapid succession once the sender is fired up; specifically:

- The first hop router, `Lager`, encapsulates the native multicast into a unicast packet sent to 10.20.128.3, the domain's RP.
- The RP decapsulates the traffic based on join state for the associated group, and then sends the native multicast down the shared tree. Given the current join state, the traffic should be sent from the RP to `Stout` and `Porter`, and then to receiver `Cider`.
- The presence of multicast traffic results in the creation of a multicast route in transit routers. This route is placed into the `inet.1` table, and you can think of it as a data-driven forwarding plane reaction to the control plane's join state. Note that without the control plane join, the data plane cannot establish these dynamic multicast forwarding states.
- Upon receipt of traffic from source 10.10.111.1 over the shared tree, router `Cider` initiates an SPT join toward the source. Once the SPT is established, multicast from 10.10.111.1 is transported directly over the SPT. To prevent duplicated packets, the first router in the data path that is on *both* the SPT and RPT (`Stout` in this case) sends an (S,G) prune toward the RP to prevent receipt of packets over both the SPT and the RPT.
- When there are no interested receivers on the RPT, the RP sends a register stop message to the source.
- Once the source is no longer active, the SPT state will eventually age out, resulting in a return to the RPT for group 225.1.1.1.

To help catch some of this behavior, PIM register message tracing is added to `Lager`:

```
[edit protocols pim]
lab@Lager# show traceoptions
file pim;
flag register detail;
```

Multicast pings are now initiated at `Lager`:

```
[edit]
lab@Ale# run ping ttl 5 225.1.1.1 interface fe-0/0/0.111 bypass-routing
PING 225.1.1.1 (225.1.1.1): 56 data bytes
64 bytes from 10.10.11.3: icmp_seq=0 ttl=61 time=16.776 ms
64 bytes from 10.10.11.3: icmp_seq=1 ttl=61 time=20.144 ms
. . .
```

The output confirms that responses are being received from 10.10.11.3, the address of `Cider`'s `fe-0/0/1.100` interface. The presence of replies is a most auspicious beginning, to be sure. Meanwhile, back at `Lager`, the following trace output is observed:

```
Sep 27 00:55:10.983201 PIM SENT 10.10.128.2 -> 10.20.128.3 V2 Register Flags:
0x40000000 Border: 0 Null: 1 Source 10.10.111.1 Group 225.1.1.1 sum 0x43f1 len 28
Sep 27 00:55:10.993582 PIM fe-0/0/0.2131 RECV 10.20.128.3 -> 10.10.128.2 V2
RegisterStop Source 10.10.111.1 Group 225.1.1.1 sum 0x80d1 len 18
```

The trace confirms that, as predicted, the first hop router sent a register message to the RP for source 10.10.111.1 and group 225.1.1.1, and the RP later generated a register stop for this (S,G) pair, thus indicating that no more listeners are present on the shared tree. This is a good indication that the SPT cutover was successful. Next, the resulting (S,G) join state is examined at `Cider`:

```
[edit protocols]
lab@Cider# run show pim join 225.1.1.1 extensive
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/1.100
    Upstream neighbor: 10.10.11.2
    Upstream state: Join to RP
    Downstream neighbors:
        Interface: Local

Group: 225.1.1.1
    Source: 10.10.111.1
    Flags: sparse,spt
    Upstream interface: fe-0/0/1.100
    Upstream neighbor: 10.10.11.2
    Upstream state: Join to Source
    Keepalive timeout: 355
    Downstream neighbors:
        Interface: Local
```

`Cider`'s display confirms that SPT join state is now also present for the 225.1.1.1 group. `Cider` remains on the RPT via its (*,G) join in case any other sender becomes active for the 225.1.1.1 group—this is an ASM example, after all. The join state at `Stout` also shows an SPT and RPT, but the RPT has been pruned for this (S,G) pair, given the presence of an SPT between the sender and receiver:

```
[edit]
lab@stout# run show pim join 225.1.1.1 extensive
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/0.3141
    Upstream neighbor: 10.20.129.2
    Upstream state: Join to RP
    Downstream neighbors:
        Interface: fe-0/0/1.1331
            10.20.131.1 State: Join Flags: SRW Timeout: 179

Group: 225.1.1.1
    Source: 10.10.111.1
```

```
        Flags: sparse,spt
        Upstream interface: fe-0/0/0.2131
        Upstream neighbor: 10.10.131.1
        Upstream state: Join to Source, Prune to RP
        Keepalive timeout: 303
        Downstream neighbors:
            Interface: fe-0/0/1.1331
                10.20.131.1 State: Join Flags: S Timeout: 179
```

The join state at Stout is as expected. It too remains on the shared tree for group 225.1.1.1, in case any additional sources become active, and it too has generated an SPT join directly toward the source, as a result of receiving an (S,G) join on its downstream interface, as sent by Porter. The highlights call out the topology difference between the shared and source trees, with the shared tree at Stout pointing toward the RP while the source tree points toward the source. Stout has pruned source 10.10.111.1 from the shared tree, a state that is reflected at the RP:

```
    [edit]
    lab@PBR# run show pim join 225.1.1.1 extensive
    Instance: PIM.master Family: INET

    Group: 225.1.1.1
        Source: *
        RP: 10.20.128.3
        Flags: sparse,rptree,wildcard
        Upstream interface: Local
        Upstream neighbor: Local
        Upstream state: Local RP
        Downstream neighbors:
            Interface: fe-0/0/0.3141
                10.20.129.1 State: Join Flags: SRW Timeout: 156

    Group: 225.1.1.1
        Source: 10.10.111.1
        Flags: sparse,spt
        Upstream interface: fe-0/0/0.111
        Upstream neighbor: Direct
        Upstream state: Local Source, Local RP
        Keepalive timeout: 337
        Downstream neighbors:
            Interface: fe-0/0/0.3141 (pruned)
                10.20.129.1 State: Prune Flags: SR Timeout: 156
```

With the PIM sparse mode control plane looking good, you examine the data plane state as it relates to the (S,G) flow currently active in the network:

```
    [edit]
    lab@stout# run show multicast route detail
    Family: INET

    Group: 225.1.1.1
        Source: 10.10.111.1/32
        Upstream interface: fe-0/0/0.2131
        Downstream interface list:
            fe-0/0/1.1331
        Session description: MALLOC
        Statistics: 0 kBps, 1 pps, 1966 packets
        Next-hop ID: 348
        Upstream protocol: PIM
```

The highlights call out the expected upstream and downstream (incoming/outgoing) interfaces. Including the `detail` switch displays current traffic stats for each forwarding cache entry. When a well-known group address is detected, the session description reflects the associated application. In this case, no application is associated with 225.0.0.1, so the display simply indicates that the session belongs to the multicast allocation address space (MALLOC). The next hop ID field is used to tie this route into a forwarding table entry in the Packet Forwarding Engine (PFE). You can display the multicast forwarding table to confirm that this next hop ID is associated with the 10.10.111.1, 225.1.1.1 tuple:

```
[edit]
lab@stout# run show route forwarding-table multicast destination
225.1.1.1
Routing table: inet
Internet:
Destination        Type RtRef Next hop        Type Index NhRef Netif
225.1.1.1.10.10.111.1/64
                   user     0                  mcrt   348     1
```

To actually display what the forwarding table does with the next hop index of 348, you have to access the PFE directly. The following commands are performed for illustrative purposes, and they use unsupported shell commands. Remember: you should use hidden and shell commands only under direct guidance of JTAC.

```
[edit]
lab@stout# run start shell
% su
Password:
root@stout% vty 1

BSD platform (Pentium processor, 84MB memory, 8192KB flash)
```

A shell is started and the user becomes root, because only the root user has access to the `vty` command used to attach to the forwarding devices daemon (fwdd) process. You connect to the software-based PFE, which on a J-series router is called fwdd, by connecting to `tnp` address 1. Once connected to the PFE, information is displayed for the next hop value of 348:

```
FWDD(stout vty)# show nhdb id 348
Nexthop Info:
  ID    Type     Interface    Next Hop Addr Protocol   Encap     MTU
---- ------- ------------  -------------- -------- ---------  ----
 348 MultiRT -              -                  IPv4         -     0
               fe-0/0/1.1331                   IPv4  Ethernet
```

The PFE output confirms that currently, a single outgoing interface is associated with next hop ID 348. A multicast route entry can have numerous next hop interfaces when the topology requires such replication. You now exit out of the vty connection and the shell to return to the CLI:

```
FWDD(stout vty)# exit

root@stout% exit
% exit

[edit]
lab@stout#
```

Multicast routes in a forwarding state are placed into the inet.1 route table. Unlike a learned route, information in inet.1 is a cache entry that is driven by the actual flow of traffic—the entry ages out a short while after traffic cessation.

```
[edit]
lab@stout# run show route table inet.1 detail

inet.1: 1 destinations, 1 routes (1 active, 0 holddown, 0 hidden)
225.1.1.1.10.10.111.1/64 (1 entry, 1 announced)
        *PIM    Preference: 105
                Next hop type: Multicast (IPv4)
                Next-hop reference count: 2
                State: <Active Int>
                Age: 39:25
                Task: PIM.master
                Announcement bits (1): 0-KRT
                AS path: I
```

The show multicast usage command is also handy when you want to determine the number and relative activity level of the various sources in your network:

```
[edit]
lab@stout# run show multicast usage
Group           Sources Packets             Bytes
225.1.1.1       1       2516                211344


Prefix          /len Groups Packets             Bytes
10.10.111.1     /32  1      2516                211344
```

Note that multicast usage information is displayed both by group and by (S,G) pairing. Multicast traffic generation is stopped at Ale:

```
64 bytes from 10.10.11.3: icmp_seq=7227 ttl=61 time=10.564 ms
^C
--- 225.1.1.1 ping statistics ---
7228 packets transmitted, 7228 packets received, 0% packet loss
round-trip min/avg/max/stddev = 8.079/21.507/201.323/10.705 ms
```

The lack of data plane activity results in aging out of the forwarding state. Because the receiver is still interested in group 225.1.1.1, the control plane join state is refreshed and remains:

```
[edit]
lab@stout# run show multicast route extensive source-prefix 10.10.111.1
Family: INET
Group: 225.1.1.1
    Source: 10.10.111.1/32
    Upstream interface: fe-0/0/0.2131
    Downstream interface list:
        fe-0/0/1.1331
    Session description: MALLOC
    Statistics: 0 kBps, 0 pps, 7306 packets
    Next-hop ID: 348
    Upstream protocol: PIM
    Route state: Active
    Forwarding state: Forwarding
    Cache lifetime/timeout: 171 seconds
    Wrong incoming interface notifications: 1

[edit]
lab@stout# run show pim join extensive 225.1.1.1
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/0.3141
    Upstream neighbor: 10.20.129.2
    Upstream state: Join to RP
    Downstream neighbors:
        Interface: fe-0/0/1.1331
            10.20.131.1 State: Join Flags: SRW Timeout: 178

Group: 225.1.1.1
    Source: 10.10.111.1
    Flags: sparse,spt
    Upstream interface: fe-0/0/0.2131
    Upstream neighbor: 10.10.131.1
    Upstream state: Join to Source, Prune to RP
    Keepalive timeout: 169
    Downstream neighbors:
        Interface: fe-0/0/1.1331
            10.20.131.1 State: Join Flags: S Timeout: 178
```

After a few minutes, the (S,G) forwarding state is flushed from the network:

```
[edit]
lab@stout# run show multicast route extensive source-prefix
10.10.111.1
Family: INET
```

This result confirms expected PIM sparse mode control and data plane state and delivery of the multicast test traffic to the receiver by the returned echo replies. These results complete the PIM sparse mode with static RP configuration scenario.

PIM Sparse Mode with Static RP Summary

This section demonstrated the configuration and operational verification of a PIM-based IP multicast network that used a statically defined RP. In the next section, we will build on this experience by adding dynamic RP electing using the bootstrap protocol.

Configure PIM Sparse Mode with Bootstrap RP

In this section, we will convert the existing multicast topology from a statically defined RP to a bootstrap learned RP. As part of this conversion, the network is being redesigned to add a second RP for redundancy. The configuration objectives are as follows:

- Remove the static RP definition from all routers.
- Configure `Stout` as a second RP for the 224/4 group range.
- Use bootstrap-based RP election, and make sure that `PBR` is the BSR when operational.
- Ensure that there is no single point of RP/BSR failure in the network.

The new redundancy requirements make it clear that the network will need two RPs and two candidate BSRs. Further, the bootstrap priority will need to be higher (more preferred) at `PBR` to ensure that it is the BSR when operational. Figure 10-15 shows the updated topology.

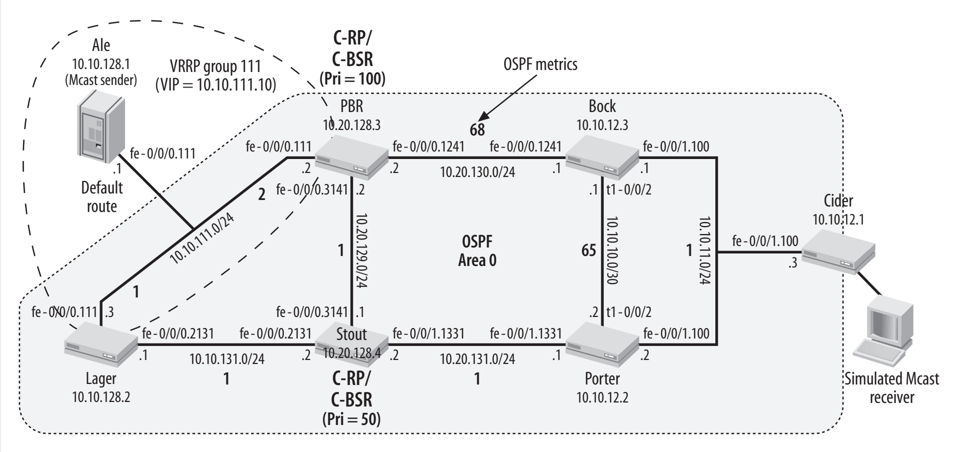


Figure 10-15. Bootstrap RP election

The figure shows that both PBR and Stout are configured to function as candidate RPs and candidate BSRs (C-RP and C-BSR). Although not technically necessary, currently it is a best practice to make the C-RP and C-BSR functionality collocated, given that the loss of either function kills PIM sparse mode operation and negates any benefits associated with distributing C-BSR and C-RP functionality among different nodes. The higher BSR priority setting at PBR results in its election as the domain's BSR when operational; otherwise, Stout steps in to take over.

When both RPs are operational, the BSR advertises a candidate RP set that lists *both* of the domain's RPs. Each PIM router hashes against this set to choose which of the two RPs to use for a specific group range. The hashing function ensures that all routers choose the same candidate RP for the same groups, and that a consecutive set of four groups always map to the same RP. The latter functionality is designed to accommodate applications that use consecutive groups for various elements that make up a single session—for example, an audio channel and the corresponding video stream—by helping to ensure similar latency among the session's component streams.

The static RP definition is removed from routers Lager, Stout, Bock, Porter, and Cider (not shown), and attention is focused on the need to configure candidate BSR functionality at PBR. The configuration is rather straightforward—all that is required is a single statement to enable BSR and assign a priority:

```
[edit protocols pim]
lab@PBR# show
rp {
    bootstrap-priority 100;
    local {
        address 10.20.128.3;
    }
}
interface fe-0/0/0.3141;
interface fe-0/0/0.1241;
interface fe-0/0/0.111;
```

The priority setting of 100 makes PBR a candidate BSR—note that a value of 0 does not disable BSR functionality, but such a setting does make it less likely that candidate PBR will become the BSR. Once a lower priority is set in the soon-to-be-configured Stout, you ensure that PBR is the domain's BSR when operational. In this example, the bootstrap statement is configured directly at the [edit protocols pim rp] hierarchy. The same set of options is available on a per-family basis using the family keyword:

```
[edit protocols pim]
lab@PBR# set rp bootstrap family inet ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
+ export               Bootstrap export policy
+ import              Bootstrap import policy
  priority            Eligibility to be the bootstrap router (0..255)
```

The import and export keywords link to one or more policy statements that filter bootstrap messages from being received or transmitted, respectively. Normally, you use such policy at the edges of a PIM domain to prevent routers in a remote domain from using the domain's local BSR, and vice versa.

After committing the change, BSR election begins and PBR starts a countdown timer intended to reduce thrashing by allowing time for any C-BSR messages to propagate through the domain before a decision is made as to which C-BSR should win to become the BSR. Use the show pim bootstrap command to display information about the domain's candidate BSRs:

```
[edit protocols pim]
lab@PBR# commit
commit complete

[edit protocols pim]
lab@PBR# run show pim bootstrap
Instance: PIM.master

BSR            Pri Local address           Pri State      Timeout
None             0 10.20.128.3             100 Candidate       54
None             0 (null)                    0 InEligible       0
```

PBR is the only router now configured to be a C-BSR, and therefore it easily wins the election to become the domain's BSR:

```
[edit protocols pim]
lab@PBR# run show pim bootstrap
Instance: PIM.master

BSR              Pri Local address           Pri State      Timeout
10.20.128.3      100 10.20.128.3             100 Elected         37
None               0 (null)                    0 InEligible       0
```

In the display, each router shows a null entry, as well as an entry for its loopback address and local C-BSR priority. C-BSR information that is learned is displayed on the lefthand side. The output from PBR makes it clear that the local router is also the BSR, and that it has a priority of 100.

For proper BSR operation, a candidate BSR must have a routable address assigned to its lo0 interface. This is true even when a different address, perhaps one assigned to a physical interface, is configured as the BSR address. This requirement stems from an implementation decision that forces C-BSR messages to be sourced from the local router's lo0 address—C-BSR messages cannot be sent if no lo0 address is configured or if the only address configured is a 127.*x*.*x*.*x* loopback. You can commit such a configuration, and the result is not particularly easy to troubleshoot given that the symptom is simply a lack of generated C-BSR messages.

A few moments later, proper bootstrap operation is confirmed when all other routers have chosen the same C-BSR, as shown for Cider:

```
[edit]
lab@Cider# run show pim bootstrap
Instance: PIM.master

BSR              Pri Local address           Pri State      Timeout
10.20.128.3      100 10.10.12.1                0 InEligible     112
None               0 (null)                    0 InEligible       0
```

The show pim bootstrap display at Cider confirms that it has received the C-BSR message that originated at PBR and was propagated via hop-by-hop multicast to all BSR-enabled routers. The presence of a single C-BSR with priority 100 is confirmed, as is election of PBR as the BSR:

```
[edit]
lab@Cider# run show pim rps
Instance: PIM.master
Address family INET
RP address       Type        Holdtime Timeout Groups Group prefixes
10.20.128.3      bootstrap        150     125      2 224.0.0.0/4

Address family INET6
```

The show pim rps display further confirms that an RP has been learned for the 224/4 range via the bootstrap protocol. With things working properly at the first C-BSR/C-RP, it's time to bring up the domain's backup C-BSR/C-RP. The configuration of Stout is modified and displayed:

```
[edit protocols pim]
lab@stout# show | compare
[edit protocols pim rp]
+  bootstrap-priority 50;
+  local {
+      address 10.20.128.4;
+  }
-  static {
-      address 10.20.128.3;
-  }
```

After waiting a minute or two for things to settle down, verification starts at Stout. The expectation is that Stout confirms PBR as the elected BSR while also listing itself as a viable contender:

```
BSR              Pri Local address           Pri State      Timeout
10.20.128.3      100 10.20.128.4              50 Candidate      123
None               0 (null)                    0 InEligible       0
```

The output confirms those expectations and shows that BSR is operating as desired between the domain's two candidate BSRs. RP set information is displayed next:

```
[edit protocols pim]
lab@stout# run show pim rps
Instance: PIM.master
```

```
Address family INET
RP address       Type        Holdtime Timeout Groups Group prefixes
10.20.128.3      bootstrap        150     137      1 224.0.0.0/4
10.20.128.4      bootstrap        150     137      1 224.0.0.0/4
10.20.128.4      static             0    None      1 224.0.0.0/4
```

The show pim rps command output lists both of the domain's RPs as having been learned via bootstrap; the local RP definition at Stout is also listed as learned statically. Back at the last hop router, Cider, the state of RPs is also as expected:

```
edit]
lab@Cider# run show pim rps
Instance: PIM.master
Address family INET
RP address       Type        Holdtime Timeout Groups Group prefixes
10.20.128.3      bootstrap        150     101      1 224.0.0.0/4
10.20.128.4      bootstrap        150     101      1 224.0.0.0/4
```

Awesome! And some folks think this multicast stuff is hard to understand. PIM join state is displayed at Cider. The display illustrates the bootstrap RP hashing function, in that the two joins associated with the listening SAP process hashed to a different RP:

```
[edit]
lab@Cider# run show pim join
Instance: PIM.master Family: INET

Group: 224.2.127.254
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/1.100

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.4
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/1.100
```

Once again, connectivity is verified at the sender:

```
[edit]
lab@Ale# run ping ttl 5 225.1.1.1 interface fe-0/0/0.111 bypass-routing
PING 225.1.1.1 (225.1.1.1): 56 data bytes
64 bytes from 10.10.11.3: icmp_seq=0 ttl=61 time=87.388 ms
. . .
```

So is the data-driven switch to an SPT at the last hop router:

```
[edit]
lab@Cider# run show pim join 225.1.1.1 detail
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.4
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/1.100

Group: 225.1.1.1
    Source: 10.10.111.1
    Flags: sparse,spt
    Upstream interface: fe-0/0/1.100
```

Before calling it quits, redundancy is verified by deactivating the RP and BSR functionality at PBR. The confirmed option is added to the commit to evoke automatic restoration of the previous (and currently active) configuration to save some keystrokes:

```
[edit protocols pim]
lab@PBR# deactivate rp

[edit protocols pim]
lab@PBR# show
inactive: rp {
    bootstrap-priority 100;
    local {
        address 10.20.128.3;
    }
}
interface fe-0/0/0.3141;
interface fe-0/0/0.1241;
interface fe-0/0/0.111;

[edit protocols pim]
lab@PBR# commit confirmed 3
commit confirmed will be automatically rolled back in 3 minutes
  unless confirmed
commit complete

# commit confirmed will be rolled back in 3 minutes
[edit protocols pim]
```

Failover behavior is confirmed back at Cider:

```
[edit]
lab@Cider# run show pim bootstrap
Instance: PIM.master

BSR              Pri Local address           Pri State      Timeout
10.20.128.4      50  10.10.12.1                0 InEligible     103
None               0 (null)                    0 InEligible       0
```

The display confirms the removal of PBR as a candidate RP and the election of the remaining C-BSR (Stout), which is now the best choice. The join state takes a little while to catch up, but after a short while all joins are pointing to the remaining RP:

```
 [edit]
lab@Cider# run show pim join
Instance: PIM.master Family: INET

Group: 224.2.127.254
    Source: *
    RP: 10.20.128.4
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/1.100

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.4
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/1.100

Group: 225.1.1.1
    Source: 10.10.111.1
    Flags: sparse,spt
    Upstream interface: fe-0/0/1.100
```

Once the automatic rollback occurs at PBR, things return to the expected state, which completes verification of the PIM sparse mode with bootstrap protocol scenario:

```
[edit]
lab@Cider# run show pim bootstrap
Instance: PIM.master

BSR               Pri Local address           Pri State      Timeout
10.20.128.3       100 10.10.12.1                0 InEligible      88
None                0 (null)                    0 InEligible       0
```

Troubleshoot a Bootstrap Problem

The Beer-Co topology has been altered to interface to another routing domain, as shown in Figure 10-16.

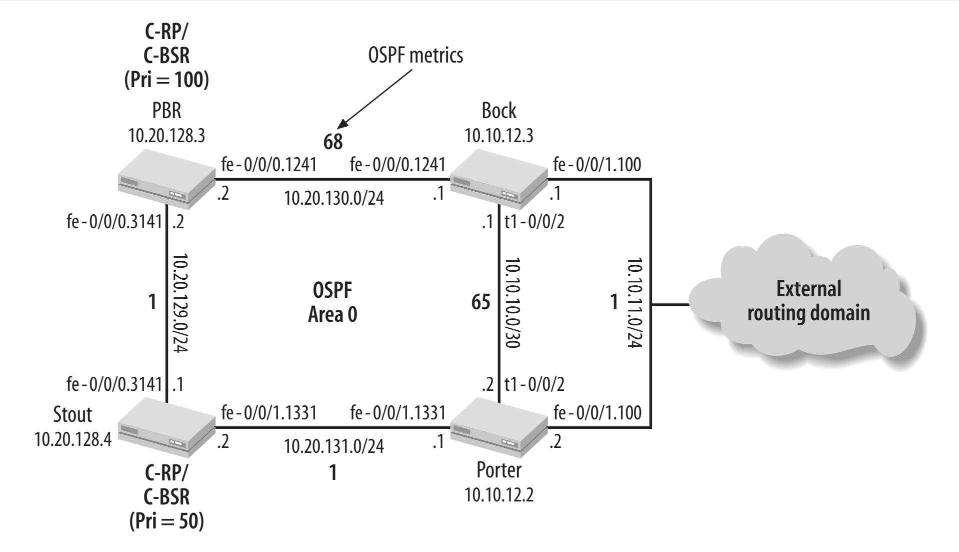


Figure 10-16. PIM BSR troubleshooting topology

Figure 10-16 details how PIMv1 has been configured on the now *external* interfaces at `Bock` and `Porter` to prevent the leaking of bootstrap protocol messages to and from the other routing domain. Recall that PIMv1 does not support bootstrap, making this a common approach to scoping BSR messages. The problem is that `Bock` does not display any learned BSRs, and therefore there is no bootstrap learned RP at `Bock`:

```
[edit]
lab@Bock# show protocols pim
interface fe-0/0/0.1241;
interface fe-0/0/1.100 {
    version 1;
}
interface t1-0/0/2.0;

[edit]
lab@Bock# run show pim bootstrap
Instance: PIM.master

BSR                  Pri Local address      Pri State      Timeout
None                   0 10.10.12.3           0 InEligible       0
None                   0 (null)               0 InEligible       0
[edit]
lab@Bock# run show pim rps
Instance: PIM.master
```

All other routers display the expected BSR and RP set information. `Bock` was working properly prior to the shift to PIMv1, and connectivity over all of its interfaces has been verified with successful pings to direct neighbors.

Lacking any better suggestions, PIM bootstrap tracing is added to the configuration, and after a short while trace output is observed:

```
[edit protocols pim]
lab@Bock# show traceoptions
file pim;
flag bootstrap detail;

[edit protocols pim]
lab@Bock# run monitor start pim

*** pim ***
Sep 28 02:27:19.848100 PIM fe-0/0/0.1241 RECV 10.20.130.2 ->
224.0.0.13 V2 Bootstrap sum 0x6ab2 len 46
Sep 28 02:27:19.848182    tag 52078 masklen 30 priority 100 bootstrap
router 10.20.128.3
Sep 28 02:27:19.848208       group 224.0.0.0 count 2 fragcount 2
Sep 28 02:27:19.848230          rp address 10.20.128.3 holdtime 150
priority 1
Sep 28 02:27:19.848247          rp address 10.20.128.4 holdtime 150
priority 1
Sep 28 02:27:19.857917 PIM t1-0/0/2.0 RECV 10.10.10.2 -> 224.0.0.13
V2 Bootstrap sum 0x0cba len 46
Sep 28 02:27:19.858018    tag 10599 masklen 30 priority 100 bootstrap
router 10.20.128.3
```

```
Sep 28 02:27:19.858042       group 224.0.0.0 count 2 fragcount 2
Sep 28 02:27:19.858060          rp address 10.20.128.3 holdtime 150
priority 1
Sep 28 02:27:19.858073          rp address 10.20.128.4 holdtime 150
priority 1
```

The trace output is at once good and bad; good because it shows that valid bootstrap messages are being received on both of Bock's PIMv2-enabled interfaces, and bad because no obvious error or reason is displayed as to why the messages do not result in election of a BSR at Bock. Given that things worked until the shift to PIMv1 on fe-0/0/1.100, you decide to temporarily deactivate the fe-0/0/1 interface:

```
[edit]
lab@Bock# deactivate interfaces fe-0/0/1

[edit]
lab@Bock# commit
commit complete

[edit]
lab@Bock# run show pim bootstrap
Instance: PIM.master

BSR                 Pri Local address       Pri State      Timeout
10.20.128.3         100 10.10.12.3            0 InEligible     100
None                  0 (null)                0 InEligible       0
```

Quite interesting; the output confirms proper BSR election as long as the PIMv1 interface is deactivated—which makes little sense given that PIMv1 does not even support the BSR protocol! The change is rolled back to reactivate the fe-0/0/1.100 interface.

Strange; very strange indeed—recalling that RPF checks are critical to multicast operation, you display the RPF route to 10.20.128.3 from Bock:

```
[edit]
lab@Bock# run show multicast rpf 10.20.128.3
Multicast RPF table: inet.0 , 21 entries

10.20.128.3/32
    Protocol: OSPF
    Interface: fe-0/0/1.100
    Neighbor: 10.10.11.2
```

The display shows that Bock considers 10.10.11.2 as the RFP neighbor for the 10.20.128.3 route, which is reachable over the 10.10.11.0/24 subnet. Interestingly, this is also the interface that was set to PIMv1, and this explains the problem: PIM control messages generally have to be received on the RPF interface to their source; otherwise, they are ignored. For the specific behavior discussed here, Section 3.6.3 of RFC 2362 states:

> When a router receives a Bootstrap message sent to 'ALL-PIM-ROUTERS' group, it performs the following:
>
> 1 If the message was not sent by the RPF neighbor towards the BSR address, the message is dropped.

The problem now becomes clear—given the OSPF metrics in effect, Bock expects to receive BSR messages on its fe-0.0/1/100 interface and is dropping BSR messages received on those interfaces that are not on the RPF path back to the BSR. Several solutions present themselves:

- Alter IGP metrics so that Bock no longer sees its fe-0/0/1.100 interface as the RPF interface back to the BSR—that is, either increase the 10.10.11.0 subnet metric or reduce the 10.20.130.0 or 10.10.10.0 subnet metric.
- Reconfigure the network to move BSR functionality to a node whose RPF check does not point to Bock's fe-0/0/1.100 interface. This option is not really viable in the sample topology unless a new router is added.
- Add a new link, or add PIM to a previously nonmulticast-enabled link, in order to affect a new RPF topology, again with the intent of removing fe-0/0/1.100 from the RPF check back to PBR.

Policy-based filtering of bootstrap messages is not considered here because in this scenario, it relies on the administration of the remote autonomous system (AS) to apply import policy to filter bootstrap messages exchanged over the shared LAN between Bock and Porter; egress filtering at Bock and Porter does not work because this filters all bootstrap messages from the LAN—currently Bock needs to receive the bootstrap messages from Porter over the shared LAN.

Extra points for creativity?

The solution demonstrated here is based on the "add another link" option discussed earlier, except the new link is instantiated as a Generic Routing Encapsulation (GRE) tunnel, meaning no new equipment or facilities are needed! No routing protocol operates over the tunnel—Bock uses two /32 static routes to direct traffic destined to the lo0 address of PBR and Stout over the GRE tunnel. This ensures that the only traffic subjected to the tunnel is that associated with the loopback addresses of PBR and Stout. All other traffic continues to follow the IGP's shortest path, thereby causing minimal impact to existing traffic patterns. If all this were not enough, the tunnel is instantiated between the loopback address of Bock and PBR and is routed between these addresses according to the IGP's shortest path. This means the GRE tunnel and associated static routing are not affected by the failures of individual links or interfaces, and that no policy/static routes are needed to advertise reachability to the tunnel endpoints given that the lo0s of Bock and Porter are already carried in OSPF. Because the static routes are preferred over any OSPF learned route (due to preference), the problems of receiving BSR messages on the wrong RPF interface are forever eliminated once PIM is enabled over the GRE tunnel.

The changes to Bock's configuration are shown. The changes at Porter are limited to GRE interface definition and enabling PIM on the resulting GRE interface. No static routes are needed at Porter because the 10.20.128.3 and 10.20.128.4 OSPF routes at Porter already lie on the RPF path back to PBR and Stout, respectively.

```
[edit]
lab@Bock# show interfaces gr-0/0/0
unit 0 {
    tunnel {
        source 10.10.12.3;
        destination 10.10.12.2;
    }
    family inet;
}

[edit]
lab@Bock# show routing-options
static {
    route 10.20.128.3/32 next-hop gr-0/0/0.0;
    route 10.20.128.4/32 next-hop gr-0/0/0.0;
}

[edit]
lab@Bock# show protocols pim
traceoptions {
    file pim;
    flag bootstrap detail;
}
interface fe-0/0/0.1241;
interface fe-0/0/1.100 {
    version 1;
}
interface t1-0/0/2.0;
interface gr-0/0/0.0;
```

Note that an unnumbered GRE tunnel is defined, which eliminates the need to advertise reachability to the tunnel endpoints; local tunnel traffic is based on the lo0 addresses of Bock and Porter, which are already advertised by OSPF. Verification begins by examining Bock's route to the lo0 addresses of PBR and Stout:

```
[edit]
lab@Bock# run show route 10.20.128/29

inet.0: 21 destinations, 24 routes (21 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.20.128.3/32     *[Static/5] 00:04:39
                    > via gr-0/0/0.0
                    [OSPF/10] 00:16:27, metric 3
                    > to 10.10.11.2 via fe-0/0/1.100
10.20.128.4/32     *[Static/5] 00:04:39
                    > via gr-0/0/0.0
                    [OSPF/10] 00:16:27, metric 2
                    > to 10.10.11.2 via fe-0/0/1.100
[edit]
lab@Bock# run show multicast rpf 10.20.128/29
```

```
Multicast RPF table: inet.0 , 21 entries

10.20.128.3/32
    Protocol: Static
    Interface: gr-0/0/0.0
    Neighbor: (null)

10.20.128.4/32
    Protocol: Static
    Interface: gr-0/0/0.0
    Neighbor: (null)
```

The command output confirms the presence of active static routes at Bock and that the RPF interface to these lo0 addresses now points to the GRE tunnel. Note that there is no RPF neighbor (listed as null) because the tunnel is unnumbered in this example.

PIMv2 is confirmed operational on the new GRE interface, and a PIM neighbor has been detected:

```
[edit]
lab@Bock# run show pim interfaces
Instance: PIM.master

Name                   Stat Mode       IP V State Count DR address
fe-0/0/0.1241          Up   Sparse      4 2 NotDR     1 10.20.130.2
fe-0/0/1.100           Up   Sparse      4 1 NotDR     2 10.10.11.3
gr-0/0/0.0             Up   Sparse      4 2 P2P       1
pe-0/0/0.32769         Up   Sparse      4 2 P2P       0
pe-0/0/0.32770         Up   Sparse      4 2 P2P       0
t1-0/0/2.0             Up   Sparse      4 2 P2P       1
```

The RPF issue with received bootstrap messages is resolved, thus allowing Bock to learn the domain's C-BSRs. With knowledge of the domain's BSR, Bock goes on to learn the domains RPs:

```
[edit]
lab@Bock# run show pim bootstrap
Instance: PIM.master

BSR             Pri Local address           Pri State      Timeout
10.20.128.3     100 10.10.12.3                0 InEligible     125
None              0 (null)                    0 InEligible       0

[edit]
lab@Bock# run show pim rps
Instance: PIM.master
Address family INET
RP address        Type        Holdtime Timeout Groups Group prefixes
10.20.128.3       bootstrap        150     139      1 224.0.0.0/4
10.20.128.4       bootstrap        150     139      1 224.0.0.0/4
```

IGP connectivity is confirmed from Bock to the loopback address of PBR:

```
 [edit]
lab@Bock# run traceroute 10.20.128.3
traceroute to 10.20.128.3 (10.20.128.3), 30 hops max, 40 byte packets
 1  10.10.12.2 (10.10.12.2)  105.258 ms  71.311 ms  11.741 ms
 2  10.20.131.2 (10.20.131.2)  9.808 ms  9.401 ms  9.677 ms
 3  10.20.128.3 (10.20.128.3)  10.100 ms  29.484 ms  9.734 ms
```

And the use of PIMv1 on the 10.10.11/24 subnet prevents learning of the BSR at router Cider. This completes the PIM bootstrap troubleshooting exercise.

```
lab@Cider# run show pim bootstrap
Instance: PIM.master

BSR             Pri Local address          Pri State      Timeout
None              0 10.10.12.1               0 InEligible      26
None              0 (null)                   0 InEligible       0
```

PIM Sparse Mode with Bootstrap RP Summary

In this section, you configured the bootstrap protocol to dynamically communicate RP to group mappings. The bootstrap protocol allows all routers to select the same RP for a given group, thereby spreading the multicast load among the set of RPs, with the hashing function determining which groups are handled by which RP. This section also showed how RPF checks can cause control plane messages to be ignored, and it provided a creative solution using a GRE tunnel that required no additional hardware.

In the next section, you will deploy Anycast-RP to support dynamic RP election and load balancing with this same multicast group.

PIM-Based Anycast-RP

The final multicast configuration exercise in this chapter involves deployment of Anycast-RP, with emphasis on a PIM-only solution. An alternative configuration using MSDP is also provided.

With both auto-RP and BSR, only one RP is permitted to be active for any given group at any one time. Anycast-RP relaxes this restriction and allows multiple RPs to be active for the same group at the same time. Anycast-RP requires a mechanism by which the multiple RPs share information about active sources. This inter-RP communication has historically been performed by MSDP, but JUNOS software also supports the PIM-only Anycast-RP solution, as specified in RFC 4610. The PIM-based solution is attractive because it eliminates all need for MSDP within an organization, allowing MSDP deployment as needed, and then only for its original purpose of interdomain multicast support.

Because of the common RP address that is shared among all the RPs, receivers simply send their joins to the metrically closest Anycast-RP, and they are unaware of the presence of multiple RPs.

The configuration objectives are as follows:

- Stout and Bock remain RPs, but both must now use 10.255.255.1 for RP functionality.
- Do not use BSR or auto-RP.
- Ensure no single points of failure.

The requirement that no dynamic RP discovery mechanisms be used may strike you as a bit odd, especially in light of the need for network resiliency to single points of failure. Recall that with Anycast-RP, all of the RPs for a given group range use the same RP address. Therefore, as long as at least one Anycast-RP remains operational, the statically defined RP address in non-RP routers continues to provide the needed connectivity. In an Anycast-RP environment, the use of a dynamic protocol to propagate knowledge of the single RP address is a bit overkill, but certainly not illegal.

Figure 10-17 provides a high-level walkthrough of an Anycast-RP operation.

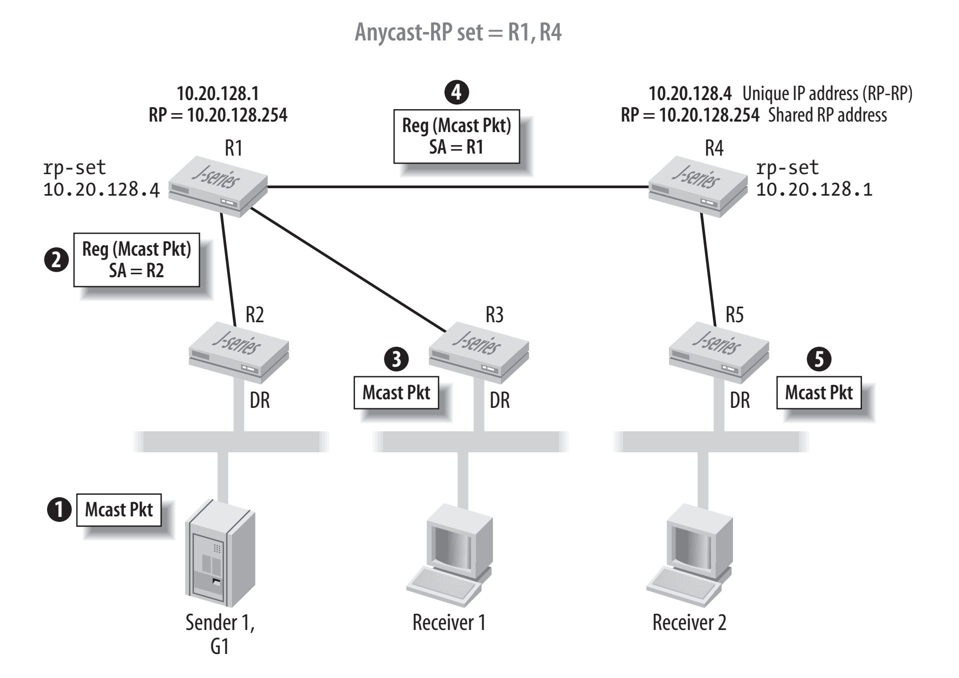


Figure 10-17. PIM Anycast-RP operation

To start, note how the domain's RPs are said to belong to an Anycast-RP set. Each RP within this set must have a unique, routable loopback address that is used for RP-RP (and other) communications, as well as a shared RP address that, in effect, represents all RPs in the set. Further, each RP in the set must have an explicit list of all other RPs, using their unique, not shared, IP address. Figure 10-17 shows how R1 and R4 have a configuration that identifies each other by their unique `lo0` IP address.

Step 1 shows Sender 1 (S1) generating native multicast to group G1. The designated router for S1 encapsulates the multicast into a register message and sends it to the Anycast-RP address at step 2. Because all RPs in the set use the same RP address, the register message is routed by the IGP to the metrically closest RP, which is R1 in this example. Note that the register message received by R1 is sourced by R2. Step 3 shows R1 sending the now native multicast (register encapsulation has been stripped) down its shared tree toward Receiver 1. At step 4, R1 creates its *own* register message with a copy of the original multicast packet, which is sent to *all* RPs in the Anycast-RP set, which in this case means that R4 receives a register message with R1 as a source. R4 behaves as any other designated router by stripping the register encapsulation and sending the native multicast down its shared tree, thus allowing R2 to obtain a copy.

Configure Anycast-RP

Figure 10-18 shows the Anycast-RP topology. It details how the domain's two RPs, `PBR` and `Stout`, share an Anycast-RP address of 10.255.255.1, in addition to maintaining their unique loopback addresses. Configuration begins with removal of any existing RP and BSR functionality at `PBR` and `Stout` (the commit is not shown):

```
[edit]
lab@PBR# delete protocols pim rp
```

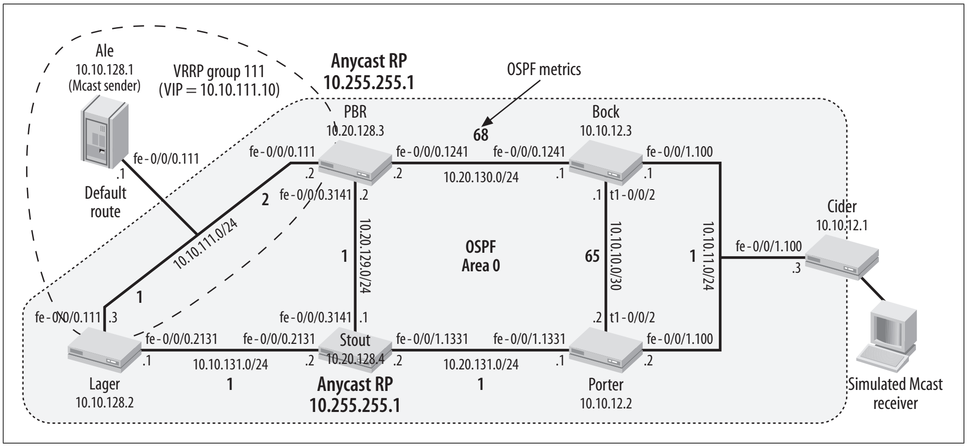


Figure 10-18. The Anycast-RP topology

This action leaves the domain with no RPs—recall that RP information was being disseminated via bootstrap, and the previous command removed all C-RP and C-BSR functionality from the domain.

Configure static RP on non-RP routers

The non-RP routers are a snap to configure; a single statement is needed to statically define the Anycast-RP address at all routers. The configuration of Lager is shown and is similar to all other non-RP nodes:

```
[edit]
lab@Lager# show protocols pim
rp {
    static {
        address 10.255.255.1;
    }
}
interface fe-0/0/0.2131;
interface fe-0/0/0.111;
```

After committing the changes, static RP operation is confirmed at Cider:

```
[edit]
lab@Cider# run show pim rps
Instance: PIM.master
Address family INET
RP address       Type        Holdtime Timeout Groups Group prefixes
10.255.255.1     static             0    None      2 224.0.0.0/4
. . .

[edit]
lab@Cider# run show pim join
Instance: PIM.master Family: INET

Group: 224.2.127.254
    Source: *
    RP: 10.255.255.1
    Flags: sparse,rptree,wildcard
    Upstream interface: unknown (no route)

Group: 225.1.1.1
    Source: *
    RP: 10.255.255.1
    Flags: sparse,rptree,wildcard
    Upstream interface: unknown (no route)
```

The output shows that the Anycast-RP address is correctly configured, but there is currently no route to the Anycast-RP address, which is expected given that the Anycast-RPs have not yet been configured.

Configure the Anycast-RPs

Configuration of the Anycast-RP begins with the addition of the shared Anycast-RP address to the lo0 interface. The existing (unique) address is flagged as primary to ensure no disruption to the IGP/BGP control plane through continued use of the unique lo0 address for non-PIM-related functions, such as OSPF/BGP router ID (RID) selection. Recall that when not explicitly set under routing-options, the RID is obtained from the primary address on the system's default interface, which is the lowest non-127.0.0.*x* address assigned to the lo0 interface.

```
[edit interfaces lo0 unit 0 family inet]
lab@PBR# set address 10.20.128.3/32 primary

[edit interfaces lo0 unit 0 family inet]
lab@PBR# set address 10.255.255.1
```

By default, the numerically lowest local IP address is considered the interface's primary address, and the lo0 interface is the default interface when a non-127.0.0.*x* address is configured. The specifics of this example happened to use a numerically higher address for the Anycast-RP function, making declaration of the existing lo0 address as primary technically unnecessary. However, making a mistake here can lead to the difficult problem of troubleshooting missing routes due to duplicate RIDs, making the extra configuration step insurance that is well worth having.

The modified lo0 configuration is shown:

```
[edit interfaces lo0 unit 0 family inet]
lab@PBR# show
address 10.20.128.3/32 {
    primary;
}
address 10.255.255.1/32;
```

Similar changes are also made to Stout's lo0 configuration. PIM-based Anycast-RP is configured at the [edit protocols pim rp local family inet] hierarchy. The updated configuration and related set commands are shown for PBR:

```
[edit protocols pim rp local family inet]
lab@PBR# show
address 10.255.255.1;
anycast-pim {
    rp-set {
        address 10.20.128.4;
    }
}

[edit protocols pim rp local family inet]
lab@PBR# show | display set
set protocols pim rp local family inet address 10.255.255.1
set protocols pim rp local family inet anycast-pim rp-set address
10.20.128.4
```

Once again, a similar configuration is added and committed at Stout, whose configuration correctly specifies PBR's unique lo0 address under its rp-set stanza.

Verify the Anycast-RPs

After a few minutes, PIM join state is examined at Cider:

```
[edit]
lab@Cider# run show pim join 225.1.1.1
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.255.255.1
    Flags: sparse,rptree,wildcard
    Upstream interface: unknown (no route)
```

The display indicates that Cider still does not know how to route to the Anycast-RP address. This is quickly confirmed with a show route command:

```
[edit]
lab@Cider# run show route 10.255.255.1
```

Going back to one of the Anycast-RPs, the problem is quickly uncovered:

```
[edit]
lab@PBR# run show ospf interface
Interface       State     Area       DR ID          BDR ID       Nbrs
fe-0/0/0.111    BDR      0.0.0.0    10.10.128.2    10.20.128.3     1
fe-0/0/0.1241   BDR      0.0.0.0    10.10.12.3     10.20.128.3     1
fe-0/0/0.3141   BDR      0.0.0.0    10.20.128.4    10.20.128.3     1
```

OSPF is not running on the lo0 interface, which prevents the newly added 10.255.255.1 Anycast-RP address from being advertised into OSPF. Recall that the JUNOS software default is to advertise a stub route to the interface from which the router obtains its RID. The router uses the primary address on the default interface—which is normally the lo0 interface by default—as the RID; this is why the 10.20.128.3 lo0 address at PBR has been advertised into OSPF despite OSPF not being enabled on that interface previously.

> They automatically advertise the source of the RID behavior changed in release 8.5 due to PR 229200. In affected releases, you should run a passive OSPF instance on the router's lo0 to ensure the route is advertised into OSPF, which is needed for proper PIM functioning.

A passive OSPF instance is configured to run on the lo0 interface of both Anycast-RPs to get both of the assigned lo0 addresses advertised into OSPF:

```
[edit]
lab@PBR# set protocols ospf area 0 interface lo0 passive
```

The OSPF database confirms that PBR is now advertising the 10.255.255.1 address:

```
[edit]
lab@PBR# show ospf database advertising-router 10.20.128.3 router
detail
```

```
    OSPF link state database, Area 0.0.0.0
 Type       ID          Adv Rtr       Seq    Age  Opt  Cksum  Len
Router  *10.20.128.3  10.20.128.3   0x800000b4  41  0x22 0xff76  84
  bits 0x2, link count 5
  id 10.10.111.3, data 10.10.111.2, Type Transit (2)
  TOS count 0, TOS 0 metric 2
  id 10.20.130.1, data 10.20.130.2, Type Transit (2)
  TOS count 0, TOS 0 metric 68
  id 10.20.129.1, data 10.20.129.2, Type Transit (2)
  TOS count 0, TOS 0 metric 1
  id 10.20.128.3, data 255.255.255.255, Type Stub (3)
  TOS count 0, TOS 0 metric 0
  id 10.255.255.1, data 255.255.255.255, Type Stub (3)
TOS count 0, TOS 0 metric 0
```

The change allows Cider to route toward the Anycast-RP address, which in turn permits it to join the shared tree for 225.1.1.1:

```
[edit]
lab@Cider# run show pim join
Instance: PIM.master Family: INET

Group: 224.2.127.254
    Source: *
    RP: 10.255.255.1
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/1.100

Group: 225.1.1.1
    Source: *
    RP: 10.255.255.1
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/1.100
```

The current route to the Anycast-RP is displayed at Cider:

```
[edit]
lab@Cider# run show route 10.255.255.1

inet.0: 20 destinations, 20 routes (20 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.255.255.1/32    *[OSPF/10] 00:03:53, metric 2
                    > to 10.10.11.2 via fe-0/0/1.100

[edit]
lab@Cider# run traceroute 10.255.255.1
traceroute to 10.255.255.1 (10.255.255.1), 30 hops max, 40 byte packets
 1  10.10.11.2 (10.10.11.2)  79.285 ms  98.810 ms  99.739 ms
 2  10.255.255.1 (10.255.255.1)  10.293 ms  9.213 ms  29.762 ms
```

The output shows that Stout is the RP currently used by Cider. Failover to metrically closest Anycast-RP is tested by increasing the path metric on the Porter–Stout link to 300:

```
lab@Porter# set protocols ospf area 0 interface fe-0/0/1.1331 metric 300
```

And the change is verified back at Cider, which still thinks it is using the same RP, but in reality, its join now goes to PBR via Bock:

```
[edit]
lab@Cider# run show pim join 225.1.1.1
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.255.255.1
    Flags: sparse,rptree,wildcard
    Upstream interface: fe-0/0/1.100

[edit]
lab@Cider# run show route 10.255.255.1

inet.0: 20 destinations, 20 routes (20 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.255.255.1/32    *[OSPF/10] 00:19:02, metric 69
                    > to 10.10.11.1 via fe-0/0/1.100

[edit]
lab@Cider# run traceroute 10.255.255.1
traceroute to 10.255.255.1 (10.255.255.1), 30 hops max, 40 byte packets
 1  10.10.11.1 (10.10.11.1)  19.018 ms  12.334 ms  16.235 ms
 2  10.255.255.1 (10.255.255.1)  9.630 ms  29.665 ms  10.108 ms
```

The final PIM configuration is shown for Anycast-RP node Stout:

```
[edit]
lab@stout# show protocols pim
rp {
    local {
        family inet {
            address 10.255.255.1;
            anycast-pim {
                rp-set {
                    address 10.20.128.3;
                }
            }
        }
    }
}
interface fe-0/0/0.2131;
interface fe-0/0/0.3141;
interface fe-0/0/1.1331;
```

The asymmetric metrics (which is hard to say) in effect cause first hop router Lager to send its register message to PBR, while receiver Cider sends its join toward Stout. When PBR receives the register message from Lager, it generates a copy, sourced from its unique lo0 address, and sends it to Anycast-RP set member Stout. This allows

Stout to delivery a copy of the multicast packet to Cider over the shared tree, which in turn generates an (S,G) join to establish an SPT. Register message tracing is added to Lager and Stout to illustrate Anycast-RP interaction:

```
[edit]
lab@Lager# run traceroute 10.255.255.1
traceroute to 10.255.255.1 (10.255.255.1), 30 hops max, 40 byte
packets
 1  10.255.255.1 (10.255.255.1)  29.511 ms  38.646 ms  10.129 ms
```

The traceroute confirms that Lager sees PBR as the metrically closest RP. The multicast source is started, and register tracing is observed at Lager. Note that the register is sourced from Lager and sent to the shared Anycast-RP address:

```
[edit]
Sep 29 06:08:13.825061 PIM SENT 10.10.128.2 -> 10.255.255.1 V2
Register Flags: 0x40000000 Border: 0 Null: 1 Source 10.10.111.1
Group 225.1.1.1 sum 0x43f1 len 28
```

The register stop back from the Anycast-RP indicates that an SPT has been established or that no more interested receivers are left on the shared tree:

```
lab@Lager# Sep 29 06:06:13.774885 PIM fe-0/0/0.2131 RECV 10.255.255.1
-> 10.10.128.2 V2 RegisterStop Source 10.10.111.1 Group 225.1.1.1 sum
0x80d1 len 18
```

The register message trace output is observed at Stout:

```
[edit]
lab@stout# Sep 29 06:45:28.549924 PIM fe-0/0/0.3141 RECV 10.20.128.3
-> 10.20.128.4 V2 Register Flags: 0x00000000 Border: 0 Null: 0 Source
 10.10.111.1 Group 225.1.1.1 sum 0xdeff len 92

Sep 29 06:45:28.553631 PIM SENT 10.20.128.4 -> 10.20.128.3 V2
RegisterStop Source 10.10.111.1 Group 225.1.1.1 sum 0x80d1 len 18
```

Stout's trace shows that it receives a register from PBR—note how the register message is sent from/to the unique lo0 addresses of PBR and Stout, respectively. This mechanism differentiates registers received from first hop routers, which are sent to the Anycast-RP address, from those received from other RPs. The former are echoed to all other RPs in the RP set, whereas the latter are absorbed and acted upon locally. Lastly, the show pim source command is executed at Stout to confirm the learning of active group 225.1.1.1 via an Anycast-RP source, as indicated by the 10.255.255.1 address:

```
[edit]
lab@stout# run show pim source detail
Instance: PIM.master Family: INET

Source 10.10.111.1
    Prefix 10.10.111.0/24
    Upstream interface fe-0/0/0.2131
```

```
        Upstream neighbor 10.10.131.1
        Active groups:225.1.1.1

    Source 10.255.255.1
        Prefix 10.255.255.1/32
        Upstream interface Local
        Upstream neighbor Local
        Active groups:225.1.1.1
            224.2.127.254
```

What about MSDP?

Anycast-RP using native PIM is somewhat new, and you may find that some of the routers in your network do not support this method. In this case, you will need to deploy Anycast-RP using MSDP peering between all the RPs in the domain. MSDP conveys information about active sources between the domain's RPs. A working MSDP configuration for the current Anycast-RP topology is added to PBR and Stout. The configuration of MSDP is similar to that of PIM-based Anycast-RP, and it involves listing the unique neighbor addresses of all Anycast-RPs in the domain. The shared and unique IP addresses assigned to the lo0 interface are reused from the previous PIM-based Anycast-RP example. The modified configuration at PBR is as follows:

```
[edit]
lab@PBR# show protocols pim
rp {
    local {
        address 10.255.255.1;
    }
}
interface fe-0/0/0.3141;
interface fe-0/0/0.1241;
interface fe-0/0/0.111;
[edit]
lab@PBR# show protocols msdp
peer 10.20.128.4 {
    local-address 10.20.128.3;
}
```

The `local-address` statement ensures that the remote MSDP peer recognizes the connection as coming from one of its defined peers. As with loopback-based BGP peering, one end's `local-address` should match the other end's peer definition. You can use a similar statement with PIM-based anycast, but we omitted it because by default, PIM messages are sourced from the primary address on the lo0 interface.

After starting up the multicast source, the MSDP session state and listing of learned sources is displayed at Stout:

```
[edit]
lab@stout# run show msdp
```

```
Peer address  Local address State    Last up/down Peer-Group SA Count
10.20.128.3   10.20.128.4   Established  00:07:56           1/1

[edit]
lab@stout# run show msdp source-active
Group address   Source address  Peer address    Originator    Flags
225.1.1.1       10.10.111.1     10.20.128.3     10.20.128.3   Accept
```

These results complete the PIM sparse mode Anycast-RP configuration and verification example.

PIM Sparse Mode with Anycast-RP Summary

This section demonstrated a PIM-based solution to Anycast-RP and showed a working example that is based on MSDP. Because Anycast-RP has inherent fault tolerance, it's common to use a static RP definition on client routers to avoid the complexities of a dynamic RP election protocol such as the bootstrap or auto-RP protocol.

Conclusion

IP multicast offers the best of all worlds when supporting one-to-many or many-to-many applications. Using a unicast model for these applications quickly stresses processing power at the source due to replication load, and maximum network bandwidth is consumed. Using broadcast is expensive for all hosts and is confined to a single segment or bridging domain. Only IP multicast offers a scalable, standardized way to handle multipoint streams in a manner that distributes replication load and conserves network bandwidth when branches have no interested listeners. Many network operators are unfamiliar with IP multicast, which limits its widespread use. Multicast should be looked at anytime a network is designed or redesigned as a potentially powerful optimization tool that can also enable the rollout of emerging virtual simulation or multiplayer applications.

PIM sparse mode has become the predominant multicast routing protocol given its support of dense, sparse, and sparse-dense modes of operation and the variety of mechanisms that can be used to dynamically distribute RP information in a fault-tolerant manner. This chapter demonstrated typical PIM sparse mode deployment scenarios using static and bootstrap-based RP dissemination, and it showed PIM- and MSDP-based examples of Anycast-RP. JUNOS software supports a wide range of IP multicast standards and makes multicast configuration and verification relatively straightforward.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- Distance Vector Multicast Routing Protocol (DVMRP)
- Protocol Independent Multicast dense mode (PIM-DM)
- Protocol Independent Multicast sparse mode (PIM-SM)
- Bootstrap, auto-RP, anycast
- Source-specific multicast (SSM)

Chapter Review Questions

1. Which RP dissemination mechanism supports load balancing within the same group?
    a. Auto-RP
    b. Anycast-RP
    c. Bootstrap
    d. Static
2. Which RP dissemination mechanism supports load balancing on a group-by-group basis?
    a. Auto-RP
    b. Anycast-RP
    c. Bootstrap
    d. Static
3. Which methods can you use to scope bootstrap messages?
    a. This is not possible given the hop-by-hop forwarding using the All PIM Routers address
    b. By configuring bootstrap import or export policy
    c. By configuring RP register policy
    d. By configuring PIMv2 on external interfaces
4. Which correctly describes sparse-dense mode operation?
    a. Flooding all traffic until a prune is received, then switching to sparse mode
    b. Operating in sparse mode until a join is received, then switching to dense mode
    c. Operating in sparse mode, with the exception of specific groups that are treated as dense
    d. Sparse-dense mode is needed to support Anycast-RP

5. Which correctly describes PIM register policy?
    a. It allows you to filter register messages to control RP usage
    b. It controls which C-RPs can register with the BSR for inclusion in the RP set
    c. It supports Anycast-RP by allowing inter-RP communication regarding active sources
    d. It controls when the last hop router decides to join an SPT
6. Which correctly describes the default JUNOS software PIM sparse mode behavior?
    a. The first hop routers initiates an SPT join as soon as the first packet is sent
    b. The last hop router initiates an SPT join as soon as the first packet is received
    c. The first hop router initiates an RPT join before the source becomes active
    d. The last hop router initiates an RPT join as soon as traffic is received over the SPT
7. What command displays dynamic multicast forwarding state in the data plane?
    a. `show pim route`
    b. `show multicast route`
    c. `show muticast rpf`
    d. `show route table inet.2`
8. Which of the following best describes an RPF check?
    a. It discards packets that are received on an interface that is not used when routing back to that source
    b. It never sends a multicast packet out the interface used to reach the source
    c. It sends an SPT join out the interface used when routing to that source
    d. All of the above
9. Which is true regarding Anycast-RP?
    a. A shared 127.0.0.1 address is added to the `lo0` interface
    b. The Anycast-RPs must communicate with each other using the Anycast-RP address
    c. Anycast-RP messages are flooded using sparse-dense mode
    d. The Anycast-RPs must communicate with each other using their unique `lo0` addresses
10. Refer to the output provided and select the best answer:

```
lab@Porter> show multicast route
Family: INET

Group: 225.1.1.1
    Source: 10.10.111.1/32
    Upstream interface: fe-0/0/1.1331
```

```
        Downstream interface list:
            fe-0/0/1.100
```

a. This is an (S,G) entry on the RPT
b. This is an (*,G) entry on the RPT
c. This entry is pruned because only one interface exists in the outgoing list
d. This entry exists in the control plane as a result of an (*,G) join
e. This entry exists in the data plane as a result of multicast traffic

11. Which of the following is true?

    a. IGMPv1 supports group leaves
    b. IGMPv3 supports group leaves and SSM joins
    c. IGMPv2 relied on the routing protocol to perform the querier function
    d. IGMP must be explicitly configured to run on PIM-enabled interfaces

12. The querier router sends a query for group 225.1.1.1. What address is the query sent to?

    a. The All PIM Routers multicast address
    b. The All Hosts multicast address
    c. The unicast address of the host that sent the membership
    d. The address associated with the group being queried

Chapter Review Answers

1. Answer: B. Only Anycast-RP allows multiple RPs to be active at the same time for the same group.
2. Answer: C. The BSR mechanism automatically balances, on a group-range basis, among a set of C-RPs using a distributed hash function.
3. Answer: B. PIM bootstrap policy can be used to filter BSR messages being sent or received. Using PIMv1 also blocks BSR, as it is not supported in that version.
4. Answer C. Sparse-dense operation defaults to sparse mode, except for groups explicitly designated as dense.
5. Answer: A. PIM register policy allows filtering of registers at the first hop, or at the RP, which controls the number of sessions on the RP.
6. Answer B. The last hop router is in charge of making the switch from RPT to SPT, and in JUNOS software this occurs upon receipt of the first packet.
7. Answer: B. The `show multicast route` command displays dynamic data plane state that results from multicast traffic. Join-related commands show control plane state.
8. Answer: D. All of the operations described are based on an RPF check.

9. Answer: D. Anycast-RP requires a shared, and unique, `lo0` address; the unique address is used for RP-RP communication.
10. Answer: E. This is a multicast route, in the data plane, which is created when allowed by join state and when data activity occurs. This is an (S,G) entry, and therefore it is not on the RPT.
11. Answer: B. IGMPv3 supports v2's group leave as well as SSM.
12. Answer: D. A group query is sent to the multicast address of the group itself.

CHAPTER 11
JUNOS Software with Enhanced Services

The release of JUNOS software with enhanced services represents a significant step forward in solving the needs of enterprise networks. This chapter is not intended to provide complete coverage of the new capabilities associated with JUNOS software with enhanced services. The goal is to prepare the reader for what is coming by providing a high-level overview of what JUNOS software with enhanced services is, detailed information on how to migrate from JUNOS to JUNOS software with enhanced services, and a before-and-after case study showing an Adaptive Services PIC (ASP)-based service set that is migrated to the new enhanced services format, along with the steps needed to validate their operation.

The JUNOS software with enhanced services topics include:

- An overview of JUNOS software with enhanced services
- Migrating from JUNOS to JUNOS software with enhanced services
- An enhanced services case study

JUNOS Software with Enhanced Services Overview

Starting with Release 8.5, you have the option of deploying JUNOS software with enhanced services on supported platforms to take advantage of significant security and service enhancements. It's important to note that even when running JUNOS software with enhanced services, JUNOS is JUNOS, and therefore, the majority of the platform concepts, command-line interface (CLI) commands, operational troubleshooting, and so on remain as covered throughout this book. This is especially true of routing protocol configuration and operational verification, which remains as before and is "classic" JUNOS all the way.

This is *not* a security-focused book, and therefore, comprehensive coverage of the JUNOS enhanced security and services feature set is not possible. This chapter covers migration of a production router from JUNOS to JUNOS software with enhanced services, and gets you familiar with what is different in the new set of enhanced services. It is expected that JUNOS software with enhanced services will continue to evolve, resulting in ongoing updates and additions to the enhanced services portfolio.

For the reader of this book, the changes related to JUNOS software with enhanced services impact those services that were handled by the J-series—for example, stateful firewalls, Network Address Translation (NAT), and IPSec virtual private networks (VPNs). With JUNOS software with enhanced services, these features are no longer ASP-based; instead, they are now based on capabilities born out of ScreenOS security solutions. Aside from the changes to security and services, as far as both configuration and general capabilities, the rest of the JUNOS configuration and operation remains unchanged. The coverage of ASP-based service sets continues to hold true for users of M- and T-series platforms, which do not support JUNOS software with enhanced services.

Supported Platforms

As of this writing, you can load JUNOS software with enhanced services on the following hardware platforms, most of which support digital signal level 3 (DS3) or T3, T1, Gigabit Ethernet, Fast Ethernet, E3, E1, serial, Asynchronous Transfer Mode over asymmetrical digital subscriber line (ATM over ADSL), ATM over symmetric high-speed digital subscriber line (ATM over SHDSL), channelized T1/E1/Integrated Services Digital Network (ISDN) Primary Rate Interface (PRI), and ISDN Basic Rate Interface (BRI) interfaces:

- J2320 and J2350 (DS3 and E3 interfaces are not supported)
- J4350
- J6350
- SSG320m and SSG350m (requires conversion kit)
- SSG520m and SSG550m (requires conversion kit)

In the future, additional platforms may offer JUNOS software with enhanced services support, so be sure to check the Juniper Networks web site for the latest platform support.

Users who purchased NetScreen Secure Security gateway (SSGm) 300 or 500 series devices can convert the machine to a J-series enhanced services router with the appropriate conversion kit. The conversion kit provides a new compact flash with JUNOS software with enhanced services and instructions on how to convert. You can also convert from a supported J-series router running JUNOS software with enhanced services to the equivalent Juniper SSGm firewall running ScreenOS, as shown in Table 11-1, using a similar process, but that is beyond the scope of our discussion.

Table 11-1 shows the mapping between SSGm and J-series router platforms.

Table 11-1. J-series to SSGm platform mapping

J-series model	SSGm model
J6350	SSG550m
J4350	SSG520m
J2350	SSG350m
J2320	SSG320m

Once you perform a conversion, you must update your support contract with the new device information in order to ensure uninterrupted access to technical acceptance and customer support. Instructions for this procedure are provided in the conversion kits or JUNOS software with enhanced services conversion guides.

Packet Versus Flow-Based Processing

Historically, Juniper Networks routers use a packet-based forwarding model, in which each packet is individually processed and routed. In contrast, the Juniper SSG security devices are based on a flow model. Handling traffic as flows offers significant benefits for stateful services. In the flow model, the initial packets of a communication are typically processed in software and are subjected to various levels of packet security inspections and validity checks, in addition to a *single* route lookup. Once the packet is deemed permissible, a corresponding session state is installed into the forwarding plane to facilitate expedited forwarding for subsequent packets belonging to the same flow. In effect, the first packets are deeply scrutinized before being routed, and the remaining packets are switched according to the session table.

A *flow* is a unidirectional sequence of packets, when combined, for a sequential set of application data for the process that generated the flow. The matching flow in the return direction is grouped to form a session, which is therefore composed of two unidirectional flows.

Security zones

To understand and appreciate JUNOS software with enhanced services operation and capabilities, you must first be familiar with the concept of security zones. The Juniper ScreenOS Integrated Security Gateway (ISG) and Secure Services Gateway (SSG) appliances are based on the concept of zones. Figure 11-1 illustrates the concept of trust and untrust zones.

In a default configuration, there is a trust zone and an untrust zone. A *security zone* is a collection of one or more network segments that regulate inbound and outbound traffic via policies; policies are optional for traffic that originates and terminates in the same zone (intrazone). The result is that devices attached to interfaces belonging

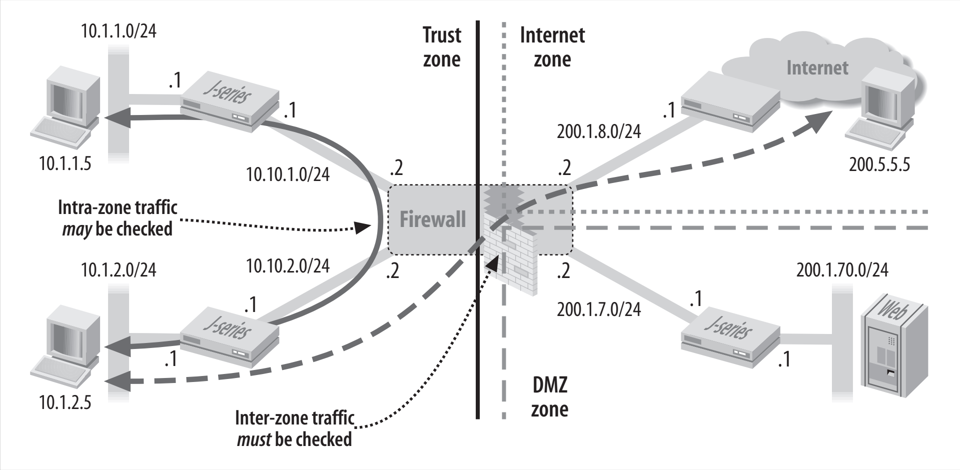


Figure 11-1. Zones and the tree of trust

to the same zone are able to communicate freely, whereas explicit policy is needed to permit communication between zones, and additional checks are leveled against traffic flowing between the trust and untrust zones.

Figure 11-1 shows a network composed of three zones and illustrates how intrazone traffic is permitted by default among all interfaces grouped into the trust zone, whereas interzone traffic must be explicitly allowed by a policy and may be subjected to deep packet inspection and other types of security services. In contrast, intrazone blocking is enabled by default for interfaces that share the same untrust zone, requiring a policy to permit communication among devices attached to different segments belonging to the same untrust zone. By grouping interfaces into zones and then managing interzone policies, you easily restrict and control interzone communications. The zone concept is also used to optimize firewall matching, as only rules that apply to the source and destination zones need to be checked.

Do I Need a Router or a Security Device?

In the past, users were expected to make some tough decisions when building out a new or existing network. Specifically, they often had to choose a device based on what was more important: world-class routing or world-class services. When both were equally important, a two-box, best-of-breed solution was often proposed. In this model, you had services/security devices that were deployed in parallel with a router infrastructure. In a divide-and-conquer model such as this, each device was left to do what it did best, with the combined effect being the best of both worlds.

Although the two-box solution was workable, and in fact is often the recommended solution today, such a design suffers from several drawbacks: two boxes are more expensive than one; there is a greater chance of failure due to more components; and generally, each new box added to the network increases overall operational costs.

Best-of-breed routing and security services

The release of JUNOS software with enhanced services holds the very real promise of eliminating the need for a two-box solution. By combining the power and proven performance of JUNOS software and its routing protocols with enhanced security and services from the best-in-class ScreenOS, users are able to get the best of both worlds, all in a single box.

The service updates in the initial release of JUNOS software with enhanced services primarily impact the security arena, and therefore, the changes in security-related services are the focus of this chapter. As noted previously, later updates may add nonsecurity-related services to the JUNOS software with enhanced services portfolio.

Architecture Changes

JUNOS software with enhanced services represents some significant changes in control plane capabilities through the introduction of new service daemons, and in packet forwarding behavior with the addition of flow-based processing. This section provides a high-level overview of the changes associated with the JUNOS software with enhanced services release.

Adding flow-based forwarding

One of the primary changes in JUNOS software with enhanced services is the addition of flow-based processing. This is along with to existing packet-based processing capabilities such as stateless firewall filters. The changes in JUNOS software with enhanced services result in a combination of packet- and flow-based treatment, as shown in Figure 11-2.

Figure 11-2 shows how the original packet-based forwarding process known as fwdd has been replaced with a flow-based process called flowd, which denotes the change from a packet- to a flow-based model. At the top of Figure 11-2, you can see that with JUNOS software, a packet can be directed into service processing as a result of an input or output filter or as a result of route lookup. In this model, forwarding is the prime concern and services were "tacked on to packets" as needed. The JUNOS software with enhanced services data plane is more service- and security-focused. All flows are inspected and passed through policy to determine whether they are allowed, at which point a single route lookup is performed. The differences can be summarized as a "route first, services maybe" philosophy in JUNOS versus a "services first, route if permitted" behavior in JUNOS software with enhanced services.

Packets are processed as flows after per-packet ingress handling and before per-packet egress handling. A *flow* is a stream of related packets that meet the same matching criteria and share the same characteristics. JUNOS software with enhanced services treats packets belonging to the same flow in the same manner. Specifically,

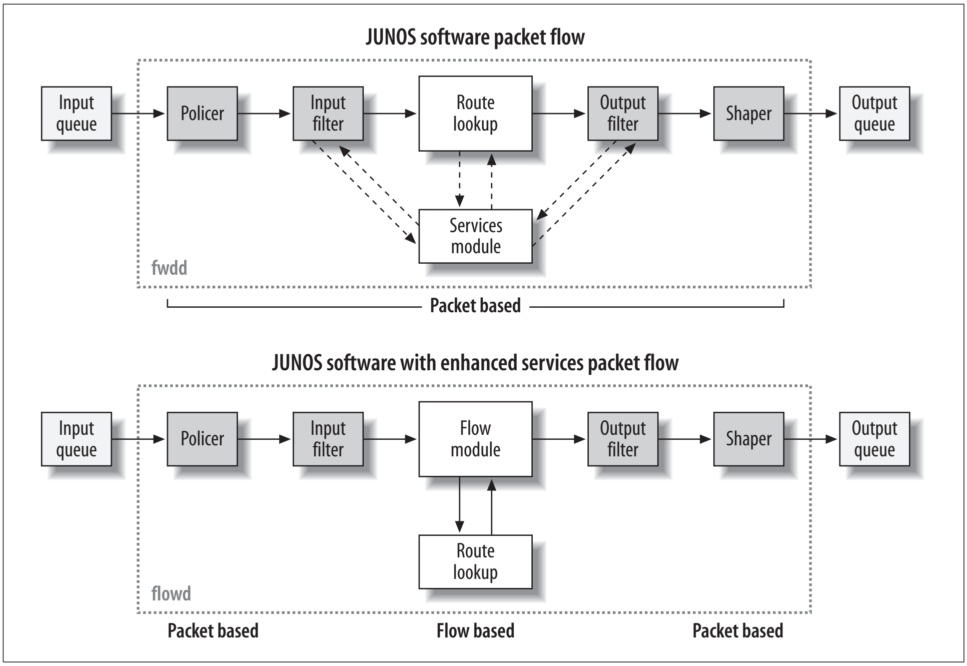


Figure 11-2. Combined packet- and flow-based processing

configuration settings that determine the fate of a packet—such as the security policy that applies to it, whether the packet is sent through an IPSec tunnel, or whether NAT is applied—are assessed for the first packet of a flow. The resultant set of actions and services is applied to the rest of the packets in the flow. The following criteria are used to determine whether a packet matches an existing flow:

- Source address
- Destination address
- Source port
- Destination port
- Protocol
- Session token

The *session token* is an internal index number that is set based on the packet's ingress zone. Packets that match an existing flow are treated according to the established flow state. Packets that do not match are treated as the first packets in a new flow and are used to create matching flow state for the related flow.

Flows and sessions. The stateful handling of flows requires the creation of a session. A session is created based on the characteristics of the first packet in a flow. Sessions are used for:

- Storing security measures to be applied to the packets of the flow
- Caching information about the state of the flow—that is, logging and counting data for a flow is cached in its session
- Allocating required resources for features such as NAT and IPSec tunnels
- Providing a framework for features such as Application Layer Gateways (ALGs) and firewall features

The combined effects of flow and session state bring together the following features and events that affect a packet as it undergoes flow-based processing:

- Flow-based forwarding
- Session management, including session aging and changes in routes, policy, and interfaces
- Management of VPNs, ALGs, and authentication
- Management of policies, NAT, zones, and screens

Each session resulting from a flow is associated with a timeout value. For example, the default timeout for the Transmission Control Protocol (TCP) is 30 minutes; the default timeout for the User Datagram Protocol (UDP) is 1 minute. When a flow is terminated, it is marked as invalid, and its timeout is reduced to 10 seconds. You can change the idle timeout value; it is designed to ensure that system resources are not tied up indefinitely on an otherwise defunct flow.

JUNOS software with enhanced services packet walk

In this section, we will follow a packet as it traverses the JUNOS software with enhanced services data plane, where it encounters a mix of packet- and flow-based handling steps. Figure 11-3 shows where the numbered events tie into the packet-handling steps described in the following text.

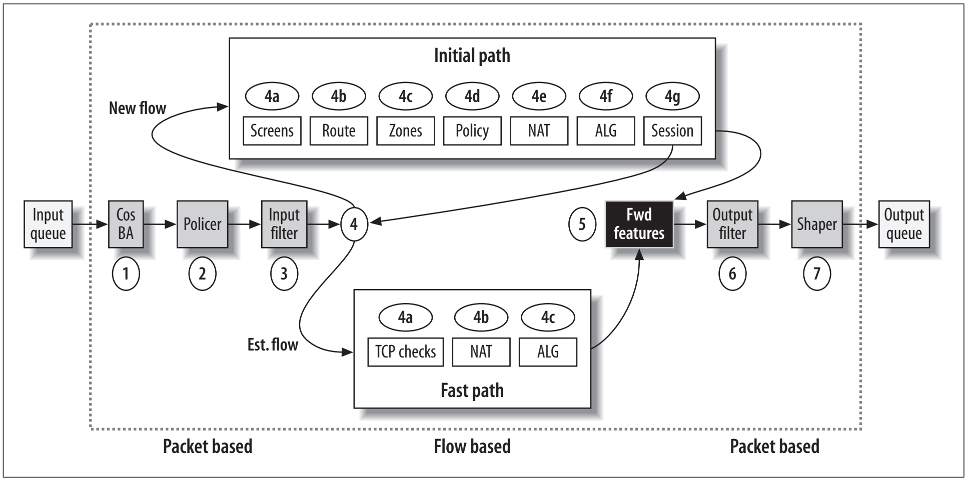


Figure 11-3. JUNOS software with enhanced services packet walk

The steps shown for the initial path represent the full set of checks and service instantiations that you can perform against the initial packets of a communications flow. In contrast, the fast path represents the streamlined steps executed for previously processed (and accepted) flows. The two-stage approach provides the ability to deeply inspect initial packets, which is computationally expensive but needed for true security, while at the same time offering high throughput by switching permitted flows based on established flow state. It should be noted that not all packets need to be touched at all possible processing points. For example, NAT is optional, and when not configured, NAT processing is not evoked. The packet processing steps are as follows:

1. Pull the packet from the queue, perform class of service (CoS) behavior aggregate (BA) classification, and note the ingress interface's zone for later policy lookup.
2. Ingress the policer/shaper.
3. Ingress the firewall filter; evoke the policer of multifield CoS classification.
4. Perform a lookup session; if no match, follow the initial path:
   a. Conduct a firewall screen check. When enabled, screen checks log or filter out packets with anomalous characteristics such as an attach signature.
   b. Perform a route lookup to determine the egress interface.
   c. Locate the destination (outgoing) zone, based on the route lookup result.
   d. Look up and execute policy based on incoming and outgoing zones; results include permit, deny, and reject.
   e. Allocate the NAT address based on the destination, source, or destination/source NAT policy directive.
   f. Set up ALGs as needed to support identified applications when NAT is active.
   g. Install a session tuple for fast path processing of related packets.

   If a session is matched, follow the fast path:

   a. Perform TCP checks to look for connection anomalies and match responses.
   b. Conduct NAT translation when evoked by policy.
   c. Perform ALG processing as needed by NAT.
5. Whether initial or fast path, perform forwarding services on the packet.
6. Perform egress firewall filtering, which can evoke a policer action.
7. Perform egress shaping or interface level policing; schedule and transmit the packet.

JUNOS Software with Enhanced Services Summary

The release of JUNOS software with enhanced services is a significant milestone in JUNOS software evolution. Looking back at Figure 11-3, you can appreciate the combined one-two punch of JUNOS software with enhanced services. You can now have the best of all worlds: the familiar JUNOS software CLI, its proven modular design that separates the control and data planes, the two-stage commit process, commit and operational scripts, and world-class routing protocol implementations. On top of this, you also get significant security and service features and enhancements. In the initial release, these enhancements are largely security-based and are derived from features available in ScreenOS. Later JUNOS software with enhanced services releases may contain additional, nonsecurity-focused features; given the modular design, just about anything is possible.

The combined packet- and flow-based processing means that packet-based features relating to firewall filters, policers, and shapers, packet classification, queuing, and CoS continue to operate as before. Likewise, ASP-based platforms such as the M10i and M7i will continue to use the service configurations and modes described in Chapters 6 and 7, which cover the introduction to services and advanced services, respectively.

For users initially deploying JUNOS software with enhanced services, the reverse stance on denying versus accepting packet flows by default may take a bit of getting used to. The choice of router versus secure operating contexts helps to mitigate this issue and allows you to deploy JUNOS software with enhanced services so that it operates like a traditional router or as an integrated firewall router, as required by the needs of your network.

Migrating from JUNOS to JUNOS Software with Enhanced Services

This section details the steps you need to follow to migrate a J-series router running JUNOS to run JUNOS software with enhanced services remotely, without losing network connectivity. Much of this information is summarized from the "JUNOS Enhanced Services Migration Guide," available at *http://www.juniper.net/techpubs/software/junos-es/junos-es85/junos-es-migration/junos-es-migration.pdf*. Users are encouraged to consult the documentation for particulars about their hardware before performing any migrations.

Not having enough free compact flash space available to perform an upgrade is common, especially on routers that have large logs, trace files, or old software packages lying about in users' home directories. The migration guide provides detailed instructions on how to free up compact flash space to enhance the chances of being able to upgrade to JUNOS software with enhanced services on systems with 256 MB compact flash chips. The instructions have you delete various temporary and unneeded files using combinations of CLI and root shell mode commands, some of which are demonstrated on the following pages.

Understanding JUNOS Software with Enhanced Services Operational Modes

A J-series Services Router running JUNOS software with enhanced services can operate as either a stateful firewall or a router, depending on whether it is in the secure or router context:

Secure context
: This mode allows a Services Router to act as a stateful firewall with only management access. To allow traffic to pass through a Services Router, you must explicitly configure a security policy for that purpose. In secure context, a Services Router forwards packets only if a security policy permits it; this is true even for traffic within the same zone (intrazone). The default intrazone block behavior in JUNOS software with enhanced services differs from that of ScreenOS, where intrazone blocking is disabled within the trust zone.

  A J-series Services Router loaded with JUNOS software with enhanced services is shipped from the factory in a secure context.

Router context
: This mode allows a Services Router to act as a router in which all management and transit traffic is allowed. In router context, an accept-all security policy is placed into effect and all interfaces are placed into the trust zone. To deny specific traffic, you must configure a security policy to do so.

Switching between secure and router contexts

Switching between secure and router contexts is not a binary function; that is, there is no single configuration statement that switches modes. Instead, the two modes are associated with a restrictive versus a permissive security policy that is configured at the `[edit security]` hierarchy. Switching between contexts does not affect the rest of the router's configuration; for example, its IP addressing and Border Gateway Protocol (BGP) session definitions remain unchanged. However, in a secure context, all communications, both between and within a given zone, must be permitted by policy. The accept-all policy associated with router context ensures that this condition is met to allow free communication among all interfaces listed in the common zone.

You can switch from router to secure context by loading the factory default configuration with a `load factory-default` command. The following settings are defined in the factory default secure context configuration:

- The built-in Gigabit Ethernet interface, ge-/0/0/0, is bound to a preconfigured zone called *trust*. All other interfaces are bound to a preconfigured zone named *untrust*.
- The ge-0/0/0 interface is configured to allow management access with Secure Shell (SSH) and Hypertext Transfer Protocol (HTTP) services enabled. The following host-inbound services are configured for the ge-0/0/0 interface in the trust zone:
  - HTTP
  - HTTPS
  - SSH
  - Dynamic Host Configuration Protocol (DHCP)
- TCP reset is enabled in the trust zone, and the default policy for the trust zone allows transmission of traffic from the trust zone to the untrust zone.
- All traffic within the trust zone is allowed.
- A screen is applied to a zone to protect against attacks launched from within the zone. The following screens are enabled for the untrust zone:
  - Internet Control Message Protocol (ICMP) Ping of Death
  - IP source route options
  - IP Teardrop
  - TCP Land attack
  - TCP SYN flood
- The default policy for the untrust zone is to deny all traffic.

The following commands load the factory default settings for JUNOS software with enhanced services Release 8.5, which places the router into a secure context. There is no root password in the default configuration, so you must assign one using the `set system root-authentication` command before you can commit.

```
[edit]
regress@propane# load factory-default
warning: activating factory configuration

[edit]
regress@propane# show | no-more
## Last changed: 2007-11-28 15:44:55 PST
system {
    autoinstallation {
        delete-upon-commit; ## Deletes [system autoinstallation] upon change/commit
        traceoptions {
            level verbose;
            flag {
                all;
            }
        }
    }
    services {
        ssh;
        web-management {
            http {
                interface ge-0/0/0.0;
            }
        }
    }
    syslog {
        user * {
            any emergency;
        }
        file messages {
            any any;
            authorization info;
        }
        file interactive-commands {
            interactive-commands any;
        }
    }
    ## Warning: missing mandatory statement(s): 'root-authentication'
}
interfaces {
    ge-0/0/0 {
        unit 0;
    }
}
security {
    screen {
        ids-option untrust-screen {
            icmp {
                ping-death;
            }
            ip {
                source-route-option;
                tear-drop;
            }
            tcp {
                syn-flood {
                    alarm-threshold 1024;
                    attack-threshold 200;
                    source-threshold 1024;
                    destination-threshold 2048;
                    queue-size 2000;
                    timeout 20;
                }
                land;
            }
        }
    }
    zones {
        security-zone trust {
            tcp-rst;
            interfaces {
                ge-0/0/0.0 {
                    host-inbound-traffic {
                        system-services {
                            http;
                            https;
                            ssh;
                            telnet;
                            dhcp;
                        }
                    }
                }
            }
        }
        security-zone untrust {
            screen untrust-screen;
        }
    }
    policies {
        from-zone trust to-zone trust {
            policy default-permit {
                match {
                    source-address any;
                    destination-address any;
                    application any;
                }
                then {
                    permit;
                }
            }
        }
        from-zone trust to-zone untrust {
            policy default-permit {
                match {
                    source-address any;
                    destination-address any;
                    application any;
                }
                then {
                    permit;
                }
            }
        }
        from-zone untrust to-zone trust {
            policy default-deny {
                match {
                    source-address any;
                    destination-address any;
                    application any;
                }
                then {
                    deny;
                }
            }
        }
    }
}
```

Note the presence of the from-zone trust to-zone trust policy that is required to permit open communication among all interfaces belonging to the trust zone. Recall that intrazone blocking is enabled in JUNOS software with enhanced services!

You can switch from secure to router context by loading the *jsr-series-routermode-factory.conf* file, which is stored in */etc/config*. The following configuration settings are defined for router context:

- A trust zone is created and all interfaces are placed into this zone.
- Flow security checks are disabled (no SYN or TCP Seq number checking).
- All host-bound services (ping, Telnet, etc.) and protocols are enabled.
- IPv6 traffic is forwarded.
- Screen options are disabled in the trust zone.
- ALG processing is not performed.

The following steps load the default router context and display the results. As with the default secure context, a root password must be assigned before you can commit:

```
[edit]
regress@propane# load override terminal /etc/config/jsr-series-routermode-factory.
conf
load complete

[edit]
regress@propane# show | no-more
## Last changed: 2007-11-28 15:54:14 PST
system {
    services {
        ssh;
        telnet;
        web-management {
            http {
                interface ge-0/0/0.0;
            }
        }
    }
    syslog {
        file messages {
            any any;
        }
    }
    ## Warning: missing mandatory statement(s): 'root-authentication'
}
interfaces {
    ge-0/0/0 {
        unit 0 {
            family inet {
                address 192.168.1.1/24;
            }
        }
    }
}
security {
    zones {
        security-zone trust {
            tcp-rst;
            host-inbound-traffic {
                system-services {
                    any-service;
                }
                protocols {
                    all;
                }
            }
            interfaces {
                all;
            }
        }
    }
    policies {
        default-policy {
            permit-all;
        }
    }
    alg {
        dns disable;
        ftp disable;
        h323 disable;
        mgcp disable;
        real disable;
        rsh disable;
        rtsp disable;
        sccp disable;
        sip disable;
        sql disable;
        talk disable;
        tftp disable;
        pptp disable;
    }
    forwarding-options {
        family {
            inet {
                mode flow-based;
            }
            inet6 {
                mode packet-based;
            }
            mpls {
                mode packet-based;
            }
        }
    }
    flow {
        allow-dns-reply;
        tcp-session {
            no-syn-check;
            no-syn-check-in-tunnel;
            no-sequence-check;
        }
    }
}
```

Migration Steps

To migrate to JUNOS software with enhanced services, the J-series Services Router must already be running JUNOS software Release 8.3 or later, and it must have a compact flash card with at least 256 MB of storage. To use the Juniper Networks migration tools, you need a web support account, which you can obtain by completing the registration form for your product at the Juniper Networks web site.

Overall, migrating from JUNOS software to JUNOS software with enhanced services is similar to upgrading JUNOS software, except that you must first convert your JUNOS configuration file to a JUNOS software with enhanced services configuration file, and then place it in a location where it is used at the next boot. You then download the JUNOS software with enhanced services package, install the image on the router, and reboot the router so that the software and configuration take effect.

> You must migrate the original configuration file and correctly copy it to */var/config* *before* you load JUNOS software with enhanced services, or you will lose network connectivity after JUNOS software with enhanced services loads. Console access is unaffected.

The minimum steps needed to migrate from the J-series running JUNOS to the J-series running JUNOS software with enhanced services are as follows:

1. Obtain a copy of the current JUNOS configuration file.
2. Migrate the JUNOS configuration to a JUNOS software with enhanced services configuration, and confirm its accuracy.
3. Copy the migrated JUNOS software with enhanced services configuration file for use when the new software is loaded.
4. Download and install the JUNOS software with enhanced services package from Juniper Networks' support site. You need a support account to obtain software packages. JUNOS software with enhanced services packages have *jsr* in the name; for example, *junos-jsr-8.5R1.1-domestic.tgz*.

It's important that you follow the specific sequence of tasks outlined here. If you install JUNOS software with enhanced services code on the router *before* uploading a migrated configuration file, you will lose IP-based remote management access and must use the console port for access to the router.

You will need root access to perform the steps detailed in the migration example. Shell and root account access is needed to copy the migrated configuration to a location where it will load after JUNOS software with enhanced services is installed, and to make space available on the compact flash for the upgrade as needed. Also, the router being migrated needs network connectivity to facilitate copying JUNOS software with enhanced services onto the router for installation.

Before performing the migration, it's a good idea to back up your current software and configuration environment by backing up your primary boot device and configuration onto a secondary storage device (such as a USB storage drive) using the `request system snapshot` command. This way, you can easily recover the previous environment if something goes wrong with the migration, as might happen in the event of a power failure, which can corrupt the process, leaving the primary flash in an unusable state.

During a successful migration, the software package completely reinstalls the system base software and the JUNOS software components. The process tries to retain configuration files, logfiles, SSH keys, and similar information from the previous version, but you should move any files you cannot stand to lose to a remote storage device for safekeeping.

Migration example

The following steps demonstrate a JUNOS to JUNOS software with enhanced services migration. The router used in the demonstration is not part of the earlier topology, because as J2300s, they do not support JUNOS software with enhanced services. To help tie things back to this example in the book, the migration router is loaded with the CoS configuration used at `PBR` from Chapter 9. The only change made to the configuration file was to replace interface `fe-0/0/0` with `ge-0/0/2` in order to accommodate the new router's interface hardware. The new `PBR` supports JUNOS software with enhanced services migration because as a J4350, it's a supported platform, it has a 256 MB flash, and it is running JUNOS software Release 8.5 (a minimum of Release 8.3 is needed). Here are the relevant details of this router's hardware configuration:

```
[edit]
lab@PBR# run show chassis hardware detail
Hardware inventory:
```

```
Item             Version  Part number  Serial number Description
Chassis                                JN1093EBXXXX  J4350
Midplane         REV 01   710-014594   NJ7284
System IO        REV 01   710-016210   NH9941        JX350 System IO
Crypto Module                                        Crypto Acceleration
Routing Engine   REV 05   710-015273   HY8015        RE-J4350-2540
  ad0     244 MB  256MB CRR            2466J7C50A62760004 Compact Flash
FPC 0                                             FPC
  PIC 0                                           4x GE Base PIC
Power Supply 0

[edit]
lab@PBR# run show version
Hostname: PBR
Model: j4350
JUNOS Software Release [8.5R1.8]
```

Step 1: Copy the current configuration file

You can copy (and back up) the current JUNOS software configuration using a variety of approaches. The file should be stored off of the router that is being migrated for safekeeping, and to allow it to be run through the migration tool as described later.

Options here include saving the configuration and then transferring the file using FTP or SCP, or using the copy and paste function of a terminal emulator program. If you are particularly nerdy, you can follow the steps outlined in the migration guide, which give you access to a root shell to deal with the *juniper.conf.gz* configuration file directly. Note that this is a compressed file (*gunzip*), and you have to decompress it before you can work with its contents. The command `gunzip juniper.conf.gz` accomplishes this task and results in a *juniper.conf* text file.

The specific approach you take really does not matter, as long as you obtain the *entire* configuration file. In this example, the user saves the complete configuration to a local file, and then displays the configuration for copying into a terminal buffer. You also could use a single `show configuration` command to copy into a terminal buffer, but the file save operation makes it easy to FTP a copy of the configuration to a new location. Once in the terminal buffer, the contents are pasted into a text editor and saved as plain text (not shown). When you save the file, make sure the text editor preserves Unix-style line breaks and does not wrap text.

It's critical that you issue the `save` command at the *root* of the configuration hierarchy to avoid missing any parts of the configuration, as shown:

```
[edit]
lab@PBR# run file show old_junos_config | no-more
version 8.5R1.8;
system {
    host-name PBR;
    ports {
        console type vt100;
    }
    root-authentication {
        encrypted-password "$1$snnzRpPx$3Qj3oNJ9VjdCY95kRrM/T/"; ## SECRET-DATA
    }
    login {
        user lab {
            uid 2003;
. . .
```

At this point, it's also a good idea to perform a system snapshot command with a supported USB media stick in the secondary flash slot. This way, if something should go wrong in the upgrade process, you can reboot from the secondary media with a `request system reboot media usb` command; if the router is not able to boot from primary flash, it automatically tries the USB device. Once booted from USB, you then perform another snapshot, this time to copy from the USB to the primary compact flash to restore the original environment.

Step 2: Migrate the existing configuration to a JUNOS software with enhanced services configuration

Juniper Networks has made a migration tool available to automate the configuration changes involved in migration from JUNOS to JUNOS software with enhanced services. To use the tool, you need a support account, which you also need in order to download JUNOS software with enhanced services. You can access the migration tool via a supported web browser at *http://migration-tools.juniper.net*.

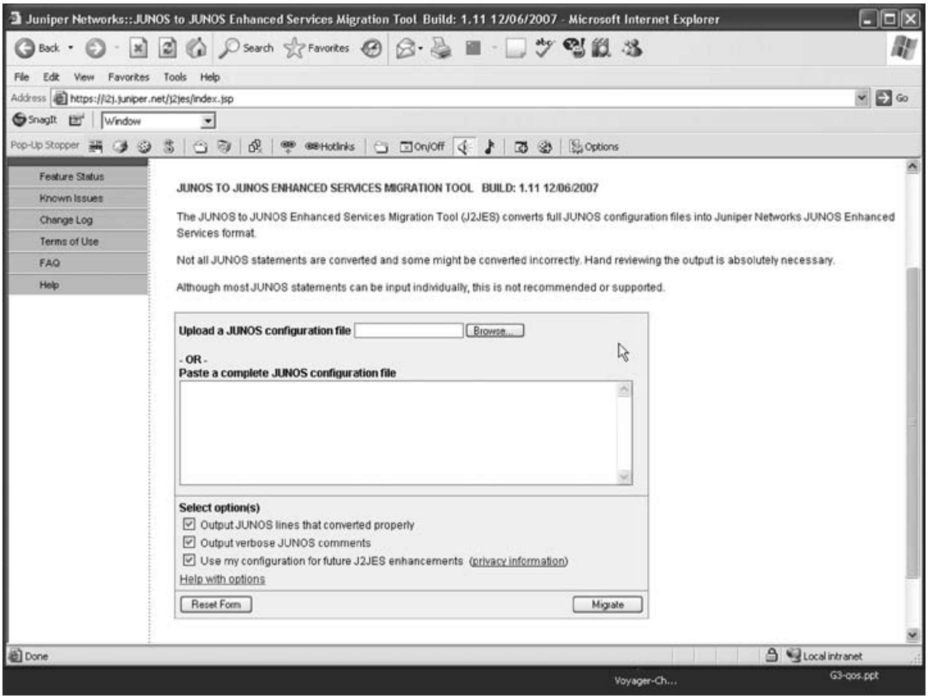
JUNOS configurations without `stateful-firewall`, `services nat`, or `services ipsec-vpn` configuration statements are converted into router context so that an explicit security policy is not required to forward packets.

In contrast, JUNOS configurations that do contain these service types are converted to a secure context mode, along with the security policies needed for communication.

As with any conversion tool, it is the user's responsibility to pay attention to any warning or error messages, which may indicate an incomplete conversion or the presence of an unsupported feature. Most of the changes in JUNOS software with enhanced services relate to services, so configurations with autonomous system (AS) Physical Interface Card (PIC)-based security or NAT-related services require more adaptation.

The migration support tool is web-based, and it supports file upload or the simple pasting of your original configuration into the web page. Cut and paste tends to be better for smaller configurations or when you wish to perform migration on only a portion of a configuration. Figure 11-4 provides an example of the JUNOS software with enhanced services migration tool's user interface.

The settings shown in Figure 11-4 confirm that all warnings and errors are enabled, which is suggested to ensure that you are alerted to any possible issue with the conversion process. After uploading or pasting the configuration, simply click the



Address: https://j2j.juniper.net/j2jes/index.jsp

JUNOS TO JUNOS ENHANCED SERVICES MIGRATION TOOL BUILD: 1.11 12/06/2007

The JUNOS to JUNOS Enhanced Services Migration Tool (J2JES) converts full JUNOS configuration files into Juniper Networks JUNOS Enhanced Services format.

Not all JUNOS statements are converted and some might be converted incorrectly. Hand reviewing the output is absolutely necessary.

Although most JUNOS statements can be input individually, this is not recommended or supported.

Upload a JUNOS configuration file

- OR -

Paste a complete JUNOS configuration file

Select option(s)

☑ Output JUNOS lines that converted properly

☑ Output verbose JUNOS comments

☑ Use my configuration for future J2JES enhancements (privacy information)

Help with options

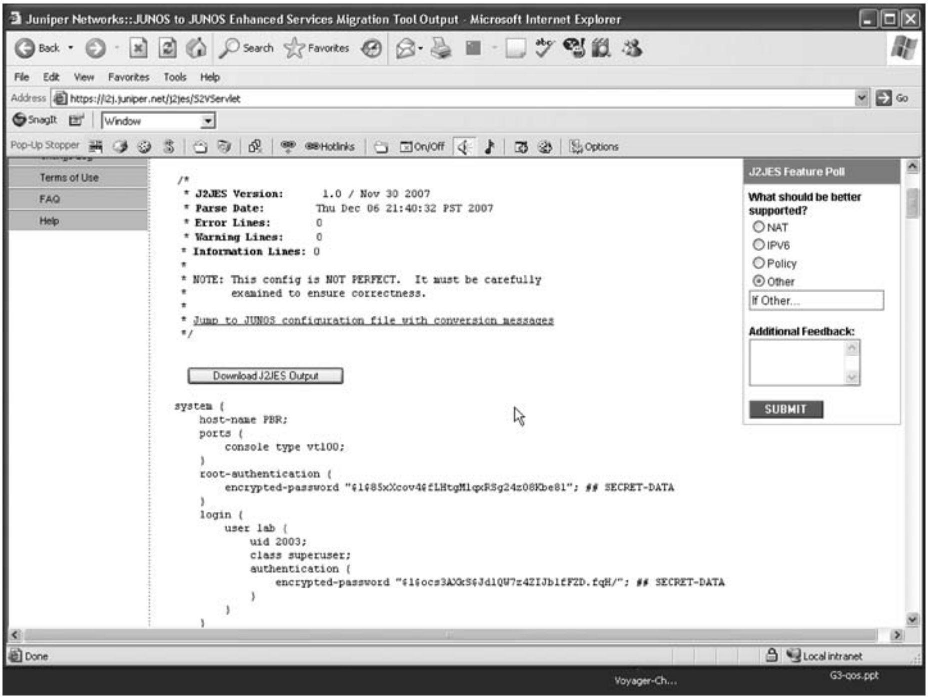
Figure 11-4. The JUNOS software with enhanced services migration tool

Migrate button to convert the configuration. Figure 11-5 shows the result with the sample CoS configuration from PBR.

The key thing to note in Figure 11-5 is that no informational, error, or warning messages were generated. This pretty much confirms that all went well with the conversion, but it's *still* suggested that you closely inspect the results before loading the configuration onto the router. You can either copy the migrated configuration back into a terminal buffer or use the download option to save a local copy of the file. Given the small size of the file, this example makes use of copying the results into the terminal buffer (again, not shown).

Step 3: Copy the migrated configuration for use when JUNOS software with enhanced services loads

To accomplish this step, you will require root shell access. You need this so that you can copy the migrated configuration file to a location where it will become active when the router later reboots with the new JUNOS software with enhanced services code. This process is required because the changes added to maintain existing network connectivity *after* the conversion to JUNOS software with enhanced services are *not compatible* with the JUNOS software now running on the router. Therefore,


Juniper Networks::JUNOS to JUNOS Enhanced Services Migration Tool Output - Microsoft Internet Explorer
Back
Search
Favorites
File Edit View Favorites Tools Help
Address https://i2j.juniper.net/j2jes/S2VServlet
Go
SnagIt
Window
Pop-Up Stopper
Hotlinks
On/Off
Options
Terms of Use
FAQ
Help
Download J2JES Output
Done
Local intranet
Voyager-Ch...
G3-qos.ppt

```
/*
 * J2JES Version:      1.0 / Nov 30 2007
 * Parse Date:        Thu Dec 06 21:40:32 PST 2007
 * Error Lines:        0
 * Warning Lines:      0
 * Information Lines: 0
 *
 * NOTE: This config is NOT PERFECT.  It must be carefully
 *       examined to ensure correctness.
 *
 * Jump to JUNOS configuration file with conversion messages
 */

system {
    host-name PBR;
    ports {
        console type vt100;
    }
    root-authentication {
        encrypted-password "$1$85xXcov4$fLHtgMlqxRSg24z08Kbe81"; ## SECRET-DATA
    }
    login {
        user lab {
            uid 2003;
            class superuser;
            authentication {
                encrypted-password "$1$ocs3AXKS$Jd1QW7z4ZIJb1fFZD.fqH/"; ## SECRET-DATA
            }
        }
    }
```

J2JES Feature Poll

What should be better supported?

○ NAT
○ IPV6
○ Policy
● Other

If Other...

Additional Feedback:

SUBMIT

Figure 11-5. Viewing migration results

simply trying to paste the configuration using a `load override terminal` command results in load errors and the resulting loss of the JUNOS software with enhanced services-specific parts of the configuration that were added by the migration tool—and committing such a configuration will result in loss of network connectivity, requiring console access to recover.

To begin, you must get a copy of the migrated configuration file onto the router. Restating what we discussed earlier, you cannot use the load merge or override function at this time, because of the JUNOS software with enhanced services-specific components of the migrated configuration file. The router needs to have network connectivity so that JUNOS software with enhanced services can later be copied and installed, which means you can use file transfer protocols to accomplish this task. You can also access a shell to evoke the vi editor, paste the terminal buffer contents in insert mode, and then save the file. Because vi can be a bit frustrating to folks who are not familiar with its use, this process is demonstrated:

```
[edit]
lab@PBR# run start shell
% vi es_migrated_conf
```

You should now have a vi editor window open, which appears as shown:

```
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
es_migrated_conf: new file: line 1
```

You now press Esc-i to switch to insert mode—nothing obvious will happen, but you may hear a keyboard beep when you press the Esc key. You can now perform a paste operation from your terminal emulation program to paste the migrated configuration file into the vi editor:

```
system {
    host-name PBR;
    ports {
        console type vt100;
    }
    root-authentication {
        encrypted-password "$1$85xXcov4$fLHtgMlqxRSg24zO8Kbe81"; ## SECRET-DATA
    }
    login {
        user lab {
            uid 2003;
            class superuser;
            authentication {
                encrypted-password "$1$ocs3AXkS$JdlQW7z4ZIJblfFZD.fqH/"; ## SECR

. . .
```

Once the paste is complete, you exit the vi editor while saving changes by pressing Esc-Z-Z—vi is case-sensitive, and those are uppercase *Z*s. You should see a line such as the following confirming the size of the file written to the media:

```
es_migrated_conf: new file: 40 211 lines, 4975 characters
%
```

Once stored on the router, go to a shell and rename the file to *juniper.conf*, as shown:

```
% ls -la
total 34
drwxr-xr-x    3 lab   staff   512 Nov 28 13:16 .
drwxr-xr-x  217 root  wheel  4096 Nov 28 12:21 ..
drwxr-xr-x    2 lab   staff   512 Nov 28 12:21 .ssh
-rw-r--r--    1 lab   staff  5032 Nov 28 12:46 old_junos_config
-rw-r--r--    1 lab   staff  5725 Nov 28 13:16 es_migrated.conf
% mv es_migrated.conf juniper.conf
% ls -la
total 34
drwxr-xr-x    3 lab   staff   512 Nov 28 13:16 .
drwxr-xr-x  217 root  wheel  4096 Nov 28 12:21 ..
drwxr-xr-x    2 lab   staff   512 Nov 28 12:21 .ssh
-rw-r--r--    1 lab   staff  5032 Nov 28 12:46 old_junos_config
-rw-r--r--    1 lab   staff  5725 Nov 28 13:16 juniper.conf
```

You must now su to root to execute commands that back up the existing *juniper.conf* to a new directory; this is done for safekeeping. You then copy the new *juniper.conf* into the location of the original *juniper.conf* file:

```
% su
Password:
```

After successfully switching to the root user, change to the */config* directory:

```
root@propane% cd /config
```

A new directory is created to store a copy of the current configuration:

```
root@propane% mkdir backup
```

And the current configuration environment is moved into the backup directory:

```
root@propane% mv /juniper.conf* backup/

root@PBR% ls backup/
juniper.conf.1.gz       juniper.conf.3.gz
juniper.conf.2.gz       juniper.conf.gz
```

With the original configuration safely backed up, the migration configuration file is copied to the */config* directory, where it will be evoked at the next boot:

```
root@propane% cp /var/home/lab/juniper.conf ./
```

The results are confirmed:

```
root@PBR% pwd
/config
root@PBR% ls
backup          juniper.conf
```

It is good to take one last look at the final *juniper.conf* file with vi or by dumping its contents to screen using the cat command in order to confirm that no corruption has occurred during the file transfer or editing and renaming processes, such as could happen with incorrect FTP transfer mode (ASCII should be used when working with the plain-text, uncompressed format file), or more likely because a Windows text editor inserted incompatible line breaks (also called end-of-line characters). In this example, things seem all right with the file:

```
root@PBR% cat juniper.conf | more
    system {
    host-name PBR;
    ports {
        console type vt100;
    }
    root-authentication {
        encrypted-password "$1$85xXcov4$fLHtgMlqxRSg24zO8Kbe81"; ## SECRET-DATA
    }
    login {
        user lab {
            uid 2003;
            class superuser;
            authentication {
                encrypted-password "$1$ocs3AXkS$JdlQW7z4ZIJblfFZD.fqH/"; ## SECRET-
DATA
            }
        }
    }
    services {
        ftp;
        ssh;
        telnet;
. . .
```

Note that a commit is not performed at this time because the new portions of the configuration file will not be understood by the JUNOS software now running. The new configuration is used later when you reboot as part of loading JUNOS software with enhanced services.

Step 4: Copy and install JUNOS software with enhanced services

With the original configuration migrated to be compatible with JUNOS software with enhanced services and now placed where it will take effect at the next reboot, it is time to obtain and load the desired JUNOS software with enhanced services package. Before attempting to load the new package, it is a good idea to first free up as much space as possible

Free up space. The limited compact flash storage space, combined with the lack of a hard drive for storing images that are being unpacked for installation, can create problems when you attempt to upgrade or downgrade JUNOS versions on any J-series router, regardless of whether they are JUNOS software with enhanced services packages or not. The following steps are general approaches to freeing up compact flash space. You will need root access to delete any files that are owned by root.

First, we use the CLI cleanup utility to rid ourselves of the easy, low-hanging fruit:

```
lab@propane> request system storage cleanup

List of files to delete:

         Size Date         Name
   449B Nov 26 23:03 /cf/var/log/install.0.gz
  7581B Nov 28 13:49 /cf/var/log/messages.0.gz
  6383B Nov 28 13:49 /cf/var/log/security.0.gz
Delete these files ? [yes,no] (no) yes
```

Next, delete the backup software package, if present. This package is used after an upgrade to revert back to the previous version using a `request system software rollback` command. The rollback image is no longer needed as the current software environment is being upgraded.

```
lab@propane> request system software delete-backup
Delete backup system software package [yes,no] (no) yes

lab@propane>
```

Confirm that you have enough compact flash space. The release notes for JUNOS software with enhanced services software Release 8.5R1 provide the following compact flash space guidelines:

> To copy the software image to the router and install using that image, you need at least 130 MB of available space on the compact flash.
>
> To install the software without copying the software image to the router you need at least 68 MB. You use the `no-copy` and `unlink` options with the `request system software add` command to prevent copying the package on the router during installation.

The `show system storage` command displays used and free space on the compact flash:

```
lab@propane> show system storage
Filesystem         Size       Used      Avail  Capacity   Mounted on
/dev/ad0s1a        213M       113M        98M       54%  /
devfs              1.0K       1.0K         0B      100%  /dev
devfs              1.0K       1.0K         0B      100%  /dev/
. . .
```

In this case, 98 MB of space is available on the flash, which is more than sufficient when the `no-copy` and `unlink` switches are added.

Install JUNOS software with enhanced services. You are now ready to upgrade the router to run JUNOS software with enhanced services. It is assumed that you have obtained the desired package from the Juniper support web site, and that the image is in place on the router being migrated. Good housekeeping says the package should be stored in the */var/tmp* directory, but this requires root access.

Tips for Freeing More Space

Large files left in user directories or in nonstandard places may consume so much space that you are not able to load a new software package. If you have shell access, try this handy command:

```
lab@propane> start shell
% find -x /cf -type f -exec du {} \; | sort -n
find: /cf/var/cron/tabs: Permission denied
. . .
0       /cf/etc/namedb/resolver.cache
. . .
448     /cf/var/log/dcd
1024    /cf/var/log/chassisd
1440    /cf/var/log/httpd
107776  /cf/var/tmp/junos-jsr-8.5R1.8-domestic.tgz
114512  /cf/packages/junos-8.5R1.8-domestic
```

The output is sorted from smallest to largest files found, so you want to focus on the entries near the end of the display. Once you know where the large files are, it is a simple matter to delete or move them off the router as desired. In this example, the largest files on the systems are the soon-to-be-installed JUNOS software with enhanced services in */var/tmp* and the currently installed JUNOS version in */var/cf*. Any other large files in user directories or in the */tmp* or */var/tmp* directory are good candidates for deletion. Note that symbolic links result in */var/home* being mapped to */cf/var/home*; therefore, you can use either path:

```
root@PBR% cd /var/home/
root@PBR% pwd
/cf/var/home
```

To perform the upgrade, issue the `request system software add` command followed by the path and name of the JUNOS software with enhanced services package to be installed—in this example, you must use include the `no-copy` and `unlink` switches because of space issues described previously, and you should *also* add the `no-validate` switch.

The `no-validate` option is used here to avoid validation of the active configuration, which is the previous, nonmigrated version, against the new software that is being installed. After installation, the migrated JUNOS software with enhanced services-compatible configuration file will be read by the new software, and all will be well.

```
lab@propane>request system software add jsr-8.5R1.8-domestic.tgz no-
copy unlink no-validate
WARNING: Unpacking package junos-8.5R1.8.tgz in /var/tmp/pkg_instmp
6287/junos-8.5R1.8
Installing package '/var/tmp/pkg_instmp6287/junos-8.5R1.8' ...
Verified junos-boot-jsr-8.5R1.8.tgz signed by PackageProduction_8_5_0
Verified junos-jsr-8.5R1.8-domestic signed by PackageProduction_8_5_0
Available space: 92264 require: 2405
WARNING: junos-8.5R1.8-domestic is already installed,
WARNING: moving it aside.
ls: junos.old: No such file or directory
JUNOS 8.5R1.8 will become active at next reboot
WARNING: A reboot is required to load this software correctly
WARNING:     Use the 'request system reboot' command
WARNING:         when software installation is complete
Saving state for rollback ...
Removing /var/tmp/pkg_instmp6287/junos-8.5R1.8
```

If desired, you can add the `reboot` switch to the `request system software` command to avoid having to reboot the router to complete installation. In this case, we can reboot at our leisure, but the suspense is getting heavy, so it's time to get it on, so to speak:

```
lab@propane> request system reboot
Reboot the system ? [yes,no] (no) yes
```

After a few minutes, the installation completes and your old router is back, except now it's capable of taking advantage of JUNOS software with enhanced services features:

```
Local package initialization:.
starting local daemons:.
kern.securelevel: -1 -> 1
Wed Nov 28 22:18:53 UTC 2007

PBR (ttyd0)

login: lab
Password:

--- JUNOS 8.5R1.8 built 2007-11-05 18:58:07 UTC
lab@PBR> show version
Hostname: PBR
Model: j4350
JUNOS Software Release [8.5R1.8] Enhanced Services
```

So, what changed?

The migrated configuration file—which as you may recall was based on the CoS configuration used at `PBR` in Chapter 9—is displayed. The only JUNOS software with enhanced services-specific addition is the new `security` stanza, displayed here:

```
regress@hay_PBR_r1> configure
Entering configuration mode

[edit]
regress@hay_PBR_r1# show services security {
    zones {
        security-zone Trust {
            host-inbound-traffic {
                system-services {
                    all;
                }
                protocols {
                    all;
                }
            }
            interfaces {
                all;
            }
        }
    }
    policies {
        default-policy {
            permit-all;
        }
    }
}
```

The effect of this stanza is to place JUNOS software with enhanced services into router context with resultant permissive connectivity for all interfaces and protocols. This is expected because the migrated configuration did not contain any security-related services. You can still use stateless filters to protect the router's control plane. This mode of operation is as close as you can get to having JUNOS software with enhanced services operate like standard JUNOS software.

Recall that router context is indicated by a default security policy that permits all communications. However, it's impossible to configure such a policy in a manner that will block communication of new interfaces or services/protocols unless you also update the security stanza to accommodate the additions. Consider this permissive security stanza:

```
[edit]
lab@PBR# show security
zones {
    security-zone Trust {
        host-inbound-traffic {
            system-services {
                ftp;
                http;
                https;
                ping;
                ssh;
                telnet;
                traceroute;
            }
        }
        interfaces {
            fe-0/0/0.1241 {
                host-inbound-traffic {
                    protocols {
                        ospf;
                    }
                }
            }
            fe-0/0/0.412 {
                host-inbound-traffic {
                    protocols {
                        ospf;
                    }
                }
            }
            lo0.0;
        }
    }
}
policies {
    default-policy {
        permit-all;
    }
}
```

Even though there is a single trust zone and permissive accept-all policy, the lack of `interface all`, `protocols all`, or `services all` statements means that each new interface or service/protocol needs to be explicitly added. The point of all this is that there can be various levels of router context. A *true* router context uses the `all` keyword to accommodate future changes without the need for security modifications, just like regular JUNOS software.

A note on IPv6 and MPLS. IPv4 traffic is always handled as a flow in JUNOS software with enhanced services. In the initial release, flow-based forwarding for IPv6 and Multiprotocol Label Switching (MPLS) is not available. To prevent summary dropping of this traffic, you must add the following to the `[edit security]` stanza:

```
forwarding-options {
    family {
        inet6 {
            mode packet-based;
        }
        mpls {
            mode packet-based;
        }
    }
}
```

The `set` commands used to create router context are provided:

```
[edit]
lab@PBR# show security | display set
set security zones security-zone HOST host-inbound-traffic system-
services any-
service
set security zones security-zone HOST host-inbound-traffic protocols
all
set security zones security-zone HOST interfaces all
set security policies default-policy permit-all
set security forwarding-options family inet6 mode packet-based
set security forwarding-options family mpls mode packet-based
```

JUNOS Software with Enhanced Services Migration Summary

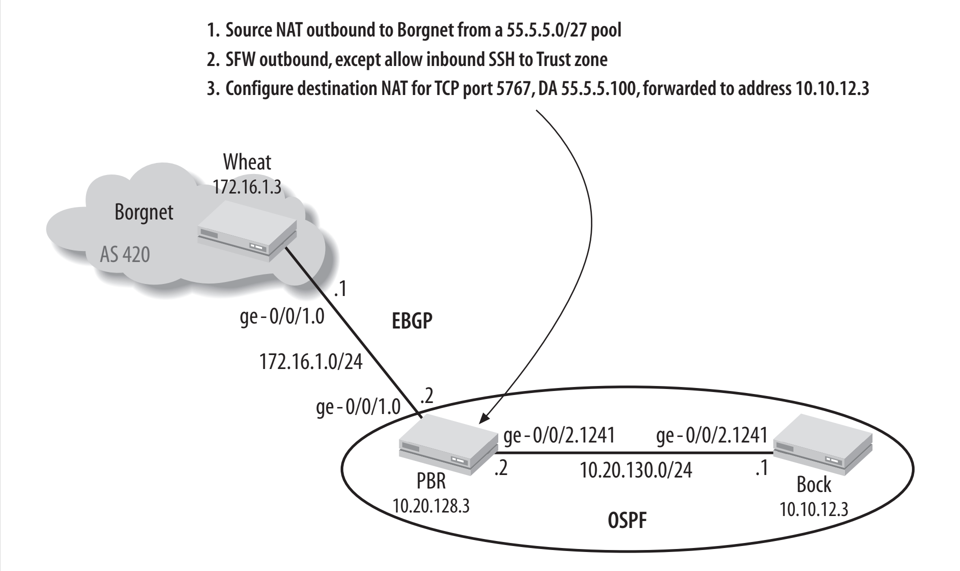
The migration from JUNOS software to JUNOS software with enhanced services is possible on many J-series and SSGm platforms. The migration steps are similar to performing a regular JUNOS upgrade, except there is a configuration conversion and a need to place the converted file in a location that is used when booting with the new software.

The web-based migration tool requires a support account, but it makes the ASP-based service's migration set to the ScreenOS service relatively straightforward. Before attempting to migrate, consult the web site for platform requirements, compact flash size, and available space. Having console access is always best when performing this type of process, but it is possible to perform the upgrade without losing network access.

Service Migration Case Study: JUNOS to JUNOS Software with Enhanced Services

This section focuses on a JUNOS configuration with ASP-based services that is migrated to JUNOS with JUNOS software with enhanced services, and therefore demonstrates much of the new configuration syntax for NAT and stateful-firewall services. The point of this exercise is to provide an example of the same set of services, in the same network context, along with the operational mode commands that are used to display and debug flow state.

Figure 11-6 shows the network topology for the services migration case study.



1. Source NAT outbound to Borgnet from a 55.5.5.0/27 pool
2. SFW outbound, except allow inbound SSH to Trust zone
3. Configure destination NAT for TCP port 5767, DA 55.5.5.100, forwarded to address 10.10.12.3

Figure 11-6. Services migration topology

As called out in the diagram, router PBR is the services-enabled router, and therefore the focus of the example. The particulars of this topology vary slightly from the example used in other chapters. These changes result from use of a different test bed with J-series routers that support JUNOS software with enhanced services. The primary change in the topology is the shift to J4350s that use GE interfaces. The link between Wheat and PBR no longer uses virtual LAN (VLAN) tagging, in order to accommodate a switch. Also, the routers are using their ge-0/0/0 interfaces for Out of Band (OoB) management purposes, providing Telnet, FTP, and other system services. The OoB network is not shown in Figure 11-6, but evidence of its presence can be noted in some of the captures that are provided. A represented set of services have been enabled on PBR. Specifically, it is configured to:

1. Perform stateful-firewall services on all outbound traffic, except traffic in rule 2.
2. Allow incoming SSH connections, but only to interfaces within the trust zone.
3. Perform source NAT (SNAT) on all traffic transiting PBR; locally originated BGP traffic is not subjected to NAT.
4. Perform destination NAT (DNAT) on TCP packets sent to destination address 55.5.5.100, port 5767; this traffic is forwarded to 10.10.12.3.

The Original JUNOS Software ASP-Based Service Set

The key aspects of PBR's configuration are shown, before the configuration is migrated to a JUNOS software with enhanced services-compatible configuration:

```
. . .
interfaces {
    sp-0/0/0 {
        unit 0 {
            family inet;
        }
    }
ge-0/0/0 {
        unit 0 {
            description out_of_Band_management;
            family inet {
                address 192.168.14.96/24;
            }
        }
    }

    ge-0/0/1 {
        unit 0 {
            description PBR-to-Wheat;
            family inet {
                service {
                    input {
                        service-set wan-services;
                    }
                    output {
                        service-set wan-services;
                    }
                }
                address 172.16.1.2/24;
            }
        }
    }
    ge-0/0/2 {
        vlan-tagging;
        unit 1241 {
            description PBR_to_Bock;
            vlan-id 1241;
            family inet {
                address 10.20.130.2/24;
            }
        }
    }
    lo0 {
        unit 0 {
            family inet {
                address 10.20.128.3/32;
                address 55.5.5.1/32;
            }
        }
    }
}
```

The interfaces stanza matches the topology shown in Figure 11-6. Note the definition of a services interface based on an ASP service set, as indicated by the sp-0/0/0 interface. The ge-0/0/0 interface provides OoB network management.

```
routing-options {
    aggregate {
        route 10.0.0.0/8;
        route 55.5.5.0/24;
    }
    autonomous-system 1282;
}
```

There is not much to note here, other than two aggregate routes that end up being advertised to BGP peering AS Borgnet. Because SNAT is in effect, the 10.0.0.0/8 is not technically needed. Note that the lo0 interface has a 55.5.5.1/32 address, which activates the aggregate for the 55.5.5.0/24 prefix, which represents the SNAT pool of addresses that are presented to the rest of the world.

```
protocols {
    bgp {
        export send-agg;
        group as_420 {
            type external;
            neighbor 172.16.1.1 {
                peer-as 420;
            }
        }
    }
    ospf {
        export send-borgnet;
        area 0.0.0.0 {
            interface ge-0/0/2.1241;
            interface ge-0/0/1.0;
            interface lo0.0 {
                passive;
            }
        }
    }
}
```

The protocol configuration sets up the External BGP (EBGP) peering to Borgnet and Open Shortest Path First (OSPF) area 0 operation to Bock. Note that export policies are in place for both protocols. And speaking of policies, here they are:

```
    policy-options {
        policy-statement send-agg {
            from protocol aggregate;
            then accept;
        }
        policy-statement send-borgnet {
            from {
                route-filter 172.16.1.0/24 orlonger;
                route-filter 128.3.0.0/16 orlonger;
            }
            then accept;
        }
    }
```

The two policies result in the advertisement of the 10.0.0.0/8 and 55.5.5.0/24 aggregates to Borgnet and the redistribution of the Borgnet BGP peering and loopback addresses through advertisement of the directly connected 172.16.1.0/24 route into OSPF:

```
    services {
        stateful-firewall {
            rule all-algs {
                match-direction output;
                term 1 {
                    from {
                        application-sets junos-algs-outbound;
                    }
                    then {
                        accept;
                    }
                }
                term 2 {
                    then {
                        accept;
                    }
                }
            }
            rule all-ssh {
                match-direction input;
                term 1 {
                    from {
                        applications [ junos-ssh junos-bgp ];
                    }
                    then {
                        accept;
                    }
                }
                term 2 {
                    from {
                        destination-address {
                            55.5.5.100/32;
                        }
                    }
                    then {
                        accept;
                    }
                }
            }
        }
        nat {
            pool ext-block {
                address-range low 55.5.5.2 high 55.5.5.30;
                port automatic;
            }
            rule translate-all {
                match-direction output;
                term 1 {
                    from {
                        source-address {
                            10.0.0.0/8;
                        }
                    }
                    then {
                        translated {
                            source-pool ext-block;
                            translation-type {
                                source dynamic;
                            }
                        }
                    }
                }
            }
            rule pin-hole {
                match-direction input;
                term 1 {
                    from {
                        destination-address {
                            55.5.5.100/32;
                        }
                        applications special-port-map;
                    }
                    then {
                        translated {
                            destination-prefix 10.10.12.3/32;
                            translation-type {
                                destination static;
                            }
                        }
                    }
                }
            }
        }
        service-set wan-services {
            stateful-firewall-rules all-algs;
            stateful-firewall-rules all-ssh;
            nat-rules translate-all;
            nat-rules pin-hole;
            interface-service {
                service-interface sp-0/0/0.0;
            }
        }
    }
    applications {
        application special-port-map {
            protocol tcp;
            destination-port 5767;
        }
    }
```

The services configuration sets up a service set called wan-services, which provides a stateful firewall for all incoming traffic, except BGP, SSH, and a pinhole that is opened for TCP traffic sent to port 5767 and destination address 55.5.5.100. In the latter case, matching traffic has the destination address changed to 10.10.12.3, which is the loopback address of Bock. All traffic from the 10.0.0.0/8 space undergoes SNAT using a pool of addresses ranging from 55.5.5.2–55.5.5.30. Note that the 55.5.5.1 address assigned to the lo0 interface is left outside the NAT pool, as is the 55.5.5.100 destination address associated with pinhole traffic.

Original ASP-based service set: Operational analysis

Confirmation begins with the verification of BGP and OSPF at PBR:

```
[edit]
regress@hay_PBR_r1# run show bgp summary
Groups: 1 Peers: 1 Down peers: 0
Table   Tot Paths  Act Paths Suppressed  History Damp State  Pending
inet.0          1          1          0        0          0        0
Peer         AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
172.16.1.1        420         69         74       0       0
30:35 1/1/0               0/0/0
```

```
[edit]
regress@hay_PBR_r1# run show ospf neighbor
Address       Interface         State     ID             Pri  Dead
10.20.130.1   ge-0/0/2.1241     Full      10.255.14.97   128    33
```

To test the services, a Telnet session to 55.5.5.100, port 5767, is generated at Wheat, while pings are generated from Bock to Wheat's loopback address. The pings succeed (not shown), but the Telnet session that originated at Wheat to port 5767 is expected to fail. This is because there is no TCP process listening at port 5767 on Bock. Despite the connection failure, there are ways to confirm that DNAT is working.

The flow session table is displayed at PBR. Note that the current JUNOS ASP-based services are displayed using a show services command:

```
[edit]
regress@hay_PBR_r1# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: wan-services
Flow                                    State    Dir       Frm count
TCP        172.16.1.3:62162 -> 55.5.5.100:5767  Forward  I          1
    NAT dest       55.5.5.100:5767    ->      10.10.12.3:5767
TCP        10.10.12.3:5767  -> 172.16.1.3:62162 Forward  O          0
    NAT source      10.10.12.3:5767    ->      55.5.5.100:5767
```

The first pair of session entries reflects the DNAT pinhole traffic. Note the 5767 port number and TCP protocol, and that the destination address is translated to 10.10.12.3. The next entry is the return traffic that is the TCP reset that results because there is no process listening at Bock. The I and O flags indicate input versus output.

```
ICMP        172.16.1.3:1044  ->       55.5.5.2       Watch    I   2
    NAT dest         55.5.5.2:1044    ->     10.20.130.1:20783
ICMP       10.20.130.1:20783 ->     172.16.1.3       Watch    O  2
    NAT source     10.20.130.1:20783   ->       55.5.5.2:1044
```

This pair of entries represents the ping traffic generated at Bock. Note that the outgoing flow is undergoing SNAT, having the 10.20.13.1 address translated to a 55.5.5.5.2 address in this example.

```
TCP       172.16.1.2:64827 ->   172.16.1.1:179   Forward  O     146
TCP       172.16.1.1:179   ->   172.16.1.2:64827 Forward  I     144
```

The final pair of entries represents the BGP session (port 179), which is not subjected to SNAT due to the 172.16.1.2 address from which the BGP session originates. DNAT forwarding behavior (despite actual inability to form a Telnet connection) is confirmed by monitoring traffic at Bock's ge-0/0/2 interface:

```
21:01:38.368620  In IP 172.16.1.3.62269 > 10.10.12.3.5767: S 2699291864:2699291864(0)
win 65535 <mss 1460,nop,wscale 1,nop,nop,
timestamp 1790573405 0,sackOK,eol>
21:01:38.368639 Out IP 10.10.12.3.5767 > 172.16.1.3.62269: R 0:0(0)
ack 1 win 0
```

The traffic shows an incoming TCP connection request (SYN and ACK flags set) sent to destination port 5767, from 172.16.1.3. Note that Bock resets the connection, which is expected behavior here. DNAT port-forwarding success is not contingent on the device that receives the data actually *wanting* the traffic—the receipt alone is enough to confirm DNAT.

You can assume that an SSH session originated at Wheat to any of the 10.0.0.0/8 addresses within Beer-Co is successful (not shown). The same connection request using Telnet fails, due to the stateful firewall that is in effect.

The Migrated JUNOS Software with Enhanced Services Configuration

The original, ASP-based configuration shown earlier is run through the migration tool, for use with JUNOS software with enhanced services. The file is then copied and renamed on the router, and JUNOS software with enhanced services is loaded, as per the procedure detailed in "Migrating from JUNOS to JUNOS Software with Enhanced Services," earlier in this chapter. The altered portions of the migrated configuration are shown, and are commented on as appropriate. The first change to note is that the ASP-based sp-0/0/0 services interface has been removed. Note that a services interface is not present in the migrated configuration. In JUNOS software with enhanced services, a services interface is used to support route-based VPNs; it's called an st0 (secure tunnel) interface. This interface does not exist in the migrated configuration because no VPNs were defined.

The first section in the new stanza at the [edit security] hierarchy defines the NAT pool used in both DNAT and SNAT. The NAT pool names are the choice of the migration tool, and you can change them if desired.

```
[edit]
regress@hay_PBR_r1# show security
nat {
    destination-nat pool_10_10_12_3 address 10.10.12.3;
    interface ge-0/0/1.0 {
        source-nat {
            pool ext-block {
                address-range {
                    low 55.5.5.2 high 55.5.5.30;
                }
            }
        }
    }
}
. . .
```

The next section of the security stanza defines the security zones:

```
    . . .
zones {
        security-zone external_wan-services {
            host-inbound-traffic {
                system-services {
                    ftp;
                    ssh;
                    telnet;
                }
            }
            interfaces {
                ge-0/0/1.0;
            }
        }
        security-zone internal_wan-services {
            address-book {
                address address_55_5_5_100_32 55.5.5.100/32;
                address address_10_0_0_0_8 10.0.0.0/8;
            }
            host-inbound-traffic {
                system-services {
                    ftp;
                    ssh;
                    telnet;
                }
            }
            interfaces {
                ge-0/0/2.1241 {
                    host-inbound-traffic {
                        protocols {
                            ospf;
                        }
                    }
                }
                ge-0/0/0.0 {
                    host-inbound-traffic {
                        protocols {
                            ospf;
                        }
                    }
                }
                lo0.0 {
                    host-inbound-traffic {
                        protocols {
                            ospf;
                        }
                    }
                }
            }
        }
    }
. . .
```

The zones configuration defines two security zones: an `external-wan-services` zone that is associated with the EBGP peering interface and an `internal-wan-services` zone housing the internal and OoB interfaces. Figure 11-7 shows the resultant zone configuration.

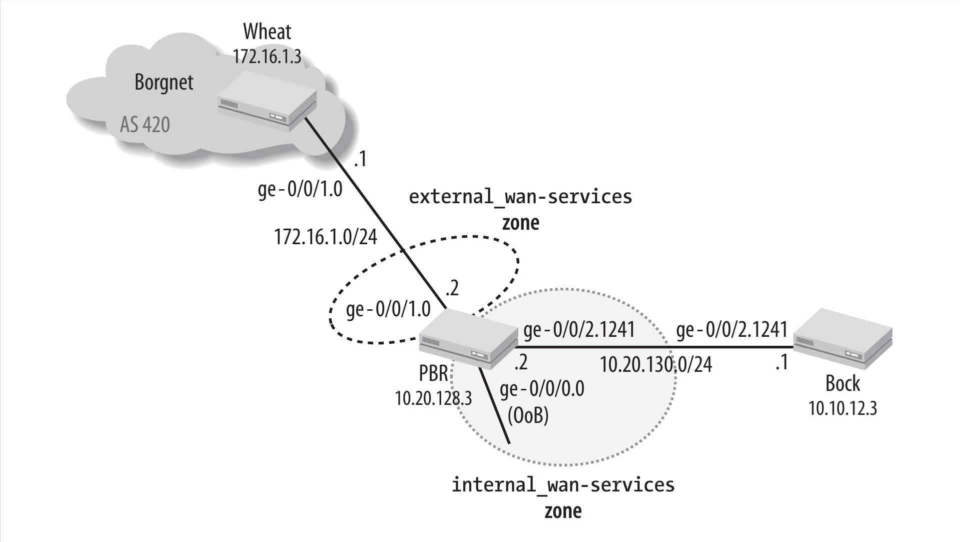


Figure 11-7. The migrated zone configuration

The external-wan-services zone is set to support a limited subset of host services. Note that some of these services were not reachable from external hosts in the original, ASP-based configuration. The presence of additional host services helps in fault isolation, and you can remove it later if desired—for example, to prevent Telnet access to the local router over the 172.16.1.0/24 subnet. BGP does not have to be explicitly allowed on the ge-0/0/1 interface because, as you will soon see, the stateful firewall is configured to allow incoming BGP (and SSH).

The internal-wan-services zone includes the router's lo0 interface, the ge-0/0/0 OoB interface, and the ge-0/0/2 interface that connects to Bock. This zone allows a wider range of system services, which is in keeping with the higher level of trust for this internal zone and which explicitly allows OSPF on the lo0 and ge-0/0/2 interfaces. It seems that ping was not added to the list of supported services during the migration, which means that internal ping testing is not possible until the list of supported host services is modified, a behavior that differs from the premigration environment. Also worth noting here is that the list of supported services or protocols always takes the *most specific* application. This means that when an interface has no explicit list of services, as in this example, the interface inherits the services specified under inbound host traffic. However, if you add a specific service to an interface, that interface no longer inherits the values of the inbound host services settings. The same is true for protocols. To provide an example, if you added BGP to inbound host traffic, you would expect to see that BGP traffic is *not* accepted by any of the interfaces. This is because as configured, each interface has its own protocol stanza and therefore ignores the protocols specified under inbound host traffic.

Adding a new interface, or adding a new protocol such as Internal BGP (IBGP) to the ge-0/0/2 interface, requires updates to the internal-wan-services zone to permit communications, given the secure context that resulted from migration of a configuration that used ASP-based stateful services.

The two address book entries create symbolic name-to-prefix mappings that are later used in NAT-related policy actions. The policy portion of the security stanza is examined:

```
        . . .
    policies {
        from-zone internal_wan-services to-zone external_wan-services {
            policy all-algs_1 {
                match {
                    source-address any;
                    destination-address any;
                    application cjunos-algs-outbound;
                }
                then {
                    permit;
                }
            }
            policy translate-all_1 {
                match {
                    source-address address_10_0_0_0_8;
                    destination-address any;
                    application any;
                }
                then {
                    permit {
                        source-nat {
                            pool ext-block;
                        }
                    }
                }
            }
        }
        from-zone external_wan-services to-zone internal_wan-services {
            policy all-ssh_1 {
                match {
                    source-address any;
                    destination-address any;
                    application [ junos-ssh junos-bgp ];
                }
                then {
                    permit;
                }
            }
            policy pin-hole_1 {
                match {
                    source-address any;
                    destination-address address_55_5_5_100_32;
                    application special-port-map;
```

```
              }
              then {
                  permit {
                      destination-nat {
                          pool_10_10_12_3;
                      }
                  }
              }
          }
      }
   }
}
```

The internal_wan-services to-zone external_wan-services policy chain controls communications from the internal to external WAN services zones. Therefore, it evokes ALGs, and then SNAT for source addresses that fall in the 10.0.0.0/8 range.

The external_wan-services to-zone internal_wan-services policy chain is used for flows that enter the external WAN services zone and egress on the internal WAN services zone. Here we see the explicit acceptance of both BGP and SSH via the all-ssh_1 policy. The pin-hole_1 policy then matches on an address book entry for 55.5.5.100, along with an application port map, to evoke DNAT based on the 10.10.12.3 address pool. All other incoming traffic must have matching state, or the stateful-firewall function discards the traffic, preventing it from entering the internal WAN services zone.

It's worth noting that the migration tool did not provide a policy to permit communications between interfaces belonging to the internal-wan-services zone. Recall that unlike ScreenOS, which has intrazone blocking disabled for the trust zone, the 8.5 version of JUNOS software with enhanced services has intrazone blocking enabled, for all zones—in effect, there is no differentiation between a zone named "trust" and one named "untrust" from a security policy perspective. As a result, you can expect that Bock will be able to ping the 10.20.130.2 interface address of PBR, which is accepted by the self-traffic policy (described shortly), whereas a ping or Telnet request to PBR's loopback address fails. The following policy can be added (but is not in this example) to allow unfettered communications among all interfaces in the internal zone:

```
from-zone internal_wan-services to-zone internal_wan-services {
    policy default-permit {
        match {
            source-address any;
            destination-address any;
            application any;
        }
        then {
            permit;
        }
    }
}
```

The remaining area of change in the migration is the [edit applications] stanza, as shown:

```
[edit]
regress@hay_PBR_r1# show applications
applications {
    application special-port-map {
        protocol tcp;
        destination-port 5767;
    }
    /* Applications not listed are not supported */
    application-set cjunos-algs-outbound {
        application junos-ftp;
        application junos-tftp;
        application junos-rpc-portmap-tcp;
        application junos-rpc-portmap-udp;
        application junos-rsh;
        application junos-rtsp;
        application junos-sqlnet-v1;
        application junos-sqlnet-v2;
        application junos-h323;
        application junos-realaudio;
        application junos-dce-rpc-portmap;
        application junos-sip;
    }
}
```

The applications group lists the custom port map used in the pinhole/DNAT and displays the currently supported ALGs.

Confirm JUNOS software with enhanced services operation

The confirmation of JUNOS software with enhanced services operation follows the same functional lines. However, now you use a show security command to monitor NAT, the stateful firewall, and other security-related services.

To ensure clean flow state, begin by clearing all flows. This is a disruptive operation and results in loss of management Telnet/SSH sessions, when used with the all keyword. Note that at this time, the OoB management session is cleared and console access is used to keep session state to a minimum.

```
regress@hay_PBR_r1> clear security flow session all
This command will terminate the current session too.
Continue? [yes,no] (no)yes
```

Once again, OSPF and BGP operation is confirmed:

```
regress@hay_PBR_r1> show ospf neighbor
Address       Interface          State    ID              Pri  Dead
10.20.130.1   ge-0/0/2.1241       Full    10.255.14.97    128    35

regress@hay_PBR_r1> show bgp summary
Groups: 1 Peers: 1 Down peers: 0
```

```
Table   Tot Paths  Act Paths Suppressed  History Damp State  Pending
inet.0          1          1          0        0          0        0
Peer            AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
172.16.1.1    420      2931      2966       0       6    6:33:21 1/1/0
0/0/0
```

The output confirms that both OSPF and BGP are operational: good. Once again, `Bock` generates pings toward `Wheat`, but this time rapid pings are used, and `Wheat` opens an SSH session to the loopback address of `PBR`. Both the pings and SSH connection are successful (not shown). The rapid pings are necessary because the stateful-firewall state ages out quickly for ICMP, so a higher volume of traffic ensures that the ICMP session state is present when the CLI command is executed.

The flow session state is displayed at PBR using the `show security flow session` command:

```
regress@hay_PBR_r1> show security flow session
Session ID: 1284, Policy name: self-traffic-policy/1, Timeout: 58
  In: 10.20.130.1/1 --> 224.0.0.5/1;ospf, If: ge-0/0/2.1241
  Out: 224.0.0.5/1 --> 10.20.130.1/1;ospf, If: .local..0
```

The first session represents OSPF traffic to and from the `ge-0/0/2` interface, and is expected. Note that this traffic is accepted because OSPF is listed as a supported protocol under the `ge-0/0/2.1241` interface. This results in acceptance of the traffic via a nonuser-configurable *self-traffic* policy. The self-traffic policy is evoked when traffic is addressed to the ingress interface itself, as opposed to being addressed to the loopback or other interface address.

```
Session ID: 1285, Policy name: self-traffic-policy/1, Timeout: 1788
  In: 172.16.1.2/59024 --> 172.16.1.1/179;tcp, If: .local..0
Out: 172.16.1.1/179 --> 172.16.1.2/59024;tcp, If: ge-0/0/1.0
```

The next flow represents the EBGP session to `Wheat`, as indicated by the TCP protocol and 179 port values. As the EBGP peering session is interface-based, you again see acceptance via the self-traffic policy.

```
Session ID: 1539, Policy name: all-ssh_1/9, Timeout: 1780
  In: 172.16.1.1/58495 --> 10.10.12.3/22;tcp, If: ge-0/0/1.0
  Out: 10.10.12.3/22 --> 172.16.1.1/58495;tcp, If: ge-0/0/2.1241
```

The next flow is for the SSH test traffic originated at `Wheat`, which terminates at `Bock`'s `lo0` interface in this example. Note that SNAT is not performed for flows that are initiated from the untrust to `internal-wan-services` zone, as doing so would break the communications. `Wheat` in this case expects a response from the SSH session's target address, not from a SNAT pool address.

```
Session ID: 11748, Policy name: translate-all_1/8, Timeout: 60
  In: 10.20.130.1/10091 --> 172.16.1.3/14391;icmp, If: ge-0/0/2.1241
  Out: 172.16.1.3/14391 --> 55.5.5.26/1394;icmp, If: ge-0/0/1.0

4 sessions displayed
```

The final flow entry represents the ICMP test traffic from `Bock` to `Wheat`. Once again, SNAT operation is confirmed by the presence of a 55.5.5.*x* address in the outbound direction.

The destination and source NAT pools are also verified:

```
[edit security]
regress@hay_PBR_r1# run show security nat destination-nat summary
Pool name          Address range                   Port
pool_10_10_12_3    10.10.12.3
[edit security]
regress@hay_PBR_r1# run show security nat source-nat summary
Pool name       Address low     Address high    Interface       PAT
ext-block       55.5.5.2        55.5.5.30       ge-0/0/1.0      yes
```

The command output confirms that both DNAT and SNAT are correctly configured.

> Though not shown, ping and Telnet traffic generated at `Bock` to `PBR`'s 10.20.130.2 `ge-0/0/2.1241` interface address succeeds, as expected. The same traffic fails when addressed to its 10.20.128.3 `lo0` address due to lack of a policy that permits intrazone traffic in the `internal-wan-services` zone, as described previously.

Troubleshoot a flow problem

With the stateful-firewall and NAT aspects of the services configuration confirmed, it's time to move on to the DNAT function for TCP traffic sent to 55.5.5.100:5767. The connection is expected to fail again, but this time, rather than timing out as before, it is now observed to fail immediately:

```
regress@best_Wheat_r0> telnet 55.5.5.100 port 5767
Trying 55.5.5.100...
telnet: connect to address 55.5.5.100: Connection refused
telnet: Unable to connect to remote host
```

Also, a `monitor interface traffic ge-0/0/2` command at `Bock` does not confirm the receipt of the DNAT traffic (not shown). In addition, upon examining the flow session table at `PBR`, there is no evidence of session state for the DNAT traffic.

Although complete coverage of the new services tracing and debug tools is outside the context of this chapter, the lack of DNAT operation affords a chance to demonstrate a typical flow-based troubleshooting scenario. You begin by configuring flow packet drop tracing. Note that most of the main hierarchies at the `[edit security]` stanza have their own tracing capability. For example, to trace and debug firewall authentication, configure tracing at the `[edit security firewall-authentication]` hierarchy.

A Word on Session Timeouts

The flow-based nature of JUNOS software with enhanced services results in a need to age out inactive flows to ensure that flow state does not grow without bounds. The default settings result in TCP-based session timeouts of 1,800 seconds, or 30 minutes. Additionally, the default settings do not reset (clear) TCP sessions upon age out. This can result in the sensation of a "hung terminal" session, where you find the terminal session unresponsive—as though the router had crashed. This behavior differs from that of JUNOS software, which has no such session timeouts given its packet-based forwarding paradigm.

There are a few ways to minimize these issues. First, you can add the `tcp-rst` option to the management traffic's ingress zone. This results in the TCP session clearing upon timeout, which leaves no doubt as to the connection status, thus minimizing the sensation of a hung terminal session. Another option is to configure longer session timeouts for local host management traffic, which is practical only when you have a specific policy for this management traffic; that is, you are not in router context with an accept-all policy. The code example shown matches on the `junos-ssh` ALG permitted by the `all-ssh_1` policy and sets the TCP session timeout to a value of 3,600 seconds, or one hour (24 hours/86,400 seconds is the maximum). Note that a strict security policy favors the timely closing of idle management sessions, and that the following code also affects the timeout of transit SSH sessions, which can lead to excessive resource consumption should you encounter a large number of SSH sessions:

```
application junos-ssh {
    protocol tcp;
    inactivity-timeout 3600;
}

regress@hay_PBR_r1> show security flow session
. .
Session ID: 206256, Policy name: all-ssh_1/9, Timeout: 3590
  In: 172.16.1.1/50327 --> 10.20.128.3/22;tcp, If: ge-0/0/1.0
  Out: 10.20.128.3/22 --> 172.16.1.1/50327;tcp, If: .local..0
```

First, the list of security hierarchies is shown, and then the trace configuration for flows:

```
[edit security]
regress@hay_PBR_r1# set ?
Possible completions:
> alg                  Configure ALG security options
+ apply-groups         Groups from which to inherit configuration
data
+ apply-groups-except  Don't inherit configuration data from these
groups
> authentication-key-chains  Authentication key chain configuration
> certificates         X.509 certificate configuration
> firewall-authentication  Firewall authentication parameters
> flow                 FLOW configuration
> forwarding-options   Security-forwarding-options configuration
> ike                  IKE configuration
> ipsec                IPSec configuration
> nat                  Configure Network Address Translation
> pki                  PKI service configuration
> policies             Configure Network Security Policies
> rtlog-options
> screen               Configure screen feature
> ssh-known-hosts      SSH known host list
> traceoptions         Network security daemon tracing options
> zones                Zone configuration

[edit security]
regress@hay_PBR_r1# show flow
traceoptions {
    file flow;
    flag packet-drops;
}
```

With the flow tracing configuration in effect, the DNAT traffic is again generated at Wheat. A flow trace can be rather chatty, so you can use the CLI match function to quickly find interesting data. In this example, the following trace output is observed:

```
*** flow ***
. . .
Dec  6 20:28:47 20:28:47.475440:CID-0:RT:55.5.5.100/5767,6
Dec  6 20:28:47 20:28:47.475446:CID-0:RT:<Root VSYS(I)>

Dec  6 20:28:47 20:28:47.475449:CID-0:RT:flow_first_routing: DEST
route-lookup failed, dropping pkt and not creating session nh:
4294967295
. . .
```

The trace output shows that a matching flow was in fact dropped by the root virtual system, with the cause being a lack of destination route. This behavior strikes a bell with regard to ScreenOS behavior for DNAT. When performing DNAT, ScreenOS requires a static route to the DNAT destination address—55.5.5.100 in this case—in order to determine the egress interface, and therefore the egress zone. This is needed because the security policy chain is a function of ingress zone to egress zone. This theory is confirmed with a show route at PBR:

```
[edit]
regress@hay_PBR_r1# run show route 55.5.5.100

inet.0: 31 destinations, 31 routes (30 active, 0 holddown, 1 hidden)
+ = Active Route, - = Last Active, * = Both

55.5.5.0/24        *[Aggregate/130] 23:07:08
                      Reject
```

It would appear that a reject next hop does not identify the egress zone, unless you consider /dev/null a zone. A quick static route hack is added:

```
[edit]
regress@hay_PBR_r1# show routing-options static
route 55.5.5.100/32 next-hop 10.20.130.1;
```

The DNAT test traffic is again generated. Note that the session is observed to time out, rather than being immediately closed:

```
regress@best_Wheat_r0> telnet 55.5.5.100 port 5767
Trying 55.5.5.100...
```

Matching flow state is now found in the session table:

```
[edit]
regress@hay_PBR_r1# run show security flow session
Session ID: 201676, Policy name: pin-hole_1/11, Timeout: 14
  In: 172.16.1.1/59547 --> 55.5.5.100/5767;tcp, If: ge-0/0/1.0
  Out: 10.10.12.3/5767 --> 172.16.1.1/59547;tcp, If: ge-0/0/2.1241
. . . .
```

Although not shown, a `monitor traffic interface ge-0/0/2` command at Bock also confirms receipt of the DNAT forwarded traffic. This completes the verification of stateful services and confirms that the formally ASP-based services have been successfully migrated to operate in the JUNOS software with enhanced services environment.

Some other interesting commands

In this section, we will run a few interesting commands to demonstrate various commands that are useful when monitoring or troubleshooting JUNOS software with enhanced services. The `show security zones` command displays interface-to-zone mapping information. Recall that policy is not needed for communication among interfaces in the same zone:

```
[edit security]
regress@hay_PBR_r1# run show security zones

Security zone: Untrust
  Send reset for non-SYN session TCP packets: Off
  Policy configurable: Yes
  Interfaces bound: 1
  Interfaces:
    st0.0

Security zone: external_wan-services
  Send reset for non-SYN session TCP packets: Off
  Policy configurable: Yes
  Interfaces bound: 1
  Interfaces:
    ge-0/0/1.0

Security zone: internal_wan-services
  Send reset for non-SYN session TCP packets: Off
  Policy configurable: Yes
  Interfaces bound: 3
  Interfaces:
    ge-0/0/0.0
    ge-0/0/2.1241
    lo0.0

Security zone: junos-global
  Send reset for non-SYN session TCP packets: Off
  Policy configurable: Yes
  Interfaces bound: 0
Interfaces:
```

To display policy information, as needed for communication among zones, use the show security policies command:

```
[edit]
regress@hay_PBR_r1# run show security policies
Default policy: deny-all
From zone: Trust, To zone: Untrust
  Policy: allow-all, State: enabled, Index: 4, Sequence number: 1
    Source addresses: any
    Destination addresses: any
    Applications: any
    Action: permit, source nat
From zone: Untrust, To zone: Trust
  Policy: all-ssh, State: enabled, Index: 5, Sequence number: 1
    Source addresses: any
    Destination addresses: any
    Applications: junos-ssh
    Action: permit
  Policy: pin-hole, State: enabled, Index: 6, Sequence number: 2
    Source addresses: any
    Destination addresses: address_55_5_5_100_32
    Applications: special-port-map
    Action: permit, destination nat
```

The default deny-all policy confirms a secure context. For both interzone and intrazone communications to succeed, the traffic must be explicitly accepted by a user policy.

JUNOS Software with Enhanced Services Summary

It's true, the services syntax has changed in JUNOS software with enhanced services. This is a change made necessary by the shift from ASP-based service sets to enhanced functionality made available by leveraging the world-class security features of ScreenOS.

Putting the functionality enhancements aside, many find the new syntax to be intuitive, especially if they have experience with ScreenOS and the associated NetScreen security devices.

Juniper Networks has made migration tools available to help ease the transition in services syntax, making the shift to JUNOS software with enhanced services something that should be considered, especially by enterprises that now deploy a two-box solution for their security and routing needs.

Conclusion

JUNOS software with enhanced services represents a significant increase in security, and in general services capabilities for supported platforms. With JUNOS software with enhanced services, users are no longer forced to compromise either services or routing when they opt for a single-box solution. Formerly, this required a multiple-chassis, best-of-breed approach, which added cost and complexity to the network.

In addition to the one-box benefits, that one box is found to run JUNOS software, albeit with enhanced services enabled. This means that all the benefits and advantages of JUNOS are still available, and the majority of operational experience carries directly over, allowing you to immediately feel at home when using JUNOS software with enhanced services.

It is expected that JUNOS software with enhanced services will continue to be expanded, meaning that new services and capabilities will be added. Consult the Juniper Networks web site for the latest information on JUNOS software with enhanced services features and capabilities.

Exam Topics

Currently, the Juniper Networks Certified Internet Expert (JNCIE-ER) examination is based on ASP service sets. As with all exam topics, this is subject to change. Candidates should consult the Juniper Networks web site for up-to-date information on certification examination tracks and topics.

Chapter Review Questions

1. What is the difference between secure and router context?
    a. There is no real difference; both modes support firewall and routing
    b. In secure context, you get the stateful firewall; in router context, you get routing
    c. Secure context has a default deny-all policy whereas router context has an accept-all policy
    d. Both modes have a default deny-all policy, but in router context, all interfaces are in the same zone
2. What is true regarding zones?
    a. You are limited to no more than five
    b. Each zone is restricted to a single interface
    c. Policy is needed to communicate between zones, unless in router context
    d. Policy is needed to communicate between zones

3. What is the result of loading a JUNOS software configuration into a JUNOS software with enhanced services router?
   a. Nothing, they are compatible
   b. You lose all connectivity, including console
   c. You retain console access, but all network connectivity is lost
   d. None of the above; the different hardware platforms make this impossible
4. What is the name of the services interface in JUNOS software with enhanced services?
   a. `sp-0/0/0`
   b. `st-0/0/0`
   c. `es-0/0/0`
   d. The zone-based nature means that a services interfaces is not required
5. Looking back at Figure 11-6, does the following session entry, as taken from `PBR`, indicate that NAT has been performed?

   ```
   Session ID: 1285, Policy name: self-traffic-policy/1, Timeout: 1784
     In: 172.16.1.2/59024 --> 172.16.1.1/179;tcp, If: .local..0
     Out: 172.16.1.1/179 --> 172.16.1.2/59024;tcp, If: ge-0/0/1.0
   ```

   a. No, NAT is not being performed
   b. Yes, NAT is being performed
   c. Only SNAT is being performed
   d. Only DNAT is being performed
6. To the person who configures a J-series router, what has changed when running JUNOS software with enhanced services?
   a. ASP-based services such as IPSec, the stateful firewall, and NAT
   b. ASP services and routing protocol configuration
   c. The entire CLI has changed to accommodate new services
   d. Nothing; the new services are configured the same way as before
7. Which platform supports JUNOS software with enhanced services?
   a. M7i
   b. M10i and m7i
   c. Only J-series
   d. Certain J-series platforms and SSG 320m/350m platforms with a conversion kit

Chapter Review Answers

1. Answer: C. In secure mode, an implicit deny-all policy is in effect. In router context, an explicit accept-all policy is used. Even so, interfaces and their protocols have to be listed in a zone for communication to occur.
2. Answer: D. Policy is always needed to permit traffic between zones.
3. Answer: C. The lack of a security stanza in the original JUNOS configuration results in no interfaces, in any zones, preventing network connectivity.
4. Answer: B. A services interface is still required, to be placed in the untrust zone, for example. In this way, policy can evaluate traffic that is flowing across the services interface.
5. Answer: A. The use of 172.16.1.0/24 addressing indicates that no NAT has been performed. SNAT would involve 55.5.5.0/27, and DNAT was using 10.10.12.3 in this example. Note that self-generated traffic does not go through the NAT/policy engine.
6. Answer: A. Rest assured that the majority of JUNOS software and the CLI are the same. Only services configuration has changed.
7. Answer: D. ASIC-based platforms such as the M7i and M10i do not support enhanced services. Certain J-series and SSG platforms can be loaded/converted to operate with enhanced services.

Glossary

AAL
: Asynchronous Transfer Mode (ATM) adaptation layer. A series of protocols enabling various types of traffic, including voice, data, image, and video, to run over an ATM network.

AAL5 mode
: Asynchronous Transfer Mode (ATM) adaptation Layer 5. One of four ATM adaptation layers (AALs) recommended by the ITU-T. AAL5 is used predominantly for the transfer of classical IP over ATM. AAL5 is the least complex of the current AAL recommdations. It offers low-bandwidth overhead and simpler processing requirements in exchange for reduced bandwidth capacity and error-recovery capability. It is a Layer 2 circuit transport mode that allows you to send ATM cells between ATM2 intelligent queuing (IQ) interfaces across a Layer 2 circuit-enabled network. You use Layer 2 circuit AAL5 transport mode to tunnel a stream of AAL5-encoded ATM segmentation and reassembly protocol data units (SAR-PDUs) over a Multiprotocol Label Switching (MPLS) or IP backbone. *See also* cell-relay mode, Layer 2 circuits, standard AAL5 mode, trunk mode.

ABR
: Area border router. Router that belongs to more than one area. Used in Open Shortest Path First (OSPF). *See also* OSPF.

access concentrator
: Router that acts as a server in a Point-to-Point Protocol over Ethernet (PPPoE) session—for example, an E-series router.

accounting services
: Method of collecting network data related to resource usage.

ACFC
: Address and Control Field Compression. Enables routers to transmit packets without the two 1-byte address and control fields (0xff and 0x03) (which are normal for Point-to-Point Protocol [PPP]-encapsulated packets), thus transmitting less data and conserving bandwidth. ACFC is defined in RFC 1661, “The Point-to-Point Protocol (PPP).” *See also* PFC.

active route
: Route chosen from all routes in the route table to reach a destination. Active routes are installed into the forwarding table.

adaptive services
: Set of services or applications that you can configure on an Adaptive Services PIC (ASP). The services and applications include stateful firewall, Network Address Translation (NAT), intrusion detection services (IDSs), Internet Protocol Security (IPSec), Layer 2 Tunneling Protocol (L2TP), and voice services. *See also* tunneling protocol.

address match conditions

Use of an IP address as a match criterion in a routing policy or a firewall filter.

adjacency

Portion of the local routing information that pertains to the reachability of a single neighbor over a single circuit or interface.

Adjacency-RIB-In

Logical software table that contains Border Gateway Protocol (BGP) routes received from a specific neighbor.

Adjacency-RIB-Out

Logical software table that contains Border Gateway Protocol (BGP) routes to be sent to a specific neighbor.

ADM

Add/drop multiplexer. SONET functionality that allows lower-level signals to be dropped from a high-speed optical connection.

ADSL

Asymmetrical digital subscriber line. A technology that allows more data to be sent over existing copper telephone lines, using the public switched telephone network (PSTN). ADSL supports data rates from 1.5 Mbps to 9 Mbps when receiving data (downstream rate), and from 16 Kbps to 640 Kbps when sending data (upstream rate).

ADSL interface

Asymmetrical digital subscriber line interface. Physical WAN interface that connects a router to a digital subscriber line access multiplexer (DSLAM). An ADSL interface allocates line bandwidth asymmetrically. Downstream (provider-to-customer) data rates can be up to 8 Mbps for ADSL, 12 Mbps for ADSL2, and 25 Mbps for ADSL2+. Upstream (customer-to-provider) rates can be up to 800 Kbps for ADSL and 1 Mbps for ADSL2 and ADSL2+, depending on the implementation.

ADSL2 interface

ADSL interface that supports ITU-T Standard G.992.3 and ITU-T Standard G.992.4. ADSL2 allocates downstream (provider-to-customer) data rates of up to 12 Mbps and upstream (customer-to-provider) rates of up to 1 Mbps.

ADSL2+ interface

ADSL interface that supports ITU-T Standard G.992.5. ADSL2+ allocates downstream (provider-to-customer) data rates of up to 25 Mbps and upstream (customer-to-provider) rates of up to 1 Mbps.

AES

Advanced Encryption Standard. Defined in FIPS PUB 197. The AES algorithm uses keys of 128, 192, or 256 bits to encrypt and decrypt data in blocks of 128 bits.

aggregate route

Combination of groups of routes that have common addresses into a single entry in a route table.

aggregated interface

Logical bundle of physical interfaces. The aggregated interface is managed as a single interface with one IP address. Network traffic is dynamically distributed across ports, so administration of data flowing across a given port is done automatically within the aggregated link. Using multiple ports in parallel provides redundancy and increases the link speed beyond the limits of any single port.

AH

Authentication header. A component of the IPSec protocol used to verify that the contents of a packet have not changed, and to validate the identity of the sender.

ALI

ATM line interface. Interface between Asynchronous Transfer Mode (ATM) and 3G systems. *See also* ATM.

ANSI

American National Standards Institute. The U.S. representative to the ISO.

APN

Access point name. When mobile stations connect to IP networks over a wireless network, the GGSN uses the APN to distinguish among the connected IP networks (known as *APN networks*). In addition to identifying these connected networks, an APN is also a configured entity that hosts the wireless sessions, which are called Packet Data Protocol (PDP) contexts.

APQ

Alternate priority queuing. Dequeuing method that has a special queue, similar to strict-priority queuing (SPQ), which is visited only 50% of the time. The packets in the special queue still have a predictable latency, although the upper limit of the delay is higher than that with SPQ. Since the other configured queues share the remaining 50% of the service time, queue starvation is usually avoided. *See also* SPQ.

APS

Automatic Protection Switching. Technology used by SONET add/drop multiplexers (ADMs) to protect against circuit faults between the ADM and a router and to protect against failing routers.

area

1.Routing subdomain that maintains detailed routing information about its own internal composition as well as routing information that allows it to reach other routing subdomains. In Intermediate System-to-Intermediate System Level 1 (IS-IS), an area corresponds to a Level 1 subdomain. 2. In IS-IS and Open Shortest Path First (OSPF), a set of contiguous networks and hosts within an autonomous system (AS) that have been administratively grouped together.

ARP

Address Resolution Protocol. Protocol used for mapping IPv4 addresses to media access control (MAC) addresses. *See also* NDP.

AS

Autonomous system. Set of routers under a single technical administration. Each AS normally uses a single Interior Gateway Protocol (IGP) and metrics to propagate routing information within the set of routers. Also called a *routing domain*.

ASBR

Autonomous system boundary router. In Open Shortest Path First (OSPF), a router that exchanges routing information with routers in other autonomous systems (ASs).

ASBR Summary LSA

OSPF link-state advertisement (LSA) sent by an area border router (ABR) to advertise the router ID of an autonomous system boundary router (ASBR) across an area boundary. *See also* ASBR.

AS external link advertisement

OSPF link-state advertisement (LSA) sent by autonomous system boundary routers (ASBRs) to describe external routes that they have detected. These LSAs are flooded throughout the autonomous system (AS) (except for stub areas).

ASIC

Application-specific integrated circuit. Specialized processors that perform specific functions on the router.

ASM

1. Adaptive Services Module. On a Juniper Networks M7i router, provides the same functionality as the Adaptive Services PIC (ASP). 2. Any Source Multicast. A network that supports both one-to-many and many-to-many communication models. An ASM network must determine all the sources of a group and deliver all of them to interested subscribers.

ASP

Adaptive Services PIC. *See* adaptive services.

AS path

In the Border Gateway Protocol (BGP), the route to a destination. The path consists of the autonomous system (AS) numbers of all routers that a packet must go through to reach a destination.

ATM

Asynchronous Transfer Mode. A high-speed multiplexing and switching method utilizing fixed-length cells of 53 octets to support multiple types of traffic.

ATM-over-ADSL interface
: Asynchronous Transfer Mode (ATM) interface used to send network traffic through a point-to-point connection to a DSL access multiplexer (DSLAM). ATM-over-ADSL interfaces are intended for asymmetrical digital subscriber line (ADSL) connections only, not for direct ATM connections.

atomic
: Smallest possible operation. An atomic operation is performed either entirely or not at all. For example, if machine failure prevents a transaction from completing, the system is rolled back to the start of the transaction, with no changes taking place.

AUC
: Authentication center. Part of the Home Location Register (HLR) in third-generation (3G) systems; performs computations to verify and authenticate a mobile phone user.

automatic policing
: Policer that allows you to provide strict service guarantees for network traffic. Such guarantees are especially useful in the context of differentiated services for traffic-engineered label-switched paths (LSPs), providing better emulation for Asynchronous Transfer Mode (ATM) wires over a Multiprotocol Label Switching (MPLS) network.

auto-negotiation
: Used by Ethernet devices to configure interfaces automatically. If interfaces support different speeds or different link modes (half duplex or full duplex), the devices attempt to settle on the lowest common denominator.

autonomous system external link advertisement
: OSPF link-state advertisement (LSA) sent by autonomous system boundary routers (ASBRs) to describe external routes that they have detected. These LSAs are flooded throughout the autonomous system (AS) (except for stub areas).

autonomous system path
: In the Border Gateway Protocol (BGP), the route to a destination. The path consists of the autonomous system (AS) numbers of all the routers a packet must pass through to reach a destination.

auto-RP
: Method of electing and announcing the rendezvous point-to-group address mapping in a multicast network. JUNOS software supports this vendor-proprietary specification. *See also* RP.

backbone area
: In Open Shortest Path First (OSPF), an area that consists of all networks in area ID 0.0.0.0, their attached routers, and all area border routers (ABRs).

backbone router
: Open Shortest Path First (OSPF) router with all operational interfaces within area 0.0.0.0.

backplane
: *See* midplane.

backup designated router
: Open Shortest Path First (OSPF) router on a broadcast segment that monitors the operation of the designated router and takes over its functions if the designated router fails.

BA classifier
: Behavior aggregate classifier. A method of classification that operates on a packet as it enters the router. The packet header contents are examined, and this single field determines the class-of-service (CoS) settings applied to the packet. *See also* multifield classifier.

bandwidth
: Range of transmission frequencies that a network can use, expressed as the difference between the highest and lowest frequencies of a transmission channel. In computer networks, greater bandwidth indicates a faster data transfer rate capacity.

bandwidth model
: In Differentiated-Services-aware traffic engineering, determines the value of the available bandwidth advertised by the Interior Gateway Protocols (IGPs).

bandwidth on demand
: 1. A technique to temporarily provide additional capacity on a link to handle

bursts in data, videoconferencing, or other variable bit rate applications. Also called *flexible bandwidth allocation*. 2. On a Services Router, an Integrated Services Digital Network (ISDN) cost-control feature defining the bandwidth threshold that must be reached on links before a Services Router initiates additional ISDN data connections to provide more bandwidth.

BBFD

Bidirectional Forwarding Detection. A simple hello mechanism that detects failures in a network. Used with routing protocols to speed up failure detection.

B-channel

Bearer channel. A 64 Kbps channel used for voice or data transfer on an Integrated Services Digital Network (ISDN) interface. *See also* D-channel.

BECN

Backward explicit congestion notification. In a Frame Relay network, a header bit transmitted by the destination device requesting that the source device send data more slowly. BECN minimizes the possibility that packets will be discarded when more packets arrive than can be handled. *See also* FECN.

Bellman-Ford algorithm

Algorithm used in distance-vector routing protocols to determine the best path to all routes in the network.

BERT

Bit error rate test. A test that can be run on the following interfaces to determine whether they are operating properly: E1, E3, T1, T3, and channelized (DS3, OC3, OC12, and STM1) interfaces.

BGP

Border Gateway Protocol. Exterior gateway protocol used to exchange routing information among routers in different autonomous systems (ASs).

bit field match conditions

Use of fields in the header of an IP packet as match criteria in a firewall filter.

bit rate

Number of bits transmitted per second.

BITS

Building Integrated Timing Source. Dedicated timing source that synchronizes all equipment in a particular building.

Blowfish

Unpatented, symmetric cryptographic method developed by Bruce Schneier and used in many commercial and freeware software applications. Blowfish uses variable-length keys of up to 448 bits.

BOOTP

Bootstrap protocol. A User Datagram Protocol (UDP)/IP-based protocol that allows a booting host to configure itself dynamically and without user supervision. BOOTP provides a means to notify a host of its assigned IP address, the IP address of a boot server host, and the name of a file to be loaded into memory and executed. Other configuration information, such as the local subnet mask, the local time offset, the addresses of default routers, and the addresses of various Internet servers, can also be communicated to a host using BOOTP.

bootstrap router

Single router in a multicast network responsible for distributing candidate rendezvous point (RP) information to all Physical Interface Module (PIM)-enabled routers.

BPDU

Bridge protocol data unit. A Spanning Tree Protocol hello packet that is sent out at intervals to exchange information across bridges and detect loops in a network topology.

BRI

Basic Rate Interface. Integrated Services Digital Network (ISDN) interface intended for home and small enterprise applications. BRI consists of two 64 Kbps B-channels to carry voice or data, and one 16 Kbps D-channel for control and signaling. *See also* B-channel; D-channel.

bridge

Device that uses the same communications protocol to connect and pass packets between two network segments. A bridge operates at Layer 2 of the Open Systems Interconnection (OSI) reference model.

broadcast

Operation of sending network traffic from one network node to all other network nodes.

BSC

Base station controller. Key network node in third-generation (3G) systems that supervises the functioning and control of multiple base transceiver stations.

BSS

Base station subsystem. Composed of the base transceiver station (BTS) and base station controller (BSC).

BSSGP

Base Station System GPRS Protocol. Processes routing and quality-of-service (QoS) information for the base station subsystem (BSS).

BTS

Base transceiver station. Mobile telephony equipment housed in cabinets and collocated with antennas. (Also known as a radio base station.)

buffers

Memory space for handling data in transit. Buffers compensate for differences in processing speed between network devices and handle bursts of data until they can be processed by slower devices.

bundle

1. Multiple physical links of the same type, such as multiple asynchronous lines, or physical links of different types, such as leased synchronous lines and dial-up asynchronous lines. 2. Collection of software that makes up a JUNOS software release.

bypass LSP

Carries traffic for a label-switched path (LSP) whose link-protected interface has failed. A bypass LSP uses a different interface and path to reach the same destination.

CA

Certificate authority. A trusted third-party organization that creates, enrolls, validates, and revokes digital certificates. The CA guarantees a user's identity and issues public and private keys for message encryption and decryption (coding and decoding).

CAC

Call admission control. In Differentiated-Services-aware traffic engineering, checks for adequate bandwidth on the path before the label-switched path (LSP) is established. If the bandwidth is insufficient, the LSP is not established and an error is reported.

CAIDA

Cooperative Association for Internet Data Analysis. An association that provides tools and analyses promoting the engineering and maintenance of a robust, scalable Internet infrastructure. One tool, cflowd, allows you to collect an aggregate of sampled flows and send the aggregate to a specified host that runs the cflowd application available from CAIDA.

callback

Alternative feature to dial-in that enables a J-series Services Router to call back the caller from the remote end of a backup Integrated Services Digital Network (ISDN) connection. Instead of accepting a call from the remote end of the connection, the router rejects the call, waits a configured period of time, and calls a number configured on the router's dialer interface. *See also* dial-in.

caller ID

Telephone number of the caller on the remote end of a backup Integrated Services Digital Network (ISDN) connection, used to dial in and to identify the caller. Multiple caller IDs can be configured on an ISDN dialer interface. During dial-in, the router matches the incoming call's caller ID against the caller IDs configured on its dialer interfaces. Each dialer interface accepts calls only from callers whose caller IDs are configured on it.

CAMEL

Customized Applications of Mobile Enhanced Logic. An ETSI standard for GSM networks that enhances the provision of Intelligent Network services.

candidate configuration

File maintained by the JUNOS software containing changes to the router's active configuration. This file becomes the active configuration when a user issues the `commit` command.

candidate RP advertisements

Information sent by routers in a multicast network when they are configured as a local rendezvous point (RP). This information is unicast to the bootstrap router (BSR) for the multicast domain.

carrier-of-carriers VPN

Virtual private network (VPN) service supplied to a network service provider that is supplying either Internet service or VPN service to an end customer. For a carrier-of-carriers VPN, the customer's sites are configured within the same autonomous system (AS).

CB

Control Board. On a T640 routing node, part of the host subsystem that provides control and monitoring functions for router components.

CBC

Cipher block chaining. A mode of encryption using 64 or 128 bits of fixed-length blocks in which each block of plain text is XORed with the previous cipher text block before being encrypted. *See also* XOR.

CBR

Constant bit rate. For ATM1 and ATM2 intelligent queuing (IQ) interfaces, data that is serviced at a constant, repetitive rate. CBR is used for traffic that does not need to periodically burst to a higher rate, such as nonpacketized voice and audio.

CCC

Circuit cross-connect. A JUNOS software feature that allows you to configure transparent connections between two circuits. A circuit can be a Frame Relay data-link connection identifier (DLCI), an Asynchronous Transfer Mode (ATM) virtual channel (VC), a Point-to-Point Protocol (PPP) interface, a Cisco High-Level Data Link Control (HDLC) interface, or a Multiprotocol Label Switching (MPLS) label-switched path (LSP).

CDMA

Code Division Multiple Access. Technology for digital transmission of radio signals between, for example, a mobile telephone and a base transceiver station (BTS).

CDMA2000

Radio transmission and backbone technology for the evolution to third-generation (3G) mobile networks.

CDR

Call Detail Record. A record containing data (such as origination, termination, length, and time of day) unique to a specific call.

CE device

Customer edge device. Router or switch in the customer's network that is connected to a service provider's provider edge (PE) router and participates in a Layer 3 virtual private network (VPN).

cell relay

Data transmission technology based on the use of small, fixed-size packets (cells) that can be processed and switched in hardware at high speeds. Cell relay is the basis for many high-speed network protocols, including Asynchronous Transfer Mode (ATM) and IEEE 802.6.

cell-relay mode

Layer 2 circuit transport mode that sends Asynchronous Transfer Mode (ATM) cells between ATM2 intelligent queuing (IQ) interfaces over a Multiprotocol Label Switching (MPLS) core network. You use Layer 2 circuit cell-relay transport mode to tunnel a stream of ATM cells over an MPLS or IP backbone. *See also* AAL5 mode; Layer 2 circuits; standard AAL5 mode; trunk mode.

cell tax

Physical transmission capacity used by header information when sending data packets in an Asynchronous Transfer Mode (ATM) network. Each ATM cell uses a 5-byte header.

CFEB

Compact Forwarding Engine Board. In M7i and M10i routers, provides route lookup, filtering, and switching to the destination port.

cflowd

Application available from CAIDA that collects an aggregate of sampled flows and sends the aggregate to a specified host running the cflowd application.

CFM

Cubic feet per minute. Measure of air flow in volume per minute.

channel

Communication circuit linking two or more devices. A channel provides an input/output interface between a processor and a peripheral device, or between two systems. A single physical circuit can consist of one or many channels, or two systems carried on a physical wire or wireless medium. For example, the dedicated channel between a telephone and the central office (CO) is a twisted-pair copper wire. *See also* frequency-division multiplexed channel; time-division multiplexed channel.

channel group

Combination of DS0 interfaces partitioned from a channelized interface into a single logical bundle.

channelized E1

A 2.048 Mbps interface that can be configured as a single clear-channel E1 interface or channelized into as many as 31 discrete DS0 interfaces. On most channelized E1 interfaces, time slots are numbered from 1 through 32, and time slot 1 is reserved for framing. On some legacy channelized E1 interfaces, time slots are numbered from 0 through 31, and time slot 0 is reserved for framing.

channelized interface

Interface that is a subdivision of a larger interface, minimizing the number of Physical Interface Cards (PICs) or Physical Interface Modules (PIMs) that an installation requires. On a channelized PIC or PIM, each port can be configured as a single clear channel or partitioned into multiple discrete T3, T1, E1, and DS0 interfaces, depending on the size of the channelized PIC or PIM.

channelized T1

A 1.544 Mbps interface that can be configured as a single clear-channel T1 interface or channelized into as many as 24 discrete DS0 interfaces. Time slots are numbered from 1 through 24.

CHAP

Challenge Handshake Authentication Protocol. A protocol that authenticates remote users. CHAP is a server-driven, three-step authentication mechanism that depends on a shared secret password that resides on both the server and the client.

chassisd

Chassis daemon. A JUNOS software process responsible for managing the interaction of the router's physical components.

CIDR

Classless interdomain routing. A method of specifying Internet addresses in which you explicitly specify the bits of the address to represent the network address instead of determining this information from the first octet of the address.

CIP

Connector Interface Panel. On an M160 router, the panel that contains connectors for the Routing Engines (REs), BITS interfaces, and alarm relay contacts.

CIR

Committed information rate. The CIR specifies the average rate at which packets are admitted to the network. As each packet enters the network, it is counted. Packets that do not exceed the CIR are marked green, which corresponds to low-loss priority. Packets that exceed the CIR but are below the peak information rate (PIR) are marked yellow, which corresponds to medium loss priority. *See also* trTCM; PIR.

Cisco-RP-Announce

Message advertised into a multicast network by a router configured as a local rendezvous point (RP) in an auto-RP network. A Cisco-RP-Announce message is advertised in a dense-mode Physical Interface Module (PIM) to the 224.0.1.39 multicast group address.

Cisco-RP-Discovery

Message advertised by the mapping agent in an auto-RP network. A Cisco-RP-Discovery message contains the rendezvous point (RP) to multicast group address assignments for the domain. It is advertised in a dense-mode Physical Interface Module (PIM) to the 224.0.1.40 multicast group address.

classification

In class of service (CoS), the examination of an incoming packet that associates the packet with a particular CoS servicing level. There are two kinds of classifiers: behavior aggregate (BA) and multifield. *See also* BA classifier; multifield classifier.

classifier

Method of reading a sequence of bits in a packet header or label and determining how the packet should be forwarded internally and scheduled (queued) for output.

class type

In Differentiated-Services-aware traffic engineering, a collection of traffic flows which are treated equally in a Differentiated Services domain. A class type maps to a queue and is much like a class-of-service (CoS) forwarding class in concept. It is also known as a *traffic class*.

clear channel

Interface configured on a channelized Physical Interface Card (PIC) or Physical Interface Module (PIM) that operates as a single channel, does not carry signaling, and uses the entire port bandwidth.

CLEC

(Pronounced “see-lek”.) Competitive local exchange carrier. Company that competes with the already established local telecommunications business by providing its own network and switching.

CLEI

Common Language Equipment Identifier. Inventory code used to identify and track telecommunications equipment.

CLI

Command-line interface. Interface provided for configuring and monitoring the routing protocol software.

client peer

In a Border Gateway Protocol (BGP) route reflection, a member of a cluster that is not the route reflector. *See also* nonclient peer.

CLNP

Connectionless Network Protocol. An ISO-developed protocol for an Open Systems Interconnection (OSI) connectionless network service. CLNP is the OSI equivalent of IP.

CLNS

Connectionless Network Service. A Layer 3 protocol, similar to Internet Protocol version 4 (IPv4). CLNS uses network service access points (NSAPs) instead of the prefix addresses found in IPv4 to specify end systems and intermediate systems.

cluster

In the Border Gateway Protocol (BGP), a set of routers that have been grouped together. A cluster consists of one system that acts as a route reflector, along with any number of client peers. The client peers receive their route information only from the route reflector system. Routers in a cluster do not need to be fully meshed.

CO

Central office. The local telephone company building that houses circuit-switching equipment used for subscriber lines in a given area.

code-point alias
Name assigned to a pattern of code-point bits. This name is used, instead of the bit pattern, in the configuration of other class-of-service (CoS) components such as classifiers, drop-profile maps, and rewrite rules.

command completion
Function of a router's command-line interface (CLI) that allows a user to enter only the first few characters in any command. Users access this function through the Space bar or Tab key.

commit
JUNOS software command-line interface (CLI) configuration-mode command that saves changes made to a router configuration, verifies the syntax, applies the changes to the configuration currently running on the router, and identifies the resultant file as the current operational configuration.

commit script
Script that enforces custom configuration rules. A script runs each time a new candidate configuration is committed and inspects the configuration. If a configuration breaks your custom rules, the script can generate actions for the JUNOS software.

commit script macro
Sequence of commands that allow you to create custom configuration syntax to simplify the task of configuring a routing platform. By itself, your custom syntax has no operational impact on the routing platform. A corresponding commit script macro uses your custom syntax as input data for generating standard JUNOS configuration statements that execute your intended operation.

community
1. In the Border Gateway Protocol (BGP), a group of destinations that share a common property. Community information is included as one of the path attributes in BGP update messages. 2. In the Simple Network Management Protocol (SNMP), an authentication scheme that authorizes SNMP clients based on the source IP address of incoming SNMP packets, defines which Management Information Base (MIB) objects are available, and specifies the operations (read-only or read-write) allowed on those objects.

confederation
In the Border Gateway Protocol (BGP), a group of systems that appears to external autonomous systems (ASs) as a single AS.

configuration mode
JUNOS software mode that allows a user to alter the router's current configuration.

Connect
Border Gateway Protocol (BGP) neighbor state in which the local router has initiated the Transmission Control Protocol (TCP) session and is waiting for the remote peer to complete the TCP connection.

constrained path
In traffic engineering, a path determined using the CSPF algorithm. The ERO carried in the Resource Reservation Protocol (RSVP) packets contains the constrained path information. *See also* ERO.

context node
Node that the Extensible Stylesheet Language for Transformations (XSLT) processor is currently examining. XSLT changes the context as it traverses the XML document's hierarchy. *See also* XSLT.

context-sensitive help
Function of the router's command-line interface (CLI) that allows a user to request information on the JUNOS software hierarchy. You can access context-sensitive help in both operational and configuration modes.

contributing routes
Active IP routes in the route table that share the same most-significant bits and are more specific than an aggregate or generated route.

control plane
Virtual network path used to set up, maintain, and terminate data plane connections. *See also* data plane.

core
Central backbone of the network.

CoS
: Class of service. Method of classifying traffic on a packet-by-packet basis using information in the type-of-service (ToS) byte to provide different service levels to different traffic.

cosd
: Class-of-service (CoS) process that enables the routing platform to provide different levels of service to applications based on packet classifications.

CPE
: Customer premises equipment. Telephone, modem, router, or other service provider equipment located at a customer site.

craft interface
: Mechanisms used by a Communication Workers of America craftsperson to operate, administer, and maintain equipment or provision data communications. On a Juniper Networks router, the craft interface allows you to view status and troubleshooting information and perform system control functions.

CRL
: Certificate revocation list. A list of digital certificates that have been invalidated, including the reasons for revocation and the names of the entities that issued them. A CRL prevents usage of digital certificates and signatures that have been compromised.

CRTP
: Compressed Real-Time Transport Protocol. Protocol that decreases the size of the IP, User Datagram Protocol (UDP), and Real-Time Transport Protocol (RTP) headers and works with reliable and fast point-to-point links for Voice over IP traffic. CRTP is defined in RFC 2508.

Crypto Accelerator Module
: Processor card that speeds up certain cryptographic IP Security (IPSec) services on some J-series Services Routers. For the supported cryptographic algorithms, see the J-series documentation.

Crypto Officer
: Superuser responsible for the proper operation of a router running JUNOS-FIPS software.

CSCP
: Class Selector code point. Eight Differentiated-Services code point (DSCP) values of the form *xxx*000 (where *x* can be 0 or 1). Defined in RFC 2474.

CSNP
: Complete sequence number PDU. Packet that contains a complete list of all the label-switched paths (LSPs) in the Intermediate System-to-Intermediate System Level 1 (IS-IS) database.

CSP
: Critical Security Parameter. On routers running JUNOS-FIPS software, a collection of cryptographic keys and passwords that must be protected at all times.

CSPF
: Constrained Shortest Path First. A Multiprotocol Label Switching (MPLS) algorithm that has been modified to take into account specific restrictions when calculating the shortest path across the network.

CSU/DSU
: Channel service unit/data service unit. A channel service unit connects a digital phone line to a multiplexer or other digital signal device. A data service unit connects a data terminal equipment (DTE) device to a digital phone line.

CVS
: Concurrent Versions System. A widely used version control system for software development or data archives.

daemon
: Background process that performs operations for the system software and hardware. Daemons normally start when the system software is booted, and they run as long as the software is running. In JUNOS software, daemons are also referred to as *processes*.

damping
: Method of reducing the number of update messages sent between Border Gateway Protocol (BGP) peers, thereby reducing the load on these peers without adversely affecting the route convergence time for stable routes.

database description packet
: Open Shortest Path First (OSPF) packet type used in the formation of an adjacency. The packet sends summary information about the local router's database to the neighboring router.

data-MDT
: Data-driven multicast distribution tree (MDT) tunnel. A multicast tunnel created and deleted based on defined traffic loads and designed to ease loading on the default MDT tunnel.

data packet
: Chunk of data transiting the router from the source to a destination.

data plane
: Virtual network path used to distribute data between nodes. *See also* control plane.

dcd
: Device control process. A JUNOS software interface process (daemon).

DCE
: Data circuit-terminating equipment. An RS-232-C device, typically used for a modem or printer, or a network access and packet switching node.

D-channel
: Delta channel. A circuit-switched channel that carries signaling and control for B-channels. In Basic Rate Interface (BRI) applications, it can also support customer packet data traffic at speeds up to 9.6 Kbps. *See also* B-channel; BRI.

DCU
: Destination class usage. A means of tracking traffic originating from specific prefixes on the customer edge router and destined for specific prefixes on the provider core router, based on the IP source and destination addresses.

DE
: Discard-eligible bit. In a Frame Relay network, a header bit notifying devices on the network that traffic can be dropped during congestion to ensure the delivery of higher-priority traffic.

deactivate
: Method of modifying the router's active configuration. Portions of the hierarchy marked as inactive using this command are ignored during the router's commit process as though they were not configured at all.

dead interval
: Amount of time that an Open Shortest Path First (OSPF) router maintains a neighbor relationship before declaring that neighbor as no longer operational. The JUNOS software uses a default value of 40 seconds for this timer.

dead peer detection
: *See* DPD.

default address
: Router address that is used as the source address on unnumbered interfaces.

default route
: Route used to forward IP packets when a more specific route is not present in the route table. Often represented as 0.0.0.0/0, the default route is sometimes referred to as the *route of last resort*.

demand circuit
: Network segment whose cost varies with usage, according to a service level agreement (SLA) with a service provider. Demand circuits limit traffic based on either bandwidth (bits or packets transmitted) or access time. *See also* multicast.

dense mode
: Method of forwarding multicast traffic to interested listeners. Dense mode forwarding assumes that most of the hosts on the network will receive the multicast data. Routers flood packets and prune unwanted traffic every three minutes.

DES
: Data Encryption Standard. A method for encrypting information using a 56-bit key.

Considered to be a legacy method and insecure for many applications.

designated router

In Open Shortest Path First (OSPF), a router selected by other routers that is responsible for sending link-state advertisements (LSAs) that describe the network, thereby reducing the amount of network traffic and the size of the routers' topological databases.

destination prefix length

Number of bits of the network address used for the host portion of a classless interdomain routing (CIDR) IP address.

DFC

Dynamic flow capture. Process of collecting packet flows that match a particular filter list to one or more content destinations using an on-demand control protocol that relays requests from one or more control sources.

DHCP

Dynamic Host Configuration Protocol. Allocates IP addresses dynamically so that they can be reused when no longer needed.

dial backup

Feature that reestablishes network connectivity through one or more backup Integrated Services Digital Network (ISDN) dialer interfaces after a primary interface fails. When the primary interface is reestablished, the ISDN interface is disconnected.

dialer filter

Stateless firewall filter that enables dial-on-demand routing backup when applied to a physical Integrated Services Digital Network (ISDN) interface and its dialer interface configured as a passive static route. The passive static route has a lower priority than dynamic routes. If all dynamic routes to an address are lost from the route table and the router receives a packet for that address, the dialer interface initiates an ISDN backup connection and sends the packet over it. *See also* dial-on-demand routing (DDR) backup; floating static route.

dialer interface (dl)

Logical interface for configuring dialing properties and the control interface for a backup Integrated Services Digital Network (ISDN) connection.

dialer profile

Set of characteristics configured for the Integrated Services Digital Network (ISDN) dialer interface. Dialer profiles allow the configuration of physical interfaces to be separated from the logical configuration of dialer interfaces required for ISDN connectivity. This feature also allows physical and logical interfaces to be bound together dynamically on a per-connection basis.

dialer watch

Dial-on-demand routing (DDR) backup feature that provides reliable connectivity without relying on a dialer filter to activate the Integrated Services Digital Network (ISDN) interface. The ISDN dialer interface monitors the existence of each route on a watch list. If all routes on the watch list are lost from the route table, dialer watch initiates the ISDN interface for failover connectivity. *See also* dial-on-demand routing (DDR) backup.

dial-in

Feature that enables J-series Services Routers to receive calls from the remote end of a backup Integrated Services Digital Network (ISDN) connection. The remote end of the ISDN call might be a service provider, a corporate central location, or a customer premises equipment (CPE) branch office. All incoming calls can be verified against caller IDs configured on the router's dialer interface. *See also* callback.

dial-on-demand routing (DDR) backup

Feature that provides a J-series Services Router with full-time connectivity across an Integrated Services Digital Network (ISDN) line. When routes on a primary serial T1, E1, T3, E3, Fast Ethernet, or Point-to-Point Protocol over Ethernet (PPPoE) interface are lost, an ISDN dialer interface establishes a backup connection. To save connection time costs, the Services

Router drops the ISDN connection after a configured period of inactivity. Services Routers with ISDN interfaces support two types of DDR backup: on-demand routing with a dialer filter and with a dialer watch. *See also* dialer filter; dialer watch.

Differentiated-Services-aware traffic engineering
Type of constraint-based routing that can enforce different bandwidth constraints for different classes of traffic. It can also perform call admission control (CAC) on each traffic engineering class when a label-switched path (LSP) is established.

Differentiated Services domain
Routers in a network that have Differentiated Services enabled.

Diffie-Hellman
Method of key exchange across a nonsecure environment, such as the Internet. The Diffie-Hellman algorithm negotiates a session key without sending the key itself across the network by allowing each party to pick a partial key independently and send part of it to each other. Each side then calculates a common key value. This is a symmetrical method, and keys are typically used for only a short time, then discarded and regenerated.

DiffServ
Differentiated Services (based on RFC 2474). DiffServ uses the type-of-service (ToS) byte to identify different packet flows on a packet-by-packet basis. DiffServ adds a Class Selector code point (CSCP) and a Differentiated Services code point (DSCP).

DiffServ-aware
Paradigm that gives different treatment to traffic based on the experimental (EXP) bits in the Multiprotocol Label Switching (MPLS) label header and allows you to provide multiple classes of service (CoS).

digital certificate
Electronic file based on private and public key technology that verifies the identity of the certificate's holder to protect data exchanged online. Digital certificates are issued by a certificate authority (CA).

Dijkstra algorithm
See SPF.

DIMM
Dual inline memory module. A 168-pin memory module that supports 64-bit data transfer.

direct routes
See interface routes.

disable
Method of modifying the router's active configuration. When portions of the hierarchy are marked as disabled (mainly router interfaces), the router uses the configuration but ignores the disabled portions.

discard
JUNOS software syntax command used in a routing policy or a firewall filter. The command halts the logical processing of the policy or filter when a set of match conditions is met. The specific route or IP packet is dropped from the network silently. It can also be a next hop attribute assigned to a route in the route table.

distance-vector
Method used in Bellman-Ford routing protocols to determine the best path to all routers in the network. Each router determines the distance (metric) to the destination and the vector (next hop) to follow.

Distributed Buffer Manager ASIC
Juniper Networks ASIC responsible for managing the router's packet storage memory.

DLCI
Data-link connection identifier. Identifier for a Frame Relay virtual connection (also called a *logical interface*).

DLSw
Data link switching. Method of tunneling IBM System Network Architecture (SNA) and NetBIOS traffic over an IP network. (The JUNOS software does not support NetBIOS.) *See also* tunneling protocol.

DLSw circuit
Path formed by establishing data link control (DLC) connections between an end system and a local router configured for DLSw. Each DLSw circuit is identified by

the circuit ID that includes the end system method authenticity check address, local service access point (LSAP), and DLC port ID. Multiple DLSw circuits can operate over the same DLSw connection.

DLSw connection
: Set of Transmission Control Protocol (TCP) connections between two data link switching (DLSw) peers that is established after the initial handshake and successful capabilities exchange.

DNS
: Domain Name System. A system that stores information about hostnames and domain names. DNS provides an IP address for each hostname and lists the email exchange servers accepting email addresses for each domain.

DoS
: Denial of service. A system security breach in which network services become unavailable to users.

DPD
: Dead peer detection. Protocol that recognizes the loss of the primary IPSec Internet Key Exchange (IKE) peer and establishes a secondary IPSec tunnel to a backup peer.

DRAM
: Dynamic random access memory. Storage source on the router that can be accessed quickly by a process.

drop probability
: Percentage value that expresses the likelihood that an individual packet will be dropped from the network. *See also* drop profile.

drop profile
: Mechanism of random early detection (RED) that defines parameters that allow packets to be dropped from the network. When you configure drop profiles, there are two important values: the queue fullness and the drop probability. *See also* drop probability; queue fullness; RED.

DSAP
: Destination service access point. Service access point (SAP) that identifies the destination for which a logical link control protocol data unit (LPDU) is intended.

DS0
: Digital signal level 0. In T-carrier systems, a basic digital signaling rate of 64 Kbps. The DS0 rate forms the basis for the North American digital multiplex transmission hierarchy.

DS1
: Digital signal level 1. In T-carrier systems, a digital signaling rate of 1.544 Mbps. A standard used in telecommunications to transmit voice and data among devices. Also known as T1. *See also* T1.

DS3
: Digital signal level 3. In T-carrier systems, a digital signaling rate of 44.736 Mbps. This level of carrier can transport 28 DS1-level signals and 672 DS0-level channels within its payload. Also known as T3. *See also* T3.

DSCP
: Differentiated Services code point or DiffServ code point. Values for a 6-bit field defined for IPv4 and IPv6 packet headers that can be used to enforce class-of-service (CoS) distinctions in routers.

DSU
: Data service unit. A device used to connect data terminal equipment (DTE) to a digital phone line. DSU converts digital data from a router to voltages and encoding required by the phone line. *See also* CSU/DSU.

DTCP
: Dynamic Tasking Control Protocol. A means of communicating filter requests and acknowledgments between one or more clients and a monitoring platform, used in dynamic flow capture (DFC) and flow-tap configurations. The protocol is defined in Internet draft *draft-cavuto-dtcp-00.txt*.

DTD
: Document type definition. Defines the elements and structure of an Extensible Markup Language (XML) document or data set.

DTE

Data terminal equipment. An RS-232-C interface that a computer uses to exchange information with a serial device.

DVMRP

Distance Vector Multicast Routing Protocol. Distributed multicast routing protocol that dynamically generates IP multicast delivery trees using a technique called reverse-path multicasting (RPM) to forward multicast traffic to downstream interfaces.

DWDM

Dense wavelength-division multiplexing. Technology that enables data from different sources to be carried together on an optical fiber, with each signal carried on its own separate wavelength.

dynamic label-switched path

Multiprotocol Label Switching (MPLS) network path established by signaling protocols such as the Resource Reservation Protocol (RSVP) and Label Distribution Protocol (LDP).

E1

High-speed WAN digital communications protocol that operates at a rate of 2.048 Mbps.

E3

High-speed WAN digital communications protocol that operates at a rate of 34.368 Mbps and uses time-division multiplexing to carry 16 E1 circuits.

EAL3

Common Criteria Evaluation Assurance Level 3. Evaluation Assurance Level is an assurance and compliance requirement defined by Common Criteria. Higher levels have more stringent requirements.

EBGP

External BGP. A Border Gateway Protocol (BGP) configuration in which sessions are established between routers in different autonomous systems (ASs).

E-carrier

E stands for *European*. Standards that form part of the Synchronous Digital Hierarchy (SDH), in which groups of E1 circuits are bundled onto higher-capacity E3 links between telephone exchanges or countries. E-carrier standards are used just about everywhere in the world except North America and Japan, and are incompatible with the T-carrier standards.

ECC

Error checking and correction. The process of detecting errors during the transmission or storage of digital data and correcting them automatically. This usually involves sending or storing extra bits of data according to specified algorithms.

ECSA

Exchange Carriers Standards Association. A standards organization created after the divestiture of the Bell System to represent the interests of interexchange carriers.

edge router

In Multiprotocol Label Switching (MPLS), a router located at the beginning or end of a label-switching tunnel. An edge router at the beginning of a tunnel applies labels to new packets entering the tunnel. An edge route at the end of a tunnel removes labels from packets exiting the tunnel. *See also* MPLS.

editor macros (Emacs)

Shortcut keystrokes used within the router's command-line interface (CLI). These macros move the cursor and delete characters based on the sequence you specify.

EGP

Exterior Gateway Protocol. An example is the Border Gateway Protocol (BGP).

egress router

In Multiprotocol Label Switching (MPLS), the last router in a label-switched path (LSP). *See also* ingress router.

EIA

Electronic Industries Association. A U.S. trade group that represents manufacturers of electronic devices and sets standards and specifications.

EIA-530

Serial interface that employs the EIA-530 standard for the interconnection of data terminal equipment (DTE) and data circuit-terminating equipment (DCE).

EIR
: Equipment identity register. A mobile network database that contains information about devices using the network.

embedded OS software
: Software used by a Juniper Networks router to operate the physical router components.

EMI
: Electromagnetic interference. Any electromagnetic disturbance that interrupts, obstructs, or otherwise degrades or limits the effective performance of electronics or electrical equipment.

end system
: In Intermediate System-to-Intermediate System Level 1 (IS-IS), a network entity that sends and receives packets.

EPD
: Early packet discard. For ATM2 interfaces only, a limit on the number of transmit packets that can be queued. Packets that exceed the limit are dropped. *See also* queue length.

ERO
: Explicit Route Object. An extension to the Resource Reservation Protocol (RSVP) that allows an RSVP PATH message to traverse an explicit sequence of routers that is independent of conventional shortest-path IP routing.

ESD
: Electrostatic discharge. Stored static electricity that can damage electronic equipment and impair electrical circuitry when released.

ES-IS
: End System-to-Intermediate System. Protocol that resolves Layer 3 ISO network service access points (NSAPs) to Layer 2 addresses. ES-IS resolution is similar to the way the Address Resolution Protocol (ARP) resolves Layer 2 addresses for IPv4.

ESP
: Encapsulating Security Payload. A protocol for securing packet flows for IPSec using encryption, data integrity checks, and sender authentication, which are added as a header to an IP packet. If an ESP packet is successfully decrypted, and no other party knows the secret key the peers share, the packet was not wiretapped in transit. *See also* AH.

Established
: Border Gateway Protocol (BGP) neighbor state that represents a fully functional BGP peering session.

Ethernet
: Local area network (LAN) technology used for transporting information from one location to another, formalized in the IEEE standard 802.3. Ethernet uses either coaxial cable or twisted-pair cable. Transmission speeds for data transfer range from the original 10 Mbps, to Fast Ethernet at 100 Mbps, to Gigabit Ethernet at 1000 Mbps.

ETSI
: European Telecommunications Standardization Institute. A nonprofit organization that produces voluntary telecommunications standards used throughout Europe.

eventd
: Event policy process that performs configured actions in response to events on a routing platform that trigger system log messages.

exact
: JUNOS software routing policy match type that represents only the route specified in a route filter.

exception packet
: IP packet that is not processed by the normal packet flow through the Packet Forwarding Engine (PFE). Exception packets include local delivery information, expired Time to Live (TTL) packets, and packets with an IP option specified.

Exchange
: Open Shortest Path First (OSPF) adjacency state in which two neighboring routers are actively sending database description packets to each other to exchange their database contents.

EXP bits
Experimental bits, also known as the class-of-service (CoS) bits, located in each Multiprotocol Label Switching (MPLS) label and used to encode the CoS value of a packet as it traverses a label-switched path (LSP).

export
Placing of routes from the route table into a routing protocol.

ExStart
Open Shortest Path First (OSPF) adjacency state in which the neighboring routers negotiate to determine which router is in charge of the synchronization process.

Extensible Markup Language
See XML.

external metric
Cost included in a route when Open Shortest Path First (OSPF) exports route information from external autonomous systems (ASs). There are two types of external metrics: Type 1 and Type 2. Type 1 external metrics are equivalent to the link-state metric; that is, the cost of the route, used in the internal AS. Type 2 external metrics are greater than the cost of any path internal to the AS.

FA
Forwarding adjacency. Resource Reservation Protocol (RSVP) label-switched path (LSP) tunnel through which one or more other RSVP LSPs can be tunneled.

fabric schedulers
Identify a packet as high or low priority based on its forwarding class, and associate schedulers with the fabric priorities.

failover
Process by which a standby or secondary system component automatically takes over the functions of an active or primary component when the primary component fails or is temporarily shut down or removed for servicing. During failover, the system continues to perform normal operations with little or no interruption in service. *See also* GRES.

Fast Ethernet
Term encompassing a number of Ethernet standards that carry traffic at the nominal rate of 100 Mbps, instead of the original Ethernet speed of 10 Mbps. *See also* Ethernet; Gigabit Ethernet.

fast port
Fast Ethernet port on a J4300 Services Router, and either a Fast Ethernet port or DS3 port on a J6300 Services Router. Only enabled ports are counted. A two-port Fast Ethernet Physical Interface Module (PIM) with one enabled port counts as one fast port. The same PIM with both ports enabled counts as two fast ports.

fast reroute
Mechanism for automatically rerouting traffic on a label-switched path (LSP) if a node or link in an LSP fails, thus reducing the loss of packets traveling over the LSP.

FBF
Filter-based forwarding. A filter that classifies packets to determine their forwarding path within a router. FBF is used to redirect traffic for analysis.

FCS
Frame check sequence. A calculation that is added to a frame for error control. FCS is used in High-Level Data Link Control (HDLC), Frame Relay, and other data-link layer protocols.

FDDI
Fiber Distributed Data Interface. A set of ANSI protocols for sending digital data over fiber-optic cable. FDDI networks are token-passing networks and support data rates of up to 100 Mbps (100 million bits). FDDI networks are typically used as backbones for WANs.

FEAC
Far-end alarm and control. A T3 signal used to send alarm or status information from the far-end terminal back to the near-end terminal, and to initiate T3 loopbacks at the far-end terminal from the near-end terminal.

FEB

Forwarding Engine Board. In M5 and M10 routers, provides route lookup, filtering, and switching to the destination port.

FEC

Forwarding equivalence class. Criterion used to forward a set of packets, with similar or identical characteristics, using the same Multiprotocol Label Switching (MPLS) label. Forwarding equivalence classes are defined in the base Label Distribution Protocol (LDP) specification and can be extended through the use of additional parameters. FECs are also represented in other LDPs.

FECN

Forward explicit congestion notification. In a Frame Relay network, a header bit transmitted by the source device requesting that the destination device slow down its requests for data. FECN and backward explicit congestion notification (BECN) minimize the possibility that packets will be discarded when more packets arrive than can be handled. *See also* BECN.

FIFO

First in, first out. Scheduling method in which the first data packet stored in the queue is the first data packet removed from the queue. All JUNOS software interface queues operate in this mode by default.

filter

Process or device that screens packets based on certain characteristics, such as source address, destination address, or protocol, and forwards or discards packets that match the filter. Filters are used to control data packets or local packets. *See also* packet.

FIPS

Federal Information Processing Standards. Defines, among other things, security levels for computer and networking equipment. FIPS is usually applied to military environments.

firewall

Security gateway positioned between two networks, usually between a trusted network and the Internet. A firewall ensures that all traffic that crosses it conforms to the organization's security policy. Firewalls track and control communications, deciding whether to pass, reject, discard, encrypt, or log them. Firewalls also can be used to secure sensitive portions of a local network.

firewall filter

See stateful firewall filter; stateless firewall filter.

firmware

Instructions and data programmed directly into the circuitry of a hardware device for the purpose of controlling the device. Firmware is used for vital programs that must not be lost when the device is powered off.

first in, first out

See FIFO.

flap damping

See damping.

flapping

See route flapping.

flash drive

Nonvolatile memory card in Juniper Networks M-series and T-series routing platforms used for storing a copy of the JUNOS software and the current and most recent router configurations. It also typically acts as the primary boot device.

Flexible PIC Concentrator

See FPC.

floating static route

Route with an administrative distance greater than the administrative distance of the dynamically learned versions of the same route. The static route is used only when the dynamic routes are no longer available. When a floating static route is configured on an interface with a dialer filter, the interface can be used for backup.

flood and prune

Method of forwarding multicast data packets in a dense-mode network. Flooding and pruning occur every three minutes.

flow
: Stream of routing information and packets, which are handled by the Routing Engine (RE) and the Packet Forwarding Engine (PFE). The RE handles the flow of routing information between the routing protocols and the route tables and between the route tables and the forwarding tables, as well as the flow of local packets from the router physical interfaces to the RE. The PFE handles the flow of data packets into and out of the router's physical interfaces.

flow collection interface
: Interface that combines multiple cflowd records into a compressed ASCII data file and exports the file to an FTP server for storage and analysis, allowing users to manipulate the output from traffic monitoring operations.

flow control action
: JUNOS software syntax used in a routing policy or firewall filter. It alters the default logical processing of the policy or filter when a set of match conditions is met.

flow monitoring
: Application that monitors the flow of traffic and enables lawful interception of packets transiting between two routers. Traffic flows can be passively monitored by an offline router or actively monitored by a router participating in the network.

flow-tap application
: Application that uses Dynamic Tasking Control Protocol (DTCP) requests to intercept IPv4 packets in an active monitoring router and send a copy of packets that match filter criteria to one or more content destinations. Flow-tap configurations can be used in flexible trend analysis for detecting new security threats and lawfully intercepting data.

forwarding classes
: Affect the forwarding, scheduling, and marking policies applied to packets as they transit a routing platform. The forwarding class plus the loss priority define the per-hop behavior. Also known as ordered aggregates in the IETF Differentiated Services architecture.

forwarding table
: JUNOS software forwarding information base. The JUNOS routing protocol process installs active routes from its route tables into the Routing Engine (RE) forwarding table. The kernel copies this forwarding table into the Packet Forwarding Engine (PFE), which determines which interface transmits the packets.

FPC
: Flexible PIC Concentrator. An interface concentrator on which Physical Interface Cards (PICs) are mounted. An FPC is inserted into a slot in a Juniper Networks router. *See also* PIC.

fractional E1
: Interface that contains one or more of the 32 DS0 time slots that can be reserved from an E1 interface. (The first time slot is reserved for framing.)

fractional interface
: Interface that contains one or more DS0 time slots reserved from an E1 or T1 interface. Fractional interfaces allow service providers to provision part of one E1 or T1 interface to one customer and the other part to another customer. The individual fractional interfaces connect to different destinations, and customers pay for only the bandwidth fraction used and not for the entire E1 or T1 interface.

: Fractional interfaces can be configured on both channelized Physical Interface Cards (PICs) and Physical Interface Modules (PIMs) and unchannelized, regular E1 and T1 PICs and PIMs.

fractional T1
: Interface that contains one or more of the 24 DS0 time slots that can be reserved from a T1 interface.

fragmentation
: In the Transmission Control Protocol/Internet Protocol (TCP/IP), the process of breaking packets into the smallest maximum size packet data unit (PDU) supported by any of the underlying networks. In the OSI

reference model, this process is known as segmentation. For JUNOS applications, split Layer 3 packets can then be encapsulated in Multilink Frame Relay (MLFR) or the Multilink Point-to-Point Protocol (MLPPP) for transport.

Frame Relay
: Efficient replacement for the older X.25 protocol that does not require explicit acknowledgment of each frame of data. Frame Relay allows private networks to reduce costs by using shared facilities between the endpoint switches of a network managed by a Frame Relay service provider. Individual data-link connection identifiers (DLCIs) are assigned to ensure that each customer receives only its own traffic.

frequency-division multiplexed channel
: Signals carried at different frequencies and transmitted over a single wire or wireless medium.

FRF
: Frame Relay Forum. A technical committee that promotes Frame Relay by negotiating agreements and developing standards.

FRF.15
: End-to-end Frame Relay Implementation Agreement. An implementation of Multilink Frame Relay (MLFR) using multiple virtual connections to aggregate logical bandwidth for end-to-end Frame Relay. Released by the Frame Relay Forum.

FRF.16
: Multilink Frame Relay Implementation Agreement. An implementation of Multilink Frame Relay (MLFR) in which a single logical connection is provided by multiplexing multiple physical interfaces for user-to-network interface and network-to-network interface (UNI/NNI) connections. Released by the Frame Relay Forum.

FRU
: Field-replaceable unit. A router component that customers can replace onsite.

FTP
: File Transfer Protocol. Application protocol that is part of the Transmission Control Protocol/Internet Protocol (TCP/IP) protocol stack. Used for transferring files among network nodes. FTP is defined in RFC 959.

Full
: Open Shortest Path First (OSPF) adjacency state that represents a fully functional neighbor relationship.

fxp0
: *See* management Ethernet interface.

fxp1
: JUNOS software permanent interface used for communications between the Routing Engine (RE) and the Packet Forwarding Engine (PFE). This interface is not present in all routers.

fxp2
: JUNOS software permanent interface used for communications between the Routing Engine (RE) and the Packet Forwarding Engine (PFE). This interface is not present in all routers.

Garbage Collection Timer
: Timer used in a distance-vector network that represents the time remaining before a route is removed from the route table.

G-CDR
: GGSN call detail record. Collection of charges in ASN.1 format that is eventually billed to a mobile station user.

generated route
: Summary route that uses an IP address next hop to forward packets in an IP network. A generated route is functionally similar to an aggregated route.

GGSN
: Gateway GPRS support node. A router that serves as a gateway between mobile networks and packet data networks.

Gigabit Ethernet
: Term describing various technologies for implementing Ethernet networking at a nominal speed of one gigabit per second. Gigabit Ethernet is supported over both optical fiber and twisted-pair cable. Physical

layer standards include 1000Base-T, 1Gbps over CAT-5e copper cabling, and 1000Base-SX for short to medium distances over fiber. *See also* Ethernet; Fast Ethernet.

GMPLS

Generalized Multiprotocol Label Switching. A protocol that extends the functionality of Multiprotocol Label Switching (MPLS) to include a wider range of label-switched path (LSP) options for a variety of network devices.

GPRS General Packet Radio System

A packet-switched service that allows full mobility and wide-area coverage as information is sent and received across a mobile network.

graceful restart

Process that allows a router whose control plane is undergoing a restart to continue to forward traffic while recovering its state from neighboring routers. Without graceful restart, a control plane restart disrupts services provided by the router.

graceful switchover

JUNOS software feature that allows a change from the primary device, such as a Routing Engine (RE), to the backup device without interruption of packet forwarding.

gratuitous

ARP broadcast request for a router's own IP address to check whether that address is being used by another node. Primarily used to detect IP address duplication.

GRE

Generic Routing Encapsulation. A general tunneling protocol that can encapsulate many types of packets to enable data transmission through a tunnel. GRE is used with IP to create a virtual point-to-point link to routers at remote points in a network. *See also* tunneling protocol.

GRES

Graceful Routing Engine switchover. In a router that contains a master and a backup Routing Engine (RE), allows the backup RE to assume mastership automatically, with no disruption of packet forwarding.

group

Collection of related Border Gateway Protocol (BGP) peers.

group address

IP address used as the destination address in a multicast IP packet. The group address functionally represents the senders and interested receivers for a particular multicast data stream.

G.SHDSL

Symmetric high-speed digital subscriber line (SHDSL). Standard published in 2001 by the ITU-T with recommendation ITU G.991.2 G.SHDSL. G.SHDSL incorporates features of other DSL technologies such as asymmetrical DSL (ADSL). *See also* SHDSL; ADSL.

GSM

Global System for Mobile Communications. A second-generation (2G) mobile wireless networking standard defined by ETSI that uses TDMA technology and operates in the 900 MHz radio band. *See also* TDMA.

GTP

GPRS tunneling protocol. A protocol that transports IP packets between an SGSN and a GGSN. *See also* tunneling protocol.

GTP-C

GGSN tunneling protocol, control. A protocol that allows an SGSN to establish packet data network access for a mobile station. *See also* tunneling protocol.

GTP-U

GGSN tunneling protocol, user plane. A protocol that carries mobile station user data packets. *See also* tunneling protocol.

hashing

Cryptographic technique applied over and over (iteratively) to a message of arbitrary length to produce a hash "message digest" or "signature" of fixed length that is appended to the message when it is sent. In security, used to validate that the contents of a message have not been altered in transit. The Secure Hash Algorithm (SHA-1) and Message Digest 5 (MD5) are commonly used hashes. *See also* SHA-1; MD5.

HDLC

High-Level Data Link Control. An International Telecommunication Union (ITU) standard for a bit-oriented data-link layer protocol on which most other bit-oriented protocols are based.

health monitor

JUNOS software extension to the RMON alarm system that provides predefined monitoring for filesystem, CPU, and memory usage. The health monitor also supports unknown or dynamic object instances such as JUNOS processes.

hello interval

Amount of time an Open Shortest Path First (OSPF) router continues to send a hello packet to each adjacent neighbor.

hello mechanism

Process used by a Resource Reservation Protocol (RSVP) router to enhance the detection of network outages in a Multiprotocol Label Switching (MPLS) network.

HLR

Home Location Register. Database containing information about a subscriber and the current location of a subscriber's mobile station.

HMAC

Hashed Message Authentication Code. A mechanism for message authentication that uses cryptographic hash functions. HMAC can be used with any iterative cryptographic hash function—for example, Message Digest 5 (MD5) or Secure Hash Algorithm (SHA-1)—in combination with a secret shared key. The cryptographic strength of HMAC depends on the properties of the underlying hash function. Defined in RFC 2104, "HMAC: Keyed-Hashing for Message Authentication."

hold down

Timer used by distance-vector protocols to prevent the propagation of incorrect routing knowledge to other routers in the network.

hold time

Maximum number of seconds allowed to elapse between successive keepalive or update messages that a Border Gateway Protocol (BGP) system receives from a peer.

host membership query

Internet Group Management Protocol (IGMP) packet sent by a router to determine whether interested receivers exist on a broadcast network for multicast traffic.

host membership report

Internet Group Management Protocol (IGMP) packet sent by an interested receiver for a particular multicast group address. Hosts send report messages when they first join a group or in response to a query packet from the local router.

host module

On an M160 router, provides the routing and system management functions of the router. Consists of the Routing Engine (RE) and Miscellaneous Control Subsystem (MCS).

host subsystem

On a T640 routing node, provides the routing and system management functions of the router. Consists of a Routing Engine (RE) and an adjacent Control Board (CB).

hot standby

In JUNOS, method used with link services intelligent queuing interfaces (LSQs) to enable rapid switchover between primary and secondary (backup) Physical Interface Cards (PICs). *See also* warm standby.

HSCSD

High-Speed Circuit Switched Data. Circuit-switched wireless data transmission for mobile users, at data rates up to 38.4 Kbps.

HTTP

Hypertext Transfer Protocol. Method used to publish and receive information on the Web, such as text and graphics files.

HTTPS

Hypertext Transfer Protocol over Secure Sockets Layer. Similar to HTTP, with an added encryption layer that encrypts and decrypts user page requests and pages that are returned by a web server. Used for secure communication, such as payment transactions.

IANA

Internet Assigned Numbers Authority. A regulatory group that maintains all assigned and registered Internet numbers, such as IP and multicast addresses.

IBGP

Internal BGP. A Border Gateway Protocol (BGP) configuration in which sessions are established between routers in the same autonomous system (AS).

ICMP

Internet Control Message Protocol. Used in router discovery, ICMP allows router advertisements that enable a host to discover addresses of operating routers on the subnet.

IDE

Integrated Drive Electronics. Type of hard disk on a Routing Engine (RE).

IDEA

International Data Encryption Algorithm. An algorithm that uses a 128-bit key and is one of the methods at the heart of Pretty Good Privacy (PGP). IDEA is patented by Ascom Tech AG and is popular in Europe.

Idle

Initial Border Gateway Protocol (BGP) neighbor state in which the local router refuses all incoming session requests.

IDS

Intrusion detection service. A service that inspects all inbound and outbound network activity and identifies suspicious patterns that may indicate a network or system attack from someone attempting to break into or compromise a system.

IEC

International Electrotechnical Commission. *See* ISO.

IEEE

Institute of Electrical and Electronics Engineers. An international professional society for electrical engineers.

IETF

Internet Engineering Task Force. An international community of network designers, operators, vendors, and researchers concerned with the evolution of Internet architecture and the smooth operation of the Internet.

I-frame

Information frame used to transfer data in sequentially numbered logical link control protocol data units (LPDUs) between link stations.

IGMP

Internet Group Management Protocol. Used with multicast protocols to determine whether group members are present.

IGP

Interior Gateway Protocol, such as Intermediate System-to-Intermediate System Level 1 (IS-IS), Open Shortest Path First (OSPF), and the Routing Information Protocol (RIP).

IKE

Internet Key Exchange. Part of IPSec that provides ways to securely negotiate the shared private keys that the authentication header (AH) and Encapsulating Security Payload (ESP) portions of IPSec needed to function properly. IKE employs Diffie-Hellman methods and is optional in IPSec (the shared keys can be entered manually at the endpoints).

ILMI

Integrated Local Management Interface. A specification developed by the ATM Forum that incorporates network management capabilities into the Asynchronous Transfer Mode (ATM) user-to-network interface (UNI) and provides bidirectional exchange of management information between UNI management entities (UMEs).

IMEI

International Mobile Station Equipment Identity. A unique code used to identify an individual mobile station to a GSM network.

import

Installation of routes from the routing protocols into a route table.

IMSI

International Mobile Subscriber Identity. Information that identifies a particular subscriber to a GSM network.

IMT-2000

International Mobile Telecommunications 2000. Global standard for third-generation (3G) wireless communications, defined by a set of interdependent ITU recommendations. IMT-2000 provides a framework for worldwide wireless access by linking the diverse systems of terrestrial and satellite-based networks.

inet.0

Default JUNOS software route table for IPv4 unicast routers.

inet.1

Default JUNOS software route table for storing the multicast cache for active data streams in the network.

inet.2

Default JUNOS software route table for storing unicast IPv4 routes specifically used to prevent forwarding loops in a multicast network.

inet.3

Default JUNOS software route table for storing the egress IP address of a Multiprotocol Label Switching (MPLS) label-switched path.

inet.4

Default JUNOS software route table for storing information generated by the Multicast Source Discovery Protocol (MSDP).

inet6.0

Default JUNOS software route table for storing unicast IPv6 routes.

infinity metric

Metric value used in distance-vector protocols to represent an unusable route. For the Routing Information Protocol (RIP), the infinity metric is 16.

ingress router

In Multiprotocol Label Switching (MPLS), the first router in a label-switched path (LSP). *See also* egress router.

Init

Open Shortest Path First (OSPF) adjacency state in which the local router has received a hello packet but bidirectional communication is not yet established.

insert

JUNOS software command that allows a user to reorder terms in a routing policy or a firewall filter, or to change the order of a policy chain.

instance.inetflow.0

Route table that shows route flows through the Border Gateway Protocol (BGP).

inter-AS routing

Routing of packets among different autonomous systems (ASs). *See also* EBGP.

intercluster reflection

In a Border Gateway Protocol (BGP) route reflection, the redistribution of routing information by a route reflector system to all nonclient peers (BGP peers not in the cluster). *See also* route reflection.

interface cost

Value added to all received routes in a distance-vector network before they are placed into the route table. The JUNOS software uses a cost of 1 for this value.

interface preservation

See link state replication.

interface routes

Routes that are in the route table because an interface has been configured with an IP address. Also called *direct routes*.

intermediate system

In Intermediate System-to-Intermediate System Level 1 (IS-IS), the network entity that sends and receives packets and can also route packets.

Internet Processor ASIC

Juniper Networks ASIC responsible for using the forwarding table to make routing decisions within the Packet Forwarding Engine (PFE). The Internet Processor ASIC also implements firewall filters.

interprovider VPN

Virtual private network (VPN) that provides connectivity between separate autonomous systems (ASs) with separate border edge routers. It is used by VPN customers who have connections to several different Internet service providers (ISPs), or different connections to the same ISP in different geographic regions, each of which has a different AS.

intra-AS routing

Routing of packets within a single autonomous system (AS). *See also* IBGP.

I/O Manager ASIC

Juniper Networks ASIC responsible for segmenting data packets into 64-byte J-cells and for queuing resultant cells before transmission.

IP

Internet Protocol. The protocol used for sending data from one point to another on the Internet.

IPCP

IP Control Protocol. The protocol that establishes and configures IP over the Point-to-Point Protocol (PPP).

IPSec

IP Security. A standard way to add security to Internet communications. The secure aspects of IPSec are usually implemented in three parts: the authentication header (AH), the Encapsulating Security Payload (ESP), and the Internet Key Exchange (IKE).

IQ

Intelligent queuing. M-series and T-series routing platform interfaces that offer granular quality-of-service (QoS) capabilities; extensive statistics on packets and bytes that are transmitted, received, or dropped; and embedded diagnostic tools.

IRDP

ICMP Router Discovery Protocol. A protocol that enables a host to determine the address of a router that it can use as a default gateway.

ISAKMP

Internet Security Association and Key Management Protocol. A protocol that allows the receiver of a message to obtain a public key and use digital certificates to authenticate the sender's identity. ISAKMP is key-exchange-independent; that is, it supports many different key exchanges. *See also* IKE; Oakley.

ISDN

Integrated Services Digital Network. A set of digital communications standards, which enable the transmission of information over existing twisted-pair telephone lines at higher speeds than standard analog telephone service. An ISDN interface provides multiple B-channels (bearer channels) for data and one D-channel for control and signaling information. *See also* B-channel; D-channel.

IS-IS

Intermediate System-to-Intermediate System. A link-state, interior gateway routing protocol for IP networks that also uses the Shortest Path First (SPF) algorithm to determine routes.

ISO

International Organization for Standardization. A worldwide federation of standards bodies that promotes international standardization and publishes international agreements as International Standards.

ISP

Internet service provider. A company that provides access to the Internet and related services.

ITU-T

International Telecommunication Union Telecommunication Standardization (formerly known as the CCITT). Group supported by the United Nations that makes recommendations and coordinates the development of telecommunications standards for the entire world.

ITU-T Rec. G.992.1
International standard that defines the asymmetrical digital subscriber line (ADSL). Annex A defines how ADSL works over twisted-pair copper (POTS) lines. Annex B defines how ADSL works over Integrated Services Digital Network (ISDN) lines.

jbase
JUNOS software package containing updates to the kernel.

jbundle
JUNOS software package containing all possible software package files.

J-cell
A 64-byte data unit used within the Packet Forwarding Engine (PFE). All IP packets processed by a Juniper Networks router are segmented into J-cells.

jdocs
JUNOS software package containing the documentation set.

jitter
Small random variation introduced into the value of a timer to prevent multiple timer expirations from becoming synchronized. In real-time applications such as Voice over IP and video, variation in the rate at which packets in a stream are received that can cause quality degradation.

jkernel
JUNOS software package containing the basic components of the software.

Join message
Physical Interface Module (PIM) message sent hop by hop upstream toward a multicast source or the rendezvous point (RP) of the domain. It requests that multicast traffic be sent downstream to the router originating the message.

jpfe
JUNOS software package containing the embedded OS software for operating the Packet Forwarding Engine (PFE).

jroute
JUNOS software package containing the software used by the Routing Engine (RE).

J-Web
Graphical web browser interface to the JUNOS Internet software on routing platforms. With the J-Web interface, you can monitor, configure, diagnose, and manage the routing platform from a PC or laptop that has Hypertext Transfer Protocol (HTTP) or HTTP over Secure Sockets Layer (HTTPS) enabled.

keepalive message
Message sent between network devices to inform each other that they are still active.

kernel
Basic software component of the JUNOS software. The kernel operates the various processes used to control the router's operations.

kernel forwarding table
See forwarding table.

kmd
Key management process that provides IPSec authentication services for encryption Physical Interface Cards (PICs).

L2TP
Layer 2 Tunneling Protocol. A procedure for secure communication of data across a Layer 2 network that enables users to establish Point-to-Point Protocol (PPP) sessions between tunnel endpoints. L2TP uses profiles for individual user and group access to ensure secure communication that is as transparent as possible to both end users and applications. *See also* tunneling protocol.

label
In Multiprotocol Label Switching (MPLS), a 20-bit unsigned integer from 0 through 1,048,575, used to identify a packet traveling along a label-switched path (LSP).

Label Distribution Protocol
See LDP.

label object
Resource Reservation Protocol (RSVP) message object that contains the label

value allocated to the next downstream router.

label pop operation

Function performed by a Multiprotocol Label Switching (MPLS) router in which the top label in a label stack is removed from the data packet.

label push operation

Function performed by a Multiprotocol Label Switching (MPLS) router in which a new label is added to the top of the data packet.

label request object

Resource Reservation Protocol (RSVP) message object that requests each router along the path of a label-switched path (LSP) to allocate a label for forwarding.

label swap operation

Function performed by a Multiprotocol Label Switching (MPLS) router in which the top label in a label stack is replaced with a new label before the data packet is forwarded to the next hop router.

label values

A 20-bit field in a Multiprotocol Label Switching (MPLS) header used by routers to forward data traffic along an MPLS label-switched path (LSP).

LAN PHY

Local Area Network Physical Layer Device. A physical layer device that allows 10-Gigabit Ethernet wide area links to use existing Ethernet applications. *See also* PHY; WAN PHY.

Layer 2 circuits

Collection of transport modes that accept a stream of Asynchronous Transfer Mode (ATM) cells, convert them to an encapsulated Layer 2 format, and then tunnel them over a Multiprotocol Label Switching (MPLS) or IP backbone, where a similarly configured routing platform segments these packets back into a stream of ATM cells, to be forwarded to the virtual circuit configured for the far-end routing platform. Layer 2 circuits are designed to transport Layer 2 frames between provider edge (PE) routing platforms across a Label Distribution Protocol (LDP)-signaled MPLS backbone. *See also* AAL5 mode; cell-relay mode; standard AAL5 mode; trunk mode.

Layer 2 VPN

Provides a private network service among a set of customer sites using a service provider's existing Multiprotocol Label Switching (MPLS) and IP network. A customer's data is separated from other data using software rather than hardware. In a Layer 2 VPN, the Layer 3 routing of customer traffic occurs within the customer's network.

Layer 3 VPN

Provides a private network service among a set of customer sites using a service provider's existing Multiprotocol Label Switching (MPLS) and IP network. A customer's routes and data are separated from other routes and data using software rather than hardware. In a Layer 3 VPN, the Layer 3 routing of customer traffic occurs within the service provider's network.

LCC

Line-card chassis. Term used by the JUNOS command-line interface (CLI) to refer to a T640 routing node in a routing matrix.

LCP

Link Control Protocol. A traffic controller used to establish, configure, and test data-link connections for the Point-to-Point Protocol (PPP).

LDAP

Lightweight Directory Access Protocol. Software protocol used for locating resources on a public or private network.

LDP

Label Distribution Protocol. A protocol for distributing labels in nontraffic-engineered applications. LDP allows routers to establish label-switched paths (LSPs) through a network by mapping network-layer routing information directly to data-link layer switched paths.

leaf node

Terminating node of a multicast distribution tree. A router that is a leaf node only has receivers and does not forward multicast packets to other routers.

LFI

Link fragmentation and interleaving. A method that reduces excessive delays by fragmenting long packets into smaller packets and interleaving them with real-time frames. For example, short delay-sensitive packets, such as packetized voice, can race ahead of larger delay-insensitive packets, such as common data packets.

liblicense

Library that includes messages generated for routines for software license management.

libpcap

Implementation of the pcap application programming interface. libpcap is used by a program to capture packets traveling over a network. *See also* pcap.

limited operational environment

Term used to describe the restrictions placed on FIPS-certified equipment. *See* FIPS.

line loopback

Method of troubleshooting a problem with physical transmission media in which a transmission device in the network sends the data signal back to the originating router.

link

Communication path between two neighbors. A link is up when communication is possible between the two endpoints.

link protection

Method of establishing bypass label-switched paths (LSPs) to ensure that traffic going over a specific interface to a neighboring router can continue to reach the router if that interface fails. The bypass LSP uses a different interface and path to reach the same destination.

link services intelligent queuing interfaces

See LSQ.

link-state acknowledgment

Open Shortest Path First (OSPF) data packet used to inform a neighbor that a link-state update packet has been successfully received.

link-state database

All routing knowledge in a link-state network is contained in this database. Each router runs the Shortest Path First (SPF) algorithm against this database to locate the best network path to each destination in the network.

link-state PDU

Packet that contains information about the state of adjacencies to neighboring systems.

link-state replication

Addition to the SONET Automatic Protection Switching (APS) functionality that helps to promote redundancy of the link Physical Interface Cards (PICs) used in LSQ configurations. If the active SONET PIC fails, links from the standby PIC are used without causing a link renegotiation. Also called *interface preservation*.

link-state request list

List generated by an Open Shortest Path First (OSPF) router during the exchange of database information while forming an adjacency. Advertised information by a neighbor that the local router does not contain is placed in this list.

link-state request packet

Open Shortest Path First (OSPF) data packet used by a router to request database information from a neighboring router.

link-state update

Open Shortest Path First (OSPF) data packet that contains one of multiple link-state advertisements (LSAs). It is used to advertise routing knowledge into the network.

LLC

Logical link control. Data-link layer protocol used on a LAN. LLC1 provides connectionless data transfer, and LLC2 provides connection-oriented data transfer.

LLC frame

Unit of data that contains specific information about the LLC layer and identifies line protocols associated with the layer. *See also* LLC.

LMI

Local management interface. Enhancements to the basic Frame Relay specifications provide support for the following:

- A keepalive mechanism that verifies the flow of data
- A multicast mechanism that provides a network server with a local data-link connection identifier (DLCI) and multicast DLCI
- In Frame Relay networks, global addressing that gives DLCIs global instead of local significance
- A status mechanism that provides a switch with ongoing status reports on known DLCIs

LMP

Link Management Protocol. Part of GMPLS, a protocol used to define a forwarding adjacency between peers and to maintain and allocate resources on the traffic engineering links.

load balancing

Process that installs all next hop destinations for an active route in the forwarding table. You can use load balancing across multiple paths between routers. The behavior of load balancing depends on the version of the Internet Processor ASIC in the router. Also called *per-packet load balancing*.

loading

Open Shortest Path First (OSPF) adjacency state in which the local router sends link-state request packets to its neighbor and waits for the appropriate link-state updates from that neighbor.

local packet

Chunk of data destined for or sent by the Routing Engine (RE).

local preference

Optional Border Gateway Protocol (BGP) path attribute carried in internal BGP update packets that indicate the degree of preference for an external route.

local RIB

Logical software table that contains Border Gateway Protocol (BGP) routes used by the local router to forward data packets.

local significance

Concept used in a Multiprotocol Label Switching (MPLS) network where the label values are unique only between two neighbor routers.

logical interface

On a physical interface, the configuration of one or more units that include all addressing, protocol information, and other logical interface properties that enable the physical interface to function.

logical operator

Characters used in a firewall filter to represent a Boolean AND or OR operation.

logical router

Logical routing device that is partitioned from an M-series or T-series routing platform. Each logical router independently performs a subset of the tasks performed by the main router and has a unique route table, interfaces, policies, and routing instances.

longer

JUNOS software routing policy match type that represents all routes more specific than the given subnet, but not the given subnet itself. It is similar to a mathematical greater-than operation.

loopback interface (`lo0`)

Interface that is always available because it is independent of any physical interfaces. When configured with an address, the loopback interface is the default address for the routing platform and any unnumbered interfaces. *See also* unnumbered interface.

loose hop

In the context of traffic engineering, a path that can use any router or any number of other intermediate (transit) points to reach the next address in the path. (Definition from RFC 791, modified to fit LSPs.)

loss-priority map
Maps the loss priority of incoming packets based on code point values.

lower-speed IQ interfaces
E1, NxDS0, and T1 interfaces configured on an intelligent queuing (IQ) Physical Interface Card (PIC).

LPDU
LLC protocol data unit. LLC frame on a data link switching (DLSw) network. *See* LLC frame.

LSA
Link-state advertisement. Open Shortest Path First (OSPF) data structure that is advertised in a link-state update packet. Each LSA uniquely describes a portion of the OSPF network.

LSI
Label-switched interface. A logical interface supported by the JUNOS software that provides virtual private network (VPN) services (such as VPLS and Layer 3 VPNs) normally provided by a Tunnel Services PIC.

LSP
1. Label-switched path. Sequence of routers that cooperatively perform Multiprotocol Label Switching (MPLS) operations for a packet stream. The first router in an LSP is called the ingress router, and the last router in the path is called the egress router. An LSP is a point-to-point, half-duplex connection from the ingress router to the egress router. (The ingress and egress routers cannot be the same router.) 2. *See* link-state PDU.

LSQ
Link services intelligent queuing interfaces. Interfaces configured on the Adaptive Services PIC (ASP) or Adaptive Services Module (ASM) that support Multilink Point-to-Point Protocol (MLPPP) and Multilink Frame Relay (MLFR) traffic and also fully support JUNOS class-of-service (CoS) components.

LSR
Label-switching router. A router on which Multiprotocol Label Switching (MPLS) is enabled and that can process label-switched packets.

MAC
Media access control. In the OSI seven-layer networking model defined by the IEEE, MAC is the lower sublayer of the data link layer. The MAC sublayer governs protocol access to the physical network medium. By using the MAC addresses that are assigned to all ports on a router, multiple devices on the same physical link can uniquely identify one another at the data link layer. *See also* MAC address.

MAC address
Serial number permanently stored in a device adapter to uniquely identify the device. *See also* MAC.

MAM
Maximum allocation bandwidth constraints model. In Differentiated-Services-aware traffic engineering, a constraint model that divides the available bandwidth among the different classes. Sharing of bandwidth among the class types is not allowed.

management Ethernet interface
Permanent interface that provides an out-of-band method, such as Secure Shell (SSH) and Telnet, to connect to the routing platform. The Simple Network Management Protocol (SNMP) can use the management interface to gather statistics from the routing platform. Called *fxp0* on some routing platforms. *See also* permanent interface.

mapping agent
Router used in an auto-RP multicast network to select the rendezvous point (RP) for all multicast group addresses. The RP is then advertised to all other routers in the domain.

martian address
: Network address about which all information is ignored.

martian route
: Network routes about which all information is ignored. The JUNOS software does not allow martian routes in the `inet.0` route table.

MAS
: Mobile network access subsystem. A GSN application subsystem that contains the access server.

master
: Router in control of the Open Shortest Path First (OSPF) database exchange during an adjacency formation.

match
: Logical concept used in a routing policy or firewall filter. A match denotes the criteria used to find a route or IP packet before an action is performed.

match type
: JUNOS software syntax used in a route filter to better describe the routes that should match the policy term.

MBGP
: Multiprotocol Border Gateway Protocol. An extension to the Border Gateway Protocol (BGP) that allows you to connect multicast topologies within and between BGP autonomous systems (ASs).

MBone
: Multicast Backbone. An interconnected set of subnetworks and routers that support the delivery of IP multicast traffic. The MBone is a virtual network that is layered on top of sections of the physical Internet.

MCS
: Miscellaneous Control Subsystem. On the M40e and M160 routers, provides control and monitoring functions for router components and SONET clocking for the router.

MD5
: Message Digest 5. A one-way hashing algorithm that produces a 128-bit hash used for generating message authentication signatures. MD5 is used in authentication header (AH) and Encapsulating Security Payload (ESP). *See also* hashing; SHA-1.

MDRR
: Modified deficit round-robin. A method for selecting queues to be serviced. *See* queue.

MDT
: Multicast distribution tree. The path between the sender (host) and the multicast group (receiver or listener).

mean time between failures
: *See* MTBF.

MED
: Multiple exit discriminator. An optional Border Gateway Protocol (BGP) path attribute consisting of a metric value that is used to determine the exit point to a destination when all other factors determining the exit point are equal.

mesh
: Network topology in which devices are organized in a manageable, segmented manner with many, often redundant, interconnections between network nodes.

message aggregation
: Extension to the Resource Reservation Protocol (RSVP) specification that allows neighboring routers to bundle up to 30 RSVP messages into a single protocol packet.

mgd
: Management daemon. JUNOS software process responsible for managing all user access to the router.

MIB
: Management Information Base. Definition of an object that can be managed by the Simple Network Management Protocol (SNMP).

midplane
: Physically separates front and rear cavities inside the chassis, distributes power from the power supplies, and transfers packets and signals between router components, which plug into it.

MLD

Multicast listener discovery. A protocol that manages the membership of hosts and routers in multicast groups. IPv6 multicast routers use MLD to learn, for each of their attached physical networks, which groups have interested listeners.

MLFR

Multilink Frame Relay. Logically ties together individual circuits, creating a bundle. The logical equivalent of the Multilink Point-to-Point Protocol (MLPPP), MLFR is used for Frame Relay traffic instead of Point-to-Point Protocol (PPP) traffic. FRF.15 and FRF.16 are two implementations of MLFR.

MLPPP

Multilink Point-to-Point Protocol. Enables you to bundle multiple Point-to-Point Protocol (PPP) links into a single logical link between two network devices to provide an aggregate amount of bandwidth. The technique is often called *bonding* or *link aggregation*. Defined in RFC 1990. *See also* PPP.

MMF

Multimode fiber. Optical fiber supporting the propagation of multiple frequencies of light. MMF is used for relatively short distances because the modes tend to disperse over longer lengths (called *modal dispersion*). For longer distances, single-mode fiber (sometimes called *monomode*) is used. *See also* single-mode fiber.

mobile station

Mobile device, such as a cellular phone or a mobile personal digital assistant (PDA).

mobile transport subsystem

See MTS.

MPLS

Multiprotocol Label Switching. Mechanism for engineering network traffic patterns that functions by assigning to network packets short labels that describe how to forward them through the network. Also called *label switching*. *See also* traffic engineering.

MPLS EXP classifier

Class-of-service (CoS) behavior classifier for classifying packets based on the Multiprotocol Label Switching (MPLS) experimental bit. *See also* EXP bits.

MPS

Mobile point-to-point control subsystem. A GSN application subsystem that controls all functionality associated with a particular connection.

MRRU

Maximum received reconstructed unit. Similar to the maximum transmission unit (MTU), but is specific to link services interfaces. *See also* MTU.

MSA

Multisource Agreement. The definition of a fiber-optic transceiver module that conforms to the 10-Gigabit Ethernet standard. *See also* XENPAK module.

MSC

Mobile Switching Center. Provides origination and termination functions to calls from a mobile station user.

MSDP

Multicast Source Discovery Protocol. A protocol used to connect multicast routing domains to allow the domains to discover multicast sources from other domains. It typically runs on the same router as the Physical Interface Module (PIM) sparse mode rendezvous point (RP).

MSISDN

Mobile Station Integrated Services Digital Network Number. A number that callers use to reach a mobile services subscriber.

MTBF

Mean time between failures. Measure of hardware component reliability.

MTS

Mobile transport subsystem. A GSN application subsystem that implements all the protocols used by the GSN.

MTU

Maximum transmission unit. Limit on the data size for a network.

multicast

Operation of sending network traffic from one network node to multiple network nodes.

multicast-scope number

Number used for configuring the multicast scope. Configuring a scope number constrains the scope of a multicast session. The number value can be any hexadecimal number from 0 through F. The multicast-scope value is a number from 0 through 15, or a specified keyword with an associated prefix range. For example, link-local (value = 2), corresponding prefix 224.0.0.0/24.

multiclass LSP

In Differentiated-Services-aware traffic engineering, a multiclass label-switched path (LSP) functions like a standard LSP, but also allows you to reserve bandwidth for multiple class types. The experimental (EXP) bits of the Multiprotocol Label Switching (MPLS) header are used to distinguish among class types.

multiclass MLPPP

Enables multiple classes of service while using the Multilink Point-to-Point Protocol (MLPPP). Defined in RFC 2686, "The Multi-Class Extension to Multi-Link PPP."

multifield classifier

Method for classifying traffic flows. Unlike a behavior aggregate (BA) classifier, a multifield classifier examines multiple fields in the packet to apply class-of-service (CoS) settings. Examples of fields that a multifield classifier examines include the source and destination addresses of the packet, as well as the source and destination port numbers of the packet. *See also* BA classifier; classification.

multihoming

Network topology that uses multiple connections between customer and provider devices to provide redundancy.

MVS

Mobile visitor register subsystem.

named path

JUNOS software syntax that specifies a portion of or the entire network path that should be used as a constraint in signaling a Multiprotocol Label Switching (MPLS) label-switched path (LSP).

NAPT

Network Address Port Translation. A method that translates the addresses and transport identifiers of many private hosts into a few external addresses and transport identifiers to make efficient use of globally registered IP addresses. NAPT extends the level of translation beyond that of basic Network Address Translation (NAT). *See also* NAT.

NAT

Network Address Translation. A method of concealing a set of host addresses on a private network behind a pool of public addresses. It can be used as a security measure to protect the host addresses from direct targeting in network attacks.

NCP

Network Control Protocol. A traffic controller used to establish and configure different network layer protocols for the Point-to-Point Protocol (PPP).

NDP

Neighbor Discovery Protocol. A protocol used by IPv6 nodes on the same link to discover each other's presence, determine each other's link-layer addresses, find routers, and maintain reachability information about the paths to active neighbors. NDP is defined in RFC 2461 and is equivalent to the Address Resolution Protocol (ARP) used with IPv4. *See also* ARP.

neighbor

Adjacent system reachable by traversing a single subnetwork. An immediately adjacent router. Also called a *peer*.

NET

Network entity title. Network address defined by the ISO network architecture and used in CLNS-based networks.

NetBIOS
Network basic input/output system. An application programming interface used by programs on a LAN. NetBIOS provides a uniform set of commands for requesting the lower-level services required to manage names, conduct sessions, and send datagrams between nodes on a network.

network interface
Interface, such as an Ethernet or SONET/SDH interface, which primarily provides traffic connectivity. *See also* PIC; services interface.

network link advertisement
Open Shortest Path First (OSPF) link-state advertisement (LSA) flooded throughout a single area by designated routers to describe all routers attached to the network.

network LSA
Open Shortest Path First (OSPF) link-state advertisement (LSA) sent by the designated router on a broadcast or NBMA segment. It advertises the subnet associated with the designated router's segment.

network summary LSA
Open Shortest Path First (OSPF) link-state advertisement (LSA) sent by an area border router (ABR) to advertise internal OSPF routing knowledge across an area boundary. *See also* ABR.

NIC
Network Information Center. Internet authority responsible for assigning Internet-related numbers, such as IP addresses and autonomous system (AS) numbers. *See also* IANA.

NIST
National Institute of Standards and Technology. A nonregulatory U.S. federal agency whose mission is to develop and promote measurement, standards, and technology.

NLRI
Network layer reachability information. Information carried in Border Gateway Protocol (BGP) packets and used by the Multiprotocol Border Gateway Protocol (MBGP).

nonclient peer
In a Border Gateway Protocol (BGP) route reflection, a BGP peer that is not a member of a cluster. *See also* client peer.

notification cell
JUNOS software data structure generated by the Distribution Buffer Manager ASIC that represents the header contents of an IP packet. The Internet Processor ASIC uses the notification cell to perform a forwarding table lookup.

Notification message
A Border Gateway Protocol (BGP) message that informs a neighbor about an error condition, and then in some cases terminates the BGP peering session.

not-so-stubby area
See NSSA.

NSAP
Network service access point. Connection to a network that is identified by a network address.

n-selector
Last byte of a nonclient peer address.

NSR
Nonstop routing. A high-availability feature that allows a routing platform with redundant Routing Engines (REs) to preserve routing information on the backup RE and switch over from the primary RE to the backup RE without alerting peer nodes that a change has occurred. NSR uses the graceful RE switchover (GRES) infrastructure to preserve interface, kernel, and routing information.

NSSA
Not-so-stubby area. In Open Shortest Path First (OSPF), a type of stub area in which external routes can be flooded.

NTP
Network Time Protocol. A protocol used to synchronize computer clock times on a network.

Null Register message
Physical Interface Module (PIM) message sent by the first hop router to the rendezvous point (RP). The message informs the RP that the local source is still actively

sending multicast packets into the network. *See also* RP.

numeric range match conditions
: Use of numeric values (protocol and port numbers) in the header of an IP packet to match criteria in a firewall filter.

Oakley
: Key determination protocol based on the Diffie-Hellman algorithm that provides added security, including authentication. Oakley was the key-exchange algorithm mandated for use with the initial version of ISAKMP, although other algorithms can be used. Oakley describes a series of key exchanges called *modes* and details the services provided by each; for example, Perfect Forward Secrecy for keys, identity protection, and authentication. *See also* ISAKMP.

OAM
: Operation, Administration, and Maintenance. An ATM Forum specification for monitoring Asynchronous Transfer Mode (ATM) virtual connections. OAM performs standard loopback, fault detection and notification, and remote defect identification for each connection, verifying that the connection is up and the router is operational.

OC
: Optical carrier. In SONET, the OC level indicates the transmission rate of digital signals on optical fiber.

OC3
: SONET line with a transmission speed of 155.52 Mbps (payload of 150.336 Mbps) using fiber-optic cables. For SDH interfaces, OC3 is also known as STM1.

OC12
: SONET line with a transmission speed of 622 Mbps using fiber-optic cables.

Open message
: Border Gateway Protocol (BGP) message that allows two neighbors to negotiate the parameters of the peering session.

OpenConfirm
: Border Gateway Protocol (BGP) neighbor state that shows that a valid Open message was received from the remote peer.

OpenSent
: Border Gateway Protocol (BGP) neighbor state that shows that an Open message was sent to the remote peer and the local router is waiting for an Open message to be returned.

operational mode
: JUNOS software mode that allows a user to view statistics and information about the router's current operating status.

op script
: Operational script. Extensible Stylesheet Language for Transformations (XSLT) script written to automate network troubleshooting and network management. Op scripts can perform any function available through JUNOScript remote procedure calls (RPCs).

origin
: In the Border Gateway Protocol (BGP), an attribute that describes the source of the route.

orlonger
: JUNOS software routing policy match type that represents all routes more specific than the given subnet, including the given subnet itself. It is similar to a mathematical greater-than-or-equal-to operation.

OSI
: Open Systems Interconnection. Standard reference model for how messages are transmitted between two points on a network.

OSPF
: Open Shortest Path First. A link-state Interior Gateway Protocol (IGP) that makes routing decisions based on the Shortest Path First (SPF) algorithm (also referred to as the Dijkstra algorithm).

OSPF hello packet
: Message sent by each Open Shortest Path First (OSPF) router to each adjacent router. It is used to establish and maintain the router's neighbor relationships.

overlay network

Network design in which a logical Layer 3 topology (IP subnets) is operating over a logical Layer 2 topology (Asynchronous Transfer Mode permanent virtual circuits [ATM PVCs]). Layers in the network do not have knowledge of each other, and each layer requires separate management and operation.

oversubscription

Method that allows provisioning of more bandwidth than the line rate of the physical interface.

P2MP LSP

See point-to-multipoint LSP.

package

Collection of files that make up a JUNOS software component.

packet

Fundamental unit of information (message or fragment of a message) carried in a packet-switched network; for example, the Internet. *See also* PSN.

packet aging

Occurs when packets in the output buffer are overwritten by newly arriving packets. This happens because the available buffer size is greater than the available transmission bandwidth.

packet capture

1. Packet sampling method, in which entire IPv4 packets flowing through a router are captured for analysis. Packets are captured in the Routing Engine (RE) and stored as libpcap-formatted files on the router. Packet capture files can be opened and analyzed offline with packet analyzers such as tcpdump and Ethereal. *See also* traffic sampling. 2. J-Web packet sampling method for quickly analyzing router control traffic destined for or originating from the RE. You can either decode and view the captured packets in the J-Web interface as they are captured, or save the packets to a file and analyze them offline with packet analyzers such as Ethereal. J-Web packet capture does not capture transient traffic.

Packet Forwarding Engine

Portion of the router that processes packets by forwarding them between input and output interfaces.

packet or cell switching

Transmission of packets from many sources over a switched network.

PADI

PPPoE Active Discovery Initiation packet. A Point-to-Point Protocol over Ethernet (PPPoE) initiation packet that is broadcast by the client to start the discovery process.

PADO

PPPoE Active Discovery Offer packet. A Point-to-Point Protocol over Ethernet (PPPoE) offer packet that is sent to the client by one or more access concentrators in reply to a PPPoE Active Discovery Initiation (PADI) packet.

PADR

PPPoE Active Discovery Request packet. A Point-to-Point Protocol over Ethernet (PPPoE) packet sent by the client to one selected access concentrator to request a session.

PADS

PPPoE Active Discovery Session Confirmation packet. A Point-to-Point Protocol over Ethernet (PPPoE) packet sent by the selected access concentrator to confirm the session.

PADT

PPPoE Active Discovery Termination packet. A Point-to-Point Protocol over Ethernet (PPPoE) packet sent by either the client or the access concentrator to terminate a session.

passive flow monitoring

Technique to intercept and observe specified data network traffic by using a routing platform such as a monitoring station that is not participating in the network.

path attribute

Information about a Border Gateway Protocol (BGP) route, such as the route origin, autonomous system (AS) path, and next hop router.

PathErr message

Resource Reservation Protocol (RSVP) message indicating that an error has occurred along an established path label-switched path (LSP). The message is advertised upstream toward the ingress router and does not remove any RSVP soft state from the network.

PathTear message

Resource Reservation Protocol (RSVP) message indicating that the established label-switched path (LSP) and its associated soft state should be removed by the network. The message is advertised downstream hop by hop toward the egress router.

pcap

Software library for packet capturing. *See also* libpcap.

PC Card

(Previously known as a PCMCIA Card.) The removable storage media that ships with each router that contains a copy of the JUNOS software. The PC Card is based on standards published by the Personal Computer Memory Card International Association (PCMCIA).

PCI

Peripheral Component Interconnect. Standard, high-speed bus for connecting computer peripherals. Used on the Routing Engine (RE).

PCI Express

Peripheral Component Interconnect Express. Next-generation, higher-bandwidth bus for connecting computer peripherals. A PCI Express bus uses point-to-point bus topology with a shared switch rather than the shared bus topology of a standard PCI bus. The shared switch on a PCI Express bus provides centralized traffic routing and management and can prioritize traffic. On some J-series Services Routers, PCI Express slots are backward-compatible with PCI and can accept Physical Interface Modules (PIMs) intended for either PCI Express or PCI slots.

PCMCIA

Personal Computer Memory Card International Association. Industry group that promotes standards for credit-card-size memory and I/O devices.

PDH

Plesiochronous Digital Hierarchy. Developed to carry digitized voice more efficiently. Evolved into the North American, European, and Japanese Digital Hierarchies, in which only a discrete set of fixed rates is available; namely, NxDS0 (DS0 is a 64 Kbps rate).

PDP

Packet data protocol. Network protocol, such as IP, used by packet data networks connected to a GPRS network.

PDU

Protocol data unit. A packet of data passed across a network. The term refers to a specific layer of the OSI seven-layer model and a specific protocol.

PEC

Policing equivalence classes. In traffic policing, a set of packets that are treated the same way by the packet classifier.

peer

Immediately adjacent router with which a protocol relationship has been established. Also called a *neighbor*.

peering

Practice of exchanging Internet traffic with directly connected peers according to commercial and contractual agreements.

PEM

1. Privacy Enhanced Mail. A technique for securely exchanging electronic mail over a public medium. 2. Power Entry Module. Distributes DC power within the router chassis. Supported on M40e, M160, M320, and T-series routing platforms.

penultimate router

Last transit router before the egress router in a Multiprotocol Label Switching (MPLS) label-switched path (LSP).

permanent interface

Interface that is always present in the routing platform. *See also* management Ethernet interface; transient interface.

persistent change

Commit script-generated configuration change that is copied to the candidate configuration. Persistent changes remain in the candidate configuration unless you explicitly delete them. *See also* transient change.

PE router

Provider edge router. A router in the service provider's network that is connected to a customer edge (CE) device and participates in a virtual private network (VPN).

PFC

Protocol Field Compression. Normally, Point-to-Point Protocol (PPP)-encapsulated packets are transmitted with a 2-byte protocol field. For example, IPv4 packets are transmitted with the protocol field set to 0×0021, and Multiprotocol Label Switching (MPLS) packets are transmitted with the protocol field set to 0×0281. For all protocols with identifiers from 0×0000 through 0×00ff, PFC enables routers to compress the protocol field to one byte, as defined in RFC 1661, "The Point-to-Point Protocol (PPP)." PFC allows you to conserve bandwidth by transmitting less data. *See also* ACFC.

PFS

Perfect Forward Secrecy protocol. A protocol derived from an encryption system that changes encryption keys often and ensures that no two sets of keys have any relationship to each other. If one set of keys is compromised, only communications using those keys are at risk. An example of a system that uses PFS is Diffie-Hellman.

PGM

Pragmatic General Multicast. A protocol layer that can be used between the IP layer and the multicast application on sources, receivers, and routers to add reliability, scalability, and efficiency to multicast networks.

PGP

Pretty Good Privacy. A strong cryptographic technique invented by Philip Zimmerman in 1991.

PHP

Penultimate hop popping. A mechanism used in a Multiprotocol Label Switching (MPLS) network that allows the transit router before the egress router to perform a label pop operation and forward the remaining data (often an IPv4 packet) to the egress router.

PHY

1. Special electronic integrated circuit or functional block of a circuit that performs encoding and decoding between a pure digital domain (on-off) and a modulation in the analog domain. *See also* LAN PHY; WAN PHY. 2. Open Systems Interconnection (OSI) physical layer. Layer 1 of the OSI model that defines the physical link between devices.

physical interface

Port on a Physical Interface Card (PIC) or Physical Interface Module (PIM).

Physical Interface Module

A network interface card installed in a J-series Services Router to provide physical connections to a LAN or WAN. PIMs can be fixed or removable and interchangeable. The PIM receives incoming packets from the network and transmits outgoing packets to the network. Each PIM is equipped with a dedicated network processor that forwards incoming data packets to and receives outgoing data packets from the Routing Engine (RE). During this process, the PIM performs framing and line-speed signaling for its medium type—for example, E1, serial, Fast Ethernet, or Integrated Services Digital Network (ISDN).

PIC

Physical Interface Card. A network interface-specific card that can be installed on a Flexible PIC Concentrator (FPC) in the router.

PIC I/O Manager
Juniper Networks ASIC responsible for receiving and transmitting information on the physical media. It performs media-specific tasks within the Packet Forwarding Engine (PFE).

PIR
Peak information rate. The PIR must be equal to or greater than the committed information rate (CIR), and both must be configured to be greater than 0. Packets that exceed the PIR are marked red, which corresponds to high loss priority. *See also* CIR; trTCM.

PKI
Public key infrastructure. A hierarchy of trust that enables users of a public network to securely and privately exchange data through the use of public and private cryptographic key pairs that are obtained and shared with peers through a trusted authority.

PLMN
Public Land Mobile Network. A telecommunications network for mobile stations.

PLP
Packet loss priority. Used to determine the random early detection (RED) drop profile when a packet is queued. You can set it by configuring a classifier or policer. The system supports two PLP designations: low and high.

PLP bit
Packet loss priority bit. Used to identify packets that have experienced congestion or are from a transmission that exceeded a service provider's customer service license agreement. This bit can be used as part of a router's congestion control mechanism and can be set by the interface or by a filter.

PLR
Point of local repair. The ingress router of a backup tunnel or a detour label-switched path (LSP).

point-to-multipoint connection
Unidirectional connection in which a single source system transmits data to multiple destination end systems. Point-to-multipoint is one of two fundamental connection types. *See also* point-to-point connection.

point-to-multipoint LSP
Resource Reservation Protocol (RSVP)-signaled label-switched path (LSP) with a single source and multiple destinations.

point-to-point connection
Unidirectional or bidirectional connection between two end systems. Point-to-point is one of two fundamental connection types. *See also* point-to-multipoint connection.

poison reverse
Method used in distance-vector networks to avoid routing loops. Each router advertises routes back to the neighbor it received them from with an infinity metric assigned.

policer
Filter that limits traffic of a certain class to a specified bandwidth or burst size. Packets exceeding the policer limits are discarded, or are assigned to a different forwarding class, a different loss priority, or both.

policing
Method of applying rate limits on bandwidth and burst size for traffic on a particular interface.

policy chain
Application of multiple routing policies in a single location. The policies are evaluated in a predefined manner and are always followed by the default policy for the specific application location.

pop
Removal of the last label, by a router, from a packet as it exits a Multiprotocol Label Switching (MPLS) domain.

port mirroring
Method in which a copy of an IPv4 packet is sent from the routing platform to an external host address or a packet analyzer for analysis.

PPP
Point-to-Point Protocol. A link-layer protocol that provides multiprotocol

encapsulation. PPP is used for link-layer and network-layer configuration. Provides a standard method for transporting multiprotocol datagrams over point-to-point links. Defined in RFC 1661.

pppd
: Point-to-Point Protocol daemon that processes packets that use the Point-to-Point Protocol (PPP).

PPPoE
: Point-to-Point Protocol over Ethernet. Network protocol that encapsulates Point-to-Point Protocol (PPP) frames in Ethernet frames and connects multiple hosts over a simple bridging access device to a remote access concentrator.

PPPoE over ATM
: Point-to-Point Protocol over Ethernet frames in Asynchronous Transfer Mode. Network protocol that encapsulates Point-to-Point Protocol over Ethernet (PPPoE) frames in Asynchronous Transfer Mode (ATM) frames for digital subscriber line (DSL) transmission, and connects multiple hosts over a simple bridging access device to a remote access concentrator.

precedence bits
: First three bits in the type-of-service (ToS) byte. On a Juniper Networks router, these bits are used to sort or classify individual packets as they arrive at an interface. The classification determines the queue to which the packet is directed upon transmission.

preference
: Desirability of a route to become the active route. A route with a lower preference value is more likely to become the active route. The preference is an arbitrary value from 0 through 255 that the routing protocol process uses to rank routes received from different protocols, interfaces, or remote systems.

preferred address
: On an interface, the default local address used for packets sourced by the local router to destinations on the subnet.

prefix-length-range
: JUNOS software routing policy match type representing all routes that share the same most-significant bits. The prefix length of the route must also lie between the two supplied lengths in the route filter.

primary address
: On an interface, the address used by default as the local address for broadcast and multicast packets sourced locally and sent out the interface.

primary contributing route
: Contributing route with the numerically smallest prefix and smallest JUNOS software preference value. This route is the default next hop used for a generated route.

primary interface
: Router interface that packets go out on when no interface name is specified and when the destination address does not specify a particular outgoing interface.

promiscuous mode
: Used with Asynchronous Transfer Mode (ATM) CCC Cell Relay encapsulation, enables mapping of all incoming cells from an interface port or from a virtual path (VP) to a single label-switched path (LSP) without restricting the VCI number.

protocol address
: Logical Layer 3 address assigned to an interface within the JUNOS software.

protocol families
: Grouping of logical properties within an interface configuration; for example, the `inet`, `inet4`, and Multiprotocol Label Switching (MPLS) families.

Protocol Independent Multicast
: A protocol-independent multicast routing protocol. PIM dense mode is a flood-and-prune protocol. PIM sparse mode routes to multicast groups that use join messages to receive traffic. PIM sparse-dense mode allows some multicast groups to be dense groups (flood and prune) and some groups to be sparse groups (join and leave).

protocol preference
: A 32-bit value assigned to all routes placed into the route table. The protocol preference is used as a tie breaker when multiple exact routes are placed into the table by different protocols.

provider router
: Router in the service provider's network that is not connected to a customer edge (CE) device.

Prune message
: Physical Interface Module (PIM) message sent upstream to a multicast source or the rendezvous point (RP) of the domain. The message requests that multicast traffic stop being transmitted to the router originating the message.

PSN
: Packet-switched network. Network in which messages or fragments of messages (packets) are sent to their destinations through the most expedient route, as determined by a routing algorithm. Packet switching optimizes bandwidth in a network and minimizes latency.

PSNP
: Partial sequence number PDU. A packet that contains only a partial list of the label-switched paths (LSPs) in the Intermediate System-to-Intermediate System Level 1 (IS-IS) link-state database.

public key infrastructure
: *See* PKI.

push
: Addition of a label or stack of labels, by a router, to a packet as it enters a Multiprotocol Label Switching (MPLS) domain.

PVC
: Permanent virtual circuit. A software-defined logical connection in a network. *See also* SVC.

QoS
: Quality of service. Performance, such as transmission rates and error rates, of a communications channel or system.

quad-wide
: Type of Physical Interface Card (PIC) that combines the PIC and Flexible PIC Concentrator (FPC) within a single FPC slot.

qualified next hop
: Next hop for a static route that allows a second next hop for the same static route to have different metric and preference properties from the original next hop.

querier router
: Physical Interface Module (PIM) router on a broadcast subnet responsible for generating Internet Group Management Protocol (IGMP) query messages for the segment.

queue
: First-in, first-out (FIFO) number of packets waiting to be forwarded over a router interface. You can configure the minimum and maximum sizes of the packet queue, queue admission policies, and other parameters to manage the flow of packets through the router.

queue fullness
: For random early detection (RED), the memory used to store packets expressed as a percentage of the total memory allocated for that specific queue. *See also* drop profile.

queue length
: For ATM1 interfaces only, a limit on the number of transmit packets that can be queued. Packets that exceed the limit are dropped. *See also* EPD.

queuing
: In routing, the arrangement of packets waiting to be forwarded. Packets are organized into queues according to their priority, time of arrival, or other characteristics, and are processed one at a time. After a packet is sent to the outgoing interface on a router, it is queued for transmission on the physical media. The amount of time a packet is queued on the router is determined by the availability of the outgoing physical media, bandwidth, and amount of traffic using the interface.

RA

Registration authority. A trusted third-party organization that acts on behalf of a certificate authority (CA) to verify the identity of a digital certificate user.

radio frequency interference

See RFI.

RADIUS

Remote Authentication Dial-In User Service. An authentication method for validating users who attempt to access the router using Telnet.

RBOC

(Pronounced "are-bock".) Regional Bell operating company. Regional telephone companies formed as a result of the divestiture of the Bell System.

RC2, RC4, RC5

RSA codes. A family of proprietary (RSA Data Security, Inc.) encryption schemes often used in web browsers and servers. These codes use variable-length keys up to 2,048 bits.

RDBMS

Relational database management system. A system that presents data in a tabular form with a means of manipulating the tabular data with relational operators.

RDM

Russian-dolls bandwidth allocation model. An allocation model that makes efficient use of bandwidth by allowing the class types to share bandwidth. RDM is defined in the Internet draft *draft-ietf-tewg-diff-te-russian-03.txt*, "Russian Dolls Bandwidth Constraints Model for Diff-Serv-aware MPLS Traffic Engineering."

receive

Next hop for a static route that allows all matching packets to be sent to the Routing Engine (RE) for processing.

recursive lookup

Method of consulting the route table to locate the actual physical next hop for a route when the supplied next hop is not directly connected.

RED

Random early detection. Gradual drop profile for a given class that is used for congestion avoidance. RED tries to anticipate incipient congestion by dropping a small percentage of packets from the head of the queue to ensure that a queue never actually becomes congested.

refresh reduction

In the Resource Reservation Protocol (RSVP), an extension that addresses the problems of scaling, reliability, and latency when Refresh messages are used to cover message loss.

Register message

Physical Interface Module (PIM) message unicast by the first hop router to the rendezvous point (RP) that contains the multicast packets from the source encapsulated within its data field.

Register Stop message

Physical Interface Module (PIM) message sent by the rendezvous point (RP) to the first hop router to halt the sending of encapsulated multicast packets.

registration authority

See RA.

reject

Next hop for a configured route that drops all matching packets from the network and returns an Internet Control Message Protocol (ICMP) message to the source IP address. Also used as an action in a routing policy or firewall filter.

`rename`

JUNOS software command that allows a user to change the name of a routing policy, firewall filter, or any other variable character string defined in the router configuration.

Request message

Routing Information Protocol (RIP) message used by a router to ask for all or part of the route table from a neighbor.

resolve

Next hop for a static route that allows the router to perform a recursive lookup to locate the physical next hop for the route.

Response message

Routing Information Protocol (RIP) message used to advertise routing information into a network.

result cell

JUNOS software data structure generated by the Internet Processor ASIC after performing a forwarding table lookup.

ResvConf message

Resource Reservation Protocol (RSVP) message that allows the egress router to receive an explicit confirmation message from a neighbor that its Resv message was received.

ResvErr message

Resource Reservation Protocol (RSVP) message indicating that an error has occurred along an established label-switched path (LSP). The message is advertised downstream toward the egress router and it does not remove any RSVP soft state from the network.

ResvTear message

Resource Reservation Protocol (RSVP) message indicating that the established label-switched path (LSP) and its associated soft state should be removed by the network. The message is advertised upstream toward the ingress router.

revert timer

For SONET Automatic Protection Switching (APS), a timer that specifies the amount of time (in seconds) to wait after the working circuit has become functional before making the working circuit active again.

rewrite rules

Set the appropriate class-of-service (CoS) bits in an outgoing packet. This allows the next downstream router to classify the packet into the appropriate service group.

RFC

Request for Comments. Internet standard specifications published by the Internet Engineering Task Force (IETF).

RFI

Radio frequency interface. Interference from high-frequency electromagnetic waves emanating from electronic devices.

RIB

Routing information base. A logical data structure used by the Border Gateway Protocol (BGP) to store routing information. *See also* route table.

RID

Router ID. An IP address used by a router to uniquely identify itself to a routing protocol. This address may not be equal to a configured interface address.

RIP

Routing Information Protocol. Used in IPv4 networks, a distance-vector interior gateway protocol that makes routing decisions based on hop count.

RIPng

Routing Information Protocol next generation. Used in IPv6 networks, a distance-vector interior gateway protocol that makes routing decisions based on hop count.

RMON

Remote monitoring. A standard Management Information Base (MIB) that defines current and historical media access control (MAC)-layer statistics and control objects, allowing you to capture real-time information across the entire network. This allows you to detect, isolate, diagnose, and report potential and actual network problems.

RNC

Radio network controller. Manages the radio part of the network in UMTS.

route distinguisher

A 6-byte value identifying a virtual private network (VPN) that is prefixed to an IPv4 address to create a unique IPv4 address. The new address is part of the VPN IPv4 address family, which is a Border Gateway Protocol (BGP) address family added as an extension to BGP. It allows you to configure private addresses within the VPN by preventing overlap with the private addresses in other VPNs.

route filter

JUNOS software syntax used in a routing policy to match an individual route or a group of routes.

route flapping
Condition of network instability whereby a route is announced and withdrawn repeatedly, often as a result of an intermittently failing link.

route identifier
IP address of the router from which a Border Gateway Protocol (BGP), Interior Gateway Protocol (IGP), or Open Shortest Path First (OSPF) packet originated.

route redistribution
Method of placing learned routes from one protocol into another protocol operating on the same router. The JUNOS software accomplishes this with a routing policy.

route reflection
In the Border Gateway Protocol (BGP), the configuration of a group of routers into a cluster in which one system acts as a route reflector, redistributing routes from outside the cluster to all routers in the cluster. Routers in a cluster do not need to be fully meshed.

router ID
See RID.

router-link advertisement
Open Shortest Path First (OSPF) link-state advertisement (LSA) flooded throughout a single area by all routers to describe the state and cost of the router's links to the area.

router LSA
Open Shortest Path First (OSPF) link-state advertisement (LSA) sent by each router in the network. It describes the local router's connected subnets and their metric values.

router priority
Numerical value assigned to an Open Shortest Path First (OPSF) or Intermediate System-to-Intermediate System Level 1 (IS-IS) interface that is used as the first criterion in electing the designated router or designated intermediate system, respectively.

Routing Engine
Portion of the router that handles all routing protocol processes, as well as other software processes that control the router's interfaces, some of the chassis components, system management, and user access to the router.

routing instance
Collection of route tables, interfaces, and routing protocol parameters. The set of interfaces is contained in the route tables, and the routing protocol parameters control the information in the route tables.

routing matrix
Terabit routing system interconnecting up to four T640 routing nodes and a TX Matrix platform to deliver up to 2.56 terabits per second (Tbps) of subscriber switching capacity.

route table
Common database of routes learned from one or more routing protocols. All routes are maintained by the JUNOS routing protocol process.

RP
Rendezvous point. For Physical Interface Module (PIM) sparse mode, a core router acting as the root of the distribution tree in a shared tree.

RPC
Remote procedure call. A type of protocol that allows a computer program running on one computer to cause a function on another computer to be executed without explicitly coding the details for this interaction.

rpd
JUNOS software routing protocol process (daemon). A user-level background process responsible for starting, managing, and stopping the routing protocols on a Juniper Networks router.

RPF
Reverse path forwarding. An algorithm that checks the unicast route table to determine whether there is a shortest path back to the source address of the incoming multicast packet. Unicast RPF helps to determine the source of denial-of-service (DoS) attacks and rejects packets from unexpected source addresses.

RPM

1. Reverse-path multicasting. Routing algorithm used by the Distance Vector Multicast Routing Protocol (DVMRP) to forward multicast traffic. 2. Real-Time Performance Monitoring. A tool for creating active probes to track and monitor traffic.

RRO

Record route object. A Resource Reservation Protocol (RSVP) message object that notes the IP address of each router along the path of a label-switched path (LSP).

RSVP

Resource Reservation Protocol. A signaling protocol that establishes a session between two routers to transport a specific traffic flow.

RSVP Path message

Resource Reservation Protocol (RSVP) message sent by the ingress router downstream toward the egress router. It begins the establishment of a soft state database for a particular label-switched path (LSP).

RSVP Resv message

Resource Reservation Protocol (RSVP) message sent by the egress router upstream toward the ingress router. It completes the establishment of the soft state database for a particular label-switched path (LSP).

RSVP signaled LSP

Label-switched path (LSP) that is dynamically established using Resource Reservation Protocol (RSVP) Path and Resv messages.

RSVP-TE

RSVP-traffic engineering; Resource Reservation Protocol (RSVP) with traffic engineering extensions as defined by RFC 3209. These extensions allow RSVP to establish label-switched paths (LSPs) in Multiprotocol Label Switching (MPLS) networks. *See also* MPLS; RSVP.

RTP

Real-Time Transport Protocol. An Internet protocol that provides mechanisms for the transmission of real-time data, such as audio, video, or voice, over IP networks. Compressed RTP is used for Voice over IP traffic.

RTVBR

Real-time variable bit rate. For ATM2 intelligent queuing (IQ) interfaces, data that is serviced at a higher priority rate than other VBR data. RTVBR is suitable for carrying packetized video and audio. RTVBR provides better congestion control and latency guarantees than non-real-time VBR.

SA

Security association. An IPSec term that describes an agreement between two parties about what rules to use for authentication and encryption algorithms, key exchange mechanisms, and secure communications.

sampling

Method whereby the sampling key based on the IPv4 header is sent to the Routing Engine (RE). There, the key is placed in a file, or cflowd packets based on the key are sent to a cflowd server.

SAP

1. Session Announcement Protocol. Used with multicast protocols to handle session conference announcements. 2. Service access point. Device that identifies routing protocols and provides the connection between the network interface card and the rest of the network.

SAR

Segmentation and reassembly. Buffering used with Asynchronous Transfer Mode (ATM).

SCB

System Control Board. On an M40 router, the part of the Packet Forwarding Engine (PFE) that performs route lookups, monitors system components, and controls Flexible PIC Concentrator (FPC) resets.

SCC

Switch-card chassis. Term used by the JUNOS command-line interface (CLI) to refer to the TX Matrix platform in a routing matrix.

SCEP

Simple Certificate Enrollment Protocol. A protocol for digital certificates that supports certificate authority (CA) and registration authority (RA) public key distribution, certificate enrollment, certificate revocation, certificate queries, and certificate revocation list (CRL) queries.

SCG

SONET Clock Generator. On a T640 routing node, provides the Stratum 3 clock signal for the SONET/SDH interfaces. Also provides external clock inputs.

scheduler maps

In class of service (CoS), associate schedulers with forwarding classes. *See also* schedulers; forwarding classes.

schedulers

Define the priority, bandwidth, delay buffer size, rate control status, and random early detection (RED) drop profiles to be applied to a particular forwarding class for packet transmission. *See also* scheduler maps.

scheduling

Method of determining which type of packet or queue is transmitted before another. An individual router interface can have multiple queues assigned to store packets. The router then determines which queue to service based on a particular method of scheduling. This process often involves a determination of which type of packet should be transmitted before another; for example, first in, first out (FIFO). *See also* FIFO.

SCP

Secure copy. Means of securely transferring computer files between a local and remote host or between two remote hosts, using the Secure Shell (SSH) protocol.

SCU

Source class usage. A means of tracking traffic originating from specific prefixes on the provider core router and destined for specific prefixes on the customer edge router, based on the IP source and destination addresses.

SDH

Synchronous Digital Hierarchy. A CCITT variation of the SONET standard.

SDP

Session Description Protocol. Used with multicast protocols to handle session conference announcements.

SDRAM

Synchronous dynamic random access memory. An electronic standard in which the inputs and outputs of SDRAM data are synchronized to an externally supplied clock, allowing for extremely fast consecutive read and write capacity.

SDX software

Service Deployment System software. A customizable Juniper Networks product with which service providers can rapidly deploy IP services—such as video on demand (VoD), IP television, stateful firewalls, Layer 3 virtual private networks (VPNs), and bandwidth on demand (BoD)—to hundreds of thousands of subscribers over a variety of broadband access technologies.

services interface

Interface that provides specific capabilities for manipulating traffic before it is delivered to its destination; for example, the adaptive services interface and the tunnel services interface. *See also* network interface.

session attribute object

Resource Reservation Protocol (RSVP) message object used to control the priority, preemption, affinity class, and local rerouting of the label-switched path (LSP).

SFM

Switching and Forwarding Module. On an M160 router, a component of the Packet Forwarding Engine (PFE) that provides route lookup, filtering, and switching to Flexible PIC Concentrators (FPCs).

SFP

Small form-factor pluggable transceiver. A transceiver that provides support for optical or copper cables. SFPs are hot-insertable and hot-removable. *See also* XFP.

SGSN

Serving GPRS Support Node. Device in the mobile network that requests PDP contexts with a GGSN.

SHA-1

Secure Hash Algorithm 1. A secure hash algorithm standard defined in FIPS PUB 180-1 (SHA-1). Developed by the National Institute of Standards and Technology (NIST), SHA-1 (which effectively replaces SHA-0) produces a 160-bit hash for message authentication. Longer-hash variants include SHA-224, SHA-256, SHA-384, and SHA-512 (sometimes grouped under the name "SHA-2"). SHA-1 is more secure than Message Digest 5 (MD5). *See also* hashing; MD5.

sham link

Unnumbered point-to-point intra-area link advertised by a type 1 link-state advertisement (LSA).

shaping rate

In class of service (CoS), controls the maximum rate of traffic transmitted on an interface. *See also* traffic shaping.

shared scheduling and shaping

Allocation of separate pools of shared resources to subsets of logical interfaces belonging to the same physical port.

shared tree

Multicast forwarding tree established from the rendezvous point (RP) to the last hop router for a particular group address.

SHDSL

Symmetric high-speed digital subscriber line. A standardized multirate symmetric DSL that transports rate-adaptive symmetrical data across a single copper pair at data rates from 192 Kbps to 2.3 Mbps, or from 384 Kbps to 4.6 Mbps over two pairs, covering applications served by HDSL, SDSL, T1, E1, and services beyond E1. SHDSL conforms to the following recommendations: ITU G.991.2 G.SHDSL, ETSI TS 101-524 SDSL, and the T1E1.4/2001-174 G.SHDSL. *See also* G.SHDSL.

shim header

Location of the Multiprotocol Label Switching (MPLS) header in a data packet. The JUNOS software always places (shims) the header between the existing Layer 2 and Layer 3 headers.

Shortest Path First

See SPF.

shortest-path tree

See SPT.

SIB

Switch Interface Board. On a T640 routing node, provides the switching function to the destination Packet Forwarding Engine (PFE).

signaled path

In traffic engineering, an explicit path; that is, a path determined using Resource Reservation Protocol (RSVP) signaling. The ERO carried in the packets contains the explicit path information.

Simple Network Management Protocol

See SNMP.

simplex interface

Interface that treats packets it receives from itself as the result of a software loopback process. The interface does not consider these packets when determining whether the interface is functional.

single-mode fiber

Optical fiber designed for transmission of a single ray or mode of light as a carrier and used for long-distance signal transmission. For short distances, multimode fiber is used. *See also* MMF.

SIP

Session Initiation Protocol. An Adaptive Services application protocol option used for setting up sessions between endpoints on the Internet. Examples include telephony, fax, videoconferencing, file exchange, and person-to-person sessions.

SNA

System Network Architecture. IBM proprietary networking architecture consisting of a protocol stack that is used primarily in banks and other financial transaction networks.

SNMP
Simple Network Management Protocol. A protocol governing network management and the monitoring of network devices and their functions.

soft state
In Resource Reservation Protocol (RSVP), controls state in hosts and routers that expires if not refreshed within a specified amount of time.

SONET
Synchronous Optical Network. A high-speed (up to 2.5 Gbps) synchronous network specification developed by Bellcore and designed to run on optical fiber. STS1 is the basic building block of SONET. Approved as an international standard in 1988. *See also* SDH.

source-based tree
Multicast forwarding tree established from the source of traffic to all interested receivers for a particular group address. It is often used in a dense-mode forwarding environment.

sparse mode
Method of operating a multicast domain where sources of traffic and interested receivers meet at a central rendezvous point (RP). A sparse-mode network assumes that there are very few receivers for each group address.

SPF
Shortest Path First. An algorithm used by Intermediate System-to-Intermediate System Level 1 (IS-IS) and Open Shortest Path First (OSPF) to make routing decisions based on the state of network links. Also called the *Dijkstra algorithm*.

SPI
Security Parameter Index. In IPSec, a numeric identifier used with the destination address and security protocol to identify a security association (SA). When Internet Key Exchange (IKE) is used to establish an SA, the SPI is randomly derived. When manual configuration is used for an SA, the SPI must be entered as a parameter.

SPID
Service Profile Identifier. Used only in Basic Rate Interface (BRI) implementations of the Integrated Services Digital Network (ISDN). The SPID specifies the services available on the service provider switch and defines the feature set ordered when the ISDN service is provisioned.

split horizon
Method used in distance-vector networks to avoid routing loops. Each router does not advertise routes back to the neighbor from which it received them.

SPQ
Strict-priority queuing. A dequeuing method that provides a special queue that is serviced until it is empty. The traffic sent to this queue tends to maintain a lower latency and more consistent latency numbers than traffic sent to other queues. *See also* APQ.

SPT
Shortest-path tree. An algorithm that builds a network topology that attempts to minimize the path from one router (the root) to other routers in a routing area.

SQL
Structured Query Language. International standard language used to create, modify, and select data from relational databases.

src port
Transmission Control Protocol (TCP) or User Datagram Protocol (UDP) port for the source IP address in a packet.

SS7
Signaling System 7. A protocol used in telecommunications for delivering calls and services.

SSAP
Source service access point. Device that identifies the origin of an LPDU on a data link switching (DLSw) network.

SSB
System and Switch Board. On an M20 router, a Packet Forwarding Engine (PFE) component that performs route lookups and component monitoring and monitors Flexible PIC Concentrator (FPC) operation.

SSH

Secure Shell. A protocol that uses strong authentication and encryption for remote access across a nonsecure network. SSH provides remote login, remote program execution, file copy, and other functions. In a Unix environment, SSH is intended as a secure replacement for rlogin, rsh, and rcp.

SSH/TLS

Secure Shell with Transport Layer Security. A combination of two standard methods used to secure communications over the Internet. TLS is the name of a standard protocol based on SSL 3.0 and is defined in RFC 2246. In combination, SSH/TLS is also known as SSHv2 and uses FIPS-restricted cipher sets in a FIPS environment.

SSL

Secure Sockets Layer. A protocol that encrypts security information using public–private key technology, which requires a paired private key and authentication certificate, before transmitting data across a network.

SSM

Source-specific multicast. A service that allows a client to receive multicast traffic directly from the source. Typically, SSM uses a subset of the Physical Interface Module (PIM) sparse-mode functionality along with a subset of IGMPv3 to create a shortest-path tree (SPT) between the client and the source, but it builds the SPT without the help of a rendezvous point (RP).

SSP

Switch-to-Switch Protocol. Protocol implemented between two data link switching (DLSw) routers that establishes connections, locates resources, forwards data, and handles error recovery and flow control.

SSRAM

Synchronous static random access memory. Used for storing route tables, packet pointers, and other data such as route lookups, policer counters, and other statistics to which the microprocessor needs quick access.

standard AAL5 mode

Transport mode that allows multiple applications to tunnel the protocol data units of their Layer 2 protocols over an Asynchronous Transfer Mode (ATM) virtual circuit. You use this transport mode to tunnel IP packets over an ATM backbone. *See also* AAL5 mode; cell-relay mode; Layer 2 circuits; trunk mode.

starvation

Problem that occurs when lower-priority traffic, such as data and protocol packets, is locked out (starved) because a higher-priority queue uses all of the available transmission bandwidth.

stateful firewall filter

Type of firewall filter that evaluates the context of connections, permits or denies traffic based on the context, and updates this information dynamically. Context includes IP source and destination addresses, port numbers, Transmission Control Protocol (TCP) sequencing information, and TCP connection flags. The context established in the first packet of a TCP session must match the context contained in all subsequent packets if a session is to remain active. *See also* stateless firewall filter.

stateful firewall recovery

Recovery strategy that preserves parameters concerning the history of connections, sessions, or application status before failure. *See also* stateless firewall recovery.

stateless firewall filter

Type of firewall filter that statically evaluates the contents of packets transiting the router and packets originating from or destined for the Routing Engine (RE). Packets are accepted, rejected, forwarded, or discarded and collected, logged, sampled, or subjected to classification according to a wide variety of packet characteristics. Sometimes called access control lists (ACLs) or simply firewall filters, stateless firewall filters protect the processes and resources owned by the RE. A stateless firewall filter can evaluate every packet, including fragmented packets. In contrast to a stateful firewall filter, a stateless firewall filter does not maintain information about connection states. *See also* stateful firewall filter.

stateless firewall recovery
Recovery strategy that does not attempt to preserve the history of connections, sessions, or application status before failure. *See also* stateful firewall recovery.

static LSP
See static path.

static path
In the context of traffic engineering, a static route that requires hop-by-hop manual configuration. No signaling is used to create or maintain the path. Also called a *static LSP*.

static route
Explicitly configured route that is entered into the route table. Static routes have precedence over routes chosen by dynamic routing protocols.

static RP
One of three methods of learning the rendezvous point (RP) to group address mapping in a multicast network. Each router in the domain must be configured with the required RP information.

S/T interface
System reference point/terminal reference point interface. A four-pair connection between the Integrated Services Digital Network (ISDN) provider service and the customer terminal equipment.

STM
Synchronous transport module. CCITT specification for SONET at 155.52 Mbps.

strict
In the context of traffic engineering, a route that must go directly to the next address in the path. (Definition from RFC 791, modified to fit LSPs.)

strict hop
Routers in a Multiprotocol Label Switching (MPLS) named path that must be directly connected to the previous router in the configured path.

STS
Synchronous transport signal. Synchronous transport signal level 1 is the basic building block signal of SONET, operating at 51.84 Mbps. Faster SONET rates are defined as STS-*n*, where *n* is an integer by which the basic rate of 51.84 Mbps is multiplied. *See also* SONET.

stub area
In Open Shortest Path First (OSPF), an area through which, or into which, autonomous system (AS) external advertisements are not flooded.

STU-C
Symmetric high-speed digital subscriber line (SHDSL) transceiver unit–central office. Equipment at the telephone company central office that provides SHDSL connections to remote user terminals.

STU-R
Symmetric high-speed digital subscriber line (SHDSL) transceiver unit–remote. Equipment at the customer premises that provides SHDSL connections to remote user terminals.

sub-LSP
Part of a point-to-multipoint label-switched path (LSP). A sub-LSP carries traffic from the main LSP to one of the egress Provide Edge (PE) routers. Each point-to-multipoint LSP has multiple sub-LSPs. *See also* point-to-multipoint LSP.

subnet mask
Number of bits of the network address used for the host portion of a Class A, Class B, or Class C IP address.

subrate value
Value that reduces the maximum allowable peak rate by limiting the High-Level Data Link Control (HDLC)-encapsulated payload. The subrate value must exactly match that of the remote channel service unit (CSU).

summary link advertisement
Open Shortest Path First (OSPF) link-statement advertisement (LSA) flooded throughout the advertisement's associated areas by area border routers (ABRs) to describe the routes that they know about in other areas.

SVC
: Switched virtual connection. A dynamically established, software-defined logical connection that stays up as long as data is being transmitted. When transmission is complete, the software tears down the SVC. *See also* PVC.

sysid
: System identifier. Portion of the ISO nonclient peer. The system ID can be any six bytes that are unique throughout a domain.

syslog
: System log. A method for storing messages to a file for troubleshooting or recordkeeping. It can also be used as an action within a firewall filter to store information to the *messages* file.

T1
: Basic physical layer protocol used by the Digital Signal level 1 (DS1) multiplexing method in North America. A T1 interface operates at a bit rate of 1.544 Mbps and can support 24 DS0 channels.

T3
: Physical layer protocol used by the Digital Signal level 3 (DS3) multiplexing method in North America. A T3 interface operates at a bit rate of 44.736 Mbps.

TACACS+
: Terminal Access Controller Access Control System Plus. Authentication method for validating users who attempt to access the router using Telnet.

tail drop
: Queue management algorithm for dropping packets from the input end (tail) of the queue when the length of the queue exceeds a configured threshold. *See also* RED.

T-carrier
: Generic designator for any of several digitally multiplexed telecommunications carrier systems originally developed by Bell Labs and used in North America and Japan.

TCM
: Tricolor marking. Traffic policing mechanism that extends the functionality of class-of-service (CoS) traffic policing by providing three levels of drop precedence (loss priority or PLP) instead of two. There are two types of TCM: single-rate and two-rate. The JUNOS software currently supports two-rate TCM only. *See also* trTCM.

TCP
: Transmission Control Protocol. Works in conjunction with IP to send data over the Internet. Divides a message into packets and tracks the packets from point of origin to destination.

tcpdump
: Unix packet monitoring utility used by the JUNOS software to view information about packets sent or received by the Routing Engine (RE).

TCP port 179
: Well-known port number used by the Border Gateway Protocol (BGP) to establish a peering session with a neighbor.

TDMA
: Time-Division Multiplex Access. A type of multiplexing in which two or more channels of information are transmitted over the same link, where the channels take turns to use the link. Each link is allocated a different time interval (“slot” or “slice”) for the transmission of each channel. For the receiver to distinguish one channel from the other, some kind of periodic synchronizing signal or distinguishing identifier is required. *See also* GSM.

TEI
: Terminal Endpoint Identifier. A terminal endpoint can be any Integrated Services Digital Network (ISDN)-capable device attached to an ISDN network. The TEI is a number between 0 and 127, where 0 through 63 are used for static TEI assignment, 64 through 126 are used for dynamic assignment, and 127 is used for group assignment.

terminating action
Action in a routing policy or firewall filter that halts the logical software processing of a policy or filter.

terms
Used in a routing policy or firewall filter to segment the policy or filter into small match and action pairs.

through
JUNOS software routing policy match type representing all routes that fall between the two supplied prefixes in the route filter.

Time-Division Multiplex Access
See TDMA.

time-division multiplexed channel
Channel derived from a given frequency and transmitted over a single wire or wireless medium. The channel is preassigned a time slot whether or not there is data to transmit.

timeout timer
Used in a distance-vector protocol to ensure that the current route is still usable for forwarding traffic.

TNP
Trivial Network Protocol. A Juniper Networks proprietary protocol automatically configured on an internal interface by the JUNOS software. TNP is used to communicate between the Routing Engine (RE) and components of the Packet Forwarding Engine (PFE), and is critical to the operation of the router.

token-bucket algorithm
Used in a rate-policing application to enforce an average bandwidth while allowing bursts of traffic up to a configured maximum value.

ToS
Type of service. The method of handling traffic using information extracted from the fields in the ToS byte to differentiate packet flows.

totally stubby area
Open Shortest Path First (OSPF) area type that prevents Type 3, 4, and 5 link-state advertisements (LSAs) from entering the nonbackbone area.

traffic engineering
Process of selecting the paths chosen by data traffic to balance the traffic load on the various links, routers, and switches in the network. (Definition from *http://www.ietf.org/internet-drafts/draft-ietf-mpls-framework-04.txt*.) *See also* MPLS.

traffic engineering class
In Differentiated-Services-aware traffic engineering, a paired class type and priority.

traffic engineering class map
In Differentiated-Services-aware traffic engineering, a map among the class types, priorities, and traffic engineering classes. The traffic engineering class mapping must be consistent across the Differentiated Services domain.

traffic policing
Examines traffic flows and discards or marks packets that exceed service-level agreements (SLAs).

traffic sampling
Method used to capture individual packet information of traffic flow at a specified time period. The sampled traffic information is placed in a file and stored on a server for various types of analysis. *See also* packet capture.

traffic shaping
Reduces the potential for network congestion by placing packets in a queue with a shaper at the head of the queue. Traffic shaping tools regulate the rate and volume of traffic admitted to the network. *See also* shaping rate.

transient change
Commit script-generated configuration change that is loaded into the checkout configuration, but not into the candidate configuration. Transient changes are not saved in the configuration if the associated commit script is deleted or deactivated. *See also* persistent change.

transient interface
Interface that can be configured on a routing platform depending on your network

needs. Unlike a permanent interface that is required for router operation, a transient interface can be disabled or removed without affecting the basic operation of the router. *See also* FPC; PIC; permanent interface.

transit area
: In Open Shortest Path First (OSPF), an area used to pass traffic from one adjacent area to the backbone or to another area if the backbone is more than two hops away from an area.

transit router
: In Multiprotocol Label Switching (MPLS), any intermediate router in the label-switched path (LSP) between the ingress router and the egress router.

transport mode
: IPSec mode of operation in which the data payload is encrypted, but the original IP header is left untouched. The IP addresses of the source or destination can be modified if the packet is intercepted. Because of its construction, transport mode can be used only when the communication endpoint and cryptographic endpoint are the same. Virtual private network (VPN) gateways that provide encryption and decryption services for protected hosts cannot use transport mode for protected VPN communications. *See also* tunnel mode.

transport plane
: *See* data plane.

TRAP
: Reports significant events occurring on a network device, most often errors or failures. Simple Network Management Protocol (SNMP) TRAPs are defined in either standard or enterprise-specific Management Information Bases (MIBs).

triggered updates
: Used in a distance-vector protocol to reduce the time for the network to converge. When a router has a topology change, it immediately sends the information to its neighbors instead of waiting for a timer to expire.

trTCM
: Two-rate TCM polices traffic according to the color classification (loss priority) of each packet. Traffic policing is based on two rates: the committed information rate (CIR) and the peak information rate (PIR). Two-rate TCM is defined in RFC 2698, “A Two Rate Three Color Marker.” *See also* CIR; PIR.

trunk mode
: Layer 2 circuit cell-relay transport mode that allows you to send Asynchronous Transfer Mode (ATM) cells between ATM2 intelligent queuing (IQ) interfaces over a Multiprotocol Label Switching (MPLS) core network. You use Layer 2 circuit trunk mode (as opposed to standard Layer 2 circuit cell-relay mode) to transport ATM cells over an MPLS core network that is implemented between other vendors’ switches or routers. The multiple connections associated with a trunk increase bandwidth and provide failover redundancy. *See also* AAL5 mode, cell-relay mode, Layer 2 circuits, standard AAL5 mode.

Tspec object
: Resource Reservation Protocol (RSVP) message object that contains information such as the bandwidth request of the label-switched path (LSP) as well as the minimum and maximum packets supported.

tunnel
: Private, secure path through an otherwise public network.

tunnel endpoint
: Last node of a tunnel where the tunnel-related headers are removed from the packet, which is then passed on to the destination network.

tunneling protocol
: Network protocol that encapsulates one protocol or session inside another. When protocol A is encapsulated within protocol B, A treats B as though it were a data-link layer. Tunneling can be used to transport a network protocol through a network that would not otherwise support it. Tunneling can also be used to

provide various types of virtual private network (VPN) functionality such as private addressing.

tunnel mode
: IPSec mode of operation in which the entire IP packet, including the header, is encrypted and authenticated and a new virtual private network (VPN) header is added, protecting the entire original packet. This mode can be used by both VPN clients and VPN gateways, and it protects communications that come from or go to non-IPSec systems. *See also* transport mode.

tunnel services interface
: Provides the capability of a Tunnel Services PIC on an Adaptive Services PIC (ASP). *See* Tunnel Services PIC.

Tunnel Services PIC
: Physical interface card (PIC) that allows the router to perform the encapsulation and de-encapsulation of IP datagrams. The Tunnel Services PIC supports IP-IP, Generic Routing Encapsulation (GRE), and Physical Interface Module (PIM) register encapsulation and de-encapsulation. When the Tunnel Services PIC is installed, the router can be a PIM rendezvous point (RP) or a PIM first hop router for a source that is directly connected to the router.

TX Matrix platform
: Routing platform that provides the centralized switching fabric of the routing matrix.

UDP
: User Datagram Protocol. In Transmission Control Protocol/Internet Protocol (TCP/IP), a connectionless transport layer protocol that exchanges datagrams without acknowledgments or guaranteed delivery, requiring that error processing and retransmission be handled by other protocols.

U interface
: User reference point interface. A single-pair connection between the local Integrated Services Digital Network (ISDN) provider and the customer premises equipment.

UME
: UNI management entity. The code residing in the Asynchronous Transfer Mode (ATM) devices at each end of a UNI (user-to-network interface) circuit that functions as a Simple Network Management Protocol (SNMP) agent, maintaining network and connection information specified in a Management Information Base (MIB).

UMTS
: Universal mobile telecommunications system. Provides third-generation (3G), packet-based transmission of text, digitized voice, video, and multimedia, at data rates up to 2 Mbps.

UNI
: User-to-network interface. ATM Forum specification that defines an interoperability standard for the interface between a router or an Asynchronous Transfer Mode (ATM) switch located in a private network and the ATM switches located within the public carrier networks. Also used to describe similar connections in Frame Relay networks.

unicast
: Operation of sending network traffic from one network node to another individual network node.

unit
: JUNOS software syntax that represents the logical properties of an interface.

unnumbered interface
: Logical interface that is configured without an IP address.

Update message
: Border Gateway Protocol (BGP) message that advertises path attributes and routing knowledge to an established neighbor.

update timer
: Used in a distance-vector protocol to advertise routes to a neighbor on a regular basis.

UPS
: Uninterruptible power supply. A device that sits between a power supply and a router or other device and prevents

power-source events, such as outages and surges, from affecting or damaging the device.

upto
: JUNOS software routing policy match type representing all routes that share the same most-significant bits and whose prefix length is smaller than the supplied subnet in the route filter.

UTC
: Coordinated Universal Time. Historically referred to as Greenwich Mean Time (GMT), a high-precision atomic time standard that tracks Universal Time (UT) and is the basis for legal civil time all over the world. Time zones around the world are expressed as positive and negative offsets from UTC.

UTRAN
: UMTS Terrestrial Radio Access Network. The WCDMA radio network in UMTS.

VBR
: Variable bit rate. For ATM1 and ATM2 intelligent queuing (IQ) interfaces, data that is serviced at a varied rate within defined limits. VBR traffic adds the ability to statistically oversubscribe user traffic.

VC
: Virtual circuit. A software-defined logical connection between two network devices that is not a dedicated connection but acts as though it is. It can be either permanent (PVC) or switched (SVC). VCs are used in Asynchronous Transfer Mode (ATM), Frame Relay, and X.25. *See also* VPI, VCI, PVC, SVC.

VCI
: 1. Vapor corrosion inhibitor. Small cylinder packed with the router that prevents corrosion of the chassis and components during shipment. 2. Virtual circuit identifier. A 16-bit field in the header of an Asynchronous Transfer Mode (ATM) cell that indicates the particular virtual circuit the cell takes through a virtual path. Also called a *logical interface*. *See also* VPI.

virtual channel
: Enables queuing, packet scheduling, and accounting rules to be applied to one or more logical interfaces. *See also* virtual channel group.

virtual channel group
: Combines virtual channels into a group and then applies the group to one or more logical interfaces. *See also* virtual channel.

virtual circuit
: Represents a logical connection between two Layer 2 devices in a network.

virtual link
: In Open Shortest Path First (OSPF), a link created between two routers that are part of the backbone but are not physically contiguous.

virtual loopback tunnel interface
: *See* VT.

virtual path
: Combination of multiple virtual circuits between two devices in an Asynchronous Transfer Mode (ATM) network.

VLAN
: Virtual LAN. A logical group of network devices that appear to be on the same LAN, regardless of their physical location. VLANs are configured with management software, and are extremely flexible because they are based on logical, rather than physical, connections.

VLAN-tagged frame
: Tagged frame whose tag header carries both virtual LAN (VLAN) identification and priority information.

VPI
: Virtual path identifier. An 8-bit field in the header of an Asynchronous Transfer Mode (ATM) cell that indicates the virtual path the cell takes. *See also* VCI.

VPLS
: Virtual private LAN service. An Ethernet-based multipoint-to-multipoint Layer 2 virtual private network (VPN) service used for interconnecting multiple Ethernet LANs across a Multiprotocol Label Switching (MPLS) backbone. VPLS is

specified in the IETF draft “Virtual Private LAN Service.”

VPN

Virtual private network. A private data network that uses a public Transmission Control Protocol/Internet Protocol (TCP/IP) network, typically the Internet, while maintaining privacy with a tunneling protocol, encryption, and security procedures. *See also* tunneling protocol.

VRF instance

Virtual private network (VPN) routing and forwarding instance. A Virtual Route and Forwarding (VRF) instance for a Layer 3 VPN implementation consists of one or more route tables, a derived forwarding table, a set of interfaces that use the forwarding table, and a set of policies and routing protocols that determine what goes into the forwarding table.

VRF table

Routing instance table that stores Virtual Route and Forwarding (VRF) routing information. *See also* VRF instance.

VRRP

Virtual Router Redundancy Protocol. On Fast Ethernet and Gigabit Ethernet interfaces, allows you to configure virtual default routers.

VT

Virtual loopback tunnel interface. A VT interface that loops packets back to the Packet Forwarding Engine (PFE) for further processing, such as looking up a route in a Virtual Route and Forwarding (VRF) route table or looking up an Ethernet media access control (MAC) address. A virtual loopback tunnel interface can be associated with a variety of Multiprotocol Label Switching (MPLS) and virtual private network (VPN)-related applications, including VRF routing instances, VPLS routing instances, and point-to-multipoint label-switched paths (LSPs).

warm standby

Method that enables one backup Adaptive Services PIC (ASP) to support multiple active ASPs, without providing guaranteed recovery times.

WAN PHY

Wide Area Network Physical Layer Device. A physical layer device that allows 10-Gigabit Ethernet wide-area links to use fiber-optic cables and other devices intended for SONET/SDH. *See also* LAN PHY; PHY.

WAP

Wireless Application Protocol. A standard protocol that enables mobile users to access the Internet in a limited fashion if WAP is supported and enabled on the mobile device, server, and wireless network. WAP users can send and receive email and access web sites in text format only (WAP does not support graphics).

WCDMA

Wideband Code Division Multiple Access. Radio interface technology used in most third-generation (3G) systems.

WDM

Wavelength-division multiplexing. Technique for transmitting a mix of voice, data, and video over various wavelengths (colors) of light.

WINS

Windows Internet Name Service. A Windows name resolution service for network basic input/output system (NetBIOS) names. WINS is used by hosts running NetBIOS over TCP/IP (NetBT) to register NetBIOS names and resolve NetBIOS names to IP addresses.

WRR

Weighted round-robin. Scheme used to decide the queue from which the next packet should be transmitted.

XENPAK

Standard that defines a type of pluggable fiber-optic transceiver module that is compatible with the 10-Gigabit Ethernet (10 GbE) standard.

XENPAK module

10-Gigabit Ethernet fiber-optic transceiver. XENPAK modules are hot-insertable and hot-removable. *See also* MSA.

XENPAK Multisource Agreement

See MSA.

XENPAK-SR 10BASE-SR XENPAK

Media type that supports a link length of 26 meters on standard Fiber Distributed Data Interface (FDDI) grade multimode fiber (MMF). Up to 300-meter link lengths are possible with 2000 MHz/km MMF (OM3).

XENPAK-ZR 10GBASE-ZR XENPAK

Media type used for long-reach, single-mode (80–120 km) 10-Gigabit Ethernet metro applications.

XFP

10-Gigabit small form-factor pluggable transceiver. A transceiver that provides support for fiber-optic cables. XFPs are hot-insertable and hot-removable. *See also* SFP.

XML

Extensible Markup Language. Language used for defining a set of markers, called tags, which define the function and hierarchical relationships of the parts of a document or data set.

XML schema

Definition of the elements and structure of one or more Extensible Markup Language (XML) documents. Similar to a document type definition (DTD), but with additional information and written in XML.

XOR

Exclusive or. A logical operator (exclusive disjunction) in which the operation yields the result of true when one, and only one, of its operands is true.

XPath

Standard used in Extensible Stylesheet Language for Transformations (XSLT) to specify and locate elements in the input document's Extensible Markup Language (XML) hierarchy. XPath is fully described in the World Wide Web Consortium (W3C) specification at *http://w3c.org/TR/xpath*.

XSLT

Extensible Stylesheet Language for Transformations. A standard for processing Extensible Markup Language (XML) data developed by the World Wide Web Consortium (W3C). XSLT performs XML-to-XML transformations, turning an input XML hierarchy into an output XML hierarchy. The XSLT specification is on the W3C web site at *http://www.w3c.org/TR/xslt*.

zeroize

Process of removing all sensitive information, such as cryptographic keys and user passwords, from a router running JUNOS-FIPS.

Index

We'd like to hear your suggestions for improving our indexes. Send email to *index@oreilly.com*.

Colophon

The animal on the cover of *JUNOS Enterprise Routing* is Tengmalm's owl (*Aegolius funereus*), also known in North America as the Boreal owl. The owl's distinguishing features include pale or bright yellow eyes and a brown body spotted with white flecks (its belly is usually off-white).

This solitary, largely unsociable owl lives in thick forests throughout North America and in various mountain ranges throughout Eurasia. They often nest in the old homes of woodpeckers. Although the creatures are unfriendly, they may show loyalty to their families by raising their young generation after generation in the same home.

The bird's namesake is Swedish naturalist Peter Gustaf Tengmalm, who improved upon a previous classification system for the owl. Occasionally the bird's cry will sound like the peal of a funeral bell, hence the *funereus* in its species name. In North America, scientists named the owl after the Greek god of the north wind, Boreas, referring not to the owl's voice, but to its northern habitats.

While it is known for it funereal cries, the owl's voice does carry a range of notes. A commonly heard song from the owl is its territorial call, which sounds as if the bird is singing the word "poop" several times in rapid succession. When wooing a female, the male sings a series of stutters that eventually crescendos in a long trill of up to 350 notes.

The cover image is from *Dover's Animals*. The cover font is Adobe ITC Garamond. The text font is Linotype Birka; the heading font is Adobe Myriad Condensed; and the code font is LucasFont's TheSans Mono Condensed.