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Dedications

For Jeffrey Lanier Odom. My favorite brother. Gentle soul. Lover of stupid jokes ("baby bigger," "tankety-tankety-tank," "supplies"…) Nice guy. Good friend. Miss you, bro. 10/7/1959—6/15/2009.

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Finally and foremost, many thanks to Jesus Christ, for demonstrating your love, and for helping me and my family learn better each day how to not be a clanging symbol, but instead to show others your love.

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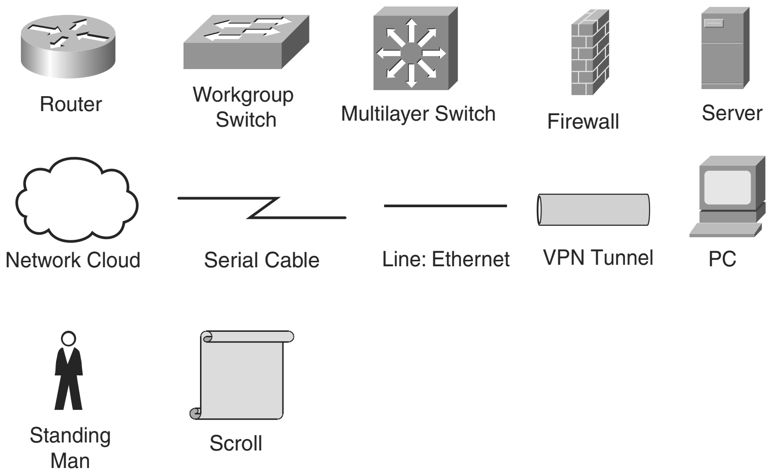

Command Syntax Conventions

The conventions used to present command syntax in this book are the same conventions used in the IOS Command Reference. The Command Reference describes these conventions as follows:

- **Boldface** indicates commands and keywords that are entered literally as shown. In actual configuration examples and output (not general command syntax), boldface indicates commands that are manually input by the user (such as a **show** command).
- *Italic* indicates arguments for which you supply actual values.
- Vertical bars (|) separate alternative, mutually exclusive elements.
- Square brackets ([ ]) indicate an optional element.
- Braces ({ }) indicate a required choice.
- Braces within brackets ([{ }]) indicate a required choice within an optional element.

Foreword

CCNP ROUTE 642-902 Official Certification Guide is an excellent self-study resource for the CCNP ROUTE exam. Passing this exam is a crucial step to attaining the valued CCNP Routing and Switching certification.

Gaining certification in Cisco technology is key to the continuing educational development of today's networking professional. Through certification programs, Cisco validates the skills and expertise required to effectively manage the modern enterprise network.

Cisco Press Certification Guides and preparation materials offer exceptional—and flexible—access to the knowledge and information required to stay current in your field of expertise or to gain new skills. Whether used as a supplement to more traditional training or as a primary source of learning, these materials offer users the information and knowledge validation required to gain new understanding and proficiencies.

Developed in conjunction with the Cisco certifications and training team, Cisco Press books are the only self-study books authorized by Cisco and offer students a series of exam practice tools and resource materials to help ensure that learners fully grasp the concepts and information presented.

Additional authorized Cisco instructor-led courses, e-learning, labs, and simulations are available exclusively from Cisco Learning Solutions Partners worldwide. To learn more, visit http://www.cisco.com/go/training.

I hope that you find these materials to be an enriching and useful part of your exam preparation.

Erik Ullanderson
Manager, Global Certifications
Learning@Cisco
January 2010

Introduction

This book focuses on one major goal: to help you prepare to pass the ROUTE exam (642-902). To help you prepare, this book achieves other useful goals as well: It explains a wide range of networking topics, shows how to configure those features on Cisco routers, and explains how to determine if the feature is working. As a result, you also can use this book as a general reference for IP routing and IP routing protocols. However, the motivation for this book, and the reason it sits within the Cisco Press Certification Guide series, is that its primary goal is to help you pass the ROUTE exam.

The rest of this introduction focuses on two topics: the ROUTE exam and a description of this book.

The CCNP ROUTE Exam

Cisco announced the ROUTE (642-902) exam in January 2010. The term ROUTE does not act as an acronym; instead, the name describes the content of the exam, which focuses on IP routing. Generally, the exam includes detailed coverage of the EIGRP, OSPF, and BGP IP routing protocols, IPv6, and a few other smaller topics related to IP routing.

Cisco first announced its initial Professional level certifications in 1998 with the CCNP Routing and Switching certification. CCNP Routing and Switching certification from its inception has included the same kinds of IP routing topics found in today's ROUTE exam, but the exam names changed over the years. The exam names have tracked the names of the associated Cisco authorized courses for the same topics: Advanced Cisco Router Configuration (ACRC) in the early days, Building Scalable Cisco Internetworks (BSCI) for much of the last 10 years, and now ROUTE, because the newly revised (in 2010) Cisco authorized course also goes by the name ROUTE.

Like its ancestors, the ROUTE exam is a part of the certification requirements for several Cisco certifications, as follows:

- Cisco Certified Networking Professional (CCNP)
- Cisco Certified Internetworking Professional (CCIP)
- Cisco Certified Design Professional (CCDP)

Each of these certifications emphasizes different perspectives on some similar topics. CCNP focuses on the skills needed by a network engineer working for an Enterprise–that is, a company that deploys networking gear for its own purposes. CCIP focuses on the skills required by network engineers deploying gear at a service provider, with the service provider then offering network services to customers. Finally, CCDP focuses more on design—but good design requires solid knowledge of the technology and configuration. So, although this book frequently refers to the most popular certification of these three—CCNP—the ROUTE exam does apply to several certifications.

Contents of the ROUTE Exam

Every student who ever takes an exam wants to know what's on the exam. As with all their exams, Cisco publishes a set of exam topics. These exam topics give general guidance as to what's on the exam.

You can find the exam topics at the Cisco website. The most memorable way to navigate is to go to www.cisco.com/go/ccnp, and look for the ROUTE exam. Also, you can go to the Cisco Learning Network website (www.cisco.com/go/learnnetspace)—a less memorable URL, but a great Cisco certification site. The Cisco Learning Network site hosts exam information, learning tools, and forums in which you can communicate with others and learn more about this and other Cisco exams.

Table I-1 lists the ROUTE exam topics, with a reference to the part of the book that covers the topic.

Table I-1 ROUTE Exam Topics

Book Part	Exam Topic
Implement an EIGRP based solution, given a network design and a set of requirements	
II	Determine network resources needed for implementing EIGRP on a network
II	Create an EIGRP implementation plan
II	Create an EIGRP verification plan
II	Configure EIGRP routing
II	Verify EIGRP solution was implemented properly using **show** and **debug** commands
II	Document results of EIGRP implementation and verification
Implement a multi-area OSPF Network, given a network design and a set of requirements	
III	Determine network resources needed for implementing OSPF on a network
III	Create an OSPF implementation plan
III	Create an OSPF verification plan
III	Configure OSPF routing
III	Verify OSPF solution was implemented properly using show and debug commands
III	Document results of OSPF implementation and verification plan
Implement an eBGP based solution, given a network design and a set of requirements	
V	Determine network resources needed for implementing eBGP on a network
V	Create an eBGP implementation plan
V	Create an eBGP verification plan
V	Configure eBGP routing
V	Verify eBGP solution was implemented properly using show and debug commands
V	Document results of eBGP implementation and verification plan

Table I-1 ROUTE Exam Topics

Book Part	Exam Topic
Implement an IPv6 based solution, given a network design and a set of requirements	
VI	Determine network resources needed for implementing IPv6 on a network
VI	Create an IPv6 implementation plan
VI	Create an IPv6 verification plan
VI	Configure IPv6 routing
VI	Configure IPv6 interoperation with IPv4
VI	Verify IPv6 solution was implemented properly using show and debug commands
VI	Document results of IPv6 implementation and verification plan
Implement an IPv4 or IPv6 based redistribution solution, given a network design and a set of requirements	
IV, VI	Create a redistribution implementation plan based upon the results of the redistribution analysis.
IV, VI	Create a redistribution verification plan
IV, VI	Configure a redistribution solution
IV, VI	Verify that a redistribution was implemented
IV, VI	Document results of a redistribution implementation and verification plan
IV, VI	Identify the differences between implementing an IPv4 and IPv6 redistribution solution
Implement Layer 3 Path Control Solution	
IV	Create a Layer 3 path control implementation plan based upon the results of the redistribution analysis.
IV	Create a Layer 3 path control verification plan
IV	Configure Layer 3 path control
IV	Verify that a Layer 3 path control was implemented
IV	Document results of a Layer 3 path control implementation and verification plan
Implement basic teleworker and branch services	
VII	Describe broadband technologies
VII	Configure basic broadband connections
VII	Describe basic VPN technologies
VII	Configure GRE
VII	Describe branch access technologies

How to Take the ROUTE Exam

As of the publication of this book, Cisco exclusively uses testing vendor Pearson Vue (www.vue.com) for delivery of all Cisco career certification exams. To register, go to www.vue.com, establish a login, and register for the 642-902 ROUTE exam. You also need to choose a testing center near to your home.

Who Should Take This Exam and Read This Book?

This book has one primary audience, with several secondary audiences. First, this book is intended for anyone wanting to prepare for the ROUTE 642-902 exam. The audience includes self-study readers—people who pass the test by studying 100 percent on their own. It includes Cisco Networking Academy students taking the CCNP curriculum, who use this book to round out their preparation as they get close to the end of the Academy curriculum.

The broader question about the audience may well be why you should take the ROUTE exam. First, the exam is required for the aforementioned CCNP, CCIP, and CCDP certifications from Cisco. These certifications exist at the midpoint of the Cisco certification hierarchy. These certifications have broader and deeper technology requirements as compared to the Cisco Certified Entry Network Technician (CCENT) and Cisco Certified Network Associate (CCNA) certifications.

The real question then about audience for this book—at least the intended audience—is whether you have motivation to get one of these Professional-level Cisco certifications. CCNP in particular happens to be a popular, well-respected certification. CCIP, although less popular in numbers, focuses on topics more important to service providers, so it gives you a good way to distinguish yourself from others looking for jobs at SP companies. CCDP has been a solid certification for a long time, particularly for engineers who spend a lot of time designing networks with customers, rather than troubleshooting.

Format of the CCNP ROUTE Exam

The ROUTE exam follows the same general format as the other Cisco exams. When you get to the testing center and check in, the proctor will give you some general instructions and then take you into a quiet room with a PC. When you're at the PC, you have a few things to do before the timer starts on your exam—for instance, you can take a sample quiz, just to get accustomed to the PC and to the testing engine. Anyone who has user-level skills in getting around a PC should have no problems with the testing environment.

When you start the exam, you will be asked a series of questions. You answer the question and then move on to the next question. *The exam engine does not let you go back and change your answer.* Yes, that's true—when you move on to the next question, that's it for the earlier question.

The exam questions can be in one of the following formats:

- Multiple choice (MC)
- Testlet
- Drag-and-drop (DND)
- Simulated lab (Sim)
- Simlet

The first three types of questions are relatively common in many testing environments. The multiple choice format simply requires that you point-and-click on a circle beside the correct answer(s). Cisco traditionally tells you how many answers you need to choose, and the testing software prevents you from choosing too many answers. Testlets are questions with one general scenario, with multiple MC questions about the overall scenario. Drag-and-drop questions require you to left-click and hold, move a button or icon to another area, and release the clicker to place the object somewhere else—typically into a list. So, for some questions, to get the question correct, you might need to put a list of five things into the proper order.

The last two types both use a network simulator to ask questions. Interestingly, the two types actually allow Cisco to assess two very different skills. First, Sim questions generally describe a problem, and your task is to configure one or more routers and switches to fix the problem. The exam then grades the question based on the configuration you changed or added. Interestingly, Sim questions are the only questions that Cisco (to date) has openly confirmed that partial credit is given.

The Simlet questions may well be the most difficult style of question on the exams. Simlet questions also use a network simulator, but instead of answering the question by changing the configuration, the question includes one or more MC questions. The questions require that you use the simulator to examine the current behavior of a network, interpreting the output of any **show** commands that you can remember to answer the question. Although Sim questions require you to troubleshoot problems related to a configuration, Simlets require you to both analyze working networks and networks with problems, correlating **show** command output with your knowledge of networking theory and configuration commands.

The Cisco Learning Network (learningnetwork.cisco.com) website has tools that let you experience the environment and see how each of these question types work. The environment should be the same as when you passed CCNA (a prerequisite for CCNP, CCIP, and CCDP).

CCNP ROUTE 642-902 Official Certification Guide

This section lists a general description of the contents of this book. The description includes an overview of each chapter, and a list of book features seen throughout the book.

Book Features and Exam Preparation Methods

This book uses several key methodologies to help you discover the exam topics on which you need more review, to help you fully understand and remember those details, and to help you prove to yourself that you have retained your knowledge of those topics. So, this book does not try to help you pass the exams only by memorization, but by truly learning and understanding the topics.

The book includes many features that provide different ways to study to be ready for the test. If you understand a topic when you read it, but do not study it any further, you probably will not be ready to pass the test with confidence. The book features included in this book give you tools that help you determine what you know, review what you know, better learn what you don't know, and be well prepared for the exam. These tools include

- **"Do I Know This Already?" Quizzes:** Each chapter begins with a quiz that helps you determine the amount of time you need to spend studying that chapter.
- **Foundation Topics:** These are the core sections of each chapter. They explain the protocols, concepts, and configuration for the topics in that chapter.
- **Exam Preparation Tasks:** The Exam Preparation Tasks section lists a series of study activities that should be done after reading the Foundation Topics section. Each chapter includes the activities that make the most sense for studying the topics in that chapter. The activities include

— **Planning Tables:** The ROUTE exam topics includes some perspectives on how an engineer plans for various tasks. The idea is that the CCNP-level engineer in particular takes the design from another engineer, plans the implementation, and plans the verification steps—handing off the actual tasks to engineers working during change-window hours. Because the engineer plans the tasks, but may not be at the keyboard when implementing a feature, that engineer must master the configuration and verification commands so that the planned commands work for the engineer making the changes off-shift. The planning tables at the end of the chapter give you the chance to take the details in the Foundation Topics core of the chapter and think about them as if you were writing the planning documents.

Key Topic

— **Key Topics Review:** The Key Topics icon is shown next to the most important items in the Foundation Topics section of the chapter. The Key Topics Review activity lists the Key Topics from the chapter, and page number. Although the contents of the entire chapter could be on the exam, you should definitely know the information listed in each key topic. Review these topics carefully.

— **Memory Tables:** To help you exercise your memory and memorize some lists of facts, many of the more important lists and tables from the chapter are included in a document on the CD. This document lists only partial information, allowing you to complete the table or list. CD-only Appendix D holds the incomplete tables, and Appendix E includes the completed tables from which you can check your work.

— **Definition of Key Terms:** Although the exams may be unlikely to ask a question such as "Define this term," the ROUTE exam requires that you learn and know a lot of networking terminology. This section lists the most important terms from the chapter, asking you to write a short definition and compare your answer to the glossary at the end of the book.

- **CD-based practice exam:** The companion CD contains an exam engine (from Boson software, www.boson.com), which includes 100 unique multiple-choice questions. Chapter 20 gives two suggestions on how to use these questions: either as study questions, or to simulate the ROUTE exam.

- **Companion website:** The website http://www.ciscopress.com/title/9781587202537 posts up-to-the-minute materials that further clarify complex exam topics. Check this site regularly for new and updated postings written by the author that provide further insight into the more troublesome topics on the exam.

Book Organization

This book contains 20 chapters, plus appendixes. The topics all focus in some way on IP routing and IP routing protocols, making the topics somewhat focused, but with deep coverage on those topics.

The book organizes the topics into seven major parts. Parts 1 and 7 include topics with less technical depth, and Parts 2 through 6 include the major technical topics in the book. The following list outlines the major part organization of this book:

Part I: "Perspectives on Network Planning": This part includes a single chapter:

- **Chapter 1: "Planning Tasks for the CCNP Exams":** This chapter discusses the CCNP ROUTE exam's perspectives on the planning process, including network design, implementation plans, and verification plans.

Part II: "EIGRP": This part starts with a CCNA-level EIGRP review and moves through EIGRP theory, configuration, authentication, route summarization, and more in the following chapters:

- **Chapter 2: "EIGRP Overview and Neighbor Relationships":** This chapter reviews CCNA-level EIGRP topics and then closely examines the concepts, configuration, and verification of EIGRP neighbor relationships.
- **Chapter 3: "EIGRP Topology, Routes, and Convergence":** This chapter examines the EIGRP topology database and the processes by which EIGRP processes this data to choose routes. It also examines the convergence process using feasible successors and with the Query process.
- **Chapter 4: "EIGRP Route Summarization and Filtering":** This chapter discusses the theory behind route summarization and route filtering. It also shows how to configure and verify both features for EIGRP.

Part III: "OSPF": Similar to Part II, this part starts with a CCNA-level OSPF review and moves through OSPF theory, configuration, authentication, metric tuning, default routing, route filtering, and route summarization, plus OSPF multiarea issues and different stubby area types, as follows:

- **Chapter 5: "OSPF Overview and Neighbor Relationships":** This chapter reviews CCNA-level OSPF topics and then closely examines the concepts, configuration, and verification of OSPF neighbor relationships.
- **Chapter 6: "OSPF Topology, Routes, and Convergence":** This chapter examines the OSPF topology database for routes internal to OSPF. The chapter also discusses how OSPF routers choose the best internal OSPF routes and how OSPF converges when a change occurs.

- **Chapter 7: "OSPF Route Summarization, Filtering, and Default Routing":** This chapter discusses the design, configuration, and verification of OSPF route summarization and route filtering. It also discusses default routes and how to manage the size of the OSPF database and IP routing tables by using stubby areas.
- **Chapter 8: "OSPF Miscellany":** This chapter discusses two additional OSPF topics: OSPF virtual links and OSPF issues when using NBMA networks (such as Frame Relay).

Part IV: "Path Control": The term path control refers to a wide variety of topics related to IP routing and IP routing protocols. This part examines the path control topics not specifically included in the other parts of the book:

- **Chapter 9: "Basic IGP Redistribution":** This chapter examines the concepts, configuration, and verification of IGP route redistribution. In particular, this chapter looks at the mechanics of redistribution without the use of route maps for any purpose.
- **Chapter 10: "Advanced IGP Redistribution":** This chapter essentially continues Chapter 9, in this case focusing on the more complex configuration and issues. In particular, this chapter shows how to manipulate and filter routes at the redistribution function by using route maps, and how to avoid routing loops and inefficient routes when multiple redistribution points exist.
- **Chapter 11: "Policy Routing and IP Service Level Agreement":** This chapter picks up two small path control topics that simply do not fit into any other broader chapter in this book: Policy Based Routing (PBR) and IP Service Level Agreement (IP SLA).

Part V: "BGP": This part assumes no prior knowledge of BGP. It first examines BGP design issues, to give perspective on why BGP works differently than its IGP cousins OSPF and EIGRP. This part examines basic BGP concepts, configuration, and verification, including the path control functions of incluencing both inbound and outbound BGP routes:

- **Chapter 12: "Internet Connectivity and BGP":** This chapter introduces BGP. It begins with a review of Internet connectivity from a Layer 3 perspective. It then looks at the basics of how BGP works. It also examines some Internet access design issues, discussing the cases in which BGP can be helpful and the cases in which BGP has no practical use.
- **Chapter 13: "External BGP":** This chapter examines the configuration and verification of BGP between an Enterprise and its ISP(s).
- **Chapter 14: "Internal BGP and BGP Route Filtering":** This chapter examines the cases in which routers in the same ASN need to become BGP peers, creating an Internet BGP connection. It also discusses the need for BGP filtering and the mechanics of configuring BGP filtering.
- **Chapter 15: "BGP Path Control":** This chapter discusses the concept of the BGP

Best Path Algorithm to choose the best BGP routes and how to influence those choices. In particular, this chapter shows the basic configuration for BGP weight, Local Preference, AS_Path length, and Multi-Exit Discriminator (MED).

Part VI: "IPv6": This part assumes no prior knowledge of IPv6. The chapters in this part work through IPv6 addressing and IGP configuration (RIPng, EIGRP for IPv6, and OSPFv3). It also discusses route redistribution for IPv6 and IPv6/IPv4 coexistence mechanisms:

- **Chapter 16: "IP Version 6 Addressing":** This chapter begins with an overview of IP Version 6 (IPv6). It then dives into IPv6 addressing concepts, plus the related protocols, including address assignment options and neighbor discovery. The chapter shows how to configure and verify IPv6 addresses on Cisco routers.
- **Chapter 17: "IPv6 Routing Protocols and Redistribution":** This chapter introduces three IPv6 IGPs: RIP Next Generation (RIPng), EIGRP for IPv6, and OSPF Version 3 (OSPFv3). The chapter focuses on basic configuration and verification. It also discusses IPv6 redistribution in comparison with IPv4 IGP redistribution.
- **Chapter 18: "IPv4 and IPv6 Coexistence":** This chapter discusses the many options to use during the potentially long migration from a purely IPv4 network to a future purely IPv6 network.

Part VII: "Branch Office Networking": This short part includes one chapter that addresses a few small topics related to branch offices that connect to their Enterprise networks using the Internet:

- **Chapter 19: "Routing over Branch Internet Connections":** Branch office routers can be configured to use the Internet as a WAN connection path back to the rest of an Enterprise network. This chapter takes a wide look at the surprisingly large number of networking functions that must occur on a branch router in such cases. It also gives examples of configurations for IPsec and GRE tunnels, DHCP server, NAT, and DSL.

Part VIII: "Final Preparation": This short part includes one chapter as well. This chapter does not include any new technical topics:

- **Chapter 20: "Final Preparation":** This chapter suggests some study strategies for your final preparation before the ROUTE exam.

In addition to the core chapters of the book, the book has several appendixes as well. Some appendixes exist in the printed book, whereas others exist in softcopy form on the CD included with the book.

Printed Appendixes

Appendixes printed in the book include

- **Appendix A, "Answers to the "Do I Know This Already?" Quizzes":** Includes the answers to all the questions from Chapters 2 through 19.
- **Appendix B, "Conversion Tables":** Lists a decimal-to-binary conversion table, decimal values 0 through 255, along with the binary equivalents. It also lists a hex-to-decimal conversion table as well.
- **Appendix C,** "CCNP **ROUTE Exam Updates**: Version 1.0"**:** Covers a variety of short topics that either clarify or expand upon topics covered earlier in the book. This appendix is updated from time to time, and posted at http://www.ciscopress.com/title/9781587202537, with the most recent version available at the time of printing included here as Appendix C. (The first page of the appendix includes instructions on how to check to see if a later version of Appendix C is available online.)

CD Appendixes

The appendixes included on the CD-ROM are

- **Appendix D, "Memory Tables":** This appendix holds the key tables and lists from each chapter with some of the content removed. You can print this appendix, and as a memory exercise, complete the tables and lists. The goal is to help you memorize facts that can be useful on the exams.
- **Appendix E, "Memory Tables Answer Key":** This appendix contains the answer key for the exercises in Appendix D.
- **Appendix F, "Completed Planning Practice Tables":** The end of Chapters 2 through 19 list planning tables that you can complete to help learn the content more deeply. If you use these tables, refer to this appendix for the suggested answers.
- **Glossary:** The glossary contains definitions for all the terms listed in the "Define Key Terms" section at the conclusion of Chapters 2 through 19.

For More Information

If you have any comments about the book, you can submit those via the www.ciscopress.com. Just go to the website, select Contact Us, and type in your message.

Cisco might make changes that affect the ROUTE exam from time to time. You should always check www.cisco.com/go/ccnp for the latest details.

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This chapter covers the following subjects:

Building the EIGRP Topology Table: This section discusses how a router seeds its local EIGRP topology table, and how neighboring EIGRP routers exchange topology information.

Building the IP Routing Table: This section explains how routers use EIGRP topology data to choose the best routes to add to their local routing tables.

Optimizing EIGRP Convergence: This section examines the items that have an impact on how fast EIGRP converges for a given route.

CHAPTER 3

EIGRP Topology, Routes, and Convergence

EIGRP, like OSPF, uses three major branches of logic, each of which populates a different table. EIGRP begins by forming neighbor relationships and listing those relationships in the EIGRP neighbor table (as described in Chapter 2, "EIGRP Overview and Neighbor Relationships"). EIGRP then exchanges topology information with these same neighbors, with newly learned information being added to the router's EIGRP topology table. Finally, each router processes the EIGRP topology table to choose the currently best IP routes, adding those IP routes to the IP routing table.

This chapter moves from the first major branch (neighborships, as covered in Chapter 2) to the second and third branches: EIGRP topology and EIGRP routes. To that end, the first major section of this chapter describes the protocol used by EIGRP to exchange the topology information and details exactly what information EIGRP puts in its messages between routers. The next major section shows how EIGRP examines the topology data to then choose the currently best route for each prefix. The final section of this chapter examines how to optimize the EIGRP convergence processes so that when the topology does change, the routers in the internetwork quickly converge to the then-best routes.

"Do I Know This Already?" Quiz

The "Do I Know This Already?" quiz allows you to assess if you should read the entire chapter. If you miss no more than one of these nine self-assessment questions, you might want to move ahead to the "Exam Preparation Tasks." Table 3-1 lists the major headings in this chapter and the "Do I Know This Already?" quiz questions covering the material in those headings, so you can assess your knowledge of these specific areas. The answers to the "Do I Know This Already?" quiz appear in Appendix A.

Table 3-1 *"Do I Know This Already?" Foundation Topics Section-to-Question Mapping*

Foundations Topics Section	Questions
Building the EIGRP Topology Table	1-3
Building the IP Routing Table	4–7
Optimizing EIGRP Convergence	8, 9

1. Which of the following are methods EIGRP uses to initially populate (seed) its EIGRP topology table, before learning topology data from neighbors? (Choose two.)
   a. By adding all subnets listed by the **show ip route connected** command
   b. By adding the subnets of working interfaces over which static neighbors have been defined
   c. By adding subnets redistributed on the local router from another routing source
   d. By adding all subnets listed by the **show ip route static** command
2. Which of the following are both advertised by EIGRP in the Update message and included in the formula for calculating the integer EIGRP metric? (Choose two.)
   a. Jitter
   b. Delay
   c. MTU
   d. Reliability
3. Router R1 uses S0/0 to connect via a T/1 to the Frame Relay service. Five PVCs terminate on the serial link. Three PVCs (101, 102, and 103) are configured on subinterface S0/0.1, and one each (104 and 105) are on S0/0.2 and S0/0.3. The configuration shows no configuration related to EIGRP WAN bandwidth control, and the **bandwidth** command is not configured at all. Which of the following is true about how IOS tries to limit EIGRP's use of bandwidth on S0/0?
   a. R1 limits EIGRP to around 250Kbps on DLCI 102.
   b. R1 limits EIGRP to around 250Kbps on DLCI 104.
   c. R1 limits EIGRP to around 150Kbps on every DLCI.
   d. R1 does not limit EIGRP because no WAN bandwidth control has been configured.
4. The output of **show ip eigrp topology** on Router R1 shows the following output, which is all the output related to subnet 10.11.1.0/24. How many feasible successor routes does R1 have for 10.11.1.0/24?

```
P 10.11.1.0/24, 2 successors, FD is 2172419
        via 10.1.1.2 (2172423/28167), Serial0/0/0.1
        via 10.1.1.6 (2172423/28167), Serial0/0/0.2
```

   a. 0
   b. 1
   c. 2
   d. 3
5. A network design shows that R1 has four different possible paths from itself to the Data Center subnets. Which of the following can influence which of those routes become feasible successor routes, assuming that you follow the Cisco recommended practice of not changing metric weights? (Choose two.)
   a. The configuration of EIGRP offset lists
   b. Current link loads

   c. Changing interface delay settings
   d. Configuration of variance

6. Router R1 is three router hops away from subnet 10.1.1.0/24. According to various **show interfaces** commands, all three links between R1 and 10.1.1.0/24 use the following settings: bandwidth: 1000, 500, 100000 and delay: 12000, 8000, 100. Which of the following answers correctly identifies a value that feeds into the EIGRP metric calculation? (Choose two correct answers.)

   a. Bandwidth of 101,500
   b. Bandwidth of about 34,000
   c. Bandwidth of 500
   d. Delay of 1200
   e. Delay of 2010
   f. Delay of 20100

7. Routers R1 and R2 are EIGRP neighbors. R1 has been configured with the **eigrp stub connected** command. Which of the following is true as a result? (Choose two correct answers.)

   a. R1 can learn EIGRP routes from R2, but R2 cannot learn EIGRP routes from R1.
   b. R1 can send IP packets to R2, but R2 cannot send IP packets to R1.
   c. R2 no longer learns EIGRP routes from R1 for routes not connected to R1.
   d. R1 no longer replies to R2's Query messages.
   e. R2 no longer sends to R1 Query messages.

8. A network design shows that R1 has four different possible paths from itself to the Data Center subnets. Which one of the following commands is most likely to show you all the possible next-hop IP addresses for these four possible routes?

   a. **show ip eigrp topology**
   b. **show ip eigrp topology all-links**
   c. **show ip route eigrp**
   d. **show ip route eigrp all-links**
   e. **show ip eigrp topology all-learned**

9. Router R1 lists 4 routes for subnet 10.1.1.0/24 in the output of the **show ip eigrp topology all-links** command. The **variance 100** command is configured, but no other related commands are configured. Which of the following rules are true regarding R1's decision of what routes to add to the IP routing table? Note that RD refers to reported distance and FD to feasible distance.

   a. Adds all routes for which the metric is <= 100 * the best metric among all routes
   b. Adds all routes because of the ridiculously high **variance** setting
   c. Adds all successor and feasible successor routes
   d. Adds all successor and feasible successor routes for which the metric is <= 100 * the best metric among all routes

Foundation Topics

Building the EIGRP Topology Table

The overall process of building the EIGRP topology table is relatively straightforward. EIGRP defines some basic topology information about each route for each unique prefix/length (subnet). This basic information includes the prefix, prefix length, metric information, and a few other details. EIGRP neighbors exchange topology information, with each router storing the learned topology information in their respective EIGRP topology table. EIGRP on a given router can then analyze the topology table, or topology database, and choose the best route for each unique prefix/length.

EIGRP uses much simpler topology data than does OSPF, which is a link state protocol that must describe the entire topology of a portion of a network with its topology database. EIGRP, essentially an advanced distance vector protocol, does not need to define nearly as much topology data, nor do EIGRP routers need to run the complex Shortest Path First (SPF) algorithm. This first major section examines the EIGRP topology database, how routers create and flood topology data, and some specific issues related to WAN links.

Seeding the EIGRP Topology Table

Before a router can send EIGRP topology information to a neighbor, that router must have some topology data in its topology table. Routers can, of course, learn about subnets and the associated topology data from neighboring routers. However to get the process started, each EIGRP router needs to add topology data for some prefixes, so it can then advertise these routes to its EIGRP neighbors. A router's EIGRP process adds subnets to its local topology table, without learning the topology data from an EIGRP neighbor, from two sources:

Key Topic

- Prefixes of connected subnets for interfaces on which EIGRP has been enabled on that router using the **network** command
- Prefixes learned by the redistribution of routes into EIGRP from other routing protocols or routing information sources

After a router adds such prefixes to its local EIGRP topology database, that router can then advertise the prefix information, along with other topology information associated with each prefix, to each working EIGRP neighbor. Each router adds any learned prefix information to their topology table, and then that router advertises the new information to other neighbors. Eventually, all routers in the EIGRP domain learn about all prefixes–unless some other feature, such as route summarization or route filtering, alters the flow of topology information.

The Content of EIGRP Update Message

EIGRP uses five basic protocol messages to do its work:

Key Topic

- Hello
- Update
- Query
- Reply
- ACK (acknowledgment)

EIGRP uses two messages as part of the topology data exchange process: Update and Ack. The Update message contains the topology information, whereas the ACK acknowledges receipt of the update packet.

The EIGRP Update message contains the following information:

- Prefix
- Prefix length
- Metric components: bandwidth, delay, reliability, and load
- Nonmetric items: MTU and hop count

Note: Many courses and books over the years have stated that MTU is part of the EIGRP metric. In practice, the MTU has never been part of the metric calculation, although it is included in the topology data for each prefix.

To examine this whole process in more detail, see Figure 3-1 and Figure 3-2. Figure 3-1 shows a portion of an Enterprise network that will be used in several examples in this chapter. Routers B1 and B2 represent typical branch office routers, each with two Frame Relay PVCs connected back to the main site. WAN1 and WAN2 are WAN distribution routers, each of which would normally have dozens or hundreds of PVCs.

The routers in Figure 3-1 have been configured and work. For EIGRP, all routers have been configured with as many defaults as possible, with the only configuration related to EIGRP being the **router eigrp 1** and **network 10.0.0.0** commands on each router.

Next, consider what Router B1 does for its connected route for subnet 10.11.1.0/24, which is located on B1's LAN. B1 matches its Fa0/0 interface IP address (10.11.1.1) due to its **network 10.0.0.0** configuration command. So as mentioned earlier, B1 seeds its own topology table with an entry for this prefix. This topology table entry also lists the interface bandwidth of the associated interface and delay of the associated interface. Using default settings for FastEthernet interfaces, B1 uses a bandwidth of 100,000 Kbps (the same as 100 Mbps) and a delay of 10, meaning 10 tens-of-microseconds. Router B1 also includes a default setting for the load (1) and reliability (255), even though the router, using the default K-value settings, will not use these values in its metric calculations. Finally, B1 adds to the topology database the MTU of the local interface and a hop count of zero because the subnet is connected.

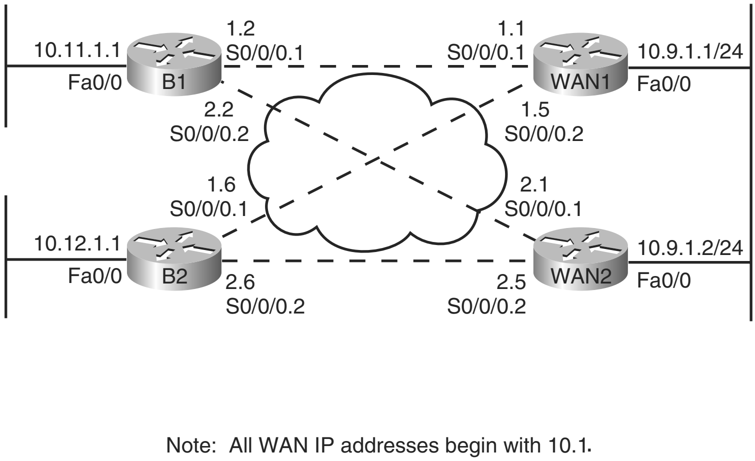

Figure 3-1 *Typical WAN Distribution and Branch Office Design*

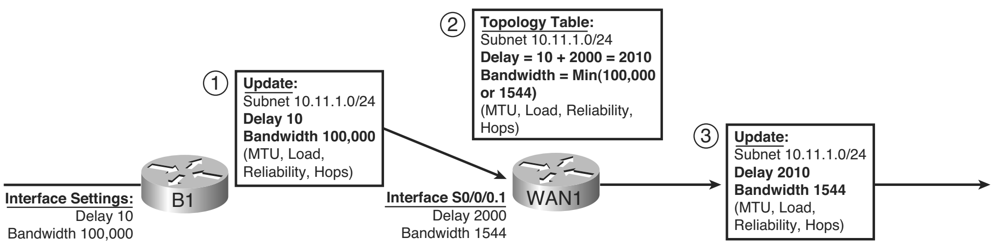

Figure 3-2 *Contents of EIGRP Update Messages*

Now that B1 has added some topology information to its EIGRP topology database, Figure 3-2 shows how B1 propagates the topology information to router WAN1 and beyond.

The steps in Figure 3-2 can be explained as follows:

Step 1. B1 advertises the prefix (10.11.1.0/24) using an EIGRP Update message. The message includes the four metric components, plus MTU and hop count–essentially the information in B1's EIGRP topology table entry for this prefix.

Step 2. WAN1 receives the Update message and adds the topology information for 10.11.1.0/24 to its own EIGRP topology table, with these changes:

a. WAN1 considers the interface on which it received the Update (S0/0/0.1) to be the outgoing interface of a potential route to reach 10.11.1.0/24.

b. WAN1 adds the delay of S0/0/0.1 (2000 tens-of-microseconds per Figure 3-2) to the delay listed in the Update message.

c. WAN1 compares the bandwidth of S0/0/0.1 (1544 Kbps per Figure 3-2) to the bandwidth listed in the Update message (100,000 Kbps) and chooses the lower value (1544) as the bandwidth for this route.

d. WAN1 also updates load (highest value), reliability (lowest value), and MTU (lowest value) based on similar comparisons, and adds 1 to the hop count.

Step 3. WAN1 then sends an Update to its neighbors, with the metric components listed in its own topology table.

This example provides a good backdrop to understand how EIGRP uses cumulative delay and minimum bandwidth in its metric calculation. Note that at Step 2, router WAN1 adds to the delay value but does not add the bandwidth. For bandwidth, WAN1 simply chooses the lowest bandwidth, comparing the bandwidth of its own interface (S0/0/0.1) with the bandwidth listed in the received EIGRP update.

Next, consider this logic on other routers—not shown in the figure—as WAN1 floods this routing information throughout the Enterprise. WAN1 then sends this topology information to another neighbor, and that router sends the topology data to another, and so on. If bandwidth of those links was 1544 or higher, the bandwidth setting used by those routers would remain the same, because each router would see that the routing update's bandwidth (1544 Kbps) was lower than the link's bandwidth. However, each router would add something to the delay.

As a final confirmation of the contents of this Update process, Example 3-1 shows the details of the EIGRP topology database for prefix 10.11.1.0/24 on both B1 and WAN1.

Example 3-1 *Topology Database Contents for 10.11.1.0/24, on B1 and WAN1*

```
! On Router B1: !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
B1#show ip eigrp topology 10.11.1.0/24
IP-EIGRP (AS 1): Topology entry for 10.11.1.0/24
  State is Passive, Query origin flag is 1, 1 Successor(s), FD is 28160
  Routing Descriptor Blocks:
  0.0.0.0 (FastEthernet0/0), from Connected, Send flag is 0x0
      Composite metric is (28160/0), Route is Internal
      Vector metric:
        Minimum bandwidth is 100000 Kbit
        Total delay is 100 microseconds
        Reliability is 255/255
        Load is 1/255
        Minimum MTU is 1500
        Hop count is 0
```

```
! On Router WAN1: !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
WAN1#show ip eigrp topology 10.11.1.0/24
IP-EIGRP (AS 1): Topology entry for 10.11.1.0/24
  State is Passive, Query origin flag is 1, 1 Successor(s), FD is 2172416
  Routing Descriptor Blocks:
  10.1.1.2 (Serial0/0/0.1), from 10.1.1.2, Send flag is 0x0
      Composite metric is (2172416/28160), Route is Internal
      Vector metric:
        Minimum bandwidth is 1544 Kbit
        Total delay is 20100 microseconds
```

```
     Reliability is 255/255
     Load is 1/255
     Minimum MTU is 1500
    Hop count is 1
```

The highlighted portions of output match the details shown in Figure 3-2, but with one twist relating to the units on the delay setting. The IOS **delay** command, which lets you set the delay, along with the data stored in the EIGRP topology database, use a unit of tens-of-microsecond. However, the **show interfaces** and **show ip eigrp topology** commands list delay in a unit of microseconds. For example, WAN1's listing of "20100 microseconds" matches the "2010 tens-on-microseconds" shown in Figure 3-2.

The EIGRP Update Process

So far, this chapter has focused on the detailed information EIGRP exchanges with a neighbor about each prefix. This section takes a broader look at the process.

When EIGRP neighbors first become neighbors, they begin exchanging topology information using Update messages using these rules:

Key Topic

- When a neighbor first comes up, the routers exchange full updates, meaning the routers exchange all topology information.
- After all prefixes have been exchanged with a neighbor, the updates cease with that neighbor if no changes occur in the network. There is no periodic reflooding of topology data.
- If something changes–for example, one of the metric components change, links fail, links recover, new neighbors advertise additional topology information–the routers send partial updates about only the prefixes whose status or metric components have changed.
- If neighbors fail and then recover, or new neighbor adjacencies are formed, full updates occur over these adjacencies.
- EIGRP uses Split Horizon rules on most interfaces by default, which impacts exactly which topology data EIGRP sends during both full and partial updates.

Split Horizon, the last item in the list, needs a little more explanation. Split Horizon limits the prefixes that EIGRP advertises out an interface. Specifically, if the currently best route for a prefix lists a particular outgoing interface, Split Horizon means that EIGRP will not include that prefix in the Update sent out that same interface. For example, router WAN1 uses S0/0/0.1 as its outgoing interface for subnet 10.11.1.0/24, so WAN1 would not advertise prefix 10.11.1.0/24 in its Update messages sent out S0/0/0.1.

Note: Route summarization and route filtering, as explained in Chapter 4, "EIGRP Route Summarization and Filtering," also affect which subsets of the topology table are flooded.

To send the Updates, EIGRP uses the *Reliable Transport Protocol (RTP)* to send the EIGRP updates and confirm their receipt. On point-to-point topologies such as serial links, MPLS VPN, and Frame Relay when using point-to-point subinterfaces, the EIGRP Update and ACK messages use a simple process of acknowledging each Update with an ACK. On multiaccess data links, EIGRP typically sends Update messages to multicast address 224.0.0.10 and expects a unicast EIGRP ACK message from each neighbor in reply. RTP manages that process, setting timers so that the sender of an Update waits a reasonable time, but not too long, before deciding whether all neighbors received the Update or whether one or more neighbors did not reply with an ACK.

Although EIGRP relies on the RTP process, network engineers cannot manipulate how it works.

WAN Issues for EIGRP Topology Exchange

With all default settings, after you enable EIGRP on all the interfaces in an internetwork, the topology exchange process typically does not pose any problems. However, a few scenarios exist, particularly on Frame Relay, which can cause problems. This section summarizes two issues and shows the solution.

Split Horizon Default on Frame Relay Multipoint Subinterfaces

IOS support for Frame Relay allows the configuration of IP addresses on the physical serial interface, multipoint subinterfaces, and point-to-point subinterfaces. Additionally, IP packets can be forwarded over a PVC even when the routers on the opposite ends do not have to use the same interface or subinterface type. As a result, many small intricacies exist in the operation of IP and IP routing protocols over Frame Relay, particularly related to default settings on different interface types.

Frame Relay supports several reasonable configuration options using different interfaces and subinterfaces, each meeting different design goals. For instance, if the design includes a few centralized WAN distribution routers, with PVCs connecting each branch router to each distribution router, both distribution and branch routers might use point-to-point subinterface. Such a choice makes the Layer 3 topology simple, with all links acting like point-to-point links from a Layer 3 perspective. This choice also removes issues such as Split Horizon.

In some cases, a design might include a small set of routers that have a full mesh of PVCs connecting each. In this case, multipoint subinterfaces might be used, consuming a single subnet, reducing the consumption of the IP address space. This choice also reduces the number of subinterfaces.

Both options–using point-to-point subinterfaces or using multipoint subinterfaces–have legitimate reasons for being used. However, when using the multipoint subinterface option, a particular EIGRP issue can occur when the following are true:

- Three or more routers, over Frame Relay, are configured as part of a single subnet.
- The routers use multipoint interfaces.
- Either permanently or for a time, a full mesh of PVCs between the routers does not exist.

For example, consider Router WAN1 shown earlier in Figure 3-1 and referenced again in Figure 3-3. In the earlier configurations, the WAN distribution routers and branch routers all used point-to-point subinterfaces and a single subnet per VC. To see the problem raised in this section, consider that same internetwork, but now the engineer has chosen to configure WAN1 to use a multipoint subinterface and a single subnet for WAN1, B1, and B2, as shown in Figure 3-3.

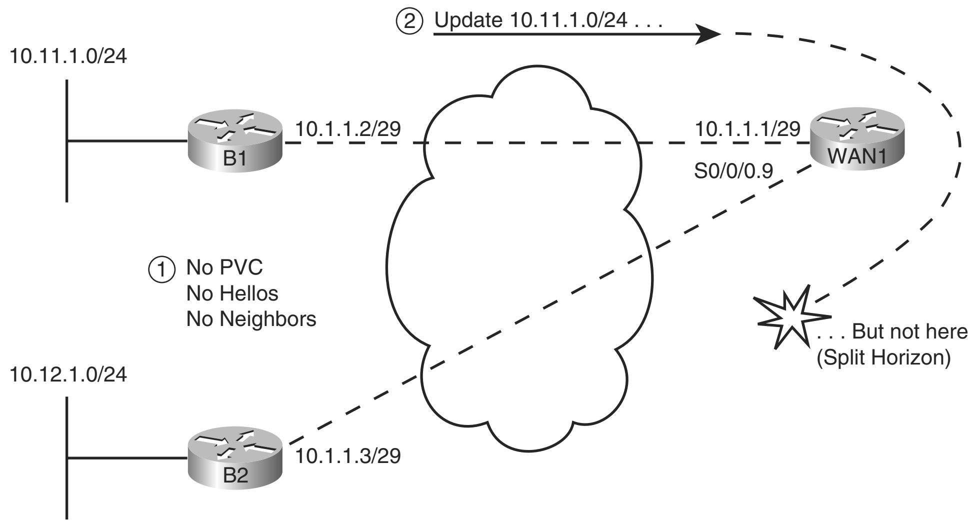

Figure 3-3 *Partial Mesh, Central Sites (WAN1) Uses Multipoint Subinterface*

The first issue to consider in this design is that B1 and B2 will not become EIGRP neighbors with each other, as noted with Step 1 in the figure. EIGRP routers must be reachable using Layer 2 frames before they can exchange EIGRP Hello messages and become EIGRP neighbors. In this case, there is no PVC between B1 and B2. B1 exchanges Hellos with WAN1, and become neighbors, as will B2 with WAN1. However, routers do not forward received EIGRP Hellos, so WAN1 will not receive a Hello from B1 and forward it to B2 or vice versa. In short, although in the same subnet (10.1.1.0/29), B1 and B2 will not become EIGRP neighbors.

The second problem occurs due to Split Horizon logic on Router WAN1, as noted with Step 2 in the figure. As shown with Step 2 in the figure, B1 could advertise its routes to WAN1, and WAN1 could advertise those routes to B2–and vice versa. However, with default settings, WAN1 will not advertise those routes due to its default setting of Split Horizon (a default interface subcommand setting of **ip split-horizon eigrp** *asn*.) As a result, WAN1 receives the Update from B1 on its S0/0/0.9 subinterface, but Split Horizon prevents WAN1 from advertising that topology data to B2 in Updates sent out interface S0/0/0.9, and vice versa.

The solution is somewhat simple–just configure the **no ip split-horizon eigrp** *asn* command on the multipoint subinterface on WAN1. The remote routers, B1 and B2 in this case, still do not become neighbors, but that does not cause a problem by itself. With Split Horizon disabled on WAN1, B1 and B2 learn routes to the other branch's subnets. Example 3-2 lists the complete configuration and the command to disable Split Horizon:

Note: Frame Relay configuration is considered a prerequisite because it is part of the CCNA exam and courses. Example 3-2 uses **frame-relay interface-dlci** commands and relies on Inverse ARP. However, if **frame-relay map** commands were used instead, disabling Inverse ARP, the EIGRP details discussed in this example would remain unchanged.

Example 3-2 *Frame Relay Multipoint Configuration on WAN1*

```
! On Router WAN1: !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
interface Serial0/0/0
 no ip address
 encapsulation frame-relay

interface Serial0/0/0.9 multipoint
 ip address 10.1.1.1 255.255.255.248
 no ip split-horizon eigrp 1
 frame-relay interface-dlci 103
 frame-relay interface-dlci 104
!
router eigrp 1
 network 10.0.0.0
```

Note: The [**no**] **ip split-horizon** command controls Split Horizon behavior for RIP; the [**no**] **ip split-horizon eigrp** *asn* command controls Split Horizon behavior for EIGRP.

Displaying the EIGRP Split Horizon state of an interface is an unusually difficult piece of information to find without simply displaying the configuration. By default, IOS enables EIGRP Split Horizon. To find the setting for an interface, look for the presence or absence of the **no ip split-horizon eigrp** command on the configuration. Also, the **debug ip eigrp** command output displays messages stating when prefixes are not advertised out an interface due to split horizon.

EIGRP WAN Bandwidth Control

In a multiaccess WAN, one physical link passes traffic for multiple data link layer destinations. For example, a WAN distribution router connected to many branches using Frame Relay might literally terminate hundreds, or even thousands, of Frame Relay PVCs.

In a nonbroadcast multiaccess (NBMA) medium such as Frame Relay, when a router needs to send EIGRP updates, the Updates cannot be multicasted at Layer 2. So, the router must send a copy of the Update to each reachable neighbor. For a WAN distribution router with many Frame Relay PVCs, the sheer amount of traffic sent over the Frame Relay access link might overload the link.

The EIGRP WAN bandwidth control allows the engineer to protect a multiaccess Frame Relay interface from being overrun with too much EIGRP message traffic. By default, a router sends EIGRP messages out an interface but only up to 50 percent of the bandwidth defined on the interface with the **bandwidth** command. The engineer can adjust this percentage using the **ip bandwidth-percent eigrp** *asn percent* interface/subinterface subcommand. Regardless of the percentage, IOS then limits the rate of sending the EIGRP messages so that the rate is not exceeded. To accomplish this, IOS queues the EIGRP messages in memory, delaying them briefly.

The command to set the bandwidth percentage is simple, but there are a few caveats to keep in mind when trying to limit the bandwidth consumed by EIGRP:

- The IOS default for bandwidth on serial interfaces and subinterfaces is 1544 (Kbps).
- EIGRP limits the consumed bandwidth based on the percentage of interface/subinterface bandwidth.
- This feature keys on the bandwidth of the interface or subinterface through which the neighbor is reachable, so don't set only the physical interface bandwidth and forget the subinterfaces.
- Recommendation: Set the bandwidth of point-to-point links to the speed of the Committed Information Rate (CIR) of the single PVC on the subinterface.
- General recommendation: Set the bandwidth of multipoint subinterfaces to around the total CIR for all VCs assigned to the subinterface.
- Note that for multipoint subinterfaces, IOS WAN bandwidth control first *divides the subinterface bandwidth by the number of configured PVCs* and then determines the EIGRP percentage based on that number.

For example, consider Figure 3-4, which shows a router with one multipoint subinterface and one point-to-point subinterface. With the configuration shown in Example 3-3, WAN1 uses the following bandwidth, at most, with each neighbor:

- B1, B2, and B3: 20 Kbps (20% of 300Kbps / 3 VCs)
- B4: 30 Kbps (30% of 100 Kbps)

Example 3-3 *Configuration of WAN1, One Multipoint, One Point-to-Point*

```
! On Router WAN1: !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
interface Serial0/0/0.20 multipoint
 ip address 172.16.1.1 255.255.255.240
 frame-relay interface-dlci 201
 frame-relay interface-dlci 202
 frame-relay interface-dlci 203
```

```
  bandwidth 300
   ip bandwidth-percent eigrp 1 20
!
interface Serial0/0/0.21 point-to-point
 ip address 172.16.1.17 255.255.255.252
 frame-relay interface-dlci 221
  bandwidth 100
  ip bandwidth-percent eigrp 1 30
```

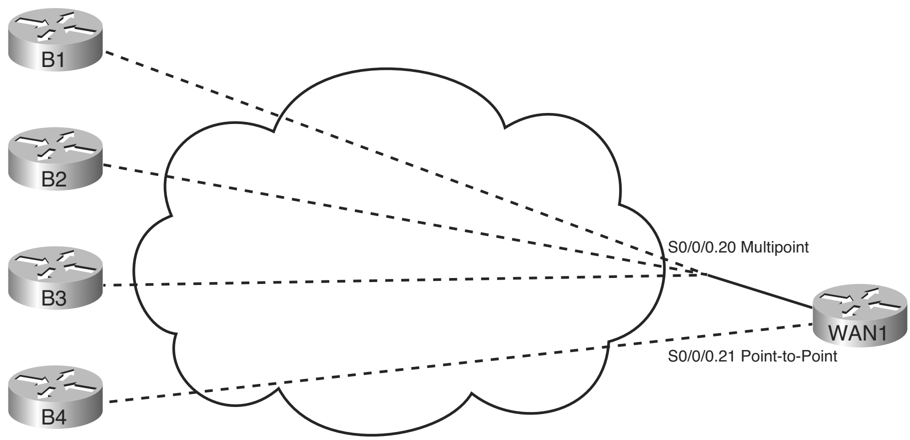

Figure 3-4 *WAN1, One Multipoint, One Point-to-Point*

Building the IP Routing Table

An EIGRP router builds IP routing table entries by processing the data in the topology table. Unlike OSPF, which uses a computationally complex SPF process, EIGRP uses a computationally simple process to determine which, if any, routes to add to the IP routing table for each unique prefix/length. This part of the chapter examines how EIGRP chooses the best route for each prefix/length and then examines several optional tools that can influence the choice of routes to add to the IP routing table.

Calculating the Metrics: Feasible Distance and Reported Distance

The EIGRP topology table entry, for a single prefix/length, lists one or more possible routes. Each possible route lists the various component metric values–bandwidth, delay, and so on. Additionally, for connected subnets, the database entry lists an outgoing interface. For routes not connected to the local router, in addition to an outgoing interface, the database entry also lists the IP address of the EIGRP neighbor that advertised the route.

EIGRP routers calculate an integer metric based on the metric components. Interestingly, an EIGRP router does this calculation both from its own perspective and from the perspective of the next-hop router of the route. The two calculated values are

Key Topic

- **Feasible Distance (FD):** Integer metric for the route, from the local router's perspective, used by the local router to choose the best route for that prefix.
- **Reported Distance (RD):** Integer metric for the route, from the neighboring router's perspective (the neighbor that told the local router about the route). Used by the local router when converging to new routes.

Note: Some texts use the term *Advertised Distance (AD)* instead of Reported Distance (RD) as used in this book. Be ready for either term on the CCNP ROUTE exam. However, this book uses RD exclusively.

Routers use the FD to determine the best route, based on the lowest metric, and use the RD when falling back to an alternative route when the best route fails. (EIGRP's use of the RD is explained in the upcoming section "Successor and Feasible Successor Concepts.") Focusing on the FD, when a router has calculated the integer FD for each possible route to reach a single prefix/length, that router can then consider adding the lowest-metric route to the IP routing table.

As a reminder, the following formula shows how EIGRP calculates the metric, assuming default settings of the EIGRP metric weights (K-values). The metric calculation grows when the slowest bandwidth in the end-to-end route decreases (the slower the bandwidth, the worse the metric), and its metric grows (gets worse) when the cumulative delay grows:

Metric = 256 * ((10^7 / slowest-bandwidth) + cumulative-delay)

An example certainly helps in this case. Figure 3-5 repeats some information about the topology exchange process between Routers B1 and WAN1 (refer to Figure 3-1), essentially showing the metric components as sent by B1 to WAN1 (Step 1) and the metric components from WAN1's perspective (Step 2).

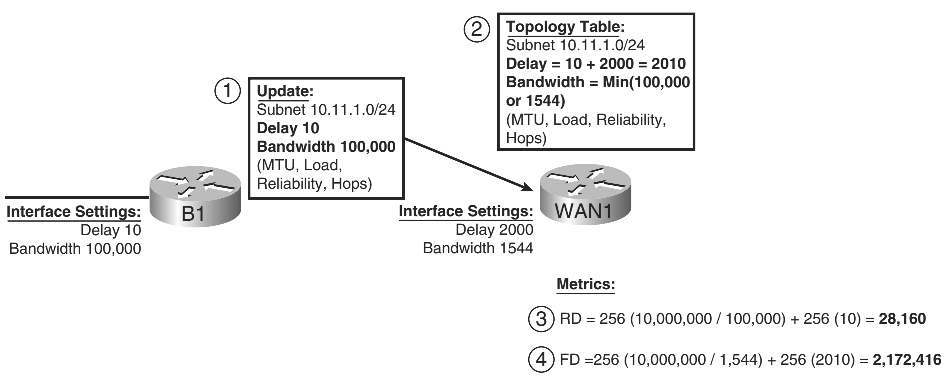

Figure 3-5 *Example Calculation of RD and FD on Router WAN1*

Steps 3 and 4 in Figure 3-5 show WAN1's calculation of the RD and FD for 10.11.1.0/24, respectively. Router WAN1 takes the metric components as received from B1, and plugs them into the formula, to calculate the RD, which is the same integer metric that Router

B1 would have calculated as its FD. Step 4 shows the same formula but with the metric components as listed at Step 2–after the adjustments made on WAN1. Step 4 shows WAN1's FD calculation, which is much larger due to the much lower constraining bandwidth plus the much larger cumulative delay.

WAN1 chooses its best route to reach 10.11.1.0/24 based on the lowest FD among all possible routes. Looking back to the much more detailed Figure 3-1, presumably a couple of other routes might have been possible, but WAN1 happens to choose the route shown in Figure 3-5 as its best route. As a result, WAN1's **show ip route** command lists the FD calculated in Figure 3-5 as the metric for this route, as shown in Example 3-4.

Example 3-4 *Router WAN1's EIGRP Topology and IP Route Information for 10.11.1.0/24*

```
! Below, note that WAN1's EIGRP topology table lists two possible next-hop
! routers: 10.1.1.2 (B1) and 10.9.1.2 (WAN2). The metric for each route,
! the first number in parenthesis, shows that the lower metric route is the one
! through 10.1.1.2 as next-hop. Also note that the metric components
! match Figure 3-5.
!
WAN1#show ip eigrp topo 10.11.1.0/24
IP-EIGRP (AS 1): Topology entry for 10.11.1.0/24
  State is Passive, Query origin flag is 1, 1 Successor(s), FD is 2172416
  Routing Descriptor Blocks:
  10.1.1.2 (Serial0/0/0.1), from 10.1.1.2, Send flag is 0x0
      Composite metric is (2172416/28160), Route is Internal
      Vector metric:
        Minimum bandwidth is 1544 Kbit
        Total delay is 20100 microseconds
        Reliability is 255/255
        Load is 1/255
        Minimum MTU is 1500
        Hop count is 1
  10.9.1.2 (FastEthernet0/0), from 10.9.1.2, Send flag is 0x0
      Composite metric is (2174976/2172416), Route is Internal
      Vector metric:
        Minimum bandwidth is 1544 Kbit
        Total delay is 20200 microseconds
        Reliability is 255/255
        Load is 1/255
        Minimum MTU is 1500
        Hop count is 2
!
! The next command not only lists the IP routing table entry for 10.11.1.0/24,
! it also lists the metric (FD), and components of the metric.
!
WAN1#show ip route 10.11.1.0
Routing entry for 10.11.1.0/24
```

```
    Known via "eigrp 1", distance 90, metric 2172416, type internal
    Redistributing via eigrp 1
    Last update from 10.1.1.2 on Serial0/0/0.1, 00:02:42 ago
    Routing Descriptor Blocks:
    * 10.1.1.2, from 10.1.1.2, 00:02:42 ago, via Serial0/0/0.1
        Route metric is 2172416, traffic share count is 1
        Total delay is 20100 microseconds, minimum bandwidth is 1544 Kbit
        Reliability 255/255, minimum MTU 1500 bytes
        Loading 1/255, Hops 1
!
! Below, the route for 10.11.1.0/24 is again listed, with the metric (FD), and
! the same next-hop and outgoing interface information.
!
WAN1#show ip route eigrp
     10.0.0.0/8 is variably subnetted, 7 subnets, 2 masks
D       10.11.1.0/24 [90/2172416] via 10.1.1.2, 00:10:40, Serial0/0/0.1
D       10.12.1.0/24 [90/2172416] via 10.1.1.6, 00:10:40, Serial0/0/0.2
D       10.1.2.0/30 [90/2172416] via 10.9.1.2, 00:10:40, FastEthernet0/0
D       10.1.2.4/30 [90/2172416] via 10.9.1.2, 00:10:40, FastEthernet0/0
```

EIGRP Metric Tuning

EIGRP metrics can be changed using several methods: setting interface bandwidth, setting interface delay, changing the metric calculation formula by configuring k-values, and even by adding to the calculated metric using offset-lists. In practice, the most reasonable and commonly used methods are to set the interface delay and the interface bandwidth. This section examines all the methods, in part so you will know which useful tools exist, and in part to make you aware of some other design issues that then might impact the routes chosen by EIGRP.

Configuring Bandwidth and Delay

The **bandwidth** and **delay** interface subcommands set the bandwidth and delay associated with the interface. The commands themselves require little thought, other than keeping the units straight. The unit for the **bandwidth** command is Kilobits/second, and the **delay** command uses a unit of tens-of-microseconds.

If a design requires that you influence the choice of route by changing bandwidth or delay, setting the delay value is typically the better choice. IOS uses the bandwidth setting of an interface for many other reasons: calculating interface utilization, as the basis for several QoS parameters, and for SNMP statistics reporting. However, the delay setting has little influence on other IOS features besides EIGRP, so the better choice when influencing EIGRP metrics is to tune the delay.

Table 3-2 lists some of the common default values for both bandwidth and delay. As a reminder, **show** commands list the bandwidth in Kbps, which matches the **bandwidth** command, but lists the delay in microseconds, which does not match the tens-of-microseconds unit of the **delay** command.

Table 3-2 *Common Defaults for Bandwidth and Delay*

Interface Type	Bandwidth (Kbps)	Delay (Microseconds)
Serial	1544	20,000
GigE	1,000,000	10
FastE	100,000	100
Ethernet	10,000	1000

Note that on LAN interfaces that can run at different speeds, the bandwidth and delay settings default based on the current actual speed of the interface.

Choosing Bandwidth Settings on WAN Subinterfaces

Frame Relay and Metro Ethernet installations often use an access link with a particular physical sending rate–clock rate if you will–but with the contracted speed, over time, being more or less than the speed of the link. For example, with Frame Relay, the provider may supply a full T1 access link, so configuring **bandwidth 1544** for such an interface is reasonable. However, the subinterfaces have one or more PVCs associated with them, and those PVCs each have Committed Information Rates (CIR) that are typically less than the access link's clock speed. However, the cumulative CIRs for all PVC often exceeds the clock rate of the physical interface. Conversely, MetroE designs use Ethernet access links of 10 Mbps, 100 Mbps, or 1 Gbps actual link speed, but often the business contract limits the amount of traffic to some number below that link speed.

Choosing a useful interface **bandwidth** setting on the subinterfaces in a Frame Relay or MetroE design requires some thought, with most of the motivations for choosing one number or another being unrelated to EIGRP. For example, imagine the network shown in Figure 3-6. Router WAN1 has a single T1 (1.544 Mbps) access link. That interface has one multipoint subinterface, with three PVCs assigned to it. It also has nine other point-to-point subinterfaces, each with a single PVC assigned.

For the sake of discussion, the design in Figure 3-6 oversubscribes the T1 access link off Router WAN1 by a 2:1 factor. Assume all 12 PVCs have a CIR of 256 Kbps, making the total bandwidth for the 12 PVCs roughly 3 Mbps. The design choice to oversubscribe the access link may be reasonable given the statistical chance of all sites sending at the same time.

Now imagine that Router WAN1 has been configured with subinterfaces as shown in the figure:

- S0/0/0.20 - multipoint, 3 PVCs
- S0/0/0.21 through S0/0/0.29 – point-to-point, 1 PVC each

Next, consider the options for setting the **bandwidth** command's value on these 10 subinterfaces. The point-to-point subinterfaces could be set to match the CIR of each PVC (256 Kbps in this example). You could choose to set the bandwidth based on the CIR of all combined PVCs on the multipoint subinterface–in this case, setting **bandwidth 768** on multipoint subinterface s0/0/0.20. However, these bandwidths would total about 3 Mbps–twice the actual speed of WAN1's access link. Alternatively, you could set the various bandwidths so that the total matches the 1.5 Mbps of the access link. Or you could

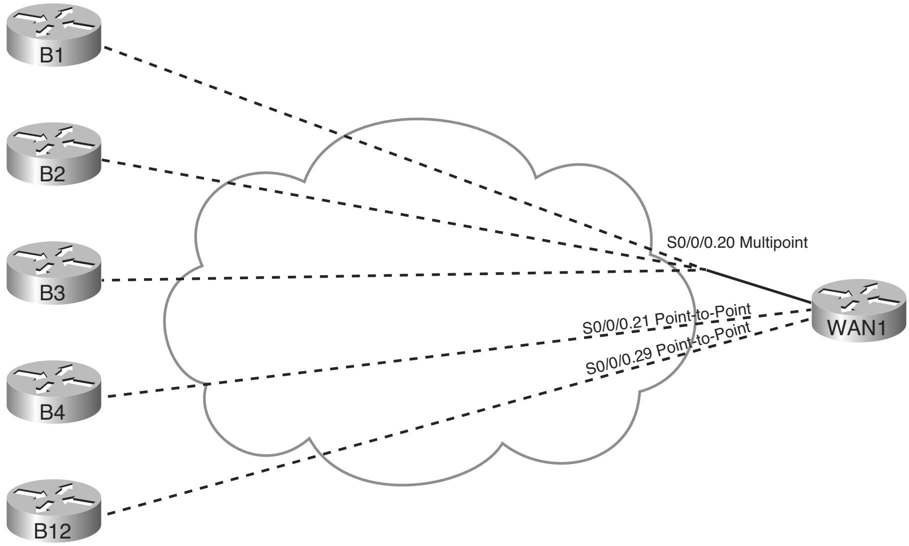

Figure 3-6 *One Multipoint and Nine Point-to-Point Subinterfaces*

split the difference, knowing that during times of low activity to most sites that the sites with active traffic get more than their CIR's worth of capacity anyway.

As mentioned earlier, these bandwidth settings impact much more than EIGRP. The settings impact interface statistics, both in **show** commands and in SNMP reporting. They impact QoS features to some extent as well. Given that the better option for setting EIGRP metrics is to set the interface delay, EIGRP metric tuning may not be the driving force behind the decision as to what bandwidth values to use. However, some installations may change these values over time while trying to find the right compromise numbers for features other than EIGRP. So, you need to be aware that changing those values may result in different EIGRP metrics and impact the choices of best routes.

Similar issues exist on the more modern Layer 2 WAN services like MetroE, particularly with the multipoint design of VPLS. Figure 3-7 shows a design that might exist after migrating the internetwork of Figure 3-6 to VPLS. Router WAN1 has been replaced by a Layer 3 switch, using a Gigabit interface to connect to the VPLS service. The remote sites might use the same routers as before, using a FastEthernet interface, or might be replaced with Layer 3 switch hardware as well.

Concentrating on the mechanics of what happens at the central site, WAN1 might use 802.1Q trunking. With 12 remote sites, WAN1 configures 12 VLAN interfaces, one per VLAN, with a different subnet used for the connection to each remote branch. Such a design, from a Layer 3 perspective, looks like the age-old Frame Relay design with a point-to-point link from the main site to each remote branch.

Additionally, the VPLS business contract might specify that WAN1 cannot send more than 200 Mbps of traffic into the VPLS cloud, with the excess being discarded by the VPLS service. To prevent unnecessary discards, the engineer likely configures a feature called *shaping*, which slows down the traffic leaving the Gi0/1 interface of WAN1 (regardless of VLAN). To meet the goal of 200 Mbps, WAN1 would send only part of the

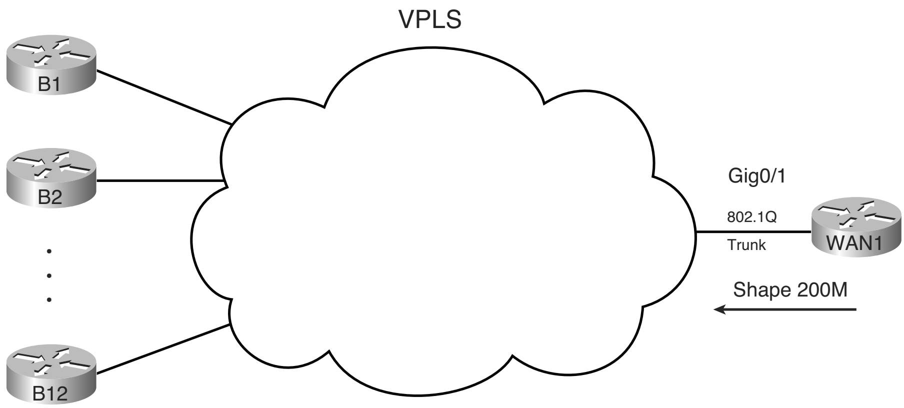

Figure 3-7 *VPLS Service–Issues in Choosing Bandwidth*

time–in this case averaging a sending rate of 1/5th of the time–so that the average rate is 1/5th of 1 Gbps, or 200 Mbps.

Of note with the shaping function, the shaping feature typically limits the cumulative traffic on the interface, not per VLAN (branch). As a result, if the only traffic waiting to be sent by WAN1 happens to be destined for branch B1, WAN1 sends 200 MBps of traffic to just branch B1.

Pulling the discussion back around to EIGRP, as with Frame Relay, other design and implementation needs may drive the decision to set or change the bandwidth on the associated interfaces. In this case, Layer 3 switch WAN1 probably has 12 VLAN interfaces. Each VLAN interface can be set with a bandwidth that influences EIGRP route choices. Should this setting be 1/12th of 1 Gbps, which is the speed at which the bits are actually sent? 1/12th of 200 Mbps, the shaping rate? Or knowing that a site might get most or all of that 200 Mbps for some short period of time, should the bandwidth be set somewhere in between? As with Frame Relay, there is no set answer; for the sake of EIGRP, be aware that changes to the bandwidth settings impact the EIGRP metrics.

Metric Weights (K-values)

Engineers can change the EIGRP metric calculation by configuring the weightings (also called k-values) applied to the EIGRP metric calculation. To configure new values, use the **metric weights** *tos k1 k2 k3 k4 k5* command in EIGRP configuration mode. To configure this command, configure any integer 0–255 inclusive for the five k-values. By default, k1 = k3 = 1, and the others default to 0. The **tos** parameter has only one valid value, 0, and can be otherwise ignored.

The full EIGRP metric formula is as follows. Note that some items reduce to 0 if the corresponding k-values are also set to 0. The listed formula is correct with default K-values. However, if K5 were set to 1 instead of the default of 0 the formula show would be incorrect. The last fraction, K5/(reliability+K4), would then be multiplied by the result from the rest of the formula.

$$256^* \left(K1\left(\frac{10^7}{BW}\right) + \frac{K2\left(\frac{10^7}{BW}\right)}{(256\text{-}Load)} + K3(delay) + \frac{K5}{(Reliability + K4)} \right)$$

EIGRP requires that two routers' k-values match before those routers can become neighbors. Also note that Cisco recommends against using k-values k2, k4, and k5, because a nonzero value for these parameters causes the metric calculation to include interface load and reliability. The load and reliability change over time, which causes EIGRP to reflood topology data, and may cause routers to continually choose different routes (route flapping).

Offset Lists

EIGRP Offset Lists, the final tool for manipulating the EIGRP metrics listed in this chapter, allow an engineer to simply add a value–an offset, if you will-to the calculated integer metric for a given prefix. To do so, an engineer can create and enable an EIGRP Offset List that defines the value to add to the metric, plus some rules regarding which routes should be matched and therefore have the value added to their computed FD.

An Offset List can perform the following functions:

- Match prefixes/prefix lengths using an IP ACL, so that the offset is applied only to routes matched by the ACL with a permit clause
- Match the direction of the Update message, either sent (out) or received (in)
- Match the interface on which the Update is sent or received
- Set the integer metric added to the calculation for both the FD and RD calculations for the route

The configuration itself uses the following command in EIGRP configuration mode, in addition to any referenced IP ACLs:

offset-list {*access-list-number* ¦ *access-list-name*} {**in** ¦ **out**} **offset** [*interface-type interface-number*]

For example, consider again branch office Router B1 in Figure 3-1, with its connection to both WAN1 and WAN2 over a Frame Relay network. Formerly, WAN1 calculated a metric of 2,172,416 for its route, through B1, to subnet 10.11.1.0/24. (Refer to Figure 3-5 for the math behind WAN1's calculation of its route to 10.11.1.0/24.) Router B1 also calculated a value of 28,160 for the RD of that same direct route. Example 3-5 shows the addition of an offset on WAN1, for received updates from Router B1.

Example 3-5 *Inbound Offset of 3 on WAN1, for Updates Received on S0/0/0.1*

```
WAN1(config)#access-list 11 permit 10.11.1.0
WAN1(config)#router eigrp 1
WAN1(config-router)#offset-list 11 in 3 Serial0/0/0.1
WAN1(config-router)#end

Mar  2 11:34:36.667: %DUAL-5-NBRCHANGE: IP-EIGRP(0) 1: Neighbor 10.1.1.2
(Serial0/0/0.1) is resync: peer graceful-restart
WAN1#show ip eigrp topo 10.11.1.0/24
IP-EIGRP (AS 1): Topology entry for 10.11.1.0/24
  State is Passive, Query origin flag is 1, 1 Successor(s), FD is 2172416
```

```
  Routing Descriptor Blocks:
  10.1.1.2 (Serial0/0/0.1), from 10.1.1.2, Send flag is 0x0
      Composite metric is (2172419/28163), Route is Internal
      Vector metric:
        Minimum bandwidth is 1544 Kbit
        Total delay is 20100 microseconds
        Reliability is 255/255
        Load is 1/255
        Minimum MTU is 1500
        Hop count is 1
! output omitted for brevity
```

The configuration has two key elements: ACL 11 and the **offset-list** command. ACL 11 matches prefix 10.11.1.0, and that prefix only, with a permit clause. The **offset-list 11 in 3 s0/0/0.1** command tells Router WAN1 to examine all EIGRP Updates received on S0/0/0.1, and if prefix 10.11.1.0 is found, add 3 to the computed FD and RD for that prefix.

The **show ip eigrp topology 10.11.1.0/24** command in Example 3-5 shows that the FD and RD, highlighted in parentheses, are now each three larger as compared with the earlier metrics.

Next, continuing this same example, Router B1 has now been configured to add an offset (4) in its sent updates to all routers, but for prefix 10.11.1.0/24 only.

Example 3-6 *Outbound Offset of 4 on B1, for Updates Sent to All Neighbors, 10.11.1.0/24*

```
B1(config)#access-list 12 permit 10.11.1.0
B1(config)#router eigrp 1
B1(config-router)#offset-list 12 out 4
B1(config-router)#end
B1#
```

```
! Back to router WAN1
WAN1#show ip eigrp topology
IP-EIGRP Topology Table for AS(1)/ID(10.9.1.1)

Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status
```

```
P 10.11.1.0/24, 1 successors, FD is 2172419
        via 10.1.1.2 (2172423/28167), Serial0/0/0.1
! lines omitted for brevity
```

Note that the metrics, both FD and RD, are now four larger than in Example 3-5.

Optimizing EIGRP Convergence

The previous major section of this chapter focused on how EIGRP calculates metrics and how to change that metric calculation. However, that section discussed only one motivation for changing the metric: to make a router pick one route instead of another. This section, which focuses on optimizing the EIGRP convergence process, discusses another reason for choosing to manipulate the EIGRP metric calculations: faster convergence.

EIGRP converges very quickly, but EIGRP does not achieve the most optimal fast convergence times in all conditions. One design goal might be to tune EIGRP configuration settings so that EIGRP uses the faster convergence methods for as many routes as possible, and when not possible, that EIGRP converge as quickly as it can without introducing routing loops. As a result, routers might converge in some cases in a second instead of tens of seconds (from the point of a router realizing that a route has failed).

For those of you who have not thought about EIGRP convergence before now, you must first get a comfortable understanding of the concept of EIGRP Feasible Successors–the first topic in this section. Following that, the text examines the EIGRP query process. This section ends with EIGRP load balancing, which both allows spreading the load across multiple routes in addition to improving EIGRP convergence.

Fast Convergence to Feasible Successors

Earlier in this chapter, under the heading “Calculating the Metrics: Feasible Distance and Reported Distance,” the text explains how a router, for each possible route, calculates two metric values. One value is the *feasible distance* (FD), which is the metric from that router’s perspective. The other metic is the *reported distance* (RD), which is the integer metric from the perspective of the next-hop router.

EIGRP routers use the RD value when determining if a possible route can be considered to be a loop-free backup route called a *feasible successor*. This section explains the concepts and shows how to confirm the existence or nonexistence of such routes.

Successor and Feasible Successor Concepts

For each prefix/prefix length, when multiple possible routes exist, the router chooses the route with the smallest integer metric (smallest FD). EIGRP defines each such route as the *successor route* for that prefix, and EIGRP defines the next-hop router in such a route as the *successor*. EIGRP then creates an IP route for this prefix, with the successor as the next-hop router, and places that route into the IP routing table.

If more than one possible route exists for a given prefix/prefix length, the router examines these other (non-successor) routes and asks this question: Can any of these routes be used immediately if the currently best route fails, without causing a routing loop? EIGRP runs a simple algorithm to identify which routes could be used without causing a routing loop, and EIGRP keeps these loop-free backup routes in its topology table. Then, if the successor route (the best route) fails, EIGRP then immediately uses the best of these alternate loop-free routes for that prefix.

EIGRP calls these alternative, immediately usable, loop-free routes *feasible* successor routes, because they can feasibly be used as a new successor route when the current successor route fails. The next-hop router of such a route is called the *feasible successor*.

> **Note:** In general conversation, the term *successor* may refer to the route or specifically to the next-hop router. Likewise, the term *feasible successor* may refer to the route, or the next-hop router, of an alternative route.

A router determines if a route is a feasible successor based on the *feasibility condition*, defined as follows:

Key Topic

> If a non-successor route's RD is less than the FD, the route is a feasible successor route.

Although technically correct, the preceding definition is much more understandable with an example as shown in Figure 3-8. The figure illustrates how EIGRP figures out which routes are feasible successors for Subnet 1.

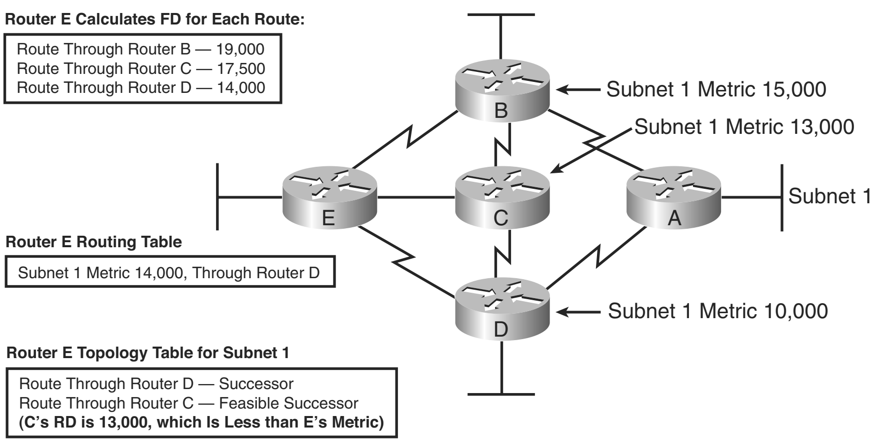

Figure 3-8 *Successors and Feasible Successors with EIGRP*

In Figure 3-8, Router E learns three routes to Subnet 1, from Routers B, C, and D. After calculating each route's metric, Router E finds that the route through Router D has the lowest metric. Router E adds this successor route for Subnet 1 to its routing table, as shown. The FD in this case for this successor route is 14,000.

EIGRP decides if a route can be a feasible successor if the reported distance for that route (the metric as calculated on that neighbor) is less than its own best computed metric (the FD). When that neighbor has a lower metric for its route to the subnet in question, that route is said to have met the *feasibility condition*.

For example, Router E computes a metric (FD) of 14,000 on its successor route (through Router D). Router C's computed metric–E's RD for this alternate router through Router C–is 13,000, which is lower than E's FD (14,000). As a result, E knows that C's best route for this subnet could not possible point toward router E, so Router E believes that its route, to Subnet 1, through Router C, would not cause a loop. As a result, Router E marks its topology table entry for the route through Router C as a feasible successor route.

Conversely, E's RD for the route through Router B, to Subnet 1, is 15,000, which is larger than Router E's FD of 14,000. So, this alternative route does not meet the feasibility condition, so Router E does not consider the route through Router B a feasible successor route.

If the route to Subnet 1 through Router D fails, Router E can immediately put the route through Router C into the routing table without fear of creating a loop. Convergence occurs almost instantly in this case. However, if both C and D fail, E would not have a feasible successor route, and would have to do additional work, as described later in the section "Converging by Going Active," before using the route through Router B.

By tuning EIGRP metrics, an engineer can create feasible successor routes in cases where none existed, improving convergence.

Verification of Feasible Successors

Determining which prefixes have both successor and feasible successor routes is somewhat simple if you keep the following in mind:

Key Topic

- The **show ip eigrp topology** command does not list all known EIGRP routes, but instead lists only successor and feasible successor routes.
- The **show ip eigrp topology all-links** command lists all possible routes, including those that are neither successor nor feasible successor routes.

For example, consider Figure 3-9, which again focuses on Router WAN1's route to Router B1's LAN subnet, 10.11.1.0/24. The configuration on all routers has reverted back to defaults for all settings that impact the metric: default bandwidth and delay, no offset lists, and all interfaces are up.

Figure 3-9 shows the three topologically possible routes to reach 10.11.1.0/24, labeled 1, 2, and 3. Route 1, direct to Router B1, is the current successor. Route 3, which goes to another branch router, back to the main site, and then to Router B1, is probably a route you would not want to use anyway. However, route 2, through WAN2, would be a reasonable back-up route.

If the PVC between WAN1 and B1 failed, WAN1 would converge to route 2 from the figure. However, with all default settings, route 2 is not an FS route, as demonstrated in Example 3-7.

Example 3-7 *Only a Successor Route on WAN1 for 10.11.1.0/24*

```
WAN1#show ip eigrp topology
IP-EIGRP Topology Table for AS(1)/ID(10.9.1.1)
```

```
Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status

P 10.11.1.0/24, 1 successors, FD is 2172416
        via 10.1.1.2 (2172416/28160), Serial0/0/0.1
! lines omitted for brevity; no other lines of output pertain to 10.11.1.0/24.

WAN1#show ip eigrp topology all-links
IP-EIGRP Topology Table for AS(1)/ID(10.9.1.1)

Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status

P 10.11.1.0/24, 1 successors, FD is 2172416, serno 45
        via 10.1.1.2 (2172416/28160), Serial0/0/0.1
        via 10.9.1.2 (2174976/2172416), FastEthernet0/0
! lines omitted for brevity; no other lines of output pertain to 10.11.1.0/24.
```

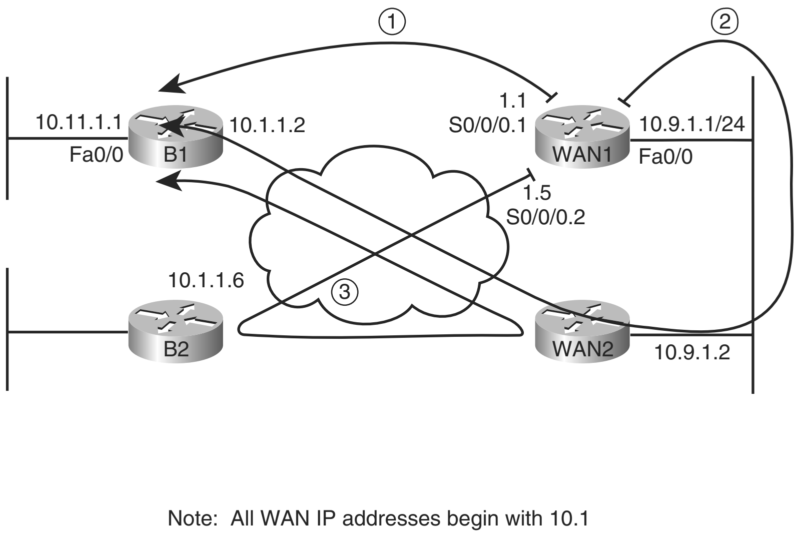

Figure 3-9 *Three Possible Routes from WAN1 to 10.11.1.0/24*

A quick comparison of the two commands show that the **show ip eigrp topology** command shows only one next-hop address (10.1.1.2), whereas the **show ip eigrp topology all-links** command shows two (10.1.1.2 and 10.9.1.2). The first command lists only successor and feasible successor routes, so in this case, only one such route for 10.11.1.0/24 exists—the successor route, direct to B1 (10.1.1.2).

The output of the **show ip eigrp topology all-links** command is particularly interesting in this case. It lists two possible next-hop routers: 10.1.1.2 (B1) and 10.9.1.2 (WAN2). It does not list the route through Router B2 (10.1.1.6) at all, because B2's current successor route for 10.11.1.0/24 is through WAN1. EIGRP Split Horizon rules tell B2 to not advertise 10.11.1.0/24 to WAN1.

Next, focus on the route labeled as option 2 in Figure 3-9, the route from WAN1, to WAN2, then to B1. Per the **show ip eigrp topology all-links** command, this route has an RD of 2,172,416–the second number in parenthesis as highlighted toward the end of Example 3-7. WAN1's successor route has a FD of that exact same value. So, this one possible alternate route for 10.11.1.0/24, through WAN2, does not meet the feasibility condition–but just barely. To be an FS route, the route's RD must be less than the FD, and in this example, the two are equal.

To meet the design requirement for quickest convergence, you could use any method to manipulate the metrics such that either WAN2's metric for 10.11.1.0 is lower, or WAN1's metric for its successor route is higher. Example 3-8 shows the results of simply adding back the offset-list on WAN1, as seen in Example 3-5, which increases WAN1's metric by 3.

Example 3-8 *Increasing WAN1's Metric for 10.11.1.0/24, Creating an FS Route*

```
WAN1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
WAN1(config)#access-list 11 permit 10.11.1.0
WAN1(config)#router eigrp 1
WAN1(config-router)#offset-list 11 in 3 s0/0/0.1
WAN1(config-router)#^Z
WAN1#show ip eigrp topology
IP-EIGRP Topology Table for AS(1)/ID(10.9.1.1)

Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status

P 10.11.1.0/24, 1 successors, FD is 2172419
        via 10.1.1.2 (2172419/28163), Serial0/0/0.1
        via 10.9.1.2 (2174976/2172416), FastEthernet0/0
! lines omitted for brevity; no other lines of output pertain to 10.11.1.0/24.
```

Note that now WAN1's successor route FD is 2,172,419, which is higher than WAN2's (10.9.1.2's) RD of 2,172,416. As a result, WAN1's route through WAN2 (10.9.1.2) now meets the feasibility condition. Also, the **show ip eigrp topology** command, which lists only successor and feasible successor routes, now lists this new feasible successor route. Also note that the output still states "1 successor," so this counter indeed counts successor routes and does not include FS routes.

When EIGRP on a router notices that a successor route has been lost, if a feasible successor exists in the EIGRP topology database, EIGRP places that feasible successor route into the routing table. The elapsed time from noticing that the route failed, until the route is replaced, is typically less than 1 second. (A Cisco Live conference presentation asserts this convergence approaches 200 milliseconds.) With well-tuned EIGRP Hold Timers and with feasible successor routes, convergence time can be held low.

Converging by Going Active

When EIGRP removes a successor route and no FS route exists, the router begins a process by which the router discovers if any loop-free alternative routes each reach that prefix. This process is called *going active* on a route. Routes for which the router has a successor route, and no failure has yet occurred, remain in a passive state. Routes for which the successor route fails, with no feasible successor routes, move to an active state, as follows:

Key Topic

- Change the state, as listed in the **show ip eigrp topology** command, from passive (p) to active (a).
- Send EIGRP *Query* messages to every neighbor except the neighbor in the failed route. The Query asks a neighbor whether that neighbor has a loop-free route for the listed prefix/length.
- The neighbor considers itself to have a loop-free route if that neighbor is passive for that prefix/length. If so, the neighbor 1) sends an EIGRP Reply message, telling the original router that it does indeed have a loop-free route and 2) does not forward the Query.
- If the neighbor itself is active on this route, that neighbor 1) floods EIGRP Query messages to its neighbors and 2) does not immediately send an EIGRP Reply back to the original router–instead waiting on replies to its own set of Query messages.
- When a router has received Reply messages from all neighbors to which it sent any Query messages, that router can then send a Reply message to any of its neighbors as necessary.
- When a router has received a Reply for all its Query messages, that router may safely use the best of the routes confirmed to be loop free.

Note: The EIGRP convergence process when going active on a route is sometimes also referenced by the name of the underlying algorithm, named Diffusing Update Algorithm (DUAL).

The process can and does work well in many cases, often converging to a new route in less than 10 seconds. However, in internetworks with many remote sites, with much redundancy, and with a large number of routers in a single end-to-end route, convergence when going active can be inefficient. For example, consider the internetwork in Figure 3-10. The figure shows five branch routers as an example, but the internetwork has 300 branch routers, each with a PVC connected to two WAN routers, WAN1 and WAN2. When Router WAN1 loses its route for the LAN subnet at branch B1, without an FS route, the Query process can get out of hand.

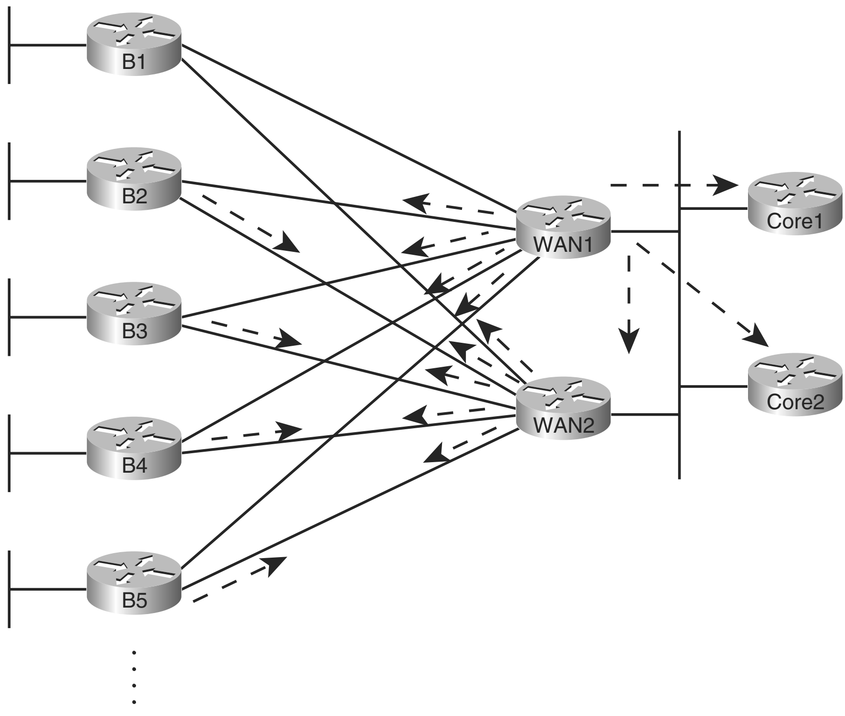

Figure 3-10 *Issues with Query Scope*

The arrowed lines show WAN1's Query messages and the reaction by several other routers to forward the Query messages. Although only 5 branch routers are shown, WAN1 would forward Query messages to 299 branch routers. WAN2 would do the same, assuming its route to B1's LAN also failed. These branch routers would then send Query messages back to the WAN routers. The network would converge, but more slowly than if an FS route existed.

Note: EIGRP sends every Query and Reply message using RTP, so every message is acknowledged using an EIGRP ACK message.

By configuring EIGRP so that a router has FS routes for most routes, the whole Query process can be avoided. However, in some cases, creating FS routes for all routes on all routers is impossible, so engineers should take action to limit the scope of queries. The next two sections discuss two tools—stub routers and route summarization—that help reduce the work performed by the DUAL algorithm and the scope of Query messages.

The Impact of Stub Routers on Query Scope

Some routers, by design, should not be responsible for forwarding traffic between different sites. For example, consider the familiar internetwork shown throughout this chapter, most recently in Figure 3-10, and focus on the branch routers. If WAN2's LAN interface failed, and WAN1's PVC to B1 failed, then a route still exists from the core to branch B1's 10.11.1.0/24 subnet: WAN1–B2–WAN2–B1. (This is the same long route shown as route 3 in Figure 3-9.) However, this long route consumes the link bandwidth between the core and branch B2, and the traffic to/from B1 will be slower. Users at both branches will suffer, and these conditions may well be worse than just not using this long route.

Route filtering could be used to prevent WAN1 from learning such a route. However, using route filtering would require a lot of configuration on all the branch routers, with specifics for the subnets–and it would have to change over time. A better solution exists, which is to make the branch routers stub routers. EIGRP defines *stub routers* as follows:

> A router that should not forward traffic between two remote EIGRP-learned subnets.

Key Topic

To accomplish this goal, the engineer configures the stub routers using the **eigrp stub** command. Stub routers do not advertise EIGRP-learned routes from one neighbor to other EIGRP neighbors. Additionally, and possibly more significantly, nonstub routers note which EIGRP neighbors are stub routers, and the nonstub routers do not send Query messages to the stub routers. This action greatly reduces the scope of Query messages when a route goes active, in addition to preventing the long, circuitous, and possibly harmful route.

The **eigrp stub** command has several options. When issued simply as **eigrp stub**, the router uses default parameters, which are the **connected** and **summary** options. (Note that IOS adds these two parameters onto the command as added to the running-config.) Table 3-3 lists the **eigrp stub** command options and explains some of the logic behind using them.

Table 3-3 *Parameters on the eigrp stub Command*

Key Topic

Option	This router is allowed to...
Connected	Advertise connected routes but only for interfaces matched with a **network** command.
Summary	Advertise auto-summarized or statically configured summary routes.
Static	Advertises static routes, assuming the **redistribute static** command is configured.
Redistributed	Advertises redistributed routes, assuming redistribution is configured.
Receive-only	Does not advertise any routes. This option cannot be used with any other option.

Note that stub routers still form neighborships, even in receive-only mode. The stub router simply performs less work and reduces the Query Scope because neighbors will not send these routers any Query messages.

For example, Example 3-9 shows the **eigrp stub connected** command on Router B2, with the results being noticable on WAN1 (**show ip eigrp neighbors detail**).

Example 3-9 *Evidence of Router B2 as an EIGRP Stub Router*

```
B2#configure terminal
B2(config)#router eigrp 1
B2(config-router)#eigrp stub connected
B2(config-router)#
Mar  2 21:21:52.361: %DUAL-5-NBRCHANGE: IP-EIGRP(0) 1: Neighbor 10.9.1.14
(FastEthernet0/0.12) is down: peer info changed
! A message like the above occurs for each neighbor.
```

```
WAN1#show ip eigrp neighbors detail
IP-EIGRP neighbors for process 1
H   Address                 Interface       Hold Uptime   SRTT   RTO  Q  Seq
                                            (sec)         (ms)       Cnt Num
1   10.9.1.2                Fa0/0             11 00:00:04    7   200  0  588
   Version 12.4/1.2, Retrans: 0, Retries: 0, Prefixes: 8
2   10.1.1.6                Se0/0/0.2         13 00:21:23    1   200  0  408
   Version 12.4/1.2, Retrans: 2, Retries: 0, Prefixes: 2
   Stub Peer Advertising ( CONNECTED ) Routes
   Suppressing queries
0   10.9.1.6                Fa0/0.4           12 00:21:28    1   200  0  175
   Version 12.2/1.2, Retrans: 3, Retries: 0, Prefixes: 6
```

The Impact of Summary Routes on Query Scope

In addition to EIGRP stub routers, route summarization also limits EIGRP Query scope and therefore improves convergence time. The reduction in Query scope occurs due to the following rule:

Key Topic

If a router receives an EIGRP Query for a prefix/prefix length, does not have an exactly matching (both prefix and prefix length) route, but does have a summary route that includes the prefix/prefix length, that router immediately sends an EIGRP Reply and does not flood the Query to its own neighbors.

For example, consider Figure 3-11. Multilayer Switches C1 and C2 sit in the core of the network shown in various other figures in this chapter, and both C1 and C2 run EIGRP. The IP subnetting design assigns all branch office LAN subnets from the range 10.11.0.0/16 and 10.12.0.0/16. As such, Routers WAN1 and WAN2 advertise summary routes for these ranges, rather than for individual subnets. So, under normal operation, ignoring the whole Query scope issue, C1 and C2 would never have routes for individual branch subnets like 10.11.1.0/24 but would have routes for 10.11.0.0/16 and 10.12.0.0/16.

The figure highlights three steps:

Step 1. WAN1 and WAN2 advertise summary routes, so that C1, C2, and all other routers in the core have a route for 10.11.0.0/16 but not a route for 10.11.1.0/24.

Step 2. Some time in the future, WAN1 loses its route for 10.11.1.0/24, so WAN1 sends a Query for 10.11.1.0/24 to C1 and C2.

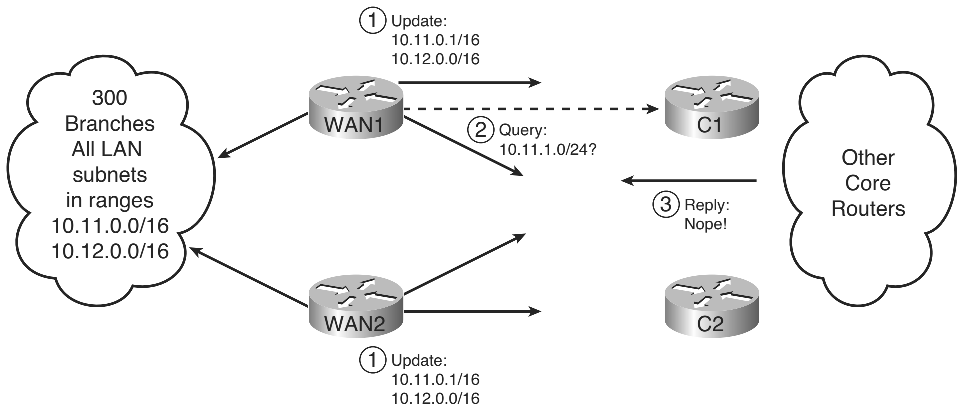

Figure 3-11 *Route Summaries Limiting Query Scope*

Step 3. C1 and C2 send an EIGRP Reply immediately afterward, because both do not have a route for that specific prefix/length (10.11.1.0/24), but both do have a summary route (10.11.0.0/16) that includes that range of addresses.

Chapter 4, "EIGRP Route Summarization and Filtering," explains the configuration of EIGRP route summarization as an end to itself.

Stuck in Active

When a router notices a route failure and moves a route from passive to active state, that router sends Query messages to its neighbors. With a sufficiently large network, particularly when routers exist several router hops away, the number of Queries may not only be large, but there also may be a string of routers that all must wait on multiple Reply messages before they can, in turn, issue a Reply. For example, in Figure 3-12, Router R1 must wait on routers R11, R12, and R13 to send a Reply. R11 must wait on routers R21, R22, and R23. R21 must wait on three other routers, and so on–meaning that R1 may have to wait quite a while before getting a response.

Although the design shown in Figure 3-12 is admittedly contrived, the point is that a router may wait awhile before getting a Reply message in response to each Query message for an Active route. A router cannot use any alternative paths for that route until all such Reply messages have been received.

To deal with this potentially long time, IOS first sets a limit on how long it should take to receive all such replies. That timer, called the *active timer*, is set to 3 minutes by default. (The timer can be configured for an entire EIGRP process using the **timers active-time** *time* EIGRP subcommand, with a units of a number of minutes.) Routes for which a router does not receive a Reply within the active timer are considered to be Stuck-in-Active (SIA) routes.

IOS has two major branches of logic when reacting to SIA routes. Earlier versions of IOS took a rather drastic action, bringing down the uncooperative neighbors that had yet to send back an EIGRP Reply for that route. For example, in Figure 3-12, if R1 received Reply messages from R11 and R12, but not R13, and the active timer expired, R1 would bring

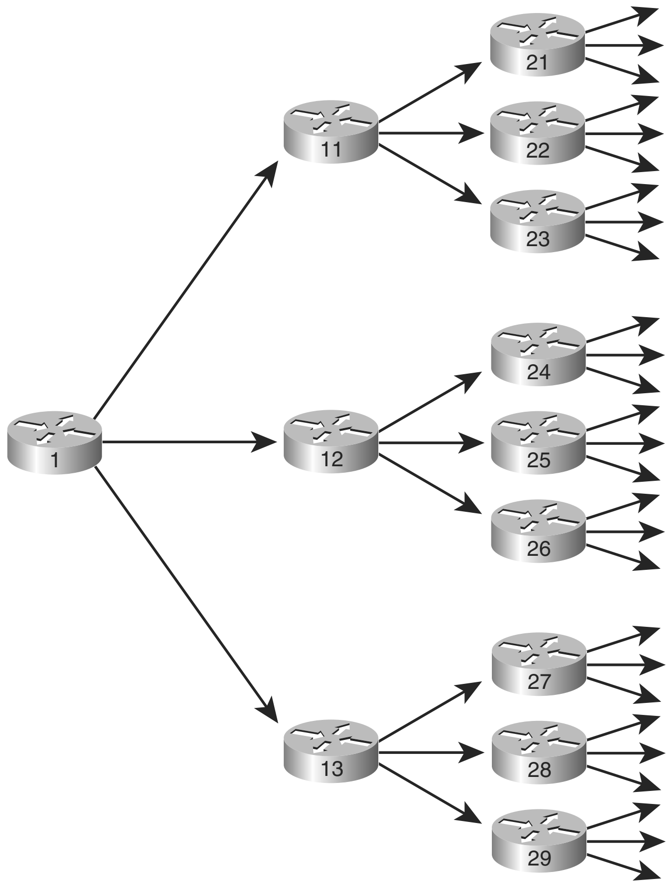

Figure 3-12 *Network Design That Causes Unreasonably Long Convergence*

down the neighborship with R13. The active route would be considered to have failed, and all routes known through the failed neighbor would also be considered to have failed–possibly generating more Query messages for other routes.

Later IOS versions (beginning in the 12.2 mainline) make an attempt to avoid failing the neighborship. At the halfway point through the Active timer–a seemingly long 90 seconds by default–a router sends an SIA-Query (Stuck-in-Active query) EIGRP message to each neighbor that has yet to send back a Reply. The purpose of the message is to either get an SIA-Reply back, meaning that the neighbor really is still waiting for replies to its own queries, or to get nothing in reply. In the first case, because the neighbor is alive and still working, there is no need to kill the neighborship. In the second case, the neighbor was not able to reply, so the action of failing the neighborship is reasonable.

Unequal Metric Route Load Sharing

Convergence to a feasible successor route should happen within a second after a router realizes the successor route has failed. Even in large well-designed networks, particularly with features like stub routers and route summarization in use, convergence can still happen in a reasonable amount of time even when going active. The next feature, load sharing, takes convergence to another level, giving instantaneous convergence, while reaching other goals as well.

IOS allows routing protocols to place multiple routes into the routing table for an individual prefix/length. IOS then balances traffic across those routes, by default balancing traffic on a per-destination IP address basis.

Load balancing, sometimes called load sharing, provides a primary benefit of making use of the available bandwidth, rather than using some links as simply backup links. For example, with the two-PVC designs repeatedly shown in this chapter (Figures 3-1, 3-9, and 3-10), without load sharing, a branch router would send traffic over one PVC, but not both. With load sharing, some traffic would flow over each PVC.

A useful secondary benefit–faster convergence–occurs when using load balancing. By placing multiple routes into the routing table for a single prefix, convergence happens essentially instantly. For example, if a branch router has two routes for each data center subnet—one using each PVC that connects the branch to the core—and one of the routes fails, the other route is already in the routing table. In this case, the router does not need to look for FS routes nor go active on the route. The router uses the usual EIGRP convergence tools only when all such routes are removed from the routing table.

The load balancing configuration requires two commands, one of which already defaults to a reasonable setting. First, you need to define the number of allowed routes for each prefix/prefix length using the **maximum-paths** *number* EIGRP subcommand. The default setting of 4 is often big enough, because most internetworks do not have enough redundancy to have more than four possible routes.

Note: The maximum number of paths varies based on IOS version and router platform. However, for the much older IOS versions, the maximum was 6 routes, with later versions typically supporting 16 or more.

The second part of the load balancing configuration overcomes a challenge introduced by EIGRP's metric calculation. The EIGRP integer metric calculation often results in 8-to-10-digit integer metrics, so the metrics of competing routes are seldom the exact same value. Calculating the exact same metric for different routes for the same prefix is statistically unlikely.

IOS includes the concept of EIGRP *variance* to overcome this problem. Variance lets you tell IOS that the EIGRP metrics can be close in value and still be considered worthy of being added to the routing table—and you can define how close.

The **variance** *multiplier* EIGRP router subcommand defines an integer between 1 and 128. The router then multiplies the variance times the successor route's FD–the metric of the best route to reach that subnet. Any FS routes whose metric is less than or equal to the product of the variance times the FD are considered to be equal routes and may be placed into the routing table, up to the number of routes defined by the **maximum-paths** command.

For example, consider the example as shown in Figure 3-13 and Table 3-4. In this example, to keep the focus on the concepts, the metrics are small easy-to-compare numbers, rather than the usual large EIGRP metrics. The example focuses on R4's three possible routes to reach Subnet 1. The figure shows the RD of each route next to Routers R1, R2, and R3, respectively.

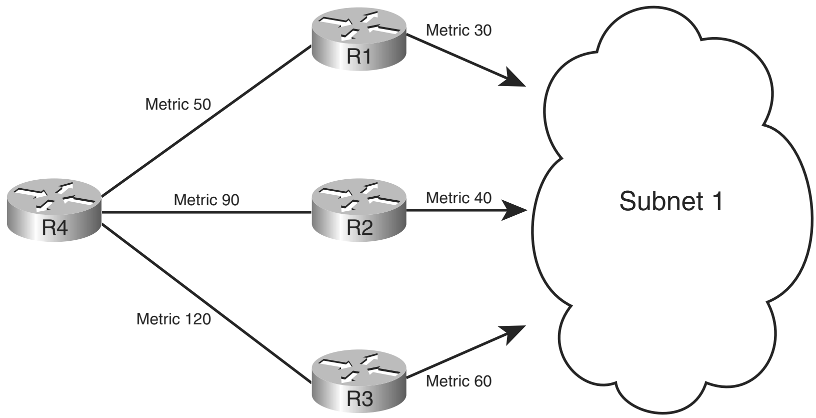

Figure 3-13 *Example of the Use of Variance*

Before considering the variance, note that in this case the route through R1 is the successor route because it has the lowest metric. This also means that the FD is 50. The route through R2 is an FS route because its RD of 40 is less than the FD of 50. The route through R3 is not an FS route, because R3's RD of 60 is more than the FD of 50.

At a default variance setting of 1, the metrics must be exactly equal to be considered equal, so only the successor route is added to the routing table (the route through R1). With variance 2, the FD (50) is multiplied by the variance (2) for a product of 100. The route through R2, with FD 90, is less than 100, so R4 will add the route through R2 to the routing table as well. The router can then load balance traffic across these two routes. Table 3-4 summarizes these cases, plus one other, which is described after the table.

Table 3-4 *Example of Routes Chosen as Equal Due to Variance*

Next-hop	Metric	RD	Added to Routing Table at Variance 1?	Added to Routing Table at Variance 2?	Added to Routing Table at Variance 3?
R1	50	30	Yes	Yes	Yes
R2	90	40	No	Yes	Yes
R3	120	60	No	No	No

In the third case, with variance 3, the product of the FD (50) times 3 results equals 150. All three routes' calculated metrics (their FD values) are less than 150. However, the route through R3 is not an FS route, so it cannot be added to the routing table for fear of causing a routing loop. So, R4 adds only the routes through R1 and R2 to its IP routing table. (Note that the variance and maximum-paths settings can be verified by using the **show ip protocols** command.)

The following list summarizes the key points about variance:

Key Topic

- The variance is multiplied by the current FD (the metric of the best route to reach the subnet).
- Any FS routes whose calculated metric is less than or equal to the product of variance times FD are added to the IP routing table, assuming the **maximum-paths** setting allows more routes.
- Routes that are neither successor nor feasible successor can never be added to the IP routing table, regardless of the variance setting.

When the routes have been added to the routing table, the router supports a couple of methods for how to load balance traffic across the routes. The router can balance the traffic proportionally with the metrics, meaning that lower metric routes send more packets. Also, the router can send all traffic over the lowest-metric route, with the other routes just being in the routing table for faster convergence in case the best route fails.

Exam Preparation Tasks

Planning Practice

The CCNP ROUTE exam expects test takers to review design documents, create implementation plans, and create verification plans. This section provides exercises that may help you to take a step back from the minute details of the topics in this chapter so that you can think about the same technical topics from the planning perspective.

For each planning practice table, simply complete the table. Note that any numbers in parentheses represent the number of options listed for each item in the solutions in Appendix F, "Completed Planning Practice Tables."

Design Review Table

Table 3-5 lists several design goals related to this chapter. If these design goals were listed in a design document, and you had to take that document and develop an implementation plan, what implementation options come to mind? For any configuration items, a general description can be used, without concern about the specific parameters.

Table 3-5 *Design Review*

Design Goal	Possible Implementation Choices Covered in This Chapter
Limit consumption of IP subnets in Frame Relay WAN design.	
In a relatively slow Frame Relay WAN, protect against consuming too much bandwidth with overhead EIGRP traffic.	
Plan to change bandwidth from 1X CIR to 2X CIR on all Frame Relay subinterfaces.	
Plan to set bandwidth to values other than actual interface speeds to manipulate EIGRP metrics.	
A goal of ensuring all remote routers' secondary EIGRP routes does not require Queries for convergence.	
What tools can we use to meet the design goal of fast convergence? (four items)	

Implementation Plan Peer Review Table

Table 3-6 shows a list of questions that others might ask, or that you might think about, during a peer review of another network engineer's implementation plan. Complete the table by answering the questions.

Table 3-6 *Notable Questions from This Chapter to Consider During an Implementation Plan Peer Review*

Question	Answer
A Frame Relay multipoint interface, with 20 PVCs attached, has a configuration for 10% of the bandwidth to be used for EIGRP. How much is allocated per PVC?	
Could any planned topologies have EIGRP Split Horizon issues?	
A configuration lists the **no ip split-horizon** command—when would that matter?	
The plan calls for setting all EIGRP K-values to 1. What negative effect could this have on routes in the IP routing table?	
The configuration uses offset lists. Will that impact the calculation of FD and/or RD?	
The plan lists a sample configuration migrating an interface from **delay 20** to **delay 200**. How much will the metric go up?	
The plan shows the use of the **variance 4** command. What must be configured to add other routes to a routing table? (two items)	

Create an Implementation Plan Table

To practice skills useful when creating your own EIGRP implementation plan, list in Table 3-7 configuration commands related to the configuration of the following features. You may want to record your answers outside the book and set a goal to complete this table (and others like it) from memory during your final reviews before taking the exam.

Table 3-7 *Implementation Plan Configuration Memory Drill*

Feature	Configuration Commands/Notes
Enabling EIGRP on interfaces	
Enabling or disabling Split Horizon for EIGRP	
Setting the Bandwidth consumed by EIGRP on an interface	
Setting an interface's logical bandwidth	
Setting an interface's logical delay	
K-values	
Configuring an EIGRP offset list that matches a prefix	
Configuring an EIGRP offset list that matches a prefix and prefix length	
Configuring unequal cost load balancing	
Configure an EIGRP stub router	

Choose Commands for a Verification Plan Table

To practice skills useful when creating your own EIGRP verification plan, list in Table 3-8 all commands that supply the requested information. You may want to record your answers outside the book, and set a goal to complete this table (and others like it) from memory during your final reviews before taking the exam.

Key Topic

Table 3-8 *Verification Plan Memory Drill*

Information Needed	Command
The composite metric values for all EIGRP prefixes.	
Display EIGRP Split Horizon settings.	
Calculate the maximum bandwidth EIGRP will consume on a physical or point-to-point subinterface.	
Calculate the maximum bandwidth EIGRP will consume per PVC on a multipoint Frame Relay subinterface.	
Display the increase in RD after implementing an EIGRP offset list.	
Display interface bandwidth and delay settings.	
Lists EIGRP K-values.	
Find the number of successor and feasible successor routes.	
Find all routes, including non-successors.	
Determine if the local router is a stub router.	
Determine if a neighboring router is a stub router.	
Find the current setting of variance and maximum-paths.	
Display messages each time EIGRP suppresses a prefix advertisement due to Split Horizon.	

Key Topic

Review all the Key Topics

Review the most important topics from the chapter, noted with the key topics icon in the outer margin of the page. Table 3-9 lists a reference of these key topics and the page numbers on which each is found.

Table 3-9 *Key Topics for Chapter 3*

Key Topic Element	Description	Page Number
List	Three sources for seeding a local router's EIGRP topology table	60
List	EIGRP message types (5)	61
List	Rules for EIGRP topology exchange	64
Definitions	Feasible Distance, Reported Distance	70
Definition	Feasibility Condition	79
Figure 3-8	Conceptual view of successors and feasible successors	79
List	Two commands to find all EIGRP routes versus all successor/feasible successor routes	80
List	EIGRP process of finding routes when going active	83
Definition	EIGRP stub router	85
Table 3-3	List of options on the **eigrp stub** command	85
Definition	Rule by which summary routes reduce Query scope	86
List	Rules for unequal-cost multipath	91

Complete the Tables and Lists from Memory

Print a copy of Appendix D, "Memory Tables," (found on the CD) or at least the section for this chapter, and complete the tables and lists from memory. Appendix E, "Memory Tables Answer Key," also on the CD, includes completed tables and lists to check your work.

Define Key Terms

Define the following key terms from this chapter, and check your answers in the glossary.

feasibility condition, feasible distance, feasible successor, full update, partial update, reported distance, advertised distance, successor, Split Horizon, bandwidth, delay, K-value, offset list, going active, DUAL, Query scope, EIGRP stub router, unequal-cost load balancing, variance

This chapter covers the following subjects:

Route Filtering: This section examines how to filter prefixes from being sent in EIGRP Updates or filter them from being processed when received in an EIGRP Update.

Route Summarization: This section discusses the concepts and configuration of EIGRP route summarization.

Default Routes: This section examines the benefits of using default routes, and the mechanics of two methods for configuring default routes with EIGRP.

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