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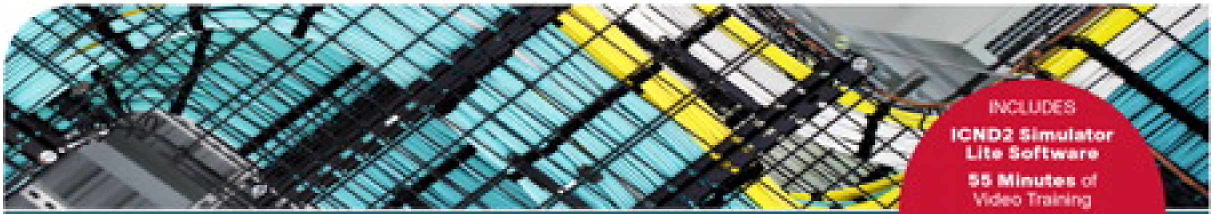

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Official Cert Guide

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Wendell Odom with contributing author Scott Hogg

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Dedications

For Kris Odom, my wonderful wife: The best part of everything we do together in life. Love you, doll.

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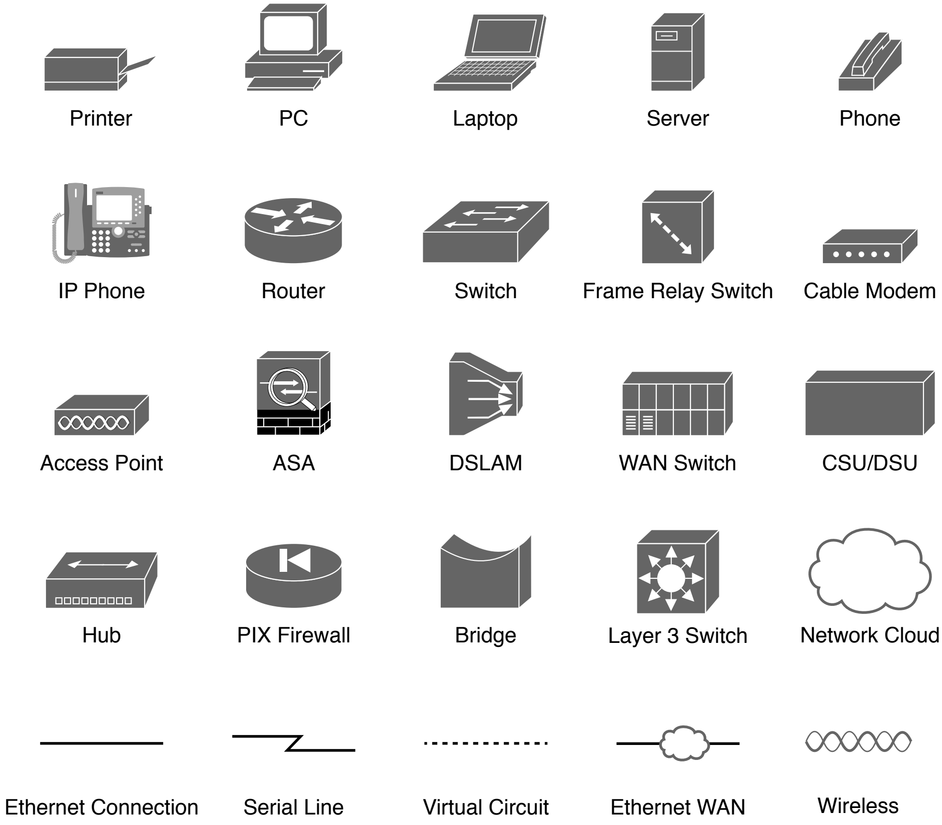


Command Syntax Conventions

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.

Introduction

About the Exams

Congratulations! If you're reading far enough to look at this book's Introduction, you've probably already decided to go for your Cisco certification. If you want to succeed as a technical person in the networking industry at all, you need to know Cisco. Cisco has a ridiculously high market share in the router and switch marketplace, with more than 80 percent market share in some markets. In many geographies and markets around the world, networking equals Cisco. If you want to be taken seriously as a network engineer, Cisco certification makes perfect sense.

The Exams to Achieve CCENT and CCNA R&S

Cisco announced changes to the CCENT and CCNA Routing and Switching certifications, and the related 100-105 ICND1, 200-105 ICND2, and 200-125 CCNA exams, early in the year 2016. Most everyone new to Cisco certifications begins with either CCENT or CCNA Routing and Switching (CCNA R&S). However, the paths to certification are not quite obvious at first.

The CCENT certification requires a single step: pass the ICND1 exam. Simple enough.

Cisco gives you two options to achieve CCNA R&S certification, as shown in Figure I-1: pass both the ICND1 and ICND2 exams, or just pass the CCNA exam. Both paths cover the same exam topics, but the two-exam path does so spread over two exams rather than one. You also pick up the CCENT certification by going through the two-exam path, but you do not when working through the single-exam (200-125) option.

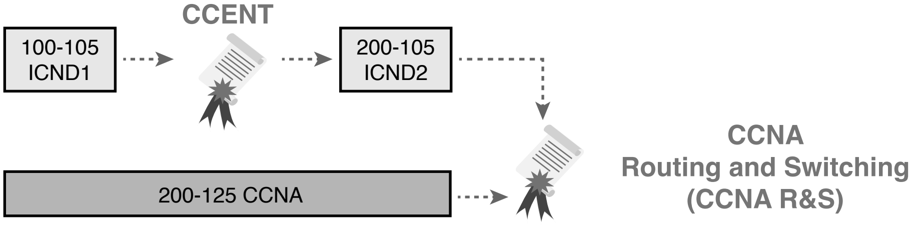


Figure I-1 *Cisco Entry-Level Certifications and Exams*

Note that Cisco has begun referencing some exams with a version number on some of their websites. If that form holds true, the exams in Figure I-1 will likely be called version 3 (or v3 for short). Historically, the 200-125 CCNA R&S exam is the seventh separate version of the exam (which warrants a different exam number), dating back to 1998. To make sure you reference the correct exam, when looking for information, using forums, and registering for the test, just make sure to use the correct exam number as shown in the figure.

Types of Questions on the Exams

The ICND1, ICND2, and CCNA R&S exams all follow the same general format. At the testing center, you sit in a quiet room with a PC. Before the exam timer begins, you have a chance to do a few other tasks on the PC; for instance, you can take a sample quiz just to get accustomed to the PC and the testing engine. Anyone who has user-level skills in getting around a PC should have no problems with the testing environment. The question types are

- Multiple-choice, single-answer
- Multiple-choice, multiple-answer
- Testlet (one scenario with several multiple-choice questions)
- Drag-and-drop
- Simulated lab (sim)
- Simlet

You should take the time to learn as much as possible by using the Cisco Certification Exam Tutorial, which you can find by going to Cisco.com and searching for "exam tutorial." This tool walks through each type of question Cisco may ask on the exam.

Although the first four types of questions in the list should be familiar to anyone who has taken standardized tests or similar tests in school, the last two types are more common to IT tests and Cisco exams in particular. Both use a network simulator to ask questions, so that you control and use simulated Cisco devices. In particular:

- **Sim questions:** You see a network topology, a lab scenario, and can access the devices. Your job is to fix a problem with the configuration.
- **Simlet questions:** This style combines sim and testlet question formats. Like a sim question, you see a network topology, a lab scenario, and can access the devices. However, like a testlet, you also see several multiple-choice questions. Instead of changing/fixing the configuration, you answer questions about the current state of the network.

Using these two question styles with the simulator enables Cisco to test your configuration skills with sim questions, and your verification and troubleshooting skills with simlet questions.

What's on the CCNA Exams...and in the Book?

Ever since I was in grade school, whenever the teacher announced that we were having a test soon, someone would always ask, "What's on the test?" Even in college, people would try to get more information about what would be on the exams. At heart, the goal is to know what to study hard, what to study a little, and what to not study at all.

You can find out more about what's on the exam from two primary sources: this book and the Cisco website.

The Cisco Published Exam Topics

First, Cisco tells the world the specific topics on each of their certification exams. For every Cisco certification exam, Cisco wants the public to know both the variety of topics and what kinds of knowledge and skills are required for each topic. Just go to http://www.cisco.com/go/certifications, look for the CCENT and CCNA Routing and Switching pages, and navigate until you see the exam topics.

Note that this book lists those same exam topics in Appendix L, "Exam Topic Cross Reference." This PDF appendix lists two cross references: one with a list of the exam topics in the order in which Cisco lists them on their website; and the other with a list of chapters in this book with the corresponding exam topics included in each chapter.

Cisco does more than just list the topic (for example, IPv4 addressing); they also list the depth to which you must master the topic. The primary exam topics each list one or more verbs that describe the skill level required. For example, consider the following exam topic, which describes one of the most important topics in both CCENT and CCNA R&S:

> Configure, verify, and troubleshoot IPv4 addressing and subnetting

Note that this one exam topic has three verbs (configure, verify, and troubleshoot). So, you should be able to not only configure IPv4 addresses and subnets, but also understand them well enough to verify that the configuration works, and to troubleshoot problems when it is not working. And if to do that you need to understand concepts and need to have other knowledge, those details are implied. The exam questions will attempt to assess whether you can configure, verify, and troubleshoot.

The Cisco exam topics provide the definitive list of topics and skill levels required by Cisco for the exams. But the list of exam topics provides only a certain level of depth. For example, the ICND1 100-105 exam topics list has 41 primary exam topics (topics with verbs), plus additional subtopics that provide more details about that technology area. Although very useful, the list of exam topics would take about five pages of this book if laid out in a list.

You should take the time to not only read the exam topics, but read the short material above the exam topics as listed at the Cisco web page for each certification and exam. Look for notices about the use of unscored items, and how Cisco intends the exam topics to be a set of general guidelines for the exams.

This Book: About the Exam Topics

This book provides a complete study system for the Cisco published exam topics for the ICND2 200-105 exam. All the topics in this book either directly relate to some ICND2 exam topic or provide more basic background knowledge for some exam topic. The scope of the book is defined by the exam topics.

For those of you thinking more specifically about the CCNA R&S certification, and the CCNA 200-125 single-exam path to CCNA, this book covers about one-half of the CCNA exam topics. The *CCENT/CCNA ICND1 100-105 Official Cert Guide* (and ICND1 100-105 exam topics) covers about half of the topics listed for the CCNA 200-125 exam, and this book (and the ICND2 200-105 exam topics) covers the other half. In short, for content, CCNA = ICND1 + ICND2.

Book Features

This book (and the related *CCENT/CCNA ICND1 100-105 Official Cert Guide*) goes beyond what you would find in a simple technology book. It gives you a study system designed to help you not only learn facts but also to develop the skills you need to pass the exams. To do that, in the technology chapters of the book, about three-quarters of the chapter is about the technology, and about one-quarter is for the related study features.

The "Foundation Topics" section of each chapter contains rich content to explain the topics on the exam and to show many examples. This section makes extensive use of figures, with lists and tables for comparisons. It also highlights the most important topics in each chapter as key topics, so you know what to master first in your study.

Most of the book's features tie in some way to the need to study beyond simply reading the "Foundation Topics" section of each chapter. The rest of this section explains these book features. And because the book organizes your study by chapter, and then by part (a part contains multiple chapters), and then a final review at the end of the book, the next section of this Introduction discusses the book features introduced by chapter, part, and for final review.

Chapter Features and How to Use Each Chapter

Each chapter of this book is a self-contained short course about one topic area, organized for reading and study as follows:

- **"Do I Know This Already?" quiz:** Each chapter begins with a prechapter quiz.
- **Foundation Topics:** This is the heading for the core content section of the chapter.
- **Chapter Review:** This section includes a list of study tasks useful to help you remember concepts, connect ideas, and practice skills-based content in the chapter.

Figure I-2 shows how each chapter uses these three key elements. You start with the "Do I Know This Already?" (DIKTA) quiz. You can use the score to determine whether you already know a lot, or not so much, and determine how to approach reading the Foundation Topics (that is, the technology content in the chapter). When finished with the Foundation Topics, use the Chapter Review tasks to start working on mastering your memory of the facts and skills with configuration, verification, and troubleshooting.

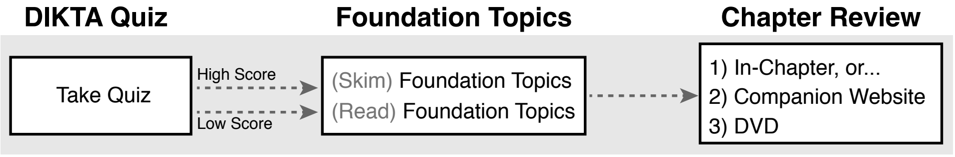


Figure I-2 *Three Primary Tasks for a First Pass Through Each Chapter*

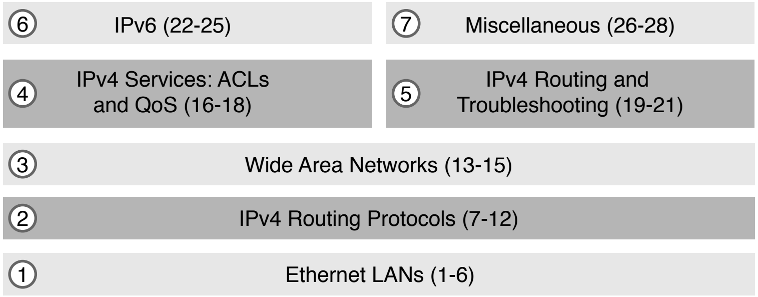
In addition to these three main chapter features, each "Chapter Review" section presents a variety of other book features, including the following:

- **Review Key Topics:** In the "Foundation Topics" section, the Key Topic icon appears next to the most important items, for the purpose of later review and mastery. While all content matters, some is, of course, more important to learn, or needs more review to master, so these items are noted as key topics. The "Review Key Topics" section lists the key topics in a table; scan the chapter for these items to review them.

- **Complete Tables from Memory:** Instead of just rereading an important table of information, some tables have been marked as memory tables. These tables exist in the Memory Table app that is available on the DVD and from the companion website. The app shows the table with some content removed, and then reveals the completed table, so you can work on memorizing the content.
- **Key Terms You Should Know:** You do not need to be able to write a formal definition of all terms from scratch. However, you do need to understand each term well enough to understand exam questions and answers. This section lists the key terminology from the chapter. Make sure you have a good understanding of each term, and use the DVD Glossary to cross-check your own mental definitions.
- **Labs:** Many exam topics use the verbs "configure," "verify," and "troubleshoot"; all these refer to skills you should practice at the command-line interface (CLI) of a router or switch. The Chapter Review refers you to these other tools. The Introduction's section titled "About Building Hands-On Skills" discusses your options.
- **Command References:** Some book chapters cover a large number of router and switch commands. This section includes reference tables for the commands used in that chapter, along with an explanation. Use these tables for reference, but also use them for study—just cover one column of the table, and see how much you can remember and complete mentally.
- **Review DIKTA Questions:** Re-answering the DIKTA questions from the chapter is a useful way to review facts. The Part Review element that comes at the end of each book Part suggests that you repeat the DIKTA questions. The Part Review also suggests using the Pearson IT Certification Practice Test (PCPT) exam software that comes with the book, for extra practice in answering multiple-choice questions on a computer.

Part Features and How to Use Part Review

The book organizes the chapters into seven parts. Each part contains a number of related chapters. Figure I-3 lists the titles of the parts and identifies the chapters in those parts by chapter numbers.


6
IPv6 (22-25)
7
Miscellaneous (26-28)
4
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5
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3
Wide Area Networks (13-15)
2
IPv4 Routing Protocols (7-12)
1
Ethernet LANs (1-6)

Figure I-3 *The Book Parts and Corresponding Chapter Numbers*

Each book part ends with a “Part Review” section that contains a list of activities for study and review, much like the “Chapter Review” section at the end of each chapter. However, because the Part Review takes place after completing a number of chapters, the Part Review includes some tasks meant to help pull the ideas together from this larger body of work. The following list explains the types of tasks added to each Part Review beyond the types mentioned for the Chapter Review:

- **Answer Part Review Questions:** The books come with exam software and databases of questions. One database holds questions written specifically for Part Reviews. These questions tend to connect multiple ideas together, to help you think about topics from multiple chapters, and to build the skills needed for the more challenging analysis questions on the exams.
- **Mind Maps:** Mind maps are graphical organizing tools that many people find useful when learning and processing how concepts fit together. The process of creating mind maps helps you build mental connections. The Part Review elements make use of mind maps in several ways: to connect concepts and the related configuration commands, to connect **show** commands and the related networking concepts, and even to connect terminology. (For more information about mind maps, see the section “About Mind Maps” later in this Introduction.)
- **Labs:** Each “Part Review” section will direct you to the kinds of lab exercises you should do with your chosen lab product, labs that would be more appropriate for this stage of study and review. (Check out the later section “About Building Hands-On Skills” for information about lab options.)

In addition to these tasks, many “Part Review” sections have you perform other tasks with book features mentioned in the “Chapter Review” section: repeating DIKTA quiz questions, reviewing key topics, and doing more lab exercises.

Final Review

Chapter 29, “Final Review,” lists a series of preparation tasks that you can best use for your final preparation before taking the exam. Chapter 29 focuses on a three-part approach to helping you pass: practicing your skills, practicing answering exam questions, and uncovering your weak spots. To that end, Chapter 29 uses the same familiar book features discussed for the Chapter Review and Part Review elements, along with a much larger set of practice questions.

Other Features

In addition to the features in each of the core chapters, this book, as a whole, has additional study resources, including the following:

- **DVD-based practice exams:** The companion DVD contains the powerful Pearson IT Certification Practice Test (PCPT) exam engine. You can take simulated ICND2 exams, as well as CCNA exams, with the DVD and activation code included in this book. (You can take simulated ICND1 and CCNA R&S exams with the DVD in the *CCENT/CCNA ICND1 100-105 Official Cert Guide*.)

- **CCNA ICND2 Simulator Lite:** This lite version of the best-selling CCNA Network Simulator from Pearson provides you with a means, right now, to experience the Cisco CLI. No need to go buy real gear or buy a full simulator to start learning the CLI. Just install it from the DVD in the back of this book.
- **eBook:** If you are interested in obtaining an eBook version of this title, we have included a special offer on a coupon card inserted in the DVD sleeve in the back of the book. This offer allows you to purchase the *CCNA Routing and Switching ICND2 200-105 Official Cert Guide Premium Edition eBook and Practice Test* at a 70 percent discount off the list price. In addition to three versions of the eBook, PDF (for reading on your computer), EPUB (for reading on your tablet, mobile device, or Nook or other eReader), and Mobi (the native Kindle version), you also receive additional practice test questions and enhanced practice test features.
- **Mentoring Videos:** The DVD included with this book includes four other instructional videos about the following topics: OSPF, EIGRP, EIGRP metrics, plus PPP and CHAP.
- **Companion website:** The website http://www.ciscopress.com/title/9781587205798 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.
- **PearsonITCertification.com:** The website http://www.pearsonitcertification.com is a great resource for all things IT-certification related. Check out the great CCNA articles, videos, blogs, and other certification preparation tools from the industry's best authors and trainers.
- **CCNA Simulator:** If you are looking for more hands-on practice, you might want to consider purchasing the CCNA Network Simulator. You can purchase a copy of this software from Pearson at http://pearsonitcertification.com/networksimulator or other retail outlets. To help you with your studies, I have created a mapping guide that maps each of the labs in the simulator to the specific sections in these CCNA cert guides. You can get this mapping guide for free on the Extras tab of the companion website.
- **Author's website and blogs:** I maintain a website that hosts tools and links that are useful when studying for CCENT and CCNA. The site lists information to help you build your own lab, study pages that correspond to each chapter of this book and the ICND1 book, and links to my CCENT Skills blog and CCNA Skills blog. Start at http://www.certskills.com; click the Blog tab for a page about the blogs in particular, with links to the pages with the labs related to this book.

A Big New Feature: Review Applications

One of the single biggest new features of this edition of the book is the addition of study apps for many of the Chapter Review activities. In the past, all Chapter Review activities used only the book chapter, or the chapter plus a DVD-only appendix. Readers tell us they find that content useful, but the content is static.

This book and the *CCENT/CCNA ICND1 100-105 Official Cert Guide* are the first Cisco Press Cert Guides with extensive interactive applications. Basically, most every activity that can be done in the "Chapter Review" sections can now be done with an application. The apps can be found both on the DVD that comes with the book and on the book's companion website. On the DVD you can find the apps under the "Chapter and Part Review" tab.

The advantages of using these apps are as follows:

- **Easier to use:** Instead of having to print out copies of the appendixes and do the work on paper, these new apps provide you with an easy-to-use, interactive experience that you can easily run over and over.
- **Convenient:** When you have a spare 5–10 minutes, go to the book's website, and review content from one of your recently finished chapters.
- **Untethered from book/DVD:** Because these apps are available on the book's companion website in addition to the DVD, you can access your review activities from anywhere—no need to have the book or DVD with you.
- **Good for tactile learners:** Sometimes looking at a static page after reading a chapter lets your mind wander. Tactile learners may do better by at least typing answers into an app, or clicking inside an app to navigate, to help keep you focused on the activity.

Our in-depth reader surveys show that readers who use the Chapter Review tools like them, but that not everyone uses them consistently. So, we want to increase the number of people using the review tools, and make them both more useful and more interesting. Table I-1 summarizes these new applications and the traditional book features that cover the same content.

Table I-1 Book Features with Both Traditional and App Options

Feature	Traditional	App
Key Topics	Table with list; flip pages to find	Key Topics Table app
Config Checklist	Just one of many types of key topics	Config Checklist app
Memory Table	Two static PDF appendixes (one with sparse tables for you to complete, one with completed tables)	Memory Table app
Key Terms	Listed in each "Chapter Review" section, with the Glossary in the back of the book	Glossary Flash Cards app
IPv4 ACL Practice	A static PDF appendix (D) with practice problems	An interactive app that asks the same problems as listed in the appendix

How to Get the Electronic Elements of This Book

Traditionally, all chapter review activities use the book chapter plus appendixes, with the appendixes often being located on the DVD. But most of that content is static—useful, but static.

If you buy the print book, and have a DVD drive, you have all the content on the DVD. Just spin the DVD and use the disk menu (which should automatically start) to explore all the content.

If you buy the print book but do not have a DVD drive, you can get the DVD files by registering your book on the Cisco Press website. To do so, simply go to http://www.ciscopress.com/register and enter the ISBN of the print book: 9781587205798. After you have registered your book, go to your account page and click the **Registered Products** tab. From there, click the **Access Bonus Content** link to get access to the book's companion website.

If you buy the *CCNA Routing and Switching ICND2 200-105 Official Cert Guide Premium Edition eBook and Practice Test* from Cisco Press, your book will automatically be registered on your account page. Simply go to your account page, click the **Registered Products** tab, and select **Access Bonus Content** to access the book's companion website.

If you buy the eBook from some other bookseller, the very last page of your eBook file will contain instructions for how to register the book and access the companion website. The steps are the same as noted earlier for those who buy the print book but do not have a DVD drive.

Book Organization, Chapters, and Appendixes

This book contains 28 core chapters, Chapters 1 through 28, with Chapter 29 as the "Final Review" chapter. Each core chapter covers a subset of the topics on the ICND2 exam. The core chapters are organized into sections. The core chapters cover the following topics:

Part I: Ethernet LANs

- **Chapter 1, "Implementing Ethernet Virtual LANs,"** explains the concepts and configuration surrounding virtual LANs, including VLAN trunking.
- **Chapter 2, "Spanning Tree Protocol Concepts,"** discusses the concepts behind IEEE Spanning Tree Protocol (STP) and how it makes some switch interfaces block frames to prevent frames from looping continuously around a redundant switched LAN.
- **Chapter 3, "Spanning Tree Protocol Implementation,"** shows how to configure and verify STP on Cisco switches.
- **Chapter 4, "LAN Troubleshooting,"** examines the most common LAN switching issues and how to discover those issues when troubleshooting a network. The chapter includes troubleshooting topics for STP/RSTP, Layer 2 EtherChannel, LAN switching, VLANs, and VLAN trunking.
- **Chapter 5, "VLAN Trunking Protocol,"** shows how to configure, verify, and troubleshoot the use of VLAN Trunking Protocol (VTP) to define and advertise VLANs across multiple Cisco switches.
- **Chapter 6, "Miscellaneous LAN Topics,"** as the last chapter in the book specifically about LANs, discusses a variety of small topics, including: 802.1x, AAA authentication, DHCP snooping, switch stacking, and chassis aggregation.

Part II: IPv4 Routing Protocols

- **Chapter 7, "Understanding OSPF Concepts,"** introduces the fundamental operation of the Open Shortest Path First (OSPF) protocol, focusing on link state fundamentals, neighbor relationships, flooding link state data, and calculating routes based on the lowest cost metric.

- **Chapter 8, "Implementing OSPF for IPv4,"** takes the concepts discussed in the previous chapter and shows how to configure and verify those same features.
- **Chapter 9, "Understanding EIGRP Concepts,"** introduces the fundamental operation of the Enhanced Interior Gateway Routing Protocol (EIGRP) for IPv4 (EIGRPv4), focusing on EIGRP neighbor relationships, how EIGRP calculates metrics, and how it quickly converges to alternate feasible successor routes.
- **Chapter 10, "Implementing EIGRP for IPv4,"** takes the concepts discussed in the previous chapter and shows how to configure and verify those same features.
- **Chapter 11, "Troubleshooting IPv4 Routing Protocols,"** walks through the most common problems with IPv4 routing protocols, while alternating between OSPF examples and EIGRP examples.
- **Chapter 12, "Implementing External BGP,"** examines the basics of the Border Gateway Protocol (BGP) and its use between an enterprise and an ISP, showing how to configure, verify, and troubleshoot BGP in limited designs.

Part III: Wide Area Networks

- **Chapter 13, "Implementing Point-to-Point WANs,"** explains the core concepts of how to build a leased-line WAN and the basics of the two common data link protocols on these links: HDLC and PPP.
- **Chapter 14, "Private WANs with Ethernet and MPLS,"** explores the concepts behind building a WAN service using Ethernet through different Metro Ethernet services, as well as using Multiprotocol Label Switching (MPLS) VPNs.
- **Chapter 15, "Private WANs with Internet VPNs,"** works through a variety of conceptual material, plus some configuration and verification topics, for several technologies related to using the Internet to create a private WAN connection between different enterprise sites.

Part IV: IPv4 Services: ACLs and QoS

- **Chapter 16, "Basic IPv4 Access Control Lists,"** examines how standard IP ACLs can filter packets based on the source IP address so that a router will not forward the packet.
- **Chapter 17, "Advanced IPv4 Access Control Lists,"** examines both named and numbered ACLs, and both standard and extended IP ACLs.
- **Chapter 18, "Quality of Service (QoS),"** discusses a wide variety of concepts all related to the broad topic of QoS.

Part V: IPv4 Routing and Troubleshooting

- **Chapter 19, "IPv4 Routing in the LAN,"** shows to a configuration and troubleshooting depth different methods to route between VLANs, including Router on a Stick (ROAS), Layer 3 switching with SVIs, Layer 3 switching with routed ports, and using Layer 3 EtherChannels.
- **Chapter 20, "Implementing HSRP for First-Hop Routing,"** discusses the need for a First Hop Redundancy Protocol (FHRP), and specifically how to configure, verify, and troubleshoot Hot Standby Router Protocol (HSRP)

- **Chapter 21, "Troubleshooting IPv4 Routing,"** looks at the most common IPv4 problems and how to find the root causes of those problems when troubleshooting.

Part VI: IPv6

- **Chapter 22, "IPv6 Routing Operation and Troubleshooting,"** reviews IPv6 routing as discussed in the ICND1 book. It then shows some of the most common problems with IPv6 routing and discusses how to troubleshoot these problems to discover the root cause.
- **Chapter 23, "Implementing OSPF for IPv6,"** explores OSPFv3 and its use as an IPv6 routing protocol, showing traditional configuration, verification, and troubleshooting topics.
- **Chapter 24, "Implementing EIGRP for IPv6,"** takes the EIGRP concepts discussed for IPv4 in Chapter 9 and shows how those same concepts apply to EIGRP for IPv6. It then shows how to configure, verify, and troubleshoot EIGRP for IPv6.
- **Chapter 25, "IPv6 Access Control Lists,"** examines the similarities and differences between IPv4 ACLs and IPv6 ACLs, then shows how to configure, verify, and troubleshoot IPv6 ACLs.

Part VII: Miscellaneous

- **Chapter 26, "Network Management,"** discusses several network management topics that Cisco did not choose to put into ICND1, namely: SNMP, IP SLA, and SPAN.
- **Chapter 27, "Cloud Computing,"** is one of two chapters about topics that strays from traditional CCNA R&S topics as one of the Cisco emerging technology topics. This chapter explains the basic concepts and then generally discusses the impact that cloud computing has on a typical enterprise network.
- **Chapter 28, "SDN and Network Programmability,"** is the other chapter that moves away from traditional CCNA R&S topics to discuss many concepts and terms related to how Software Defined Networking (SDN) and network programmability are impacting typical enterprise networks.

Part VIII: Final Prep

- **Chapter 29, "Final Review,"** suggests a plan for final preparation once you have finished the core parts of the book, in particular explaining the many study options available in the book.

Part IX: Appendixes (In Print)

- **Appendix A, "Numeric Reference Tables,"** lists several tables of numeric information, including a binary-to-decimal conversion table and a list of powers of 2.
- **Appendix B, "CCNA ICND2 200-105 Exam Updates,"** is a place for the author to add book content mid-edition. Always check online for the latest PDF version of this appendix; the appendix lists download instructions.
- The **Glossary** contains definitions for all of the terms listed in the "Key Terms You Should Know" sections at the conclusion of Chapters 1 through 28.

Part X: DVD Appendixes

The following appendixes are available in digital format on the DVD that accompanies this book:

- **Appendix C, "Answers to the 'Do I Know This Already?' Quizzes,"** includes the explanations to all the questions from Chapters 1 through 28.
- **Appendix D, "Practice for Chapter 16: Basic IPv4 Access Control Lists,"** is a copy of the *CCENT/CCNA ICND1 100-105 Official Cert Guide*'s Appendix I.
- **Appendix E, "Mind Map Solutions,"** shows an image of sample answers for all the part-ending mind map exercises.
- **Appendix F, "Study Planner,"** is a spreadsheet with major study milestones, where you can track your progress through your study.
- **Appendix G, "Learning IPv4 Routes with RIPv2,"** explains how routers work together to find all the best routes to each subnet using a routing protocol. This chapter also shows how to configure the RIPv2 routing protocol for use with IPv4. (This appendix is a copy of ICND1's Chapter 19, and is included with the ICND2 book for convenience.)
- **Appendix H, "Understanding Frame Relay Concepts,"** explains how to build a Frame Relay WAN between routers, focusing on the protocols and concepts rather than the configuration. (This chapter is a chapter that covers old exam topics from the previous edition of the book, included here for those who might be interested.)
- **Appendix I, "Implementing Frame Relay,"** takes the concepts discussed in Appendix H and shows how to configure, verify, and troubleshoot those same features. (This chapter is a chapter that covers old exam topics from the previous edition of the book, included here for those who might be interested.)
- **Appendix J, "IPv4 Troubleshooting Tools,"** focuses on how to use two key troubleshooting tools to find routing problems: the **ping** and **traceroute** commands. (This appendix is a copy of ICND1's Chapter 23, and is included with the ICND2 book for convenience.)
- **Appendix K, "Topics from Previous Editions,"** is a collection of information about topics that have appeared on previous versions of the CCNA exams. While you most likely will not encounter exam questions on these topics, the concepts are still of interest to someone with the CCENT or CCNA certification.
- **Appendix L, "Exam Topic Cross Reference,"** provides some tables to help you find where each exam objective is covered in the book.

ICND1 Chapters in this Book

For this current edition of the ICND1 and ICND2 Cert Guides, I designed several chapters to be used in both books. These chapters include some topics that are listed in the exam topics of both exams:

- Chapter 1, "Implementing Ethernet Virtual LANs" (Chapter 11 in the ICND1 100-101 book).
- Chapter 16, "Basic IPv4 Access Control Lists" (Chapter 25 in the ICND1 100-101 book).

- Chapter 17, "Advanced IPv4 Access Control Lists" (Chapter 26 in the ICND1 100-101 book).
- Chapter 21, "Troubleshooting IPv4 Routing" (Chapter 24 in the ICND1 100-101 book).

I designed these four chapters for use in both books to be a help to those reading both books while avoiding any problems for those who might be reading only this ICND2 Cert Guide. Cisco has traditionally had some topics that overlap between the two exams that make up the two-exam path to CCNA R&S, and this current pair of exams is no exception. So, for those of you who have already read the ICND1 100-101 book, you can move more quickly through the above four chapters in this book. If you did not read the ICND1 100-101 book, then you have all the material you need right here in this book.

Extra Content Found in DVD Appendixes

Note that several appendixes on the DVD, namely G, H, I, J, and K, contain extra content outside the ICND2 200-105 exam topics. This short section explains why.

First, two appendixes are here to aid the transition when Cisco announced the exams. Appendixes G (about RIP) and J (about **ping** and **traceroute**) are copies of two chapters in the ICND1 100-105 book, and are part of the exam topics for the ICND1 100-105 exam. These two chapters might be particularly useful for anyone who was far along in their studies on the date when Cisco announced the ICND1 100-105 and ICND2 200-105 exams in 2016. I included Appendixes G and J to aid that transition for those who buy the ICND2 200-105 Cert Guide but not the ICND1 100-105 Cert Guide.

Three other appendixes are included for instructors who use these books for classes, as well as for the occasional reader who is mostly interested in the technology instead of the certification. Appendixes H, I, and K contain content that is no longer mentioned by the exam topics for the current exams. Appendixes H and I are copies of complete chapters about Frame Relay from the prior edition of this book, and Appendix K is a compilation of small topics I removed from the prior edition of this book when creating this current edition. This material might be helpful to some instructors during the transition time for their courses, or for those who want to read more broadly just for the sake of learning.

You do not need to use these extra appendixes (G through K) to prepare for the ICND2 200-105 exam or the CCNA R&S 200-125 exam, but feel free to use them if you are interested.

Reference Information

This short section contains a few topics available for reference elsewhere in the book. You may read these when you first use the book, but you may also skip these topics and refer back to them later. In particular, make sure to note the final page of this introduction, which lists several contact details, including how to get in touch with Cisco Press.

Install the Pearson IT Certification Practice Test Engine and Questions

This book, like many other Cisco Press books, includes the rights to use the Pearson IT Certification Practice Test (PCPT) software, along with rights to use some exam questions related to this book. PCPT has many options, including the option to answer questions in study mode, so you can see the answers and explanations for each question as you go along; the option to take a simulated exam that mimics real exam conditions; and the option to view questions in flash card mode, where all the answers are stripped out, challenging you to answer questions from memory.

You should install PCPT so it is ready to use even for the earliest chapters. This book's Part Review sections ask you specifically to use PCPT, and you can even take the DIKTA chapter quizzes using PCPT.

NOTE The right to use the exams associated with this book is based on an activation code. For those with a paper book, the code is in the DVD sleeve at the back of the book. (Flip over the paper with the exam activation code to find a one-time-use coupon code for 70 percent off the purchase of the *CCNA Routing and Switching ICND2 200-105 Official Cert Guide, Premium Edition eBook and Practice Test*.) For those who purchase the Premium Edition eBook and Practice Test directly from the Cisco Press website, the activation code will be populated on your account page after purchase. For those who purchase a Kindle edition, the access code will be supplied directly from Amazon. Note that if you purchase an eBook version from any other source, the practice test is not included, as other vendors are not able to vend the required unique access code. *Do not lose the activation code.*

PCPT Exam Databases with This Book

This book includes an activation code that allows you to load a set of practice questions. The questions come in different exams or exam databases. When you install the PCPT software and type in the activation code, the PCPT software downloads the latest version of all these exam databases. And with the ICND2 book alone, you get six different "exams," or six different sets of questions, as listed in Figure I-4.

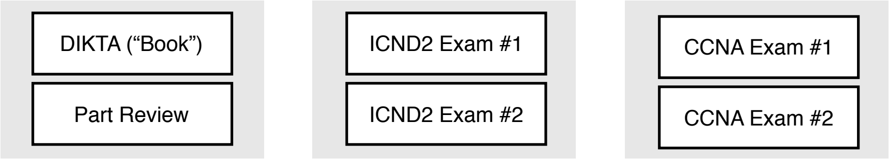


Figure I-4 *PCPT Exams/Exam Databases and When to Use Them*

You can choose to use any of these exam databases at any time, both in study mode and practice exam mode. However, many people find it best to save some of the exams until exam review time, after you have finished reading the entire book. Figure I-4 begins to suggest a plan, spelled out here:

- During Part Review, use PCPT to review the DIKTA questions for that part, using study mode.
- During Part Review, use the questions built specifically for Part Review (the Part Review questions) for that part of the book, using study mode.
- Save the remaining exams to use with the "Final Review" chapter at the end of the book; if preparing for the ICND2 exam, use those practice exams, but if preparing for the CCNA exam, use those exams.

The two modes inside PCPT give you better options for study versus practicing a timed exam event. In study mode, you can see the answers immediately, so you can study the topics more easily. Also, you can choose a subset of the questions in an exam database; for instance, you can view questions from only the chapters in one part of the book.

PCPT practice mode lets you practice an exam event somewhat like the actual exam. It gives you a preset number of questions, from all chapters, with a timed event. Practice exam mode also gives you a score for that timed event.

How to View Only DIKTA Questions by Chapter or Part

Most chapters begin with a DIKTA quiz. You can take the quiz to start a chapter, take it again during Chapter Review for more practice, and, as suggested in the "Part Review" sections, repeat the questions for all chapters in the same part.

You can use the DIKTA quiz as printed in the book, or use the PCPT software. The book lists the questions, with the letter answers on the page following the quiz. Appendix C, on the DVD, lists the answers along with an explanation; you might want to keep that PDF handy.

Using PCPT for these questions has some advantages. It gives you a little more practice in how to read questions from testing software. Also, the explanations to the questions are conveniently located in the PCPT software.

To view these DIKTA questions inside the PCPT software, you need to select **Book Questions**, which is the way PCPT references questions found inside the printed book. Then you have to deselect all chapters (with a single click), and then select one or more chapters, as follows:

Step 1. Start the PCPT software.

Step 2. From the main (home) menu, select the item for this product, with a name like *CCNA Routing and Switching ICND2 200-105 Official Cert Guide*, and click **Open Exam**.

Step 3. The top of the next window that appears should list some exams; check the **ICND2 Book Questions** box, and uncheck the other boxes. This selects the "book" questions (that is, the DIKTA questions from the beginning of each chapter).

Step 4. On this same window, click at the bottom of the screen to deselect all objectives (chapters). Then select the box beside each chapter in the part of the book you are reviewing.

Step 5. Select any other options on the right side of the window.

Step 6. Click **Start** to start reviewing the questions.

How to View Part Review Questions

The exam databases you get with this book include a database of questions created solely for study during the Part Review process. DIKTA questions focus more on facts, to help you determine whether you know the facts contained within the chapter. The Part Review questions instead focus more on application of those facts to typical real scenarios, and look more like real exam questions.

To view these questions, follow the same process as you did with DIKTA/book questions, but select the Part Review database rather than the book database. PCPT has a clear name for this database: Part Review Questions.

About Mind Maps

Mind maps are a type of visual organization tool that you can use for many purposes. For instance, you can use mind maps as an alternative way to take notes.

You can also use mind maps to improve how your brain organizes concepts. Mind maps improve your brain's connections and relationships between ideas. When you spend time thinking about an area of study, and organize your ideas into a mind map, you strengthen existing mental connections and create new connections, all into your own frame of reference.

In short, mind maps help you internalize what you learn.

Each mind map begins with a blank piece of paper or blank window in a mind mapping application. You then add a large central idea, with branches that move out in any direction. The branches contain smaller concepts, ideas, commands, pictures…whatever idea needs to be represented. Any concepts that can be grouped should be put near each other. As need be, you can create deeper and deeper branches, although for this book's purposes, most mind maps will not go beyond a couple of levels.

NOTE Many books have been written about mind maps, but Tony Buzan often gets credit for formalizing and popularizing mind maps. You can learn more about mind maps at his website, http://www.tonybuzan.com.

For example, Figure I-5 shows a sample mind map that begins to output some of the IPv6 content from Part VIII of the ICND1 book. You might create this kind of mind map when reviewing IPv6 addressing concepts, starting with the big topic of "IPv6 addressing," and then writing down random terms and ideas. As you start to organize them mentally, you draw lines connecting the ideas, reorganize them, and eventually reach the point where you believe the organization of ideas makes sense to you.

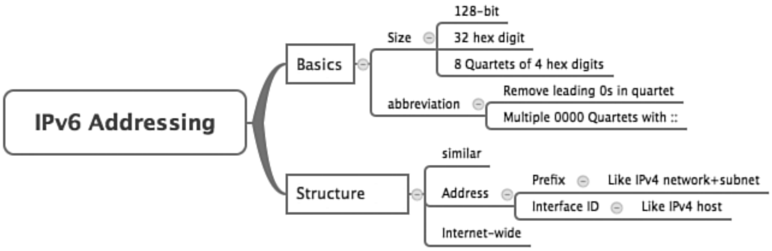


Figure I-5 *Sample Mind Map*

Mind maps may be the least popular but most effective study tool suggested in this book. I personally find a huge improvement in learning new areas of study when I mind map; I hope you will make the effort to try these tools and see if they work well for you too.

Finally, for mind mapping tools, you can just draw them on a blank piece of paper, or find and download a mind map application. I have used Mind Node Pro on a Mac, and we build the sample mind maps with XMIND, which has free versions for Windows, Linux, and OS X.

About Building Hands-On Skills

You need skills in using Cisco routers and switches, specifically the Cisco CLI. The Cisco CLI is a text-based command-and-response user interface; you type a command, and the device (a router or switch) displays messages in response. To answer sim and simlet questions on the exams, you need to know a lot of commands, and you need to be able to navigate to the right place in the CLI to use those commands.

This section walks through the options included in the book, with a brief description of lab options outside the book.

Config Lab Exercises

Some router and switch features require multiple configuration commands. Part of the skill you need to acquire is the ability to remember which configuration commands work together, which ones are required, and which ones are optional. So, the challenge level goes beyond just picking the right parameters on one command. You have to choose which commands to use, in which combination, typically on multiple devices. And getting good at that kind of task requires practice.

The Config Labs feature, introduced as a new feature in this edition of the book, helps provide that practice. Each lab presents a sample lab topology, with some requirements, and you have to decide what to configure on each device. The answer then shows a sample configuration. You job is to create the configuration, and then check your answer versus the supplied answer.

Also for the first time, this edition places the content not only outside the book but also on the author's blog site. To reach my blog sites for ICND1 content or for ICND2 content (two different blogs) and access the Config Labs feature, you can start at my blog launch site (blog.certskills.com) and click from there.

blog.certskills.com/ccent/ Wendell's CCENT (ICND1): In the menus, navigate to **Hands On > Config Lab**

blog.certskills.com/ccna/ Wendell's CCNA (ICND2): In the menus, navigate to **Hands On > Config Lab**

Both blogs are geared toward helping you pass the exams, so feel free to look around. Note that the Config Lab posts should show an image like this in the summary:

Figure I-6 *Config Lab Logo in the Author's Blogs*

These Config Labs have several benefits, including the following:

- **Untethered and responsive:** Do them from anywhere, from any web browser, from your phone or tablet, untethered from the book or DVD.
- **Designed for idle moments:** Each lab is designed as a 5- to 10-minute exercise if all you are doing is typing in a text editor or writing your answer on paper.
- **Two outcomes, both good:** Practice getting better and faster with basic configuration, or if you get lost, you have discovered a topic that you can now go back and reread to complete your knowledge. Either way, you are a step closer to being ready for the exam!
- **Blog format:** Allows easy adds and changes by me, and easy comments by you.
- **Self-assessment:** As part of final review, you should be able to do all the Config Labs, without help, and with confidence.

Note that the blog organizes these Config Lab posts by book chapter, so you can easily use these at both Chapter Review and Part Review. See the "Your Study Plan" element that follows the Introduction for more details about those review sections.

A Quick Start with Pearson Network Simulator Lite

The decision of how to get hands-on skills can be a little scary at first. The good news is that you have a free and simple first step to experience the CLI: Install and use the Pearson NetSim Lite that comes with this book.

This book comes with a lite version of the best-selling CCNA Network Simulator from Pearson, which provides you with a means, right now, to experience the Cisco CLI. No need to go buy real gear or buy a full simulator to start learning the CLI. Just install NetSim Lite from the DVD in the back of this book.

The latest version of NetSim Lite includes labs associated with Part II of this book. Part I includes concepts only, with Part II being the first part with commands. So, make sure and use NetSim Lite to learn the basics of the CLI to get a good start.

Of course, one reason that NetSim Lite comes on the DVD is that the publisher hopes you will buy the full product. However, even if you do not use the full product, you can still learn from the labs that come with NetSim Lite while deciding about what options to pursue.

NOTE The ICND1 and ICND2 books each contain a different version of the Sim Lite product, each with labs that match the book content. If you bought both books, make sure you install both Sim Lite products.

The Pearson Network Simulator

The Config Labs and the Pearson Network Simulator Lite both fill specific needs, and they both come with the book. However, you need more than those two tools.

The single best option for lab work to do along with this book is the paid version of the Pearson Network Simulator. This simulator product simulates Cisco routers and switches so that you can learn for the CCENT and CCNA R&S certifications. But more importantly, it focuses on learning for the exam by providing a large number of useful lab exercises. Reader surveys tell us that those people who use the Simulator along with the book love the learning process, and rave about how the book and Simulator work well together.

Of course, you need to make a decision for yourself, and consider all the options. Thankfully, you can get a great idea of how the full Simulator product works by using the Pearson Network Simulator Lite product included with the book. Both have the same base code and same user interface, and the same types of labs. Try the Lite version, and check out the full product. There is a full product for CCENT only, and another for CCNA R&S (which includes all the labs in the CCENT product, plus others for the ICND2 parts of the content).

Note that the Simulator and the books work on a different release schedule. For a time in 2016, the version of the Simulator available for purchase will be the Simulator created for the previous versions of the exams (ICND1 100-101, ICND2 200-101, and CCNA 200-120). That product includes approximately 80 percent of the CLI topics in the ICND1 100-105 and ICND2 200-105 books. So during that time, the Simulator is still very useful.

On a practical note, when you want to do labs while reading a chapter or doing Part Review, the Simulator organizes the labs to match the book. Just look for the "Sort by Chapter" tab in the Simulator's user interface. However, during the months in 2016 for which the available Simulator is the older edition listing the older exams in the title, you will need to refer back to a PDF that lists those labs versus this book's organization; find that PDF at http://www.ciscopress.com/title/9781587205798.

More Lab Options

If you decide against using the full Pearson Network Simulator, you still need hands-on experience. You should plan to use some lab environment to practice as much CLI interaction as possible.

First, you can use real Cisco routers and switches. You can buy them, new or used, or borrow them at work. You can rent them for a fee. If you have the right mix of gear, you could even do the Config Lab exercises from my blog on that gear, or try and re-create examples from the book.

Cisco offers a virtualization product that lets you run router and switch operating system (OS) images in a virtual environment. This tool, the Virtual Internet Routing Lab (VIRL), lets you create a lab topology, start the topology, and connect to real router and switch OS images. Check out http://virl.cisco.com for more information.

You can even rent virtual Cisco router and switch lab pods from Cisco, in an offering called Cisco Learning Labs.

All these previously mentioned options cost some money, but the next two are generally free to the user, but with a different catch for each. First, GNS3 works somewhat like VIRL, creating a virtual environment running real Cisco IOS. However, GNS3 is not a Cisco product, and cannot provide you with the IOS images for legal reasons.

Cisco also makes a simulator that works very well as a learning tool: Cisco Packet Tracer. However, Cisco intends Packet Tracer for use by people currently enrolled in Cisco Networking Academy courses, and not for the general public. So, if you are part of a Cisco Academy, definitely use Packet Tracer.

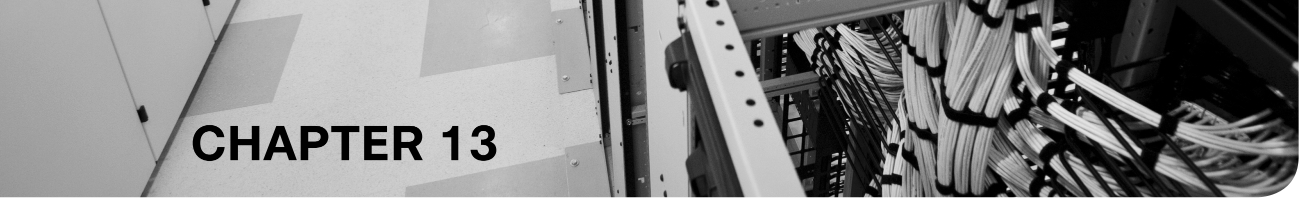
This book does not tell you what option to use, but you should plan on getting some hands-on practice somehow. The important thing to know is that most people need to practice using the Cisco CLI to be ready to pass these exams.

For More Information

If you have any comments about the book, submit them via http://www.ciscopress.com. Just go to the website, select **Contact Us**, and type your message.

Cisco might make changes that affect the CCNA certification from time to time. You should always check http://www.cisco.com/go/ccna and http://www.cisco.com/go/ccent for the latest details.

The *CCNA ICND2 200-105 Official Cert Guide* helps you attain CCNA Routing and Switching certification. This is the CCNA and ICND2 certification book from the only Cisco-authorized publisher. We at Cisco Press believe that this book certainly can help you achieve CCNA certification, but the real work is up to you! I trust that your time will be well spent.



CHAPTER 13

Implementing Point-to-Point WANs

This chapter covers the following exam topics:

3.0 WAN Technologies

3.1 Configure and verify PPP and MLPPP on WAN interfaces using local authentication

Leased-line WANs—also known as serial links—require much less thought than many other topics, at least to the depth required for the CCENT and CCNA R&S exams. That simplicity allows the Cisco exams to discuss leased lines briefly for the ICND1 exam, while using leased lines as part of larger discussions of IP routing.

This chapter finally takes the discussion of leased-line WANs deeper than has been discussed so far. This chapter briefly repeats the leased line concepts from the ICND1 book, to lay a foundation to discuss other concepts. More important, this chapter looks at the configuration, verification, and troubleshooting steps for leased lines that use the familiar High-level Data Link Control (HDLC) data-link protocol and the Point-to-Point Protocol (PPP).

This chapter breaks the material down into three major sections. The first looks at leased-line WANS that use HDLC, by reviewing and adding details about the physical links themselves, along with HDLC (and related) configuration. The second major section discusses PPP, an alternate data-link protocol that you can use instead of HDLC, with a focus on concepts and configuration. The final major section then discusses typical root causes of serial link problems and how to find those problems.

"Do I Know This Already?" Quiz

Take the quiz (either here, or use the PCPT software) if you want to use the score to help you decide how much time to spend on this chapter. The answers are at the bottom of the page following the quiz, and the explanations are in DVD Appendix C and in the PCPT software.

Table 13-1 "Do I Know This Already?" Foundation Topics Section-to-Question Mapping

Foundation Topics Section	Questions
Leased-Line WANs with HDLC	1–2
Leased-Line WANs with PPP	3–6
Troubleshooting Serial Links	7

1. In the cabling for a leased line, which of the following usually connects to a four-wire line provided by a telco?

a. Router serial interface without internal CSU/DSU

b. CSU/DSU

c. Router serial interface with internal transceiver

d. Switch serial interface

2. Two routers connect with a serial link, each using its S0/0/0 interface. The link is currently working using PPP. The network engineer wants to migrate to use the Cisco-proprietary HDLC that includes a protocol type field. Which of the following commands can be used to migrate to HDLC successfully? (Choose two answers.)

   a. **encapsulation hdlc**

   b. **encapsulation cisco-hdlc**

   c. **no encapsulation ppp**

   d. **encapsulation-type auto**

3. Which of the following PPP authentication protocols authenticates a device on the other end of a link without sending any password information in clear text?

   a. MD5

   b. PAP

   c. CHAP

   d. DES

4. Two routers have no initial configuration whatsoever. They are connected in a lab using a DTE cable connected to R1 and a DCE cable connected to R2, with the DTE and DCE cables then connected to each other. The engineer wants to create a working PPP link by configuring both routers. Which of the following commands are required in the R1 configuration for the link to reach a state in which R1 can ping R2's serial IP address, assuming that the physical back-to-back link physically works? (Choose two answers.)

   a. **encapsulation ppp**

   b. **no encapsulation hdlc**

   c. **clock rate**

   d. **ip address**

5. Consider the following excerpt from the output of a **show** command:

```
Serial0/0/1 is up, line protocol is up
  Hardware is GT96K Serial
  Internet address is 192.168.2.1/24
  MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation PPP, LCP Open
  Open: CDPCP, IPCP, loopback not set
```

   Which of the following are true about this router's S0/0/1 interface? (Choose two answers.)

   a. The interface is using HDLC.

   b. The interface is using PPP.

   c. The interface currently cannot pass IPv4 traffic.

   d. The link should be able to pass PPP frames at the present time.

6. Two routers, R1 and R2, connect to each other using three serial links. The network engineer configures these links to be part of the same multilink PPP group, along with configuring CHAP configuration, IPv4, and OSPFv2 using interface configuration. Which of the following answers list a configuration command along with the correct configuration mode for that command? (Choose two answers.)
   a. **encapsulation ppp** while in multilink interface configuration mode
   b. **ip address** address mask while in serial interface configuration mode
   c. **ppp authentication chap** while in multilink interface configuration mode
   d. **ip ospf 1 area 0** while in serial interface configuration mode
   e. **ppp multilink** while in serial interface configuration mode

7. Consider the following excerpt from the output of a **show interfaces** command on an interface configured to use PPP:

```
Serial0/0/1 is up, line protocol is down
  Hardware is GT96K Serial
  Internet address is 192.168.2.1/24
```

   A ping of the IP address on the other end of the link fails. Which of the following are reasons for the failure, assuming that the problem listed in the answer is the only problem with the link? (Choose two answers.)
   a. The CSU/DSU connected to the other router is not powered on.
   b. The IP address on the router at the other end of the link is not in subnet 192.168.2.0/24.
   c. CHAP authentication failed.
   d. The router on the other end of the link has been configured to use HDLC.
   e. None of the above.

Foundation Topics

Leased-Line WANs with HDLC

A physical leased-line WAN works a lot like in an Ethernet crossover cable connecting two routers, but with no distance limitations. As shown in Figure 13-1, each router can send at any time (full duplex). The speed is also symmetric, meaning that both routers send bits at the same speed.

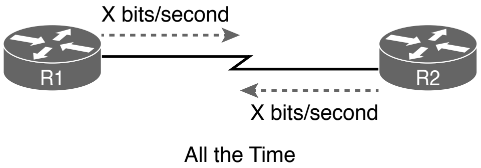


Figure 13-1 *Leased Line: Same Speed, Both Directions, Always On*

Although the leased line provides a physical layer bit transmission facility, routers also need to use a data link protocol on the WAN link to send bits over the link. The story should be familiar by now: routers receive frames in LAN interfaces, and then the router de-encapsulates the network layer packet. Before forwarding the packet, the router encapsulates the packet inside a WAN data link protocol like High-level Data Link Control (HDLC), as shown at Step 2 of Figure 13-2.

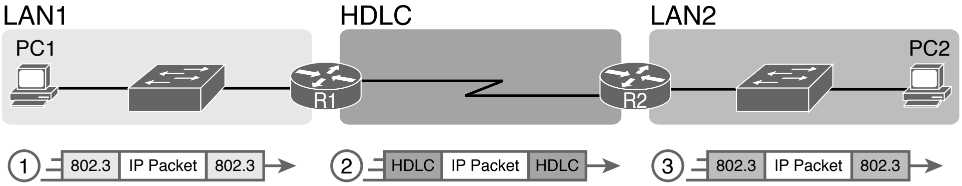


Figure 13-2 *Routers and Their Use of HDLC to Encapsulate Packets*

These first two figures review some of the Layer 1 and Layer 2 details, respectively, of leased-line WANs. This first major section of this chapter begins by discussing these links again, first with the Layer 1 details, followed by the Layer 2 details. This section ends with an explanation of HDLC configuration details.

Layer 1 Leased Lines

Leased lines have been around a long time, roughly 20 years longer than LANs. However, they still exist today as a WAN service.

As a result of their long history in the market, the networking world has used a large number of different terms. First, the term *leased line* refers to the fact that the company using the leased line does not own the line, but instead pays a monthly lease fee to use it. Often, you lease the service from a telephone company, or *telco*. However, many people today use the generic term *service provider* to refer to a company that provides any form of WAN connectivity, including Internet services. Table 13-2 lists some of those names so that you can understand the different terms you will encounter in a real networking job.

Table 13-2 Different Names for a Leased Line

Name	Meaning or Reference
Leased circuit, circuit	The words *line* and *circuit* are often used as synonyms in telco terminology; *circuit* makes reference to the electrical circuit between the two endpoints.
Serial link, serial line	The words *link* and *line* are also often used as synonyms. *Serial* in this case refers to the fact that the bits flow serially and that routers use serial interfaces.
Point-to-point link, point-to-point line	Refers to the fact that the topology stretches between two points, and two points only. (Some older leased lines allowed more than two devices.)
T1	A specific type of leased line that transmits data at 1.544 megabits per second (1.544 Mbps).
WAN link, link	Both these terms are very general, with no reference to any specific technology.

Answers to the "Do I Know This Already?" quiz:

1 B **2** A, C **3** C **4** A, D **5** B, D **6** A, E **7** C, D

The Physical Components of a Leased Line

To create a leased line, the telco must create some physical transmission path between the two routers on the ends of the link. The physical cabling must leave the buildings where each router sits. Then the telco must create the equivalent of a two-pair circuit from end to end, with one circuit to send data in each direction (full duplex). Figure 13-3 shows one such example, in which the telco uses a couple of traditional central office (CO) switches to create a short leased line between two routers.

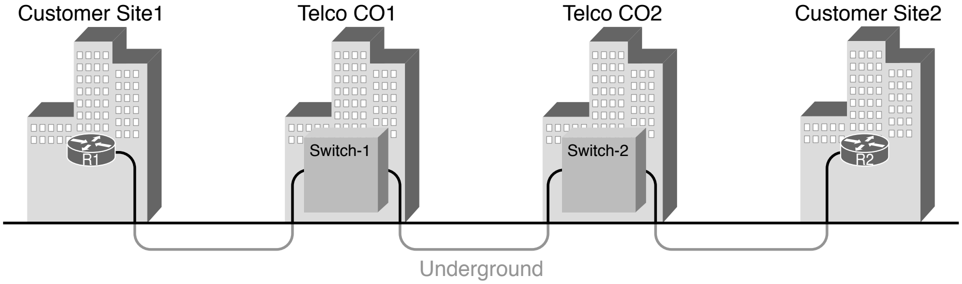


Figure 13-3 *Possible Cabling Inside a Telco for a Short Leased Line*

The details in the center of Figure 13-3 probably show more than you ever need to know about leased-line WANs, at least from the enterprise customer perspective. More commonly, most network engineers think more about a leased line from the perspective of Figure 13-4, which shows a few key components and terms for the equipment on the ends of a leased line, as follows:

Customer premises equipment (CPE): This telco term refers to the gear that sits at their customers' sites on the ends on the link.

Channel service unit/data service unit (CSU/DSU): This device provides a function called *clocking*, in which it physically controls the speed and timing at which the router serial interface sends and receives each bit over the serial cable.

Serial cable: This is a short cable that connects the CSU and the router serial interface.

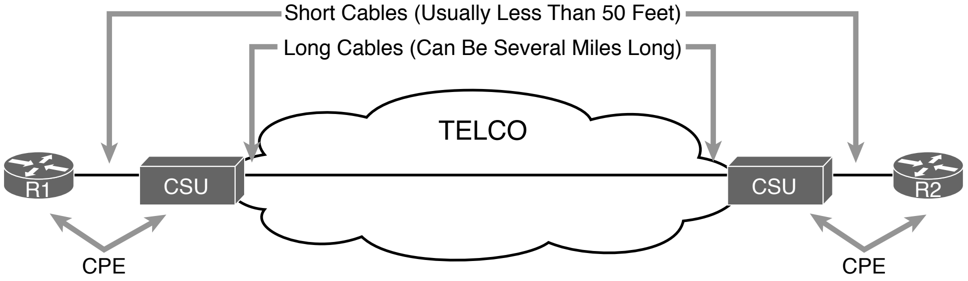

Short Cables (Usually Less Than 50 Feet)
Long Cables (Can Be Several Miles Long)
TELCO
R1
CSU
CSU
R2
CPE
CPE

Figure 13-4 *Point-to-Point Leased Line: Components and Terminology*

The CPE includes several separately orderable parts. When using an external CSU/DSU, a serial cable must be used to connect the CSU to the router serial interface. These serial interfaces usually exist as part of a removable card on the router, called either WAN interface cards (WIC), High-speed WICs (HWIC), or Network Interface Modules (NIM). Most of the serial interfaces use one style (size/shape) of physical connector called a smart serial connector, whereas the CSU has one of several other types of connectors. So, when installing the leased line, the engineer must choose the correct cable type, with connectors to match the WIC on one end and the CSU/DSU on the other. Figure 13-5 shows a drawing of one type of serial cable, with the smart serial connector on the left, and the popular V.35 connector on the right. The figure shows a side view of the entire cable, plus direct views into the connector on the ends of the cable.

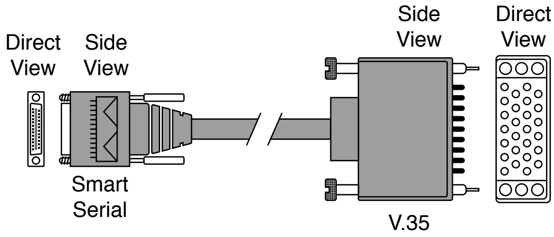


Figure 13-5 *Serial Cables Used Between a CSU and a Router*

Today, many leased lines make use of Cisco WICs with an integrated CSU/DSU. That is, the WIC hardware includes the same functions as a CSU/DSU, so an external CSU/DSU is not needed. Compared to Figure 13-4, the external CSU/DSU and serial cable on each end are not needed, with the cable from the telco connecting directly to the WIC.

Figure 13-6 shows a photo of a router with two NIM slots. Each slot currently shows a faceplate with no NIM cards installed. The foreground of the figure shows a NIM with two serial ports, with smart serial interfaces. The cable end on the left of the drawing in Figure 13-5 would attach to one of these smart serial ports on the NIM in Figure 13-6.

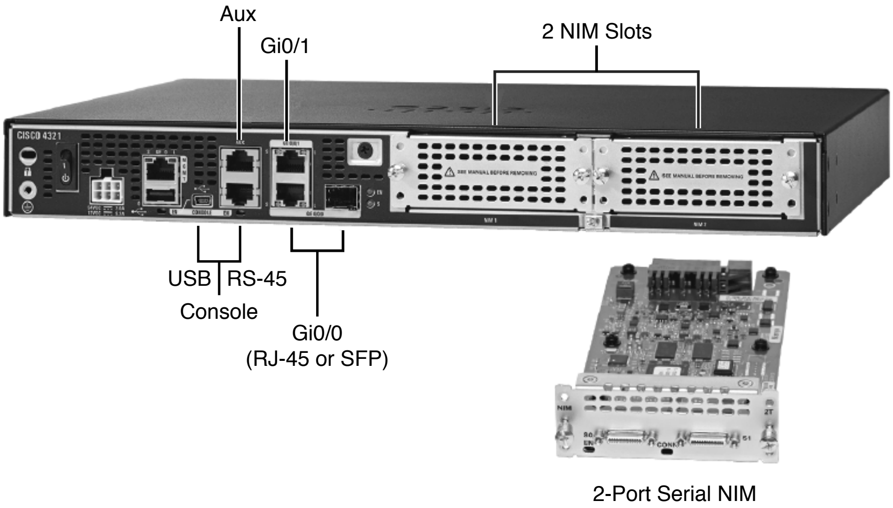


Figure 13-6 *Photo of Router with Serial NIM on the Right*

Telcos offer a wide variety of speeds for leased lines. However, a telco customer cannot pick just any speed. Instead, the speeds follow the standards of an age-old technology called the T-carrier system.

Back in the 1950s and 1960s, the U.S.-based Bell companies developed and deployed digital voice and the T-carrier system. As part of that work, they standardized different transmission speeds, including 64 Kbps, 1.544 Mbps, and 44.736 Mbps.

Those same Bell companies developed time-division multiplexing (TDM) technology that let them combine multiples of these base speeds onto a single line. For instance, one popular standard, a Digital Signal level 1 (DS1), or T1, combines 24 DS0s (at 64 Kbps) plus 8 Kbps of overhead into one physical line that runs at 1.544 Mbps. However, to allow flexibility of speeds offered to customers, the telco could install a T1 line to many sites, but run some at slower speeds and some at faster speeds—as long as those speeds were multiples of 64 Kbps.

Now back to the idea of the speed of a leased line. What can you actually buy? Basically, at slower speeds, you get any multiple of 64 Kbps, up to T1 speed. At faster speeds, you can get multiples of T1 speed, up to T3 speed. Table 13-3 summarizes the speeds typically seen in the United States, with a few from Europe.

Key Topic

Table 13-3 WAN Speed Summary

Names of Line	Bit Rate
DS0	64 Kbps
Fractional T1	Multiples of 64 Kbps, up to 24X
DS1 (T1)	1.544 Mbps (24 DS0s, for 1.536 Mbps, plus 8 Kbps overhead)
E1 (Europe)	2.048 Mbps (32 DS0s)
Fractional T3	Multiples of 1.536 Mbps, up to 28X
DS3 (T3)	44.736 Mbps (28 DS1s, plus management overhead)
E3 (Europe)	Approx. 34 Mbps (16 E1s, plus management overhead)

The Role of the CSU/DSU

For our last bit of discussion about WAN links in a working enterprise internetwork, next consider the role of the CSU/DSU (called CSU for short). For the sake of discussion, the next few paragraphs, leading up to Figure 13-7, assume a leased line with external CSU/DSUs, like earlier in Figure 13-4.

The CSU sits between the telco leased line and the router; it understands both worlds and their conventions at Layer 1. On the telco side, that means the CSU connects to the line from the telco, so it must understand all these details about the T-carrier system, TDM, and the speed used by the telco. On the router side of the equation, the CSU connects to the router, with roles called the DCE and DTE, respectively. The CSU, acting as DCE (data circuit-terminating equipment), controls the speed of the router serial interface. The router, acting as DTE (data terminal equipment), is controlled by the clocking signals from the CSU (DCE). That is, the CSU tells the router when to send and receive bits; the router attempts to send and receive bits only when the DCE creates the correct electrical impulses (called clocking) on the cable. Figure 13-7 shows a diagram of those main concepts of the role of the CSU/DSU.

Key Topic

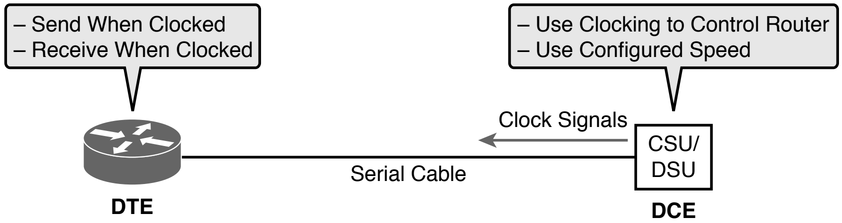


Figure 13-7 *DCE and DTE Roles for a CSU/DSU and a Router Serial Interface*

Building a WAN Link in a Lab

On a practical note, to prepare for the CCENT and CCNA R&S exams, you might choose to buy some used router and switch hardware for hands-on practice. If you do, you can create the equivalent of a leased line, without a real leased line from a telco, and without CSU/DSUs, just using a cabling trick. This short discussion tells you enough information to create a WAN link in your home lab.

First, when building a real WAN link with a real telco facility between sites, the serial cables normally used between a router and an external CSU/DSU are called *DTE cables*. That is, the serial cables in earlier Figure 13-4 are DTE cables.

You can create an equivalent WAN link just by connecting two routers' serial interfaces using one DTE cable and a slightly different DCE cable, with no CSUs and with no leased line from the telco. The DCE cable has a female connector, and the DTE cable has a male connector, which allows the two cables to be attached directly. That completes the physical connection, providing a path for the data. The DCE cable also does the equivalent of an Ethernet crossover cable by swapping the transmit and receive wire pairs, as shown in Figure 13-8.

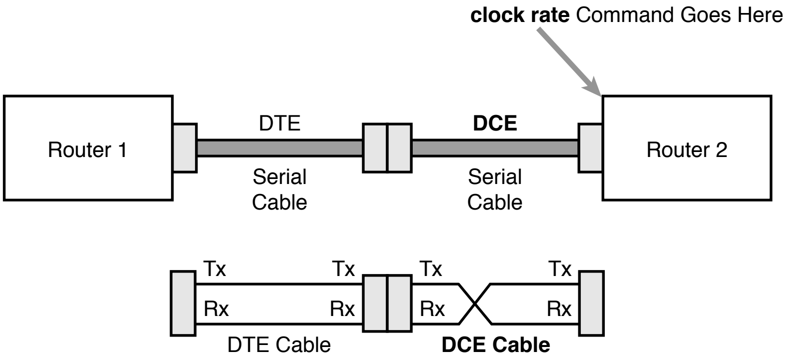


Figure 13-8 *Serial Cabling Uses a DTE Cable and a DCE Cable*

The figure shows the cable details at the top, with the wiring details at the bottom. In particular, at the bottom of the figure, note that the DTE serial cable acts as a straight-through cable and does not swap the transmit and receive pair, whereas the DCE cable does swap the pairs.

NOTE Many vendors, for convenience, sell a single cable that combines the two cables shown in Figure 13-8 into a single cable. Search online for "Cisco serial crossover" to find examples.

Finally, to make the link work, the router with the DCE cable installed must provide clocking. A router serial interface can provide clocking, but it can do so only if a DCE cable is connected to the interface and by the configuration of the **clock rate** command. Newer IOS versions will sense the presence of a DCE cable and automatically set a clock rate, so that the link will work, but old IOS versions require that you configure the **clock rate** command.

Layer 2 Leased Lines with HDLC

A leased line provides a Layer 1 service. It promises to deliver bits between the devices connected to the leased line. However, the leased line itself does not define a data link layer protocol to be used on the leased line. HDLC provides one option for a data link protocol for a leased line.

HDLC has only a few big functions to perform with the simple point-to-point topology of a point-to-point leased line. First, the frame header lets the receiving router know that a new frame is coming. Plus, like all the other data link protocols, the HDLC trailer has a Frame Check Sequence (FCS) field that the receiving router can use to decide whether the frame had errors in transit, and if so, discard the frame.

Cisco adds another function to the ISO standard HDLC protocol by adding an extra field (a Type field) to the HDLC header, creating a Cisco-specific version of HDLC, as shown in Figure 13-9. The Type field allows Cisco routers to support multiple types of network layer packets to cross the HDLC link. For example, an HDLC link between two Cisco routers can forward both IPv4 and IPv6 packets because the Type field can identify which type of packet is encapsulated inside each HDLC frame.

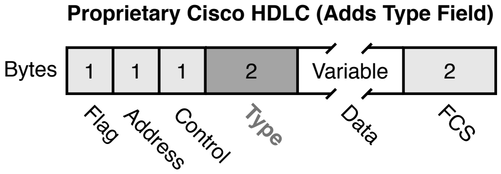


Figure 13-9 *Cisco HDLC Framing*

Today, the HDLC Address and Control fields have little work to do. For instance, with only two routers on a link, when a router sends a frame, it is clear that the frame is sent to the only other router on the link. Both the Address and Control fields had important purposes in years past, but today they are unimportant.

Routers use HDLC just like any other data link protocol used by routers: to move packets to the next router. Figure 13-10 shows three familiar routing steps, with the role of HDLC sitting at Step 2.

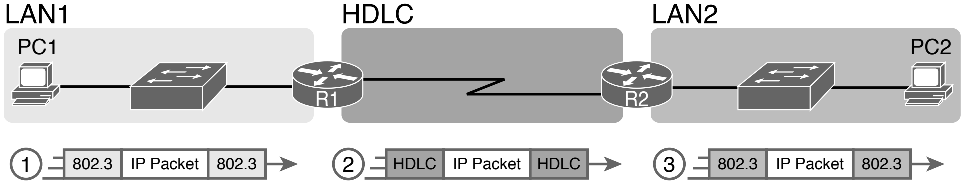


Figure 13-10 *General Concept of Routers De-encapsulating and Re-encapsulating IP Packets*

Here is a walkthrough of the steps in the figure:

1. To send the IP packet to router R1, PC1 encapsulates the IP packet in an Ethernet frame.
2. Router R1 de-encapsulates (removes) the IP packet, encapsulates the packet into an HDLC frame using an HDLC header and trailer, and forwards the HDLC frame to router R2.
3. Router R2 de-encapsulates (removes) the IP packet, encapsulates the packet into an Ethernet frame, and forwards the Ethernet frame to PC2.

In summary, a leased line with HDLC creates a WAN link between two routers so that they can forward packets for the devices on the attached LANs. The leased line itself provides the physical means to transmit the bits, in both directions. The HDLC frames provide the means to encapsulate the network layer packet correctly so it crosses the link between routers.

Configuring HDLC

Think back to router Ethernet interfaces for a moment. Router Ethernet interfaces require no configuration related to Layers 1 and 2 for the interface to be up and working, forwarding IP traffic. The Layer 1 details occur by default once the cabling has been installed correctly. Router Ethernet interfaces, of course, use Ethernet as the data link protocol by default. The router only needs to configure an IP address on the interface, and possibly enable the interface with the **no shutdown** command if the interface is in an "administratively down" state.

Similarly, serial interfaces on Cisco routers need no specific Layer 1 or 2 configuration commands. For Layer 1, the cabling needs to be completed, of course, but the router attempts to use the serial interface once the **no shutdown** command is configured. For Layer 2, IOS defaults to use HDLC on serial interfaces. As on Ethernet interfaces, router serial interfaces usually only need an **ip address** command, and possibly the **no shutdown** command, assuming both routers' interfaces otherwise have default settings.

Config Checklist

However, many optional commands exist for serial links. The following list outlines some configuration steps, listing the conditions for which some commands are needed, plus commands that are purely optional:

Step 1. Use the **ip address** *address mask* command in interface configuration mode to configure the interface IP address.

Step 2. The following tasks are required only when the specifically listed conditions are true:

A. If an **encapsulation** *protocol* interface subcommand already exists, for a non-HDLC protocol, use the **encapsulation hdlc** command in interface configuration mode to enable HDLC. Alternatively, use the **no encapsulation** *protocol* command in interface configuration mode to use the default setting of HDLC as the data link protocol.

B. If the interface line status is administratively down, use the **no shutdown** command in interface configuration mode to enable the interface.

- **C.** If the serial link is a back-to-back serial link in a lab (or a simulator), use the **clock rate** *speed* command in interface configuration mode to configure the clocking rate. Use this command only on the one router with the DCE cable (per the **show controllers serial** *number* command).

Step 3. The following steps are always optional and have no impact on whether the link works and passes IP traffic:

- **A.** Use the **bandwidth** *speed-in-kbps* command in interface configuration mode to configure the link's documented speed so that it matches the actual clock rate of the link.
- **B.** For documentation purposes, use the **description** *text* command in interface configuration mode to configure a description of the purpose of the interface.

In practice, when you configure a Cisco router with no preexisting interface configuration and install a normal production serial link with CSU/DSUs, the **ip address** and **no shutdown** commands are likely the only configuration commands you would need.

Figure 13-11 shows a sample internetwork, and Example 13-1 shows the matching HDLC configuration. In this case, the serial link was created with a back-to-back serial link in a lab, requiring Steps 1 (**ip address**) and 2C (**clock rate**) from the preceding list. It also shows optional Step 3B (**description**).

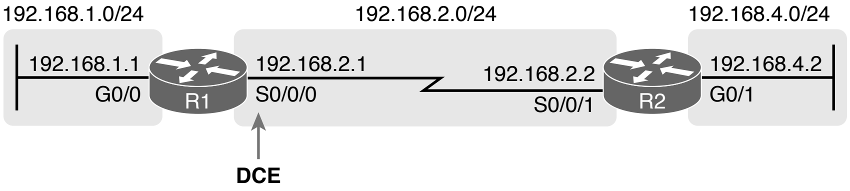


Figure 13-11 *Typical Serial Link Between Two Routers*

Example 13-1 *HDLC Configuration*

```
R1# show running-config
! Note - only the related lines are shown
interface GigabitEthernet0/0
 ip address 192.168.1.1 255.255.255.0
!
interface Serial0/0/0
 ip address 192.168.2.1 255.255.255.0
 description link to R2
 clock rate 2000000
!
router eigrp 1
 network 192.168.1.0
 network 192.168.2.0
```

The configuration on R1 is relatively simple. The matching configuration on R2's S0/0/1 interface simply needs an **ip address** command plus the default settings of **encapsulation hdlc** and **no shutdown**. The **clock rate** command would not be needed on R2 because R1 has the DCE cable, so R2 must be connected to a DTE cable.

Example 13-2 lists two commands that confirm the configuration on R1 and some other default settings. First, it lists the output from the **show controllers** command for S0/0/0, which confirms that R1 indeed has a DCE cable installed and that the clock rate has been set to 2000000 bps. The **show interfaces S0/0/0** command lists the various configuration settings near the top, including the default encapsulation value (HDLC) and default bandwidth setting on a serial interface (1544, meaning 1544 Kbps or 1.544 Mbps). It also lists the IP address, prefix-style mask (/24), and description, as configured in Example 13-1.

Example 13-2 *Verifying the Configuration Settings on R1*

```
R1# show controllers serial 0/0/0
Interface Serial0/0/0
Hardware is SCC
DCE V.35, clock rate 2000000
! lines omitted for brevity

R1# show interfaces s0/0/0
Serial0/0/0 is up, line protocol is up
  Hardware is WIC MBRD Serial
  Description: link to R2
  Internet address is 192.168.2.1/24
  MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation HDLC, loopback not set
  Keepalive set (10 sec)
  Last input 00:00:01, output 00:00:00, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: fifo
  Output queue: 0/40 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
     276 packets input, 19885 bytes, 0 no buffer
     Received 96 broadcasts (0 IP multicasts)
     0 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort
     284 packets output, 19290 bytes, 0 underruns
     0 output errors, 0 collisions, 5 interface resets
     0 unknown protocol drops
     0 output buffer failures, 0 output buffers swapped out
     7 carrier transitions
     DCD=up  DSR=up  DTR=up  RTS=up  CTS=up
```

Finally, the router uses the serial interface only if it reaches an up/up interface status, as shown in the first line of the output of the **show interfaces S0/0/0** command in Example 13-2. Generally speaking, the first status word refers to Layer 1 status, and the second refers to Layer 2 status. For a quicker look at the interface status, instead use either the **show ip interface brief** or **show interfaces description** commands, as listed in Example 13-3.

Example 13-3 *Brief Lists of Interfaces and Interface Status*

```
R1# show ip interface brief
Interface                  IP-Address      OK? Method Status                Protocol
GigabitEthernet0/0         192.168.1.1     YES manual up                    up
GigabitEthernet0/1         unassigned      YES manual administratively down down
Serial0/0/0                192.168.2.1     YES manual up                    up
Serial0/0/1                unassigned      YES NVRAM  administratively down down
Serial0/1/0                unassigned      YES NVRAM  administratively down down
Serial0/1/1                unassigned      YES NVRAM  administratively down down

R1# show interfaces description
Interface                      Status         Protocol Description
Gi0/0                          up             up       LAN at Site 1
Gi0/1                          admin down     down
Se0/0/0                        up             up       link to R2
Se0/0/1                        admin down     down
Se0/1/0                        admin down     down
Se0/1/1                        admin down     down
```

Leased-Line WANs with PPP

Point-to-Point Protocol (PPP) plays the same role as HDLC: a data link protocol for use on serial links. However, HDLC was created for a world without routers. In contrast, PPP, defined in the 1990s, was designed with routers, TCP/IP, and other network layer protocols in mind, with many more advanced features.

This second major section of this chapter first discusses PPP concepts, including one example of a more advanced PPP feature (authentication). This section ends with some configuration examples using PPP.

PPP Concepts

PPP provides several basic but important functions that are useful on a leased line that connects two devices:

- Definition of a header and trailer that allows delivery of a data frame over the link
- Support for both synchronous and asynchronous links
- A protocol Type field in the header, allowing multiple Layer 3 protocols to pass over the same link
- Built-in authentication tools: Password Authentication Protocol (PAP) and Challenge Handshake Authentication Protocol (CHAP)

- Control protocols for each higher-layer protocol that rides over PPP, allowing easier integration and support of those protocols

The next several pages take a closer look at the protocol field, authentication, and the control protocols.

PPP Framing

Unlike the standard version of HDLC, the PPP standard defines a protocol field. The protocol field identifies the type of packet inside the frame. When PPP was created, this field allowed packets from the many different Layer 3 protocols to pass over a single link. Today, the protocol Type field still provides the same function, usually supporting packets for the two different versions of IP (IPv4 and IPv6). Figure 13-12 shows the PPP framing, which happens to mirror the Cisco-proprietary HDLC framing that includes a protocol Type field (as shown earlier in Figure 13-9).

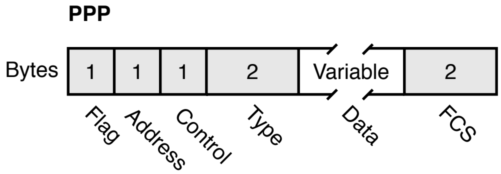


Figure 13-12 *PPP Framing*

PPP Control Protocols

In addition to HDLC-like framing, PPP defines a set of Layer 2 control protocols that perform various link control functions. The idea of these extra protocols works a little like how Ethernet includes additional protocols like Spanning Tree Protocol (STP). Ethernet has headers and trailers to deliver frames, plus it defines overhead protocols like STP to help make the frame forwarding process work better. Likewise, PPP defines the frame format in Figure 13-12, plus it defines other protocols to help manage and control the serial link.

PPP separates these control protocols into two main categories:

Key Topic

- **Link Control Protocol (LCP):** This one protocol has several different individual functions, each focused on the data link itself, ignoring the Layer 3 protocol sent across the link.
- **Network Control Protocols (NCP):** This is a category of protocols, one per network layer protocol. Each protocol performs functions specific to its related Layer 3 protocol.

The PPP LCP implements the control functions that work the same regardless of the Layer 3 protocol. For features related to any higher-layer protocols, usually Layer 3 protocols, PPP uses a series of PPP *control protocols* (CP), such as IP Control Protocol (IPCP). PPP uses one instance of LCP per link and one NCP for each Layer 3 protocol defined on the link. For example, on a PPP link using IPv4, IPv6, and Cisco Discovery Protocol (CDP), the link uses one instance of LCP plus IPCP (for IPv4), IPv6CP (for IPv6), and CDPCP (for CDP).

Table 13-4 summarizes the functions of LCP, gives the LCP feature names, and describes the features briefly. Following the table, the text explains one of the features, PPP authentication, in more detail. Later, the section “Implementing Multilink PPP” discusses the Multilink PPP (MLPPP) feature.

Table 13-4 PPP LCP Features

Function	LCP Feature	Description
Looped link detection	Magic number	Detects whether the link is looped, and disables the interface, allowing rerouting over a working route
Error detection	Link-quality monitoring (LQM)	Disables an interface that exceeds an error percentage threshold, allowing rerouting over better routes
Multilink support	Multilink PPP	Load balances traffic over multiple parallel links
Authentication	PAP and CHAP	Exchanges names and passwords so that each device can verify the identity of the device on the other end of the link

PPP Authentication

In networking, *authentication* gives one device a way to confirm that another device is truly the correct and approved device with which communications should occur. In other words, authentication confirms that the other party is the authentic other party, and not some imposter.

For instance, with PPP, if R1 and R2 are supposed to be communicating over a serial link, R1 might want R2 to somehow prove that the device claiming to be R2 really is R2. In that scenario, R1 wants to authenticate R2, with the authentication process providing a way for R2 to prove its identity.

WAN authentication is most often needed when dial lines are used. However, the configuration of the authentication features remains the same whether a leased line or dial line is used.

PPP defines two authentication protocols: PAP and CHAP. Both protocols require the exchange of messages between devices, but with different details. With PAP, the process works with the to-be-authenticated device starting the messages, claiming to be legitimate by listing a secret password in clear text, as shown in Figure 13-13.

Key Topic

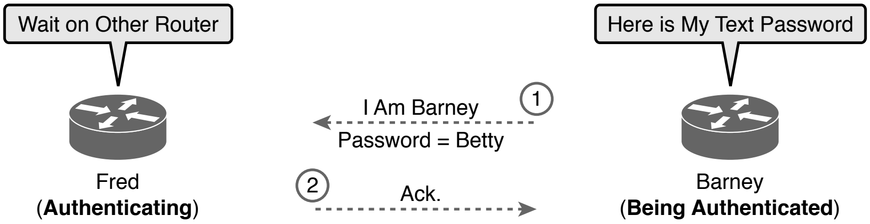


Figure 13-13 *PAP Authentication Process*

In the figure, when the link comes up, authentication takes two steps. At Step 1, Barney sends the shared password in clear text. Fred, who wants to authenticate Barney—that is, confirm that Barney is the real Barney—sees the password. Fred, configured with Barney's name and password, checks that configuration, confirming that it is the correct password, and sends back an acknowledgment that Barney has passed the authentication process.

CHAP, a much more secure option, uses different messages, and it hides the password. With CHAP, the device doing the authentication (Fred) begins with a message called a *challenge*, which asks the other device to reply. The big difference is that the second message in the flow (as shown in Figure 13-14) hides the authentication password by instead sending a hashed version of the password. Router Fred has been preconfigured with Barney's name and password in such a way that Fred can confirm that the hashed password sent by Barney is indeed the same password that Fred lists in his configuration for Barney. If the password is indeed the correct password, Fred sends back a third message to confirm the successful authentication of Barney.

Key Topic

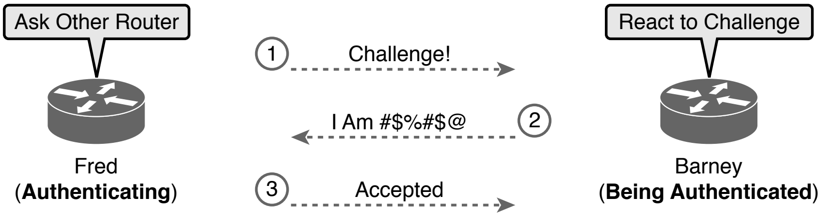


Figure 13-14 *CHAP Authentication Process*

Both Figures 13-13 and 13-14 show authentication flows when authentication works. When it fails (for instance, if the passwords do not match), a different final message flows. Also, if the authentication fails, PPP leaves the interface in an up/down state, and the router cannot forward and receive frames on the interface.

PAP flows are much less secure than CHAP because PAP sends the hostname and password in clear text in the message. These can be read easily if someone places a tracing tool in the circuit. CHAP instead uses a one-way hash algorithm, called message digest 5 (MD5), with input to the algorithm being a password that never crosses the link plus a shared random number.

The CHAP process also uses a hash value only one time so that an attacker cannot just make a copy of the hashed value and send it at a later date. To make that work, the CHAP challenge (the first CHAP message) states a random number. The challenged router runs the hash algorithm using the just-learned random number and the secret password as input, and sends the results back to the router that sent the challenge. The router that sent the challenge runs the same algorithm using the random number (sent across the link) and the password (as stored locally); if the results match, the passwords must match. Later, the next time the authentication process work occurs, the authenticating router generates and uses a different random number.

PAP and CHAP are a few examples of the work done by PPP's LCP. The next topic looks at how to configure and verify PPP.

Implementing PPP

Configuring PPP, as compared to HDLC, requires only one change: using the **encapsulation ppp** command on both ends of the link. As with HDLC, other items can be optionally configured, such as the interface **bandwidth**, and a **description** of the interface. And of course, the interface must be enabled (**no shutdown**). But the configuration to migrate from HDLC to PPP just requires the **encapsulation ppp** command on both routers' serial interfaces.

Example 13-4 shows a simple configuration using the two routers shown in Figure 13-11, the same internetwork used for the HDLC example. The example includes the IP address configuration, but the IP addresses do not have to be configured for PPP to work.

Example 13-4 *Basic PPP Configuration*

```
! The example starts with router R1
interface Serial0/0/0
 ip address 192.168.2.1 255.255.255.0
 encapsulation ppp
 clockrate 2000000
```

```
! Next, the configuration on router R2
interface Serial0/0/1
 ip address 192.168.2.2 255.255.255.0
 encapsulation ppp
```

The one **show** command that lists PPP details is the **show interfaces** command, with an example from R1 listed in Example 13-5. The output looks just like it does for HDLC up until the first highlighted line in the example. The two highlighted lines confirm the configuration ("Encapsulation PPP"). These lines also confirm that LCP has completed its work successfully, as noted with the "LCP Open" phrase. Finally, the output lists the fact that two CPs, CDPCP and IPCP, have also successfully been enabled—all good indications that PPP is working properly.

Example 13-5 *Finding PPP, LCP, and NCP Status with* **show interfaces**

```
R1# show interfaces serial 0/0/0
Serial0/0/0 is up, line protocol is up
  Hardware is WIC MBRD Serial
  Description: link to R2
  Internet address is 192.168.2.1/24
  MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation PPP, LCP Open
  Open: IPCP, CDPCP, loopback not set
! Lines omitted for brevity
```

Implementing PPP CHAP

The simplest version of CHAP configuration requires only a few commands. The configuration uses a password configured on each router. (As an alternative, the password could be configured on an external authentication, authorization, and accounting [AAA] server outside the router.)

To configure PPP along with CHAP on an interface that has all default configuration on the serial interfaces of both routers, follow these steps:

Config Checklist

Step 1. Use the **encapsulation ppp** command in interface configuration mode, on the serial interfaces on both routers, to enable PPP on the interfaces.

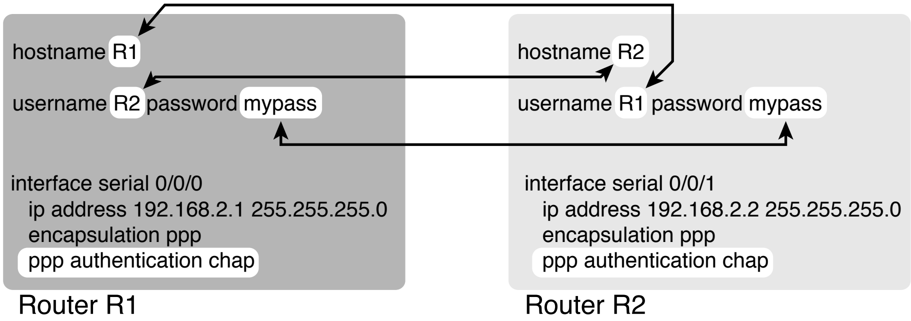
Step 2. Define the usernames and passwords used by the two routers:

A. Use the **hostname** *name* command in global configuration mode on each router, to set the local router's name to use when authenticating.

B. Use the **username** *name* **password** *password* command in global configuration mode on each router, to define the name (case-sensitive) used by the neighboring router, and the matching password (case-sensitive). (The name in the **username** command should match the name in the neighboring router's **hostname** command.)

Step 3. Use the **ppp authentication chap** command in interface configuration mode on each router to enable CHAP on each interface.

Figure 13-15 shows the configuration on both R1 and R2 to both enable PPP and add CHAP to the link. The figure shows how the name in the **hostname** command on one router must match the **username** command on the other router. It also shows that the password defined in each **username** command must be the same (mypass in this case).



```
hostname R1

username R2 password mypass

interface serial 0/0/0
  ip address 192.168.2.1 255.255.255.0
  encapsulation ppp
  ppp authentication chap
```

```
hostname R2

username R1 password mypass

interface serial 0/0/1
  ip address 192.168.2.2 255.255.255.0
  encapsulation ppp
  ppp authentication chap
```

Figure 13-15 *CHAP Configuration*

You can confirm that CHAP authentication has succeeded in a couple of ways. First, if CHAP authentication is enabled but CHAP authentication fails, the protocol status of the interface falls to a down state. To check that status, use the usual **show interfaces** [*type number*] command or **show interfaces status** command. Additionally, if CHAP is enabled but CHAP authentication fails, the **show interfaces** command does not list "LCP Open" as shown in this example. Example 13-6 lists the output of the **show interfaces serial0/0/0** command from R1, with CHAP enabled per Figure 13-15, with CHAP working. However, note that this command does not tell us whether authentication has been configured or not.

Example 13-6 *Confirming CHAP Authentication with* **show interfaces**

```
R1# show interfaces serial 0/0/0
Serial0/0/0 is up, line protocol is up
  Hardware is WIC MBRD Serial
  Description: link to R2
  Internet address is 192.168.2.1/24
  MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation PPP, LCP Open
  Open: IPCP, CDPCP, loopback not set
  Keepalive set (10 sec)
! Lines omitted for brevity
```

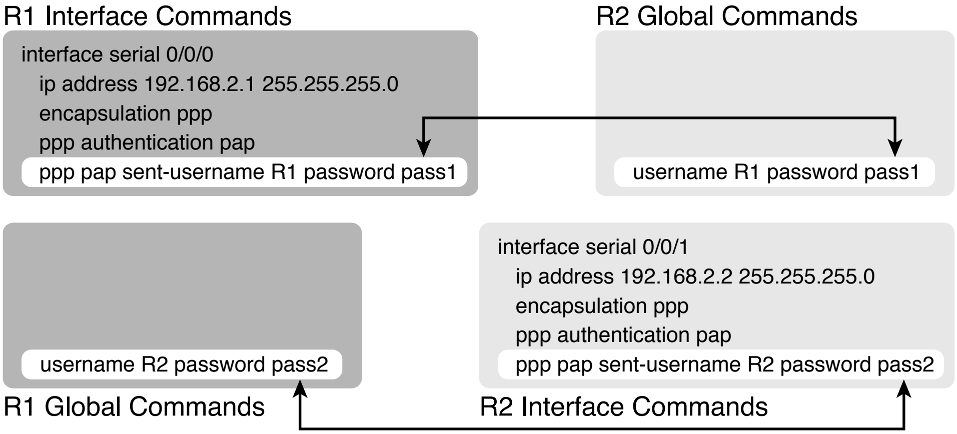
```
R1# show ppp all
Interface/ID OPEN+ Nego* Fail-     Stage    Peer Address    Peer Name
------------ -------------------- -------- --------------- --------------------
Se0/0/0      LCP+ CHAP+ IPCP+ CDP> LocalT   192.168.2.2     R2
```

The more obvious way to confirm that CHAP works is to use the **show ppp all** command, as shown at the end of Example 13-6. This command lists a single line per PPP connection in the router. The highlighted header in the example is the column where this command lists various PPP protocols and their status, with a plus sign (+) meaning that the listed protocol is OPEN, and a minus sign (–) meaning that the protocol has failed. The highlighted parts of this command in the example confirm that Serial0/0/0 uses PPP, with CHAP authentication, and that CHAP authentication worked (as proved by the OPEN status of the CHAP protocol).

Implementing PPP PAP

PAP configuration differs from CHAP configuration in a couple of ways. First, PAP uses the similar **authentication ppp pap** command instead of the **authentication ppp chap** command. Then, PAP configures the sent username/password pair much differently than CHAP. A router defines the username/password pair it will send using the **ppp pap sent-username** command, configured as an interface subcommand. Once sent, the other router receives that username/password pair, and compares those values with its various **username password** global commands. Figure 13-16 shows a completed configuration for two routers (R1 and R2), with emphasis on matching the **ppp pap sent-username** command on one router with the **username password** commands on the other router.

Key Topic



```
interface serial 0/0/0
  ip address 192.168.2.1 255.255.255.0
  encapsulation ppp
  ppp authentication pap
  ppp pap sent-username R1 password pass1
```

```
username R1 password pass1
```

```
username R2 password pass2
```

```
interface serial 0/0/1
  ip address 192.168.2.2 255.255.255.0
  encapsulation ppp
  ppp authentication pap
  ppp pap sent-username R2 password pass2
```

Figure 13-16 *PAP Configuration*

Example 13-7 now shows two commands used to verify PAP operation. In particular, note that the **show interfaces** command tells us nothing more and nothing less as compared to using CHAP authentication. The line protocol status being up confirms that authentication, if configured, worked. (However, nothing in the **show interfaces** command output tells us whether or not CHAP or PAP has been configured.) As with CHAP, the LCP status of Open also confirms that authentication worked, again assuming authentication is configured.

However, just as is the case when using CHAP, or when using no authentication at all, this command does not confirm whether authentication has been configured or, if it is configured, which authentication protocol is used. The better confirmation comes from the **show ppp all** command at the bottom of the example, which identifies PAP as configured on interface Serial0/0/0, and in this case the protocol is OPEN, meaning that authentication worked.

Example 13-7 *Configuring and Verifying PAP Authentication*

```
R1# show interfaces serial 0/0/0
Serial0/0/0 is up, line protocol is up
  Hardware is WIC MBRD Serial
  Description: link to R2
  Internet address is 192.168.2.1/24
  MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation PPP, LCP Open
  Open: IPCP, CDPCP, loopback not set
  Keepalive set (10 sec)
! Lines omitted for brevity
R1# show ppp all
Interface/ID OPEN+ Nego* Fail-     Stage    Peer Address    Peer Name
------------ --------------------- -------- --------------- --------------------
Se0/0/0      LCP+ PAP+ IPCP+ CDPC> LocalT   192.168.2.2     ciscouser2
```

Finally, note that you can configure the interface to try using the PAP process first, but if the other side does not support PAP, it then tries CHAP. You can configure to try PAP first or CHAP first. Just configure the commands to support both, and add the **ppp authentication pap chap** command to try PAP first, or the **ppp authentication chap pap** command to try CHAP first.

Implementing Multilink PPP

Network designers sometimes use multiple parallel serial links between two routers, rather than a single serial link. That motivation may be to improve availability, so if one link fails, at least the others are working. The motivation may be simple economics—it may be cheaper to install two or three parallel T1 lines (at about 1.5 Mbps each) rather than move up to the next faster type of line, a T3 line, using a fractional T3 service. Whatever the reasons, you end up with a design that looks like the design in Figure 13-17, with multiple serial links between two routers.

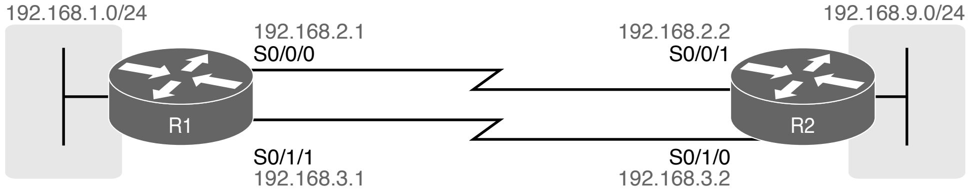


Figure 13-17 *Multiple Parallel Serial Links Between Routers*

If the network engineer configures the parallel serial links as discussed so far in this chapter, each link has IP addresses and can be used to forward IP packets. To make that happen, the interior routing protocol would run over each of the parallel links, with routing protocol neighbor relationships formed over each link. As a result, each router would learn multiple routes to every remote destination subnet—one such route for each parallel link.

Figure 13-18 shows the concept of having multiple equal-metric routes, one for each of the parallel serial links. It shows the same design as Figure 13-17, with two links. R1 has one route for network 192.168.9.0/24 over the top link, and one over the bottom link. If using EIGRP, R1 would have two EIGRP neighbor relationships with R2, one over each link.

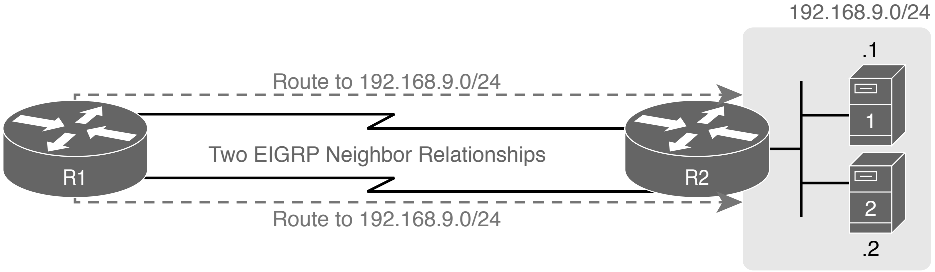


Figure 13-18 *Two IP Routes for One Network, One Per Parallel Serial Link*

The Layer 3 routing logic in Cisco IOS will then balance packets across the multiple links using the routes as shown in the figure. By default, IOS balances on a destination-by-destination address basis—for instance, in Figure 13-18, all packets to 192.168.9.1 might flow over the top link, with all packets going to destination address 192.168.9.2 being routed over the lower link. IOS can be configured to balance on a packet-by-packet basis.

Using the Layer 3 features discussed in the last page or so works, and works well in many cases. However, PPP offers a feature that simplifies the Layer 3 operations in topologies that use multiple parallel PPP links, with a feature called Multilink PPP (MLPPP).

Multilink PPP Concepts

Multilink PPP (MLPPP) is a PPP feature useful when using multiple parallel serial links between two devices. It provides two important features. First, it reduces the Layer 3 complexity by making the multiple serial interfaces on each router look like a single interface from a Layer 3 perspective. Instead of multiple subnets between routers, with multiple routing protocol neighbor relationships, and multiple equal-metric routes learned for each remote subnet, routers would have one subnet between routers, one routing protocol neighbor relationship, and one route per destination subnet. Figure 13-19 shows these main ideas for the same physical topology shown in Figure 13-18, which has multiple physical links.

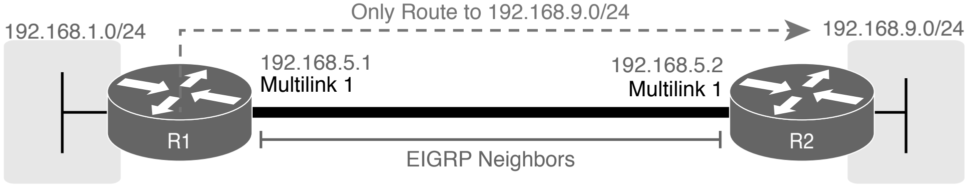


Figure 13-19 *Layer 3 Concept Created by Multilink Interface*

MLPPP makes the multiple physical links work like a single link by using a virtual interface called a multilink interface. The Layer 3 configuration (like IPv4 and IPv6 addresses and routing protocol interface subcommands) is added to the multilink interface. Then the configuration associates the physical serial interfaces with the multilink interface, connecting the Layer 2 logic that works with the multiple serial links with the Layer 3 logic that works on the single multilink interface.

In addition to simplifying Layer 3 details as just described, MLPPP balances the frames sent at Layer 2 over the multiple links. With MLPPP, a router's Layer 3 forwarding logic forwards each packet out the multilink interface. When IOS internally routes a packet out a multilink interface, MLPPP load-balancing logic takes over, encapsulating the packet into a new data link frame, and load balancing the frame.

Interestingly, MLPPP load balances the data link frame by fragmenting the frame into multiple smaller frames, one per active link, as shown with the process in Figure 13-20. Steps 1 and 2 show normal routing, with an encapsulated IP packet arriving at Step 1, and the router making the usual routing decision at Step 2. However, with the packet exiting a multilink interface, MLPPP fragments the packet into pieces (called fragments), with a PPP header/trailer around each, with a few extra header bytes to manage the fragmentation process. The receiving router reassembles the fragments back into the original packet (Step 4), with normal IP routing shown at Step 5.

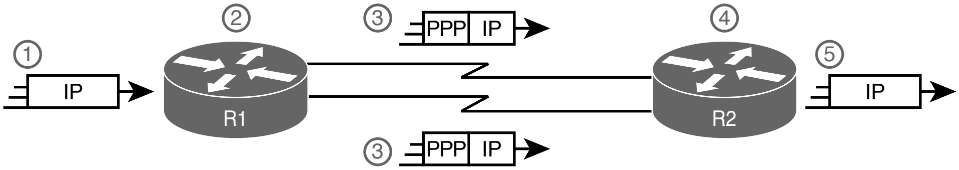


Figure 13-20 *Layer 2 Fragmentation to Balance Traffic over Multiple Links*

MLPPP's load-balancing process allows for some small variations in the sizes of the fragments, but for the most part, Cisco routers will balance the bytes sent equally across the active links in the multilink bundle. For instance, if three links are active, the router forwards about one-third of the byte volume of traffic.

Configuring MLPPP

Implementing MLPPP requires a longer configuration than most features discussed in this book. So first, to set the context a bit, think about these main three configuration requirements for MLPPP:

Key Topic

Step 1. Configure matching multilink interfaces on the two routers, configuring the interface subcommands for all Layer 3 features (IPv4, IPv6, and routing protocol) under the multilink interfaces (and not on the serial interfaces).

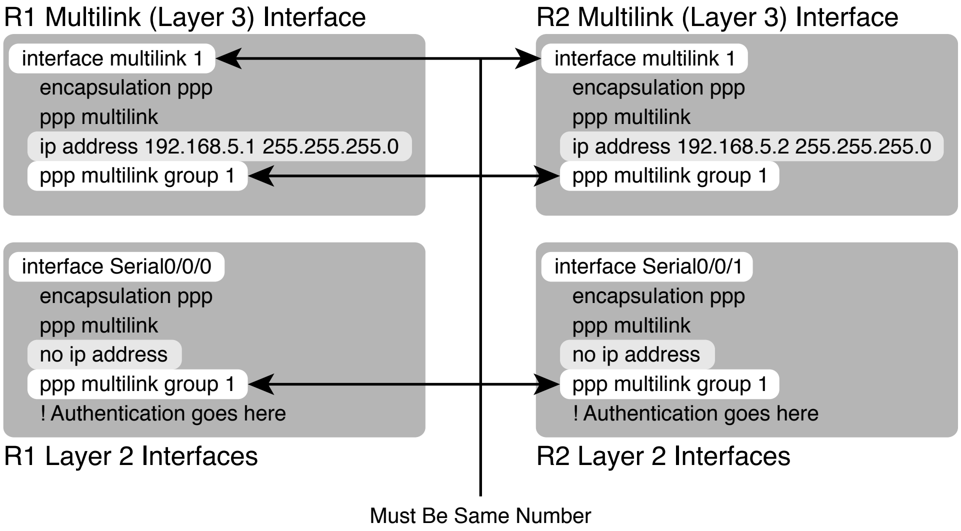
Step 2. Configure the serial interfaces with all Layer 1 and 2 commands, like **clock rate** (Layer 1) and **ppp authentication** (Layer 2).

Step 3. Configure some PPP commands on both the multilink and serial interfaces, to both enable MLPPP and associate the multilink interface with the serial interfaces.

Figure 13-21 shows all the specific MLPPP commands in a working example. The example is based on the design in Figures 13-19 and 13-20. Note that for space, Figure 13-21 shows the configuration for only one of the two serial interfaces, but all serial interfaces would have the same subcommands when used for MLPPP.

First, focus on the six configuration commands noted with white highlight boxes in Figure 13-21 as pointed to with arrows. The **interface multilink 1** command on each router creates the multilink interface on that router. The network engineer chooses the interface number, but the number must be the same on both routers, or the link will not work. Additionally, the multilink interfaces and the physical serial interfaces must all have both a **ppp multilink group 1** command, and they must all again refer to that same number (1 in this example). Any number in range could be used, but the number must match with the commands highlighted in the figure.

Key Topic


R1 Multilink (Layer 3) Interface
R2 Multilink (Layer 3) Interface
R1 Layer 2 Interfaces
R2 Layer 2 Interfaces
Must Be Same Number

```
interface multilink 1
  encapsulation ppp
  ppp multilink
  ip address 192.168.5.1 255.255.255.0
  ppp multilink group 1
```

```
interface multilink 1
  encapsulation ppp
  ppp multilink
  ip address 192.168.5.2 255.255.255.0
  ppp multilink group 1
```

```
interface Serial0/0/0
  encapsulation ppp
  ppp multilink
  no ip address
  ppp multilink group 1
  ! Authentication goes here
```

```
interface Serial0/0/1
  encapsulation ppp
  ppp multilink
  no ip address
  ppp multilink group 1
  ! Authentication goes here
```

Figure 13-21 *MLPPP Configuration*

Now look at the **ip address** commands. Note that the configuration shows IPv4 addresses configured on the multilink interfaces, but no IPv4 address at all on the serial interface. In short, the multilink interface has the Layer 3 configuration, and the serial interfaces do not. As a result, the routing and routing protocol logic will work with the multilink interface.

Finally, note that both the multilink and serial interfaces have two additional commands: **encapsulation ppp** (which enables PPP), and **ppp multilink** (which adds multilink support).

NOTE Figure 13-21 shows only one serial interface, but each serial interface in the multilink group would need the same configuration.

Verifying MLPPP

To verify that an MLPPP interface is working, it helps to think about the Layer 3 features separately from Layer 1 and Layer 2 details. For Layer 3, all the usual IPv4, IPv6, and routing protocol commands will now list the multilink interface rather than the physical serial interfaces. You can also just ping the IP address on the other end of the multilink to test the link. Example 13-8 shows a few commands to confirm the current working state of the MLPPP link, taken from the working configuration in Figure 13-21.

Example 13-8 *Verifying Layer 3 Operations with an MLPPP Multilink Interface*

```
R1# show ip route
! Legend omitted for brevity

      192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.1.0/24 is directly connected, GigabitEthernet0/0
L        192.168.1.1/32 is directly connected, GigabitEthernet0/0
      192.168.5.0/24 is variably subnetted, 3 subnets, 2 masks
C        192.168.5.0/24 is directly connected, Multilink1
L        192.168.5.1/32 is directly connected, Multilink1
C        192.168.5.2/32 is directly connected, Multilink1
D     192.168.9.0/24 [90/1343488] via 192.168.5.2, 16:02:07, Multilink1

R1# show ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(1)
                   Xmit Queue   PeerQ        Mean   Pacing Time   Multicast    Pending
Interface    Peers  Un/Reliable  Un/Reliable  SRTT   Un/Reliable   Flow Timer   Routes
Mu1            1        0/0         0/0         1       0/8           50           0
Gi0/0          1        0/0         0/0         1       0/0           50           0

R1# show ip interface brief
Interface                  IP-Address      OK? Method Status                Protocol
Embedded-Service-Engine0/0 unassigned      YES NVRAM  administratively down down
GigabitEthernet0/0         192.168.1.1     YES manual up                    up
GigabitEthernet0/1         unassigned      YES manual up                    up
Serial0/0/0                unassigned      YES manual up                    up
Serial0/0/1                unassigned      YES manual administratively down down
Serial0/1/0                unassigned      YES NVRAM  administratively down down
Serial0/1/1                unassigned      YES NVRAM  up                    up
Multilink1                 192.168.5.1     YES manual up                    up
```

Working from the top of the example to the bottom, note that the IPv4 routing table lists interface multilink 1 as the outgoing interface in a variety of routes. However, the two serial interfaces are not listed at all, because they do not have IP addresses and the router's routing logic works with the multilink interface instead. Similarly, the **show ip eigrp interfaces** command lists interfaces on which EIGRP is enabled, listing Mu1 (Multilink 1), and not listing either of the two serial interfaces in the MLPPP bundle. Finally, note that the **show ip interface brief** command does list both the serial interfaces and the multilink interface, but the output confirms that no IP address has been configured on the serial interfaces, as noted with the "unassigned" text under the IP-Address column.

Each multilink interface has a line and protocol status like any other interface, and if that status is up/up, IOS believes the multilink interface is working. By default, that working state implies that at least one of the physical links in the MLPPP group is also working—that is, some of the physical links can fail, and the multilink stays up. You can always directly verify the serial interfaces in the multilink group with the same commands discussed earlier in the chapter (**show controllers**, **show interfaces**). Additionally, the two commands in Example 13-9 give some insight into the specifics of MLPPP operation.

Example 13-9 *Verifying Operational Details of an MLPPP Group*

```
R1# show interfaces multilink 1
Multilink1 is up, line protocol is up
  Hardware is multilink group interface
  Internet address is 192.168.5.1/24
  MTU 1500 bytes, BW 3088 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation PPP, LCP Open, multilink Open
  Open: IPCP, CDPCP, loopback not set
  Keepalive set (10 sec)
! lines omitted for brevity

R1# show ppp multilink

Multilink1
  Bundle name: R2
  Remote Username: R2
  Remote Endpoint Discriminator: [1] R2
  Local Username: R1
  Local Endpoint Discriminator: [1] R1
  Bundle up for 16:50:33, total bandwidth 3088, load 1/255
  Receive buffer limit 24000 bytes, frag timeout 1000 ms
    0/0 fragments/bytes in reassembly list
    0 lost fragments, 96 reordered
    0/0 discarded fragments/bytes, 0 lost received
    0x654D7 received sequence, 0x654D5 sent sequence
  Member links: 2 active, 0 inactive (max 255, min not set)
    Se0/1/1, since 16:50:33
    Se0/0/0, since 16:23:16
No inactive multilink interfaces
```

First, notice that the **show interfaces multilink 1** command lists many familiar details and some mentions about multilink. In particular, the output shows the traditional line and protocol status, both in an up state, meaning that the interface is working. On the sixth line, the output mentioned a working multilink state of "Open" in the section about PPP control protocols, confirming that MLPPP is in effect.

Finally, the output of the **show ppp multilink** command identifies the links configured in each multilink bundle, as well as which ones are active. In this case, on R1, interfaces S0/0/0 and S0/1/1 are active, as highlighted at the bottom of the example. The timer to the side shows that both have been active a little over 16 hours. Seeing these two interfaces in the list confirms not only that the physical interfaces are working, but that the MLPPP configuration includes both of these links in multilink group 1.

Troubleshooting Serial Links

This final major section discusses how to isolate and find the root cause of problems related to topics covered earlier in this chapter. Also, this section does not attempt to repeat the IP troubleshooting coverage in Part II of this book, but it does point out some of the possible symptoms on a serial link when a Layer 3 subnet mismatch occurs on opposite ends of a serial link, which prevents the routers from routing packets over the serial link.

A simple **ping** command can determine whether a serial link can or cannot forward IP packets. A ping of the other router's serial IP address—for example, a working **ping 192.168.2.2** command on R1 in Figure 13-11, the figure used for both the HDLC and PPP configuration examples—proves that the link either works or does not.

If the **ping** does not work, the problem could be related to functions at Layer 1, 2, or 3. The best way to isolate which layer is the most likely cause is to examine the interface status codes described in Table 13-5.

Table 13-5 Interface Status Codes and Typical Meanings When a Ping Does Not Work

Line Status	Protocol Status	Likely General Reason/Layer
Administratively down	Down	Interface shutdown
Down	Down	Layer 1
Up	Down	Layer 2
Up	Up	Layer 3

The serial link verification and troubleshooting process should begin with a simple three-step process:

Step 1. From one router, ping the other router's serial IP address.

Step 2. If the ping fails, examine the interface status on both routers and investigate problems related to the likely problem areas listed in Table 13-5.

Step 3. If the ping works, also verify that any routing protocols are exchanging routes over the link, as discussed in Chapter 11, "Troubleshooting IPv4 Routing Protocols."

NOTE The interface status codes can be found using the **show interfaces**, **show ip interface brief**, and **show interfaces description** commands.

The rest of this section explores the specific items to be examined when the ping fails, based on the combinations of interface status codes listed in Table 13-5.

Troubleshooting Layer 1 Problems

The interface status codes, or interface state, play a key role in isolating the root cause of problems on serial links. In fact, the status on both ends of the link may differ, so it is important to examine the status on both ends of the link to help determine the problem.

For example, a serial link fails when just one of the two routers has administratively disabled its serial interface with the **shutdown** interface subcommand. When one router shuts down its serial interface, the other router sits in a down/down state (line status down, line protocol status down), assuming the second router's interface is not also shut down. The solution is to just configure a **no shutdown** interface configuration command on the interface.

A serial interface with a *down* line status on both ends of the serial link—that is, both ends in a down/down state—usually points to some Layer 1 problem. Figure 13-22 summarizes the most common causes of this state. In the figure, R2's serial interface has no problems at all; the center and left side of the figure show common root causes that then result in R2's serial interface being in a down/down state.

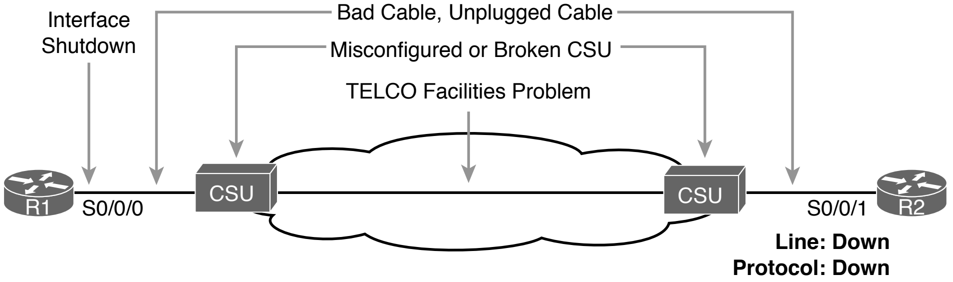


Figure 13-22 *Problems That Result in a Down/Down State on Router R2*

Troubleshooting Layer 2 Problems

Data link layer problems on serial links usually result in at least one of the routers having a serial interface status of up/down. In other words, the line status (the first status code) is up, while the second status (the line protocol status) is down. Table 13-6 lists some of these types of problems.

Table 13-6 Likely Reasons for Data Link Problems on Serial Links

Line Status	Protocol Status	Likely Reason
Up	Down on both ends[1]	Mismatched **encapsulation** commands
Up	Down on one end, up on the other	Keepalive disabled on the end in an up state when using HDLC
Up	Down on both ends	PAP/CHAP authentication failure

[1] In this case, the state may flap from up/up, to up/down, to up/up, and so on, while the router keeps trying to make the encapsulation work.

The first of these problems—a mismatch between the configured data link protocols—is easy to identify and fix. The **show interfaces** command lists the encapsulation type on about the seventh line of the output, so using this command on both routers can quickly identify the problem. Alternatively, a quick look at the configuration, plus remembering that HDLC is the default serial encapsulation, can confirm whether the encapsulations are mismatched. The solution is simple: Reconfigure one of the two routers to match the other router's **encapsulation** command.

The other two root causes require a little more discussion to understand the issue and determine if they are the real root cause. The next two sections take a closer look at each.

Keepalive Failure

The router *keepalive* feature helps a router notice when a link is no longer functioning. Once a router believes the link no longer works, the router can bring down the interface, allowing the routing protocol to converge to use other routes it they exist.

The keepalive function on an interface causes routers to send keepalive messages to each other every keepalive interval, defaulting to 10 seconds. For instance, on a serial link between R1 and R2, R1 sends a keepalive message every 10 seconds, and R2 expects to receive those keepalive messages every 10 seconds. If R2 fails to receive the keepalive messages for a set number of consecutive keepalive intervals (usually three or five intervals), R2 believes R1 has failed, and R2 changes the link to an up/down state. The keepalive process happens in both directions as well—R1 sends keepalives with R2 expecting to receive them, and R2 sends keepalives with R1 expecting to receive them.

A keepalive mismatch occurs when one router has keepalives enabled and one router does not. That combination is a mistake, and should not be used. Note that this keepalive mismatch mistake only breaks HDLC links; the PPP keepalive feature prevents the problem. Figure 13-23 shows one such example with HDLC and with R1 mistakenly disabling keepalives.

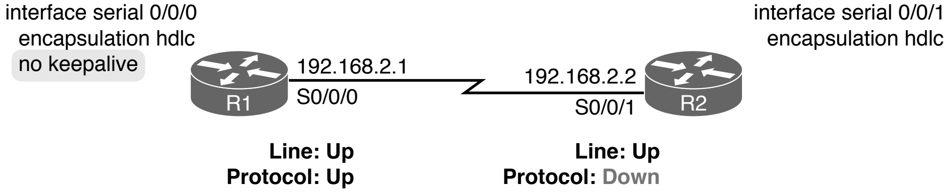


Figure 13-23 *Results when Using HDLC with a Keepalive Mismatch*

Note that the router interface that disables keepalives remains in an up/up state. In the scenario shown in Figure 13-23, R2's interface fails because

- R1 does not send keepalive messages, because keepalives are disabled.
- R2 still expects to receive keepalive messages, because keepalives are enabled.

You can verify the keepalive setting by looking at the configuration or by using the **show interfaces** command. The examples in this chapter list several examples of the **show interfaces** command that happen to list the text "Keepalive set (10 second)," meaning that keepalives are enabled with a 10-second interval. R1 would list the text "Keepalive not set" in this case.

PAP and CHAP Authentication Failure

As mentioned earlier, a failure in the PAP/CHAP authentication process results in both router interfaces failing to an up and down state. As shown in Examples 13-6 and 13-7, you can use the **show interfaces** and **show ppp all** commands to look further into the status of the PPP authentication process. By doing so, you can isolate and discover the root cause of why the interface is in an up/down state, ruling out or ruling in PPP authentication as the root cause.

Another deeper method to troubleshoot PPP authentication problems uses the **debug ppp authentication** command.

CHAP uses a three-message exchange, as shown back in Figure 13-14, with a set of messages flowing for authentication in each direction by default. If you enable the debug, shut down the link, and bring it back up, you will see debug messages that match that three-way exchange. If authentication fails, you see a failure message at the point at which the process fails, which may help you decide what specifically needs to be fixed.

Example 13-10 shows the three related debug messages when a link comes up. The network connects R1's S0/0/0 to router R2. The example extracts the three related debug messages from what would be a few dozen debug messages, so you would have to look for these. However, the output highlights the important parts of the process as seen back in Figure 13-14, as follows:

1. The "O" refers to output, meaning that this local router, R1, has output (sent) a Challenge message. Note the "from R1" at the end of the debug message, stating who the message is from.
2. The "I" refers to input, meaning that this local router, R1, has input (received) a Response message. Note the "from R2" at the end of the line.
3. The "O FAILURE" refers to R1 sending out a Failure message, telling R2 that the authentication process failed.

Example 13-10 *Debug Messages on Router R1 Confirming the Failure of CHAP*

```
R1# debug ppp authentication
PPP authentication debugging is on
! Lines omitted for brevity
*Nov 18 23:45:48.820: Se0/0/0 CHAP: O CHALLENGE id 1 len 23 from "R1"
*Nov 18 23:45:48.820: Se0/0/0 CHAP: I RESPONSE id 1 len 23 from "R2"
*Nov 18 23:45:48.820: Se0/0/0 CHAP: O FAILURE id 1 len 25 msg is "Authentication
  failed"
```

While using a **debug** command may tell us something about the problem, it does not always point to the specific command that is misconfigured. In this case, the fact that both routers send at least one CHAP message implies that both router interfaces can send frames, and that they have enabled CHAP. It looks more like R1 has rejected the hashed password supplied by R2. Note that this example was built by changing the **username** command to have an incorrect password, so that the CHAP process worked but the authentication was rejected.

Troubleshooting Layer 3 Problems

This chapter suggests that the best starting place to troubleshoot serial links is to ping the IP address of the router on the other end of the link—specifically, the IP address on the serial link. Interestingly, the serial link can be in an up and up state but the ping can still fail because of Layer 3 misconfiguration. In some cases, the ping may work but the routing protocols might not be able to exchange routes. This short section examines the symptoms, which differ slightly depending on whether HDLC or PPP is used and the root cause.

First, consider an HDLC link on which the physical and data link details are working fine. In this case, both routers' interfaces are in an up and up state. However, if the IP addresses configured on the serial interfaces on the two routers are in different subnets, a ping to the IP address on the other end of the link will fail because the routers do not have a matching route. For example, consider an example with a working HDLC link with the IP addresses shown earlier in Figure 13-23. Then, if R1's serial IP address remained 192.168.2.1, and R2's was changed to 192.168.3.2 (instead of 192.168.2.2), still with a mask of /24, the two routers would have connected routes to different subnets. They would not have a route matching the opposite router's serial IP address.

Finding and fixing a mismatched subnet problem with HDLC links is relatively simple. You can find the problem by doing the usual first step of pinging the IP address on the other end of the link and failing. If both interfaces have a status of up/up, the problem is likely this mismatched IP subnet.

For PPP links with the same IP address/mask misconfiguration, the ping to the other router's IP address actually works. However, the IP subnet mismatch still prevents EIGRP and OSPF neighbor relationships from forming, so it is still a good idea to follow the rules and put both serial interface IP addresses in the same subnet.

PPP makes the ping work with the mismatched subnet by adding a host route, with a /32 prefix length, for the IP address of the other router. Example 13-11 shows the working PPP link with addresses in different subnets.

NOTE A route with a /32 prefix, representing a single host, is called a *host route*.

Example 13-11 *PPP Allowing a Ping over a Serial Link, Even with Mismatched Subnets*

```
R1# show ip route
! Legend omitted for brevity
      192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.1.0/24 is directly connected, GigabitEthernet0/0
L        192.168.1.1/32 is directly connected, GigabitEthernet0/0
      192.168.2.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.2.0/24 is directly connected, Serial0/0/0
L        192.168.2.1/32 is directly connected, Serial0/0/0
      192.168.3.0/32 is subnetted, 1 subnets
C        192.168.3.2 is directly connected, Serial0/0/0

R1# ping 192.168.3.2
```

```
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.3.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/2/4 ms
```

The first highlighted line in the example shows the normal connected route on the serial link, for network 192.168.2.0/24. R1 thinks this subnet is the subnet connected to S0/0/0 because of R1's configured IP address (192.168.2.1/24). The second highlighted line shows the host route created by PPP, specifically for R2's new serial IP address (192.168.3.2). (R2 will have a similar route for 192.168.2.1/32, R1's serial IP address.) So, both routers have a route to allow them to forward packets to the IP address on the other end of the link, even though the other router's address is in a different subnet. This extra host route allows the ping to the other side of the serial link to work in spite of the addresses on each end being in different subnets.

Table 13-7 summarizes the behavior on HDLC and PPP links when the IP addresses on each end do not reside in the same subnet but no other problems exist.

Table 13-7 Summary of Symptoms for Mismatched Subnets on Serial Links

Symptoms When IP Addresses on a Serial Link Are in Different Subnets	HDLC	PPP
Does a ping of the other router's serial IP address work?	No	Yes
Can routing protocols exchange routes over the link?	No	No

Chapter Review

One key to doing well on the exams is to perform repetitive spaced review sessions. Review this chapter's material using either the tools in the book, DVD, or interactive tools for the same material found on the book's companion website. Refer to the "Your Study Plan" element for more details. Table 13-8 outlines the key review elements and where you can find them. To better track your study progress, record when you completed these activities in the second column.

Table 13-8 Chapter Review Tracking

Review Element	Review Date(s)	Resource Used
Review key topics		Book, DVD/website
Review key terms		Book, DVD/website
Repeat DIKTA questions		Book, PCPT
Do labs		Blog
Review memory tables		Book, DVD/website
Review config checklists		Book, DVD/website
Review command tables		Book

Review All the Key Topics

Key Topic

Table 13-9 Key Topics for Chapter 13

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List	Comparison of PPP LCP and NCP	341
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Figure 13-14	Example of messages sent by CHAP	343
Figure 13-16	Sample PAP configuration	346
List	MLPPP major configuration concepts	349
Figure 13-21	Sample MLPPP configuration	350

Key Terms You Should Know

leased line, telco, serial link, WAN link, T1, DS0, DS1, T3, customer premises equipment, CSU/DSU, serial cable, DCE, DTE, HDLC, PPP, CHAP, PAP, IP Control Protocol, keepalive, Link Control Protocol, Multilink PPP

Command References

Tables 13-10 and 13-11 list configuration and verification commands used in this chapter. As an easy review exercise, cover the left column in a table, read the right column, and try to recall the command without looking. Then repeat the exercise, covering the right column, and try to recall what the command does.

Table 13-10 Chapter 13 Configuration Command Reference

Command	Description
encapsulation {**hdlc** | **ppp**}	Interface subcommand that defines the serial data-link protocol
[**no**] **shutdown**	Administratively disables (**shutdown**) or enables (**no shutdown**) the interface in whose mode the command is issued
clock rate *speed*	Serial interface subcommand that, when used on an interface with a DCE cable, sets the clock speed in bps
bandwidth *speed-kbps*	Interface subcommand that sets the router's opinion of the link speed, in kilobits per second, but has no effect on the actual speed
description *text*	Interface subcommand that can set a text description of the interface
ppp authentication {**pap** | **chap**}	Interface subcommand that enables only PAP or only CHAP authentication
username *name* **password** *secret*	Global command that sets the password that this router expects to use when authenticating the router with the listed hostname
ppp pap sent-username *name* **password** *secret*	Interface subcommand that defines the username/password pair sent over this link when using PAP authentication

13

Command	Description
interface multilink *number*	Creates a multilink interface and moves the user to interface configuration mode on that interface
ppp multilink	Interface subcommand that enables MLPPP features
ppp multilink group *number*	Interface subcommand that associates the interface with a particular multilink interface and multilink group

Table 13-11 Chapter 13 EXEC Command Reference

Command	Description
show interfaces [*type number*]	Lists statistics and details of interface configuration, including the encapsulation type
show interfaces [*type number*] **description**	Lists a single line per interface (or if the interface is included, just one line of output total) that lists the interface status and description
show ip interface brief	Lists one line of output per interface, with IP address and interface status
show controllers serial *number*	Lists whether a cable is connected to the interface, and if so, whether it is a DTE or DCE cable
show ppp multilink	Lists detailed status information about each of the PPP multilink groups configured on the router
show ppp all	Lists one line of status information per PPP link on the router, including the status for each control protocol
debug ppp authentication	Generates messages for each step in the PAP or CHAP authentication process
debug ppp negotiation	Generates **debug** messages for the LCP and NCP negotiation messages sent between the devices

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