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Cisco[®]

A Beginner's Guide

*Toby J. Velte, Ph.D.
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A Beginner's Guide

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A Beginner's Guide

Fifth Edition

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**For my family and friends—you are awesome.
To my sons, Luke, Jack, and Joey—I am immensely
proud of you.**

—ATV

**To my children, Connor and Olivia,
for showing me how fun learning can be.**

—TJV

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At a Glance

Part I Cisco Overview

1	Cisco and the Internet	3
2	Networking Primer	35
3	Cisco Certifications	89

Part II Cisco Internetworking Tools

4	Routing Overview	123
5	Routing Platforms	145
6	Configuring Routing	183
7	Switches	223
8	Security Overview	273
9	Access Control	319
10	Security Appliances	353
11	Cisco Unified Wireless	403

Part III Cisco Business Solutions		
12	Cisco VoIP	453
13	Data Center and Virtualization	489
14	Cisco Content Networking and Video Solutions	521
Part IV Designing Cisco Networks		
15	Routing Protocols	557
16	Network Management	603
17	Network Design Process	661
18	Troubleshooting Cisco Networks	709
	Index	757



Contents

Acknowledgments	xix
Introduction	xxi

Part I

Cisco Overview

1 Cisco and the Internet	3
Internetworking	4
Cisco's Position in the Computer Industry	6
The Internet Landscape	8
Internetworking's Five Major Device Types	9
Basic Internetwork Topologies	12
Internetwork Players	14
Internetworking Protocols	16
Routing vs. Switching	17
Other Internetworking Trends	19
Cisco's Offerings	21
Competition	22
Who Wants to Be a Millionaire?	22
Cisco Solutions	27
Cisco Innovation	31

2 Networking Primer	35
Bits and Bytes	36
How Computers Understand Data	36
OSI Reference Model	40
The Seven-Layer Stack	40
OSI Implementation by Layer	43
Network Technologies	44
Ethernet	45
Gigabit, 10 Gigabit, 40 Gigabit, and 100 Gigabit Ethernet	47
Wireless	48
WAN Technologies	51
Dial-in Technologies	52
WAN Trunk Technologies	56
TCP/IP	59
TCP/IP Messaging	60
The Transport Layer	66
IP Addressing	70
The IP Address Format	70
IP Address Classes	73
Private Addressing	74
Subnetting	75
IP Version 6	81
Putting It All Together	88
3 Cisco Certifications	89
Certifications Overview	91
Career Certifications and Paths	92
Entry Level	92
Associate	93
Professional	93
Expert	93
Architect	94
Specialist	95
Certification Tracks	95
Routing and Switching	95
Design	96
Network Security	98
Wireless	99
Voice	101
Service Provider	103
Service Provider Operations	103

Technician Certifications	105
CCT Routing & Switching	106
CCT Data Center	106
CCT TelePresence	107
Specialist Certifications	107
Collaboration Certifications	107
Data Center Certifications	109
Operating System Software (Cisco IOS XR Specialist)	113
Security Certifications	114
Video Certifications	116
Where to Get Help	119
Websites	119
Classes	120

Part II

Cisco Internetworking Tools

4 Routing Overview	123
How Routers Work	126
Routing for Efficiency	126
Routers and the Internet	126
Optical Routers	129
IOS: The Internetwork Operating System	132
Router Security	139
Router Administrative Security	139
Router Network Security	139
Router Passwords	141
5 Routing Platforms	145
Router Hardware	146
Router Memory	147
Router Ports and Modules	149
Cisco Router Models	152
Essential Files	158
Communicating with IOS	158
Meet IOS 12.4T (A.K.A. the “OLD” IOS)	160
IP Mobility	162
Meet IOS Release 15 (A.K.A. the “New” IOS)	164
Meet NX-OS	168
Meet IOS XR	169
Using IOS Commands	170
Overview of Router Modes	176
The Configuration File’s Central Role	178

6	Configuring Routing	183
	Communicating with a Router	184
	The Console Port	185
	The Auxiliary Port	188
	SSH/Telnet	188
	The HTTP Server User Interface	190
	Essential Router Commands	191
	Password Recovery	193
	Recovering Enable Passwords	193
	Recovering Passwords from Older Cisco Routers	197
	Step-by-Step Router Configuration	198
	Setup Mode	198
	Giving a Router an Identity	202
	Examining Device Status	203
	Cisco Discovery Protocol	204
	Changes in IOS from Release 12.4 to Release 15	206
	Using Applications to Help Configure Routers	209
	Cisco Configuration Professional	209
	What's Next	222
7	Switches	223
	Network Topologies	225
	The Importance of Network Domains	229
	Cabling Defines Network Speed and Distance	232
	Cisco Switches	240
	How an Individual Switch Works	240
	Switched Networking Basics	242
	Designing Switched Internetworks	243
	VLANs	248
	SmartOperations	250
	Cisco's Switched Network Products	251
	Configuring and Managing Cisco Switches	257
	Cisco Network Assistant	258
	Features	259
	Installation	259
	Views	260
	Interaction	262
	Communities	264
	Using CNA	267
8	Security Overview	273
	Overview of Network Security	276
	Traffic-Based Security	277
	User-Based Security	278

Authentication, Authorization, and Accounting	282
Overview of the AAA Model	283
How AAA Works	290
Dynamic Access Lists	310
Lock-and-Key Using a Local User Database	311
Best Practices	312
Reviewing Logs	312
Securing Protocols	314
Physical Security	315
Keep Current on Your Devices	317
9 Access Control	319
Cisco SecureX Architecture	320
Overview	320
Cisco SecureX Framework	321
Identity Management	324
Cisco TrustSec	325
Cisco Secure Access Control Server (ACS)	326
Cisco Network Admission Control (NAC)	327
Identity Services Engine (ISE)	330
The Access Lists	332
Network Address Translation	336
Virtual Private Networks	338
What Composes a VPN?	339
Cisco's Solution	342
Digging a Tunnel	345
Summary	351
10 Security Appliances	353
Firewalls	354
Firewall Basics	354
How Firewalls Work	359
The IOS Firewall Feature Set	368
ASA Firewall OS's Adaptive Security Algorithm	379
ASA OS 9	385
Adaptive Security Appliances	386
Access Routers	391
Overview	392
Models	392
Cisco Cloud Web Security	393
How Cisco Cloud Web Security Works	393
Example of Cisco Cloud Web Security	393
Cisco Security Manager	394

Integrated Services Router	394
The Right Tool for the Right Job	395
Models	395
Specialized Modules	397
Firewall Services Module and ASA Service Modules	397
Cisco Wireless Service Module (WiSM2)	399
Intrusion Prevention System	400
Summary	402
11 Cisco Unified Wireless	403
Introduction to Wireless Networking	404
The Roots of Wireless Networking	404
Benefits	405
WLANs	407
How They Work	408
Architecture	410
Technologies	413
Cisco Wireless Networking	420
Philosophy	421
Cisco's Offerings	422
Access Point Configuration	435
Site Survey	435
AP Placement	436
Interference	436
Initial Autonomous AP Settings	437
Security	441
Antenna Placement	450
Summary	450

Part III

Cisco Business Solutions

12 Cisco VoIP	453
VoIP	454
Introduction to VoIP	455
Building VoIP Networks	457
H.323	465
SIP	469
SCCP	470
Implementation	471
Cisco Unified Communications	474
Cisco Unified Communications Manager	474
Cisco Business Edition	480
IP Phones	481

Cisco Unified Communications Gateways	483
TelePresence	483
Collaborations	485
Summary	487
13 Data Center and Virtualization	489
Storage Area Networks	491
Storage Needs	491
Fibre Channel	492
Other SAN Protocols	495
Designing and Building a SAN	496
Cisco MDS Switches and Directors	502
Technologies	502
Hardware	508
Software	512
Private Cloud	517
Cisco Unified Computing System	518
Cisco Intelligent Automation for Cloud	520
14 Cisco Content Networking and Video Solutions	521
Content Delivery Networks	522
Meet the CDN	522
Cisco's Solution	525
ACNS	533
Wide Area Application Engine	534
Cisco Wide Area File System	536
Caching	538
Web Cache Communication Protocol	539
Freshness	539
Content Engine Caching	540
Video	548
Video Entertainment	549
Video Collaboration	551
Video Intelligence	552

Part IV

Designing Cisco Networks

15 Routing Protocols	557
Overview of Routing Protocols	558
Routing Protocol Basics	559
Routing Protocol Architectures	578
How Routing Protocols Are Implemented	582

Overview of Cisco Routing Protocols	588
Cisco's Interior Gateway Routing Protocol	588
Configuring RIP 2	594
Configuring Open Shortest Path First	595
Border Gateway Protocol	597
Multiprotocol Label Switching	599
Cisco's Routing Protocol Strategy	602
16 Network Management	603
Overview of Network Management	604
The Evolution of Management Tools	606
Network Management Tools Today	608
Trends in Enterprise System Management	612
SNMP Is IP's Common Management Platform	614
What Is SNMP?	614
SNMP Polling and Managed Objects	615
The MIB	616
Polling Groups and Data Aggregation	622
SNMP Commands	625
Thresholds	625
Events and Traps	626
RMON: Hardware Probes for Switched Networks	628
NetFlow: Software Traffic Flow-Recording	632
Cisco's SNMP and RMON Implementations	637
Cisco Prime Infrastructure	641
Cisco Network Assistant	646
Features	646
Installation	647
Views	648
Interaction	650
Communities	651
Using CNA	654
Summary	660
17 Network Design Process	661
Internetwork Design Basics	662
Internetworking Basics Reviewed	662
The Three-Layer Hierarchical Design Model	669
Design Methods	674
Designing to Fit Needs	679
Understanding Existing Internetworks	681
Characterizing Networks	682

Cisco Network Designs	687
Logical Network Design	687
Campus Network Designs	694
18 Troubleshooting Cisco Networks	709
The Mechanics of Network Troubleshooting	710
Network Troubleshooting Methods	711
Troubleshooting Host IP Configuration	714
Isolating Connectivity Problems	719
Troubleshooting WAN Links	734
Client-Server VPNs	740
Troubleshooting Cisco Hardware	742
Inspecting Devices	742
The Reboot Test	744
Troubleshooting Network Configurations	745
Wireless Networks	745
Troubleshooting Network Performance	753
Index	757

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Introduction

The volume in your hands is the fifth edition of the worldwide, best-selling introduction to Cisco networking. Since its introduction, each edition of this book has sold tens of thousands of copies worldwide. It is used as courseware in a variety of schools and has been translated into numerous languages, including Spanish, Chinese, Czech, Japanese, Korean, Serbian, Arabic, and German. This level of interest confirms what you already know—Cisco is, and likely will continue to be, a huge player in the communications industry, and people want to better understand how this behemoth works.

Although six years have passed since writing the fourth edition, this book has remained quite popular, and we felt that another refresh was in order. As with the fourth edition, we took the book apart and reexamined it, chapter by chapter. Although we were hard-pressed to find material we thought was no longer pertinent, we certainly found new subjects that just had to be discussed. For instance, Cisco has really kicked up its collaboration efforts with its Cisco Unified Communications solution. With a whole new philosophy and line of products, it's something that needed coverage. In the fourth edition, we really got into the topic of Voice over IP (VoIP). Although this remains pertinent, Cisco has developed the technology into different ways to communicate and collaborate—be it voice, video, or through its own social media offerings. Also, because wireless has become such an indispensable part of networks, that content has been bolstered as well, including configuration details. It's no surprise that security continues to be an important topic, so we also beefed up that content. But at the heart of Cisco's products and technologies are its switches and routers—and we haven't shoved them aside for the new stuff. Of course, all the chapters were updated to cover the latest hardware and software offerings from Cisco.

So what's the reason for all of this work and revision? We continue to think there is an enormous need by networking professionals for a clear, concise introduction to Cisco and its technologies. What is truly needed is a simple understanding of networking and Cisco's role in networking to make sense of many IT issues. So the story begins . . .

Who Should Read This Book

This book is designed for anybody new to internetworking. It covers what one might refer to as the Internet's technical infrastructure. The software on your desktop or laptop—the web browser, FTP software, or instant messenger—is only the tip of the iceberg. Over the past 30 years, an ever-growing group of dedicated computer scientists, telecommunications engineers, and programmers has been busy designing and building a global infrastructure that is revolutionizing commerce and culture alike. Internetworking has taken on a language all its own—separate even from that used by the computer industry at large.

This book is for aspiring professionals interested in learning about the networking giant, managers in the computing industry whose knowledge of internetworking is weak, computer platform and software pros, and even individuals in the general public with a taste for technology.

This book is for those interested in the Internet and internetworking, not just in Cisco. Technology basics are covered generically before delving into Cisco particulars. Cisco is used for all examples in this book because it has the biggest and most comprehensive product line in the industry and is still the most important player in the field.

For those of you interested in pursuing Cisco certification, read this book to be introduced to industry background, concepts, terms, and technology. Then go on to a test preparation book to nail down your CCNA test.

What This Book Covers

The following is a chapter-by-chapter breakdown of the subject matter covered in this book.

Part I: Cisco Overview

Chapter 1: Cisco and the Internet The Internet represents the biggest and fastest economic change in history, and sooner or later all our lives will be profoundly affected by it (if they haven't been already). This chapter surveys the Internet as a phenomenon, with a particular eye toward Cisco Systems and how its IOS operating software has vaulted the company to a position among the computer industry elite, alongside Apple, Microsoft, and IBM. The internetworking industry is outlined, and how Cisco's product line matches up to industry niches is explained.

Chapter 2: Networking Primer Modern internetworking is the culmination of dozens of sophisticated technologies. This chapter explains things from the wire up,

starting with electrons passing across cables, up through binary bits and bytes. The major LAN technologies such as Ethernet and Wi-Fi are explained, right down to how they differ and which are rising or fading from use, including high-speed backbone technologies such as ATM, MPLS, and Ethernet. The seven-layer Open Systems Interconnection (OSI) reference model is explained, including the inner workings of the TCP/IP protocol suite—the software used to run the Internet. You'll learn the difference between connection-oriented and connectionless networking, and how domain names are translated to numerical IP addresses. The important networking fundamentals of IP addressing and subnet masks are explained in detail. Broadband technologies such as DSL, cable, and ISDN are covered, as are WAN trunk technologies such as T1 and T3, Frame Relay, and MPLS.

Chapter 3: Cisco Certifications Like Microsoft and other tech powerhouses, Cisco has a full-fledged certification program for technicians working on their products. This chapter details the subjects and skill levels, and sorts out such details as how Cisco certifications for design differ from the ones already in place for network support, and so forth. Complete explanations are given of exam objectives for each certification. We also highlight a number of ways you can find help preparing for the Cisco exams. This chapter is a must read for anyone interested in pursuing a career in internetworking, or faced with recruiting and managing Cisco certified personnel.

Part II: Cisco Internetworking Tools

Chapter 4: Routing Overview This chapter focuses on Cisco routing basics. Routing is the bedrock of Cisco's technologies. And we cover basic router hardware components from the printed circuit board up through the CPU, explaining how network administrators can log in to Cisco routing devices to work on them, even rebooting in to ROM to perform such basic tasks as password recovery. The major software components in Cisco routing devices are also surveyed, including the Cisco IOS command interface and feature sets. Cisco's router product line is reviewed here, including some tips on how to select the best routing device to solve a particular internetworking problem.

Chapter 5: Routing Platforms There are many ways in which Cisco devices transfer network traffic around the Internet, and this chapter takes a close look at those devices, specifically router hardware. This is the chapter in which we look at the router itself, and talk about its components and Cisco's router product line. In addition to the hardware, we'll introduce you to the important software components, including the configuration file and the operating systems—IOS and IOS XR—which are the heart of these devices.

Chapter 6: Configuring Routing In this chapter we delve deeper into the heart of the router and discuss how, specifically, the device is configured. We'll talk about the different ways you can connect with the router and what you need to say to get the router to do what you want. The chapter will show you how to use the command line, as well as use the Cisco Configuration Professional application for an easy, graphical user interface method of router configuration.

Chapter 7: Switches The so-called *access layer* is where host devices such as PCs and servers plug in to internetworks. This chapter explains internetwork topology basics, cabling specifications, what bandwidth is, and what distinguishes collision and broadcast domains. High-end LAN backbone switches are also covered, from the perspective of one of the most important subjects in the industry today—whether to design routed or switched networks. The more technical dimensions of switched networking are introduced, including switching protocols, virtual LANs (VLANs), and multilayered switching. Cisco's switch product lines are reviewed.

Chapter 8: Security Overview Security is a hot topic—certainly one that can (and does) fill books all on its own. In this chapter we'll give you a basic overview of security matters, including traffic-based security (which applies to the traffic from your applications) and user-based security (which is used to set and enforce passwords to access networks and authorizations to use network resources). This chapter first covers the underlying industry standards for security, especially the AAA (Authentication, Authorization, and Accounting) standard. AAA is covered at the command level. Cisco offers several user and device-based security products and allows for implementation of many network security protocols: primarily RADIUS (an industry standard), its proprietary TACACS+, and 802.1X. These are reviewed in detail. Because security is such an important issue—and such a moving target—we'll also talk about best practices to ensure you are meeting your network security needs.

Chapter 9: Access Control Although it's necessary to keep the bad guys out of your network, it is equally as important to ensure the good guys can get in. To that end, Cisco has developed a number of technologies and techniques to ensure network security, while providing a mechanism through which authorized users can gain access to the network. In this chapter we will talk about such Cisco technologies as SecureX and TrustSec. We'll also talk about the access control list, Cisco's line of Access Control Servers, and its implementation of virtual private networks (VPNs).

Chapter 10: Security Appliances There was a time when a discussion of Cisco security devices would have been about one topic—firewalls. In this chapter, we talk about Cisco's firewalls, specific models, how they are configured, and how they are managed. Although the firewall is still a huge subject in the world of security devices, it is no longer the only game in town. Cisco has broadened its lineup with Adaptive Security Appliances and Integrated Services Routers. In addition, we'll also discuss what Cisco has to offer for cloud-based security needs as well as specialized modules that can be added to modular switches.

Chapter 11: Cisco Unified Wireless Until recently, the only way to connect a client to an internetwork was via a thin piece of cable snaking into the back of the PC. As efficient as this has been, it was only a matter of time before someone figured out how to cut the cord and let devices communicate with each other in a wireless medium. And, as it happens—especially in this age of smartphones and tablets—wireless is critical. In this chapter, we cover the fundamentals of wireless networking, and then delve into Cisco's solution. Wireless networking is no longer a “gee-whiz” technology. Today it is mandatory. Wireless networking brings the power of computing

and network connectivity to a range of useful applications and is beneficial to fields from healthcare to education and everything in between. Cisco offers solutions for both wireless LANs and wireless WANs with its Aironet and Airespace series. We'll discuss and then show you how to configure them.

Part III: Cisco Business Solutions

Chapter 12: Cisco VoIP Networks and internetworks are great ways to move data from place to place. However, it isn't just text files and the fourth-quarter earnings statements that can traverse a Cisco-based network infrastructure. Thanks to Voice over IP (VoIP), your organization can use its internetwork as the backbone of your telecommunications system. Additionally, customers who need to get in contact with your organization will benefit from Cisco Unified Communications. It's a new way to deploy VoIP that delivers rich, robust tools in voice, video, and overall intelligence.

Chapter 13: Data Center and Virtualization With benefits of the Information Age comes a hefty issue—where do we *keep* all that information? In this chapter, we examine storage area networks (SANs), which are akin to LANs but are built with the goal of information storage. We'll talk about SAN designs and construction and then look at the products Cisco offers for its SAN solutions. Another big topic in the world of computing and networking these days has been “the cloud.” In this chapter we will talk about Cisco's offerings for private cloud computing systems as well as mechanisms for virtualization.

Chapter 14: Cisco Content Networking and Video Solutions These days, organizations offer more and richer information on their websites. However, as more people request data from various locations, the need arises to direct the client to the closest, fastest repository of that information. Content delivery networks (CDNs) help resolve congested networks because clients are given the data they need from the best location. This chapter covers CDN basics, along with Cisco's product line for this technology. Additionally, we cover the topic of caching, a way in which service providers and large organizations can maintain frequently accessed web information so that it can be delivered without having to repeatedly go to the Internet to access it.

Part IV: Designing Cisco Networks

Chapter 15: Routing Protocols Large internetworks, or the Internet, for that matter, wouldn't be possible without routing protocols. This chapter covers fundamental problems confronting any internetwork, as well as how routing protocols are used to adapt to shifting traffic patterns, emerging problems, and topology changes. Basic routing protocol technology is covered here, as are the various major routing protocols in use today—both open standard protocols (RIP, OSPF, BGP) and Cisco-proprietary protocols (IGRP and EIGRP). Cisco's routing protocols are overviewed, down to the command level where routing metrics are set to modify network behavior to meet enterprise requirements.

Chapter 16: Network Management Network management has become a major issue as internetworks have grown in size and complexity. This chapter

covers the standards and technologies that underlie network management systems: the Simple Network Management Protocol (SNMP), remote monitor instrumentation (RMON), and the management information base (MIB). Issues surrounding network management standards are covered, as is Cisco's approach to implementing them. SNMP configuration is introduced at the command level, and Cisco's premiere network management software products—Cisco Prime Infrastructure and Cisco Network Assistant—are also reviewed.

Chapter 17: Network Design Process There are basics that must be covered when considering any network design decision, whether for a whole new internetwork or a modest expansion of an existing one. The classic three-layer hierarchical design model is reviewed in terms of what to look for in the access, distribution, and backbone layers. Key design subjects such as topology meshing and load balancing are reviewed. How to perform a comprehensive network needs analysis and how to translate it into design solutions using Cisco products is explained, covering such design factors as routing protocols, address design, routing versus switching, WAN services, and traffic load-balancing.

Chapter 18: Troubleshooting Cisco Networks You've arrived as a network pro when you can troubleshoot an internetwork. This chapter surveys typical internetwork problems and the proper methodology for diagnosing and fixing them. Key Cisco IOS troubleshooting commands are reviewed in terms of how to handle connectivity issues, performance bottlenecks, and other problems. Particular attention is paid to how to track down and isolate configuration problems, how to tune routing protocol metrics, and how to troubleshoot WAN services such as serial line links. Additionally, we cover common wireless network problems, along with how to troubleshoot network performance issues.

How to Read This Book

This book can be picked up and read from the beginning of any chapter. Chapters covering technology start out with the basics and give explanations from the standpoint of the technology's historical background, how it developed, and what the issues and trends surrounding it are. Only then is Cisco specifically covered in terms of IOS commands, Cisco software tools, and Cisco hardware and software products.

This book doesn't try to reinvent the wheel by publishing yet another glossary on internetworking terms and acronyms. Every term introduced in this book is defined and explained in context. But the book should be read with the reader's browser pointed to Cisco's website at www.cisco.com. Although this book stands on its own, it never hurts to browse around to help reinforce newly learned subject matter. Cisco's website contains a wealth of product illustrations, white papers, and other materials. In particular, readers of this book should visit Cisco's excellent online glossary of Cisco Internetworking Terms and Acronyms:

[http://docwiki.cisco.com/w/index.php?title=Category:Internetworking_Terms_and_Acronyms_\(ITA\)](http://docwiki.cisco.com/w/index.php?title=Category:Internetworking_Terms_and_Acronyms_(ITA))



PART I

Cisco Overview





CHAPTER 1

Cisco and the Internet

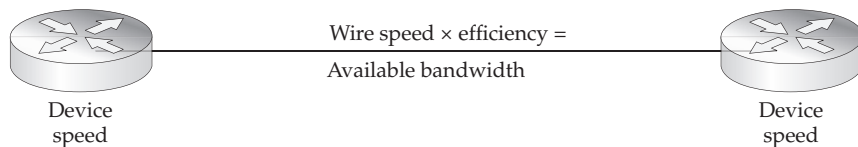


The Internet is amazing. There's just no other word to describe a technology that few had even heard of 20 years ago, yet now dominates so much of our collective consciousness. The gold fever surrounding the Internet makes the 1849 California gold rush seem insignificant in comparison. You've no doubt heard the analogies and the clichés—the Internet is the fastest-growing market in history, the fastest-growing technology in history, and the first truly global, real-time marketplace of goods, services, and ideas. The Internet has brought and will continue to bring profound change to all sectors, from business to education to entertainment. The Internet is the information superhighway—that's our road to the future.

Internetworking

The most surprising thing about all the breathless web hype is that most of it is true. Most research houses estimate Internet growth at about 18 percent annually. In fact, we reached the two-billion-user mark sometime in 2010, and this number will continue to rise. There are now 225 million registered Internet domain names, and there are billions of web pages, up from just a million of them a scant 20 years ago. In 2012, advertisers spent an estimated US\$39.5 billion on Internet-based ads. No matter how tired we are of hearing this litany of numbers, it is still impressive.

Although most press coverage dotes on visible technologies, such as browsers and cellular Internet phones, the real action is in Internet infrastructure. Billions are invested by serious players who foresee a day when virtually all mass media—radio, telephone, and television—converge onto the Internet. This convergence will use the Internet as a single “pipe” through which virtually all communication will travel. There's disagreement about whether the Internet pipe will run over wireless devices, telephone lines, cable TV wires, or even satellites. In fact, it seems that, for the time being, it's all of the above. However, battle lines are being drawn every day by a multitude of businesses, and a lot of money is being invested. The bets are large, because winning the Internet infrastructure game promises untold riches.



Users connect to servers over this Internet infrastructure, yet few are aware of just how it works. Bandwidth isn't just a matter of telecommunications media running over high-speed, fiber-optic cable. The networking devices sitting at each end of the cables are every bit as important. In many situations, the speed of these devices is as big a factor in the Internet's bandwidth as telecom media.

Voice over IP (VoIP) telephony, streaming media services, videoconferencing, and server-based file storage used to be things associated with a corporate infrastructure. But let's put some names to these services as we know them today: Vonage, Netflix, Skype, and Dropbox.

None of these companies could exist in their present state without Cisco's innovations. Cisco has spent the better part of the last decade acquiring companies that produce technologies of every flavor imaginable—and found ways to integrate them within every layer of Cisco's portfolio. From uber-fast Internet backbone devices, to data-streaming management systems for Internet content providers, to corporate campuses that are wireless mobility enabled, to data centers having switches with direct integration to storage and servers, to home users with USB storage-enabled Wi-Fi routers, Cisco touches every facet of our daily lives.

This book surveys internetworking's infrastructure from the ground up, starting with the underlying technology, up through the product level. If you're a beginner, read this book and you'll know the basics of internetworking. It's written from the perspective of the premier manufacturer of internetworking technology: Cisco Systems. Because the technologies are covered generically, you'll understand the systems and components needed to make any internetwork run, not just one built from Cisco products. But make no mistake: This book is about *infrastructure*—that is, about the devices over which internetworks operate:

- **Routers** These devices route data between networks, such as local area networks (LANs), wide area networks (WANs), and metro area networks (MANs). Routers put the *inter* in internetworking. Without them, the Internet would not be possible. Routers use Internet Protocol (IP) addresses to figure out how to best route packets through internetworks.
- **Switches** These devices also forward data on and between LANs, and have replaced the hub as the de facto standard for connecting workstations and servers to the network. Switches are faster than routers, but most don't look high enough in the stack to see or use IP addresses and, therefore, don't have the capability routers do for finding paths through large internetworks. There are, however, switches that incorporate routing. They are commonly referred to as "layer 3 switches," and we'll discuss them in more detail in an upcoming chapter.
- **Firewalls** Although these can be understood simply as special routers that filter packets to secure data connections between internal and external networks, they are highly evolved security devices that examine communications between devices at many layers and then take specific actions or determine what to allow and what to block.
- **Access servers** These dedicated devices answer phone calls from remote users and connect them to the internetwork. Most access servers are used by Internet service providers (ISPs) to connect home users and small businesses to the Internet.

Collectively, these devices make up the Internet's infrastructure. The only other major ingredient is telecommunications links to make WAN connections. In this book, we'll cover each device type as it exists within Cisco's product line as well as review WAN technologies. Doing so (from the perspective of Cisco's product line) will give you a more detailed look at the inner workings of internetwork devices.

Cisco's Position in the Computer Industry

We all know that Microsoft Windows is, at this point, the world's most dominant computer operating system. But here's a pop quiz: Can you name the second most important operating system? Choose one:

- **z/OS** This is IBM's proprietary operating system that runs mainframe computers. This OS's stranglehold on the central corporate and government data centers that handle financial accounting and other sensitive transactions has been released, with estimates as high as 80 percent of mainframes today operating on Linux.
- **Unix/Linux** There are actually about a dozen proprietary versions of Unix from such computer manufacturers as Apple, Sun, HP, Compaq, Novell, and IBM. Linux is no longer the "new" kid on the block, and due to the flexibility inherent to the OS, it is hot on the heels of good-old UNIX and will soon become the predominant server operating system in enterprise-class client/server applications.
- **IOS** IOS Stands for Internetwork Operating System, and is Cisco Systems' proprietary operating system for its line of internetworking hardware.

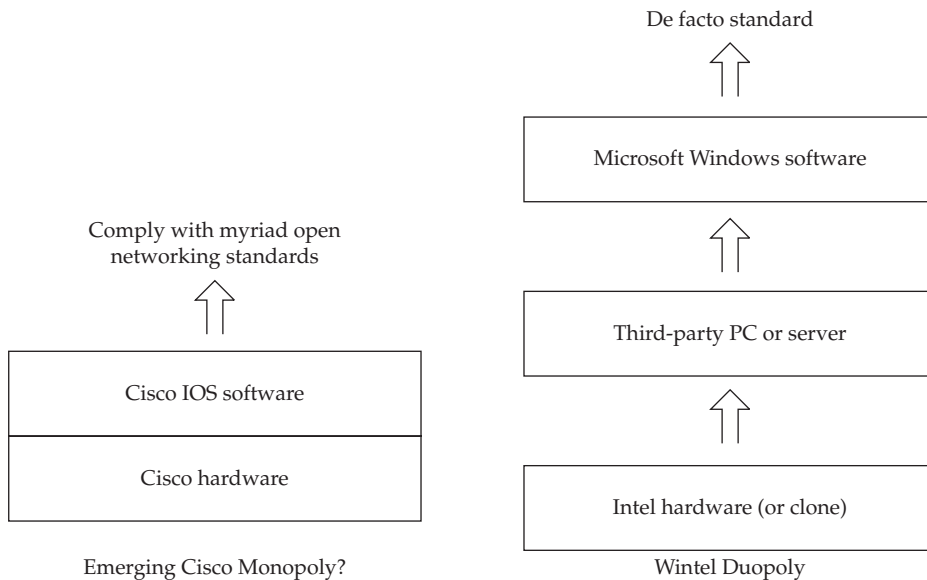
Because this is a Cisco book, this is sort of a loaded question. IOS is the second most important operating system—and by a wide margin. We assert this partly because all Unix flavors and z/OS have lost their edge. Unix, having lost market share to Microsoft Windows, Linux, and MVS, although still a mission-critical technology, has stopped growing altogether. However, the main reason IOS is so important is that Cisco has over a 77 percent share of the Internet router market, and the Internet is the fastest-growing market in history.



NOTE Cisco's IOS (Internetwork Operating System) should not be confused with Apple's iOS (formerly iPhone Operating System).

To put that in perspective, Cisco has about the same market share in router technology as Intel enjoys in Windows (or Wintel) hardware platforms. The Wintel regime has been attacked as a monopoly by competitors and the U.S. Department of Justice. Not so with Cisco. IOS is their proprietary operating system architecture, and it runs on their hardware only. This means that Cisco's market leadership garners both hardware and software revenues and gives the company total architectural control over its products.

Cisco's present position has its strengths and weaknesses compared to the Wintel duopoly. On the negative side of the ledger, Cisco products are largely used to run truly open-standard protocols, which reduces the extent to which they can leverage product architecture to assert market control. Cisco doesn't widely freeze any competitor out of design cycles to prepare products that implement emerging technologies, because the technologies implement open standards. On the positive side, Cisco is a single company that makes its own products. This contrasts favorably to Wintel, a pair of companies that rely on hundreds of PC manufacturers to deliver their respective products to a highly fragmented market.



Financially speaking, by the turn of the millennium, Cisco was riding a gravy train with biscuit wheels. Even though most people couldn't tell Cisco from Crisco, chances are some part of their life was touched by a Cisco product. Maybe their computer network at work utilized Cisco gear; maybe the ISP they used for Internet connectivity relied on Cisco gear. But the fact of the matter is that at one point in history, Cisco was the most valuable company on the face of the planet. In March 2000—less than two decades after the company was founded—the company reached a value of half a trillion dollars.

More than a year later, however, all that changed. When the dot-com bubble burst, Cisco fell hard. Many companies no longer needed Cisco's gadgets, and by the spring of 2001, Cisco faced a \$2 billion write-off. From its leadership position, with its stock trading at a high of \$146 per share in March 2000, Cisco's stock dipped to a low of just over \$8 per share in October 2002. Though Cisco fell, it didn't fall as hard as those companies that had to close up shop. Cisco has hung in there and has made a steady climb back to profitability. At the beginning of 2006, Cisco stock was trading at around \$20 per share and in mid-2007 was up as high as \$33 with revenues of \$6.6 billion.

Since the 2008 global recession began, Cisco has again leveled out and has held steadily around \$20 a share. The upshot of this lesson in finances? Cisco was down, but they were never out.

This book is not an endorsement of Cisco, however. Like any industry powerhouse, the company has its faults and is duly criticized in these pages when appropriate. But whether you're an individual mulling a career move or a manager weighing your company's Internet strategy, learning how Cisco technology works is your best possible introduction to the world of internetworking.

The Internet Landscape

The Internet isn't a single technology; instead, it's a collection of related technologies that make internetworking possible:

- **Physical media** From connectors to high-speed, fiber-optic cables, the physical links that connect everything together are the foundation of networking.
- **Network technologies** LAN protocols run what happens over the wire. The best known is Ethernet, but there are other important ones.
- **TCP/IP** The Transmission Control Protocol/Internet Protocol is what binds the Internet together. IP handles addressing, and TCP handles messaging. Also included in the Internet Protocol suite is User Datagram Protocol (UDP), which is used to send faster and timelier datagrams in a network. Internet Control Message Protocol (ICMP) is another component that is used to send error messages in a network.
- **Operational technologies** Internetworks rely on a number of underlying standards and protocols to operate themselves. Without them, internetworking wouldn't be practical.
- **Application protocols** Network applications define the kinds of useful tasks internetworks can do—from file transfers to web page downloads.

To engineer its products, the networking industry uses a seven-layer architectural guideline called the Open Systems Interconnection (OSI) reference model. It's no coincidence that the preceding list of enabling technologies more or less adheres to the OSI model, from the physical level up.

Before we proceed, a quick word to make sure our terminology is clear: The *Internet* is a global interconnection of individual internetworks. An *internetwork* is any collection of local area networks (LANs) under a single administrative regime (usually an enterprise or an Internet service provider). A private internetwork is mechanically the same as the open Internet. A *host* is a user device, such as a PC, server, mainframe, or printer. A *device* is a piece of networking equipment, such as a router. The generic terms *node* and *station* refer to both hosts and devices. A *LAN segment* is a network medium that hosts a share. An *application protocol* is a software standard that operates web browsers, file

transfers, e-mails, and other useful functions. An *intranet* is an internal internetwork operating as a private Web, with enterprise applications software used through web browsers instead of a more traditional graphical user interface (GUI) such as Microsoft Windows.

From a technical standpoint, private internetworks are composed of the same pieces as the Internet itself. The only thing that distinguishes the Internet from a large internetwork is its openness.

Internetworking's Five Major Device Types

A *switch* connects hosts to the internetwork. Switches function much like their predecessor, the network hub; however, they are fundamentally different in that they form a virtual circuit between the sending and receiving hosts. In other words, the switch's bandwidth is reserved for a single switched connection between two hosts as if it were 100 percent dedicated to that virtual circuit. Switches are able to do this by using better electronics than those used by hubs to "slice" bandwidth time into slivers—called *channels*—large enough to service each switch port. Switches have almost all but replaced hubs.

