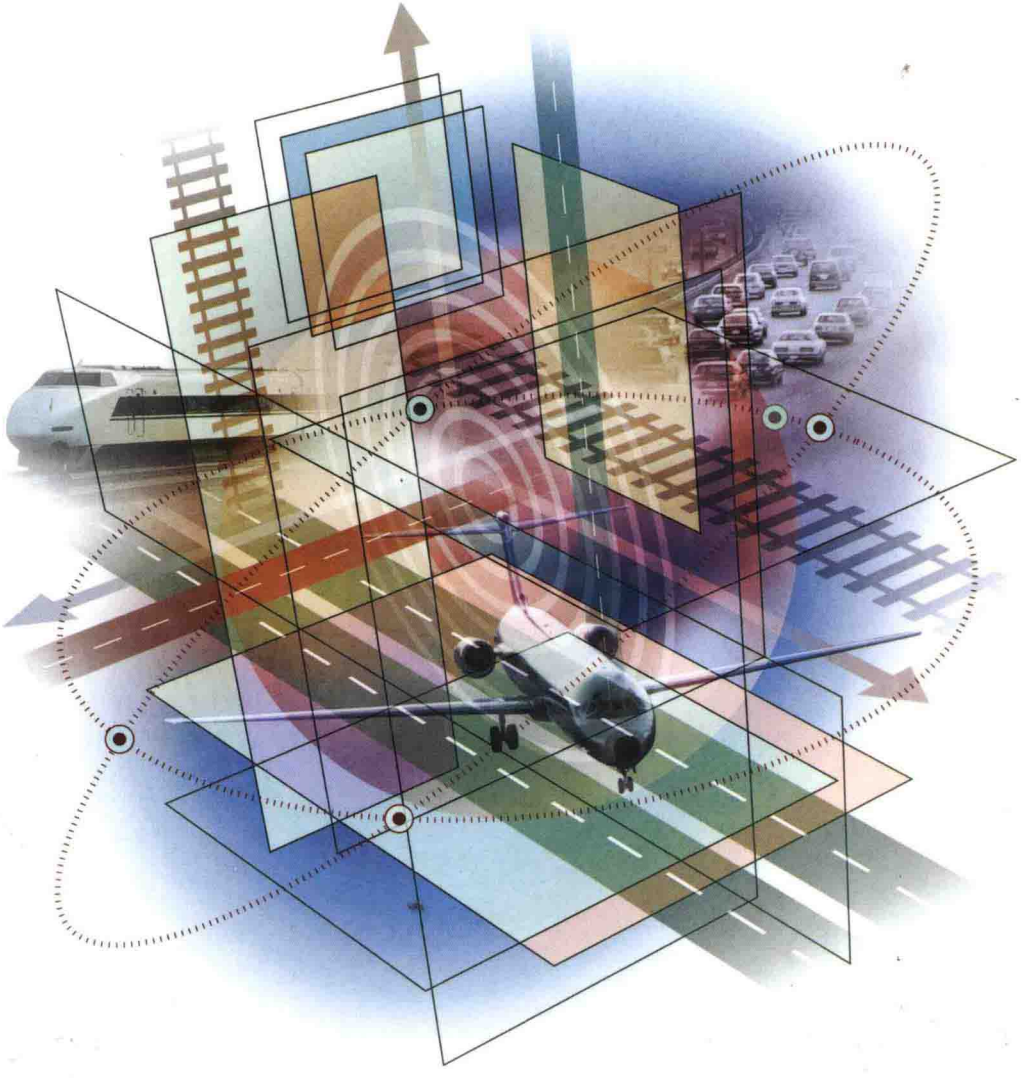
COMPUTER NETWORKING WITH INTERNET PROTOCOLS AND TECHNOLOGY



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For my loving wife
A

WEB SITE FOR COMPUTER NETWORKING WITH INTERNET PROTOCOLS AND TECHNOLOGY

The Web site at WilliamStallings.com/CNIP/CNIP1e.html provides support for instructors and students using the book. It includes the following elements.

Course Support Materials

The course support materials include

- Copies of figures from the book in PDF format
- Copies of tables from the book in PDF format
- A set of PowerPoint slides for use as lecture aids
- Computer Science Student Support Site: contains a number of links and documents that the student may find useful in his/her ongoing computer science education. The site includes a review of basic, relevant mathematics; advice on research, writing, and doing homework problems; links to computer science research resources, such as report repositories and bibliographies; and other useful links.
- An errata sheet for the book, updated at most monthly

CNIP Courses

The CNIP1e Web site includes links to Web sites for courses taught using the book. These sites can provide useful ideas about scheduling and topic ordering, as well as a number of useful handouts and other materials.

Useful Web Sites

The CNIP1e Web site includes links to relevant Web sites, organized by chapter. The links cover a broad spectrum of topics and will enable students to explore timely issues in greater depth.

Supplemental Documents

The CNIP1e Web site includes a number of documents that expand on the treatment in the book. Topics include standards organizations, Sockets, TCP/IP checksum, URL/URI, BNF, and ASCII.

Internet Mailing List

An Internet mailing list is maintained so that instructors using this book can exchange information, suggestions, and questions with each other and the author. Subscription information is provided at the book's Web site.

Simulation and Modeling Tools

The Web site includes links to the *cnet* Web site and the *modeling tools* Web site. These packages can be used to analyze and experiment with protocol and network design issues. Each site includes downloadable software and background information. The instructor's manual includes more information on loading and using the software and suggested student projects. See Appendix B for more information.

PREFACE

This book does not pretend to be a comprehensive record; but it aims at helping to disentangle from an immense mass of material the crucial issues and cardinal decisions. Throughout I have set myself to explain faithfully and to the best of my ability.

—*The World Crisis,* Winston Churchill

BACKGROUND

Data network communication and distributed applications rely on underlying communications software that is independent of applications and relieves the application of much of the burden of reliably exchanging data. This communications software is organized into a protocol architecture, the most important incarnation of which is the TCP/IP protocol suite. The TCP/IP protocol suite is now dominant, in terms of products, deployment in data networks, and ongoing computer network research. The most prominent incarnation of this suite is in the Internet and its millions of attached computers.

OBJECTIVES

The objective of this book is to provide an up-to-date survey of developments in the areas of computer networks and Internet-based protocols and algorithms. Central problems that confront the network designer are the need to support multimedia and real-time traffic, the need to control congestion, and the need to provide different levels of quality of service (QoS) to different applications.

The following basic themes serve to unify the discussion:

- **Principles:** Although the scope of this book is broad, there are a number of basic principles that appear repeatedly as themes and that unify this field. Examples are multiplexing, flow control, and error control. The book highlights these principles and contrasts their application in specific areas of technology.
- **Design approaches:** The book examines alternative approaches to meeting specific communication requirements.
- **Standards:** Standards have come to assume an increasingly important, indeed dominant, role in this field. An understanding of the current status and future direction of technology requires a comprehensive discussion of the related standards.

INTENDED AUDIENCE

This book is intended for both a professional and an academic audience. For the professional interested in this field, the book serves as a basic reference volume and is suitable for self study.

As a textbook, it is suitable for an advanced undergraduate or graduate course. The book treats a number of advanced topics and provides a brief survey of the required elementary topics. After Part One, the parts are relatively independent. Fewer parts could be covered for a shorter course, and the parts can be covered in any order.

PLAN OF THE BOOK

The book is divided into seven parts:

- Overview
- Internet Applications
- Transport Protocols
- Quality of Service in IP Networks
- Internet Routing
- Network and Link Layers
- Management Topics

In addition, the book includes an extensive glossary, a list of frequently used acronyms, and a bibliography. Each chapter includes a list of key words, review questions, problems, suggestions for further reading, and pointers to relevant Web sites.

The book is intended for both an academic and a professional audience. For the professional interested in this field, the book serves as a basic reference volume and is suitable for self-study. As a textbook, it can be used for a one-semester or two-semester course. It covers the material in the Communication and Networking core course of the joint ACM/IEEE Computing Curricula 2001. The chapters and parts of the book are sufficiently modular to provide a great deal of flexibility in the design of courses.

TOP-DOWN AND BOTTOM-UP APPROACHES

The book is laid out to present the material in a top-down fashion. This has the advantage of immediately focusing on the most visible part of the material, the applications, and then seeing, progressively, how each layer is supported by the next layer down. This approach makes the most sense for many instructors and students. The application layer is the most visible layer to the student and typically provides the most interest. An understanding of the applications motivates the mechanisms found at the transport layer. The treatment of the application and transport layers enables the student to understand the many design issues at the internet layer, including quality of service and routing issues. Finally, computer networks and data link mechanisms can be treated.

Some readers, and some instructors, are more comfortable with a bottom-up approach. With this approach, each part builds on the material in the previous part, so that it is always clear how a given layer of functionality is supported from below. Accordingly, the book is organized in a modular fashion. After reading Part One, the other parts can be read in a number of possible sequences. See Chapter 0 for a description of each part and for a discussion of the order in which the book can be taught.

INTERNET SERVICES FOR INSTRUCTORS AND STUDENTS

There is a Web site for this book that provides support for students and instructors. The page includes links to relevant sites, transparency masters of figures and tables in the book in PDF (Adobe Acrobat) format, PowerPoint slides, and sign-up information for the book's Internet

mailing list. The Web page is at WilliamStallings.com/CNIP/CNIP1e.html; see the section, "Web Site for Computer Networking with Internet Protocols and Technology," following this Preface, for more information. An Internet mailing list has been set up so that instructors using this book can exchange information, suggestions, and questions with each other and with the author. As soon as typos or other errors are discovered, an errata list for this book will be available at WilliamStallings.com. Finally, I maintain the Computer Science Student Resource Site at WilliamStallings.com/StudentSupport.html.

PROJECTS FOR TEACHING COMPUTER NETWORKING

For many instructors, an important component of a computer networks/Internet protocol course is a project or set of projects by which the student gets hands-on experience to reinforce concepts from the text. This book provides an unparalleled degree of support for including a projects component in the course. The instructor's manual not only includes guidance on how to assign and structure the projects, but also includes a set of suggested projects that covers a broad range of topics from the text, including:

- **Sockets programming projects:** The manual includes series of assignments that instruct the student to research a particular topic on the Web or in the literature, and write a report.
- **Simulation projects:** The manual provides support for the use of the *cnet* simulation package: The *cnet* network simulator enables experimentation with various data link layer, network layer, routing and transport layer protocols, and with various network configurations.
- **Performance modeling projects:** An alternative to simulation for assessing the performance of a communications system or networking protocol is analytic modeling. The *tools* package of software serves as the basis for developing such projects.
- **Research projects:** The manual includes series of assignments that instruct the student to research a particular topic on the Web or in the literature, and write a report.
- **Reading/report assignments:** The manual includes a list of papers in the literature, one or more for each chapter, that can be assigned for the student to read and then write a short report.

See Appendix B for details.

ACKNOWLEDGMENTS

This book has benefited from review by a number of people, who gave generously of their time and expertise. The following people reviewed the original manuscript proposal and made numerous detailed suggestions: Paul Tymann (Rochester Institute of Technology), William Perrizo (North Dakota State), and Kenneth Weber (Mount Union College). The following people reviewed portions of the material in the book: Michael J. Donahoo (Baylor University), Gary Harkin (Montana State University), Larry Owens (California State U. Fresno), S. Hossein Hosseini (U. of Wisconsin—Milwaukee), and Dr. Charles Baker (Southern Methodist University).

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CONTENTS

Web Site for Computer Networking with Internet Protocols and Technology vi

Preface xi

Chapter 0 Reader's Guide 2

0.1 Outline of the Book 3
0.2 Internet and Web Resources for this Book 5
0.3 Internet Standards 6

PART ONE OVERVIEW 11

Chapter 1 Data Networks and the Internet 12

1.1 Data Networks 13
1.2 The Internet 24
1.3 An Example Configuration 30
1.4 Intranets 31
1.5 Extranets 35
1.6 Recommended Reading and Web Sites 36
1.7 Key Terms, Review Questions, and Problems 37

Chapter 2 Protocols and the TCP/IP Protocol Suite 38

2.1 The Need for a Protocol Architecture 39
2.2 A Simple Protocol Architecture 40
2.3 OSI 46
2.4 The TCP/IP Protocol Architecture 54
2.5 Internetworking 61
2.6 Recommended Reading and Web Sites 65
2.7 Key Terms, Review Questions, and Problems 68
Appendix 2A The Trivial File Transfer Protocol 70

PART TWO APPLICATIONS 75

Chapter 3 Traditional Applications 76

3.1 Terminal Access—Telnet 77
3.2 File Transfer—FTP 86
3.3 Electronic Mail—SMTP and MIME 95
3.4 Recommended Reading and Web Sites 110
3.5 Key Terms, Review Questions, and Problems 110

Chapter 4 Modern Applications 114

4.1 Web Access—HTTP 116
4.2 Internet Directory Service—DNS 128
4.3 Voice Over IP and Multimedia Support—SIP 137
4.4 Sockets 148
4.5 Recommended Reading and Web Sites 157
4.6 Key Terms, Review Questions, and Problems 158

PART THREE TRANSPORT PROTOCOLS 161

Chapter 5 Congestion and Performance Issues 162

5.1 The Need for Speed and Quality of Service 164
5.2 Performance Requirements 169
5.3 Performance Metrics 173
5.4 The Effects of Congestion 179
5.5 Congestion Control 184
5.6 Traffic Management 187
5.7 The Need for Flow and Error Control 188
5.8 Self-Similar Traffic 191
5.9 Recommended Reading and Web Sites 193
5.10 Key Terms, Review Questions, and Problems 194
Appendix 5A Queuing Effects 195

Chapter 6 Transport Protocols 202

6.1 Connection-Oriented Transport Protocol Mechanisms 204
6.2 TCP Services 221
6.3 Transmission Control Protocol 226
6.4 UDP 234
6.5 Recommended Reading and Web Sites 235
6.6 Key Terms, Review Questions, and Problems 235

Chapter 7 TCP Traffic Control 238

7.1 TCP Flow Control and Error Control 240
7.2 TCP Congestion Control 246
7.3 Explicit Congestion Notification 263
7.4 Recommended Reading and Web Sites 266
7.5 Key Terms, Review Questions, and Problems 267

PART FOUR QUALITY OF SERVICE IN IP NETWORKS 270

Chapter 8 Internet Protocols 272

8.1 Principles of Internetworking 273
8.2 Internet Protocol 281
8.3 IPv6 290
8.4 Recommended Reading and Web Sites 300
8.5 Key Terms, Review Questions, and Problems 301

Chapter 9 Integrated and Differentiated Services 304

9.1 Integrated Services Architecture (ISA) 306
9.2 Queuing Discipline 314
9.3 Random Early Detection 321
9.4 Differentiated Services 327
9.5 Recommended Reading and Web Sites 336
9.6 Key Terms, Review Questions, and Problems 338
Appendix 9A Real-Time Traffic 340

Chapter 10 Protocols for QoS Support 344

10.1 Resource Reservation: RSVP 346
10.2 Multiprotocol Label Switching 357
10.3 Real-Time Transport Protocol (RTP) 368
10.4 Recommended Reading and Web Sites 378
10.5 Key Terms, Review Questions, and Problems 379

PART FIVE INTERNET ROUTING 382

Chapter 11 Interior Routing Protocols 384

11.1 Internet Routing Principles 385
11.2 Least-Cost Algorithms 393
11.3 Distance-Vector Protocol: RIP 399
11.4 Link-State Protocol: OSPF 405
11.5 Recommended Reading and Web Sites 414
11.6 Key Terms, Review Questions, and Problems 414

Chapter 12 Exterior Routing Protocols and Multicast 418

12.1 Path-Vector Protocols: BGP and IDRP 419
12.2 Multicasting 425
12.3 Recommended Reading and Web Sites 441
12.4 Key Terms, Review Questions, and Problems 442

PART SIX NETWORK AND LINK LAYERS 445

Chapter 13 Wide Area Networks 446

13.1 Frame Relay 447
13.2 Asynchronous Transfer Mode (ATM) 451
13.3 Cellular Wireless Networks 460
13.4 Recommended Reading and Web Sites 468
13.5 Key Terms, Review Questions, and Problems 469

Chapter 14 Data Link Control 472

14.1 Flow Control 473
14.2 Error Detection 479
14.3 Error Control 482
14.4 High-Level Data Link Control (HDLC) 487
14.5 Recommended Reading 494
14.6 Key Terms, Review Questions, and Problems 495
Appendix 14A Cyclic Redundancy Check 498
Appendix 14B Performance Issues 503

Chapter 15 Local Area Networks 510

15.1 The Emergence of High-Speed LANs 511
15.2 LAN Protocol Architecture 513
15.3 Ethernet 517
15.4 Bridges, Hubs, and Switches 522
15.5 High-Speed Ethernet 528
15.6 Wireless LANs 534
15.7 Recommended Reading and Web Sites 542
15.8 Key Terms, Review Questions, and Problems 543

PART SEVEN MANAGEMENT TOPICS 545

Chapter 16 Network Security 546

16.1 Security Requirements and Attacks 548
16.2 Confidentiality with Symmetric Encryption 550
16.3 Message Authentication and Hash Functions 559
16.4 Public-Key Encryption and Digital Signatures 565
16.5 Secure Socket Layer and Transport Layer Security 572
16.6 IPv4 and IPv6 Security 577
16.7 Recommended Reading and Web Sites 582
16.8 Key Terms, Review Questions, and Problems 582

Chapter 17 Network Management 586

17.1 Network Management Requirements 588
17.2 Network Management Systems 592
17.3 Simple Network Management Protocol (SNMP) 593
17.4 Recommended Reading and Web Sites 603
17.5 Key Terms, Review Questions, and Problems 604

APPENDICES 605

Appendix A RFCs Cited in This Book 605

Appendix B Projects for Teaching Computer Networks 608

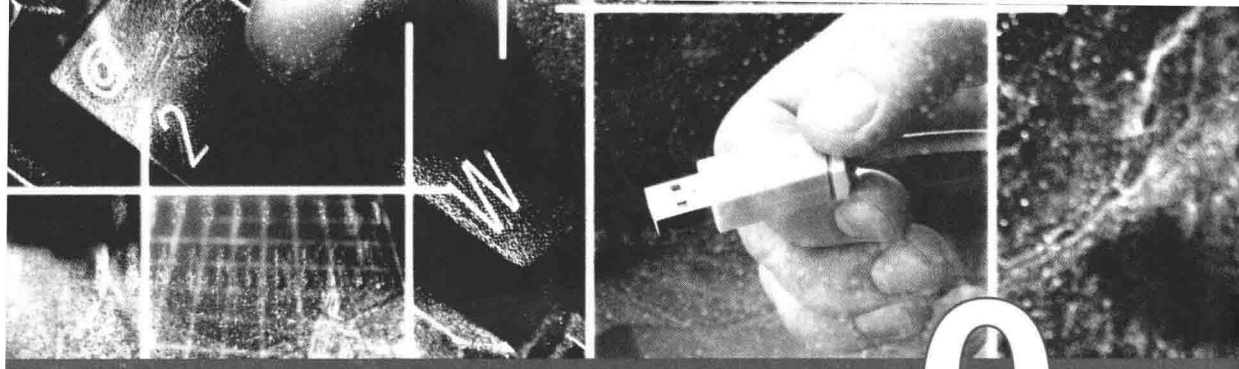
B.1 Sockets Programming Projects 608
B.2 Simulation Projects 609
B.3 Performance Modeling 609
B.4 Research Projects 610
B.5 Reading/Report Assignments 610

Glossary 611

Acronyms 617

References 619

Index 627



CHAPTER 0

READER'S GUIDE

0.1 Outline of the Book

0.2 Internet and Web Resources for this Book

Web Sites for this Book
Other Web Sites
USENET Newsgroups

0.3 Internet Standards

The Internet Organizations and RFC Publication
The Standardization Process
Internet Standards Categories
Other RFC Types

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