

Contents

Preface xvii

Trademarks xxiii

Chapter 1 Introduction 1

- 1.1 OVERVIEW OF THE INTERNET 2
 - 1.1.1 Networks 2
 - 1.1.2 Switching 4
 - 1.1.3 The Internet 6
 - 1.1.4 Accessing the Internet 7
 - 1.1.5 Hardware and Software 8
- 1.2 PROTOCOL LAYERING 9
 - 1.2.1 Scenarios 9
 - 1.2.2 TCP/IP Protocol Suite 12
 - 1.2.3 The OSI Model 20
- 1.3 INTERNET HISTORY 22
 - 1.3.1 Early History 22
 - 1.3.2 Birth of the Internet 22
 - 1.3.3 Internet Today 24
- 1.4 STANDARDS AND ADMINISTRATION 24
 - 1.4.1 Internet Standards 24
 - 1.4.2 Internet Administration 26
- 1.5 END-CHAPTER MATERIALS 27
 - 1.5.1 Further Reading 27
 - 1.5.2 Key Terms 28
 - 1.5.3 Summary 28
- 1.6 PRACTICE SET 29
 - 1.6.1 Quizzes 29
 - 1.6.2 Questions 29
 - 1.6.3 Problems 30
- 1.7 SIMULATION EXPERIMENTS 31
 - 1.7.1 Applets 31
 - 1.7.2 Lab Assignments 32

Chapter 2 Application Layer 33

- 2.1 INTRODUCTION 34
 - 2.1.1 Providing Services 35
 - 2.1.2 Application-Layer Paradigms 36

2.2	CLIENT-SERVER PARADIGM	38
2.2.1	Application Programming Interface	39
2.2.2	Using Services of the Transport Layer	43
2.3	STANDARD CLIENT-SERVER APPLICATIONS	44
2.3.1	World Wide Web and HTTP	44
2.3.2	FTP	59
2.3.3	Electronic Mail	63
2.3.4	TELNET	76
2.3.5	Secure Shell (SSH)	78
2.3.6	Domain Name System (DNS)	81
2.4	PEER-TO-PEER PARADIGM	92
2.4.1	P2P Networks	92
2.4.2	Distributed Hash Table (DHT)	95
2.4.3	Chord	97
2.4.4	Pastry	104
2.4.5	Kademlia	108
2.4.6	A Popular P2P Network: BitTorrent	112
2.5	SOCKET INTERFACE PROGRAMMING	114
2.5.1	Socket Interface in C	114
2.6	END-CHAPTER MATERIALS	128
2.6.1	Further Reading	128
2.6.2	Key Terms	129
2.6.3	Summary	129
2.7	PRACTICE SET	130
2.7.1	Quizzes	130
2.7.2	Questions	130
2.7.3	Problems	132
2.8	SIMULATION EXPERIMENTS	136
2.8.1	Applets	136
2.8.2	Lab Assignments	136
2.9	PROGRAMMING ASSIGNMENT	137
	Chapter 3 Transport Layer	139
3.1	INTRODUCTION	140
3.1.1	Transport-Layer Services	141
3.2	TRANSPORT-LAYER PROTOCOLS	154
3.2.1	Simple Protocol	154
3.2.2	Stop-and-Wait Protocol	155
3.2.3	Go-Back- <i>N</i> Protocol (GBN)	160
3.2.4	Selective-Repeat Protocol	166
3.2.5	Bidirectional Protocols: Piggybacking	173
3.2.6	Internet Transport-Layer Protocols	173
3.3	USER DATAGRAM PROTOCOL (UDP)	175
3.3.1	User Datagram	175
3.3.2	UDP Services	176
3.3.3	UDP Applications	179
3.4	TRANSMISSION CONTROL PROTOCOL (TCP)	181
3.4.1	TCP Services	181
3.4.2	TCP Features	184

3.4.3	Segment	185
3.4.4	A TCP Connection	188
3.4.5	State Transition Diagram	194
3.4.6	Windows in TCP	198
3.4.7	Flow Control	200
3.4.8	Error Control	205
3.4.9	TCP Congestion Control	213
3.4.10	TCP Timers	223
3.4.11	Options	227
3.5	END-CHAPTER MATERIALS	227
3.5.1	Further Reading	227
3.5.2	Key Terms	227
3.5.3	Summary	228
3.6	PRACTICE SET	228
3.6.1	Quizzes	228
3.6.2	Questions	229
3.6.3	Problems	232
3.7	SIMULATION EXPERIMENTS	239
3.7.1	Applets	239
3.7.2	Lab Assignments	240
3.8	PROGRAMMING ASSIGNMENT	240

Chapter 4 Network Layer 241

4.1	INTRODUCTION	242
4.1.1	Network-Layer Services	243
4.1.2	Packet Switching	246
4.1.3	Network-Layer Performance	251
4.1.4	Network-Layer Congestion	255
4.1.5	Structure of A Router	258
4.2	NETWORK-LAYER PROTOCOLS	261
4.2.1	IPv4 Datagram Format	262
4.2.2	IPv4 Addresses	269
4.2.3	Forwarding of IP Packets	286
4.2.4	ICMPv4	295
4.3	UNICAST ROUTING	299
4.3.1	General Idea	300
4.3.2	Routing Algorithms	302
4.3.3	Unicast Routing Protocols	313
4.4	MULTICAST ROUTING	333
4.4.1	Introduction	333
4.4.2	Multicasting Basics	336
4.4.3	Intradomain Routing Protocols	343
4.4.4	Interdomain Routing Protocols	349
4.5	NEXT GENERATION IP	350
4.5.1	Packet Format	351
4.5.2	IPv6 Addressing	353
4.5.3	Transition from IPv4 to IPv6	358
4.5.4	ICMPv6	359

- 4.6 END-CHAPTER MATERIALS 361
 - 4.6.1 Further Reading 361
 - 4.6.2 Key Terms 361
 - 4.6.3 Summary 362
- 4.7 PRACTICE SET 362
 - 4.7.1 Quizzes 362
 - 4.7.2 Questions 363
 - 4.7.3 Problems 366
- 4.8 SIMULATION EXPERIMENTS 373
 - 4.8.1 Applets 373
 - 4.8.2 Lab Assignments 373
- 4.9 PROGRAMMING ASSIGNMENT 374

Chapter 5 Data-Link Layer: Wired Networks 375

- 5.1 INTRODUCTION 376
 - 5.1.1 Nodes and Links 377
 - 5.1.2 Two Types of Links 377
 - 5.1.3 Two Sublayers 378
- 5.2 DATA LINK CONTROL (DLC) 378
 - 5.2.1 Framing 378
 - 5.2.2 Flow and Error Control 381
 - 5.2.3 Error Detection and Correction 382
 - 5.2.4 Two DLC Protocols 396
- 5.3 MULTIPLE ACCESS PROTOCOLS (MAC) 403
 - 5.3.1 Random Access 404
 - 5.3.2 Controlled Access 416
 - 5.3.3 Channelization 419
- 5.4 LINK-LAYER ADDRESSING 419
- 5.5 WIRED LANS: ETHERNET PROTOCOL 428
 - 5.5.1 IEEE Project 802 428
 - 5.5.2 Standard Ethernet 429
 - 5.5.3 Fast Ethernet (100 Mbps) 436
 - 5.5.4 Gigabit Ethernet 437
 - 5.5.5 10-Gigabit Ethernet 438
 - 5.5.6 Virtual LANs 438
- 5.6 OTHER WIRED NETWORKS 442
 - 5.6.1 Point-to-Point Networks 443
 - 5.6.2 SONET 448
 - 5.6.3 Switched Network: ATM 455
- 5.7 CONNECTING DEVICES 460
 - 5.7.1 Repeaters or Hubs 460
 - 5.7.2 Link-Layer Switches 461
 - 5.7.3 Routers 463
- 5.8 END-CHAPTER MATERIALS 464
 - 5.8.1 Recommended Reading 464
 - 5.8.2 Key Terms 464
 - 5.8.3 Summary 465

- 5.9 PRACTICE SET 466
 - 5.9.1 Quizzes 466
 - 5.9.2 Questions 466
 - 5.9.3 Problems 468
- 5.10 SIMULATION EXPERIMENTS 476
 - 5.10.1 Applets 476
 - 5.10.2 Lab Assignments 477
- 5.11 PROGRAMMING ASSIGNMENTS 477

Chapter 6 Wireless Networks and Mobile IP 479

- 6.1 WIRELESS LANs 480
 - 6.1.1 Introduction 480
 - 6.1.2 IEEE 802.11 Project 483
 - 6.1.3 Bluetooth 495
 - 6.1.4 WiMAX 501
- 6.2 OTHER WIRELESS NETWORKS 503
 - 6.2.1 Channelization 503
 - 6.2.2 Cellular Telephony 510
 - 6.2.3 Satellite Networks 521
- 6.3 MOBILE IP 527
 - 6.3.1 Addressing 527
 - 6.3.2 Agents 529
 - 6.3.3 Three Phases 530
 - 6.3.4 Inefficiency in Mobile IP 535
- 6.4 END-CHAPTER MATERIALS 536
 - 6.4.1 Further Reading 536
 - 6.4.2 Key terms 537
 - 6.4.3 Summary 537
- 6.5 PRACTICE SET 538
 - 6.5.1 Quizzes 538
 - 6.5.2 Questions 538
 - 6.5.3 Problems 540
- 6.6 SIMULATION EXPERIMENTS 545
 - 6.6.1 Applets 545
 - 6.6.2 Lab Assignments 545
- 6.7 PROGRAMMING ASSIGNMENT 545

Chapter 7 Physical Layer and Transmission Media 547

- 7.1 DATA AND SIGNALS 548
 - 7.1.1 Analog and Digital 549
 - 7.1.2 Transmission Impairment 556
 - 7.1.3 Data Rate Limits 558
 - 7.1.4 Performance 560
- 7.2 DIGITAL TRANSMISSION 563
 - 7.2.1 Digital-to-Digital Conversion 563
 - 7.2.2 Analog-to-Digital Conversion 569

7.3	ANALOG TRANSMISSION	574
	7.3.1 Digital-to-Analog Conversion	574
	7.3.2 Analog-to-Analog Conversion	579
7.4	BANDWIDTH UTILIZATION	581
	7.4.1 Multiplexing	581
	7.4.2 Spread Spectrum	587
7.5	TRANSMISSION MEDIA	591
	7.5.1 Guided Media	591
	7.5.2 Unguided Media: Wireless	596
7.6	END-CHAPTER MATERIALS	598
	7.6.1 Recommended Reading	598
	7.6.2 Key Terms	598
	7.6.3 Summary	599
7.7	PRACTICE SET	600
	7.7.1 Quizzes	600
	7.7.2 Questions	600
	7.7.3 Problems	601
Chapter 8 Multimedia and Quality of Service		607
8.1	COMPRESSION	608
	8.1.1 Lossless Compression	608
	8.1.2 Lossy Compression	617
8.2	MULTIMEDIA DATA	623
	8.2.1 Text	623
	8.2.2 Image	623
	8.2.3 Video	627
	8.2.4 Audio	629
8.3	MULTIMEDIA IN THE INTERNET	630
	8.3.1 Streaming Stored Audio/Video	631
	8.3.2 Streaming Live Audio/Video	634
	8.3.3 Real-Time Interactive Audio/Video	635
8.4	REAL-TIME INTERACTIVE PROTOCOLS	641
	8.4.1 Rationale for New Protocols	642
	8.4.2 RTP	645
	8.4.3 RTCP	648
	8.4.4 Session Initialization Protocol (SIP)	651
	8.4.5 H.323	658
	8.4.6 SCTP	660
8.5	QUALITY OF SERVICE	674
	8.5.1 Data-Flow Characteristics	674
	8.5.2 Flow Classes	675
	8.5.3 Flow Control to Improve QoS	676
	8.5.4 Integrated Services (IntServ)	682
	8.5.5 Differentiated Services (DiffServ)	686
8.6	END-CHAPTER MATERIALS	687
	8.6.1 Recommended Reading	687
	8.6.2 Key Terms	688
	8.6.3 Summary	688

8.7	PRACTICE SET	689
	8.7.1 Quizzes	689
	8.7.2 Questions	689
	8.7.3 Problems	692
8.8	SIMULATION EXPERIMENTS	700
	8.8.1 Applets	700
	8.8.2 Lab Assignments	700
8.9	PROGRAMMING ASSIGNMENTS	700

Chapter 9 Network Management 701

9.1	INTRODUCTION	702
	9.1.1 Configuration Management	702
	9.1.2 Fault Management	704
	9.1.3 Performance Management	705
	9.1.4 Security Management	705
	9.1.5 Accounting Management	705
9.2	SNMP	706
	9.2.1 Managers and Agents	706
	9.2.2 Management Components	707
	9.2.3 An Overview	709
	9.2.4 SMI	710
	9.2.5 MIB	713
	9.2.6 SNMP	716
9.3	ASN.1	722
	9.3.1 Language Basics	723
	9.3.2 Data Types	723
	9.3.3 Encoding	726
9.4	END-CHAPTER MATERIALS	726
	9.4.1 Further Reading	726
	9.4.2 Key Terms	727
	9.4.3 Summary	727
9.5	PRACTICE SET	727
	9.5.1 Quizzes	727
	9.5.2 Questions	727
	9.5.3 Problems	729

Chapter 10 Network Security 731

10.1	INTRODUCTION	732
	10.1.1 Security Goals	732
	10.1.2 Attacks	733
	10.1.3 Services and Techniques	734
10.2	CONFIDENTIALITY	735
	10.2.1 Symmetric-Key Ciphers	735
	10.2.2 Asymmetric-Key Ciphers	746
10.3	OTHER ASPECTS OF SECURITY	751
	10.3.1 Message Integrity	751
	10.3.2 Message Authentication	752
	10.3.3 Digital Signature	753

10.3.4	Entity Authentication	758
10.3.5	Key Management	761
10.4	INTERNET SECURITY	766
10.4.1	Application-Layer Security	767
10.4.2	Transport-Layer Security	776
10.4.3	Network-Layer Security	782
10.5	FIREWALLS	792
10.5.1	Packet-Filter Firewall	793
10.5.2	Proxy Firewall	793
10.6	END-CHAPTER MATERIALS	794
10.6.1	Further Reading	794
10.6.2	Key Terms	794
10.6.3	Summary	795
10.7	PRACTICE SET	796
10.7.1	Quizzes	796
10.7.2	Questions	796
10.7.3	Problems	798
10.8	SIMULATION EXPERIMENTS	803
10.8.1	Applets	803
10.8.2	Lab Assignments	803
10.9	PROGRAMMING ASSIGNMENTS	803

Chapter 11 Socket Programming In Java 805

11.1	INTRODUCTION	806
11.1.1	Addresses and Ports	806
11.1.2	Client-Server Paradigm	809
11.2	PROGRAMMING WITH UDP	810
11.2.1	Iterative Approach	810
11.2.2	Concurrent Approach	820
11.3	PROGRAMMING WITH TCP	823
11.3.1	Iterative Approach	823
11.3.2	Concurrent Approach	832
11.4	END-CHAPTER MATERIALS	835
11.4.1	Further Reading	835
11.4.2	Key terms	835
11.4.3	Summary	835
11.5	PRACTICE SET	836
11.5.1	Quizzes	836
11.5.2	Questions	836
11.5.3	Problems	838
11.6	PROGRAMMING ASSIGNMENTS	838

Appendix A Unicode 841

Appendix B Positional Numbering System 845

Appendix C HTML, CSS, XML, and XSL 853

Appendix D Miscellaneous Information 861

Appendix E 8B/6T Code 865

Glossary 867

References 901

Index 905