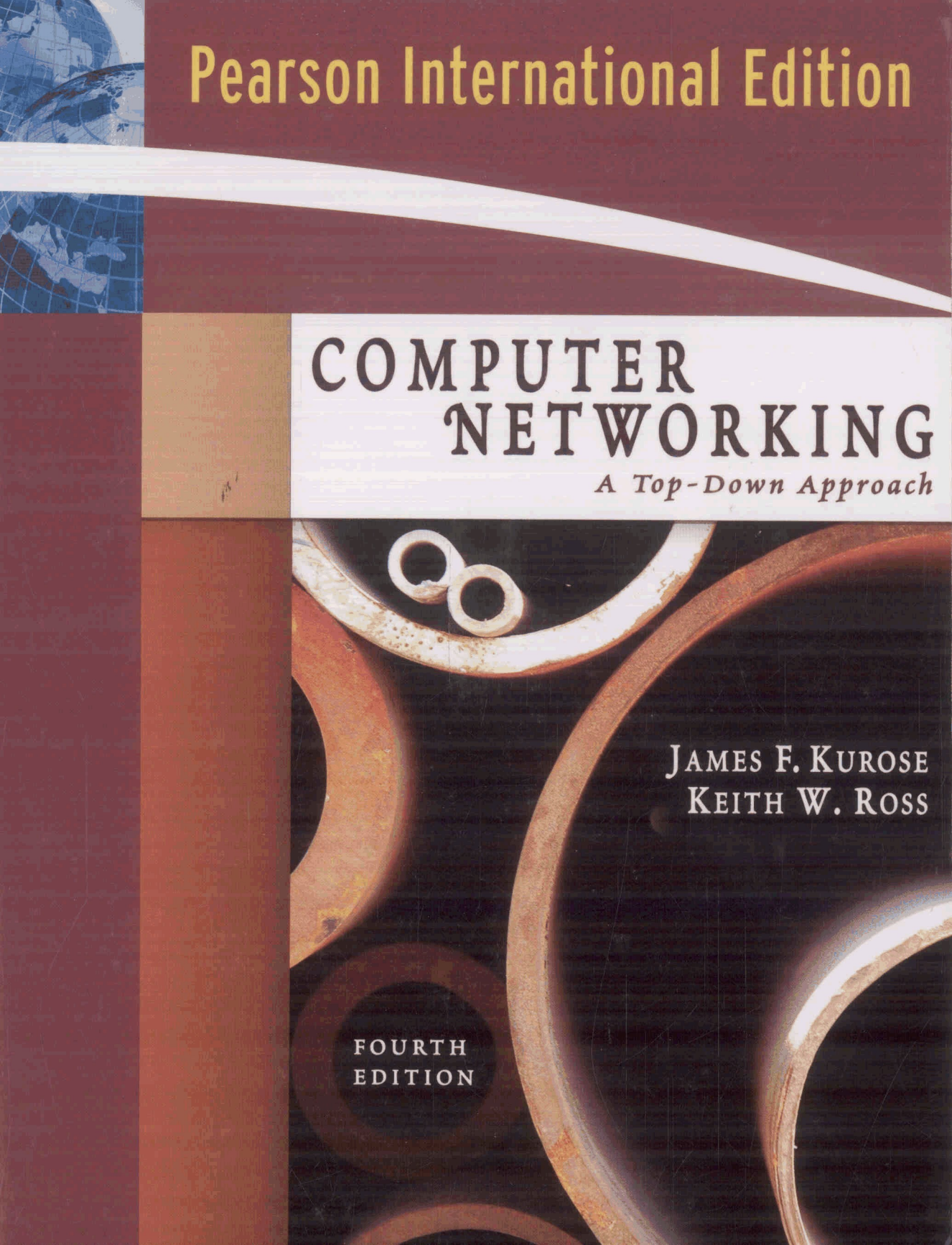




Pearson International Edition

COMPUTER NETWORKING

A Top-Down Approach

JAMES F. KUROSE
KEITH W. ROSS

FOURTH
EDITION

Table of Contents

Chapter 1	Computer Networks and the Internet	27
1.1	What Is the Internet?	28
1.1.1	A Nuts-and-Bolts Description	28
1.1.2	A Services Description	31
1.1.3	What Is a Protocol?	33
1.2	The Network Edge	35
1.2.1	Client and Server Programs	38
1.2.2	Access Networks	38
1.2.3	Physical Media	45
1.3	The Network Core	48
1.3.1	Circuit Switching and Packet Switching	48
1.3.2	How Do Packets Make Their Way Through Packet-Switched Networks?	56
1.3.3	ISPs and Internet Backbones	57
1.4	Delay, Loss, and Throughput in Packet-Switched Networks	59
1.4.1	Overview of Delay in Packet-Switched Networks	59
1.4.2	Queuing Delay and Packet Loss	63
1.4.3	End-to-End Delay	66
1.4.4	Throughput in Computer Networks	68
1.5	Protocol Layers and Their Service Models	71
1.5.1	Layered Architecture	71
1.5.2	Messages, Segments, Datagrams, and Frames	77
1.6	Networks Under Attack	79
1.7	History of Computer Networking and the Internet	84
1.7.1	The Development of Packet Switching: 1961–1972	84
1.7.2	Proprietary Networks and Internetworking: 1972–1980	86
1.7.3	A Proliferation of Networks: 1980–1990	88
1.7.4	The Internet Explosion: The 1990s	89
1.7.5	Recent Developments	90
1.8	Summary	91
	Road-Mapping This Book	92

Homework Problems and Questions	93
Problems	95
Discussion Questions	101
Ethereal Lab	102
Interview: Leonard Kleinrock	103

Chapter 2 Application Layer 107

2.1	Principles of Network Applications	108
2.1.1	Network Application Architectures	108
2.1.2	Processes Communicating	111
2.1.3	Transport Services Available to Applications	114
2.1.4	Transport Services Provided by the Internet	116
2.1.5	Application-Layer Protocols	120
2.1.6	Network Applications Covered in This Book	121
2.2	The Web and HTTP	122
2.2.1	Overview of HTTP	122
2.2.2	Non-persistent and Persistent Connections	124
2.2.3	HTTP Message Format	127
2.2.4	User-Server Interaction: Cookies	132
2.2.5	Web Caching	134
2.2.6	The Conditional GET	138
2.3	File Transfer: FTP	140
2.3.1	FTP Commands and Replies	142
2.4	Electronic Mail in the Internet	142
2.4.1	SMTP	145
2.4.2	Comparison with HTTP	148
2.4.3	Mail Message Formats and MIME	149
2.4.4	Mail Access Protocols	152
2.5	DNS—The Internet's Directory Service	156
2.5.1	Services Provided by DNS	157
2.5.2	Overview of How DNS Works	159
2.5.3	DNS Records and Messages	165
2.6	Peer-to-Peer Applications	170
2.6.1	P2P File Distribution	171
2.6.2	Searching for Information in a P2P Community	177
2.6.3	Case Study: P2P Internet Telephony with Skype	183
2.7	Socket Programming with TCP	185
2.7.1	Socket Programming with TCP	186
2.7.2	An Example Client-Server Application in Java	188
2.8	Socket Programming with UDP	195
2.9	Summary	203

Homework Problems and Questions	204
Problems	206
Discussion Questions	213
Socket Programming Assignments	214
Ethereal Labs	216
Interview: Bram Cohen	218

Chapter 3	Transport Layer	221
3.1	Introduction and Transport-Layer Services	222
3.1.1	Relationship Between Transport and Network Layers	222
3.1.2	Overview of the Transport Layer in the Internet	225
3.2	Multiplexing and Demultiplexing	227
3.3	Connectionless Transport: UDP	234
3.3.1	UDP Segment Structure	238
3.3.2	UDP Checksum	238
3.4	Principles of Reliable Data Transfer	240
3.4.1	Building a Reliable Data Transfer Protocol	242
3.4.2	Pipelined Reliable Data Transfer Protocols	251
3.4.3	Go-Back-N (GBN)	254
3.4.4	Selective Repeat (SR)	259
3.5	Connection-Oriented Transport: TCP	266
3.5.1	The TCP Connection	267
3.5.2	TCP Segment Structure	269
3.5.3	Round-Trip Time Estimation and Timeout	274
3.5.4	Reliable Data Transfer	278
3.5.5	Flow Control	286
3.5.6	TCP Connection Management	288
3.6	Principles of Congestion Control	295
3.6.1	The Causes and the Costs of Congestion	296
3.6.2	Approaches to Congestion Control	302
3.6.3	Network-Assisted Congestion-Control Example: ATM ABR Congestion Control	303
3.7	TCP Congestion Control	305
3.7.1	Fairness	313
3.8	Summary	316
	Homework Problems and Questions	319
	Problems	321
	Discussion Questions	330
	Programming Assignments	331
	Ethereal Labs	331
	Interview: Sally Floyd	333

Chapter 4	The Network Layer	335
4.1	Introduction	336
4.1.1	Forwarding and Routing	338
4.1.2	Network Service Models	340
4.2	Virtual Circuit and Datagram Networks	343
4.2.1	Virtual-Circuit Networks	344
4.2.2	Datagram Networks	347
4.2.3	Origins of VC and Datagram Networks	349
4.3	What's Inside a Router?	350
4.3.1	Input Ports	352
4.3.2	Switching Fabric	354
4.3.3	Output Ports	357
4.3.4	Where Does Queuing Occur?	357
4.4	The Internet Protocol (IP): Forwarding and Addressing in the Internet	360
4.4.1	Datagram Format	362
4.4.2	IPv4 Addressing	368
4.4.3	Internet Control Message Protocol (ICMP)	383
4.4.4	IPv6	386
4.4.5	A Brief Introduction into IP Security VPNs	392
4.5	Routing Algorithms	394
4.5.1	The Link-State (LS) Routing Algorithm	397
4.5.2	The Distance-Vector (DV) Routing Algorithm	401
4.5.3	Hierarchical Routing	409
4.6	Routing in the Internet	413
4.6.1	Intra-AS Routing in the Internet: RIP	414
4.6.2	Intra-AS Routing in the Internet: OSPF	418
4.6.3	Inter-AS Routing: BGP	421
4.7	Broadcast and Multicast Routing	428
4.7.1	Broadcast Routing Algorithms	429
4.7.2	Multicast	434
4.8	Summary	441
	Homework Problems and Questions	442
	Problems	445
	Discussion Questions	455
	Programming Assignment	456
	Ethereal Labs	457
	Interview: Vinton G. Cerf	458

Chapter 5	The Link Layer and Local Area Networks	461
5.1	Link Layer: Introduction and Services	463
5.1.1	The Services Provided by the Link Layer	463
5.1.2	Where Is the Link Layer Implemented?	466

5.2	Error-Detection and -Correction Techniques	468
5.2.1	Parity Checks	470
5.2.2	Checksumming Methods	472
5.2.3	Cyclic Redundancy Check (CRC)	472
5.3	Multiple Access Protocols	475
5.3.1	Channel Partitioning Protocols	477
5.3.2	Random Access Protocols	479
5.3.3	Taking-Turns Protocols	486
5.3.4	Local Area Networks (LANs)	487
5.4	Link-Layer Addressing	489
5.4.1	MAC Addresses	489
5.4.2	Address Resolution Protocol (ARP)	491
5.5	Ethernet	491
5.5.1	Ethernet Frame Structure	497
5.5.2	CSMA/CD: Ethernet's Multiple Access Protocol	501
5.5.3	Ethernet Technologies	503
5.6	Link-Layer Switches	506
5.6.1	Forwarding and Filtering	507
5.6.2	Self-Learning	509
5.6.3	Properties of Link-Layer Switching	510
5.6.4	Switches Versus Routers	511
5.7	PPP: The Point-to-Point Protocol	513
5.7.1	PPP Data Framing	515
5.8	Link Virtualization: A Network as a Link Layer	517
5.8.1	Asynchronous Transfer Mode (ATM) Networks	518
5.8.2	Multiprotocol Label Switching (MPLS)	523
5.9	Summary	526
	Homework Problems and Questions	527
	Problems	529
	Discussion Questions	534
	Ethereal Labs	535
	Interview: Simon S. Lam	536

Chapter 6 Wireless and Mobile Networks 539

6.1	Introduction	540
6.2	Wireless Links and Network Characteristics	545
6.2.1	CDMA	548
6.3	WiFi: 802.11 Wireless LANs	552
6.3.1	The 802.11 Architecture	553
6.3.2	The 802.11 MAC Protocol	557
6.3.3	The IEEE 802.11 Frame	563
6.3.4	Mobility in the Same IP Subnet	567

6.3.5	Advanced Features in 802.11	568
6.3.6	Beyond 802.11: Bluetooth and WiMAX	570
6.4	Cellular Internet Access	574
6.4.1	An Overview of Cellular Architecture	574
6.4.2	Cellular Standards and Technologies: A Brief Survey	577
6.5	Mobility Management: Principles	581
6.5.1	Addressing	583
6.5.2	Routing to a Mobile Node	585
6.6	Mobile IP	590
6.7	Managing Mobility in Cellular Networks	596
6.7.1	Routing Calls to a Mobile User	597
6.7.2	Handoffs in GSM	598
6.8	Wireless and Mobility: Impact on Higher-layer Protocols	601
6.9	Summary	604
	Homework Problems and Questions	605
	Problems	606
	Discussion Questions	610
	Ethereal Labs	610
	Interview: Charlie Perkins	611

Chapter 7 Multimedia Networking 615

7.1	Multimedia Networking Applications	616
7.1.1	Examples of Multimedia Applications	616
7.1.2	Hurdles for Multimedia in Today's Internet	619
7.1.3	How Should the Internet Evolve to Support Multimedia Better?	620
7.1.4	Audio and Video Compression	622
7.2	Streaming Stored Audio and Video	626
7.2.1	Accessing Audio and Video Through a Web Server	626
7.2.2	Sending Multimedia from a Streaming Server to a Helper Application	628
7.2.3	Real-Time Streaming Protocol (RTSP)	630
7.3	Making the Best of the Best-Effort Service	634
7.3.1	The Limitations of a Best-Effort Service	634
7.3.2	Removing Jitter at the Receiver for Audio	637
7.3.3	Recovering from Packet Loss	640
7.3.4	Distributing Multimedia in Today's Internet: Content Distribution Networks	644
7.3.5	Dimensioning Best-Effort Networks to Provide Quality of Service	647
7.4	Protocols for Real-Time Interactive Applications	649
7.4.1	RTP	649
7.4.2	RTP Control Protocol (RTCP)	654

7.4.3	SIP	657
7.4.4	H.323	663
7.5	Providing Multiple Classes of Service	665
7.5.1	Motivating Scenarios	666
7.5.2	Scheduling and Policing Mechanisms	671
7.5.3	Diffserv	678
7.6	Providing Quality of Service Guarantees	683
7.6.1	A Motivating Example	683
7.6.2	Resource Reservation, Call Admission, Call Setup	685
7.6.3	Guaranteed QoS in the Internet: Intserv and RSVP	687
7.7	Summary	690
	Homework Problems and Questions	691
	Problems	692
	Discussion Questions	699
	Programming Assignment	700
	Interview: Henning Schulzrinne	702

Chapter 8 Security in Computer Networks 705

8.1	What Is Network Security?	706
8.2	Principles of Cryptography	709
8.2.1	Symmetric Key Cryptography	711
8.2.2	Public Key Encryption	717
8.3	Message Integrity	722
8.3.1	Cryptographic Hash Functions	723
8.3.2	Message Authentication Code	725
8.3.3	Digital Signatures	727
8.4	End-Point Authentication	733
8.4.1	Authentication Protocol <i>ap1.0</i>	734
8.4.2	Authentication Protocol <i>ap2.0</i>	735
8.4.3	Authentication Protocol <i>ap3.0</i>	736
8.4.4	Authentication Protocol <i>ap3.1</i>	737
8.4.5	Authentication Protocol <i>ap4.0</i>	737
8.4.6	Authentication Protocol <i>ap5.0</i>	739
8.5	Securing E-mail	742
8.5.1	Secure E-mail	743
8.5.2	PGP	746
8.6	Securing TCP Connections: SSL	748
8.6.1	The Big Picture	750
8.6.2	A More Complete Picture	753
8.7	Network-Layer Security: IPsec	754
8.7.1	Authentication Header (AH) Protocol	755
8.7.2	The ESP Protocol	757

8.7.3	SA and Key Management	757
8.8	Securing Wireless LANs	758
8.8.1	Wired Equivalent Privacy (WEP)	758
8.8.2	IEEE802.11i	761
8.9	Operational Security: Firewalls and Intrusion Detection Systems	763
8.9.1	Firewalls	763
8.9.2	Intrusion Detection Systems	770
8.10	Summary	774
	Homework Problems and Questions	775
	Problems	776
	Discussion Questions	779
	Ethereal Lab	780
	Interview: Steven M. Bellovin	781

Chapter 9 Network Management 783

9.1	What Is Network Management?	784
9.2	The Infrastructure for Network Management	788
9.3	The Internet-Standard Management Framework	792
9.3.1	Structure of Management Information: SMI	794
9.3.2	Management Information Base: MIB	798
9.3.3	SNMP Protocol Operations and Transport Mappings	801
9.3.4	Security and Administration	803
9.4	ASN.1	807
9.5	Conclusion	812
	Homework Problems and Questions	813
	Problems	813
	Discussion Questions	814
	Interview: Jeff Case	815

References	817
-------------------	------------

Index	847
--------------	------------