CONTENTS

	Prefa	ce xxix
	Trad	e Mark xxxviii
	PAR	ΓI: Overview 1
L	Chap	oter 1 Introduction 3
	11	DATA COMMUNICATIONS 4 1.1.1 Components 4
		1.1.2 Data Representation 5
		1.1.3 Data Flow 6
	1,2	NETWORKS 7
		1.2.1 Network Criteria 7
		1.2.2 Physical Structures 8
	1.3	NETWORK TYPES 13
	V	1.3.1 Local Area Network 13
		1.3.2 Wide Area Network 14
		1.3.3 Switching 15
		1.3.4 The Internet 17
		1.3.5 Accessing the Internet 18
	1.4	INTERNET HISTORY 19
	V	1.4.1 Early History 19
		1.4.2 Birth of the Internet 20
		1.4.3 Internet Today 22
	1.5	STANDARDS AND ADMINISTRATION 22
		1.5.1 Internet Standards 22
		1.5.2 Internet Administration 24
	1.6	END-CHAPTER MATERIALS 25
		1.6.1 Recommended Reading 25
		1.6.2 Key Terms 25
		1.6.3 Summary 26
	1.7	PRACTICE SET 27
	\checkmark	1.7.1 Quizzes 27
		1.7.2 Questions 27
		1.7.3 Problems 28
	1.8	SIMULATION EXPERIMENTS 28
		1.8.1 Applets 28
		1.8.2 Lab Assignments 28
	Chap	oter 2 Network Models 31
V	21/	PROTOCOL LAYERING 32
	\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	2.1.1 Scenarios 32
	•	2.1.2 Principles of Protocol Layering 34
		2.1.3 Logical Connections 35

2.2	TCP/IP PROTOCOL SUITE 35
	2.2.1 Layered Architecture 35
	2.2.2 Layers in the TCP/IP Protocol Suite 37
	2.2.3 Description of Each Layer 38
	2.2.4 Encapsulation and Decapsulation 41
	2.2.5 Addressing 42
	2.2.6 Multiplexing and Demultiplexing 43
. 2.3	THE OSI MODEL 44
	2.3.1 OSI versus TCP/IP 45
	2.3.2 Lack of OSI Model's Success 45
2 1	END-CHAPTER MATERIALS 46
	2.4.1 Recommended Reading 46
	2.4.2 Key Terms 46
	2.4.3 Summary 46
2.5	
2.3	PRACTICE SET 47
	2.5.1 Quizzes 47
	2.5.2 Questions 47
	2.5.3 Problems 48
PΔRT	II: Physical Layer 51
	•
Chap	ter 3 Introduction to Physical Layer 53
3 1/	DATA AND SIGNALS 54
V .	3.1.1 Analog and Digital Data 55
	3.1.2 Analog and Digital Signals 55
	3.1.3 Periodic and Nonperiodic 56
2 8	-
1 3/2	PERIODIC ANALOG SIGNALS 56
	3.2.1 Sine Wave 56
	3.2.2 Phase 59
	3.2.3 Wavelength 61
	3.2.4 Time and Frequency Domains 61
	3.2.5 Composite Signals 63
2 2	3.2.6 Bandwidth 65
30	DIGITAL SIGNALS 68
	3.3.1 Bit Rate 69
	3.3.2 Bit Length 69
	3.3.3 Digital Signal as a Composite Analog Signal 70
2/	3.3.4 Transmission of Digital Signals 70
34	TRANSMISSION IMPAIRMENT 76
	3.4.1 Attenuation 77
	3.4.2 Distortion 79
	3.4.3 Noise 79
3.5/	DATA RATE LIMITS 81
V	3.5.1 Noiseless Channel: Nyquist Bit Rate 81
	3.5.2 Noisy Channel: Shannon Capacity 82
	3.5.3 Using Both Limits 83

/	
3.6	PERFORMANCE 84
	3.6.1 Bandwidth 84
	3.6.2 Throughput 85
	3.6.3 Latency (Delay) 85
	3.6.4 Bandwidth-Delay Product 87
,	3.6.5 Jitter 88
13.7	END-CHAPTER MATERIALS 89
	3.7.1 Recommended Reading 89
	3.7.2 Key Terms 89
	3.7.3 Summary 89
3.8	PRACTICE SET 90
	3.8.1 Quizzes 90
	3.8.2 Questions 90
	3.8.3 Problems 91
3.9	SIMULATION EXPERIMENTS 94
	3.9.1 Applets 94
Chap	ter 4 Digital Transmission 95
41	DIGITAL-TO-DIGITAL CONVERSION 96
$\sqrt{}$	4.1.1 Line Coding 96
	4.1.2 Line Coding Schemes 100
	4.1.3 Block Coding 109
	4.1.4 Scrambling 113
142	ANALOG-TO-DIGITAL CONVERSION 115
	4.2.1 Pulse Code Modulation (PCM) 115
	4.2.2 Delta Modulation (DM) 123
13/	TRANSMISSION MODES 125
7	4.3.1 Parallel Transmission 125
	4.3.2 Serial Transmission 126
. 4 1	END-CHAPTER MATERIALS 129
\ \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	4.4.1 Recommended Reading 129
	4.4.2 Key Terms 130
	4.4.3 Summary 130
45/	PRACTICE SET 131
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	4.5.1 Quizzes 131
	4.5.2 Questions 131
	4.5.3 Problems 131
4.6	SIMULATION EXPERIMENTS 134
	4.6.1 Applets 134
	TI
Chap	ter 5 Analog Transmission 135
5/	DIGITAL-TO-ANALOG CONVERSION 136
1 1	5.1.1 Aspects of Digital-to-Analog Conversion 137
	5.1.2 Amplitude Shift Keying 138
	5.1.3 Frequency Shift Keying 140
	5.1.4 Phase Shift Keying 142
	5.1.5 Quadrature Amplitude Modulation 146
	Zanoramie i impirade modulation 140

5.2 5.3 5.4 5.5	ANALOG-TO-ANALOG CONVERSION 147 5.2.1 Amplitude Modulation (AM) 147 5.2.2 Frequency Modulation (FM) 148 5.2.3 Phase Modulation (PM) 149 END-CHAPTER MATERIALS 151 5.3.1 Recommended Reading 151 5.3.2 Key Terms 151 5.3.3 Summary 151 PRACTICE SET 152 5.4.1 Quizzes 152 5.4.2 Questions 152 5.4.3 Problems 153 SIMULATION EXPERIMENTS 154
	5.5.1 Applets 154
Chap	ter 6 Bandwidth Utilization: Multiplexing and Spectrum Spreading 155
6.1	MULTIPLEXING 156 6.1.1 Frequency-Division Multiplexing 157 6.1.2 Wavelength-Division Multiplexing 162
62	 6.1.3 Time-Division Multiplexing 163 SPREAD SPECTRUM 175 6.2.1 Frequency Hopping Spread Spectrum 176 6.2.2 Direct Sequence Spread Spectrum 178
6,8	END-CHAPTER MATERIALS 180 6.3.1 Recommended Reading 180 6.3.2 Key Terms 180
6.4	6.3.3 Summary 180 PRACTICE SET 181 6.4.1 Quizzes 181 6.4.2 Questions 181
6.5	6.4.3 Problems 182 SIMULATION EXPERIMENTS 184 6.5.1 Applets 184
Chap	ter 7 Transmission Media 185
7.1 7.2	INTRODUCTION 186 GUIDED MEDIA 187 7.2.1 Twisted-Pair Cable 187 7.2.2 Coaxial Cable 190 7.2.3 Fiber-Optic Cable 192
7.3	UNGUIDED MEDIA: WIRELESS 197 7.3.1 Radio Waves 199 7.3.2 Microwaves 200 7.3.3 Infrared 201

7.4	END-CHAPTER MATERIALS 202
	7.4.1 Recommended Reading 202
	7.4.2 Key Terms 202
	7.4.3 Summary 203
7.5	PRACTICE SET 203
	7.5.1 Quizzes 203
	7.5.2 Questions 203
	7.5.3 Problems 204
Chap	oter 8 Switching 207
8.1	INTRODUCTION 208
	8.1.1 Three Methods of Switching 208
	8.1.2 Switching and TCP/IP Layers 209
8.2	CIRCUIT-SWITCHED NETWORKS 209
	8.2.1 Three Phases 211
	8.2.2 Efficiency 212
	8.2.3 Delay 213
8.3	PACKET SWITCHING 213
	8.3.1 Datagram Networks 214
	8.3.2 Virtual-Circuit Networks 216
8.4	STRUCTURE OF A SWITCH 222
	8.4.1 Structure of Circuit Switches 222
	8.4.2 Structure of Packet Switches 226
8.5	END-CHAPTER MATERIALS 230
	8.5.1 Recommended Reading 230
	8.5.2 Key terms 230
	8.5.3 Summary 230
8.6	PRACTICE SET 231
	8.6.1 Quizzes 231
	8.6.2 Questions 231
	8.6.3 Problems 231
8.7	SIMULATION EXPERIMENTS 234
	8.7.1 Applets 234
DA DI	「III: Data-Link Layer 235
	oter 9 Introduction to Data-Link Layer 237
Cilap	THE S IMPOUNCTION TO DUIG-LINK Layer 237
9.1	INTRODUCTION 238
	9.1.1 Nodes and Links 239
	9.1.2 Services 239
	9.1.3 Two Categories of Links 241
	9.1.4 Two Sublayers 242
9.2	LINK-LAYER ADDRESSING 242
	9.2.1 Three Types of addresses 244
	9.2.2 Address Resolution Protocol (ARP) 245
	9.2.3 An Example of Communication 248

9.3 9.4	END-CHAPTER MATERIALS 252 9.3.1 Recommended Reading 252 9.3.2 Key Terms 252 9.3.3 Summary 252 PRACTICE SET 253 9.4.1 Quizzes 253 9.4.2 Questions 253 9.4.3 Problems 254
Chap	ter 10 Error Detection and Correction 257
10.1	INTRODUCTION 258 10.1.1 Types of Errors 258 10.1.2 Redundancy 258 10.1.3 Detection versus Correction 258 10.1.4 Coding 259
10.2	BLOCK CODING 259 10.2.1 Error Detection 259
10.3	CYCLIC CODES 264
V	10.3.1 Cyclic Redundancy Check 264
	10.3.2 Polynomials 267
	10.3.3 Cyclic Code Encoder Using Polynomials 26910.3.4 Cyclic Code Analysis 270
	10.3.5 Advantages of Cyclic Codes 274
	10.3.6 Other Cyclic Codes 274
	10.3.7 Hardware Implementation 274
10.4	CHECKSUM 277
	10.4.1 Concept 278
	10.4.2 Other Approaches to the Checksum 281
19.5	FORWARD ERROR CORRECTION 282
	10.5.1 Using Hamming Distance 283
	10.5.2 Using XOR 283
	10.5.3 Chunk Interleaving 283
	10.5.4 Combining Hamming Distance and Interleaving 284
10/	10.5.5 Compounding High- and Low-Resolution Packets 284
10.6	END-CHAPTER MATERIALS 285
	10.6.1 Recommended Reading 285 10.6.2 Key Terms 286
	10.6.3 Summary 286
10/7	PRACTICE SET 287
110.7	10.7.1 Quizzes 287
	10.7.2 Questions 287
	10.7.3 Problems 288
10.8	SIMULATION EXPERIMENTS 292
	10.8.1 Applets 292

10.9 PROGRAMMING ASSIGNMENTS 292

Chap	ter 11 Data Link Control (DLC) 293
11.1	DLC SERVICES 294
	11.1.1 Framing 294
	11.1.2 Flow and Error Control 297
	11.1.3 Connectionless and Connection-Oriented 298
11.2	DATA-LINK LAYER PROTOCOLS 299
	11.2.1 Simple Protocol 300
	11.2.2 Stop-and-Wait Protocol 301
	11.2.3 Piggybacking 304
11.3	HDLC 304
	11.3.1 Configurations and Transfer Modes 305
	11.3.2 Framing 305
11.4	
	11.4.1 Services 309
	11.4.2 Framing 310
	11.4.3 Transition Phases 311
	11.4.4 Multiplexing 312
11.5	
	11.5.1 Recommended Reading 319
	11.5.2 Key Terms 319
11.6	11.5.3 Summary 319
11.6	
	11.6.1 Quizzes 320
	11.6.2 Questions 320 11.6.3 Problems 321
11.7	
11./	SIMULATION EXPERIMENTS 323 11.7.1 Applets 323
11.8	
Chap	ter 12 Media Access Control (MAC) 325
12.1	RANDOM ACCESS 326
	12.1.1 ALOHA 326
	12.1.2 CSMA 331
	12.1.3 CSMA/CD 334
	12.1.4 CSMA/CA 338
12.2	CONTROLLED ACCESS 341
	12.2.1 Reservation 341
	12.2.2 Polling 342
	12.2.3 Token Passing 343
12.3	CHANNELIZATION 344
	12.3.1 FDMA 344
	12.3.2 TDMA 346
	12.3.3 CDMA 347
12.4	END-CHAPTER MATERIALS 352
	12.4.1 Recommended Reading 352
	12.4.2 Key Terms 353
	12.4.3 Summary 353

12.5	12.5.1 Quizzes 354 12.5.2 Questions 354
12.6	12.5.3 Problems 356 SIMULATION EXPERIMENTS 360 12.6.1 Applets 360
12.7	**
Chap	ter 13 Wired LANs: Ethernet 361
13.1	ETHERNET PROTOCOL 362 13.1.1 IEEE Project 802 362 13.1.2 Ethernet Evolution 363
13.2	13.2.1 Characteristics 364 13.2.2 Addressing 366 13.2.3 Access Method 368 13.2.4 Efficiency of Standard Ethernet 370
13.3	13.2.5 Implementation 370 13.2.6 Changes in the Standard 373 FAST ETHERNET (100 MBPS) 376 13.3.1 Access Method 377 13.3.2 Physical Layer 377
13.4	· · · · · · · · · · · · · · · · · · ·
13.5	10 GIGABIT ETHERNET 382 13.5.1 Implementation 382
13.6	END-CHAPTER MATERIALS 383 13.6.1 Recommended Reading 383 13.6.2 Key Terms 383 13.6.3 Summary 383
13.7	
13.8	SIMULATION EXPERIMENTS 385 13.8.1 Applets 385 13.8.2 Lab Assignments 386
Chap	ter 14 Other Wired Networks 387
14.1	TELEPHONE NETWORKS 388 14.1.1 Major Components 388 14.1.2 LATAS 388 14.1.3 Signaling 390 14.1.4 Services Provided by Telephone Networks 393 14.1.5 Dial-Up Service 394 14.1.6 Digital Subscriber Line (DSL) 396

14.2	CABL	E NETWORKS 397
	14.2.1	Traditional Cable Networks 397
	14.2.2	Hybrid Fiber-Coaxial (HFC) Network 398
		Cable TV for Data Transfer 399
14.3	SONE	T 400
	14.3.1	Architecture 401
		SONET Layers 403
		SONET Frames 404
		STS Multiplexing 412
		SONET Networks 415
		Virtual Tributaries 420
14.4	ATM	
		Design Goals 422
		Problems 422
		Architecture 425
14.5		CHAPTER MATERIALS 429
	14.5.1	Recommended Reading 429
	14.5.2	Key Terms 430
4.4.6		Summary 431
14.6	_	TICE SET 432
		Quizzes 432
		Questions 432
	14.6.3	Problems 433
Chap	ter 15	Wireless LANs 435
•		
Chap 15.1	INTRO	DDUCTION 436
•	INTRO 15.1.1	
•	INTRO 15.1.1 15.1.2	DDUCTION 436 Architectural Comparison 436
•	INTRO 15.1.1 15.1.2 15.1.3	DDUCTION 436 Architectural Comparison 436 Characteristics 438
15.1	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1	DDUCTION 436 Architectural Comparison 436 Characteristics 438 Access Control 438 802.11 PROJECT 439 Architecture 440
15.1	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1	DDUCTION 436 Architectural Comparison 436 Characteristics 438 Access Control 438 802.11 PROJECT 439
15.1	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2	DDUCTION 436 Architectural Comparison 436 Characteristics 438 Access Control 438 802.11 PROJECT 439 Architecture 440
15.1	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4	DDUCTION 436 Architectural Comparison 436 Characteristics 438 Access Control 438 802.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446 Physical Layer 448
15.1	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4	DDUCTION 436 Architectural Comparison 436 Characteristics 438 Access Control 438 802.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446
15.1	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4	DDUCTION 436 Architectural Comparison 436 Characteristics 438 Access Control 438 802.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446 Physical Layer 448 TOOTH 451 Architecture 451
15.1 15.2 15.3	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4 BLUE 15.3.1 15.3.2	DDUCTION 436 Architectural Comparison 436 Characteristics 438 Access Control 438 802.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446 Physical Layer 448 TOOTH 451 Architecture 451 Bluetooth Layers 452
15.1	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4 BLUE 15.3.1 15.3.2	DDUCTION 436 Architectural Comparison 436 Characteristics 438 Access Control 438 802.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446 Physical Layer 448 TOOTH 451 Architecture 451
15.1 15.2 15.3	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4 BLUE 15.3.1 15.3.2 END-	DDUCTION 436 Architectural Comparison 436 Characteristics 438 Access Control 438 802.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446 Physical Layer 448 TOOTH 451 Architecture 451 Bluetooth Layers 452
15.1 15.2 15.3	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4 BLUE 15.3.1 15.3.2 END- 15.4.1 15.4.2	Architectural Comparison 436 Characteristics 438 Access Control 438 BO2.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446 Physical Layer 448 TOOTH 451 Architecture 451 Bluetooth Layers 452 CHAPTER MATERIALS 458 Further Reading 458 Key Terms 458
15.1 15.2 15.3 15.4	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4 BLUE 15.3.1 15.3.2 END-0 15.4.1 15.4.2 15.4.3	Architectural Comparison 436 Characteristics 438 Access Control 438 802.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446 Physical Layer 448 TOOTH 451 Architecture 451 Bluetooth Layers 452 CHAPTER MATERIALS 458 Further Reading 458 Key Terms 458 Summary 458
15.1 15.2 15.3	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4 BLUE 15.3.1 15.3.2 END- 15.4.1 15.4.2 15.4.3 PRAC	DDUCTION 436 Architectural Comparison 436 Characteristics 438 Access Control 438 802.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446 Physical Layer 448 TOOTH 451 Architecture 451 Bluetooth Layers 452 CHAPTER MATERIALS 458 Further Reading 458 Key Terms 458 Summary 458 TICE SET 459
15.1 15.2 15.3 15.4	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4 BLUE 15.3.1 15.3.2 END- 15.4.1 15.4.2 15.4.3 PRAC 15.5.1	DDUCTION 436 Architectural Comparison 436 Characteristics 438 Access Control 438 802.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446 Physical Layer 448 TOOTH 451 Architecture 451 Bluetooth Layers 452 CHAPTER MATERIALS 458 Further Reading 458 Key Terms 458 Summary 458 TICE SET 459 Quizzes 459
15.1 15.2 15.3 15.4	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4 BLUE 15.3.1 15.3.2 END-0 15.4.1 15.4.2 15.4.3 PRAC 15.5.1 15.5.2	Architectural Comparison 436 Characteristics 438 Access Control 438 B02.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446 Physical Layer 448 TOOTH 451 Architecture 451 Bluetooth Layers 452 CHAPTER MATERIALS 458 Further Reading 458 Key Terms 458 Summary 458 TICE SET 459 Quizzes 459 Questions 459
15.1 15.2 15.3 15.4	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4 BLUE 15.3.1 15.3.2 END-0 15.4.1 15.4.2 15.4.3 PRAC 15.5.1 15.5.2 15.5.3	Architectural Comparison 436 Characteristics 438 Access Control 438 BO2.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446 Physical Layer 448 TOOTH 451 Architecture 451 Bluetooth Layers 452 CHAPTER MATERIALS 458 Further Reading 458 Key Terms 458 Summary 458 TICE SET 459 Quizzes 459 Questions 459 Problems 460
15.1 15.2 15.3 15.4	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4 BLUE 15.3.1 15.3.2 END-0 15.4.1 15.4.2 15.4.3 PRAC 15.5.1 15.5.2 15.5.3 SIMU	DDUCTION 436 Architectural Comparison 436 Characteristics 438 Access Control 438 802.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446 Physical Layer 448 TOOTH 451 Architecture 451 Bluetooth Layers 452 CHAPTER MATERIALS 458 Further Reading 458 Key Terms 458 Summary 458 TICE SET 459 Quizzes 459 Questions 459 Problems 460 LATION EXPERIMENTS 463
15.1 15.2 15.3 15.4	INTRO 15.1.1 15.1.2 15.1.3 IEEE 3 15.2.1 15.2.2 15.2.3 15.2.4 BLUE 15.3.1 15.3.2 END-0 15.4.1 15.4.2 15.4.3 PRAC 15.5.1 15.5.2 15.5.3 SIMU	Architectural Comparison 436 Characteristics 438 Access Control 438 BO2.11 PROJECT 439 Architecture 440 MAC Sublayer 441 Addressing Mechanism 446 Physical Layer 448 TOOTH 451 Architecture 451 Bluetooth Layers 452 CHAPTER MATERIALS 458 Further Reading 458 Key Terms 458 Summary 458 TICE SET 459 Quizzes 459 Questions 459 Problems 460