C O N T E N T S

	Preface			
1	Introduction			
	1.1	Elements of a Digital Communication System	1	
	1.2	Communication Channels and Their Characteristics	3	
	1.3	Mathematical Models for Communication Channels	10	
	1.4	A Historical Perspective in the Development of Digital Communications	13	
	1.5	Overview of the Book	15	
	1.6	Bibliographical Notes and References	16	
2	Probability and Stochastic Processes			
	2.1	Probability	17 17	
		2.1.1 Random Variables, Probability Distributions, and Probability Densities 2.1.2 Functions of Random Variables 2.1.3 Statistical	17	
		Averages of Random Variables 2.1.4 Some Useful Probability		
		Distributions 2.1.5 Upper Bounds on the Tail Probability 2.1.6		
		Sums of Random Variables and the Central Limit Theorem		
	2.2	Stochastic Processes	61	
		2.2.1 Statistical Averages 2.2.2 Power Density Spectrum 2.2.3		
		Response of a Linear Time-Invariant System to a Random Input		
		Signal 2.2.4 Sampling Theorem for Band-Limited Stochastic		
		Processes 2.2.5 Discrete-Time Stochastic Signals and Systems 2.2.6		
		Cyclostationary Processes		
	2.3	Bibliographical Notes and References	75	
		Problems	75	
3	Sou	rce Coding	80	
	3.1	Mathematical Models for Information Sources	80	
	3.2	A Logarithmic Measure of Information	82	
		3.2.1 Average Mutual Information and Entropy 3.2.2 Information		
		Measures for Continuous Random Variables		
	3.3	Coding for Discrete Sources	90	
		3.3.1 Coding for Discrete Memoryless Sources 3.3.2 Discrete		
		Stationary Sources 3.3.3 The Lempel-Ziv Algorithm		

	3.4	Coding for Analog Sources—Optimum Quantization 3.4.1 Rate-Distortion Function 3.4.2 Scalar Quantization 3.4.3 Vector Quantization	103
	3.5		121
		Coding 3.5.3 Model-Based Source Coding	
	3.6	<u>-</u> .	140
		Problems	141
4	Cha	aracterization of Communication Signals and Systems	148
	4.1		148
		4.1.1 Representation of Band-Pass Signals 4.1.2 Representation of	
	•	Linear Band-Pass Systems 4.1.3 Response of a Band-Pass System to	
		a Band-Pass Signal 4.1.4 Representation of Band-Pass Stationary	
		Stochastic Processes	
	4.2	~ • •	158
		4.2.1 Vector Space Concepts 4.2.2 Signal Space Concepts 4.2.3	
	4.3	Orthogonal Expansions of Signals Representation of Digitally Modulated Signals	168
	4.3	4.3.1 Memoryless Modulation Methods 4.3.2 Linear Modulation with	108
		Memory 4.3.3 Non-linear Modulation Methods with Memory—	
		CPFSK and CPM	
	4.4		201
		4.4.1 Power Spectra of Linearly Modulated Signals 4.4.2 Power	
		Spectra of CPFSK and CPM Signals 4.4.3 Power Spectra of	
		Modulated Signals with Memory	
	4.5	Bibliographical Notes and References	221
		Problems	222
5		timum Receivers for the Additive White Gaussian Noise	
		nnel	231
	5.1	Optimum Receiver for Signals Corrupted by Additive White Gaussian Noise	231
		5.1.1 Correlation Demodulator 5.1.2 Matched-Filter Demodulator	
		5.1.3 The Optimum Detector / 5.1.4 The Maximum-Likelihood	
		Sequence Detector 5.1.5 A Symbol-by-Symbol MAP Detector for	
		Signals with Memory	
	5.2	Performance of the Optimum Receiver for Memoryless Modulation	254
		5.2.1 Probability of Error for Binary Modulation 5.2.2 Probability of	
		Error for M-ary Orthogonal Signals / 5.2.3 Probability of Error for	
		M-ary Biorthogonal Signals 5.2.4 Probability of Error for Simplex	
		Signals 5.2.5 Probability of Error for M-ary Binary-Coded	
		Signals 5.2.6 Probability of Error for M-ary PAM 5.2.7	
		Probability of Error for M-ary PSK 5.2.8 Differential PSK (DPSK)	

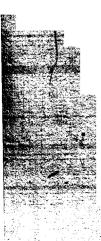
		and Its Performance 5.2.9 Probability of Error for QAM 5.2.10 Comparison of Digital Modulation Methods	
	5.3	Optimum Receiver for CPM Signals	283
		5.3.1 Optimum Demodulation and Detection of CPM 5.3.2	
		Performance of CPM Signals 5.3.3 Symbol-by-Symbol Detection of	
		CPM Signals 5.3.4 Suboptimum Demodulation and Detection of CPM Signals	
	5.4	Optimum Receiver for Signals with Random Phase in AWGN Channel 5.4.1 Optimum Receiver for Binary Signals 5.4.2 Optimum Receiver for M-ary Orthogonal Signals 5.4.3 Probability of Error for Envelope Detection of M-ary Orthogonal Signals 5.4.4 Probability of Error for Envelope Detection of Correlated Binary Signals	300
	5.5	Performance Analysis for Wireline and Radio Communication Systems 5.5.1 Regenerative Repeaters / 5.5.2 Link Budget Analysis in Radio Communication Systems	313
	5.6	Bibliographical Notes and References	318
	0.0	Problems	319
6	Cai	rier and Symbol Synchronziation	333
	6.1	Signal Parameter Estimation	333
		6.1.1 The Likelihood Function 6.1.2 Carrier Recovery and Symbol	
		Synchronization in Signal Demodulation	
	6.2	Carrier Phase Estimation	338
		6.2.1 Maximum-Likelihood Carrier Phase Estimation 6.2.2 The	
		Phase-Locked Loop 6.2.3 Effect of Additive Noise on the Phase Estimate 6.2.4 Decision-Directed Loops 6.2.5 Non-Decision-	
		Directed Loops	
	6.3	Symbol Timing Estimation	359
		6.3.1 Maximum-Likelihood Timing Estimation 6.3.2 Non-Decision-	339
		Directed Timing Estimation	
	6.4	= 4,	366
	6.5	Performance Characteristics of ML Estimators	368
	6.6	Bibliographical Notes and References	371
		Problems	372
7	Cha	nnel Capacity and Coding	376
	7.1	Channel Models and Channel Capacity	376
		7.1.1 Channel Models 7.1.2 Channel Capacity 7.1.3 Achieving	5,0
		Channel Capacity with Orthogonal Signals 7.1.4 Channel Reliability Functions	
	7.2	Random Selection of Codes	392
		7.2.1 Random Coding Based on M-ary Binary-Coded Signals 7.2.2	
		Random Coding Based on M-ary Multiamplitude Signals / 7.2.3	
		Comparison of R ₀ * with the Capacity of the AWGN Channel	
	7.3	Communication System Design Based on the Cutoff Rate	402

	7.4	Bibliographical Notes and References Problems				
8	Block and Convolutional Channel Codes					
	8.1	Linear Block Codes 8.1.1 The Generator Matrix and the Parity Check Matrix 8.1.2 Some Specific Linear Block Codes 8.1.3 Cyclic Codes 8.1.4 Optimum Soft-Decision Decoding of Linear Block Codes 8.1.5 Hard-Decision Decoding of Linear Block Codes 8.1.6 Comparison of Performance Between Hard-Decision and Soft-Decision Decoding 8.1.7 Bounds on Minimum Distance of Linear Block Codes 8.1.8 Nonbinary Block Codes and Concatenated Block Codes 8.1.9 Interleaving of Coded Data for Channels with Burst Errors 8.1.10 Serial and Parallel Concatenated Block Codes				
	8.2	Convolutional Codes 8.2.1 The Transfer Function of a Convolutional Code 8.2.2 Optimum Decoding of Convolutional Codes—The Viterbi Algorithm 8.2.3 Probability of Error for Soft-Decision Decoding 8.2.4 Probability of Error for Hard-Decision Decoding 8.2.5 Distance Properties of Binary Convolutional Codes 8.2.6 Punctured Convolutional Codes 8.2.7 Other Decoding Algorithms for Convolutional Codes 8.2.8 Practical Considerations in the Application of Convolutional Codes 8.2.9 Nonbinary Dual-k Codes and Concatenated Codes 8.2.10 Parallel and Serial Concatenated Convolutional Codes	471			
	8.3	Coded Modulation for Bandwidth-Constrained Channels—Trellis-Code Modulation	d 522			
	8.4	Bibliographical Notes and References Problems	539 541			
9	Sig	nal Design for Band-Limited Channels	548			
	9.1 9.2	Characterization of Band-Limited Channels Signal Design for Band-Limited Channels 9.2.1 Design of Band-Limited Signals for No Intersymbol Interference—The Nyquist Criterion 9.2.2 Design of Band-Limited Signals with Controlled ISI—Partial-Response Signals 9.2.3 Data Detection for Controlled ISI 9.2.4 Signal Design for Channels with Distortion	548 554			
	9.3	Probability of Error in Detection of PAM 9.3.1 Probability of Error for Detection of PAM with Zero ISI 9.3.2 Probability of Error for Detection of Partial-Response Signals	574			
	9.4	Modulation Codes for Spectrum Shaping	578			
	9.5	Bibliographical Notes and References Problems	588 588			

10	Com	munication Through Band-Limited Linear Filter Channels	598
	10.1	Optimum Receiver for Channels with ISI and AWGN 10.1.1 Optimum Maximum-Likelihood Receiver 10.1.2 A Discrete- Time Model for a Channel with ISI 10.1.3 The Viterbi Algorithm for the Discrete-Time White Noise Filter Model 10.1.4 Performance of MLSE for Channels with ISI	599
	10.2	Linear Equalization 10.2.1 Peak Distortion Criterion 10.2.2 Mean-Square-Error (MSE) Criterion 10.2.3 Performance Characteristics of the MSE Equalizer 10.2.4 Fractionally Spaced Equalizers 10.2.5 Baseband and Passband Linear Equalizers	616
	10.3	Decision-Feedback Equalization 10.3.1 Coefficient Optimization 10.3.2 Performance Characteristics of DFE 10.3.3 Predictive Decision-Feedback Equalizer 10.3.4 Equalization at the Transmitter—Tomlinson—Harashima Precoding	638
	10.4	Reduced Complexity ML Detectors	647
	10.5	Iterative Equalization and Decoding—Turbo Equalization	649
	10.6	Bibliographical Notes and References Problems	651 652
11	Ada	ptive Equalization	660
	11.1	Adaptive Linear Equalizer 11.1.1 The Zero-Forcing Algorithm 11.1.2 The LMS Algorithm 11.1.3 Convergence Properties of the LMS Algorithm 11.1.4 Excess MSE Due to Noisy Gradient Estimates 11.1.5 Accelerating the Initial Convergence Rate in the LMS Algorithm 11.1.6 Adaptive Fractionally Spaced Equalizer—The Tap Leakage Algorithm 11.1.7 An Adaptive Channel Estimator for ML Sequence Detection	660
	11.2	Adaptive Decision-Feedback Equalizer	677
	11.3	Adaptive Equalization of Trellis-Coded Signals	678
	11.4	Recursive Least-Squares Algorithms for Adaptive Equalization 11.4.1 Recursive Least-Squares (Kalman) Algorithm 11.4.2 Linear Prediction and the Lattice Filter	682
	11.5	Self-Recovering (Blind) Equalization 11.5.1 Blind Equalization Based on the Maximum-Likelihood Criterion 11.5.2 Stochastic Gradient Algorithms 11.5.3 Blind Equalization Algorithms Based on Second- and Higher-Order Signal Statistics	693
	11.6		704
		Problems	705
12	Mul	tichannel and Multicarrier Systems	709
	12.1	Multichannel Digital Communications in AWGN Channels 12.1.1 Binary Signals 12.1.2 M-ary Orthogonal Signals	709

xvi

	12.2	William Communications	715	
	12.2.1 Capacity of a Nonideal Linear Filter Channel 12.2.2 An			
		FFT-Based Multicarrier System 12.2.3 Minimizing Peak-to-Average		
		Ratio in the Multicarrier Systems		
	12.3	Bibliographical Notes and References	723	
		Problems	724	
			706	
13	Spre	ad Spectrum Signals for Digital Communications	726	
	13.1	Model of Spread Spectrum Digital Communication System	728	
	13.2	Direct Sequence Spread Spectrum Signals	729	
		13.2.1 Error Rate Performance of the Decoder 13.2.2 Some		
		Applications of DS Spread Spectrum Signals / 13.2.3 Effect of Pulsed		
		Interference on DS Spread Spectrum Systems 13.2.4 Excision of		
		Narrowband Interference in DS Spread Spectrum Systems 13.2.5		
		Generation of PN Sequences		
	13.3	Frequency-Hopped Spread Spectrum Signals	771	
		13.3.1 Performance of FH Spread Spectrum Signals in an AWGN		
		Channel 13.3.2 Performance of FH Spread Spectrum Signals in		
		Partial-Band Interference 13.3.3 A CDMA System Based on FH		
		Spread Spectrum Signals	704	
	13.4	Other Types of Spread Spectrum Signals	784	
	13.5	Synchronization of Spread Spectrum Systems	786 792	
	13.6	Bibliographical Notes and References	794	
		Problems	רכו	
14	Digi	tal Communications through Fading Multipath Channels	800	
	14.1	Characterization of Fading Multipath Channels	801	
	14.1	14.1.1 Channel Correlation Functions and Power Spectra / 14.1.2		
		Statistical Models for Fading Channels		
	14.2	and the state of t	:1814	
	14.3		816	
	14.4		821	
		14.4.1 Binary Signals 14.4.2 Multiphase Signals 14.4.3 M-ary		
		Orthogonal Signals		
	14.5	Digital Signaling over a Frequency-Selective, Slowly Fading Channel	840	
		14.5.1 A Tapped-Delay-Line Channel Model 14.5.2 The RAKE		
		Demodulator 14.5.3 Performance of RAKE Demodulator 14.5.4		
		Receiver Structures for Channels with Intersymbol Interference		
	14.6	Coded Waveforms for Fading Channels	85	
		14.6.1 Probability of Error for Soft-Decision Decoding of Linear		
		Binary Block Codes / 14.6.2 Probability of Error for Hard-Decision		
		Decoding of Linear Binary Block Codes 14.6.3 Upper Bounds on		
		the Performance of Convolutional Codes for a Rayleigh Fading		
		Channel 14.6.4 Use of Constant-Weight Codes and Concatenated		
		Codes for a Fading Channel 14.6.5 System Design Based on the		



			ate 14.6.6 Performance of Coded Phase-Coherent ication Systems—Bit-Interleaved Coded Modulation 14.6.7		
	Trel	lis-Ce	oded Modulation		
14.7	Mul	tiple-	Antenna Systems	878	
14.8	Bibli	ogra	phical Notes and References	885	
	Prob	olems		887	
15 Mult	tiuser	r Co	mmunications	896	
15.1	Intro	oduct	tion to Multiple Access Techniques	896	
15.2			of Multiple Access Methods	899	
15.3			vision Multiple Access	905	
	15.3 Rece Inter	.1 Cl eiver	DMA Signal and Channel Models 15.3.2 The Optimum 15.3.3 Suboptimum Detectors 15.3.4 Successive nce Cancellation 15.3.5 Performance Characteristics of		
15.4			Access Methods	922	
13.4	LOHA Systems and Protocols 15.4.2 Carrier Sense and Protocols	722			
15.5 Bibliographical Notes and References					
	Prob	olems		933	
Appendix	A	The	Levinson-Durbin Algorithm	939	
Appendix	В	Erro	or Probability for Multichannel Binary Signals	943	
Appendix			or Probabilities for Adaptive Reception of M-Phase		
		Sign		949	
		C.1	Mathematical Model for M-Phase Signaling Communication		
			System	949	
		C.2	Characteristic Function and Probability Density Function of		
		~ ~	the Phase θ	952	
		C.3	Error Probabilities for Slowly Rayleigh Fading Channels	953	
		C.4	Error Probabilities for Time-Invariant and Ricean Fading Channels	956	
Appendix	D	San	are-Root Factorization	961	
	ע	Squ	······································	701	
References		-		963	