

Contents

Preface	xi
Acknowledgements	xv
List of Abbreviations	xvii
List of Symbols	xxi
1 Introduction to Digital Communications	1
1.1 Basic System Model	1
1.1.1 Introduction	1
1.1.2 Multiple Access Techniques	3
1.1.3 Principle Structure of SISO Systems	5
1.2 Characteristics of Mobile Radio Channels	8
1.2.1 Equivalent Baseband Representation	8
1.2.2 Additive White Gaussian Noise	11
1.2.3 Frequency-Selective Time-Variant Fading	12
1.2.4 Systems with Multiple Inputs and Outputs	16
1.3 Signal Detection	18
1.3.1 Optimal Decision Criteria	18
1.3.2 Error Probability for AWGN Channel	20
1.3.3 Error and Outage Probability for Flat Fading Channels	22
1.3.4 Time-Discrete Matched Filter	25
1.4 Digital Linear Modulation	27
1.4.1 Introduction	27
1.4.2 Amplitude Shift Keying (ASK)	28
1.4.3 Quadrature Amplitude Modulation (QAM)	30
1.4.4 Phase Shift Keying (PSK)	33
1.5 Diversity	36
1.5.1 General Concept	36
1.5.2 MRC for Independent Diversity Branches	40
1.5.3 MRC for Correlated Diversity Branches	47
1.6 Summary	49

2	Information Theory	51
2.1	Basic Definitions	51
2.1.1	Information, Redundancy, and Entropy	51
2.1.2	Conditional, Joint and Mutual Information	53
2.1.3	Extension for Continuous Signals	56
2.1.4	Extension for Vectors and Matrices	57
2.2	Channel Coding Theorem for SISO Channels	58
2.2.1	Channel Capacity	58
2.2.2	Cutoff Rate	59
2.2.3	Gallager Exponent	62
2.2.4	Capacity of the AWGN Channel	64
2.2.5	Capacity of Fading Channel	68
2.2.6	Channel Capacity and Diversity	70
2.3	Channel Capacity of MIMO Systems	73
2.4	Channel Capacity for Multiuser Communications	78
2.4.1	Single Antenna AWGN Channel	78
2.4.2	Single Antenna Flat Fading Channel	82
2.4.3	Multiple Antennas at Transmitter and Receiver	85
2.5	Summary	89
3	Forward Error Correction Coding	91
3.1	Introduction	92
3.2	Linear Block Codes	94
3.2.1	Description by Matrices	94
3.2.2	Simple Parity Check and Repetition Codes	97
3.2.3	Hamming and Simplex Codes	98
3.2.4	Hadamard Codes	99
3.2.5	Trellis Representation of Linear Block Codes	99
3.3	Convolutional Codes	100
3.3.1	Structure of Encoder	101
3.3.2	Graphical Description of Convolutional Codes	104
3.3.3	Puncturing Convolutional Codes	105
3.3.4	ML Decoding with Viterbi Algorithm	106
3.4	Soft-Output Decoding of Binary Codes	109
3.4.1	Log-Likelihood Ratios – A Measure of Reliability	109
3.4.2	General Approach for Soft-Output Decoding	112
3.4.3	Soft-Output Decoding for Walsh Codes	114
3.4.4	BCJR Algorithm for Binary Block Codes	115
3.4.5	BCJR Algorithm for Binary Convolutional Codes	118
3.4.6	Implementation in Logarithmic Domain	120
3.5	Performance Evaluation of Linear Codes	121
3.5.1	Distance Properties of Codes	121
3.5.2	Error Rate Performance of Codes	125
3.5.3	Information Processing Characteristic	131

3.6	Concatenated Codes	135
3.6.1	Introduction	135
3.6.2	Performance Analysis for Serial Concatenation	137
3.6.3	Performance Analysis for Parallel Concatenation	141
3.6.4	Turbo Decoding of Concatenated Codes	146
3.6.5	EXIT Charts Analysis of Turbo Decoding	153
3.7	Low-Density Parity Check (LDPC) Codes	160
3.7.1	Basic Definitions and Encoding	160
3.7.2	Graphical Description	165
3.7.3	Decoding of LDPC Codes	167
3.7.4	Performance of LDPC Codes	169
3.8	Summary	171
4	Code Division Multiple Access	173
4.1	Fundamentals	174
4.1.1	Direct-Sequence Spread Spectrum	174
4.1.2	Direct-Sequence CDMA	181
4.1.3	Single-User Matched Filter (SUMF)	185
4.1.4	Spreading Codes	191
4.2	OFDM-CDMA	194
4.2.1	Multicarrier Transmission	194
4.2.2	Orthogonal Frequency Division Multiplexing	195
4.2.3	Combining OFDM and CDMA	200
4.3	Low-Rate Channel Coding in CDMA Systems	208
4.3.1	Conventional Coding Scheme (CCS)	209
4.3.2	Code-Spread Scheme (CSS)	210
4.3.3	Serially Concatenated Coding Scheme (SCCS)	211
4.3.4	Parallel Concatenated Coding Scheme (PCCS)	214
4.3.5	Influence of MUI on Coding Schemes	216
4.4	Uplink Capacity of CDMA Systems	219
4.4.1	Orthogonal Spreading Codes	220
4.4.2	Random Spreading Codes and Optimum Receiver	220
4.4.3	Random Spreading Codes and Linear Receivers	222
4.5	Summary	225
5	Multisuser Detection in CDMA Systems	227
5.1	Optimum Detection	227
5.1.1	Optimum Joint Sequence Detection	228
5.1.2	Joint Preprocessing and Subsequent Separate Decoding	229
5.1.3	Turbo Detection with Joint Preprocessing and Separate Decoding	231
5.2	Linear Multisuser Detection	233
5.2.1	Decorrelator (Zero-Forcing, ZF)	233
5.2.2	Minimum Mean Squared Error Receiver (MMSE)	236
5.2.3	Linear Parallel Interference Cancellation (PIC)	240
5.2.4	Linear Successive Interference Cancellation (SIC)	243

5.3	Nonlinear Iterative Multiuser Detection	245
5.3.1	Nonlinear Devices	245
5.3.2	Uncoded Nonlinear Interference Cancellation	247
5.3.3	Nonlinear Coded Interference Cancellation	253
5.4	Combining Linear MUD and Nonlinear SIC	258
5.4.1	BLAST-like Detection	258
5.4.2	QL Decomposition for Zero-Forcing Solution	258
5.4.3	QL Decomposition for MMSE Solution	268
5.4.4	Turbo Processing	270
5.5	Summary	273
6	Multiple Antenna Systems	275
6.1	Introduction	275
6.2	Spatial Diversity Concepts	277
6.2.1	Receive Diversity	277
6.2.2	Performance Analysis of Space–Time Codes	279
6.2.3	Orthogonal Space–Time Block Codes	282
6.2.4	Space–Time Trellis Codes	293
6.3	Multilayer Transmission	304
6.3.1	Channel Knowledge at the Transmitter and Receiver	304
6.3.2	Channel Knowledge only at the Receiver	306
6.3.3	Performance of Multilayer Detection Schemes	308
6.3.4	Lattice Reduction-Aided Detection	312
6.4	Linear Dispersion Codes	319
6.4.1	LD Description of Alamouti’s Scheme	320
6.4.2	LD Description of Multilayer Transmissions	321
6.4.3	LD Description of Beamforming	321
6.4.4	Optimizing Linear Dispersion Codes	322
6.4.5	Detection of Linear Dispersion Codes	323
6.5	Information Theoretic Analysis	323
6.5.1	Uncorrelated MIMO Channels	323
6.5.2	Correlated MIMO Channels	325
6.6	Summary	328
Appendix A	Channel Models	329
A.1	Equivalent Baseband Representation	329
A.2	Typical Propagation Profiles for Outdoor Mobile Radio Channels	330
A.3	Moment-Generating Function for Ricean Fading	331
Appendix B	Derivations for Information Theory	333
B.1	Chain Rule for Entropies	333
B.2	Chain Rule for Information	333
B.3	Data-Processing Theorem	334
Appendix C	Linear Algebra	335
C.1	Selected Basics	335

CONTENTS	ix
C.2 Householder Reflections and Givens Rotation	341
C.3 LLL Lattice Reduction	343
Bibliography	347
Index	359

