
Contents

1	Introduction	1
	<i>Ivan R.S. Casella and Alagan Anpalagan</i>	
1.1	Motivation for this book	3
1.2	Chapters overview	4
	References	7
2	Fundamentals of digital communications	9
	<i>Ivan R.S. Casella</i>	
2.1	Introduction	9
2.1.1	Communication system model	10
2.1.2	Communication channels	11
2.2	Review of fundamentals	13
2.2.1	Nyquist sampling theorem	13
2.2.2	Bandwidth	15
2.2.3	Power and energy	15
2.2.4	Measuring efficiency of communication systems	17
2.3	Vector signal space	18
2.3.1	Definition of the signal space	18
2.3.2	Gram–Schmidt and the geometric representation of signals	20
2.3.3	Karhunen–Loève and the geometric representation of noise	21
2.3.4	Optimum receiver structure (MAP/ML criteria)	22
2.3.5	Decision region and error probability	27
2.3.6	Error probability bounds	28
2.4	Baseband digital communication systems	29
2.4.1	Line coding	30
2.4.2	Complex-valued M-ary PAM	30
2.5	Bandpass digital communication systems	31
2.5.1	Some important bandpass digital schemes	32
2.5.2	Performance of bandpass digital schemes in AWGN	38
2.6	Bandlimited transmission	40
2.6.1	Nyquist criterion for zero ISI	41
2.6.2	Multipath fading channels	43
2.6.3	Equalization	46

2.7	Synchronization	52
2.7.1	Carrier synchronization	53
2.7.2	Timing synchronization	54
2.8	Conclusion remarks and trends in digital communications	54
	References	55
3	Basis of error correction coding	59
	<i>Marco A. Cazarotto Gomes and Murilo B. Loiola</i>	
3.1	Linear block code	61
3.1.1	Parity check matrix	63
3.1.2	Low-density parity-check	65
3.1.3	Reed–Solomon codes	67
3.2	Convolutional codes	68
3.3	Turbo codes	76
3.4	Final remarks	80
	References	80
4	Principles of orthogonal frequency division multiplexing and single carrier frequency domain equalisation	83
	<i>Cristiano Panazio and Renato Lopes</i>	
4.1	Introduction	83
4.2	Mathematical preliminaries and basic concepts	84
4.2.1	The basics of OFDM	85
4.2.2	The basics of SC	86
4.3	Frequency domain equalisation	87
4.3.1	The channel distortion as a simple entrywise product	87
4.3.2	The cyclic prefix technique	89
4.3.3	OFDM equalisation	93
4.3.4	SC frequency domain equalisation	94
4.4	Simulation results	97
4.5	Peak-to-average power	101
4.6	Concluding remarks and further considerations	103
	References	103
5	Modern power line communication technologies	107
	<i>Samuel C. Pereira, Ivan R.S. Casella, and Carlos E. Capovilla</i>	
5.1	Introduction to PLC technologies	107
5.2	Advantages and disadvantages of PLC technologies	109
5.2.1	Advantages of PLC technologies	110
5.2.2	Disadvantages of PLC technologies	110

5.3	History of PLC technologies	111
5.4	PLC classification, frequency bands and standards	114
5.4.1	UNB-PLC systems and its applications	114
5.4.2	Standards and frequency bands for UNB-PLC systems	117
5.4.3	NB-PLC systems and its applications	117
5.4.4	Frequency bands for NB-PLC systems	118
5.4.5	Standards for NB-PLC systems	120
5.4.6	BB-PLC systems and its applications	125
5.4.7	Frequency bands for BB-PLC systems	125
5.4.8	Standards for BB-PLC systems	127
5.5	Conclusion remarks	130
	References	130
6	Power line communication channel models	139
	<i>Ricardo Suyama</i>	
6.1	Multipath propagation model	140
6.2	Noise in PLC channels	142
6.2.1	Colored background noise	143
6.2.2	Narrowband noise	144
6.2.3	Impulsive noise	145
6.2.4	Markov–Gaussian noise model	150
6.2.5	Noise in narrowband systems	152
6.3	Generating channels for broadband PLC	155
6.4	Generating channels for narrowband PLC	156
6.5	Extensions to MIMO PLC	157
6.6	Concluding remarks	158
	Acknowledgement	159
	References	159
7	Narrowband power line communication systems	163
	<i>Samuel C. Pereira, Ivan R.S. Casella, and Carlos E. Capovilla</i>	
7.1	PHY layer description of PRIME, G3-PLC and IEEE 1901.2 standards	164
7.1.1	PHY frame	165
7.1.2	Scrambling schemes	171
7.1.3	Forward error correction system	172
7.1.4	OFDM generation	179
7.1.5	G3-PLC/IEEE 1901.2 ATM function	184
7.2	Simulation of PRIME and G3-PLC/IEEE 1901.2 PHY layers	185
7.2.1	AWGN channel	186
7.2.2	Multipath fading channel	187
7.2.3	AWGN channel with periodic impulsive noise	189
7.2.4	Multipath fading channel with periodic impulsive noise	193
7.3	Conclusion remarks	196
	References	196

8	Broadband power line communication systems	199
	<i>Ivan R.S. Casella, Samuel C. Pereira, and Carlos E. Capovilla</i>	
8.1	Physical layer description of IEEE 1901-2010	200
8.1.1	Physical layer frames	201
8.1.2	Scrambling schemes	208
8.1.3	Forward error correction system	209
8.1.4	OFDM generation	219
8.1.5	Tone mapping	224
8.2	Simulation of FFT-OFDM and W-OFDM PHY layers	226
8.2.1	AWGN channel	227
8.2.2	Multipath fading channel	229
8.2.3	AWGN channel with periodic impulsive noise	231
8.2.4	Multipath fading channel with periodic impulsive noise	234
8.3	Conclusion remarks	237
	References	238
9	Power line communications for smart grids applications	241
	<i>Ivan R.S. Casella</i>	
9.1	Conventional power grids	241
9.2	Smart grids	244
9.2.1	Advanced metering infrastructure	246
9.2.2	Optimization of energy resources use and integration of renewable energy sources	247
9.2.3	Distributed generation and microgrids	247
9.2.4	Decentralized energy storage	248
9.2.5	Plug-in electric vehicles and vehicle-to-grid	249
9.2.6	Demand side management and demand response	249
9.2.7	Dynamic energy pricing	251
9.2.8	Physical and cyber security and privacy	252
9.3	Information and communication technologies for smart grids	253
9.4	Power line communication technologies for smart grids	260
9.4.1	PLCs applications in HAN/BAN/IAN	261
9.4.2	PLCs applications in NAN	262
9.4.3	PLCs applications in FAN	263
9.4.4	PLCs applications in WAN	264
9.5	Conclusion remarks	265
	References	266
10	An overview of quad-generation system for smart grid using PLC	273
	<i>Muhammad Kashif, Muhammad Naeem, Muhammad Iqbal, Waleed Ejaz, and Alagan Anpalagan</i>	
10.1	Introduction	274

10.2	Objective functions being used for the optimization of CHP and CCHP	278
10.2.1	Cost minimization and economic analysis	278
10.2.2	Energy efficiency maximization	281
10.2.3	GHGEs minimization	283
10.3	Optimization types used in CCHP	285
10.3.1	Linear programming	285
10.3.2	NLP and MINLP	286
10.3.3	BIP, DP, and MILP	287
10.4	Solution approaches and tools used to solve optimization problems related to CCHP	287
10.4.1	Solution approaches	288
10.4.2	Tools used to solve CCHP	288
10.5	Conclusion and future work	289
	References	290
11	Demand side management through PLC: concepts and challenges	295
	<i>Nikolaos G. Paterakis, Samina Subhani, and Muhammad Babar</i>	
11.1	Introduction	295
11.2	Overview of demand response	298
11.2.1	Types of demand response programs	298
11.2.2	Types of customer response	300
11.3	Benefits of demand response	301
11.3.1	Integration of high amounts of renewable energy sources	302
11.3.2	System-wide benefits	303
11.3.3	Societal benefits	303
11.4	Demand response implementation requirements	304
11.4.1	Metering, control, and communication infrastructure	304
11.4.2	Communication technologies	306
11.4.3	Standardization regarding demand response	314
11.5	Challenges and barriers to the development of demand response	315
11.6	Conclusions	317
	References	319
12	PLC for monitoring and control of distributed generators in smart grids	325
	<i>Anton Poluektov, Antti Pinomaa, Antti Kosonen, Aleksei Romanenko, and Jero Ahola</i>	
12.1	Introduction	325
12.1.1	Grid faults and islanding	325
12.1.2	Standardization and legislation	325
12.1.3	Islanding-detection methods	326

12.2	Application field	327
12.2.1	Noise scenario	328
12.2.2	Channel attenuation	329
12.2.3	Grid topology	330
12.2.4	Power distribution transformer	331
12.3	Design of a PLC solution	332
12.3.1	Signaling scheme	332
12.3.2	Coupling interfaces	332
12.3.3	Frequency band	333
12.3.4	Signaling modulation techniques	333
12.3.5	Concept evaluation, SDR platform	334
12.4	PLC concept implementation	334
12.4.1	Signaling concept	334
12.4.2	Functionality	335
12.5	Laboratory tests	336
12.5.1	Laboratory setup	336
12.5.2	Fault detection tests	336
12.5.3	Sensitivity analysis	338
12.5.4	Orthogonal frequency division multiplexing	341
12.5.5	Bypassing	343
	References	345
13	Performance evaluation of PRIME PLC modems over distribution transformers in Indian context	349
	<i>Konark Sharma and Lalit Mohan Saini</i>	
13.1	Introduction	349
13.2	Proposed algorithm	352
13.3	Field trial results and analysis	354
13.4	Final summary	358
	Acknowledgments	358
	References	359
14	Analysis of hybrid communication for smart grids	363
	<i>Fabiano Salvadori, Camila S. Gehrke, Fabricio B.S. de Carvalho, and Alexandre C. Oliveira</i>	
14.1	Wired communications for smart grid applications	365
14.1.1	Electrical wiring	366
14.1.2	Twisted pair	368
14.1.3	Optical fiber	368
14.2	Wireless communication in smart grid applications	369
14.2.1	Dedicated wireless networks	370
14.2.2	Public cellular communication networks	372
14.3	Hybrid network architecture practical application	372

14.4	Practical results	375
14.4.1	Wireless results	377
14.4.2	Power line communication tests results	379
14.5	Conclusions and perspectives	384
	References	385
15	Direct torque control for DFIG based wind turbines employing power line communication technology in smart grid environments	389
	<i>Samuel C. Pereira, Andre L.L.F. Murari, Carlos E. Capovilla, Jose A.T. Altuna, Rogerio V. Jacomini, Edmarcio A. Belati, Alfeu J. Sguarezi Filho, and Ivan R.S. Casella</i>	
15.1	Introduction	389
15.2	DFIG mathematical model and DTC principles	392
15.3	SMC technique	393
15.4	PLC principles	396
15.5	Enabling SG concept with G3-PLC	398
15.6	Conclusion remarks	403
	References	403
16	MIMO systems design for narrowband power line communication in smart distribution grids	407
	<i>Theofilos A. Papadopoulos, Andreas I. Chrysochos, and Grigoris K. Papagiannis</i>	
16.1	Introduction	407
16.2	PHY characteristics	409
16.2.1	MV network modeling	410
16.2.2	Transformer modeling	412
16.2.3	MV/LV NB-PLC channel model	413
16.2.4	Noise modeling	413
16.3	Communication channel model	414
16.3.1	Spatial channel diagonalization	415
16.3.2	Bit-loading optimization	416
16.3.3	Transmit energy optimization	416
16.3.4	Achievable data rate calculation	417
16.4	NB-PLC channel PHY characteristics	417
16.4.1	MV distribution line	417
16.4.2	MV/LV transformer	419
16.4.3	Complete distribution network	419
16.5	Data rate results	420
16.6	Conclusions	426
	Acknowledgments	426
	References	426
	Index	431