

Contents

About the Authors	xiii
About the Contributors	xv
Preface	xvii
Acknowledgments	xxiii
List of Abbreviations	xxv

Part I CELLULAR WIRELESS STANDARDS

Introduction	3
References	4
1 UMTS High-Speed Downlink Packet Access	5
1.1 Standardization and Current Deployment of HSDPA	5
1.2 HSDPA Principles	6
1.2.1 Network Architecture	7
1.2.2 Physical Layer	9
1.2.3 MAC Layer	13
1.2.4 Radio Resource Management	14
1.2.5 Quality of Service Management	16
1.3 MIMO Enhancements of HSDPA	17
1.3.1 Physical Layer Changes for MIMO	19
1.3.2 Precoding	21
1.3.3 MAC Layer Changes for MIMO	25
1.3.4 Simplifications of the Core Network	26
References	26
2 UMTS Long-Term Evolution	29
Contributed by Josep Colom Ikuno	
2.1 LTE Overview	29
2.1.1 Requirements	29
2.2 Network Architecture	31
2.3 LTE Physical Layer	33
2.3.1 LTE Frame Structure	34

2.3.2	<i>Reference and Synchronization Symbols</i>	36
2.3.3	<i>MIMO Transmission</i>	37
2.3.4	<i>Modulation and Layer Mapping</i>	39
2.3.5	<i>Channel Coding</i>	41
2.3.6	<i>Channel Adaptive Feedback</i>	45
2.4	MAC Layer	46
2.4.1	<i>Hybrid Automatic Repeat Request</i>	46
2.4.2	<i>Scheduling</i>	47
2.5	Physical, Transport, and Logical Channels	48
	References	51

Part II TESTBEDS FOR MEASUREMENTS

	Introduction	57
	Reference	58
3	On Building Testbeds	59
3.1	Basic Idea	60
3.2	Transmitter	61
3.3	Receiver	63
3.4	Synchronization	65
3.5	Possible Pitfalls	67
3.5.1	<i>Digital Baseband Hardware</i>	67
3.5.2	<i>Tool and Component Selection</i>	68
3.5.3	<i>Analog RF Front Ends</i>	69
3.5.4	<i>Cost</i>	70
3.5.5	<i>MATLAB® Code and Testbeds</i>	70
3.6	Summary	71
	References	72
4	Quasi-Real-Time Testbedding	75
4.1	Basic Idea	75
4.2	Problem Formulation	77
4.3	Employing the Basic Idea	78
4.4	Data Collection	80
4.4.1	<i>More Sophisticated Sampling Techniques</i>	81
4.4.2	<i>Variance Reduction Techniques</i>	84
4.4.3	<i>Bias</i>	85
4.4.4	<i>Outliers</i>	86
4.4.5	<i>Parameter Estimation</i>	87
4.5	Evaluating and Summarizing the Data	88
4.6	Statistical Inference	90
4.6.1	<i>Inferring the Population Mean</i>	90
4.6.2	<i>Precision and Sample Size</i>	91
4.6.3	<i>Reproducibility and Repeatability</i>	92
4.7	Measurement Automation	95

4.8	Dealing with Feedback and Retransmissions	96
	References	97

Part III EXPERIMENTAL LINK-LEVEL EVALUATION

	Introduction	101
5	HSDPA Performance Measurements	103
5.1	Mathematical Model of the Physical Layer	104
5.1.1	<i>System Model for the Channel Estimation</i>	106
5.1.2	<i>System Model for the Equalizer Calculation</i>	106
5.2	Receiver	107
5.2.1	<i>Channel Estimation</i>	107
5.2.2	<i>Equalizer</i>	112
5.2.3	<i>Further Receiver Processing</i>	113
5.3	Quantized Precoding	113
5.4	CQI and PCI Calculation	115
5.4.1	<i>HS-PDSCH Interference</i>	115
5.4.2	<i>Pilot Interference</i>	116
5.4.3	<i>Synchronization and Control Channel Interference</i>	116
5.4.4	<i>Post-equalization Noise and SINR</i>	118
5.4.5	<i>SINR to CQI Mapping</i>	119
5.5	Achievable Mutual Information	121
5.6	Measurement Results	124
5.6.1	<i>Alpine Scenario</i>	125
5.6.2	<i>Urban Scenario</i>	128
5.6.3	<i>Discussion of the Implementation Loss</i>	130
5.7	Summary	131
	References	132
6	HSDPA Antenna Selection Techniques	139
	<i>Contributed by José Antonio García-Naya</i>	
6.1	Existing Research	141
6.2	Receive Antenna Selection	142
6.2.1	<i>Antenna Selection Based on System Throughput</i>	143
6.2.2	<i>Hardware Aspects of Antenna Selection</i>	143
6.3	An Exemplary Measurement and its Results	144
6.3.1	<i>Urban Scenario</i>	144
6.3.2	<i>Experimental Assessment of Antenna Selection in HSDPA</i>	145
6.3.3	<i>Measurement Results and Discussion</i>	147
6.4	Summary	148
	References	149
7	HSDPA Antenna Spacing Measurements	153
7.1	Problem Formulation	153

7.2	Existing Research	154
7.3	Experimental Setup	155
7.4	Measurement Methodology	157
7.4.1	<i>Inferring the Mean Scenario Throughput</i>	157
7.4.2	<i>Issues Requiring Special Attention</i>	158
7.5	Measurement Results and Discussion	160
7.5.1	<i>Equal Polarization Versus Cross-Polarization</i>	160
7.5.2	<i>Channel Capacity</i>	160
7.5.3	<i>Channel Capacity Versus Mutual Information</i>	162
7.5.4	<i>Mutual Information Versus Achievable Mutual Information</i>	162
7.5.5	<i>Achievable Mutual Information Versus Throughput</i>	163
7.5.6	<i>Throughput</i>	163
7.6	Different Transmit Power Levels and Scenarios	163
	References	164
8	Throughput Performance Comparisons	167
8.1	Introduction	167
8.2	Cellular Systems Investigated: WiMAX and HSDPA	168
8.2.1	<i>WiMAX and HSDPA</i>	168
8.2.2	<i>Throughput Bounds and System Losses</i>	169
8.3	Measurement Methodology and Setup	172
8.4	Measurement Results	173
8.4.1	<i>WiMAX Results</i>	173
8.4.2	<i>HSDPA Results in Standard-Compliant Setting</i>	177
8.4.3	<i>HSDPA Results in Advanced Setting</i>	179
8.5	Summary	179
	References	182
9	Frequency Synchronization in LTE	183
	<i>Contributed by Qi Wang</i>	
9.1	Mathematical Model	184
9.2	Carrier Frequency Offset Estimation in LTE	186
9.2.1	<i>Standardized Training Symbols in LTE</i>	186
9.2.2	<i>Maximum Likelihood Estimators</i>	188
9.3	Performance Evaluation	191
9.3.1	<i>Estimation Performance</i>	192
9.3.2	<i>Post-FFT SINR</i>	194
9.3.3	<i>Post-equalization SINR and Throughput</i>	195
	References	199
10	LTE Performance Evaluation	201
	<i>Contributed by Stefan Schwarz</i>	
10.1	Mathematical Model of the Physical Layer	202
10.2	Receiver	203
10.2.1	<i>Channel Estimation</i>	204
10.2.2	<i>Data Detection</i>	205
10.2.3	<i>Further Receiver Processing</i>	206

10.3	Physical Layer Modeling	206
10.3.1	<i>Post-equalization SINR</i>	207
10.3.2	<i>SINR Averaging</i>	207
10.4	User Equipment Feedback Calculation	208
10.4.1	<i>User Equipment Feedback Indicators</i>	208
10.4.2	<i>Calculation of the CQI, PMI, and RI</i>	210
10.5	Practical Throughput Bounds	216
10.5.1	<i>Channel Capacity</i>	216
10.5.2	<i>Open-Loop Mutual Information</i>	217
10.5.3	<i>Closed-Loop Mutual Information</i>	218
10.5.4	<i>BICM Bounds</i>	219
10.5.5	<i>Achievable Throughput Bounds</i>	222
10.5.6	<i>Prediction of the Optimal Performance</i>	223
10.6	Simulation Results	224
10.6.1	<i>SISO Transmission</i>	225
10.6.2	<i>OLSM Transmission</i>	227
10.6.3	<i>CLSM Transmission</i>	229
	References	230

Part IV SIMULATORS FOR WIRELESS SYSTEMS

	Introduction	237
	References	240
11	LTE Link- and System-Level Simulation	243
	<i>Contributed by Josep Colom Ikuno</i>	
11.1	The Vienna LTE Link Level Simulator	245
11.1.1	<i>Structure of the Simulator</i>	245
11.1.2	<i>Complexity</i>	247
11.2	The Vienna LTE System Level Simulator	250
11.2.1	<i>Structure of the Simulator</i>	250
11.2.2	<i>Simulator Implementation</i>	252
11.2.3	<i>Complexity</i>	253
11.3	Validation of the Simulators	255
11.3.1	<i>3GPP Minimum Performance Requirements</i>	257
11.3.2	<i>Link- and System-Level Cross-Comparison</i>	257
11.4	Exemplary Results	259
11.4.1	<i>Link-Level Throughput</i>	259
11.4.2	<i>LTE Scheduling</i>	262
	References	265
12	System-Level Modeling for MIMO-Enhanced HSDPA	271
12.1	Concept of System-Level Modeling	271
12.2	Computationally Efficient Link-Measurement Model	273
12.2.1	<i>Receive Filter</i>	274

12.2.2	<i>WCDMA MIMO in the Network Context</i>	276
12.2.3	<i>Equivalent Fading Parameters Description</i>	278
12.2.4	<i>Generation of the Equivalent Fading Parameters</i>	284
12.2.5	<i>Influence of Non-Data Channels</i>	286
12.2.6	<i>Resulting SINR Description</i>	287
12.3	Link-Performance Model	288
12.3.1	<i>Link-Performance Model Concept</i>	289
12.3.2	<i>Training and Validation of the Model</i>	293
	References	296

Part V SIMULATION-BASED EVALUATION FOR WIRELESS SYSTEMS

	Introduction	301
13	Optimization of MIMO-Enhanced HSDPA	303
13.1	Network Performance Prediction	303
13.1.1	<i>Simulation Setup</i>	303
13.1.2	<i>Single Network Scenario Investigation</i>	304
13.1.3	<i>Average Network Performance</i>	306
13.2	RLC-Based Stream Number Decision	310
13.2.1	<i>UE Decision</i>	310
13.2.2	<i>RLC Decision</i>	311
13.2.3	<i>System-Level Simulation Results</i>	311
13.3	Content-Aware Scheduling	313
13.3.1	<i>Video Packet Prioritization in HSDPA</i>	313
13.3.2	<i>Content-Aware Scheduler</i>	314
13.3.3	<i>Simulation Results</i>	315
13.4	CPICH Power Optimization	316
13.4.1	<i>System-Level Modeling of the CPICH Influence</i>	317
13.4.2	<i>CPICH Optimization in the Cellular Context</i>	318
	References	321
14	Optimal Multi-User MMSE Equalizer	325
14.1	System Model	326
14.2	Intra-Cell Interference Aware MMSE Equalization	330
14.2.1	<i>Interference Suppression Capability</i>	332
14.3	The Cell Precoding State	334
14.3.1	<i>Training-Sequence-Based Precoding State Estimation</i>	336
14.3.2	<i>Blind Precoding State Estimation</i>	337
14.3.3	<i>Estimator Performance</i>	339
14.4	Performance Evaluation	340
14.4.1	<i>Physical-Layer Simulation Results</i>	340
14.4.2	<i>System-Level Simulation Results</i>	341
	References	343

15	LTE Advanced Versus LTE	347
	<i>Contributed by Stefan Schwarz</i>	
15.1	IMT-Advanced and 3GPP Performance Targets	348
15.2	Radio Interface Enhancements	349
	15.2.1 Bandwidth Extension	349
	15.2.2 Enhanced MIMO	350
	15.2.3 Uplink Improvements	351
	15.2.4 Beyond Release 10	352
15.3	MIMO in LTE Advanced	354
	15.3.1 Codebook-Based Precoding	354
	15.3.2 Non-Codebook-Based Precoding	356
15.4	Physical-Layer Throughput Simulation Results	359
	15.4.1 Eight-Antenna Transmission	359
	15.4.2 Comparison between LTE and LTE Advanced	363
	15.4.3 Comparison of SU-MIMO and MU-MIMO	363
	References	366
	Index	369