Table of Contents

Introduction xi

Chapter 1. Information Theoretic Capacity of WiMAX 1
Tijani CHAHED, Laura COTTATELLUCCI, Rachid ELAZOUZI, Sophie GAULT and Gaoning HE

1.1. System description 1
1.1.1. Subchannelization 2
1.1.2. Adaptive modulation and coding 3
1.1.3. Diversity 3
1.1.4. MAC functionalities 4
1.1.5. Optional features 5
1.2. Achievable rates and resource allocation in single cells: problem formulation 5
1.2.1. General formulation 6
1.2.2. Fairness 8
1.2.3. Unified approach 9
1.3. Fundamental algorithms for maximizing the achievable rates in a multi-user OFDM cell 10
1.3.1. Waterfilling for capacity-achieving Gaussian inputs 10
1.3.2. Mercury/waterfilling for maximizing achievable rates with arbitrary input constellations 16
1.4. Resource allocation algorithms in a single-cell OFDMA network . . . 20
1.4.1. Minimum sum power 20
1.4.2. Sum rate maximization 24
1.4.3. Fair allocation 26
1.4.4. Proportional fairness 30
1.4.5. Max-min fairness 31
1.4.6. Sum rate maximization in the UL 31
1.4.7. Fair game-theoretic approach in the UL 32
1.5. Enhancements in the single-cell context 34
1.5.1. Multiple antenna arrays at the transmitter and the receiver 34
1.5.2. Bitloading 37

1.6. Resource allocation in multicell OFDMA networks 38
1.7. Achievable rates and resource allocation in OFDMA networks with relays 40
1.8. Conclusion 43
1.9. Bibliography 43

Chapter 2. WiMAX Network Capacity and Radio Resource Management 49
Tijani CHAHED, Ikbal CHAMMAKHI MSADAA, Rachid ELAZOUZI, Fethi FILALI, Salah-Eddine ELAYOUBI, Benoit FOURESTIÉ, Thierry PEYRE and Chadi TARHINI

2.1. Survey on RRM proposals 49
2.1.1. IEEE 802.16 QoS support 50
2.1.2. Scheduling and connection admission control challenges 53
2.1.3. Scheduling proposals. 54
2.1.4. Connection admission control proposals 67
2.2. Capacity at the MAC layer 71
2.2.1. Contention mode: binary exponential backoff 71
2.2.2. Literature on MAC 73
2.2.3. Problem formulation 74
2.2.4. Performance analysis. 77
2.2.5. Numerical analysis 79
2.2.6. Fixed point analysis 81
2.2.7. Request queueing 83
2.3. Erlangian approach 87
2.3.1. Problem formulation 87
2.3.2. Sub-carrier allocations 87
2.3.3. Interference 88
2.3.4. AMC and cell decomposition. 91
2.3.5. Flow throughput 94
2.3.6. Capacity evaluation. 95
2.4. Conclusion 99
2.5. Bibliography 99

Chapter 3. WiMAX and End-to-End QoS Support 105
Mohammmad Abdul AWAL and Lila BOUKHATEM

3.1. Introduction. 105
3.2. WiMAX Network Reference Model 107
3.2.1. Mobile station (MS) 109
3.2.2. Access Service Network (ASN) 109
3.2.3. Connectivity Service Network (CSN). 110
3.2.4. Reference point (RP). 111
3.2.5. Base station (BS) 112
3.2.6. ASN Gateway (ASN-GW) 113

3.3. WiMAX end-to-end network architecture . . . 113
3.3.1. Mobile station (MS) . . . 114
3.3.2. Base station (BS) . . . 115
3.3.3. ASN Gateway (ASN-GW) . . . 116
3.3.4. Core network . . . 116
3.3.5. Services . . . 117
3.3.6. Other networks . . . 117
3.4. QoS support . . . 117
3.4.1. Native QoS in WiMAX . . . 118
3.4.2. Ensuring layer 2 E2E QoS . . . 121
3.4.3. Ensuring layer 3 E2E QoS . . . 123
3.4.4. Ensuring layer 4 E2E QoS . . . 130
3.5. Ensuring inter-technology E2E QoS . . . 132
3.6. Conclusion . . . 135
3.7. Bibliography . . . 136

Chapter 4. Coexistence between 802.16 Systems Operating in Shared Bands . . . 139
Mariana GOLDHAMER, David GRANDBLAISE, Harry BIMS, Shulan FENG, Paul PIGGIN, John SYDOR and Xuyong WU

4.1. Introduction . . . 139
4.1.1. Motivation for developing the IEEE P802.16h amendment . . . 139
4.1.2. History of the IEEE 802.16h PAR . . . 141
4.1.3. Frequency bands of interest to IEEE 802.16h . . . 142
4.1.4. Detection of specific spectrum users . . . 146
4.1.5. Technical constraints in the development of IEEE 802.16h coexistence solutions . . . 147
4.2. Specific mechanisms . . . 151
4.2.1. Introduction . . . 151
4.2.2. Basic media access for coordinated coexistence . . . 152
4.2.3. Interference detection . . . 161
4.2.4. Interference avoidance . . . 166
4.2.5. Inter-system cooperation . . . 173
4.3. Conclusion . . . 185
4.4. Bibliography . . . 185

Chapter 5. System Level Simulation . . . 187
Wen ZHOU and Philippe SARTORI

5.1. Introduction . . . 187
5.2. System-level versus link-level modeling . . . 188
5.2.1. Link-level analysis . . . 188
5.2.2. System-level analysis . . . 191
5.3. System-modeling concepts . . . 194

5.3.1. Propagation models. 194
5.3.2. Modeling of a network. 202
5.3.3. Frequency-reuse plan 204
5.4. Link estimation methods 206
5.4.1. Modified Shannon limit model 207
5.4.2. Effective exponential SINR mapping (EESM). 209
5.4.3. Performance of EESM 212
5.4.4. Improvements to EESM 217
5.4.5. Advanced ESM 223
5.4.6. Other ESM techniques 226
5.5. Use of advanced LEP to improve link adaptation 227
5.5.1. Fast link adaptation. 228
5.5.2. Slow link adaptation 231
5.6. Example of system level studies 232
5.6.1. Impact of frequency reuse on system performance 232
5.6.2. Impact of multi-antenna techniques on spectrum efficiency. 235
5.6.3. Impact of scheduler. 238
5.7. Bibliography 243

Chapter 6. Self-organized and Bio-inspired Radio Resource Management for WiMAX 245
He XIAOBEN, Mugdim BUBLIN, Jyri HÄMÄLÄINEN and Riku JÄNTTI

6.1. Introduction. 245
6.1.1. Research contributions. 246
6.1.2. Chapter outline 247
6.2. Self-organized and bio-inspired RRM principles. 247
6.2.1. Robin Hood philosophy: a distributed approach. 248
6.2.2. Proactive donation philosophy: a self-organized approach 248
6.3. Interference mitigation 249
6.3.1. Soft-frequency reuse 249
6.3.2. Dynamic downlink chunk allocation 254
6.3.3. Adaptive scheduler 258
6.4. Femtocells 264
6.4.1. Motivation behind femtocells. 265
6.4.2. Self-organization aspects 265
6.4.3. Interference 266
6.5 Conclusions 267
6.6. Bibliography 267

Chapter 7. Relaying Techniques for OFDM-MIMO Systems 271
Olga MUÑOZ, Josep VIDAL, Adrián AGUSTÍN, Sébastien SIMOENS, Eduard CALVO, Reza HOSHYAR and Yajian LIU

7.1. Introduction and motivation 271
7.1.1. Motivation 272
7.1.2. Status of relay in the current WLAN/WMAN standard 273
7.1.3. Various relaying techniques. 274
7.2. Forwarding domain 276
7.2.1. Time domain forwarding 276
7.2.2. Frequency domain forwarding 286
7.3. Pure forwarding techniques 287
7.3.1. Amplify and forward. 289
7.3.2. Decode and forward 292
7.4. Cooperative relaying 294
7.4.1. Cooperative A&F. 295
7.4.2. Cooperative D&F. 297
7.4.3. Cell capacity gain. 299
7.4.4. Modeling OFDM systems. 302
7.4.5. Simulation in the 802.16 context. 304
7.5. Conclusion 313
7.6. Bibliography 313

Chapter 8. RRM Strategies in Multihop and Cooperative Transmission. . 315
Olga MUÑOZ, Josep VIDAL, Eduard CALVO and Adrián AGUSTÍN

8.1. Introduction. 315
8.2. Bounds of the channel capacity under FUSC/PUSC mode 316
8.3. RRM techniques for downlink transmissions 320
8.3.1. Radio resource allocation for OFDM-TDMA 320
8.3.2. Radio resource allocation for OFDMA 334
8.3.3. Performance comparison of OFDMA vs. OFDM-TDMA resource allocation 340
8.3.4. QoS provision, utility functions and stability 344
8.4. Cell dimensioning for time division relaying enhanced systems 348
8.4.1. Impact of the position and number of relays on system performance 349
8.4.2. Impact of cell radius on system performance 353
8.5. Enhancing WiMAX with relay transmissions 356
8.5.1. Cooperative relaying in OFDM 357
8.5.2. Cooperative relaying in OFDMA 363
8.6. Bibliography 367

List of Acronyms 369

List of Authors 375

Index 379