

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 |
| Mohammamad 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 |