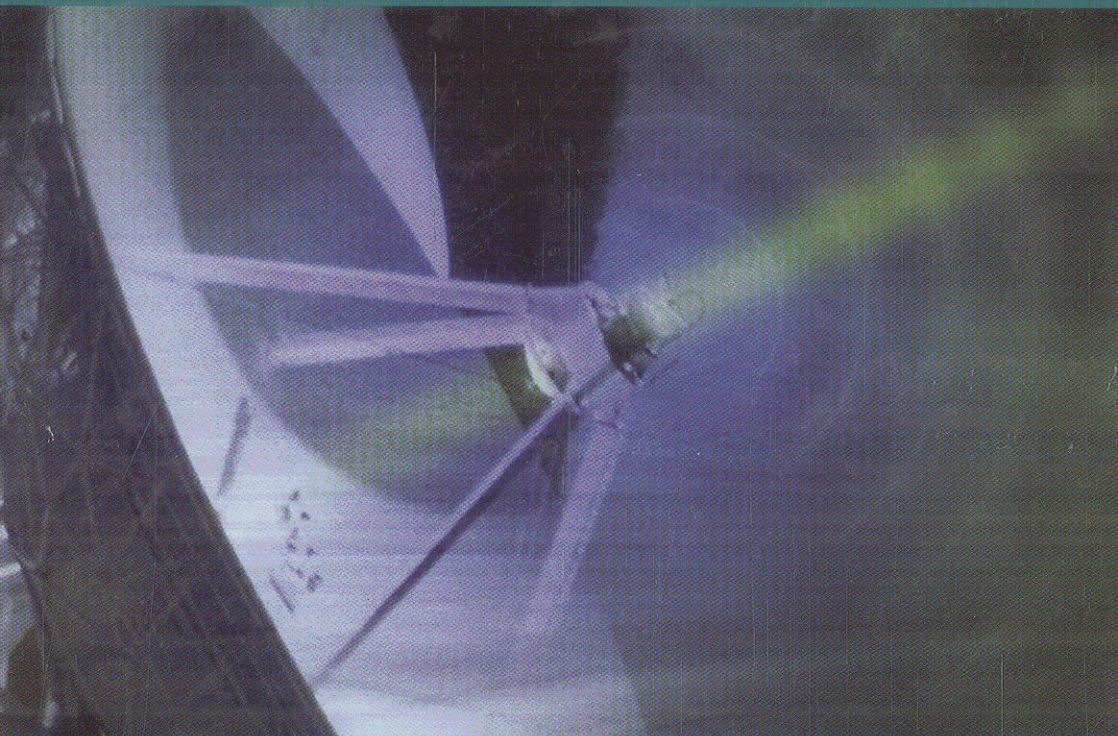


# Radio Resource Management in WiMAX

*From Theoretical Capacity  
to System Simulations*



**Edited by  
Emmanuelle Vivier**

**ISTE**

 **WILEY**

# Table of Contents

<b>Introduction</b> . . . . .	xi
<b>Chapter 1. Information Theoretic Capacity of WiMAX</b> . . . . .	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
<b>Chapter 2. WiMAX Network Capacity and Radio Resource Management</b>	<b>49</b>
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
<b>Chapter 3. WiMAX and End-to-End QoS Support</b> . . . . .	<b>105</b>
Mohammammad 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

<b>Chapter 7. Relaying Techniques for OFDM-MIMO Systems . . . . .</b>	<b>271</b>
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
<b>Chapter 8. RRM Strategies in Multihop and Cooperative Transmission. . . . .</b>	<b>315</b>
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

<b>List of Acronyms</b> . . . . .	369
<b>List of Authors</b> . . . . .	375
<b>Index</b> . . . . .	379