

# Contents

*Preface*

*page xiii*

## **Part I Basics of Wireless Networks**

<b>1</b>	<b>Introduction</b>	<b>3</b>
1.1	Basics of a Wireless Communication System	3
1.1.1	Electromagnetic Spectrum and Frequency Range	3
1.1.2	Signal Characterization	5
1.1.3	Modulation	8
1.1.4	Wireless Channel and Signal Propagation	12
1.1.5	Channel Capacity	21
1.1.6	SINR and Channel Model for Packet Communication Systems	22
1.2	Medium Access in Wireless Networks	27
1.2.1	Channel Partitioning–Based MAC	28
1.2.2	Random Access–Based MAC	34
1.2.3	Duplexing	34
1.3	Wireless Access Technologies	35
1.3.1	Cellular Wireless Technology	35
1.3.2	WLAN, WMAN, and WPAN Technologies	39
1.4	Exercises	45
	References	46
<b>2</b>	<b>Wireless Networks and Resource Allocation</b>	<b>49</b>
2.1	Protocol Layers for Data Communication	49
2.1.1	Physical Layer	49
2.1.2	Data Link Layer	50
2.1.3	Network Layer	51
2.1.4	Transport Layer	51
2.1.5	Session, Presentation, and Application Layers	51
2.2	Classification of Wireless Networks	52
2.2.1	Classification Based on Infrastructure	52
2.2.2	Classification Based on Spectrum Access	55
2.2.3	Classification Based on Heterogeneity	55

2.3	Physical Layer Issues in Wireless Networks	56
2.3.1	Basic Components	56
2.3.2	Digital Transmission Techniques	58
2.3.3	Link Adaptation	62
2.3.4	Diversity Transmission Techniques	65
2.3.5	Smart Reception/Diversity Combining Techniques	65
2.4	Radio Link Layer Issues in Wireless Networks	68
2.4.1	Multiple Access and Scheduling Methods	68
2.4.2	Error Control Methods	93
2.4.3	Power Control Methods	99
2.4.4	Cell Association, Handoff Management, and Admission Control	102
2.5	Taxonomy of Resource Allocation	105
2.6	Exercises	106
	References	110

## **Part II Techniques for Modeling and Analysis of Radio Resource Allocation Methods in Wireless Networks**

<b>3</b>	<b>Optimization Techniques</b>	117
3.1	Basics of Optimization	117
3.1.1	Convex Functions	117
3.1.2	Optimality Conditions for Unconstrained Optimization	119
3.1.3	Line Search Methods for Unconstrained Optimization	121
3.2	Convex Optimization	123
3.2.1	Introduction	123
3.2.2	Duality	124
3.2.3	KKT Conditions	125
3.2.4	Algorithms	127
3.3	Integer Programming	132
3.3.1	Cutting Plane Method	132
3.3.2	Branch and Bound Algorithm	135
3.4	Stochastic Optimization	140
3.4.1	Introduction	140
3.4.2	Robust Optimization	141
3.5	Dynamic Programming	143
3.5.1	Introduction	143
3.5.2	Examples of Dynamic Programming	145
3.6	Exercises	147
	References	153
<b>4</b>	<b>Game Theory</b>	154
4.1	Fundamentals of Game Theory	154
4.1.1	Brief History	154

4.1.2	Definition of a Game	155
4.2	Non-cooperative Game	159
4.2.1	Static Game	159
4.2.2	Dynamic Game	162
4.2.3	Bayesian Game	166
4.2.4	Evolutionary Game	168
4.3	Cooperative Game	172
4.3.1	Nash Bargaining Solution	172
4.3.2	Coalition Game	174
4.4	Auction Theory	178
4.4.1	Introduction to Auction Theory	178
4.4.2	Special Auction	180
4.5	Exercises	182
	References	186

### Part III Physical Layer Resource Allocation in Wireless Networks

<b>5</b>	<b>General System Model and Preliminary Concepts</b>	191
5.1	System Model for a General Multi-Cell Wireless Network	191
5.1.1	Modeling Path-Gains	192
5.1.2	SINR Model	194
5.1.3	Transmit Power Vector Corresponding to a Given SINR Vector	195
5.2	System Model for a Single-Cell Wireless Network	198
5.2.1	Modeling Path-Gains	198
5.3	SINR Feasibility in Interference-Limited Wireless Networks	200
5.3.1	Existence of a Positive Transmit Power Vector Corresponding to a Given SINR Vector	201
5.3.2	Existence of a <i>Constrained</i> Transmit Power Vector Corresponding to a Given SINR Vector	203
5.4	Exercises	205
	References	206
<b>6</b>	<b>Power Control in Cellular Wireless Networks</b>	207
6.1	Objectives of Power Control	207
6.1.1	Performance Measure and Objective Functions	208
6.1.2	Distributed Versus Centralized Approach	210
6.2	Different Power Control Optimization Problems	210
6.3	Closed-Loop and Open-Loop Power Control	215
6.3.1	Open-Loop Power Control	215
6.3.2	Closed-Loop Power Control	216
6.4	Distributed Power Control Algorithms	216
6.4.1	Criteria for Evaluation and Analysis of Distributed Power Control	217

6.4.2	Existing Theoretical Frameworks for Fixed-Point and Convergence Analysis	217
6.5	Distributed Target-SINR Tracking Power Control (TPC)	220
6.6	Distributed Opportunistic Power Control (OPC)	222
6.7	Distributed Dynamic Target-SINR Tracking Power Control (DTPC)	223
6.8	Exercises	227
	References	230
<b>7</b>	<b>Distributed Joint Power and Admission Control</b>	<b>231</b>
7.1	Introduction	231
7.2	Distributed Joint Power and Admission Control Algorithms	233
7.2.1	TPC with Permanent Removal (TPC-PR)	233
7.2.2	TPC with the Capability of Temporary Removal (TR)	234
7.2.3	TPC with Both Temporary and Permanent Removal (TPC-TPR)	235
7.2.4	TPC with the Capability of Temporary Removal and Feasibility Check (DFC)	235
7.2.5	TPC with Soft Removal (TPC-SR)	239
7.3	Exercises	243
	References	244
<b>8</b>	<b>Joint Power and Admission Control in Cognitive Radio Networks</b>	<b>245</b>
8.1	Introduction	245
8.2	System Model and Background	246
8.3	Protection Constraints for Primary Users and Different JPAC Problems in CRNs	249
8.4	Characterization of Feasible Interference Region	251
8.4.1	Total Received-Power-Temperature: Expressing PUs' Protection Constraints Based on FRPR	252
8.4.2	Total Inter-Cell Interference Temperature: Expressing PUs' Protection Constraints Based on FIIR	253
8.4.3	Total Cognitive Interference Temperature: Expressing PUs' Protection Constraints Based on FCIR	255
8.4.4	Example and Discussion	257
8.5	Existing Centralized JPAC Algorithms to Maximize the Number of Supported SUs Subject to PUs' Protection Constraint	259
8.5.1	A General SSA	260
8.5.2	Interference Constraint-Aware Stepwise Maximum Interference Removal Algorithm (I-SMIRA)	263
8.5.3	Link-Gain Ratio Algorithm (LGRA) and Effective Link-Gain Ratio Algorithm (ELGRA)	264
8.6	Distributed JPAC Algorithms for CRNs	267
8.6.1	TPC with PU-Protection Algorithm (TPC-PP)	267
8.6.2	Improved TPC-PP (ITPC-PP)	270

8.7	Exercises	271
	References	274
<b>9</b>	<b>Cell Association in Cellular Networks</b>	<b>276</b>
9.1	Introduction	276
9.2	System Model and Notations	276
9.3	Distributed Joint Cell Association and Power Control	278
9.4	Distributed Cell Association Schemes in Wireless Networks	281
9.4.1	Reference Signal Received Power (RSRP)-Based Cell Association Scheme	281
9.4.2	Biasing-Based Cell Range Expansion (CRE) in Wireless Networks with Heterogeneous BSs	282
9.5	Open Research Issues	284
9.6	Exercises	286
	References	287
<b>Part IV</b>	<b>Link Layer Resource Allocation in Wireless Networks</b>	
<b>10</b>	<b>Sub-Carrier/Sub-Channel Allocation in OFDMA Networks</b>	<b>291</b>
10.1	Introduction	291
10.2	OFDM-Based Multiple Access	292
10.3	Adaptive Radio Resource Allocation in OFDM Systems	293
10.3.1	System-Centric Approaches	294
10.3.2	Application-Centric Approaches	302
10.4	Open Research Issues	303
	References	304
<b>11</b>	<b>Resource Allocation in Relay-Based Networks</b>	<b>308</b>
11.1	Introduction	308
11.2	Overview of Cooperative Diversity	309
11.2.1	Amplify-and-Forward Relaying	309
11.2.2	Decode-and-Forward Relaying	310
11.2.3	Selection or Opportunistic Relaying	311
11.2.4	Incremental Relaying	312
11.2.5	Two-Way Relaying	313
11.2.6	Other Enhancements	317
11.3	Resource Allocation for Single-Carrier Systems	318
11.3.1	Power Allocation for AF Relaying	318
11.3.2	Power Allocation for Selection AF Relaying	320
11.3.3	Joint Relay Selection and Power Allocation for ANC Two-Way Relaying	321

11.4	Resource Allocation for Multi-Carrier Systems	323
11.4.1	Resource Allocation for AF Multi-Carrier Wireless Networks	324
11.4.2	Resource Allocation for DF Multi-Carrier Wireless Networks	333
11.4.3	Resource Allocation for Multi-User ANC Two-Way Relay Networks	337
11.5	Further Discussion	341
11.6	Exercises	342
	References	348
<b>12</b>	<b>Channel Allocation for Infrastructure-Based 802.11 WLANs</b>	<b>352</b>
12.1	Introduction	352
12.2	System under Consideration	353
12.2.1	Network Topology	353
12.2.2	Channelization	353
12.2.3	Medium Access Control	355
12.3	Channel Assignment and AP Placement in IEEE 802.11 WLANs	356
12.3.1	Channel Assignment	356
12.3.2	AP Placement	356
12.4	Challenges in Channel Assignment in IEEE 802.11 WLANs	356
12.5	Channel Assignment Schemes in Centrally Managed Environments	358
12.5.1	Channel Assignment with AP Placement	358
12.5.2	Channel Assignment without AP Placement	363
12.6	Channel Assignment Schemes in Uncoordinated Environments	365
12.6.1	Least Congested Channel Search (LCCS)	365
12.6.2	MinMax Approach	366
12.6.3	MinMax II Approach	367
12.6.4	Hminmax/Hsum: Weighted Coloring Approach	367
12.6.5	Pick-Rand and Pick-First Approach	368
12.6.6	Pick-Rand and Pick-First II Approach	368
12.6.7	Channel Hopping Approach	368
12.6.8	Measurement-Based No-Coord	369
12.7	Comparison among Various Channel Assignment Schemes	369
12.8	Current Practice in Channel Assignment	371
12.9	Open Research Issues	372
	References	373
<b>Part V</b>	<b>Cross-Layer Modeling for Resource Allocation in Wireless Networks</b>	
<b>13</b>	<b>Joint PHY/RLC Design in Cellular Wireless Networks</b>	<b>379</b>
13.1	Introduction	379
13.2	Radio Link Control (RLC) Protocols: ARQ and HARQ	379
13.3	Link Adaptation with Adaptive Modulation and Coding (AMC)	381

13.4	Channel Modeling	383
13.4.1	I.I.D. Channel Models	383
13.4.2	Two-State Markov Channel Model	383
13.4.3	Finite-State Markov Channel Model	386
13.5	ARQ Protocols with I.I.D. Errors	386
13.6	ARQ Protocols in Two-State Markov Channel	388
13.6.1	GBN-ARQ Protocol in Two-State Markov Channel	389
13.6.2	SR-ARQ Protocol in Two-State Markov Channel	391
13.7	Truncated ARQ Protocol with Link Adaptation under I.I.D. Channels	392
13.8	Delay Analysis of GBN-ARQ Protocol with Link Adaptation under FSMC	393
13.8.1	System and Protocol Description	394
13.8.2	Queuing Model	395
13.8.3	Derivations of Matrix Blocks in (13.57)	397
13.8.4	Delay Analysis	400
13.8.5	Numerical Example	401
13.9	Hybrid ARQ Protocol with Transmission Size Adaptation	402
13.10	Exercises	405
	References	412
	<i>Index</i>	415