

Contents

	<i>Preface</i>	<i>page xi</i>
	<i>List of Abbreviations</i>	<i>xiii</i>
1	Introduction	1
	1.1 Why Green and Soft?	1
	1.2 Green: From UE to Infrastructure	3
	1.3 Soft: From Core Network to RAN	5
	1.4 Green vs. Soft: An Unsolvable Contradiction?	7
	1.5 Rethinking Green and Soft 5G Network Design	7
	1.5.1 Rethink Shannon	8
	1.5.2 Rethink Ring and Young	9
	1.5.3 Rethink Signaling and Control	10
	1.5.4 Rethink Antenna	10
	1.5.5 Rethink Spectrum and Air Interface	11
	1.5.6 Rethink Fronthaul	11
	1.5.7 Rethink Protocol Stack	12
	1.5.8 Rethink Big Data Analytics in Wireless Communications	12
	1.6 Skeleton of This Book	13
2	Theoretical Framework toward Green Networks	16
	2.1 Metrics for Green Radio	16
	2.2 EE Study from Information Theory	19
	2.3 Fundamental EE–SE Trade-Off	23
	2.3.1 EE–SE Relation	25
	2.3.2 Bounds on the EE–SE Curve	28
	2.3.3 Further Discussion	31
	2.4 EE Design in Orthogonal Systems	32
	2.4.1 Weighted Summation EE Maximization	33
	2.4.2 Maximum-Minimal EE Maximization	38
	2.4.3 Numerical Results	40
	2.5 EE Design in Non-Orthogonal Systems	43
	2.5.1 Utopia EE	44
	2.5.2 Pareto-Optimal EE	46
	2.5.3 Numerical Results	50

Appendix 2.1	Optimization Theory for EE Design	51
A2.1.1	Fractional Programming and the Dinkelbach Algorithm	52
A2.1.2	Sum-of-Ratios Optimization	53
A2.1.3	Generalized Fractional Programming	55
A2.1.4	Multi-Objective Optimization and Weighted Tchebycheff Method	57
3	Green and Soft Network Design	61
3.1	Green and Soft Wireless Communication Network Design	61
3.1.1	E2E Network Architecture for 5G	62
3.1.2	Next-Generation Core Network	62
3.1.3	Next-Generation RAN	64
3.1.4	Next-Generation Transport Network	66
3.1.5	Key Issues of E2E Network Architecture	66
3.1.6	Summary	70
3.2	C-RAN: Revolutionary Evolution of RAN	71
3.2.1	Introduction	71
3.2.2	C-RAN Basics	72
3.2.3	Evolution of C-RAN towards 5G	73
3.2.4	NGFI: Next-Generation Fronthaul Interface	75
3.2.5	CU-DU Architecture for 5G	76
3.2.6	Rethink Protocol Stack for 5G: MCD	81
3.3	Big-Data-Enabled Mobile Network Design	90
3.3.1	Background of Big Data	90
3.3.2	Wireless Big Data	94
3.3.3	Artificial Intelligence in Wireless Networks	97
3.3.4	Application of WBD and AI into Mobile Network	98
3.3.5	Green and Soft Network Architecture with WBD	100
3.3.6	Big-Data-Enabled Automatic Network Management and Operation	106
3.3.7	Big-Data-Empowered MEC	110
3.3.8	Big-Data-Assisted Protocol Stack and Signaling Procedure Optimization	112
3.3.9	Big-Data- and AI-Enabled Radio Resource Management	116
3.3.10	Big-Data-Assisted High-Efficiency Physical Layer Operation	122
3.3.11	Big Data Platform Capabilities/Environment	125
3.3.12	Enhanced System Performance with WBD	128
4	Energy-Efficient Signaling Design and Resource Management	142
4.1	Sleeping Strategy and Cell Zooming	143
4.1.1	Dynamic Base Station Sleep Control	143
4.1.2	Cell Zooming for Green Cellular Networks	144
4.1.3	Soft-Defined Network Architecture for Green Cellular Networks	145
4.2	Joint Optimization of Uplink and Downlink Energy Efficiency	146
4.2.1	System Model and Problem Formulation	147

4.2.2	Joint Uplink and Downlink Resource Allocation	150
4.2.3	Numerical Results	153
4.3	Energy-Efficient Resource Allocation in Homogeneous Networks	155
4.3.1	System Model and Problem Formulation	157
4.3.2	Problem Analysis and the Sub-Optimal Algorithm	159
4.3.3	Numerical Results	162
4.4	Energy-Efficient Resource Allocation in Heterogenous Networks	165
4.4.1	System Model and Problem Formulation	167
4.4.2	The Multi-Objective Energy-Efficient Algorithm	169
4.4.3	Numerical Results	175
5	Software-Defined Air Interface (SDAI) for a Greener Network	182
5.1	SDAI Framework	182
5.2	Wireless Propagation in 5G Use Cases	185
5.2.1	The Importance of Propagation Channels	185
5.2.2	Channel Modeling Principle and Fundamentals	186
5.2.3	Channel Modeling Methods in Cellular Systems	186
5.2.4	New and Exciting Challenges in Channel Modeling	188
5.2.5	Concluding Remarks	191
5.3	Flexible Frame Structure	191
5.3.1	Frame Structure Design Principles	192
5.3.2	Progress of Frame Structure in 3GPP 5G NR	197
5.3.3	Concluding Remarks	197
5.4	Flexible MIMO	198
5.4.1	Unified Framework for MIMO Techniques for 5G	198
5.4.2	Schemes of Hybrid Beamforming	200
5.4.3	EE–SE Analysis of Hybrid Beamforming	202
5.4.4	Standardization	204
5.4.5	Summary	207
5.5	New Waveform	207
5.5.1	w-OFDM/f-OFDM	208
5.5.2	UFMC	209
5.5.3	FBMC	209
5.5.4	GFDM	211
5.5.5	OTFS	211
5.5.6	Variants of DFT-s-OFDM	213
5.5.7	Constant Envelope Waveform	214
5.5.8	Unified Waveform Framework	214
5.5.9	Waveform for 5G NR in 3GPP	216
5.5.10	Summary	220
5.6	Flexible Multiple Access Schemes	221
5.6.1	Potential New Multiple Access Techniques for 5G	221
5.6.2	Theoretical Analysis of a NoMA System	228

5.6.3	A Unified Framework of Multiple Access Schemes	229
5.6.4	Summary	231
5.7	Full Duplex	232
5.7.1	Interference Mitigation in Full Duplex Networks	234
5.7.2	Full Duplex Frame Structure Design	237
5.7.3	Extension of FDD and TDD to Full Duplex	239
5.7.4	Summary	240
5.8	Flexible Signaling, Control, and Protocol	241
5.8.1	Introduction	241
5.8.2	New SCP Function Components	242
5.8.3	Summary	245
6	Energy-Saving Solutions and Practices	252
6.1	Green Wireless Technologies in Cellular Networks	252
6.1.1	Energy-Saving in GSM	252
6.1.2	Energy-Saving in TD-SCDMA	253
6.1.3	Energy-Saving in LTE	253
6.2	Multi-RAT Cooperation Energy-Saving System (MCES)	255
6.2.1	Basic Principle	256
6.2.2	Functional Architecture	257
6.2.3	Technical Characteristics	258
6.2.4	Deployment Progress in China	259
6.3	WLAN Energy-Saving Technology	260
6.3.1	AP Device Shutdown	260
6.3.2	AP RF Channel Shutdown	260
6.3.3	AP Single/Dual Band Selection	261
6.4	C-RAN Field Trials	261
6.4.1	Introduction	261
6.4.2	Demonstration of WDM-Based FH Solutions	262
6.4.3	Test Methodology	262
6.4.4	C-RAN-Based UL CoMP Test	264
6.5	Green Application	267
6.5.1	Key Factors for App Power Consumption	268
6.5.2	Optimization	271
6.6	“Invisible BS”	272
6.6.1	Motivation	272
6.6.2	Powerful Baseband Platform with a Unified Design	273
6.6.3	SmarTile	275
6.6.4	Flexible Over-the-Air Calibration Scheme	279
6.6.5	High-Efficiency Heat Dissipation Testbed	282
	<i>Index</i>	287