

## Contents

1	Introduction	<i>page</i> 1
1.1	The growth of standards	1
1.2	Markets	4
1.2.1	Games controllers	4
1.2.2	Voice	5
1.2.3	Internet access	5
1.2.4	Internet connected devices	5
1.3	What is a standard?	7
1.4	Choosing a wireless standard	10
1.5	Wireless application areas	11
1.5.1	Standard vs proprietary wireless	11
1.5.2	The importance of topology	12
1.5.3	The ‘Internet of things’	13
1.6	Using this book	15
1.7	References	16
2	Fundamentals of short-range wireless	17
2.1	Basics	17
2.1.1	The connection model and topology	18
2.1.2	Latency, range and throughput	18
2.1.3	Security	18
2.2	Wireless architecture	19
2.2.1	The radio	19
2.2.2	Baseband: media access control (MAC)	20
2.2.3	Higher-layer stacks	22
2.2.4	Profiles	22
2.3	Wireless parameters	24
2.3.1	Range	25
2.3.2	Throughput	34

## vi CONTENTS

2.3.3	Interference and coexistence	36
2.3.4	Topology	42
2.3.5	Security – authentication and encryption	48
2.3.6	Power consumption	49
2.3.7	Profiles and interoperability	52
2.3.8	Voice and latency (quality of service and synchronous transmission)	53
2.3.9	Reliability	55
2.3.10	Audio and video	56
2.3.11	Usability and commissioning	57
2.4	Conclusion	58
2.5	References	59
3	Wireless security	60
3.1	Security attacks	62
3.1.1	Discovery	62
3.1.2	Eavesdropping (interception)	62
3.1.3	Denial of service	62
3.1.4	Man-in-the-middle attacks, spoofing and bluejacking	63
3.1.5	Address tracking	66
3.2	Security features	66
3.2.1	Authorisation	66
3.2.2	Authentication	67
3.2.3	Encryption	68
3.2.4	Other features	69
3.3	Generation and distribution of link keys	70
3.4	Comparison of security procedures	70
3.4.1	Susceptibility to attack	71
3.4.2	Security implementations	75
3.5	Testing security – in praise of hacking tools	79
3.6	References	80
4	Bluetooth	81
4.1	Background	81
4.2	The radio	84

4.3	Topologies	87
4.4	Connections	91
	4.4.1 Making connections	92
4.5	Transferring data	97
	4.5.1 Asynchronous links (ACL)	97
	4.5.2 Synchronous links (SCO and eSCO)	98
	4.5.3 Voice codecs	99
4.6	The lower-layer stack (the controller)	99
4.7	The higher-layer stack (the host)	100
	4.7.1 Logical link control and adaptation protocol (L2CAP)	101
	4.7.2 Service discovery protocol (SDP)	101
	4.7.3 Generic access profile (GAP)	102
	4.7.4 Bonding and pairing	102
4.8	Transport protocols	104
4.9	Profiles	104
	4.9.1 Serial port profile (SPP)	105
	4.9.2 Handsfree profile (HFP)	105
	4.9.3 Generic object-exchange profile (GOEP / OBEX)	106
	4.9.4 Personal area networking profile (PAN)	108
	4.9.5 Health device profile (HDP)	109
	4.9.6 Human interface device profile (HID)	109
	4.9.7 Advanced audio distribution profile (A2DP)	110
4.10	Power consumption	111
4.11	Bluetooth 3.0	112
4.12	References	114
5	IEEE 802.11abgn/Wi-Fi	115
	5.1 Introduction	115
	5.1.1 The difference between 802.11 and Wi-Fi	117
	5.1.2 Bluetooth 3.0	121
	5.1.3 Alphabet soup	121
	5.2 802.11 topology	121

## viii CONTENTS

5.2.1	Bridging with access points	125
5.2.2	802.11 services	127
5.3	The 802.11 radio	130
5.4	Framing	134
5.5	Modulation	137
5.6	5.1 GHz – 802.11a	140
5.7	MIMO – 802.11n	141
5.8	Making connections	143
5.9	Power management	144
5.9.1	Wireless multimedia power save	145
5.10	References	145
6	IEEE 802.15.4, ZigBee PRO, RF4CE, 6LoWPAN and Wireless HART	147
6.1	IEEE 802.15.4	148
6.1.1	The MAC	152
6.1.2	Topologies	153
6.1.3	Framing	154
6.1.4	802.15.4 security	156
6.2	ZigBee	156
6.2.1	ZigBee and ZigBee PRO	160
6.2.2	The ZigBee network	162
6.2.3	ZigBee profiles and applications	167
6.3	ZigBee RF4CE	171
6.4	6LoWPAN	172
6.5	WirelessHART	173
6.6	References	174
7	Bluetooth low energy (formerly Wibree)	176
7.1	Basic tenets	178
7.1.1	Small packet size	178
7.1.2	Autonomous controller	178
7.1.3	Duty cycle and latency	179
7.1.4	Asymmetry	179
7.1.5	Range	179
7.1.6	Ease of use	179

7.2	RF	180
7.3	Topology	180
	7.3.1 Profile roles	181
	7.3.2 Unidirectional devices	181
	7.3.3 Bidirectional devices	182
7.4	Advertising and data channels	183
	7.4.1 Advertising packets	185
	7.4.2 Response packets	186
7.5	The Bluetooth low-energy state machine	188
	7.5.1 Advertising	189
	7.5.2 Connecting	191
	7.5.3 Discovery	193
	7.5.4 Bonding	195
7.6	The Bluetooth low-energy protocol stack	195
	7.6.1 Attributes – exposing state	197
	7.6.2 Attribute PDUs	198
	7.6.3 Notifications and indications	199
	7.6.4 Characteristics	200
	7.6.5 Aggregate characteristics and time stamping	200
	7.6.6 Services	201
	7.6.7 Configuring attribute servers	202
7.7	Profiles	202
	7.7.1 Proximity	203
	7.7.2 Gateways	203
7.8	Single-mode chips	205
7.9	Dual-mode chips	206
7.10	References	207
8	Application development – configuration	208
	8.1 Topology	209
	8.1.1 Cable replacement	209
	8.1.2 Reconnection	214
	8.1.3 Multipoint	215
	8.1.4 Infrastructure (network connectivity)	218

## X CONTENTS

8.1.5	Cluster tree	220
8.1.6	Mesh	220
8.2	Data protocols	221
8.2.1	Profile or proprietary	221
8.2.2	Interfacing with external protocols	222
8.2.3	Voice, audio and codecs	223
8.2.4	Latency and time synchronisation	226
8.3	Set-up and commissioning	227
8.3.1	Pairing, bonding, association	227
8.3.2	Promiscuity	228
8.3.3	The initial connection	229
8.3.4	Out-of-band techniques	230
8.3.5	Disconnecting	231
8.3.6	Limiting broadcasts	232
8.4	Feature creep	232
8.5	Security	233
8.6	Upgrading	233
8.6.1	Upgrading mesh and cluster-tree networks	237
8.7	References	238
9	Application development – performance	239
9.1	Range and throughput	239
9.1.1	Power amplifiers and low noise amplifiers	239
9.1.2	Power control	243
9.1.3	Filtering	244
9.1.4	RF matching, tuning and PCB design	244
9.2	Choice of antenna	246
9.2.1	Gain	246
9.2.2	Directionality	246
9.2.3	Construction (technology) and size	247
9.2.4	Detuning	247
9.2.5	Polarisation and antenna radiation characteristics	248
9.2.6	Ground planes	249
9.2.7	Antenna types	250

9.2.8	Diversity and multiple antennae	252
9.2.9	One last point on antennae	253
9.3	Coexistence	253
9.3.1	Interference mitigation	253
9.3.2	Colocation	255
9.4	Power consumption	256
9.4.1	Duty cycle	257
9.4.2	Sleep modes	259
9.4.3	Functional circuitry	259
9.5	Topology effects	260
9.6	Ultra-low power and energy harvesting	261
9.7	Temperature	261
9.7.1	Working below 0 °C	262
9.7.2	Working above 50 °C	263
9.8	References	263
10	Practical considerations – production, certification and IP	264
10.1	Regulatory approval	264
10.1.1	Modular approval	266
10.1.2	Other considerations	267
10.1.3	The Radio and Telecommunications Terminal Equipment directive (R&TTE)	267
10.2	Specific absorption rate – SAR	268
10.3	Medical, automotive and aviation	268
10.4	Export controls	269
10.5	Standards-based approvals and IP licences	270
10.5.1	Standards approval hierarchies	274
10.5.2	Specific requirements	275
10.6	Open-source protocol stacks	279
10.7	OUI – the device address	280
10.8	Production test	281
10.9	References	282
11	Implementation choices	284
11.1	Assessing the options	284

## xii CONTENTS

11.2	The design architecture	284
11.2.1	Chip-based designs	286
11.2.2	Reference designs	287
11.2.3	Modules	288
11.3	Development tools	289
11.4	Stack integration tools	289
11.5	Deciding on an implementation strategy	290
11.5.1	Bill of material cost	290
11.5.2	Development cost	290
11.5.3	Integration cost	291
11.5.4	RF design	291
11.5.5	Approvals	291
11.5.6	Time to market	291
11.5.7	Production test	291
11.5.8	Size	292
11.6	Comparison of costs	292
11.7	Longevity	294
12	Markets and applications	296
12.1	Growing the market	298
12.2	Healthcare, wellness, sports and fitness	299
12.2.1	The Continua Health Alliance	301
12.2.2	Health 2.0	302
12.2.3	Clinical asset management and lone workers	302
12.2.4	Assisted living	303
12.2.5	Sports and fitness	304
12.3	The telematics and automotive markets	305
12.3.1	Vehicle-to-vehicle communications	306
12.3.2	Vehicle and driver monitoring	308
12.4	Smart energy	309
12.4.1	The key opportunities	312
12.5	Home automation	314
12.6	Consumer electronics	316
12.6.1	Internet connected devices	316



12.7	Fashion wireless	318
12.7.1	Tags	318
12.7.2	Watches	318
12.7.3	Bracelets – the new watches	319
12.8	Industrial and automation	319
12.9	Self-powered sensors	320
12.10	Privacy concerns	320
12.11	Conclusion	321
12.12	References	322
	Glossary of acronyms and abbreviations	324
	Index	329