Contents

PREFACE **v**

Glossary **xi**

1 WIRELESS DATA COMMUNICATIONS **1**
1.1 Signal representation . . . 2
1.2 Analog to digital conversion . . . 5
1.3 Digital to analog conversion . . . 8
1.4 Architecture of an SDR application . . . 9
1.5 Quadrature modulation and demodulation . . . 11
1.6 Spread spectrum . . . 14
1.7 Antenna . . . 18
1.8 Propagation . . . 20
1.9 Ultrawideband . . . 25
1.10 Energy management . . . 27
1.11 Exercices . . . 27

2 MEDIUM ACCESS CONTROL **29**
2.1 Fundamentals of probability and statistics . . . 30
2.1.1 General concepts . . . 30
2.1.2 Random variables and distributions . . . 32
2.1.3 Counting processes . . . 34
2.2 Modeling traffic . . . 37
2.2.1 Delay models . . . 37
2.2.2 Queuing models . . . 38
2.2.3 Birth-death processes . . . 38
2.2.4 $M/M/1/\infty$ queuing system . . . 39
2.2.5 $M/M/m/\infty$ queue: m servers . . . 41
2.2.6 Queues for channel allocation . . . 43
2.2.7 Queues with reserved channels for handoffs . . . 44
2.3 Multiple access . . . 46
2.3.1 Uncoordinated access . . . 46
2.3.2 Contention-based access . . . 47
2.4 Demand assigned multiple access . . . 51
2.4.1 Bit-map . . . 51

2.4.2 Binary countdown . . . 51
2.4.3 Splitting algorithms . . . 51
2.5 Carrier sense multiple access in IEEE 802.11 . . . 53
2.5.1 Persistence . . . 54
2.5.2 Collision avoidance . . . 55
2.6 Medium access control in ad hoc networks . . . 56
2.6.1 Neighbor aware contention resolution . . . 57
2.6.2 Multiple access protocols . . . 57
2.6.3 Throughput analysis of NAMA . . . 58
2.7 Bibliographic comments . . . 60
2.8 Exercises . . . 60

3 AD HOC WIRELESS ACCESS 65
3.1 Management of Bluetooth networks . . . 66
3.1.1 Architecture . . . 66
3.1.2 The Bluetooth asymmetric protocol . . . 69
3.1.3 Bluetooth protocol architecture (IEEE 802.15) . . . 72
3.2 Model for node discovery in Bluetooth . . . 74
3.2.1 Protocols for node discovery . . . 77
3.2.2 Multiple nodes competing for air-time . . . 81
3.3 Bluetooth formation algorithms . . . 85
3.3.1 Bluetooth topology construction protocol . . . 86
3.3.2 Bluetree . . . 86
3.3.3 Tree scatternet . . . 87
3.3.4 Bluenet . . . 87
3.3.5 Scatternet formation algorithm . . . 88
3.3.6 Loop scatternet . . . 88
3.3.7 Bluestar . . . 88
3.4 Mesh mode of WiMax/802.16 . . . 89
3.4.1 Scheduling . . . 91
3.4.2 Management messages . . . 92
3.4.3 Mesh network . . . 93
3.4.4 Sleep mode . . . 96
3.5 Bibliographic comments . . . 100
3.6 Exercises . . . 101

4 WIRELESS NETWORK PROGRAMMING 105
4.1 Structure of information . . . 105
4.2 Socket . . . 107
4.3 Parameters and control . . . 109
4.4 Receiving frames . . . 110
4.5 Sending frames . . . 111
4.6 Exercices . . . 113

5 AD HOC NETWORK PROTOCOLS 115
5.1 Normal IP routing . . . 117

5.2 The reactive approach . . . 118
5.3 The proactive approach . . . 122
5.4 The hybrid approach . . . 127
5.4.1 Neighbor Discovery Protocol . . . 128
5.4.2 Intrazone Routing Protocol . . . 129
5.4.3 Interzone Routing Protocol . . . 132
5.5 Clustering . . . 134
5.6 Quality of service . . . 138
5.7 Sensor Network Protocols . . . 142
5.7.1 Flat routing . . . 142
5.7.2 Hierarchical routing . . . 142
5.7.3 ZigBee . . . 144
5.8 Exercices . . . 147

6 LOCATION AWARENESS 149
6.1 Geographic proximity . . . 150
6.1.1 Neighborhood graphs . . . 151
6.1.2 Relation between the neighborhood graphs . . . 154
6.2 Constructing spanners of ad hoc networks . . . 155
6.2.1 Gabriel test . . . 156
6.2.2 Morelia test . . . 156
6.2.3 Half space proximal test . . . 159
6.2.4 Spanner for nodes with irregular transmission ranges . . . 161
6.3 Information dissemination . . . 163
6.3.1 Compass routing in undirected planar graphs . . . 164
6.3.2 Face routing in undirected planar graphs . . . 164
6.3.3 Traversal of quasi planar graphs . . . 165
6.3.4 Routing in eulerian directed planar graphs . . . 169
6.3.5 Routing in outerplanar graphs . . . 171
6.4 Geographic location determination . . . 172
6.4.1 Radiolocation techniques . . . 172
6.4.2 Computing the geographic location . . . 175
6.4.3 Three/two neighbor algorithm . . . 176
6.4.4 Beyond distance one neighborhood . . . 178
6.5 Random unit disc graphs . . . 179
6.5.1 Poisson distribution in the plane . . . 181
6.5.2 Connectivity and k-connectivity . . . 182
6.5.3 Euclidean MST . . . 184
6.5.4 NNG and k-NNG . . . 184
6.5.5 Delaunay triangulations . . . 184
6.6 Coverage and connectivity with directional sensors . . . 186
6.6.1 Covering circles with sensors . . . 186
6.6.2 Achieving coverage . . . 187
6.7 Bibliographic comments . . . 190
6.8 Exercises . . . 191

7 AD HOC NETWORK SECURITY **197**
7.1 Authentication techniques . . . 198
7.1.1 Signatures, authentication and hashing . . . 198
7.1.2 Signatures in networking . . . 202
7.1.3 Distribution of keys . . . 207
7.2 Physical layer attacks . . . 208
7.3 Security of application protocols . . . 209
7.3.1 WiFi/802.11 confidentiality . . . 209
7.3.2 ZigBee security . . . 211
7.4 Biometrics-based key establishment . . . 214
7.5 Routing security . . . 218
7.5.1 Routing attacks . . . 218
7.5.2 Preventing malicious packet dropping . . . 220
7.5.3 Secure ad hoc distance vector routing protocol . . . 222
7.6 Broadcast security . . . 225
7.6.1 Issues and challenges . . . 225
7.6.2 BiBa broadcast authentication . . . 226
7.7 Secure location verification . . . 228
7.7.1 Simple echo protocol . . . 229
7.7.2 Echo protocol . . . 229
7.8 Security in directional antenna systems . . . 231
7.8.1 Wormhole attacks and their impact on routing protocols . . . 231
7.8.2 Zoning with directional sensors . . . 233
7.8.3 Protocols for securing neighbor discovery . . . 233
7.9 Bibliographic comments . . . 239
7.10 Exercices . . . 240

Bibliography **247**

Index **254**