

Table of contents

- **Preface** (p. xviii)
- **1 Introduction** (p. 1)
- **1.1 Standardization** (p. 1)
- **1.2 Next-generation Systems** (p. 3)
- **1.3 The IEEE 802 Project** (p. 4)
- **1.4 Motivation and Outline** (p. 5)
- **2 Wireless Communication - Basics** (p. 7)
- **2.1 Radio Transmission Fundamentals** (p. 7)
 - **2.1.1 Free-space Propagation** (p. 8)
 - **2.1.2 Two-path Propagation Over Flat Terrain** (p. 9)
 - **2.1.3 Attenuation** (p. 10)
 - **2.1.4 Fading** (p. 11)
 - **2.1.5 Shadowing** (p. 12)
 - **2.1.6 Filtering and Transmit Spectrum Masks** (p. 13)
 - **2.1.7 Propagation Models** (p. 13)
 - **2.1.7.1 One-slope Model** (p. 14)
 - **2.1.7.2 Hata-Okumura Model** (p. 14)
 - **2.1.7.3 Walfish-Ikegami Model** (p. 15)
 - **2.1.7.4 Dual-slope Model** (p. 15)
 - **2.1.7.5 Berg Model** (p. 16)
 - **2.1.8 Signal-to-Interference Ratio (SIR)** (p. 17)
 - **2.1.9 Noise - An Additional Source of Interference** (p. 18)
 - **2.1.10 Signal to Interference and Noise Ratio (SINR)** (p. 18)
 - **2.1.11 Interference Range** (p. 19)
 - **2.1.12 Digital Modulation** (p. 19)
 - **2.1.13 Modulation and Coding of Radio Signals** (p. 20)
- **2.2 Duplexing Schemes** (p. 22)
 - **2.2.1 Time Division Duplex** (p. 22)
 - **2.2.2 Frequency Division Duplex** (p. 23)
- **2.3 Multiplexing** (p. 23)
 - **2.3.1 Frequency Division Multiplex** (p. 23)
 - **2.3.2 Time Division Multiplex** (p. 24)
 - **2.3.3 Code Division Multiplex** (p. 25)
 - **2.3.4 Space Division Multiplex** (p. 25)
 - **2.3.5 Orthogonal Frequency Division Multiplex** (p. 25)
 - **2.3.5.1 Pilot Tones and Preambles** (p. 26)
 - **2.3.5.2 Fast Fourier Transformation (FFT)** (p. 27)
 - **2.3.5.3 Cyclic Prefix** (p. 28)
- **2.4 Switching in Communication Networks** (p. 29)
 - **2.4.1 Circuit Switching** (p. 29)
 - **2.4.2 Packet Switching** (p. 29)
- **2.5 Channel Coding for Error Correction and Error Detection** (p. 30)
 - **2.5.1 Forward Error Correction** (p. 30)

- **2.5.2 Automatic Repeat Request Protocols** (p. 30)
 - **2.5.2.1 Send-and-Wait** (p. 31)
 - **2.5.2.2 Go-back-N** (p. 32)
 - **2.5.2.3 Selective-Reject** (p. 32)
 - **2.5.2.4 Summary** (p. 32)
- **2.5.3 Hybrid Automatic Repeat Request** (p. 33)
- **2.6 Medium Access Control (MAC) Protocols** (p. 33)
 - **2.6.1 ALOHA** (p. 34)
 - **2.6.1.1 Pure ALOHA** (p. 35)
 - **2.6.1.2 Slotted ALOHA** (p. 36)
 - **2.6.1.3 Comparison of Pure and Slotted ALOHA** (p. 37)
 - **2.6.2 Carrier Sense Multiple Access** (p. 37)
 - **2.6.2.1 CSMA Variants** (p. 38)
 - **2.6.2.2 CSMA/CD** (p. 40)
 - **2.6.2.3 CSMA/CA** (p. 41)
 - **2.6.3 Polling** (p. 41)
 - **2.6.4 Summary** (p. 41)
 - **3 Radio Spectrum Regulation** (p. 43)
 - **3.1 Regulation Bodies and Global Institutions** (p. 44)
 - **3.1.1 International Telecommunication Union** (p. 44)
 - **3.1.2 Europe** (p. 45)
 - **3.1.3 Germany** (p. 45)
 - **3.1.4 Japan** (p. 46)
 - **3.1.5 China** (p. 46)
 - **3.1.6 United States** (p. 46)
 - **3.2 Licensed and Unlicensed Spectrum** (p. 47)
 - **3.2.1 Licensed Spectrum** (p. 47)
 - **3.2.2 The Problem with Licensing** (p. 47)
 - **3.2.3 Unlicensed Spectrum** (p. 48)
 - **3.2.3.1 Europe** (p. 48)
 - **3.2.3.2 United States** (p. 49)
 - **3.2.4 Part 15 Regulation** (p. 50)
 - **3.2.5 Tragedy of the Commons in Spectrum Regulation** (p. 50)
 - **3.3 Open Spectrum** (p. 51)
 - **3.4 Summary** (p. 52)
 - **4 Mesh Networks - Basics** (p. 53)
 - **4.1 Introduction** (p. 54)
 - **4.2 Classification of Wireless Mesh Networks** (p. 57)
 - **4.3 General Problem Statement** (p. 58)
 - **4.3.1 Path Selection** (p. 58)
 - **4.3.2 Medium Access Control** (p. 59)
 - **4.4 Exploiting the Capacity of the Radio Channel by Spatial Reuse** (p. 59)
 - **4.4.1 Hidden Devices - Potential Interferers** (p. 61)
 - **4.4.2 Exposed Devices - Unused Capacity** (p. 62)
 - **4.5 Fairness and Congestion Avoidance** (p. 63)
 - **4.6 Routing** (p. 65)

- **4.6.1 Routing Algorithms** (p. 65)
 - **4.6.1.1 Ad-hoc On-demand Distance Vector Routing (AODV)** (p. 66)
 - **4.6.1.2 Route Discovery** (p. 66)
 - **4.6.1.3 Route Maintenance** (p. 68)
 - **4.6.1.4 Local Repair** (p. 68)
- **4.6.2 Common Link Layer Behavior (Link Adaptation)** (p. 68)
- **4.6.6 Early Route Update (ERU)** (p. 73)
- **4.6.3 Link Breakage Prediction** (p. 70)
- **4.6.4 Actions for Expected Link Break** (p. 71)
- **4.6.5 Early Route Rearrangement (ERRA)** (p. 72)
- **4.6.7 Simulation Results** (p. 74)
- **4.6.8 Conclusions** (p. 75)
- **4.7 Summary** (p. 75)
- **5 IEEE 802.11 Wireless Local Area Networks** (p. 77)
 - **5.1 Scope of 802.11** (p. 77)
 - **5.2 Reference Model, Architecture, Services, Frame Formats** (p. 78)
 - **5.2.1 Reference Model** (p. 78)
 - **5.2.2 Architecture** (p. 79)
 - **5.2.3 Services** (p. 80)
 - **5.2.4 802.11 Frame Formats** (p. 80)
 - **5.3 Physical Layer** (p. 82)
 - **5.3.1 Frequency Hopping, Direct Sequence Spread Spectrum, and Infrared** (p. 83)
 - **5.3.2 802.11B Complementary Code Keying, CCK** (p. 83)
 - **5.4.1.1 Listen Before Talk** (p. 85)
 - **5.3.3 802.11A/G Orthogonal Frequency Division Multiplexing** (p. 83)
 - **5.4 Medium Access Control Protocol** (p. 84)
 - **5.4.1 Distributed Coordination Function** (p. 84)
 - **5.4.1.2 Timing and Interframe Spaces** (p. 85)
 - **5.4.1.3 Collision Avoidance** (p. 87)
 - **5.4.1.4 Recovery Procedure and Retransmissions** (p. 88)
 - **5.4.1.5 Post-backoff** (p. 88)
 - **5.4.1.6 Fragmentation** (p. 89)
 - **5.4.1.7 Hidden Stations and RTS/CTS** (p. 90)
 - **5.4.2 Synchronization and Cell Search** (p. 91)
 - **5.4.3 Scanning Procedures in WLAN 802.11** (p. 93)
 - **5.4.3.1 Passive Scanning** (p. 93)
 - **5.4.3.2 Active Scanning** (p. 93)
 - **5.5 Medium Access Control with Support for Quality-of-Service** (p. 94)
 - **5.5.4 Improvements of the Legacy 802.11 MAC** (p. 96)
 - **5.5.1 Point Coordination Function** (p. 94)
 - **5.5.2 QoS Support with PCF** (p. 95)
 - **5.5.3 QoS Support Mechanisms of 802.11E** (p. 95)
 - **5.5.5 Contention-based Medium Access** (p. 97)
 - **5.5.6 EDCA Parameters Per AC** (p. 98)
 - **5.5.7 Evaluation of Contention-based Medium Access** (p. 100)

- **5.5.7.1 Related Work** (p. 101)
- **5.5.7.2 EDCA throughput Capacity in an Isolated QBSS with Four Stations** (p. 101)
- **5.5.7.3 EDCA throughput with Increasing Number of Stations** (p. 101)
- **5.5.8 Controlled Medium Access** (p. 103)
- **5.5.8.1 QoS Guarantee with HCCA vs. EDCA** (p. 103)
- **5.5.8.2 The Superframe** (p. 105)
- **5.5.9 Block Acknowledgment** (p. 105)
- **5.5.10 Direct Link Protocol (DLP)** (p. 107)
- **5.6 Radio Spectrum Management** (p. 107)
- **5.6.1 Measurements in 802.11** (p. 107)
- **5.6.1.1 Information Transfer** (p. 107)
- **5.6.1.2 Specific Measurements in 802.11h** (p. 108)
- **5.6.1.3 Basic Report** (p. 109)
- **5.6.1.4 Clear Channel Assessment (CCA) Report** (p. 109)
- **5.6.1.5 Receive Power Indication (RPI) Histogram Report** (p. 109)
- **5.6.2 Specific Measurements in 802.11K** (p. 110)
- **5.6.2.1 Channel Load Report** (p. 111)
- **5.6.2.2 Noise Histogram Report** (p. 112)
- **5.6.2.3 Beacon Report** (p. 112)
- **5.6.2.4 Frame Report** (p. 113)
- **5.6.2.5 Hidden Station Report** (p. 113)
- **5.6.2.6 Medium Sensing Time Histogram Report** (p. 113)
- **5.6.2.7 STA Statistics Report** (p. 114)
- **5.6.2.8 LCI Report** (p. 114)
- **5.6.2.9 Measurement Pause Request** (p. 115)
- **5.7 History and Selected Sub-standards, i.e., Amendments** (p. 115)
- **5.7.1 IEEE 802.11** (p. 115)
- **5.7.2 IEEE 802.11a** (p. 115)
- **5.7.3 IEEE 802.11b** (p. 115)
- **5.7.4 IEEE 802.11c** (p. 116)
- **5.7.5 IEEE 802.11d** (p. 116)
- **5.7.6 IEEE 802.11e** (p. 116)
- **5.7.7 IEEE 802.11f** (p. 116)
- **5.7.8 IEEE 802.11g** (p. 116)
- **5.7.9 IEEE 802.11h** (p. 117)
- **5.7.10 IEEE 802.11i** (p. 117)
- **5.7.11 IEEE 802.11k** (p. 117)
- **6 IEEE 802.15 Wireless Personal Area Networks** (p. 119)
- **6.1 Scope of 802.15** (p. 120)
- **6.1.1 Objectives** (p. 120)
- **6.1.2 Different Subgroups** (p. 120)
- **6.2 802.15.3 - High-speed Wireless Personal Area Networks** (p. 121)
- **6.3 Task Group 3** (p. 122)
- **6.3.1 802.15.3 Medium Access Control** (p. 122)
- **6.3.1.1 802.15.3 Network Topology** (p. 123)

- **6.3.1.2 802.15.3 Medium Access Control** (p. 124)
- **6.3.1.3 Contention Access Period (CAP)** (p. 124)
- **6.3.1.4 Channel Time Allocation Period (CTAP)** (p. 126)
- **6.3.1.5 802.15.3 Data Transmission** (p. 126)
- **6.3.1.6 802.15.3 Network Security and Robustness** (p. 127)
- **6.3.1.7 802.15.3 Power Management** (p. 127)
- **6.3.2 802.15.3 Physical Layer** (p. 127)
- **6.4 Task Group 3a** (p. 128)
- **6.4.1 DS-UWB Proposal** (p. 129)
- **6.4.2 MB-OFDM Proposal** (p. 130)
- **6.5 Task Group 3b** (p. 133)
- **6.6 Task Group 3c** (p. 133)
- **6.7 WiMedia (Multiband OFDM) Alliance MAC Layer** (p. 134)
- **6.7.1 Overview** (p. 135)
- **6.7.2 Next Generation WPAN- WiMedia MAC** (p. 135)
 - **6.7.2.1 Medium Access** (p. 135)
 - **6.7.2.2 Prioritized Contention Access** (p. 135)
 - **6.7.2.3 Distributed Reservation Protocol** (p. 136)
 - **6.7.2.4 Transmission Opportunities** (p. 138)
 - **6.7.2.5 Acknowledgement Policies** (p. 138)
 - **6.7.2.6 Minimum Interframe Space and Frame Aggregation** (p. 138)
 - **6.7.2.7 Fragmentation and RTS/CTS Handshake** (p. 138)
 - **6.7.2.8 Beacon Period and Beacon Frames** (p. 138)
- **6.7.3 Simulative Performance Analysis** (p. 140)
- **6.7.4 Conclusion** (p. 145)
- **6.8 Next-generation WPAN Technologies** (p. 145)
- **6.8.1 Market Perspective** (p. 145)
- **6.8.2 PHY Technology** (p. 145)
- **6.8.3 MAC Design** (p. 145)
- **7.2.1 Deployment Concept** (p. 148)
- **7 IEEE 802.16 Wireless Metropolitan Area Networks**
- **7.1 Scope of 802.16** (p. 147)
- **7.2 Deployment Concept, Reference Model and Target Frequency Bands** (p. 148)
 - **7.2.2 Reference Model** (p. 149)
 - **7.2.3 Target Frequency Bands** (p. 150)
- **7.3 History and Different Subgroups** (p. 151)
 - **7.3.1 History** (p. 151)
 - **7.3.2 IEEE 802.16-2004 - Base Document** (p. 152)
 - **7.3.3 IEEE 802.16/Conformance** (p. 152)
 - **7.3.4 IEEE 802.16.2 Coexistence** (p. 152)
 - **7.3.5 IEEE 802.16e Mobility** (p. 153)
 - **7.3.6 IEEE 802.16f/g/i Network Management** (p. 153)
 - **7.3.7 IEEE 802.16h License Exempt** (p. 153)
 - **7.3.8 IEEE 802.16j Mobile Multi-hop Relay Study Group** (p. 153)
 - **7.3.9 ETSI BRAN HiperACCESS and HiperMAN** (p. 154)

- **7.3.10 WiMAX Forum** (p. 154)
- **7.3.11 Wireless Broadband (WiBro)** (p. 154)
- **7.4 Physical Layer** (p. 154)
 - **7.4.1 Orthogonal Frequency Division Multiplexing in 802.16** (p. 155)
 - **7.4.1.1 Randomizer** (p. 157)
 - **7.4.1.2 Forward Error Correction** (p. 157)
 - **7.4.1.3 Interleaving** (p. 157)
- **7.5 Medium Access Control Layer** (p. 157)
 - **7.5.1 Service-Specific Convergence Sublayer** (p. 158)
 - **7.5.1.1 Packet Convergence Sublayer** (p. 158)
 - **7.5.1.2 ATM Convergence Sublayer** (p. 159)
 - **7.5.2 MAC Common Part Sublayer** (p. 159)
 - **7.5.2.1 Duplex Modes** (p. 160)
 - **7.5.2.2 Frame Structure** (p. 160)
 - **7.5.2.3 Frame Control** (p. 162)
 - **7.5.2.4 Packet Data Unit Format** (p. 165)
 - **7.5.2.5 Fragmentation and Packing** (p. 166)
 - **7.5.2.6 Automatic Repeat Request** (p. 166)
 - **7.5.2.7 Connection Identifier** (p. 167)
 - **7.5.2.8 Network Entry** (p. 168)
 - **7.5.2.9 Connection Management** (p. 169)
 - **7.5.2.10 Bandwidth Requests and Uplink Scheduling Services** (p. 171)
 - **7.5.3 Security Sublayer** (p. 173)
- **7.6 System Profiles** (p. 173)
 - **7.6.1 MAC Profiles** (p. 173)
 - **7.6.2 Physical Layer Profiles** (p. 174)
 - **7.6.3 F Profiles, Duplexing Modes and Power Classes** (p. 174)
- **7.7 Space Division Multiple Access** (p. 174)
 - **7.7.1 PHY Layer Comprising an Antenna Array** (p. 175)
 - **7.7.2 Enhanced PHY Service Access Point** (p. 176)
 - **7.7.3 SDMA Enhanced Medium Access Control Layer** (p. 178)
 - **7.7.4 SDMA Scheduling** (p. 179)
- **7.8 Performance Evaluation of 802.16** (p. 180)
 - **7.8.1 Multi-user Multi Phy Mode Scenario** (p. 180)
 - **7.8.1.1 PHY Layer Configuration and PHY Mode Distribution** (p. 180)
 - **7.8.1.2 MAC Layer Configuration and Performance Metric** (p. 182)
 - **7.8.2 Performance Analysis** (p. 182)
 - **7.8.2.1 System Performance of the Example Scenario** (p. 183)
 - **7.8.3 Simulative Performance Evaluation** (p. 188)
 - **7.8.3.1 IEEE 802.16 Simulator** (p. 188)
 - **7.8.3.2 Simulation Results** (p. 189)
- **7.9 Performance of SDMA Enabled 802.16 Networks** (p. 192)
 - **7.9.1 Scenario and Simulation Environment** (p. 192)
 - **7.9.2 Downlink Cell Throughput** (p. 193)
 - **7.9.3 Signal to Interference Plus Noise Ratio** (p. 194)
- **7.10 Conclusion** (p. 195)

- **8.1.2 Mesh WLAN** (p. 201)
- **8 IEEE 802.11, 802.15 and 802.16 for Mesh Networks** (p. 197)
- **8.1 Approaches to Wireless Mesh Networks in IEEE and Industry** (p. 198)
- **8.1.1 Differences between Mesh WPAN, WLAN and WMAN** (p. 198)
- **8.1.2.1 802.11s** (p. 201)
- **8.1.2.2 Summary** (p. 207)
- **8.1.3 Mesh WPAN** (p. 208)
- **8.1.3.1 Status of Standardization in TG 802.15.5** (p. 208)
- **8.1.4 Mesh WMAN** (p. 209)
- **8.1.4.1 802.16 Mesh Option** (p. 210)
- **8.1.4.2 802.16j** (p. 211)
- **8.2 Extensions to IEEE 802 MAC Protocols - Homogeneous Multi-hop Networks** (p. 212)
 - **8.2.1 IEEE 802.16 Multi-hop Networks** (p. 213)
 - **8.2.1.1 Multi-hop Operation in the Time and Frequency Domain** (p. 213)
 - **8.2.1.2 MAC Subframe Embedding** (p. 214)
 - **8.2.1.3 Hierarchical Beacon with Fixed Slot Allocation** (p. 215)
 - **8.2.1.4 Time Sharing Wireless Router** (p. 216)
 - **8.2.1.5 Time Sharing Wireless Router with Spatial Reuse** (p. 217)
 - **8.2.2 IEEE 802.11e Multi-hop Networks** (p. 218)
 - **8.2.2.1 Collision Avoidance through Channel Reservation** (p. 219)
 - **8.2.2.2 Collision Avoidance by Channel Reservation with Spatial Reuse** (p. 220)
 - **8.2.3 Performance Evaluation Results** (p. 220)
 - **8.2.3.1 Scenario Description** (p. 220)
 - **8.2.3.2 Mean Delay vs. Offered Traffic** (p. 222)
 - **8.2.3.3 System Capacity vs. Distance between BS/HC and FRS** (p. 223)
 - **8.2.4 Summary** (p. 223)
- **8.3 Extensions to IEEE 802 MAC Protocols for Heterogeneous Multi-hop Networks** (p. 224)
 - **8.3.1 Overview** (p. 224)
 - **8.3.2.1 802.11 Mesh Network to Serve 802.11 Stations** (p. 225)
 - **8.3.2 Medium Access Control in Heterogeneous Mesh Networks** (p. 225)
 - **8.3.2.2 802.16 Mesh Network to Serve 802.11 Stations** (p. 225)
 - **8.3.2.3 New Mesh Network Protocol to Connect 802.16 BSs** (p. 225)
 - **8.3.3 Interworking Control of 802.16 and 802.11** (p. 227)
 - **8.3.3.1 Scenario** (p. 228)
 - **8.3.3.2 Medium Access Control** (p. 229)
 - **8.3.3.3 BSHC and Legacy 802.11 Stations** (p. 232)
 - **8.3.4 Performance Evaluation Results** (p. 233)
 - **8.3.5 Summary** (p. 235)
- **8.4 Conclusion** (p. 235)
- **9 Coexistence in IEEE 802 Networks** (p. 237)
 - **9.1 Homogeneous Coexistence - Spectrum Sharing 802.11e Networks** (p. 238)
 - **9.1.1 Coexistence Scenario** (p. 238)
 - **9.1.2 Overview** (p. 239)
 - **9.1.3 Single Stage Game** (p. 240)

- **9.1.3.1 Quality-of-Service as Utility** (p. 241)
- **9.1.3.2 Utility under Competition** (p. 243)
- **9.1.4 Behaviors in Single Stage Games** (p. 243)
 - **9.1.4.1 Cooperation through Predictable Behavior** (p. 243)
 - **9.1.4.2 Classification of the Opponent's Behavior** (p. 243)
 - **9.1.5 Equilibrium Analysis of Single Stage Game** (p. 244)
 - **9.1.6 Multi Stage Game** (p. 245)
 - **9.1.7 Strategies in Multi Stage Games** (p. 246)
 - **9.1.7.1 Static Strategies** (p. 246)
 - **9.1.7.2 Dynamic (Trigger) Strategies Grim and TitForTat** (p. 247)
 - **9.2 Heterogeneous Coexistence - Unlicensed Operation of 802.16** (p. 250)
 - **9.1.7.3 RANDOM Strategy** (p. 248)
 - **9.1.7.4 QoS Support in Multi Stage Games of Competing WLANs** (p. 248)
 - **9.1.8 Coexistence Among 802.16 Systems** (p. 249)
- **9.2.1 Coexistence Scenario** (p. 250)
 - **9.2.2 Protecting the Beginning of 802.16 MAC Frame** (p. 252)
 - **9.2.3 Protecting the 802.16 UL Subframe** (p. 253)
 - **9.2.4 Shifting the Contention Slots** (p. 253)
- **9.3 Summary and Conclusion** (p. 253)
- **10 Broadband Cellular Multi-hop Networks** (p. 255)
 - **10.1 Definitions** (p. 255)
 - **10.2 Rationale** (p. 256)
 - **10.3 Related Work** (p. 258)
 - **10.4 Relay-based Deployment Concept for Cellular Broadband Networks** (p. 259)
 - **10.4.1 Relaying Use Cases** (p. 260)
 - **10.4.1.1 Relay to Increase Coverage Range** (p. 260)
 - **10.4.1.2 Relay to Increase Cell Capacity** (p. 261)
 - **10.4.1.3 Relay to Cover Locations Heavily Shadowed from Access Point** (p. 261)
 - **10.4.1.4 Exploiting Spatial Separation of Subcells in REC** (p. 263)
 - **10.4.2 Estimation of Subcell Capacity in a Relay Enhanced Cell** (p. 264)
 - **10.4.2.1 Multi-hop throughput in Cellular Deployment** (p. 264)
 - **10.4.2.2 Subcell Capacity served by an FRS** (p. 264)
 - **10.4.2.3 Capacity of Multi-hop Links under Delay Constraint** (p. 266)
 - **10.5 Conclusions** (p. 267)
 - **11 Mutual Integration and Cooperation of Radio Access Networks** (p. 269)
 - **11.1 State-of-the-Art Overview** (p. 270)
 - **11.1.1 ETSI BRAN/3GPP** (p. 270)
 - **11.1.2 IEEE** (p. 272)
 - **11.1.2.1 IEEE 802.11u: Interworking with External Networks** (p. 272)
 - **11.1.2.2 802.21 Media Independent Handoff Working Group** (p. 273)
 - **11.1.3 IETF** (p. 274)
 - **11.1.4 ITU-T** (p. 274)
 - **11.1.5 WWRF** (p. 275)
 - **11.2 Mobility and Handover** (p. 275)
 - **11.2.1 General Aspects of Mobility** (p. 276)

- **11.2.2 Handover Aspects** (p. 277)
- **11.2.2.1 Definition** (p. 278)
- **11.2.2.2 Reasons for Handover** (p. 278)
- **11.2.2.3 Types of Handover** (p. 279)
- **11.2.2.4 Handover Control** (p. 282)
- **11.2.2.5 Layer 2 Handover** (p. 283)
- **11.2.2.6 Higher Layer Handover** (p. 283)
- **11.2.2.7 Horizontal and Vertical Handover** (p. 284)
- **11.3 Trigger** (p. 286)
- **11.3.1 Definition and Classification** (p. 286)
- **11.3.2 Decision Criteria** (p. 287)
- **12 Future Mesh Technologies** (p. 289)
- **12.1 Facts on Medium Access Control** (p. 289)
- **12.1.1 State of the Art in Medium Access Control Protocols - A Taxonomy** (p. 291)
 - **12.1.1.1 HiperLAN 2 (H/2)** (p. 291)
 - **12.1.1.2 DECT** (p. 292)
 - **12.1.1.3 GPRS** (p. 292)
- **12.1.2 Potentials and Limitations of the State-of-the-art MAC Protocols** (p. 292)
- **12.1.2.1 Reservation per Packet** (p. 293)
- **12.1.2.2 TDMA in the Short** (p. 295)
- **12.1.2.3 TDMA in the Long** (p. 296)
- **12.1.3 Key Methods for QoS Supporting Medium Access Control Protocols** (p. 296)
 - **12.1.3.1 Single-hop Links** (p. 296)
 - **12.1.3.2 Multi-hop Links** (p. 297)
- **12.2 Mesh Networking for 802.11 WLAN** (p. 298)
- **12.2.1 Mesh Distributed Coordination Function** (p. 299)
 - **12.2.1.1 TDMA Frame and Energy Signals** (p. 299)
 - **12.2.1.2 Prioritized Channel Access** (p. 300)
 - **12.2.1.6 Coexistence** (p. 305)
 - **12.2.1.3 Link Setup and Traffic Channel Reservation** (p. 303)
 - **12.2.1.4 Transmission and On-demand-TCH Turnaround** (p. 303)
 - **12.2.1.5 Packet Multiplexing and Multi-hop Operation** (p. 304)
- **12.2.2 Performance Evaluation Results** (p. 305)
- **12.2.2.1 Simulation Tool** (p. 305)
- **12.2.2.2 Simulation Results - QoS Performance in Mesh Networks** (p. 306)
- **12.3 Conclusion** (p. 308)
- **13 Cognitive Radio and Spectrum Sharing** (p. 311)
 - **13.1 From Software-defined Radio to Cognitive Radio** (p. 311)
 - **13.1.1 Software-defined Radio and Software Radio** (p. 311)
 - **13.1.2 Composite Radio and Reconfigurable Radio** (p. 312)
 - **13.1.3 Cognitive Radio** (p. 312)
 - **13.2 Cognitive Radio Networks** (p. 314)
 - **13.2.1 Essential Characteristics** (p. 315)
 - **13.2.2 Spectrum Information Base** (p. 316)

- **13.2.3 Similar Approaches and Related Work** (p. 317)
- **13.3 Spectrum Sharing and Flexible Spectrum Access** (p. 317)
- **13.3.1 Spectrum Trading** (p. 317)
- **13.3.2 Underlay and Overlay Spectrum Sharing** (p. 319)
- **13.3.2.1 Opportunistic Spectrum Usage** (p. 320)
- **13.3.2.2 IEEE 802.11k** (p. 321)
- **13.3.3 Vertical and Horizontal Spectrum Sharing** (p. 321)
- **13.3.4 Coexistence, Coordination and Cooperation** (p. 324)
- **13.4 Coexistence-based Spectrum Sharing** (p. 324)
 - **13.4.1 Dynamic Frequency Selection** (p. 325)
 - **13.4.2 Transmit Power Control** (p. 325)
 - **13.4.3 Ultra-wide Band** (p. 325)
 - **13.4.4 IEEE 802.16.2** (p. 326)
 - **13.4.5 IEEE 802.16h** (p. 326)
 - **13.4.6 IEEE 802.19** (p. 326)
- **13.5 Coordination-based Horizontal Spectrum Sharing** (p. 326)
 - **13.5.1 Common Spectrum Coordination Channel** (p. 326)
 - **13.5.2 Dynamic Spectrum Allocation** (p. 327)
 - **13.5.2.1 Brokerage-based Spectrum Sharing** (p. 321)
 - **13.5.2.2 Inter-operator Spectrum Sharing** (p. 328)
 - **13.5.3 IEEE 802.11y** (p. 328)
 - **13.5.4 Spectrum Sharing Games** (p. 328)
- **13.6 Coordination-based Vertical Spectrum Sharing** (p. 329)
 - **13.6.1 Common Control Channel** (p. 329)
 - **13.6.2 IEEE 802.22** (p. 330)
 - **13.6.3 Spectrum Pooling** (p. 330)
 - **13.6.4 Value Orientation** (p. 330)
 - **13.6.5 Spectrum Load Smoothing** (p. 330)
- **13.7 Policies and Etiquette in Spectrum Usage** (p. 331)
 - **13.7.1 Policy Framework** (p. 331)
 - **13.7.2 Spectrum Navigation** (p. 332)
 - **13.7.3 Reasoning-based Spectrum Navigation** (p. 332)
 - **13.7.3.1 Reasoning** (p. 333)
 - **13.7.3.2 Knowledge Representation** (p. 333)
 - **13.7.3.3 Traceability of Decision Making** (p. 334)
 - **13.7.4 Policy-defined Medium Access Control** (p. 334)
- **13.8 Summary and Conclusion** (p. 334)
- **14 Conclusions** (p. 337)
- **Abbreviations** (p. 345)
- **References** (p. 355)
- **Index** (p. 375)