PRINCIPLES OF WIRELESS ACCESS AND LOCALIZATION

Kaveh Pahlavan
Worcester Polytechnic Institute, Worcester, Massachusetts, USA

Prashant Krishnamurthy
University of Pittsburgh, Pittsburgh, Pennsylvania, USA

WILEY
# Contents

**Preface**

1 Introduction
   1.1 Introduction
   1.2 Elements of Information Networks
      1.2.1 Evolution of Applications, Devices, and Networks
      1.2.2 Information Network Infrastructures and Wireless Access
      1.2.3 Connection Between Wireless Access and Localization
      1.2.4 Standards Organizations for Information Networking
      1.2.5 Four Markets in the Evolution of Wireless Networking Standards
      1.2.6 Trends in Wireless Data Applications
   1.3 Evolution of Wireless Access to the PSTN
      1.3.1 Cordless Telephone Systems
      1.3.2 Cellular Telephone Networks
   1.4 Evolution of Wireless Access to the Internet
      1.4.1 Local Wireless Data Networks
      1.4.2 Wide Area Wireless Data Networks
   1.5 Evolution of Wireless Localization Technologies
      1.5.1 TOA-based Wireless Localization
      1.5.2 RSS-based Localization
   1.6 Structure of this Book
      1.6.1 Part I: Principles of Air–Interference Design
      1.6.2 Part II: Principle of Network Infrastructure Design
      1.6.3 Part III: Wireless Local Access
      1.6.4 Part IV: Wide Area Wireless Access
      1.6.5 Part V: Wireless Localization

## Part I  PRINCIPLES OF AIR–INTERFERENCE DESIGN

2 Characteristics of the Wireless Medium
   2.1 Introduction
      2.1.1 Causes of Multipath Propagation
      2.1.2 Effects of Multipath Propagation
      2.1.3 Applied Channel Models for Wireless Communication Applications
Contents

3.7  Cognitive Radio and Dynamic Spectrum Access 145
Appendix A3 145

4  Medium Access Methods 153
4.1  Introduction 153
4.2  Centralized Assigned-Access Schemes 155
   4.2.1  Frequency Division Multiple Access 156
   4.2.2  Time Division Multiple Access 159
   4.2.3  Code Division Multiple Access (CDMA) 163
   4.2.4  Comparison of CDMA, TDMA and FDMA 166
   4.2.5  Performance of Assigned-Access Methods 169
4.3  Distributed Random Access for Data Oriented Networks 173
   4.3.1  Random Access Methods for Data Services 174
   4.3.2  Access methods for LANs 180
   4.3.3  Performance of Random Access Methods 186
4.4  Integration of Voice and Data Traffic 195
   4.4.1  Access Methods for Integrated Services 195
   4.4.2  Data Integration in Voice-Oriented Networks 196
   4.4.3  Voice Integration into Data-Oriented Networks 202

Part II  PRINCIPLES OF NETWORK INFRASTRUCTURE DESIGN

5  Deployment of Wireless Networks 217
5.1  Introduction 217
5.2  Wireless Network Architectures 218
   5.2.1  Classification of Wireless Networks Based on Topologies 219
   5.2.2  Classification of Wireless Networks Based on Coverage 223
5.3  Interference in Wireless Networks 224
   5.3.1  Interference Range 225
   5.3.2  Probability of Interference 228
   5.3.3  Empirical Results 231
5.4  Deployment of Wireless LANs 233
5.5  Cellular Topology, Cell Fundamentals, and Frequency Reuse 238
   5.5.1  The Cellular Concept 239
   5.5.2  Cellular Hierarchy 241
   5.5.3  Cell Fundamentals and Frequency Reuse 243
   5.5.4  Signal to Interference Ratio Calculation 244
5.6  Capacity Expansion Techniques 248
   5.6.1  Architectural Methods for Capacity Expansion 250
   5.6.2  Channel Allocation Techniques and Capacity Expansion 260
   5.6.3  Migration to Digital Systems 267
5.7  Network Planning for CDMA Systems 268
   5.7.1  Issues in CDMA Network Planning 269
   5.7.2  Migration from Legacy Systems 270
5.8  Femtocells 270
# 6 Wireless Network Operations

## 6.1 Introduction

### 6.1.1 Operations in Cellular Telephone Networks

### 6.1.2 Operations in Wireless Local Area Networks

### 6.1.3 Operations in Wireless Personal Area Networks

## 6.2 Cell Search and Registration

## 6.3 Mobility Management

### 6.3.1 Location Management

### 6.3.2 Handoff Management

### 6.3.3 Mobile IP and IMS

## 6.4 Radio Resources and Power Management

### 6.4.1 Adjusting Link Quality

### 6.4.2 Power Control

### 6.4.3 Power Saving Mechanisms in Wireless Networks

### 6.4.4 Energy Efficient Designs

### 6.4.5 Energy Efficient Software Approaches

# 7 Wireless Network Security

## 7.1 Introduction

### 7.1.1 General Security Threats

### 7.1.2 Cryptographic Protocols for Security

## 7.2 Security in Wireless Local Networks

### 7.2.1 Security Threats

### 7.2.2 Security Protocols

## 7.3 Security in Wireless Personal Networks

### 7.3.1 Security Threats

### 7.3.2 Security Protocols

## 7.4 Security in Wide Area Wireless Networks

### 7.4.1 Security Threats

### 7.4.2 Security Protocols

## 7.5 Miscellaneous Issues

Appendix A7: An Overview of Cryptography and Cryptographic Protocols

# Part III WIRELESS LOCAL ACCESS

## 8 Wireless LANs

## 8.1 Introduction

### 8.1.1 Early Experiences

### 8.1.2 Emergence of Unlicensed Bands

### 8.1.3 Products, Bands, and Standards

### 8.1.4 Shift in Marketing Strategy

## 8.2 Wireless Local Area Networks and Standards

### 8.2.1 WLAN Standards and 802.11 Standards Activities

### 8.2.2 Ethernet and IEEE 802.11

### 8.2.3 Overview of IEEE 802.11

## 8.3 IEEE 802.11 WLAN Operations

### 8.3.1 Topology and Architecture

### 8.3.2 The IEEE 802.11 MAC Layer
9 Low Power Sensor Networks

9.1 Introduction

9.2 Bluetooth
  9.2.1 Overall Architecture
  9.2.2 Protocol Stack
  9.2.3 Physical Layer
  9.2.4 MAC Mechanism
  9.2.5 Frame Formats
  9.2.6 Connection Management
  9.2.7 Security

9.3 IEEE 802.15.4 and ZigBee
  9.3.1 Overall Architecture
  9.3.2 Protocol Stack and Operation
  9.3.3 Physical Layer
  9.3.4 MAC Layer
  9.3.5 Frame Format
  9.3.6 Comparison of ZigBee with Bluetooth and WiFi

9.4 IEEE 802.15.6 Body Area Networks
  9.4.1 What is a BAN?
  9.4.2 Overall Architecture and Applications
  9.4.3 Channel Measurement and Modeling
  9.4.4 Physical and MAC Layer

10 Gigabit Wireless

10.1 Introduction
  10.1.1 UWB Networking at 3.1–10.6 GHz
  10.1.2 Gigabit Wireless at 60 GHz

10.2 UWB Communications at 3.1–10.6 GHz
  10.2.1 Impulse Radio and Time Hopping Access
  10.2.2 Direct Sequence UWB
  10.2.3 Multi-Band OFDM
  10.2.4 Channel Models for UWB Communications

10.3 Gigabit Wireless at 60 GHz
  10.3.1 Architecture and Application Scenarios
  10.3.2 Transmission and Medium Access
  10.3.3 Channel Models for 60 GHz mmWave Networks

Part IV WIDE AREA WIRELESS ACCESS

11 TDMA Cellular Systems

11.1 Introduction

11.2 What is TDMA Cellular?
  11.2.1 Original Services and Shortcomings
  11.2.2 Reference Architecture for a Cellular Network
11.3 Mechanisms to Support a Mobile Environment 486
  11.3.1 Registration 486
  11.3.2 Call Establishment 487
  11.3.3 Handoff 488
  11.3.4 Security 490
11.4 Communication Protocols 491
  11.4.1 Layer I: Physical Layer 493
  11.4.2 Layer II: Data Link Layer 499
  11.4.3 Layer III: Networking Layer 500
11.5 Channel Models for Cellular Networks 501
  11.5.1 Path Loss Models for Cellular Networks 503
  11.5.2 Models for Scattering Function of Cellular Networks 506
11.6 Transmission Techniques in TDMA Cellular 508
11.7 Evolution of TDMA for Internet Access 512
  11.7.1 Architectural and MAC Layer Changes 512
  11.7.2 Data Rate in TDMA Packet Switched Networks 515

12 CDMA Cellular Systems 519
12.1 Introduction 519
12.2 Why CDMA? 520
12.3 CDMA Based Cellular Systems 521
12.4 Direct Sequence Spread Spectrum 522
  12.4.1 Receiver Processing with Direct Sequence Spread Spectrum 523
  12.4.2 Channelization using Orthogonal Sequences 525
  12.4.3 Multipath Diversity with PN Sequences 528
12.5 Communication Channels and Protocols in Example CDMA Systems 534
  12.5.1 The 2G CDMA System 534
  12.5.2 The 3G UMTS System 543
12.6 Cell Search, Mobility, and Radio Resource Management in CDMA 546
  12.6.1 Cell Search 546
  12.6.2 Soft Handoff 548
  12.6.3 Power Control 552
12.7 High Speed Packet Access 554

13 OFDM and MIMO Cellular Systems 561
13.1 Introduction 561
13.2 Why OFDM? 562
  13.2.1 Robustness in Multipath Dispersion 563
  13.2.2 Flexible Allocation of Resources 567
  13.2.3 Challenges with OFDM 569
13.3 Multiple Input Multiple Output 572
  13.3.1 Diversity 573
  13.3.2 Spatial Multiplexing 575
  13.3.3 Beamforming 576
13.4 WiMax 576
  13.4.1 General Architecture of WiMax 579
  13.4.2 MAC Layer of WiMAX 581
  13.4.3 PHY Layer of WiMax 582
16.2.2 Wi-Fi Localization: TOA versus RSS 656
16.2.3 How does RSS-based Wi-Fi Localization Work? 657

16.3 Comparison of Wi-Fi Localization Systems 657
16.3.1 RTLS: Wi-Fi Localization for RFID Applications 658
16.3.2 WPS: Software GPS 660

16.4 Practical TOA Measurement 665
16.4.1 Measurement of TOA using a Narrowband Carrier Phase 665
16.4.2 Wideband TOA Measurement and Super-resolution Algorithm 666
16.4.3 UWB TOA Measurement 667

16.5 Localization in the Absence of DP 669
16.5.1 Ranging Error in the Absence of DP 670
16.5.2 Effects of Bandwidth 671
16.5.3 Localization using Multipath Diversity 672
16.5.4 Cooperative Localization Using Spatial Diversity 673

16.6 Challenges in Localization inside the Human Body 675
16.6.1 Bounds on RSS-based Localization inside the Human Body 676
16.6.2 Challenges in TOA-based RF Localization inside the Human Body 679
16.6.3 Modeling of Wideband RF Propagation from inside the Human Body 681

References 687

Index 701