



Introduction to **Wireless Digital Communication**

Robert W. Heath, Jr.

Communications Engineering and Emerging Technologies Series | **Theodore S. Rappaport, Series Editor**

Introduction to Wireless Digital Communication

Introduction to Wireless Digital Communication: A Signal Processing Perspective

Table of Contents

Cover

Half Title

Title Page

Copyright Page

Contents

Preface

Acknowledgments

About the Author

1 Introduction

1.1 Introduction to Wireless Communication

1.2 Wireless Systems

1.2.1 Broadcast Radio

1.2.2 Broadcast Television

1.2.3 Cellular Communication Networks

1.2.4 Wireless Local Area Networks (WLANs)

1.2.5 Personal Area Networks (PANs)

1.2.6 Satellite Systems

1.2.7 Wireless Ad Hoc Networks

1.2.8 Wireless Sensor Networks

1.2.9 Underwater Communication

1.3 Signal Processing for Wireless Communication

Table of Contents

- 1.4 Contributions of This Book
- 1.5 Outline of This Book
- 1.6 Symbols and Common Definitions
- 1.7 Summary
- Problems

2 An Overview of Digital Communication

- 2.1 Introduction to Digital Communication
- 2.2 Overview of a Wireless Digital Communication Link
- 2.3 Wireless Channel
 - 2.3.1 Additive Noise
 - 2.3.2 Interference
 - 2.3.3 Path Loss
 - 2.3.4 Multipath Propagation
- 2.4 Source Coding and Decoding
 - 2.4.1 Lossless Source Coding
 - 2.4.2 Lossy Source Coding
- 2.5 Encryption and Decryption
- 2.6 Channel Coding and Decoding
- 2.7 Modulation and Demodulation
 - 2.7.1 Baseband Modulation
 - 2.7.2 Passband Modulation
 - 2.7.3 Demodulation with Noise
 - 2.7.4 Demodulation with Channel Impairments

- 2.8 Summary
- Problems

3 Signal Processing Fundamentals

- 3.1 Signals and Systems

Table of Contents

3.1.1 Types of Signals and Notation

3.1.2 Linear Time-Invariant Systems

3.1.3 The Fourier Transform

3.1.4 Bandwidth of a Signal

3.1.5 Sampling

3.1.6 Discrete-Time Processing of Bandlimited Continuous-Time Signals

3.2 Statistical Signal Processing

3.2.1 Some Concepts from Probability

3.2.2 Random Processes

3.2.3 Moments of a Random Process

3.2.4 Stationarity

3.2.5 Ergodicity

3.2.6 Power Spectrum

3.2.7 Filtering Random Signals

3.2.8 Gaussian Random Processes

3.2.9 Random Vectors and Multivariate Random Processes

3.3 Signal Processing with Passband Signals

3.3.1 UpconversionCreating a Passband Signal

3.3.2 DownconversionExtracting a Complex Baseband Signal from a
Passband Signal

3.3.3 Complex Baseband Equivalent Channel

3.3.4 Pseudo-baseband Equivalent Channel

3.3.5 The Discrete-Time Equivalent Channel

3.4 Multirate Signal Processing

3.4.1 Downsampling

3.4.2 Upsampling

3.4.3 Polyphase Decomposition

3.4.4 Filtering with Upsampling and Downsampling

3.4.5 Changing the Sampling Rate

3.5 Linear Estimation

Table of Contents

3.5.1 Linear Algebra

3.5.2 Least Squares Solution to a System of Linear Equations

3.5.3 Maximum Likelihood Parameter Estimation in AWGN

3.5.4 Linear Minimum Mean Squared Error Estimation

3.6 Summary

Problems

4 Digital Modulation and Demodulation

4.1 Transmitter for Complex Pulse-Amplitude Modulation

4.2 Symbol Mapping and Constellations

4.2.1 Common Constellations

4.2.2 Symbol Mean

4.2.3 Symbol Energy

4.3 Computing the Bandwidth and Power of $x(t)$

4.4 Communication in the AWGN Channel

4.4.1 Introduction to the AWGN Channel

4.4.2 Receiver for Complex Pulse-Amplitude Modulation in AWGN

4.4.3 Pulse Shape Design for the AWGN Channel

4.4.4 Symbol Detection in the AWGN Channel

4.4.5 Probability of Symbol Error Analysis

4.5 Digital Implementation of Pulse Shaping

4.5.1 Transmit Pulse Shaping

4.5.2 Receiver Matched Filtering

4.6 Summary

Problems

5 Dealing with Impairments

5.1 Frequency-Flat Wireless Channels

5.1.1 Discrete-Time Model for Frequency-Flat Fading

5.1.2 Symbol Synchronization

Table of Contents

- 5.1.3 Frame Synchronization
- 5.1.4 Channel Estimation
- 5.1.5 Equalization
- 5.1.6 Carrier Frequency Offset Synchronization
- 5.2 Equalization of Frequency-Selective Channels**
 - 5.2.1 Discrete-Time Model for Frequency-Selective Fading
 - 5.2.2 Linear Equalizers in the Time Domain
 - 5.2.3 Linear Equalization in the Frequency Domain with SC-FDE
 - 5.2.4 Linear Equalization in the Frequency Domain with OFDM
- 5.3 Estimating Frequency-Selective Channels**
 - 5.3.1 Least Squares Channel Estimation in the Time Domain
 - 5.3.2 Least Squares Channel Estimation in the Frequency Domain
 - 5.3.3 Direct Least Squares Equalizer
- 5.4 Carrier Frequency Offset Correction in Frequency-Selective Channels**
 - 5.4.1 Model for Frequency Offset in Frequency-Selective Channels
 - 5.4.2 Revisiting Single-Frequency Estimation
 - 5.4.3 Frequency Offset Estimation and Frame Synchronization Using Periodic Training for Single-Carrier Systems
 - 5.4.4 Frequency Offset Estimation and Frame Synchronization Using Periodic Training for OFDM Systems
- 5.5 Introduction to Wireless Propagation**
 - 5.5.1 Mechanisms of Propagation
 - 5.5.2 Propagation Modeling
- 5.6 Large-Scale Channel Models**
 - 5.6.1 Friis Free-Space Model
 - 5.6.2 Log-Distance Path-Loss Model
 - 5.6.3 LOS/NLOS Path-Loss Model
 - 5.6.4 Performance Analysis Including Path Loss
- 5.7 Small-Scale Fading Selectivity**

Table of Contents

- 5.7.1 Introduction to Selectivity
- 5.7.2 Frequency-Selective Fading
- 5.7.3 Time-Selective Fading
- 5.7.4 Signal Models for Channel Selectivity

5.8 Small-Scale Channel Models

- 5.8.1 Flat-Fading Channel Models
- 5.8.2 Frequency-Selective Channel Models
- 5.8.3 Performance Analysis with Fading Channel Models

5.9 Summary

Problems

6 MIMO Communication

6.1 Introduction to Multi-antenna Communication

- 6.1.1 Single-Input Multiple-Output (SIMO)
- 6.1.2 Multiple-Input Single-Output (MISO)
- 6.1.3 Multiple-Input Multiple-Output (MIMO)

6.2 Receiver Diversity for Flat-Fading SIMO Systems

- 6.2.1 SIMO Flat-Fading Channel Models
- 6.2.2 Antenna Selection
- 6.2.3 Maximum Ratio Combining

6.3 Transmit Diversity for MISO Systems

- 6.3.1 MISO Flat-Fading Channel Models
- 6.3.2 Why Spatial Repetition Does Not Work
- 6.3.3 Transmit Beamforming
- 6.3.4 Limited Feedback Beamforming
- 6.3.5 Reciprocity-Based Beamforming
- 6.3.6 The Alamouti Code
- 6.3.7 Space-Time Coding

6.4 MIMO Transceiver Techniques

- 6.4.1 Spatial Multiplexing

Table of Contents

6.4.2 MIMO Flat-Fading Channel Models

6.4.3 Detection and Equalization for Spatial Multiplexing

6.4.4 Linear Precoding

6.4.5 Extensions to Limited Feedback

6.4.6 Channel Estimation in MIMO Systems

6.4.7 Going Beyond the Flat-Fading Channel to Frequency-Selective
Channels

6.5 MIMO-OFDM Transceiver Techniques

6.5.1 System Model

6.5.2 Equalization and Detection

6.5.3 Precoding

6.5.4 Channel Estimation

6.5.5 Carrier Frequency Synchronization

6.6 Summary

Problems

References

Index