

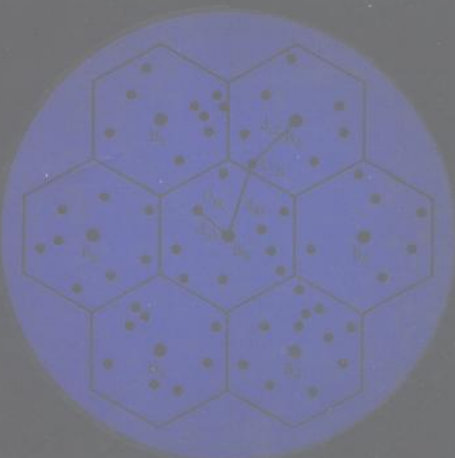
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《通信与信息科学教育丛书》

WIRELESS

communications

Principles & Practice



无线通信原理与应用

[美] Theodore S. Rappaport

WIRELESS COMMUNICATIONS
PRINCIPLES & PRACTICE



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PUBLISHING HOUSE OF ELECTRONICS INDUSTRY
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电子工业出版社

Publishing House of Electronics Industry

北京·BEIJING

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内 容 简 介

本书是一本经典的大学通信专业入门教材。全书深入浅出地讨论了无线通信的相关基础理论,并涉及到了第三代系统的基本发展方向和有关问题。全书共分十章,从实际应用的角度,结合理论对无线通信系统的各个方面做了精辟的论述和统计。全书语言生动、流畅,非常适合于有一定通信理论基础的工程技术人员和在校相关专业的师生阅读。

Wireless Communications Principles and Practice/Theodore S. Rappaport

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Original edition published by Prentice Hall, Inc., a Simon & Schuster Company.

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原 书 名: Wireless Communications Principles and Practice

书 名: 无线通信原理与应用

著 作 者: [美] Theodore S. Rappaport

策 划: 图书策划开发部

责任编辑: 张毅 徐翌

印 刷 者: 北京民族印刷厂

装 订 者: 河北省涿州桃园装订厂

出版发行: 电子工业出版社 URL: <http://www.phei.com.cn>

北京市海淀区万寿路 173 信箱 邮编 100036

经 销: 各地新华书店

开 本: 850 × 1168 1/32 印张: 20.625

版 次: 1998 年 9 月第 1 版 1999 年 3 月第 2 次印刷

书 号: ISBN 7-5053-4886-8
TN·1190

定 价: 35.00 元

版权贸易合同登记号 图字:01-98-1778

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近年来,通信与信息科技发展之快和应用之广,大大超出了人们的预料和专家的预测。从国民经济到社会生活的日益信息化,标志着通信与信息科技的空前发展。

为了满足高等院校师生教改和教学的需求以及广大技术人员学习通信与信息新技术的需要,电子工业出版社约请北京地区的清华大学、北京大学、北京航空航天大学、北京邮电大学、北方交通大学,南京地区的东南大学、解放军通信工程学院、南京邮电学院,上海地区的上海交通大学、成都地区的西南交通大学、电子科技大学,西安地区的西安电子科技大学、西安交通大学,天津地区的南开大学,深圳地区的深圳大学,东北地区的哈尔滨工业大学等全国知名高等院校教学第一线上的教授和信息产业部有关科研院所的专家,请他们推荐和反复论证,从国外优秀的英文版教材中精选出版了这套《通信与信息科学教育丛书》(影印版)。

本套丛书可作为高等院校通信、计算机、电子信息等专业的高年级本科生、研究生的教材或教学参考书,也适合广大信息产业技术人员参考。

本套丛书所选取的均是国际上通信与信息科学领域具有代表性的经典名著,它们在全世界许多大学被用作教材或教学参考书。其主要特点是具有较强的先进性、实用性和权威性。丛书内容丰富,深入浅出,层次清楚,理论与应用并重,能够较好地引导读者将现代通信与信息科学的原理、技术与应用有机结合。我们希望本套丛书能够进一步推动国内高等院校教学与国际接轨,同时满足广大技术人员及时学习通信与信息科学领域中新知识的需求。

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1998年8月

Preface

The purpose of this text is to initiate the newcomer to cellular radio and wireless personal communications, one of the fastest growing fields in the engineering world. Technical concepts which are at the core of design, implementation, research, and invention of wireless communication systems are presented in an order that is conducive to understanding general concepts, as well as those specific to particular cellular and personal communication systems and standards. This text is based upon my experiences as an educator, researcher, and consultant, and is modeled from an academic course developed for electrical engineering students as well as a self-study course for practicing engineers and technicians, developed at the request of the Institute of Electrical and Electronics Engineers (IEEE). References to journal articles are used liberally throughout this text to enable the interested reader to delve into additional reading that is always required to master any field. However, for handbook or classroom use, or for those who find it difficult to pursue outside reading, this text has been written as a complete, self-contained teaching and reference book. Numerous examples and problems have been provided to help the reader solidify the material.

This book has been designed for the student or practicing engineer who is already familiar with technical concepts such as probability, communication theory, and basic electromagnetics. However, like the wireless communications industry itself, this book combines material from many different technical disciplines, so it is unlikely that any one person will have had introductory courses for all of the topics covered. To accommodate a wide range of backgrounds, important concepts throughout the text are developed from first principles, so that readers learn the foundations of wireless communications. This approach

makes it possible to use this book as a handbook within industry, or as a teaching tool in a classroom setting.

The material and chapter sequence in this text have been adapted from an entry-level graduate course which I first taught in 1991 at the Virginia Polytechnic Institute and State University. Chapter 1 demonstrates the rapid growth of cellular radio throughout the world and provides a glimpse into the future. Chapter 2 covers cellular radio concepts such as frequency reuse and handoff, which are at the core of providing wireless communication service to subscribers on the move using limited radio spectrum. Chapter 2 also demonstrates how interference between mobiles and base stations affects the capacity of cellular systems. Chapter 3 presents radio propagation path loss and log-normal shadowing and describes different ways to model and predict the large-scale effects of radio propagation in many operating environments. Chapter 4 covers small-scale propagation effects such as fading, time delay spread, and Doppler spread, and describes how to measure and model the impact that signal bandwidth and motion have on the instantaneous received signal through the multipath channel. Radio wave propagation has historically been the most difficult problem to analyze and design for, since unlike a wired communication system which has a constant, stationary transmission channel (i.e., a wired path), radio channels are random and undergo shadowing and multipath fading, particularly when one of the terminals is in motion.

Chapter 5 provides extensive coverage of the most common analog and digital modulation techniques used in mobile communications and demonstrates trade-offs that must be made in selecting a modulation method. Issues such as receiver complexity, modulation and demodulation implementation, bit error rate analysis for fading channels, and spectral occupancy are presented. Channel coding, adaptive equalization, and antenna diversity concepts are presented in Chapter 6. In portable radio systems where people communicate while walking or driving, these methods may be used individually or in tandem to improve the quality (that is, reduce the bit error rate) of digital mobile radio communications in the presence of fading and noise.

Chapter 7 provides an introduction to speech coding. In the past decade there has been remarkable progress in decreasing the needed data rate of high quality digitized speech, which enables wireless system designers to match end-user services to network architectures. Principles which have driven the development of adaptive pulse code modulation and linear predictive coding techniques are presented, and how these techniques are used to evaluate speech quality in existing and proposed cellular, cordless, and personal communication systems are discussed. Chapter 8 introduces time, frequency, and code division multiple access, as well as more recent multiple access techniques such as packet reservation and space division multiple access. Chapter 8 also describes how each access method can accommodate a large number of mobile users and

demonstrates how multiple access impacts capacity and the network infrastructure of a cellular system. Chapter 9 describes networking considerations for wide area wireless communication systems, and presents practical networking approaches that are in use or have been proposed for future wireless systems. Chapter 10 unites all of the material from the first nine chapters by describing and comparing the major existing and proposed cellular, cordless, and personal communication systems throughout the world. The trade-offs made in the design and implementation of wireless personal communications systems are illuminated in this final chapter. The compilation of the major wireless standards makes Chapter 10 particularly useful as a single source of information for a wide range of systems.

Appendices which cover trunking theory, noise calculations, and the Gaussian approximation for spread spectrum code division systems provide details for those interested in solving practical wireless communications problems.

For industry use, Chapters 1—4 and 8 will benefit working engineers in the cellular system design and radio frequency (RF) testing/maintenance/measurement areas. Chapters 5—7 are tailored for modem designers and digital signal processing (DSP) engineers new to wireless. Chapters 9 and 10 should have broad appeal to network operators and managers, as well as working engineers.

To use this text at the undergraduate level, the instructor may wish to concentrate on Chapters 1—5, or Chapters 1—4, and 8, leaving the other chapters for treatment in a second semester undergraduate course or a graduate level course. Alternatively, traditional undergraduate courses on communications or network theory may find in Chapters 1, 2, 3, 5, 7, 8, and 9 useful material that can be inserted easily into the standard curriculum. In using this text at the graduate level, I have been successful in covering most of the material in Chapters 1—8 during a standard half-year semester. In Chapters 9 and 10, I have attempted to cover important but rarely compiled information on practical network implementations and worldwide standards.

Without the help and ingenuity of several former Virginia Tech graduate students, this text could not have been written. I am pleased to acknowledge the help and encouragement of Rias Muhamed, Varun Kapoor, Kevin Saldanha, and Anil Doradla – students I met in class while teaching the course *Cellular Radio and Personal Communications*. Kevin Saldanha also provided camera ready copy for this text (which turned out to be no small task!). The assistance of these students in compiling and editing materials for several chapters of this text was invaluable, and they were a source of constant encouragement throughout the project. Others who offered helpful suggestions, and whose research efforts are reflected in portions of this text, include Scott Seidel, Joe Liberti, Dwayne Hawbaker, Marty Feuerstein, Yingie Li, Ken Blackard, Victor Fung, Weifang Huang, Prabhakar Koushik, Orlando Landron, Francis Dominique, and Greg Bump. Zhi-

gang Rong, Jeff Laster, Michael Buehrer, Keith Brafford, and Sandip Sandhu also provided useful suggestions and helpful reviews of early drafts.

This text benefits greatly from practical input provided by several industry reviewers. Roman Zaputowycz of Bell Atlantic Mobile Systems, Mike Bamburak of McCaw Communications, David McKay of Ortel, Jihad Hermes of PrimeCo, Robert Rowe of Ariel Communications, William Gardner of Qualcomm, and John Snapp of AT&T Wireless provided extremely valuable input as to what materials were most important, and how they could best be presented for students and practicing engineers. Marty Feuerstein of Lucent Technologies and Mike Lord of Cellular One provided comprehensive reviews which have greatly improved the manuscript. The technical staff at Grayson Electronics also provided feedback and practical suggestions during the development of this text.

From the academic perspective, a number of faculty in the wireless communications field provided useful suggestions which I readily incorporated. These reviewers include Prof. J. Keith Townsend of North Carolina State University and Prof. William H. Tranter of the University of Missouri-Rolla. Professors Jeffrey Reed and Brian Woerner of Virginia Tech also provided excellent recommendations from a teaching perspective. I am grateful for the invaluable contributions from all of these individuals. Also, I wish to thank the numerous faculty, students, and practicing engineers from around the world who have provided valuable feedback and who caught the many typos that are, hopefully, now corrected in this printing.

I am pleased to acknowledge the support of the National Science Foundation, the Defense Advanced Research Project Agency, and the many sponsors and friends of the Mobile & Portable Radio Research Group, who have supported our research and educational activities in wireless communications since 1990. It is from the excellent faculty at Purdue University, particularly my advisor, Clare D. McGillem, that I formally learned about communications and how to build a research program. I consider myself fortunate to have been one of the many graduate students who was stimulated to pursue a dual career in engineering and education upon graduation from Purdue.

Finally, it is a pleasure to acknowledge my family and students, who put up with my preoccupation on this project, Barbara Coburn and Jill Cals of the IEEE, who championed the IEEE self-study course on the same subject, and Karen Gettman and Camille Trentacoste of Prentice Hall, who commissioned this work and helped me bring this text to you.

Theodore S. Rappaport

Contents

Preface	xi
1 Introduction to Wireless Communication Systems	1
1.1 Evolution of Mobile Radio Communications	1
1.2 Mobile Radiotelephone in the U.S.	4
1.3 Mobile Radio Systems Around the World	6
1.4 Examples of Mobile Radio Systems	9
1.4.1 Paging Systems	11
1.4.2 Cordless Telephone Systems	13
1.4.3 Cellular Telephone Systems	14
1.4.4 Comparison of Common Mobile Radio Systems	17
1.5 Trends in Cellular Radio and Personal Communications	20
1.6 Problems	22
2 The Cellular Concept — System Design Fundamentals	25
2.1 Introduction	25
2.2 Frequency Reuse	26
2.3 Channel Assignment Strategies	30
2.4 Handoff Strategies	31
2.4.1 Prioritizing Handoffs	34
2.4.2 Practical Handoff Considerations	34
2.5 Interference and System Capacity	37
2.5.1 Co-channel Interference and System Capacity	37
2.5.2 Adjacent Channel Interference	41
2.5.3 Power Control for Reducing Interference	43
2.6 Trunking and Grade of Service	44

2.7 Improving Capacity in Cellular Systems	54
2.7.1 Cell Splitting	54
2.7.2 Sectoring	57
2.7.3 A Novel Microcell Zone Concept	61
2.8 Summary	63
2.9 Problems	63
3 Mobile Radio Propagation: Large-Scale Path Loss	69
3.1 Introduction to Radio Wave Propagation	69
3.2 Free Space Propagation Model	70
3.3 Relating Power to Electric Field	74
3.4 The Three Basic Propagation Mechanisms	78
3.5 Reflection	78
3.5.1 Reflection from Dielectrics	79
3.5.2 Brewster Angle	84
3.5.3 Reflection from Perfect Conductors	85
3.6 Ground Reflection (2-ray) Model	85
3.7 Diffraction	90
3.7.1 Fresnel Zone Geometry	91
3.7.2 Knife-edge Diffraction Model	94
3.7.3 Multiple Knife-edge Diffraction	99
3.8 Scattering	100
3.8.1 Radar Cross Section Model	101
3.9 Practical Link Budget Design using Path Loss Models	102
3.9.1 Log-distance Path Loss Model	102
3.9.2 Log-normal Shadowing	104
3.9.3 Determination of Percentage of Coverage Area	106
3.10 Outdoor Propagation Models	110
3.10.1 Longley-Rice Model	110
3.10.2 Durkin's Model — A Case Study	111
3.10.3 Okumura Model	116
3.10.4 Hata Model	119
3.10.5 PCS Extension to Hata Model	120
3.10.6 Walfisch and Bertoni Model	120
3.10.7 Wideband PCS Microcell Model	121
3.11 Indoor Propagation Models	123
3.11.1 Partition Losses (same floor)	123
3.11.2 Partition Losses between Floors	126
3.11.3 Log-distance Path Loss Model	126
3.11.4 Ericsson Multiple Breakpoint Model	128
3.11.5 Attenuation Factor Model	128
3.12 Signal Penetration into Buildings	131
3.13 Ray Tracing and Site Specific Modeling	132
3.14 Problems	133

4 Mobile Radio Propagation: Small-Scale Fading and Multipath	139
4.1 Small-Scale Multipath Propagation	139
4.1.1 Factors Influencing Small-Scale Fading	140
4.1.2 Doppler Shift	141
4.2 Impulse Response Model of a Multipath Channel	143
4.2.1 Relationship Between Bandwidth and Received Power	147
4.3 Small-Scale Multipath Measurements	153
4.3.1 Direct RF Pulse System	154
4.3.2 Spread Spectrum Sliding Correlator Channel Sounding	155
4.3.3 Frequency Domain Channel Sounding	158
4.4 Parameters of Mobile Multipath Channels	159
4.4.1 Time Dispersion Parameters	160
4.4.2 Coherence Bandwidth	163
4.4.3 Doppler Spread and Coherence Time	165
4.5 Types of Small-Scale Fading	167
4.5.1 Fading Effects Due to Multipath Time Delay Spread	168
4.5.2 Fading Effects Due to Doppler Spread	170
4.6 Rayleigh and Ricean Distributions	172
4.6.1 Rayleigh Fading Distribution	172
4.6.2 Ricean Fading Distribution	174
4.7 Statistical Models for Multipath Fading Channels	176
4.7.1 Clarke's Model for Flat Fading	177
4.7.2 Simulation of Clarke and Gans Fading Model	181
4.7.3 Level Crossing and Fading Statistics	185
4.7.4 Two-ray Rayleigh Fading Model	188
4.7.5 Saleh and Valenzuela Indoor Statistical Model	188
4.7.6 SIRCIM and SMRCIM Indoor and Outdoor Statistical Models	189
4.8 Problems	192
5 Modulation Techniques for Mobile Radio	197
5.1 Frequency Modulation vs. Amplitude Modulation	198
5.2 Amplitude Modulation	199
5.2.1 Single Sideband AM	202
5.2.2 Pilot Tone SSB	203
5.2.3 Demodulation of AM signals	206
5.3 Angle Modulation	206
5.3.1 Spectra and Bandwidth of FM Signals	208
5.3.2 FM Modulation Methods	209
5.3.3 FM Detection Techniques	211
5.3.4 Tradeoff Between SNR and Bandwidth in an FM Signal	219
5.4 Digital Modulation — an Overview	220
5.4.1 Factors That Influence the Choice of Digital Modulation	221
5.4.2 Bandwidth and Power Spectral Density of Digital Signals	224
5.4.3 Line Coding	225
5.5 Pulse Shaping Techniques	225
5.5.1 Nyquist Criterion for ISI Cancellation	227

5.5.2 Raised Cosine Rolloff Filter	229
5.5.3 Gaussian Pulse-shaping Filter	233
5.6 Geometric Representation of Modulation Signals	234
5.7 Linear Modulation Techniques	238
5.7.1 Binary Phase Shift Keying (BPSK)	238
5.7.2 Differential Phase Shift Keying (DPSK)	242
5.7.3 Quadrature Phase Shift Keying (QPSK)	243
5.7.4 QPSK Transmission and Detection Techniques	246
5.7.5 Offset QPSK	247
5.7.6 $\pi/4$ QPSK	249
5.7.7 $\pi/4$ QPSK Transmission Techniques	249
5.7.8 $\pi/4$ QPSK Detection Techniques	252
5.8 Constant Envelope Modulation	254
5.8.1 Binary Frequency Shift Keying	256
5.8.2 Minimum Shift Keying (MSK)	259
5.8.3 Gaussian Minimum Shift Keying (GMSK)	261
5.9 Combined Linear and Constant Envelope Modulation Techniques	267
5.9.1 M-ary Phase Shift Keying (MPSK)	267
5.9.2 M-ary Quadrature Amplitude Modulation (QAM)	270
5.9.3 M-ary Frequency Shift Keying (MFSK)	272
5.10 Spread Spectrum Modulation Techniques	274
5.10.1 Pseudo-noise (PN) Sequences	275
5.10.2 Direct Sequence Spread Spectrum (DS-SS)	276
5.10.3 Frequency Hopped Spread Spectrum (FH-SS)	278
5.10.4 Performance of Direct Sequence Spread Spectrum	280
5.10.5 Performance of Frequency Hopping Spread Spectrum	283
5.11 Modulation Performance in Fading and Multipath Channels	284
5.11.1 Performance of Digital Modulation in Slow, Flat Fading Channels	285
5.11.2 Digital Modulation in Frequency Selective Mobile Channels	289
5.11.3 Performance of $\pi/4$ DQPSK in Fading and Interference	290
5.12 Problems	294
6 Equalization, Diversity, and Channel Coding	299
6.1 Introduction	299
6.2 Fundamentals of Equalization	300
6.3 A Generic Adaptive Equalizer	303
6.4 Equalizers in a Communications Receiver	307
6.5 Survey of Equalization Techniques	308
6.6 Linear Equalizers	310
6.7 Nonlinear Equalization	312
6.7.1 Decision Feedback Equalization (DFE)	313
6.7.2 Maximum Likelihood Sequence Estimation (MLSE) Equalizer	315
6.8 Algorithms for Adaptive Equalization	316
6.8.1 Zero Forcing Algorithm	318
6.8.2 Least Mean Square Algorithm	319
6.8.3 Recursive Least Squares Algorithm	321
6.8.4 Summary of Algorithms	323

6.9 Fractionally Spaced Equalizers	323
6.10 Diversity Techniques	325
6.10.1 Derivation of Selection Diversity Improvement	326
6.10.2 Derivation of Maximal Ratio Combining Improvement	328
6.10.3 Practical Space Diversity Considerations	330
6.10.4 Polarization Diversity	332
6.10.5 Frequency Diversity	335
6.10.6 Time Diversity	335
6.11 RAKE Receiver	336
6.12 Interleaving	338
6.13 Fundamentals of Channel Coding	339
6.14 Block Codes	340
6.14.1 Examples of Block Codes	344
6.14.2 Case Study of Reed-Solomon Codes	346
6.15 Convolutional Codes	352
6.15.1 Decoding of Convolutional Codes	354
6.16 Coding Gain	356
6.17 Trellis Coded Modulation	356
6.18 Problems	357
7 Speech Coding	361
7.1 Introduction	361
7.2 Characteristics of Speech Signals	363
7.3 Quantization Techniques	365
7.3.1 Uniform Quantization	365
7.3.2 Nonuniform Quantization	365
7.3.3 Adaptive Quantization	368
7.3.4 Vector Quantization	368
7.4 Adaptive Differential Pulse Code Modulation	369
7.5 Frequency Domain Coding of Speech	371
7.5.1 Sub-band Coding	372
7.5.2 Adaptive Transform Coding	375
7.6 Vocoders	376
7.6.1 Channel Vocoders	376
7.6.2 Formant Vocoders	377
7.6.3 Cepstrum Vocoders	377
7.6.4 Voice-Excited Vocoder	378
7.7 Linear Predictive Coders	378
7.7.1 LPC-Vocoders	378
7.7.2 Multi-pulse Excited LPC	381
7.7.3 Code-Excited LPC	382
7.7.4 Residual Excited LPC	383
7.8 Choosing Speech Codecs for Mobile Communications	384
7.9 The GSM Codec	387
7.10 The USDC Codec	389
7.11 Performance Evaluation of Speech Coders	389
7.12 Problems	392

8 Multiple Access Techniques for Wireless Communications	395
8.1 Introduction	395
8.1.1 Introduction to Multiple Access	396
8.2 Frequency Division Multiple Access (FDMA)	397
8.3 Time Division Multiple Access (TDMA)	400
8.4 Spread Spectrum Multiple Access	404
8.4.1 Frequency Hopped Multiple Access (FHMA)	404
8.4.2 Code Division Multiple Access (CDMA)	405
8.4.3 Hybrid Spread Spectrum Techniques	407
8.5 Space Division Multiple Access (SDMA)	409
8.6 Packet Radio	410
8.6.1 Packet Radio Protocols	411
8.6.2 Carrier Sense Multiple Access (CSMA) Protocols	415
8.6.3 Reservation Protocols	416
8.6.4 Capture Effect in Packet Radio	416
8.7 Capacity of Cellular Systems	417
8.7.1 Capacity of Cellular CDMA	422
8.7.2 Capacity of CDMA with Multiple Cells	425
8.7.3 Capacity of Space Division Multiple Access	431
8.8 Problems	437
9 Wireless Networking	439
9.1 Introduction to Wireless Networks	439
9.2 Differences Between Wireless and Fixed Telephone Networks	441
9.2.1 The Public Switched Telephone Network (PSTN)	441
9.2.2 Limitations in Wireless Networking	443
9.2.3 Merging Wireless Networks and the PSTN	444
9.3 Development of Wireless Networks	445
9.3.1 First Generation Wireless Networks	445
9.3.2 Second Generation Wireless Networks	448
9.3.3 Third Generation Wireless Networks	449
9.4 Fixed Network Transmission Hierarchy	449
9.5 Traffic Routing in Wireless Networks	450
9.5.1 Circuit Switching	452
9.5.2 Packet Switching	452
9.5.3 The X.25 Protocol	454
9.6 Wireless Data Services	455
9.6.1 Cellular Digital Packet Data (CDPD)	455
9.6.2 Advanced Radio Data Information Systems (ARDIS)	457
9.6.3 RAM Mobile Data (RMD)	457
9.7 Common Channel Signaling (CCS)	458
9.7.1 The Distributed Central Switching Office for CCS	459
9.8 Integrated Services Digital Network (ISDN)	461
9.8.1 Broadband ISDN and ATM	463
9.9 Signaling System No. 7 (SS7)	463
9.9.1 Network Services Part (NSP) of SS7	465

9.9.2 The SS7 User Part	466
9.9.3 Signaling Traffic in SS7	467
9.9.4 SS7 Services	468
9.9.5 Performance of SS7	469
9.10 An example of SS7 — Global Cellular Network Interoperability	469
9.11 Personal Communication Services/Networks (PCS/PCN)	472
9.11.1 Packet vs. Circuit switching for PCN	472
9.11.2 Cellular Packet-Switched Architecture	473
9.12 Protocols for Network Access	477
9.12.1 Packet Reservation Multiple Access (PRMA)	478
9.13 Network Databases	479
9.13.1 Distributed Database for Mobility Management	479
9.14 Universal Mobile Telecommunication System (UMTS)	480
9.15 Summary	481
10 Wireless Systems and Standards	483
10.1 AMPS and ETACS	483
10.1.1 AMPS and ETACS System Overview	484
10.1.2 Call Handling in AMPS and ETACS	485
10.1.3 AMPS and ETACS Air Interface	487
10.1.4 N-AMPS	491
10.2 United States Digital Cellular (IS-54)	491
10.2.1 USDC Radio Interface	493
10.2.2 United States Digital Cellular Derivatives (IS-94 and IS-136)	500
10.3 Global System for Mobile (GSM)	500
10.3.1 GSM Services and Features	501
10.3.2 GSM System Architecture	502
10.3.3 GSM Radio Subsystem	505
10.3.4 GSM Channel Types	507
10.3.5 Example of a GSM Call	512
10.3.6 Frame Structure for GSM	513
10.3.7 Signal Processing in GSM	515
10.4 CDMA Digital Cellular Standard (IS-95)	519
10.4.1 Frequency and Channel Specifications	520
10.4.2 Forward CDMA Channel	521
10.4.3 Reverse CDMA Channel	527
10.4.4 IS-95 with 14.4 kbps Speech Coder [ANS95]	533
10.5 CT2 Standard For Cordless Telephones	533
10.5.1 CT2 Services and Features	533
10.5.2 The CT2 Standard	534
10.6 Digital European Cordless Telephone (DECT)	535
10.6.1 Features and Characteristics	535
10.6.2 DECT Architecture	536
10.6.3 DECT Functional Concept	537
10.6.4 DECT Radio Link	538

10.7 PACS — Personal Access Communication Systems	539
10.7.1 PACS System Architecture	540
10.7.2 PACS Radio Interface	541
10.8 Pacific Digital Cellular (PDC)	543
10.9 Personal Handyphone System (PHS)	544
10.10 U.S. PCS and ISM Bands	544
10.11 U.S. Wireless Cable Television	547
10.12 Summary of Standards Throughout the World	548
10.13 Problems	551
APPENDICES	
A Trunking Theory	555
A.1 Erlang B	556
A.1.1 Derivation of Erlang B	556
A.2 Erlang C	561
A.2.1 Derivation of Erlang C	561
B Noise Figure Calculations for Link Budgets	565
C Gaussian Approximations for Spread Spectrum CDMA	569
C.1 The Gaussian Approximation	577
C.2 The Improved Gaussian Approximation (IGA)	582
C.3 A Simplified Expression for the Improved Gaussian Approximation (SEIGA)	585
D Q, erf & erfc Functions	593
D.1 The Q-Function	593
D.2 The erf and erfc functions	595
E Mathematical Tables	599
F Abbreviations and Acronyms	607
G References	617
Index	635

Introduction to Wireless Communication Systems

The ability to communicate with people on the move has evolved remarkably since Guglielmo Marconi first demonstrated radio's ability to provide continuous contact with ships sailing the English channel. That was in 1897, and since then new wireless communications methods and services have been enthusiastically adopted by people throughout the world. Particularly during the past ten years, the mobile radio communications industry has grown by orders of magnitude, fueled by digital and RF circuit fabrication improvements, new large-scale circuit integration, and other miniaturization technologies which make portable radio equipment smaller, cheaper, and more reliable. Digital switching techniques have facilitated the large scale deployment of affordable, easy-to-use radio communication networks. These trends will continue at an even greater pace during the next decade.

1.1 Evolution of Mobile Radio Communications

A brief history of the evolution of mobile communications throughout the world is useful in order to appreciate the enormous impact that cellular radio and personal communication services (PCS) will have on all of us over the next several decades. It is also useful for a newcomer to the cellular radio field to understand the tremendous impact that government regulatory agencies and service competitors wield in the evolution of new wireless systems, services, and technologies. While it is not the intent of this text to deal with the techno-political aspects of cellular radio and personal communications, techno-politics are a fundamental driver in the evolution of new technology and services, since radio spectrum usage is controlled by governments, not by service providers, equipment manufacturers, entrepreneurs, or researchers. Progressive involvement in