

Wireless Mobile Communication Systems  
Principles and Practice

主编 窦峥 项建弘 齐琳 张晓林 杨晓冬 张雅彬

# 无线移动通信系统 原理与应用

主审 郭黎利

黑龙江科学技术出版社

电子与通信教材系列

双语版

# 无线移动通信系统 原理与应用

Wireless Mobile Communication Systems  
Principles and Practice

主编 窦峥 项建弘 齐琳 张晓林 杨晓冬 张雅彬

主审 郭黎利

黑龙江科学技术出版社  
中国·哈尔滨

---

**图书在版编目(CIP)数据**

无线移动通信系统原理与应用:英汉对照/窦崢等主编.  
—哈尔滨:黑龙江科学技术出版社,2008.7  
ISBN 978-7-5388-5836-5

I.无… II.窦… III.无线电通信:移动通信-通信系统-英、汉 IV.TN929.5

中国版本图书馆 CIP 数据核字(2008)第 098996 号

---

责任编辑 盛晓光

封面设计 刘 洋

**无线移动通信系统原理与应用**

WUXIAN YIDONG TONGXIN XITONG YUANLI YU YINGYONG

主编 窦崢 项建弘 齐琳 张晓林 杨晓冬 张雅彬

---

**出 版** 黑龙江科学技术出版社

(150001 哈尔滨市南岗区建设街 41 号)

电话 (0451)53642106 电传 53642143(发行部)

**印 刷** 哈尔滨市工大节能印刷厂

**发 行** 黑龙江科学技术出版社

**开 本** 787×1092 1/16

**印 张** 39.375

**字 数** 600 000

**版 次** 2008 年 6 月第 1 版·2008 年 6 月第 1 次印刷

**印 数** 1-1 000

**书 号** ISBN 978-7-5388-5836-5/TP·117

**定 价** 60.00 元

## 前 言

如今在通信领域里,发展最快、应用最广泛的就是无线电通信技术,人们将二者合称为无线移动通信。在该领域里工作和学习的学生、大学教师、研究人员等,都希望有一本在理论、技术和应用方面理解的系统而又全面的双语教材。本书就是为满足这一需求而进行的有益探索。由于本书阐述的重点是无线移动通信系统,因此,编者在简单回顾了一定的基础理论之后,编入了一些技术开发、设计和应用的相关内容。这样,认真学习过本教材的学生就可以顺利的成为一名称职的无线移动通信系统的设计工程师,符合本科及研究生培养的需要。

近年来,蜂窝无线移动通信系统的发展经历了从模拟网到数字网、从频分多址(FDMA)到时分多址(TDMA)和码分多址(CDMA)的过程。无线通信的使用在世界范围内已经得到戏剧性的扩展。虽然大多数的无线移动通信系统仍然主要承载语音业务,但随着无线移动通信系统技术的不断提高,信道带宽的不断增加,越来越多的服务已经开始利用它们从事数据和图象业务。无线局域网(例如Wi-Fi)、UWB、Zigbee等新技术已经渐渐流行起来,并正在融入全球化的蜂窝网络。

本书采用英汉对照的方式来方便教学与研究,主要面向已经掌握诸如概率论、通信原理和电磁场与电磁波等专业技术概念的通信专业学生。本书中的重要概念都是围绕原理展开,引用若干教材和期刊文章,提供给感兴趣的学生阅读,拓展学生思路,便于学生掌握无线通信技术的基础。同时,为了帮助读者巩固所学知识,本书还提供了大量的例子和习题。

全书共分7章,第一章介绍了无线通信技术的发展,以及无线系统从第一代模拟技术到第二代数字技术的演进;讲述了世界范围内蜂窝无线通信的增长和20世纪90年代中期无线通信产业的状况。第二章介绍了诸如频率复用、切换等蜂窝无线通信中的基本概念,这些概念是利用有限频带向移动用户提供无线通信的核心。还分析了移动台和基站间的干扰是怎样影响蜂窝系统容量的。第三章介绍了无线传输路径损耗、链路预算和对数正态阴影衰落的问题,并描述了许多不同运营环境中无线电波传播的大、小尺度衰减效应的建模和预测方法。第四章在通信原理掌握的常见的模拟和数字调制的基础之上,讲述了在选择调制方式时的评价方法,此外还讨论了诸如接收机的复杂度、衰落信道条件下,与频谱的利用率等问题。第五章主要介绍信道编码、语音编码的基本原理和框架。本章还提到了推动自适应脉冲编码调制和线性预测编码原理,并讨论了在已有的和将来的蜂窝、无线与个人通信系统中评估语音质量。第六章介绍了时分、频分和码分多址技术,以及最新的分组预留和空分多址等多址接入技术。讲述了每种接入方式是如何容纳大量移动用户的,并解释了多址技术是如何影响蜂窝系统的容量和网络结构。第七章总体介绍了第三代(3G)移动通信、无线局域网(WLAN)、本地多点业务分配系统(LMDS)及蓝牙技术。该内容可以抽出来作为当前无线系统的例子使用。

在这里我还要感谢参加工作的各位教授、专家、老师与参加翻译、编辑和出版的同志们。各位专家的认真负责、严谨细致和精益求精的精神才使得该双语教材成功出版。这里还要感谢王月倩、杜鹃、杨倩、赵冰、叶大鹏、姜晓斐等研究生,为最后的校对工作付出的辛勤努力。

本书由于编者水平有限,难免还存在一些不足之处,希望批评指正。

## Contents

|         |   |     |
|---------|---|-----|
| 1       | Introduction to Wireless Communication System.....        | 12  |
| 1.1     | Evolution of Mobile Radio Communications.....             | 12  |
| 1.2     | Mobile Radiotelephony in the U.S.....                     | 16  |
| 1.3     | Mobile Radio Systems Around the World.....                | 22  |
| 1.4     | Examples of Wireless Communication Systems .....          | 26  |
| 1.4.1   | Cordless Telephone Systems.....                           | 30  |
| 1.4.2   | Cellular Telephone Systems.....                           | 30  |
| 1.4.3   | Comparison of Common Wireless Communication Systems.....  | 36  |
| 1.5     | Trends in Cellular Radio and Personal Communications..... | 38  |
| 1.6     | Problems.....   | 42  |
| 2       | The Cellular System Design Fundamentals.....              | 46  |
| 2.1     | Introduction.....   | 46  |
| 2.2     | Frequency reuse: introduction of cells.....               | 48  |
| 2.3     | Channel Assignment Strategies.....                        | 54  |
| 2.4     | Interference and System Capacity.....                     | 58  |
| 2.4.1   | Co-channel interference and System Capacity.....          | 58  |
| 2.4.2   | Adjacent Channel interference.....                        | 68  |
| 2.4.3   | Channel Planning for Wireless System.....                 | 72  |
| 2.4.4   | SIR Calculations in Wireless System.....                  | 74  |
| 2.4.4.1 | One-dimension case.....                                   | 74  |
| 2.4.4.2 | Two-dimension cell clusters.....                          | 76  |
| 2.4.5   | Power Control for Reducing Interference.....              | 86  |
| 2.5     | Handoff Strategies.....                                   | 104 |
| 2.5.1   | Priorizing Handoff.....                                   | 110 |
| 2.5.2   | Pracitcal Handoff Consideration.....                      | 110 |
| 2.6     | Trunking and Grade of Service.....                        | 114 |

# 目 录

|                           |     |
|---------------------------|-----|
| 第1章 无线移动通信系统概述.....       | 13  |
| 1.1 移动无线通信的发展.....        | 13  |
| 1.2 美国移动无线电话.....         | 17  |
| 1.3 全球移动通信系统.....         | 23  |
| 1.4 无线移动通信系统的实例.....      | 27  |
| 1.4.1 无绳电话.....           | 30  |
| 1.4.2 蜂窝式无线移动通信系统.....    | 30  |
| 1.4.3 几种常见无线通信系统的比较.....  | 37  |
| 1.5 蜂窝无线通信和个人通信的发展趋势..... | 39  |
| 1.6 习题.....               | 43  |
| 第2章 蜂窝无线移动通信系统设计基础.....   | 47  |
| 2.1 概述.....               | 47  |
| 2.2 频率复用和小区导论.....        | 49  |
| 2.3 信道分配策略.....           | 55  |
| 2.4 干扰与系统容量.....          | 59  |
| 2.4.1 同频干扰和系统容量.....      | 59  |
| 2.4.2 邻频干扰.....           | 69  |
| 2.4.3 无线通信系统的信道规划.....    | 73  |
| 2.4.4 无线通信系统的信干比计算.....   | 75  |
| 2.4.5.1 一维小区.....         | 75  |
| 2.4.5.2 二维小区簇.....        | 77  |
| 2.4.5 功率控制.....           | 87  |
| 2.5 切换策略.....             | 105 |
| 2.5.1 优先切换.....           | 110 |
| 2.5.2 实际切换中需要注意的问题.....   | 110 |
| 2.6 中继和服务等级.....          | 115 |

|       |   |     |
|-------|---|-----|
| 2.7   | Traffic Handling Capacity and Probabilistic signal calculation..... | 128 |
| 2.7.1 | Erlang performance and cell sizing.....                             | 128 |
| 2.7.2 | Probabilistic signal calculations.....                              | 134 |
| 2.8   | Improving Coverage and Capacity in Cellular Systems.....            | 142 |
| 2.8.1 | Cell Splitting.....   | 144 |
| 2.8.2 | Sectoring.....  | 150 |
| 2.8.3 | Repeater for Range Extension.....                                   | 156 |
| 2.8.4 | A Microcell Zone Concep.....  | 159 |
| 2.9   | Summary.....  | 162 |
| 2.10  | Problems.....   | 162 |
| 3     | Characteristics of the Mobile Radio Propagation Phenomena.....      | 166 |
| 3.1   | Introduction to Radio Wave Propagation.....                         | 166 |
| 3.2   | The Three Basic Propagation Mechanisms.....                         | 176 |
| 3.2.1 | Reflection.....   | 178 |
| 3.2.2 | Diffraction.....  | 190 |
| 3.2.3 | Scattring.....  | 208 |
| 3.3   | Characteristics of the mobile radio environment.....                | 214 |
| 3.3.1 | Random channel characterization.....                                | 242 |
| 3.3.2 | Terminal mobility and rate of fading.....                           | 250 |
| 3.3.3 | Multipath and frequency-selective fading.....                       | 256 |
| 3.3.4 | Fading mitigation techniques.....                                   | 272 |
| 3.4   | Practical Link Budget Design Using Path Loss Models.....            | 292 |
| 3.4.1 | Log-distance Path Loss Model.....                                   | 293 |
| 3.4.2 | Log-normal Shadowing.....   | 294 |
| 3.4.3 | Determination of Percentage of Coverage Area.....                   | 296 |
| 3.5   | Outdoor Propagation Models.....                                     | 304 |
| 3.5.1 | Longley-Rice Model.....   | 306 |
| 3.5.2 | Durkin's Model—A Case Study.....                                    | 308 |
| 3.5.3 | Okumura Model.....  | 316 |
| 3.5.4 | Hata Model.....   | 320 |

---

|                              |     |
|------------------------------|-----|
| 2.7 流量控制与信号概率计算.....         | 129 |
| 2.7.1 爱尔兰厄兰性能和小区尺寸.....      | 129 |
| 2.7.2 信号的概率计算.....           | 135 |
| 2.8 提高系统容量策略.....            | 143 |
| 2.8.1 小区分裂.....              | 145 |
| 2.8.2 裂向(划分扇区).....          | 151 |
| 2.8.3 使用中继器扩大覆盖范围.....       | 157 |
| 2.8.4 微小区的概念.....            | 159 |
| 2.9 小结.....                  | 163 |
| 2.10 习题.....                 | 163 |
| 第3章 移动无线电传播现象的特性.....        | 167 |
| 3.1 无线电波传播介绍.....            | 167 |
| 3.2 三种基本传播机制.....            | 177 |
| 3.2.1 电波反射现象.....            | 179 |
| 3.2.2 电波绕射现象.....            | 191 |
| 3.2.3 电波散射现象.....            | 209 |
| 3.3 移动通信中无线介质的特性.....        | 215 |
| 3.3.1 随机信道特性.....            | 243 |
| 3.3.2 终端移动和衰落速率.....         | 251 |
| 3.3.3 多径和频率选择性衰落.....        | 257 |
| 3.3.4 改善衰落的技术.....           | 273 |
| 3.4 运用路径损耗模型进行实际的链路预算设计..... | 293 |
| 3.4.1 对数距离路径损耗模型.....        | 293 |
| 3.4.2 对数正态阴影.....            | 295 |
| 3.4.3 确定覆盖面积的百分率.....        | 297 |
| 3.5 室外传播模型.....              | 305 |
| 3.5.1 Longley — Rice 模型..... | 307 |
| 3.5.2 Durkin 模型:一个实例研究.....  | 309 |
| 3.5.3 Okumura 模型.....        | 317 |
| 3.5.4 Hata 模型.....           | 322 |



|       |   |     |
|-------|---|-----|
| 3.5.5 | PCS Extension to Hata Model.....                                      | 323 |
| 3.6   | Indoor Propagation Models.....  | 324 |
| 3.6.1 | Partition Losses (same floor).....                                    | 324 |
| 3.6.2 | Partition Losses between Floors.....                                  | 330 |
| 3.6.3 | Log-distance Path Loss Model.....                                     | 330 |
| 3.6.4 | Ericsson Multiple Breakpoint Model.....                               | 332 |
| 3.6.5 | Attenuation Factor Model.....   | 334 |
| 3.7   | Signal Penetration into Buildings.....                                | 342 |
| 3.8   | Ray Tracing and Site Specific Modeling.....                           | 342 |
| 3.9   | Problems.....   | 344 |
| 4     | Modulation Techniques for Mobile Radio.....                           | 348 |
| 4.1   | Introduction to digital modulation techniques.....                    | 350 |
| 4.2   | Signal Shaping.....   | 358 |
| 4.3   | Modulation in Cellular Wireless System.....                           | 368 |
| 4.4   | Orthogonal Frequency-division multiplexing (OFDM) .....               | 392 |
| 4.5   | Modulation Performance in Fading and Multipath Channels.....          | 402 |
| 4.5.1 | Perfomance of Digital Modulation in Slow Flat-Fading<br>Channels..... | 402 |
| 4.5.2 | Digital Modulation in Frequency Selective Mobile Channels...          | 408 |
| 4.5.3 | Performance of $\pi/4$ DQPSK in Fading and Interference.....          | 412 |
| 4.6   | Problems.....   | 418 |
| 5     | Coding Techniques for Mobile Radio.....                               | 422 |
| 5.1   | Fundamentals of Channel Coding.....                                   | 422 |
| 5.2   | Turbo Coding.....   | 424 |
| 5.3   | Coding Gain.....  | 434 |
| 5.4   | Speech Coding.....  | 436 |
| 5.5   | Vocoders.....   | 438 |
| 5.6   | Linear Predictive Coders.....   | 444 |
| 5.6.1 | LPC Vocoders.....   | 444 |
| 5.6.2 | Multipulse Excited LPC.....   | 448 |

|                                      |     |
|--------------------------------------|-----|
| 3.5.5 Hata 模型的 PCS 扩展.....           | 323 |
| 3.6 室内传播模型.....                      | 325 |
| 3.6.1 分隔损耗(同楼层) .....                | 325 |
| 3.6.2 楼层间分隔损耗.....                   | 331 |
| 3.6.3 对数距离路径损耗模型.....                | 331 |
| 3.6.4 Ericsson 多重断点模型.....           | 333 |
| 3.6.5 衰减因子模型.....                    | 335 |
| 3.7 建筑物信号穿透.....                     | 343 |
| 3.8 射线跟踪和特定站址建模.....                 | 343 |
| 3.9 习题.....                          | 345 |
| 第 4 章 移动无线电中的调制技术.....               | 349 |
| 4.1 数字调制技术简介.....                    | 351 |
| 4.2 信号成型.....                        | 359 |
| 4.3 蜂窝无线系统中的调制.....                  | 369 |
| 4.4 正交频分复用.....                      | 393 |
| 4.5 衰落和多径信道中的调制性能.....               | 402 |
| 4.5.1 在慢速、平坦衰落信道中数字调制的性能.....        | 403 |
| 4.5.2 频率选择性移动信道中的数字调制.....           | 409 |
| 4.5.3 衰落和干扰中的 $\pi/4$ DQPSK 的性能..... | 413 |
| 4.6 习题.....                          | 419 |
| 第 5 章 移动通信系统编码技术.....                | 423 |
| 5.1 信道编码技术基础.....                    | 423 |
| 5.2 Turbo 码.....                     | 425 |
| 5.3 编码增益.....                        | 435 |
| 5.4 语音编码.....                        | 437 |
| 5.5 声码器.....                         | 439 |
| 5.6 线性预测编码器.....                     | 445 |
| 5.6.1 线性预测编码声码器.....                 | 445 |
| 5.6.2 多脉冲激励 LPC.....                 | 449 |

|         |   |     |
|---------|---|-----|
| 5.6.3   | Code-excited LPC.....                                     | 448 |
| 5.6.4   | Residual Excited LPC.....                                 | 450 |
| 5.7     | Choosing Speech Codecs for Mobile Communication.....      | 454 |
| 5.8     | The GSM Codec.....  | 458 |
| 5.9     | Performance Evaluation of Speech Coders.....              | 462 |
| 5.10    | Problems.....   | 464 |
| 6       | Access and Scheduling Techniques in Cellular Systems..... | 468 |
| 6.1     | Time-division multiple access (TDMA) .....                | 470 |
| 6.2     | Code-division multiple access (CDMA).....                 | 476 |
| 6.3     | Space Division Multiple Access(SDMA) .....                | 482 |
| 6.4     | Packet Radio.....   | 486 |
| 6.4.1   | Reservation Protocols.....                                | 488 |
| 6.4.2   | Packet Reservation Multiple Access(PRMA) .....            | 494 |
| 6.4.3   | Capture Effect in PR.....                                 | 494 |
| 6.4.4   | Scheduling in Packet-based Cellular Systems.....          | 496 |
| 6.5     | Capacity of Cellular Systems.....                         | 514 |
| 6.5.1   | CDMA Capacity: Single-cell Case.....                      | 514 |
| 6.5.2   | An Aside: Probability of Bit Error Consideration.....     | 518 |
| 6.5.3   | CDMA Capacity Calculations: CDMA Compared with TDMA.....  | 524 |
| 6.5.4   | Capacity of Space Division Multiple Access.....           | 540 |
| 6.6     | Problems.....   | 548 |
| 7       | Modern Wireless Communication Systems.....                | 550 |
| 7.1     | Second Generation (2G) Cellular Networks.....             | 552 |
| 7.1.1   | Evolution to 2.5G Wireless Networks.....                  | 558 |
| 7.1.2   | Evolution for 2.5G TDMA Standards.....                    | 560 |
| 7.1.2.1 | HSCSD for 2.5G GSM.....                                   | 560 |
| 7.1.2.2 | GPRS for 2.5G GSM and IS-136.....                         | 560 |
| 7.1.2.3 | EDGE for 2.5G GSM and IS-136.....                         | 566 |
| 7.1.3   | IS-95B for 2.5G CDMA.....                                 | 566 |
| 7.2     | Third Generation (3G) Wireless Network.....               | 568 |

---

|  |     |
|--|-----|
| 5.6.3 码激励 LPC.....                       | 449 |
| 5.6.4 剩余激励 LPC.....                      | 451 |
| 5.7 为移动通信选择语音编解码器.....                   | 455 |
| 5.8 GSM 编解码器.....                        | 459 |
| 5.9 语音编码器的性能评估.....                      | 463 |
| 5.10 习题.....                             | 465 |
| 第 6 章 蜂窝系统接入和调度技术.....                   | 469 |
| 6.1 时分多址接入技术.....                        | 471 |
| 6.2 码分多址接入技术.....                        | 477 |
| 6.3 空分多址 (SDMA) .....                    | 483 |
| 6.4 分组无线电.....                           | 487 |
| 6.3.1 预留协议.....                          | 489 |
| 6.3.2 分组预留多址.....                        | 495 |
| 6.3.3 分组无线电的截获效应.....                    | 495 |
| 6.3.4 基于分组的蜂窝系统调度.....                   | 497 |
| 6.5 蜂窝系统的容量.....                         | 515 |
| 6.5.1 CDMA 容量: 单小区情况.....                | 515 |
| 6.5.2 误比特率的考虑.....                       | 519 |
| 6.5.3 CDMA 容量计算: CDMA 与 TDMA 相比较.....    | 525 |
| 6.5.4 SDMA 的容量.....                      | 541 |
| 6.6 习题.....                              | 549 |
| 第 7 章 现代无线移动通信系统.....                    | 551 |
| 7.1 2G 蜂窝网络.....                         | 553 |
| 7.1.1 2.5G 移动无线网络的发展.....                | 559 |
| 7.1.2 2.5G TDMA 标准的发展.....               | 561 |
| 7.1.2.1 2.5G GSM 的发展: HSCSD.....         | 561 |
| 7.1.2.2 2.5G GSM 与 IS-136 的发展: GPRS..... | 561 |
| 7.1.2.3 2.5G GSM 与 IS-136 的发展: EDGE..... | 567 |
| 7.1.3 2.5G CDMA 的发展: IS-95B.....         | 567 |
| 7.2 3G 无线网络.....                         | 569 |

|           |  |     |
|-----------|--|-----|
| 7.2.1     | 3G W-CDMA(UMTS) .....                                | 572 |
| 7.2.2     | 3G CDMA2000.....                                     | 574 |
| 7.2.3     | 3G TD-SCDMA.....                                     | 578 |
| 7.3       | Wireless Local Loop (WLL) and LMDS.....              | 578 |
| 7.4       | IEEE802.11/Wireless Local Area Networks (WLAN) ..... | 588 |
| 7.5       | Bluetooth and Personal Area Networks (PANs) .....    | 602 |
| 7.6       | Problems.....  | 604 |
| APPENDICE |  |     |
| A         | Refernces.....                                       | 606 |

---

|  |     |
|--|-----|
| 7.2.1 3G W-CDMA(UMTS).....                               | 573 |
| 7.2.2 3G CDMA2000.....                                   | 575 |
| 7.2.3 3G TD-SCDMA.....                                   | 579 |
| 7.3 Wireless Local Loop (WLL) and LMDS.....              | 579 |
| 7.4 IEEE802.11/Wireless Local Area Networks (WLAN) ..... | 589 |
| 7.5 Bluetooth and Personal Area Networks (PANs) .....    | 603 |
| 7.6 习题.....  | 605 |
| 附 录  |     |
| 参考文献.....  | 606 |

## CHAPTER 1

# 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 technology development is vital for a government if it hopes to keep its own country competitive in the rapidly changing field of wireless personal communications.

Wireless communications is enjoying its fastest growth period in history, due to enabling technologies which permit widespread deployment. Historically, growth in the mobile communications field has come slowly, and has been coupled closely to technological improvements. The ability to provide wireless communications to an entire population was not even conceived until Bell Laboratories developed the cellular concept in the 1960s and 1970s [Nob62], [Mac79], [You79]. With the development of highly reliable, miniature, solid-state radio frequency hardware in the 1970s, the wireless communications era was born. The recent exponential growth in cellular radio and personal communication systems throughout the world is

# 第 1 章

## 无线移动通信系统概述

1897年,马可尼(Guglielmo Marconi)第一次向世人展示了无线电通信的威力,实现了在英格兰海峡行驶的船只之间保持持续的通信。从此以后,移动物体之间的通信就得到了举世瞩目的发展,全世界的人们不断地经历着新的无线通信方法的产生,并且享受着多种多样的无线通信服务。特别是在过去的十年中,无线移动通信的数字和射频电路制造技术方面取得了突破性进展。新一代大规模集成电路等技术的出现,使得移动设备的体积更小、价格更便宜、功能更可靠,这些都极大推动了移动无线通信的发展。此外,数字交换技术也推动了移动通信网络的大规模发展。相信在未来的十年中,无线移动通信将以更快的步伐向前迈进。

### 1.1 移动无线通信的发展

本书首先回顾了移动无线通信的发展历史。通过这个简短的回顾,读者可以体会到蜂窝无线通信和个人通信服务(PCS)给我们的生活所带来的巨大影响;并且在未来的几十年间,这种影响还将持续出现。同时,对于刚涉足蜂窝无线电领域的初学者而言,通过回顾无线通信的历史,可以了解到政府部门和业务竞争者在新的无线通信系统及相关服务和技术的发展中所产生的深远影响。虽然本书并没有考虑蜂窝无线通信和个人通信中相关的技术政策问题,但是必须指出,相关技术政策同样是新技术、新服务发展中的基本推动力之一,因为管理无线频谱使用的是政府部门,而不是服务提供商、设备制造商、企业家或者研究人员。因此,如果一个国家想在迅速发展的无线个人通信领域中保持竞争力,那么政府管理人员就应该不断地参与到新技术的研究和开发中。

目前,无线通信技术进入了其有史以来发展最快的时期,技术的发展使网络能够得到快速部署并广泛应用。最初,移动通信是缓慢地伴随着技术的发展而发展的。直到20世纪60年代和20世纪70年代,在贝尔实验室(Bell Laboratories)提出了蜂窝的概念([Nob62], [Mac79], [You79])之后,才出现了真正能够向所有人提供无线通信服务的技术;在20世纪70年代,随着高可靠度的、小型化的晶体射频电路的发展,无线通信的时代来临了。



directly attributable to new technologies of the 1970s, which are mature today. The future growth of consumer-based mobile and portable communication systems will be tied more closely to radio spectrum allocations and regulatory decisions which affect or support new or extended services, as well as to consumer needs and technology advances in the signal processing, access, and network areas.

The following market penetration data show how wireless communications in the consumer sector has grown in popularity. Figure 1.1 illustrates how mobile telephony has penetrated our daily lives compared with other popular inventions of the 20th century. Figure 1.1 is a bit misleading since the curve labeled "mobile telephone" does not include nontelephone mobile radio applications, such as paging, amateur radio, dispatch, citizens band (CB), public service, cordless phones, or terrestrial microwave radio systems. In fact, in 1990, licensed noncellular radio systems in the U.S. had over 12 million users, more than twice the U.S. cellular user population at that time [FCC91]. With the phenomenal growth of wireless subscribers in the late 1990s, combined with Nextel's novel business approach of purchasing private mobile radio licenses for bundling as a nationwide commercial cellular service, today's subscriber base for cellular and Personal Communication Services (PCS) far outnumbers all noncellular licensed users. Figure 1.1 shows that the first 35 years of mobile telephony saw little market penetration due to high cost and the technological challenges involved, but how, in the past decade, wireless communications has been accepted by consumers at rates comparable to television and the video cassette recorder.

By 1934, 194 municipal police radio systems and 58 state police stations had adopted amplitude modulation (AM) mobile communication systems for public safety in the U.S. It was estimated that 5,000 radios were installed in mobiles in the mid 1930s, and vehicle ignition noise was a major problem for these early mobile users [Nob62]. In 1935, Edwin Armstrong demonstrated frequency modulation (FM) for the first time, and since the late 1930s, FM has been the primary modulation technique used for mobile communication systems throughout the world. World War II accelerated the improvements of the world's manufacturing and miniaturization capabilities, and these capabilities were put to use in large one-way and two-way consumer radio and television systems following the war. The number of U.S. mobile users climbed from several thousand in 1940 to 86,000 by 1948, 695,000 by 1958, and about 1.4 million users in 1962 [Nob62]. The vast majority of mobile users in the 1960s was not connected to the public switched telephone network (PSTN), and thus was not able to directly dial telephone numbers from their vehicles. With the boom in CB radio and cordless appliances such as garage door openers and telephones, the number of users of mobile and portable radio in 1995 was about 100 million, or 37 of the U.S. population. Research in 1991 estimated between 25 and 40 million cordless telephones were in use in the U.S. [Rap91c], and this number is estimated to be over 100 million as of late 2001. The number of worldwide cellular telephone users grew from 25,000 in 1984 to about 25 million in 1993 [Kuc91], [Goo91], [ITU94], and since then subscription-based wireless services have been experiencing customer growth rates well in excess of 50 per year. As shown in Chapter 2, the worldwide subscriber base of cellular and PCS subscribers is approximately 630 million as of late 2001, compared with approximately 1 billion wired telephone lines. In the first few years of the 21st century, it is clear there will be an equal number of wireless and conventional wireline customers throughout the world! At the beginning of the 21st century, over 1 of the worldwide wireless subscriber population had already abandoned wired telephone service for home use, and had begun to rely