国外电子与通信教材系列

第三代移动通信系统原理与工程设计

—IS-95 CDMA和cdma2000

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Cellular/PCS Systems Implementation

英文版

[美] Vijay K. Garg 著

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内容简介

本书全面、系统、深入地介绍了IS-95 CDMA系统和作为国际电联规定的第三代移动通信系统标准之一的cdma2000系统，内容包括CDMA系统及其关键技术的概述，IS-95 CDMA系统结构、空中接口、信道、呼叫处理、信令、安全与识别等，并深入阐述了射频工程和容量规划方面的问题，最后详细系统地介绍了cdma2000系统。

本书内容深入浅出，既有系统完整的理论描述，又有大量详细的实例分析，是一本有关IS-95 CDMA技术难得的参考书，也可以作为高等院校通信专业的教学用书。

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序

2001年7月间，电子工业出版社的领导同志邀请各高校十几位通信领域方面的老师，商量引进国外教材问题。与会同志对出版社提出的计划十分赞同，大家认为，这对我国通信事业、特别是对高等院校通信学科的教学工作会很有好处。

教材建设是高校教学建设的主要内容之一。编写、出版一本好的教材，意味着开设了一门好的课程，甚至可能预示着一个崭新学科的诞生。20世纪40年代MIT林肯实验室出版的一套28本雷达丛书，对近代电子学科、特别是对雷达技术的推动作用，就是一个很好的例子。

我国领导部门对教材建设一直非常重视。20世纪80年代，在原教委教材编审委员会的领导下，汇集了高等院校几百位富有教学经验的专家，编写、出版了一大批教材；很多院校还根据学校的特点和需要，陆续编写了大量的讲义和参考书。这些教材对高校的教学工作发挥了极好的作用。近年来，随着教学改革不断深入和科学技术的飞速进步，有的教材内容已比较陈旧、落后，难以适应教学的要求，特别是在电子学和通信技术发展神速、可以讲是日新月异的今天，如何适应这种情况，更是一个必须认真考虑的问题。解决这个问题，除了依靠高校的老师和专家撰写新的符合要求的教科书外，引进和出版一些国外优秀电子与通信教材，尤其是有选择地引进一批英文原版教材，是会有好处的。

一年多来，电子工业出版社为此做了很多工作。他们成立了一个“国外电子与通信教材系列”项目组，选派了富有经验的业务骨干负责有关工作，收集了230余种通信教材和参考书的详细资料，调来了100余种原版教材样书，依靠由20余位专家组成的出版委员会，从中精选了40多种，内容丰富，覆盖了电路理论与应用、信号与系统、数字信号处理、微电子、通信系统、电磁场与微波等方面，既可作为通信专业本科生和研究生的教学用书，也可作为有关专业人员的参考材料。此外，这批教材，有的翻译为中文，还有部分教材直接影印出版，以供教师用英语直接授课。希望这些教材的引进和出版对高校通信教学和教材改革能起一定作用。

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。各位专家认真负责、严谨细致、不辞辛劳、不怕琐碎和精益求精的态度，充分体现了中国教育工作者和出版工作者的良好美德。

随着我国经济建设的发展和科学技术的不断进步，对高校教学工作会不断提出新的要求和希望。我想，无论如何，要做好引进国外教材的工作，一定要联系我国的实际。教材和学术专著不同，既要注意科学性、学术性，也要重视可读性，要深入浅出，便于读者自学；引进的教材要适应高校教学改革的需要，针对目前一些教材内容较为陈旧的问题，有目的地引进一些先进的和正在发展中的交叉学科的参考书；要与国内出版的教材相配套，安排好出版英文原版教材和翻译教材的比例。我们努力使这套教材能尽量满足上述要求，希望它们能放在学生们的课桌上，发挥一定的作用。

最后，预祝“国外电子与通信教材系列”项目取得成功，为我国电子与通信教学和通信产业的发展培土施肥。也恳切希望读者能对这些书籍的不足之处、特别是翻译中存在的问题，提出意见和建议，以便再版时更正。

吴佑寿

中国工程院院士、清华大学教授

“国外电子与通信教材系列”出版委员会主任

出 版 说 明

进入21世纪以来，我国信息产业在生产和科研方面都大大加快了发展速度，并已成为国民经济发展的支柱产业之一。但是，与世界上其他信息产业发达的国家相比，我国在技术开发、教育培训等方面都还存在着较大的差距。特别是在加入WTO后的今天，我国信息产业面临着国外竞争对手的严峻挑战。

作为我国信息产业的专业科技出版社，我们始终关注着全球电子信息技术的发展方向，始终把引进国外优秀电子与通信信息技术教材和专业书籍放在我们工作的重要位置上。在2000年至2001年间，我社先后从世界著名出版公司引进出版了40余种教材，形成了一套“国外计算机科学教材系列”，在全国高校以及科研部门中受到了欢迎和好评，得到了计算机领域的广大教师与科研工作者的充分肯定。

引进和出版一些国外优秀电子与通信教材，尤其是有选择地引进一批英文原版教材，将有助于我国信息产业培养具有国际竞争能力的技术人才，也将有助于我国国内在电子与通信教学工作中掌握和跟踪国际发展水平。根据国内信息产业的现状、教育部《关于“十五”期间普通高等教育教材建设与改革的意见》的指示精神以及高等院校老师们反映的各种意见，我们决定引进“国外电子与通信教材系列”，并随后开展了大量准备工作。此次引进的国外电子与通信教材均来自国际著名出版商，其中影印教材约占一半。教材内容涉及的学科方向包括电路理论与应用、信号与系统、数字信号处理、微电子、通信系统、电磁场与微波等，其中既有本科专业课程教材，也有研究生课程教材，以适应不同院系、不同专业、不同层次的师生对教材的需求，广大师生可自由选择和自由组合使用。我们还将与国外出版商一起，陆续推出一些教材的教学支持资料，为授课教师提供帮助。

此外，“国外电子与通信教材系列”的引进和出版工作得到了教育部高等教育司的大力支持和帮助，其中的部分引进教材已通过“教育部高等学校电子信息科学与工程类专业教学指导委员会”的审核，并得到教育部高等教育司的批准，纳入了“教育部高等教育司推荐——国外优秀信息科学与技术系列教学用书”。

为做好该系列教材的翻译工作，我们聘请了清华大学、北京大学、北京邮电大学、东南大学、西安交通大学、天津大学、西安电子科技大学、电子科技大学等著名高校的教授和骨干教师参与教材的翻译和审校工作。许多教授在国内电子与通信专业领域享有较高的声望，具有丰富的教学经验，他们的渊博学识从根本上保证了教材的翻译质量和专业学术方面的严格与准确。我们在此对他们的辛勤工作与贡献表示衷心的感谢。此外，对于编辑的选择，我们达到了专业对口；对于从英文原书中发现的错误，我们通过与作者联络、从网上下载勘误表等方式，逐一进行了修订；同时，我们对审校、排版、印制质量进行了严格把关。

今后，我们将进一步加强同各高校教师的密切关系，努力引进更多的国外优秀教材和教学参考书，为我国电子与通信教材达到世界先进水平而努力。由于我们对国内外电子与通信教育的发展仍存在一些认识上的不足，在选题、翻译、出版等方面的工作中还有许多需要改进的地方，恳请广大师生和读者提出批评及建议。

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Preface

The global mobile communications market is booming. There are almost 250 million users worldwide and should be nearly 1 billion by early next century. Code Division Multiple Access (CDMA) is the fastest-growing digital wireless technology, tripling its worldwide subscriber base between 1997 and 1998. There are already 30 million CDMA customers and, at the current growth rate, there will be 50 million by the millennium. The major markets for CDMA are North America, Latin America, and Asia (particularly Japan and Korea). In total, CDMA has been adopted by almost 50 countries around the world.

It is not hard to see the reasons for the success of CDMA. CDMA is an advanced digital technology that can offer about 7 to10 times the capacity of analog technologies and up to 6 times the capacity of digital technologies such as Time Division Multiple Access (TDMA). The speech quality provided by CDMA systems is far superior to any other digital cellular technology, particularly in difficult radio environments such as dense urban areas and mountainous regions. In both initial deployment and long-term operation, CDMA provides the most cost-effective solution for cellular operators. After an 18-month of market rollout, Personal Communications Services (PCS) providers have adequately demonstrated the power of CDMA technology to support a marketing strategy based on low prices and superior performance in key areas such as voice quality, system reliability, and handset battery life.

CDMA service providers have a strong advantage when pursuing the market to the minutes-of-use model, given the longevity of CDMA handset battery life and the higher quality of the voice signal. A recent analysis of wireless platform performance by the Telecommunications Research and Action Center (TRAC) found that CDMA outperformed other digital and analog technologies on every front, including signal quality, security, power consumption, and reliability. Although analog technology came out ahead in availability, all three digital services (GSM, IS-136 TDMA, and IS-95 CDMA) were rated equally over analog with respect to availability of

enhanced service features. The TRAC study found CDMA to be superior in signal security and voice quality over the other digital air interface standards. According to TRAC, CDMA has several advantages for consumers. Lower power consumption enables CDMA handsets to support up to 4 hours of talk time or 48 hours of standby time on a single battery charge. It has also been found that the soft-handoff characteristics of CDMA lead to fewer dropped calls than with GSM and IS-136 TDMA. One possible drawback for some CDMA customers is that there are some limitations on roaming capabilities. Some PCS operators with cellular affiliates are supporting dual-mode handsets to allow roaming between CDMA and analog platforms.

CDMA technology is constantly evolving to offer customers new, advanced services. The mobile data speeds offered through CDMA phones are increasing, and new voice codecs provide speech quality close to wireline. Internet access is now available through CDMA terminals. The time will soon be at hand when CDMA service providers can further exploit the enhanced service potential of their platforms. There has been much talk of so-called third-generation (3G) data capabilities, where PCS providers will be able to compete with wireline service providers at high access speeds. PCS providers are looking ahead toward providing a range of service categories such as Internet and intranet access, multimedia applications, high-speed business transactions, and telemetry. The CDMA network offers operators a smooth evolutionary path to 3G mobile systems.

The IS-95B standard is quite flexible, enabling service providers to allocate data in increments of 8 kilobits per second (kbps) within the 1.25-megahertz (MHz) CDMA channel bandwidth based on how service providers configure software download to already-installed network controllers. This means operators can implement return data speeds at rates much lower than 64 kbps, ensuring much lower power consumption in handsets than would be the case at a full 64-kbps return rate. While operators in GSM and IS-136 TDMA sectors are making efforts to ensure they won't be left behind as data becomes a factor, CDMA appears to have a clear edge in its ability to go to relatively high speeds over the existing infrastructure.

The opportunity to use the CDMA platform to add a fixed wireless service feature represents an added advantage for operators. Because CDMA has ample spectrum to provide a fixed service on top of mobile, several operators are exploring using terminals that would be able to shift the handset between fixed and mobile service, depending on where the user is. The universal handset would serve as a cordless phone in the home and as a mobile handset outside the home. The evolution to 3G will open the wireless local loop (WLL) with Public-Switched Telephone Network (PSTN) and Public Data Network (PDN) access, while providing more convenient control of applications and network resources. It will also open the door to convenient global roaming, service portability, zone-based ID and billing, and global directory access. The 3G technology is even expected to support seamless satellite interworking.

With the cornucopia of benefits surrounding CDMA, it is evident that operators using this platform will have every opportunity to grow the business once the community-based strategy begins to unfold. The question is, when will they get serious about bringing these new capabilities to market?

Recently an enhanced hybrid technology combining the CDMA air interface with the GSM network has been built, tested, and evaluated. GSM operators can save over 60% in cumulative capital costs using a GSM-CDMA overlay for network expansion of the GSM network using IS-95 CDMA radio access in addition to, or as a substitute for, TDMA radio access. This combines the spectral efficiency of CDMA with all GSM features, including seamless roaming and network services. The GSM-CDMA technology provides operators with a way to serve multiple market segments economically and to offer various services on one network platform. In addition to being a cost-effective network expansion solution, GSM-CDMA also paves an evolutionary path to 3G services including high-speed data, multimedia, and mobile/fixed convergence services.

CDMA is the selected approach for the 3G system, as evidenced by the proposals submitted by the European Telecommunications Standards Institute (ETSI), the Association Radio Industry Business (ARIB), and the Telecommunications Industry Association (TIA). The 3G cdma2000 uses a CDMA air interface based on the existing IS-95B standard to provide wireline-quality voice service and high-speed data services, ranging from 144 kbps for mobile users to 2 megabits per second (Mbps) for stationary users. It is important to note that cdma2000 is a core proposal of the TIA for International Mobile Telecommunications-2000 (IMT-2000). Moreover, support for cdma2000 is not limited to North America; Korean carriers have a great opportunity to provide 3G-like service with today's existing CDMA technology. Mobile data rates of up to 114 kbps and fixed peak rates beyond 1.5 Mbps are within reach before the end of the decade with today's CDMA technology. These capabilities will be provided without degrading the systems' voice transmission capabilities or requiring additional spectrum. This will have tremendous implications for the majority of operators that are spectrum constrained. A doubling of capacity and a 1.5-Mbps data rate capability within a 1.25-MHz channel structure look very appealing.

This book is an extension of the book *Applications of CDMA in Wireless Communications* (Garg, Smolik, and Wilkes, Prentice Hall, 1997). In that book, the primary focus was on the CDMA systems standardized by TIA and American Telecommunications Industries Standards (ATIS) as standards IS-95 and IS-665. Since the publication of that book, CDMA technology has undergone major changes and has become a viable technology for 3G systems. In this book, I discuss those aspects of CDMA that are essential to understanding system capacity. I also provide guidelines for system parameters of a CDMA network. The book outlines a migration path for CDMA to a 3G cdma2000 system.

In writing this book, I addressed the needs of practicing engineers and engineering managers by explaining CDMA concepts, system capacity, radio frequency (RF) engineering, and other important aspects of the CDMA network. Students studying courses in telecommunications will also find this book useful as they prepare for careers in the wireless industry. I included a sufficient amount of mathematics so that you can understand the operation of the CDMA network, but I tried not to overwhelm you with very complex mathematical derivations.

This book can be used by practicing telecommunications engineers involved in the design and operation of CDMA-based cellular/PCS networks as well as by senior or graduate students

in electrical engineering, telecommunications engineering, and computer engineering curricula. I assume that you have some basic background in mobile communications and CDMA technology. If you don't, the book mentioned above by Garg, Smolik, and Wilkes can provide that understanding. By selectively reading pertinent chapters of that book, telecommunications managers who are engaged in managing CDMA networks but who have little or no technical background can gain enough of an understanding of CDMA systems to read this book.

This book can be divided into four segments: Chapters 1 through 4 provide a foundation for understanding the material in subsequent chapters. Chapters 5 through 11 deal with IS-95 CDMA standards, and chapters 12 and 13 provide design aspects of a CDMA system. Chapters 14 and 15 focus on the data applications in CDMA and the evolution of IS-95 (2G system) to cdma2000 (3G system) in order to satisfy ITU IMT-2000 specifications. The following is a synopsis of the subjects covered in each chapter.

- **Chapter 1.** Major attributes of CDMA and the access technologies used for cellular/PCS systems.
- **Chapter 2.** The different types of Spread Spectrum (SS) systems that are used. The main focus is on the Direct Sequence Spread Spectrum (DSSS) techniques that are employed in CDMA. I provide a relationship to calculate the performance of a CDMA system.
- **Chapter 3.** Speech and channel coding applications in the IS-95 CDMA system.
- **Chapter 4.** The concepts of diversity reception used to improve signal-to-noise ratio (SNR) of the system; various combining schemes used to combine the signals; some practical antennas used in the cellular telephone industry.
- **Chapter 5.** Functional entities of the wireless network and the TIA-standardized interfaces between the entities. I examine the activities of the International Telecommunication Union (ITU) to add Intelligent Network (IN) to wireless systems.
- **Chapter 6.** A high-level description of the IS-95 CDMA air interface, including important aspects of the forward link (base station to mobile) and reverse link (mobile to base station) and modulation parameters for the channels.
- **Chapter 7.** Modulation schemes, bit repetition, block interleaving, and channel coding; these are used in processing logical channels on the IS-95 CDMA forward and reverse links. Details about information processing, message types, and message framing are presented for the pilot, sync, paging, and traffic channels on the forward link. Similar details are provided for the access and traffic channels on the reverse link
- **Chapter 8.** IS-95 CDMA call processing states that a mobile station (MS) goes through in getting to a traffic channel; idle handoff, slotted paging operation, CDMA registration, and authentication procedures; call flows for CDMA call origination, call termination, call release, and authentication.
- **Chapter 9.** The layering concept used to develop the protocols for IS-95 CDMA; the standardized interfaces between the functional entities, mainly the *A-Interface* and TIA IS-634-defined MSC-BS messages, message sequencing, and mandatory timers at the

BS and the MSC. The chapter also provides call flow diagrams for typical supplementary services, handoff scenarios, and Over-The-Air Service Provisioning (OTASP).

- **Chapter 10.** Handoff strategy used in IS-95 CDMA; power control schemes for the reverse and forward links.
- **Chapter 11.** Various parameters used to identify an MS including International Mobile Station Identity (IMSI), Mobile Station Number (MDN), Electronic Serial Number (ESN), and station class mark. I focus on authentication procedures, including the authentication of MS registration, MS originations, MS terminations, MS data bursts, and Temporary Mobile Station Identity (TMSI) assignment. Also discussed are unique challenge response procedures.
- **Chapter 12.** Basic guidelines for engineering a CDMA system, including a discussion of propagation models, link budgets, the transition from analog operation to CDMA operation, radio link capacity, facility engineering, border cells on a boundary between two service providers, and interfrequency handoff.
- **Chapter 13.** Procedures for calculating the capacity of the reverse and forward link of a CDMA system; a procedure to develop a link safety margin parameter for each of the forward link channels.
- **Chapter 14.** Standards for data services supported by CDMA cellular/PCS systems; highlights of the TIA IS-99, TIA IS-637, and TIA IS-657 standards. I describe the architecture for each of the four data services (e.g., packet data, asynchronous data, facsimile, and short message services) and the protocol stacks supported by these services.
- **Chapter 15.** The cdma2000, 3G evolution of IS-95. The cdma2000 Radio Transmission Technology (RTT) is a wideband, SS radio interface that uses CDMA technology to satisfy the needs of 3G wireless communication systems.

Appendix A presents traffic tables for a variety of blocking probabilities and channel numbers. **Appendix B** comprises a list of abbreviations I introduce in the text and that are common to the industry. The references cited in **Appendix C** are papers and texts that I have found useful and, when considered in addition to those cited in the text, provide a rich background for readers interested in looking into digital wireless technology in greater depth.

I suggest chapters 1–11 for those who are interested in IS-95 standards but who do not have much background in digital communications. Those who have adequate background in digital communications may skip chapters 1–4.

I recommend chapters 1, 2, 4–10, 12, and 13 for those who are involved with the design of a CDMA system. The engineering managers should use chapters 1 and 5–12 to achieve adequate knowledge of IS-95 CDMA.

I suggest chapters 1–8, 10–12, 13, and 15 for a one-semester graduate course in IS-95 CDMA and its evolution to cdma2000.

I would like to thank the many people who helped me prepare the material in this book. Bernard Goodwin provided his encouragement in motivating me to write the book. Professor Ted Rappa-

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