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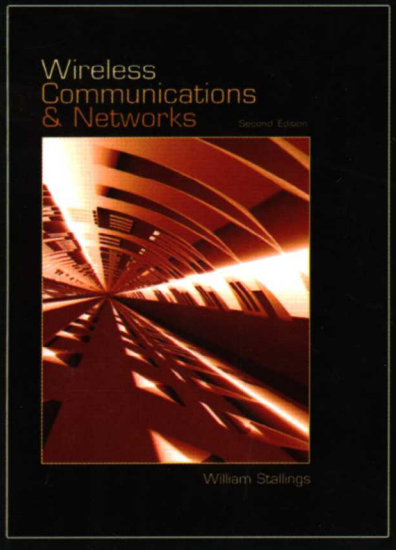
（第二版）

Wireless Communications and Networks

Second Edition



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[美] William Stallings 著

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内 容 简 介

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本书可作为通信与计算机专业本科生和研究生的教材或教学参考书。对于从事无线通信与网络方面研究的科研和工程技术人员，本书也是很好的基础性参考读物。

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北京市西三环北路 19 号外研大厦 2202 室
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出 版 说 明

21世纪初的5至10年是我国国民经济和社会发展的重要时期，也是信息产业快速发展的关键时期。在我国加入WTO后的今天，培养一支适应国际化竞争的一流IT人才队伍是我国高等教育的重要任务之一。信息科学和技术方面人才的优劣与多寡，是我国面对国际竞争时成败的关键因素。

当前，正值我国高等教育特别是信息科学领域的教育调整、变革的重大时期，为使我国教育体制与国际化接轨，有条件的高等院校正在为某些信息学科和技术课程使用国外优秀教材和优秀原版教材，以使我国在计算机教学上尽快赶上国际先进水平。

电子工业出版社秉承多年来引进国外优秀图书的经验，翻译出版了“国外计算机科学教材系列”丛书，这套教材覆盖学科范围广、领域宽、层次多，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。这些教材涉及的学科方向包括网络与通信、操作系统、计算机组织与结构、算法与数据结构、数据库与信息处理、编程语言、图形图像与多媒体、软件工程等。同时，我们也适当引进了一些优秀英文原版教材，本着翻译版本和英文原版并重的原则，对重点图书既提供英文原版又提供相应的翻译版本。

在图书选题上，我们大都选择国外著名出版公司出版的高校教材，如Pearson Education培生教育出版集团、麦格劳－希尔教育出版集团、麻省理工学院出版社、剑桥大学出版社等。撰写教材的许多作者都是蜚声世界的教授、学者，如道格拉斯·科默（Douglas E. Comer）、威廉·斯托林斯（William Stallings）、哈维·戴特尔（Harvey M. Deitel）、尤利斯·布莱克（Uyless Black）等。

为确保教材的选题质量和翻译质量，我们约请了清华大学、北京大学、北京航空航天大学、复旦大学、上海交通大学、南京大学、浙江大学、哈尔滨工业大学、华中科技大学、西安交通大学、国防科学技术大学、解放军理工大学等著名高校的教授和骨干教师参与了本系列教材的选题、翻译和审校工作。他们中既有讲授同类教材的骨干教师、博士，也有积累了几十年教学经验的老教授和博士生导师。

在该系列教材的选题、翻译和编辑加工过程中，为提高教材质量，我们做了大量细致的工作，包括对所选教材进行全面论证；选择编辑时力求达到专业对口；对排版、印制质量进行严格把关。对于英文教材中出现的错误，我们通过与作者联络和网上下载勘误表等方式，逐一进行了修订。

此外，我们还将与国外著名出版公司合作，提供一些教材的教学支持资料，希望能为授课老师提供帮助。今后，我们将继续加强与各高校教师的密切联系，为广大师生引进更多的国外优秀教材和参考书，为我国计算机科学教学体系与国际教学体系的接轨做出努力。

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PREFACE

OBJECTIVES

Wireless technology has become the most exciting area in telecommunications and networking. The rapid growth of mobile telephone use, various satellite services, and now the wireless Internet and wireless LANs are generating tremendous changes in telecommunications and networking. This book explores the key topics in the field in the following general categories:

- **Technology and architecture:** There is a small collection of ingredients that serves to characterize and differentiate wireless communication and networking, including frequency band, signal encoding technique, error correction technique, and network architecture.
- **Network type:** This book covers the important types of wireless networks, including satellite, cellular, fixed wireless access, and wireless LANs.
- **Design approaches:** The book examines alternative design choices and assesses their relative merits.
- **Applications:** A number of key technologies and applications have been developed on top of wireless infrastructures, especially mobile IP and wireless Web access.

Throughout, there is an emphasis on both technology and on standards. The book provides a comprehensive guide to understanding specific wireless standards, such as those promulgated by ITU and IEEE 802, as well as standards developed by other organizations. This emphasis reflects the importance of such standards in defining the available products and future research directions in this field.

INTENDED AUDIENCE

This book is intended for a broad range of readers who will benefit from an understanding of wireless communications and networks, and the associated technologies. This includes students and professionals in the fields of data processing and data communications, designers and implementers, and data communication and networking customers and managers. For the professional interested in this field, the book serves as a basic reference volume and is suitable for self-study.

As a textbook, it is suitable for an advanced undergraduate or graduate course. It covers the material in the CS332 Wireless and Mobile Computing advanced course of the joint ACM/IEEE Computing Curricula 2001. The chapters and parts of the book are sufficiently modular to provide a great deal of flexibility in the design of courses.

PLAN OF THE BOOK

The book treats a number of advanced topics and provides a brief survey of the required elementary topics. For the reader with little or no background in data communications, Part One and the appendices cover a number of basic topics. The book is divided into four parts:

- Technical Background
- Wireless Communication Technology

- Wireless Networking
- Wireless LANs

In addition, the book includes an extensive glossary, a list of frequently used acronyms, and a bibliography. Each chapter includes problems, suggestions for further reading, and a list of relevant Web sites. Each chapter also includes, for review, a list of key words and a number of review questions.

INTERNET SERVICES FOR INSTRUCTORS AND STUDENTS

There is a Web site for this book that provides support for students and instructors. The site includes links to other relevant sites, transparency masters of figures and tables from the book in PDF (Adobe Acrobat) format, PowerPoint slides, and sign-up information for the book's Internet mailing list. The Web page is at WilliamStallings.com/Wireless/Wireless2e.html; see Section 1.8 for more information. An Internet mailing list has been set up so that instructors using this book can exchange information, suggestions, and questions with each other and with the author. As soon as typos or other errors are discovered, an errata list for this book will be available at WilliamStallings.com. I also maintain the Computer Science Student Resource Site at WilliamStallings.com/StudentSupport.html.

WHAT'S NEW IN THE SECOND EDITION

In the three years since the first edition of this book was published, the field has seen continued innovations and improvements. In this new edition, I try to capture these changes while maintaining a broad and comprehensive coverage of the entire field. To begin the process of revision, the first edition of this book was extensively reviewed by a number of professors who teach the subject. The result is that, in many places, the narrative has been clarified and tightened, and illustrations have been improved. Also, a number of new "field-tested" problems have been added.

Beyond these refinements to improve pedagogy and user friendliness, the technical content of the book has been updated throughout, to reflect the ongoing changes in this exciting field. Every chapter has been revised. Highlights include the following:

- **Minimum shift keying:** MSK is a form of modulation that is found in some mobile communications systems. This material is now covered.
- **CDMA2000:** The first 3G (third generation) wireless system to be deployed commercially is known as CDMA2000 1xEV-DO. A discussion of this important standard is included.
- **WiMAX and IEEE 802.16a:** Work on wireless local loop has evolved, including the introduction of the WiMAX specification to provide interoperability specifications for 802.16. Chapter 11 includes new material on 802.16, including the recent 802.16a standard.
- **Orthogonal frequency division multiplexing:** The popularity of OFDM is increasing and is used in a variety of local and wide area wireless standards. The material on OFDM has been updated and expanded.
- **Wi-Fi and IEEE 802.11:** The coverage of 802.11a and 802.11b has been expanded significantly, and treatment of 802.11g had been added.
- **Data scrambling:** Scrambling is a technique often used to improve signal quality. An overview of data scrambling is provided in Chapter 14.

- **Wi-Fi protected access:** WPA has replaced Wireless Equivalent Privacy (WEP) as the specification for providing security in wireless LANs. Chapter 14 provides coverage of WPA.
- **IEEE 802.15 and personal area networks:** The initial 802.15.1 standard provides an official specification for Bluetooth, which was covered in the first edition as well as this edition. This edition also covers two new standards: the 802.15.3 high-speed wireless PAN standard and the 802.15.4 low-speed wireless PAN standard.
- **Trellis-coded modulation:** TCM is a technique that provides for efficient use of bandlimited channels; it is described in Chapter 15.

In addition, throughout the book, virtually every topic has been updated to reflect the developments in standards and technology that have occurred since the publication of the first edition.

ACKNOWLEDGMENTS

This new edition has benefited from review by a number of people, who gave generously of their time and expertise. The following people reviewed all or a large part of the manuscript: Dr. Albert Cheng (University of Houston-University Park), Dale W. Callahan (University of Alabama, Birmingham), Ravi Sankar (University of South Florida, Tampa), Pei Zheng (Arcadia University, Pennsylvania), and Anne Cox (Austin Community College, Texas).

Thanks also to the many people who provided detailed technical reviews of a single chapter: Lars Poulsen, Howard Eisenhauer, D. E. Jennings, Paul Robichaux, John Adams, Jerry Huang, Andreas Kasenides, Munira Ahmed, Hossein Izadpanah, Aaron King, Benoit d'Udekem, Marco Casole, Kevin Peterson, Dinesh Lal Pradhan, and Cathal Mc Daid.

Finally, I would like to thank the many people responsible for the publication of the book, all of whom did their usual excellent job. This includes the staff at Prentice Hall, particularly my editors Alan Apt and Toni Holm; their assistant Patrick Lindner: production manager Rose Kernan; and supplements manager Sarah Parker. Also, Jake Warde of Warde Publishers managed the reviews; and Patricia M. Daly did the copy editing.

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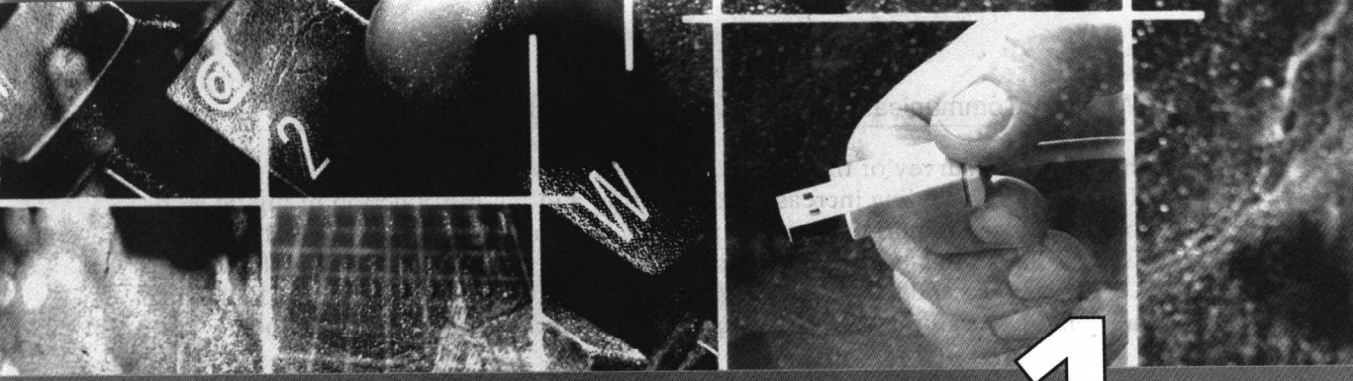

CHAPTER 1

INTRODUCTION

1.1 **Wireless Comes of Age**

1.2 **The Cellular Revolution**

1.3 **The Global Cellular Network**

1.4 **Broadband**

1.5 **Future Trends**

1.6 **The Trouble With Wireless**

1.7 **Outline of the Book**

Part One: Background
Part Two: Wireless Communication Technology
Part Three: Wireless Networking
Part Four: Wireless Local Area Networks

1.8 **Internet and Web Resources**

Web Sites for This Book
Other Web Sites
USENET Newsgroups

This book is a survey of the technology of wireless communications and networks. Many factors, including increased competition and the introduction of digital technology, have led to unprecedented growth in the wireless market. In this chapter, we discuss some of the key factors driving this new telecommunications revolution.

This book, and the accompanying Web site, covers a lot of material. Following the general discussion, this chapter gives the reader an overview of the book.

1.1 WIRELESS COMES OF AGE

Guglielmo Marconi invented the wireless telegraph in 1896.[1] In 1901, he sent telegraphic signals across the Atlantic Ocean from Cornwall to St. John's Newfoundland; a distance of about 3200 km. His invention allowed two parties to communicate by sending each other alphanumeric characters encoded in an analog signal. Over the last century, advances in wireless technologies have led to the radio, the television, the mobile telephone, and communications satellites. All types of information can now be sent to almost every corner of the world. Recently, a great deal of attention has been focused on satellite communications, wireless networking, and cellular technology.

Communications satellites were first launched in the 1960s. Those first satellites could only handle 240 voice circuits. Today, satellites carry about one-third of the voice traffic and all of the television signals between countries [EVAN98]. Modern satellites typically introduce a quarter-second propagation delay to the signals they handle. Newer satellites in lower orbits, with less inherent signal delay, have been deployed to provide data services such as Internet access.

Wireless networking is allowing businesses to develop WANs, MANs, and LANs without a cable plant. The IEEE has developed 802.11 as a standard for wireless LANs. The Bluetooth industry consortium is also working to provide a seamless wireless networking technology.

The cellular or mobile telephone is the modern equivalent of Marconi's wireless telegraph, offering two-party, two-way communication. The first-generation wireless phones used analog technology. These devices were heavy and coverage was patchy, but they successfully demonstrated the inherent convenience of mobile communications. The current generation of wireless devices is built using digital technology. Digital networks carry much more traffic and provide better reception and security than analog networks. In addition, digital technology has made possible value-added services such as caller identification. Newer wireless devices connect to the Internet using frequency ranges that support higher information rates.

The impact of wireless communications has been and will continue to be profound. Very few inventions have been able to "shrink" the world in such a manner. The standards that define how wireless communication devices interact are quickly

[1] The actual invention of radio communications more properly should be attributed to Nikola Tesla, who gave a public demonstration in 1893. Marconi's patents were overturned in favor of Tesla in 1943 [ENGE00].

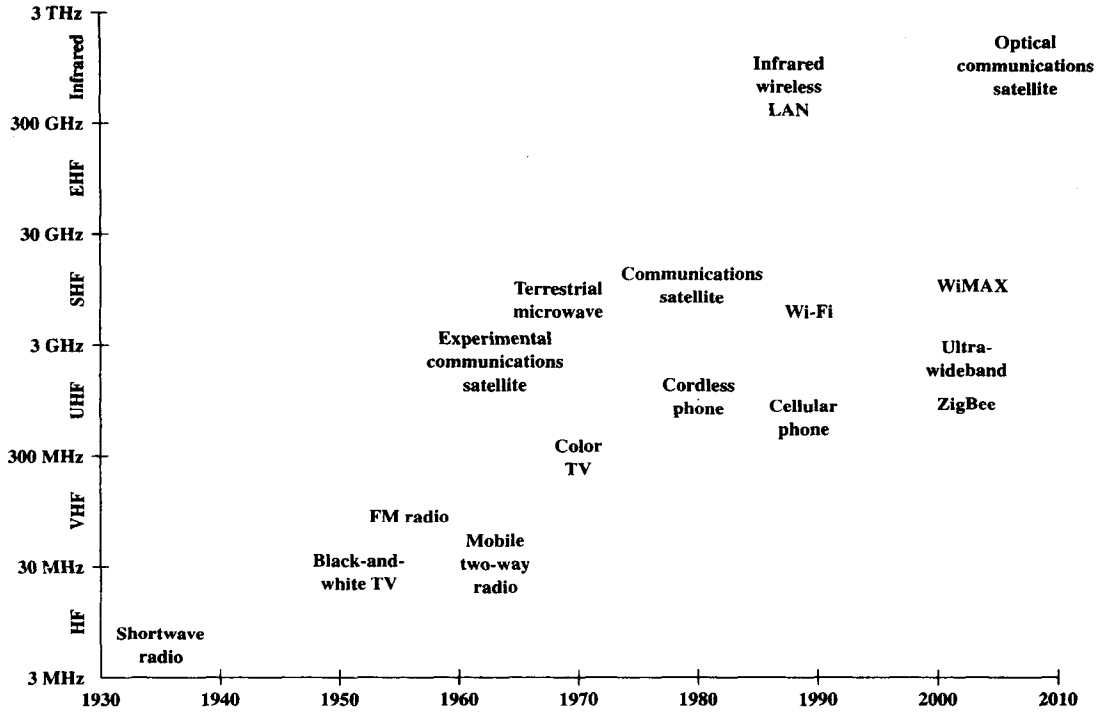

Figure 1.1 Some Milestones in Wireless Communications

converging and soon will allow the creation of a global wireless network that will deliver a wide variety of services.

Figure 1.1 highlights some of the key milestones in the development of wireless communications.[2] Wireless technologies have gradually migrated to higher frequencies. As will be seen in later chapters, higher frequencies enable the support of greater data rates and throughput.

1.2 THE CELLULAR REVOLUTION

The cellular revolution is apparent in the growth of the mobile phone market alone. In 1990, the number of users was approximately 11 million [ECON99]. Today, that number is in the billions. According to the ITU (International Telecommunications Union),[3] the number of mobile phones worldwide outnumbered fixed-line phones for the first time in 2002. The newer generation devices, with access to the Internet and built-in digital cameras, add to this momentum. There are a number of reasons

[2]Note the use of a log scale for the *y*-axis. A basic review of log scales is in the math refresher document at the Computer Science Student Resource Site at **WilliamStallings.com/StudentSupport.html.**

[3]A description of ITU and other standards-making bodies is contained in a supporting document at this book's Web site.

for the increasing dominance of mobile phones. Mobile phones are convenient; they move with people. In addition, by their nature, they are location aware. A mobile phone communicates with regional base stations that are at fixed locations.

Technical innovations have contributed to the success of mobile phones. The handsets have become smaller and lighter, battery life has increased, and digital technology has improved reception and allowed better use of a finite spectrum. As with many types of digital equipment, the costs associated with mobile telephones have been decreasing. In areas where competition flourishes, prices have dropped dramatically since 1996.

In many geographic areas, mobile telephones are the only economical way to provide phone service to the population. Operators can erect base stations quickly and inexpensively when compared with digging up ground to lay copper in harsh terrain.

Mobile telephones are only the tip of the cellular revolution. Increasingly, new types of wireless devices are being introduced. These new devices have access to the Internet. They include personal organizers and telephones, but now they have Web access, instant messaging, e-mail, and other services available on the Internet. Wireless devices in automobiles allow users to download maps and directions on demand. Soon, the devices may be able to call for help when an accident has occurred or perhaps notify the user of the lowest-priced fuel in the immediate area. Other conveniences will be available as well. For example, refrigerators may one day be able to order groceries over the Internet to replace consumed items.

The first rush to wireless was for voice. Now, the attention is on data. A big part of this market is the "wireless" Internet. Wireless users use the Internet differently than fixed users. Wireless devices have limited displays and input capabilities compared with typical fixed devices such as the PC. Transactions and messaging will be the rule instead of lengthy browsing sessions. Because wireless devices are location aware, information can be tailored to the geographic location of the user. Information will be able to find users, instead of users searching for information.

1.3 THE GLOBAL CELLULAR NETWORK

Today there is no single cellular network. Devices support one or two of a myriad of technologies and generally work only within the confines of a single operator's network. To move beyond this model, more work must be done to define and implement standards.

The ITU is working to develop a family of standards for the next-generation wireless devices. The new standards will use higher frequencies to increase capacity. The new standards will also help overcome the incompatibilities introduced as the different first- and second-generation networks were developed and deployed over the last decade.

The dominant first-generation digital wireless network in North America was the Advanced Mobile Phone System (AMPS). This network offers a data service using the Cellular Digital Packet Data (CDPD) overlay network, which provides a 19.2-kbps data rate. The CPDP uses idle periods on regular voice channels to provide the data service.

The key second-generation wireless systems are the Global System for Mobile Communications (GSM), Personal Communications Service (PCS) IS-136, and PCS

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