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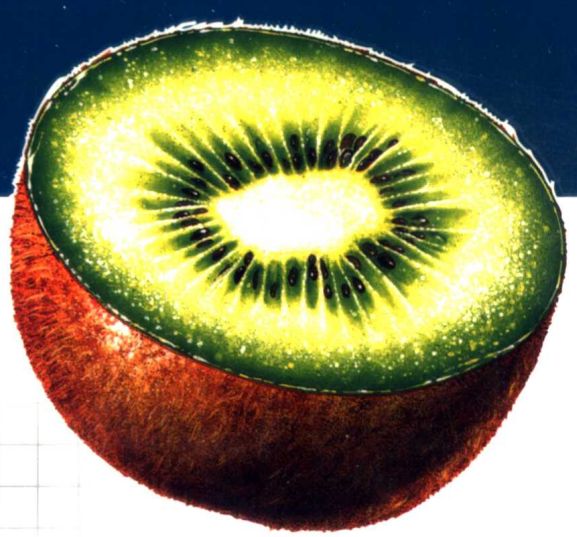
WIRELESS COMMUNICATIONS AND NETWORKS

无线通信与网络



William Stallings 著

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图书在版编目(CIP)数据

无线通信与网络 = Wireless Communications and Networks / [美]斯托林斯（Stallings, W.）著. —影印本. —北京：清华大学出版社，2003.10
（大学计算机教育国外著名教材系列）
ISBN 7-302-07413-5

Ⅰ. 无…　Ⅱ. 斯…　Ⅲ. 无线电通信—通信网—英文　Ⅳ. TN92

中国版本图书馆 CIP 数据核字（2003）第 092852 号

出 版 者：清华大学出版社　　地　　址：北京清华大学学研大厦
http://www.tup.com.cn　　邮　　编：100084
社总机：(010) 6277 0175　　客户服务：(010) 6277 6969
责任编辑：龙啟铭
印 刷 者：北京四季青印刷厂
装 订 者：三河市金元装订厂
发 行 者：新华书店总店北京发行所
开　　本：185×230　印 张：37.25
版　　次：2003 年 11 月第 1 版　2003 年 11 月第 1 次印刷
书　　号：ISBN 7-302-07413-5/TP・5475
印　　数：1~5000
定　　价：52.00 元

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 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.

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.

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. The book is designed to be self-contained. For the reader with little or no background in data communications, Part One and the appendices cover a number of basic topics.

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 in the book in PDF (Adobe Acrobat) format, and sign-up information for the book's Internet mailing list. The Web page is at WilliamStallings.com/Wireless1e.html; see Section 1.7 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.

Acknowledgments

This book has benefited from review by a number of people, who gave generously of their time and expertise. These include the following, who reviewed all or part of the manuscript as well as the book's proposal: Mario Gerla (UCLA), Jerry Place (U. of Missouri—KC), John Metzner (Penn State), Upkar Varshney (Georgia State), Peter Rha (San Francisco State), and Arthur Werbner.

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.

Steven Kilby contributed Chapter 1 and reviewed a number of chapters. His contribution is greatly appreciated. Thanks also to Richard Van Slyke of Polytechnic University of Brooklyn, who supplied many of the review questions. Tom Fronckowiak developed the PowerPoint slides for the book.

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 Toni Holm and Alan Apt and production manager Rose Kernan. Also, Jake Warde of Warde Publishers managed the supplements and reviews; Joanna V. Pomeranz at V&M managed the book's printing; and Patricia P. Daly did the copy editing.

CONTENTS

CHAPTER 1

INTRODUCTION[1]

[1]This chapter, with the exception of Section 1.7, was contributed by Steven Kilby.

This book is a survey 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, cover 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.[2] In 1901, he sent telegraphic signals across the Atlantic Ocean from Cornwall to St. John's Newfoundland; a distance of 1800 miles. 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, will soon be 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 are built using digital technology instead of analog. Digital networks can 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. The next-generation wireless device will also be digital and will connect to the Internet using new frequency ranges at 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.

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[2]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].

The standards that define how wireless communication devices interact are quickly converging and soon will allow the creation of a global wireless network that will deliver a wide variety of services.

1.2 THE CELLULAR REVOLUTION

The cellular revolution is intuitively apparent in the growth of the mobile phone market alone. In 1990, the number of users was approximately 11 million. By 2004, the number will likely be 1 billion [ECON99]. The next-generation devices, with access to the Internet, are sure to add to this momentum. One estimate is that the number of wireless Internet devices will exceed the number of wired Internet devices by 2005 [ECON99].

Phones are currently the most obvious sign of the success of wireless. Since 1996, the number of new mobile phone subscribers has exceeded the number of new fixed telephone subscribers [ECON99]. There are many reasons why this has happened. 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. Within five years wireless data service is projected to be a multibillion-dollar market [AGRA99]. A big part of this market is the "wireless" Internet. Wireless users will 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 International Telecommunication Union (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 IS-95. The PCS standard IS-136 uses time division multiple access (TDMA) while IS-95 uses code division multiple access (CDMA). The GSM and PCS IS-136 use dedicated channels at 9.6 kbps to deliver the data service.

The ITU is developing International Mobile Telecommunications-2000 (IMT-2000). This family of standards is intended to provide a seamless global network. The standards are being developed around the 2-GHz frequency band. The new standards and frequency band will provide data rates up to 2 Mbps.

In addition to defining frequency usage, encoding techniques, and transmission, standards also need to define how mobile devices will interact with the Internet. Several standards bodies and industry consortiums are working to that end. The Wireless Application Protocol (WAP) Forum is developing a common protocol that allows devices with limited display and input capabilities to access the Internet. The Internet Engineering Task Force (IETF) is developing a mobile IP standard that adapts the ubiquitous IP protocol to work within a mobile environment.

1.4 BROADBAND

The Internet is increasingly a multimedia experience. Graphics, video, and audio abound on the pages of the World Wide Web. Business communications are following the same trend. For example, e-mail frequently includes rich multimedia attachments. In order to participate fully, wireless networks require the same high data rates as their fixed counterparts. The higher data rates are obtainable with broadband wireless technology.

Broadband wireless service shares the same advantages of all wireless services: convenience and reduced cost. Operators can deploy the service faster than a fixed service and without the cost of a cable plant. The service is also mobile and can be deployed almost anywhere.

There are many initiatives developing broadband wireless standards around many different applications. The standards cover everything from the wireless LAN

to the small wireless home network. Data rates vary from 2 Mbps to well over 100 Mbps. Many of these technologies are available now and many more will become available in the next several years.

Wireless LANs (WLANs) provide network services where it is difficult or too expensive to deploy a fixed infrastructure. The primary WLAN standards are IEEE 802.11b and Europe's HiperLAN. The IEEE initiative provides for data rates as high as 11 Mbps. The European standard defines a maximum rate of 24 Mbps and a future revision will operate up to 54 Mbps.

A potential problem with 802.11b is compatibility with Bluetooth. Bluetooth is a wireless networking specification that defines wireless communications between devices such as laptops, PDAs, and mobile phones. Bluetooth and 802.11b use the same frequency band. The technologies would most likely interfere with each other if deployed in the same device.

The HomeRF initiative is developing standards to define wireless communications between products such as home computers and peripherals. HomeRF currently operates up to 2 Mbps but a new revision will operate near 10 Mbps.

1.5 THE TROUBLE WITH WIRELESS

Wireless is convenient and often less expensive to deploy than fixed services, but wireless is not perfect. There are limitations, political and technical difficulties that may ultimately prevent wireless technologies from reaching their full potential. Two issues are incompatible standards and device limitations.

As mentioned previously, in North America there are two standards for digital cellular service. Internationally, there is at least one more. A device using PCS IS-136 will not work in an area where the deployed technology is PCS IS-95. Also mentioned previously is the inability to use Bluetooth and 802.11b in the same device. These are just two examples of problems that arise when industrywide standards do not exist. The lack of an industrywide standard holds the technologies back from delivering one of the true ideals of wireless: ubiquitous access to data.

Device limitations also restrict the free flow of data. The small LCD on a mobile telephone is inadequate for displaying more than a few lines of text. In addition, most mobile wireless devices cannot access the vast majority of WWW sites on the Internet. The browsers use a special language, wireless markup language (WML), instead of the de facto standard HTML.

Most likely, no one wireless device will be able to meet every need. The potential of wireless can be met but not with a single product. Wireless will succeed because it will be integrated into a variety of devices that can meet a variety of needs.

1.6 OUTLINE OF THE BOOK

The objective of this book is to provide a comprehensive technical survey of wireless communications fundamentals, wireless networks, and wireless applications. The book is organized into four parts. The reader who is already familiar with data

communications and networking technology can safely skip or just skim Part One. Part Two discusses underlying principles common to all of the material covered in the remainder of the book and should be read next. Parts Three and Four are independent and may be covered in either order. Within Part Three, all of the chapters are more or less independent and can be read in any order depending on your level of interest. The same is true of Chapters 14 and 15 in Part Five.

Part One: Background

This part provides a preview and context for the remainder of the book, covering basic topics in data communications as well as TCP/IP. Part One, together with the appendices at the end of the book, is intended to make the book as self-contained as possible.

Chapter 2: Transmission Fundamentals

Chapter 2 provides a basic overview of transmission topics. The chapter begins with a look at some data communications concepts, including signaling techniques and analog and digital data transmission. The chapter then covers channel capacity, transmission media, and the concept of multiplexing.

Chapter 3: Communication Networks

This chapter provides an overview of comparison of basic communication network technologies, including circuit switching, packet switching, and ATM.

Chapter 4: Protocols and the TCP/IP Protocol Suite

Data network communication and distributed applications rely on underlying communications software that is independent of application and relieves the application of much of the burden of reliably exchanging data. This communications software is organized into a protocol architecture, the most important incarnation of which is the TCP/IP protocol suite. Chapter 4 introduces the concept of a protocol architecture and provides an overview of TCP/IP. Another architecture, the Open Systems Interconnection (OSI) reference model, is briefly described. Finally, the concept of internetworking and the use of TCP/IP to achieve internetworking are discussed.

Part Two: Wireless Communication Technology

This part is concerned with the underlying technology of wireless transmission and the encoding of analog and digital data for wireless transmission.

Chapter 5: Antennas and Propagation

Chapter 5 examines the fundamental principles of radio and microwave. The chapter discusses relevant aspects of antenna performance, then looks at wireless transmission modes, and finally examines the key issue of fading.

Chapter 6: Signal Encoding Techniques

Data come in both analog (continuous) and digital (discrete) form. For transmission, input data must be encoded as an electrical signal that is tailored to the

characteristics of the transmission medium. Both analog and digital data can be represented by either analog or digital signals; the relevant cases for wireless transmission are discussed in Chapter 6.

Chapter 7: Spread Spectrum

An increasingly popular form of wireless communications is known as spread spectrum. Two general approaches are used: frequency hopping and direct sequence spread spectrum. Chapter 7 provides an overview of both techniques. The chapter also looks at the concept of code division multiple access (CDMA), which is an application of spread spectrum to provide multiple access.

Chapter 8: Coding and Error Control

Wireless communications systems are highly prone to error, and virtually all wireless transmission schemes include techniques for forward error correction (FEC) by adding redundancy to the transmitted data so that bit errors can be corrected at the receiver. Chapter 8 examines FEC in detail. In addition, Chapter 8 looks at the use of redundancy for error detection, which is also found in many wireless schemes. Finally, error detection is often combined with automatic repeat request (ARQ) techniques the enable a transmitter to retransmit blocks of data in which the receiver has detected an error.

Part Three: Wireless Networking

This part examines the major types of wireless networks. These include satellite-based networks, cellular networks, cordless systems, fixed wireless access schemes, and the use of mobile IP and the Wireless Application Protocol (WAP) to provide Internet and Web access.

Chapter 9: Satellite Communications

This chapter covers the basic principles of satellite communications. It looks at geostationary satellites (GEOS), low-earth orbiting satellites (LEOS), and medium-earth orbiting satellites (MEOS). The key design issue of capacity allocation is examined in detail.

Chapter 10: Cellular Wireless Networks

Chapter 10 begins with a discussion of the important design issues related to cellular wireless networks. Next, the chapter covers the traditional mobile telephony service, now know as first-generation analog. Chapter 10 then examines second-generation digital cellular networks, looking at the two principal approaches: time division multiple access (TDMA) and code division multiple access (CDMA). Finally, an overview of third-generation networks is provided.

Chapter 11: Cordless Systems and Wireless Local Loop

Chapter 11 looks at two technologies that bring wireless access into the residence and office: cordless systems and wireless local loop (WLL). Cordless systems have evolved from the simple single-user cordless telephones used within the home to accommodate multiple users over much larger ranges. Sometimes called radio in

the loop (RITL) or fixed wireless access (FWA), WLL is a system that connects subscribers to the public switched telephone network (PSTN) using radio signals as a substitute for copper for all or part of the connection between the subscriber and the switch. Chapter 11 looks at the design issues related to WLL and then examines the IEEE 802.16 standard.

Chapter 12: Mobile IP and Wireless Access Protocol

Chapter 12 examines the modifications to IP to accommodate wireless access to the Internet. The chapter then examines the Wireless Application Protocol (WAP). WAP provides mobile users of wireless phones and other wireless terminals, such as pagers and personal digital assistants (PDAs), access to telephony and information services, including the Internet and the Web.

Part Four: Wireless Local Area Networks

In recent years, a whole new class of local area networks have arrived to provide an alternative to LANs based on twisted pair, coaxial cable, and optical fiber—wireless LANs. The key advantages of the wireless LAN are that it eliminates the wiring cost, which is often the most costly component of a LAN, and that it accommodates mobile workstations. This part examines underlying wireless LAN technology and then examines two standardized approaches to local wireless networking.

Chapter 13: Wireless LAN Technology

Wireless LANs use one of three transmission techniques: spread spectrum, narrowband microwave, and infrared. Chapter 13 provides an overview of LANs and wireless LAN technology and applications.

Chapter 14: IEEE 802.11 Wireless LAN Standard

The most significant set of standards defining wireless LANs are those defined by the IEEE 802.11 committee. Chapter 14 examines this set of standards in depth.

Chapter 15: Bluetooth

Bluetooth is an open specification for wireless communication and networking among PCs, mobile phones, and other wireless devices. Bluetooth is one of the fastest growing technology standards ever. It is intended for use within a local area. Chapter 15 examines this specification in depth.

1.7 INTERNET AND WEB RESOURCES

There are a number of resources available on the Internet and the Web to support this book and to help one keep up with developments in this field.