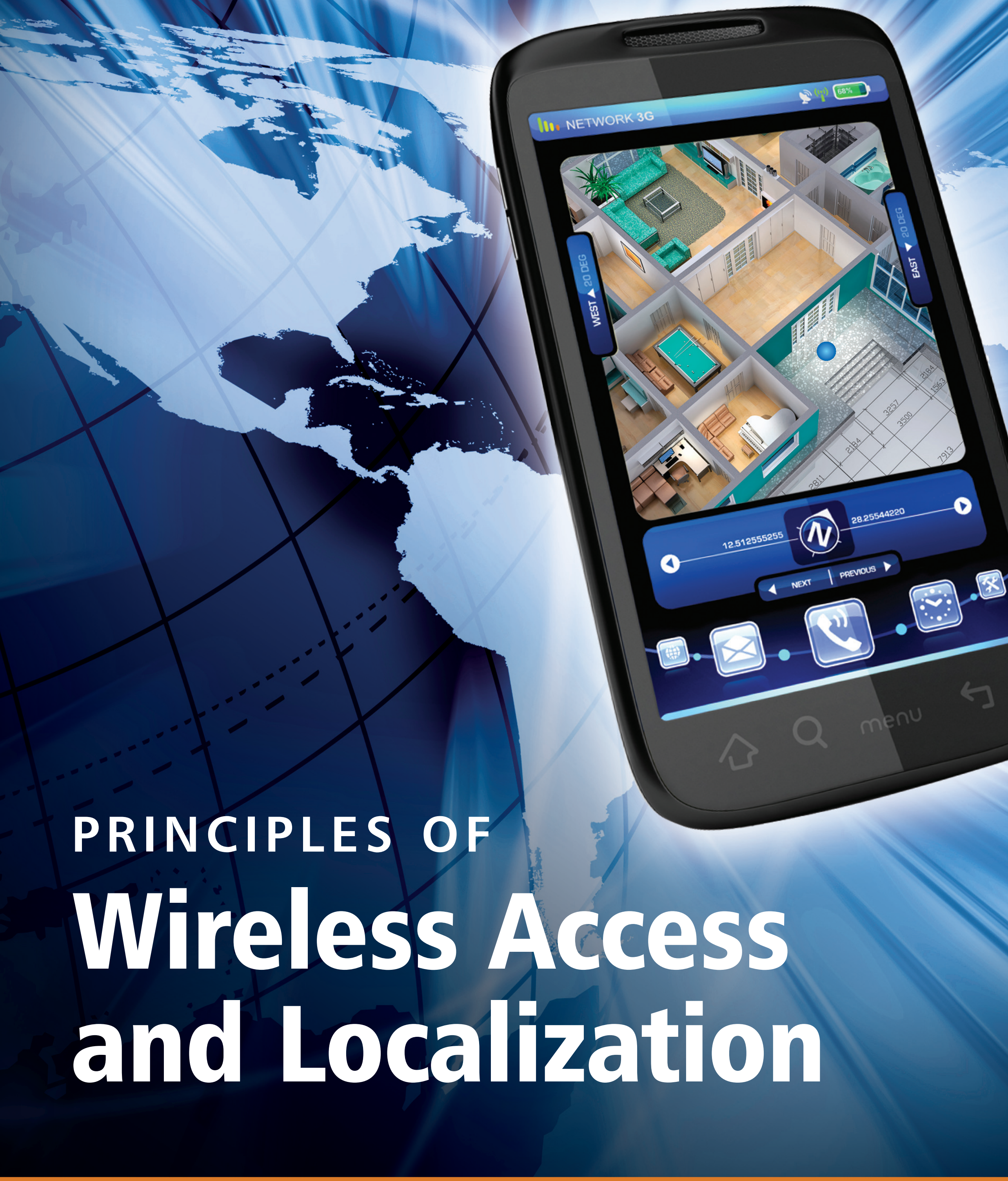

PRINCIPLES OF

Wireless Access and Localization

Kaveh Pahlavan
Prashant Krishnamurthy

WILEY

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To our wives Farzaneh and Deepika and
our children Nima, Nasim, Shriya and Rishabh

Contents

Preface

Engineering disciplines are going through a "transformation" from their traditional focused curriculum to a "multi-disciplinary" curriculum and "inter-disciplinary" research directed toward innovation and entrepreneurship. This situation demands more frequent updates and adjustments in the curriculum, project-oriented delivery of educational content, and the ability to form inter-disciplinary cooperation in research programs. A successful transformation of this form demands entrepreneurship and visionary talents to adapt to these frequent changes and industrial experiences to direct the transformation toward emerging inter-disciplinary industries. Wireless access and localization is an excellent example and one of the flagships of a multi-disciplinary area of research and scholarship, which has emerged in the past few decades. Material needed for teaching wireless access and localization includes several disciplines such as signal processing, digital communications, queueing theory, detection and estimation theory, and navigation. The content of courses on wireless access and localization are useful for traditional Electrical and Computer Engineering (ECE) and Computer Science (CS) students as well as students in emerging multi-disciplinary programs such as Robotics and Biomedical Engineering and traditional Mechanical and Civil Engineering programs, which are similar to ECE, shifting toward inter-disciplinary curriculums. Cyber physical systems play an important role in the future of these multi- and inter-disciplinary engineering programs and wireless access and localization is essential in the integration of all of these systems. Therefore, there is a need for academic courses and a comprehensive textbook to address the principles of wireless access and localization to be taught in these multi-disciplinary programs.

To prepare a textbook to be taught in academic courses in a multi-disciplinary area of technology, we need to provide selected details of practical aspects of a number of disciplines to give to the readers an intuitive feeling of how these disciplines operate and interact with one another. To achieve this goal in our book, we describe important wireless networking standards and localization technologies, classify their underlying science and engineering in a logical manner, and give detailed examples of successful science and engineering that has turned into popular applications. Selection of detailed technical material for teaching courses in a multi-disciplinary area with a large and diversified set of technical disciplinary is very challenging and these challenges become more defying in teaching wireless access and localization because in this area the emphasis of the skills needed to be taught in the course shifts in time.

The success of wireless information networks in 1990's was a motivation behind a series of textbooks describing wide and local area wireless networks [Pah95, Goo97, Wal99, Rap03, Pah02]. The technical focus of these books was on describing wide area cellular telephone networks and local wireless data networks. These books were written by professors of Electrical and Computer Engineering with different levels of emphasis on detailed description of the lower layers issues and system engineering aspects describing details of implementation of wireless networks. Wireless localization has gained significant importance in the past decade and these books do not lay emphasis on the details of wireless localization techniques. As a result, currently, there is no single textbook that integrates wireless access and localization. Wireless access and localization are extremely interrelated in applications and fundamentals of design and operation. Understanding of these technologies have tremendous amount of similarities in the implementation of the physical layer and in the understanding of fundamentals of the radio propagation in the environment.

This book provides a comprehensive treatment of the wireless access and localization technologies. The novelty of the book is that it places emphasis on radio propagation and physical layer issues related to the formation and transmission of packets as well as how the received signals can be used for RF localization in a variety of networks. The structure and sequence of material for this book was first formed in a lecture series by the principal author at the graduate school of the Worcester Polytechnic Institute (WPI), Worcester, MA entitled "Wireless Access and Localization". The principal author also taught shorter versions of the course focused on either of the two topics at different conferences and universities. The co-author of the book has taught material from this book at the University of Pittsburgh for first-year graduate and junior/senior undergraduate students in information science and telecommunications.

We have organized the book as follows: we begin with an overview of the evolution of wireless access to public switched telephone network (PSTN) and the Internet for voice-oriented and data-oriented information and an overview of wireless localization techniques followed by four parts each including several chapters. Part I contains chapters 2 to 4 and explains the principles of design and analysis of physical layers of wireless networks. In chapter 2, we begin this part by describing multipath characteristics of radio channel in indoor and urban areas, where all wireless access and localization techniques used in emerging smart wireless devices are applied. Then we explain how multipath arrival of the signal affects waveform transmission for wireless access and localization. In chapters 3 and 4, we discuss how bits are transmitted and how packets of information are formed for transmission, respectively. Part II of the book is devoted to principles for design of wireless network infrastructure. Three chapters of this part, chapters 5–7, cover deployment, operation, and security of these networks, respectively.

Part III is devoted to wireless local access technologies. Three chapters in this part cover traditional wireless local area networks (chapter 8) as well as low-power sensor technologies (chapter 9) and technologies striving for gigabit wireless access (chapter 10). Part IV of the book describes technologies used for wide area wireless cellular networks with three chapters addressing TDMA technology (chapter 11), CDMA technology (chapter 12), and OFDM/MIMO technologies (Chapter 13) employed in 2G, 3G, and 4G cellular networks, respectively. Part V covers wireless localization techniques with three chapters describing systems aspects (chapter 14), principles of wireless localizations (chapter 15), and practical aspects (chapter 16) of these technologies.

The partitioned structure of the book allows flexibility in teaching the material that is essential when it is used in different disciplines. We believe that the most difficult part of the book for the students is chapters 2–5 and chapters 15 and 16, which provide a summary through mathematical description of numerous technologies and algorithms. The rest of the chapters of the book appear mathematically simpler but carry more details of how systems work. To make the difficult parts simpler for the students, an instructor can mix these topics as appropriate. For example, the lead author teaches similar material in one of his undergraduate courses in wireless networking by first introducing the channel behavior (chapter 2), then describing assigned access methods (chapter 4) before describing TDMA cellular networks (chapter 11). Then he introduces spread spectrum modulation and coding techniques (chapters 3) and CDMA cellular networks (parts of chapters 4 and 12), and at last he covers multi-dimensional constellations (chapter 3) before he discusses wireless LANs (chapter 8). His new graduate-level course on wireless access and localization mostly covers chapters 1–5 and chapters 14–16 in depth.

In fact, we believe that this is an effective approach for enabling the understanding of the fundamental concepts of wireless access and localization in students. Therefore, depending on the selection of the material, depth of the coverage, and background of the students and the instructor, this book can be used for senior undergraduate or first- or second-year graduate courses in CS, ECE or Robotics, Biomedical, Mechanical or Civil Engineering as one course or a sequence of two courses.

The idea of writing this book first came to the authors in 2007 because of the need for a revision for the authors' previous book, Principles of Wireless Network – A unified Approach, and expanded that to include emerging wireless localization techniques. When the book was completed just before 2013, it was substantially different from the previous book and we decided to publish it as an independent book with a more relevant title: Principles of Wireless Access and Localization.

Much of the writing of the lead author in this book was accomplished during his sabbatical leave from Worcester Polytechnic Institute, Worcester, MA at School of Engineering and Applied Science of the Harvard University, Cambridge, MA during the spring semester of 2011. He would like to express his deep appreciation to the Worcester Polytechnic Institute and the Harvard University for providing him this opportunity. In particular, he thanks Prof. Vahid Tarokh of the Harvard University for his timely arrangement of the visit and Dean Cherry A. Murray of the Harvard School of Engineering and Applied Sciences for granting the visit. Also, he thanks Prof. Fred Looft, Head of the WPI ECE Department, and Provost John A. Orr of WPI at that time for their support of his sabbatical leave for the work on this project.

Much of the new material in localization and body area networking are extracted from the research work of the students at the Center for Wireless Information Network Studies (CWINS), WPI. We are pleased to acknowledge the students' and colleagues' contributions to advancing the understanding of wireless channels and its application in wireless access and localization techniques. In particular, the authors would like to thank Dr. Xinrong Li, Dr. Bardia Alavi, Dr. Nayef Alsindi, Dr. Mohammad Heidari, Dr. Ferit Akgul, Dr. Muzzafer Kanaan, Dr. Yunxing Ye, and Umair Khan of the CWINS, Prof. Sergey Makarov of WPI, Prof. Pratap Misra of Tufts University, and Mr. Ted Morgan and Dr. Farshid Alizadeh of Skyhook Wireless, who have directly or indirectly helped the authors to extend their knowledge in this field and shape their thoughts for the preparation of the new material in this book. We owe special thanks to the National Science Foundation (NSF), Defense Advanced Research Projects Agency (DARPA), National Institute of Standards and Technology (NIST), Department of Defense (DoD), and Skyhook in the United States as well as Finnish Founding Agency for Technology and Research (TEKES) and Nokia in Finland, whose support of the CWINS program at WPI enabled graduate students and the staff of CWINS to pursue continuing research in this important field. A substantial part of the new material in this book has flowed out of these sponsored research efforts.

The authors also would like to express their appreciation to Dr. Allen Levesque, for his contributions in other books with the lead author, which has indirectly impacted the formation of thoughts and the details of material presented in this book. The authors also acknowledge the indirect help of Prof. Jacques Beneat of Norwich University, VT, who prepared the solution manual of our other book, Principles of Wireless Networks – A Unified Approach. A significant number of those problems, and hence their solutions, are used in this book. They also thank Drs. Mohammad Heidari and Yunxing Ye and Bader Alkandari who are preparing the solution for this book based on the solutions in the previous book and Guanqun Bao and Bader Alkandari for their careful review of several chapters. The second author expresses his gratitude to Drs. Richard Thompson, David Tipper, Martin Weiss, and Taieb Znati of the Graduate Program in Telecommunications and Networking at Pitt. He has learnt a lot and obtained different perspectives on networking through his interaction and association with them. Like the lead author, he would like to thank his current and former students who have directly or indirectly helped him to extend his knowledge in this field and shape his thoughts for the preparation of the new material in this book. Similarly, we would like to express our appreciation to all graduates and affiliates of CWINS laboratory at WPI and many graduates from the Telecommunications Program at Pitt whose work and interaction with the authors have directly or indirectly impacted the material presented in this book.

We have not directly referenced our referral to several resources on the Internet, notably Wikipedia. While there are people who question the accuracy of online resources, they have provided us with quick pointers to information, parameters, acronyms, and other useful references, which helped us to build up a more comprehensive and up-to-date coverage of standards and technologies. We do acknowledge the benefits of these resources.

The authors also would like to thank Mark Hammond, Sarah Tilley, and Sandra Grayson of John Wiley & Sons for their assistance and useful comments during various stages of the production of the book and Shikha Jain of Aptaracorp for her help during the manuscript proofs. Finally, we would like to thank John Wiley & Sons for hosting the book's website at: http://www.wiley.com/go/pahlavan/principles.

1

Introduction

1.1 Introduction

Technological innovations by engineers during the past century have brought a deep change in our life style. Today, when we fly over a modern city at nighttime, we see a planet full of the footprints of the modern civilization made by engineers. The glowing lights below remind us of the impact made by electrical engineers, the planes we fly in and the moving cars under them remind us of the contributions of mechanical engineers, and high rise buildings and complex road systems remind us of what civil engineers have done. Through the eyes of an engineer, the glow of light, the movement of cars, and the complexity of civil infrastructure display the challenges in implementation and the size of the market for this industry and demonstrate the impact of this technology on human life. There is one industry, whose infrastructure is not seen from an airplane because it is mostly buried under the ground, but it is the most complex, it owns the largest market size, and it has enabled us to change our life style by entering the age of information technology. This industry is the *information networking industry*.

Perhaps the most prominent feature of the human species over other living species on the earth is the ability to create a sophisticated linguistic that allows us to generate information based on our experiences in life and to communicate that with others, store them in writing, and retrieve them by reading. As a result, while other species have little knowledge of their peers' experiences in other places or even living close to them, our lives are based on the retrieval of cumulative information that has been collected and stored over several thousands of years around the world. The availability of this vast treasure of information has allowed us to create an advanced civilization that is by far above the other species living on planet earth. Therefore, the availability of information has been the most important factor in the growth of our civilization. Information networks facilitate the transfer of information across the world. In the same way that highway systems facilitate the physical transfer of merchandise and people across the continents to nurture economic growth, information networks facilitate the transfer of merchandise descriptions and human thoughts to stimulate the economy. Highway systems facilitate their physical presence in diversified locations and information networks facilitate the close to instantaneous virtual presence of information about them in diversified locations. The importance of existent of information in diversified locations in the growth of our economies has resulted in huge investments in the infrastructure for information networking and the emergence of this industry as the largest industry made by engineers.

Principles of Wireless Access and Localization, First Edition. Kaveh Pahlavan and Prashant Krishnamurthy.

To have an intuitive understanding of the size of the information industry, it is illustrative to notice that the size of the budget of American Telephone and Telegraph (AT&T) Corporation in the early 1980s, before its divestiture, was close to the budget of the *fifth largest economy* of the world at that time. AT&T was the largest telecommunication company in the world and its core revenue at that time was generated mainly from wired connections to the public switched telephone network (PSTN) just for the basic telephone call application that was first patented in 1876. During the past three decades, the cellular telephone industry augmented the income of the prosperous circuit-switched telephone services with subscriber fees from approximately seven billion cellular telephone users worldwide. Today the income of the wireless industry has already surpassed the income of the wired telephone industry and this income is still dominated by the revenue from cellular telephone calls for wireless access to the PSTN and their recurring subscriber fees.

In the mid-1990s the Internet brought the data-oriented packet switched computer communication industry from a business-oriented office industry to an "everyone-use" home-oriented industry that soon generated an income comparable to that of the wired telephone and wireless access industries. At the time of writing, the *information networking industry* (including fixed and wireless telephones as well as Internet access industries) has annual revenues of a few trillion dollars and by far is the largest engineering industry in the world. The largest portion of earnings of the wireless industry is made from the revenue generated by cellular telephone calls. However, this trend is rapidly changing and the future of this industry relies on broadband wireless Internet access that has shown a rapid and continual growth to support the emerging multimedia communication networking industry and ad hoc wireless sensor networking. Sensor networks are becoming important for emerging cyber physical systems in different areas such as medicine and transportation.

The main forces behind the growth of the necessity for packet switched wireless data networks in the past few years were the sudden success of the smart phones that became an epidemic after their introduction and the unprecedented popularity of the iPhone in 2007. Smart phones, and in particular the iPhone, opened a new paradigm for a variety of data applications and nurtured the growth of social networking that was another revolution in networking applications. The exponential growth of the volume of information transfer using wireless data for multimedia and Internet browsing applications in the late 2000s caused an exponential growth in the wireless local area networking industry and forced the cellular telephone industry to shift its focus from the traditional telephone application and its quality of service to the emerging multimedia data applications which demand higher data rates but are more tolerant of delay.

The amount of information produced by these emerging devices is so vast that we need a method to filter them and capture the most useful parts for useful applications. The most popular filtering is through the association of information to the time and location (space). As a result, measuring time and location is an essential part of information processing, and engineers have tried to measure them ever more accurately throughout the centuries. In the past few centuries, we have found technologies for the precise measurement of time and the ways to make them available to a variety of applications. The localization industry for day-by-day use started in the past few decades by using radio frequency (RF) signals to measure the distance between a landmark and a mobile electronic device. First, Global Positioning System (GPS) was introduced for outdoor environments [Mis10], then the cell tower and Wi-Fi localization complemented that to extend the coverage to indoor areas [Pah02] and more recently localization is under research for inside the human body [Pah12a].

The iPhone, followed by other smart phones, also introduced the first popular and inexpensive wireless localization techniques on a massivescale. The availability of localization and the popularity of mobile computing initiated another round of growth in application development on smart devices using wireless localization. In early 2007, the localization for smart devices was built on a few popular applications such as turn by turn direction finding. By the year 2010 around 15%

of over 100 000 applications developed for the iPhone were using wireless localization [Mor10]. The popularity of multimedia and location-enriched applications on mobile smart devices has radically shifted the habits of humans in their communications and information processing and it has profoundly affected the way that we live and relate to others.

The purpose of this book is to provide the reader with a textbook for understanding the principles of wireless access and localization. Wireless access and localization is a multidisciplinary technology; to understand this industry we need to learn about a number of disciplines to develop an intuitive feeling of how these disciplines interact with one another. To achieve this goal we provide an overview of the important wireless access and localization applications and technologies, describe and classify their underlying science and engineering principles in a logical manner, give detailed examples of successful standards and products, and provide a vision of the evolving technologies. In this first chapter, we provide an overview of the wireless industry and its path of evolution. The next three chapters describe the fundamental principles of the radio propagation, transmission schemes, and medium access control techniques in wireless networks. The succeeding three chapters examine principles of wireless network infrastructure deployment, operation and security. The following three chapters describe the popular wireless local area networks and personal area networks that have evolved to complement them by supporting low-power sensor networking and high-speed gigabit wireless multimedia applications. The next three chapters provide the details of different generations of wireless wide-area cellular networks. The last three chapters of the book are devoted to wireless localization techniques.

In the remainder of this chapter, we first provide the elements of a wireless network and then we give a summary of the evolution of important standards and technologies for wireless networking as well as evolution of technologies for wireless localization. Finally, we give an outline of the chapters of this book and how they relate to one another.

1.2 Elements of Information Networks

Information networks have evolved to interconnect networking enabled devices over a geographical area to share information generated by an application in the device. Figure 1.1 illustrates the abstract of this basic concept. The information source could be the voice of a human being creating an electronic signal on a telephone device connected to a local public branch switch or the PSTN to transfer that information to another geographical location. The information source could be a video stream from a video camera or sensor data from a robot that is sent through a networking interface card to a local area network or the Internet to be delivered to another networking enabled device in a geographically separated location. The sensor data for example, could be used for remotely navigating the robot. The information could be a simple on–off signal generated by a light switch in one location to be transferred by a communication networking interface protocol to another location to turn a light bulb on. What is common among all of these examples is an *application* that needs the *transfer* of a certain amount of *information* from one location to another, a *network* that can carry the information and an *interface device* that shapes the information to a format or protocol suitable for a particular networking technology.

Figure 1.2 shows a diagram of the elements affecting information networks and the relationships among them. Information generated by an application is delivered to a communication device that uses the network and delivers that information to another location. When the network includes multiple service providers, the interface between the device and the network should be *standardized* to allow communication among different network providers and various user devices. Standardization also allows multivendor operation so that different manufacturers can design different parts of the

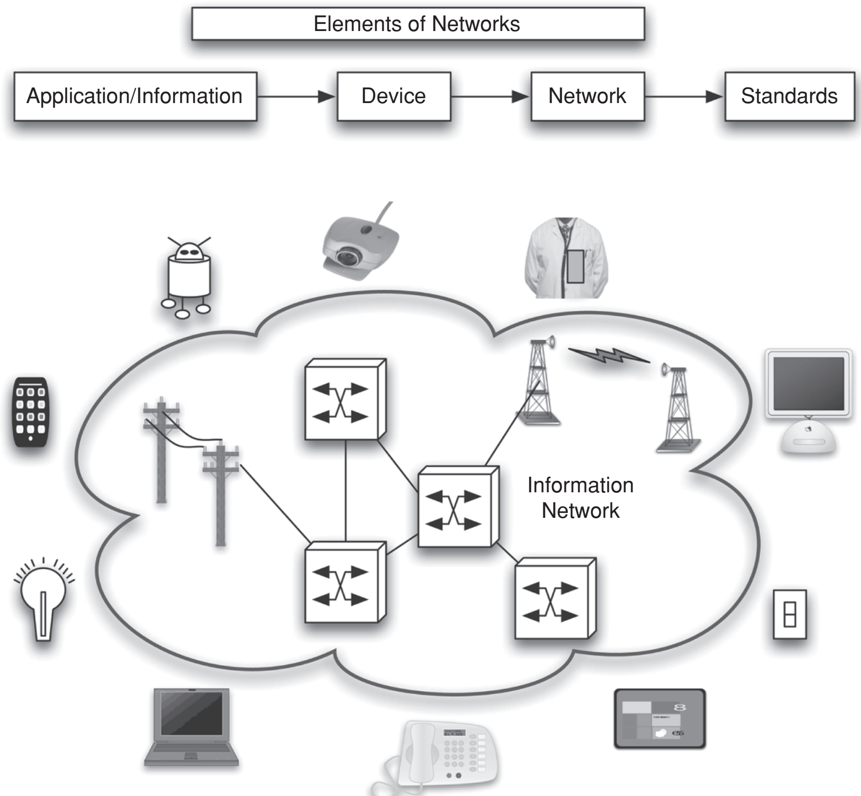

Figure 1.1 Abstract of the general concept of information networking.

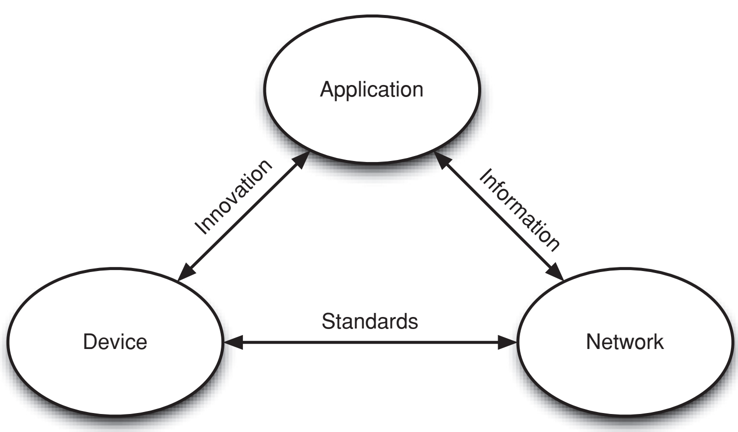

Figure 1.2 Elements of information networking.

network. Applications, telecommunication devices, and communication networks evolve in time to support innovations that enable new applications. These are the new applications that fuel the economy and the progress in the quality of life over time. For example, the introduction of iPhones and iPads opened a new horizon for hundreds of thousands of new applications in the past few years. The evolution of these devices was enabled by the availability of reliable wireless mobile data cellular services, Wi-Fi and Bluetooth technologies for wireless access to the PSTN and Internet, as well as GPS chipsets, Wi-Fi, and cell tower wireless localization technologies for localization using radio frequency (RF) signals. These applications are changing how we work, eat, and socialize; so in fact they are instrumental in the evolution of our habits.

1.2.1 Evolution of Applications, Devices, and Networks

Figure 1.3 illustrates the evolution of applications, devices, and networks. The first communication device that enabled a popular application was the Morse pad for the telegraph application that was invented in the 1837. The telegraph was the very first short messaging system (SMS). It needed two operators familiar with the Morse code to transfer a message between two nodes of the telecommunication network. The operator at one node would read the message and re-route it to another location in the network that was closer to the destination. The message would go along the network from node to node until it reached the destination. These operators were like "human routers" for the first telecommunication network. The operators could have a coffee between the time they received a message and the time they transmitted it to the next node because data

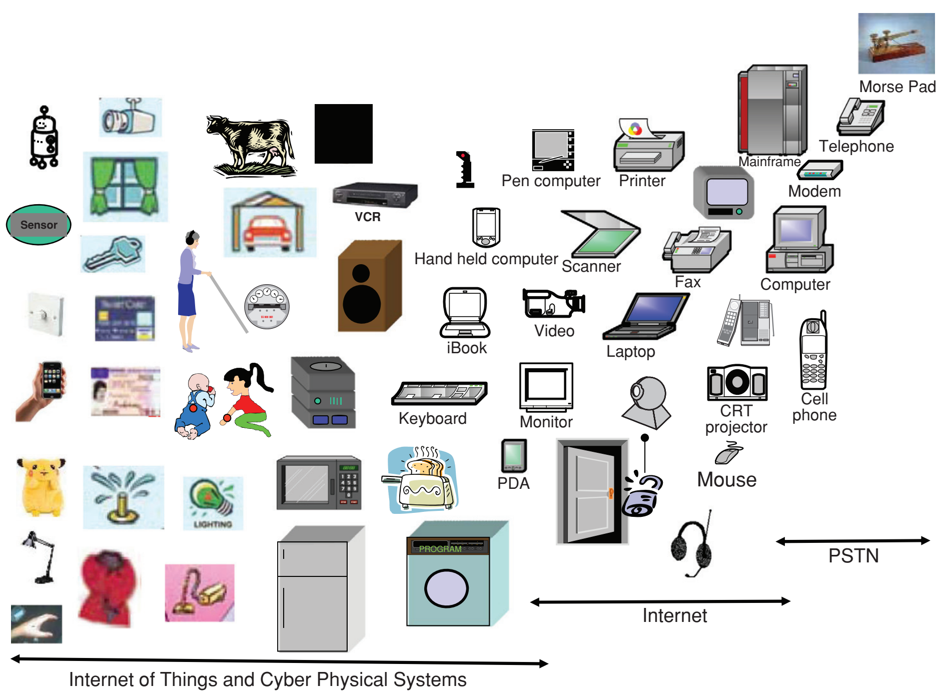

Figure 1.3 Evolution of applications, devices, and networks.

applications can tolerate such delay to a certain extent. The transmission technique for the device was digital communication. Therefore, the telegraph could be considered the first packet switched digital network with human routers designed for data burst SMS applications.

The more popular telephone network, which was invented in 1876, operated using analog telephone devices. The user of the device would connect to the operator and the operator would communicate with other operators to establish a line between the source and the destination before conversation starts and information gets transferred along the network. The operator in this application had to work hard to establish the connection fast enough and to maintain that connection during the period of information transmission or streaming of the conversation in both directions. The operator in this case was a human switch that was expected to establish the connection quickly and to maintain that connection during the communication period. Therefore, the telephone network was an analog connection-based circuit-switched network originally designed for voice applications. The Morse pad that was the device used for the telegraph network needed a specialized operator capable of using the code for data communications; as a result the telegraph industry evolved as an office-based application with certain limitations on its size. The telephone devices, however, could be used by anyone and they penetrated the home market; thus orders of magnitude higher numbers of telephone devices were sold and the telephone network became much larger than telegraph network generating tremendously larger revenue for the company. By considering the telephone and telegraph networks, we observe that at the beginning of the twentieth century, the telecommunications industry had already been exposed to a number of important issues, which played similar roles during the entire course of the past century and culminated in the emergence of modern wireless networks. Among these important issues were analog versus digital, voice versus data, packet-switched versus circuit-switched networking, and home versus office networking.

The next popular telecommunication devices related to information networks were voice-band modems. These devices emerged after the Second World War to allow communication between computers and computer terminals located in geographically separated areas. Computer networks, which evolved that way, extended the SMS supported by the telegraph to other data applications such as file transfer and remote terminal access. The size of the computer communication industry was still very small compared to the telephone industry until the penetration of the Internet into homes and through the use of desktop and laptop computers. The evolution of computer networks opened up new applications and communication devices such as printers, scanners, fax machines, video cameras, and monitors that could attach to them.

The popularity of wireless networks started with cellular and cordless telephones during the 1980s, extending voice applications across local and wide area networks. During the 1990s, wireless local area networking (WLAN) technology emerged and nurtured mobile computing to connect laptops (which were the primary mobile computing devices at the time) in homes and small office networks. In the 2000s, wireless personal area networking (WPAN) technology allowed communications between and with sensors that can virtually connect the Internet to everything to create the Internet of Things.

The latest devices that heavily impacted the evolution of information networking technology were mobile smart devices. The introduction of the iPhone in 2007 opened a new horizon for wireless data applications that demanded more efficient networks to support these data applications. Smart phones, lead by the iPhone, created a platform for running data-consuming applications such as YouTube access and web browsing on a wireless platform. This demand further increased the popularity of WLANs and forced cellular telephone service providers to move to physical layer technologies used in WLANs to increase the supported data rates. At the time of writing cyber physical systems are emerging to facilitate the massive data processing collected from distributed sensors for medical, transportation, power distribution, and other applications.

1.2.2 *Information Network Infrastructures and Wireless Access*

To support the transmission of voice, data, and video, several wired information network infrastructures have evolved throughout the past century. Wireless networks allow a mobile wireless device to access these wired information network infrastructures. At first glance, it may appear that a wireless network is only an antenna site or a base station connected to one of the switches or routers in the wired information infrastructure that enables a mobile terminal to be connected to the backbone network. In reality, in addition to the antenna site, a wireless network also needs to add its own mobility-aware switches, databases, and base station control devices to be able to support mobility and manage scarce radio resources when a mobile terminal changes its connection point to the network. Therefore, a wireless network has its own fixed infrastructure with mobility-aware switches and networked connections, similar to other wired infrastructures, as well as antenna sites and mobile terminals.

When the geographical coverage area of a network is very large, the cost of deployment and maintenance of the infrastructure is very high and a service provider makes the investment to build the network infrastructure. To compensate for that large investment, the service provider leases the infrastructure access to subscribers. We refer to these large infrastructures as backbone or wide-area wired backbone networks. The two major examples of these backbone networks are the PSTN and the Internet, each having a number of service providers in different countries. Wireless access to these networks is either through wide-area wireless cellular networks, which allow for wireless access over a large area of coverage through a service provider, or smaller networks, owned by private enterprise or individuals. These smaller networks form the so-called local, personal, and body area networks. Local area networks are either wired or wireless and the backbone networks are mostly wired networks. In this book we address wireless networking technologies while details of wired wide and local area networks are addressed in [Pah09].

Figure 1.4 shows the overall picture for wired and wireless telephone services using PSTN. The PSTN, which was designed to provide wired telephone services, is augmented by a wireless fixed infrastructure to support the mobility of a mobile device that communicates with several base stations mounted over antenna posts. The PSTN infrastructure consists of switches, point-to-point connections, and computers used for the operation and maintenance of the network. The fixed infrastructure of the cellular telephone service has its own mobility-aware switches, point-to-point connections, and other hardware and software elements that are needed for the mobile network

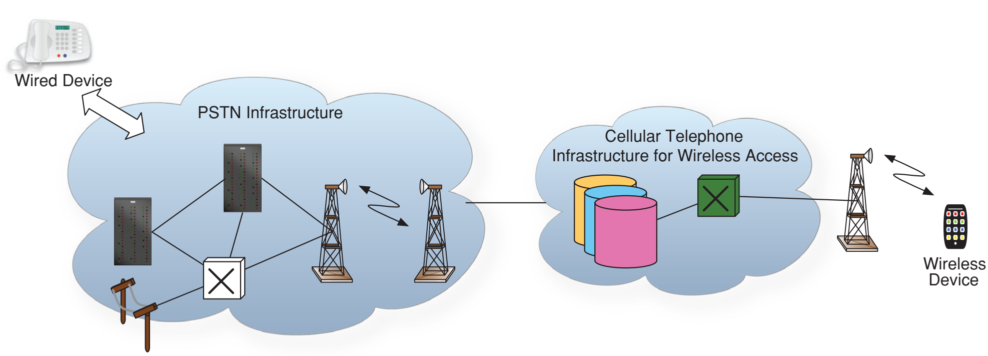

Figure 1.4 The PSTN and its extension to cellular telephone services.

operation and maintenance. A wireless telecommunication device, for example a smart phone, can connect to the PSTN infrastructure by replacing the wire attachment with radio transceivers. But, for the wireless device to change its point of contact, switches in the PSTN must be able to support mobility. Switches in the PSTN infrastructure were not originally designed to support mobility. To solve this problem, cellular telephone service providers have added their own fixed infrastructure with mobility-aware switches. The fixed infrastructure of the cellular telephone service provider is an interface between the base stations and the PSTN infrastructure that implements the environment to support mobility. The simplest wireless access to the PSTN is though a cordless telephone. This does not have any switch in the infrastructure and basically operates as a wireless connection between a handset and a telephone connected by wire to the PSTN and mostly through a standard or a proprietary protocol.

In the same way that a telephone service provider needs to add its own infrastructure to allow a mobile telephone to connect to the PSTN, a wireless data network provider needs its own infrastructure to support wireless Internet access. Figure 1.5 shows the traditional wireless data infrastructure and the additional wireless data infrastructure that allows wireless connection to the Internet. The traditional data network consists of routers, point-to-point connections, and computers for operation and maintenance. The elements of a wireless network include mobile devices, access points, mobility aware routers, and point-to-point connections. If the wireless data access intends to provide wide area coverage for the wireless data service, the new infrastructure has to support all the functionalities needed to support mobility. In simpler applications, such as a hot-spot or for home access, the wireless infrastructure does not necessarily need to be aware of mobility because connection to the Internet is through one access point only. However, to allow users with mobile devices to be able to connect to different access points, there is a need to support mobility through protocols and hardware.

The main difference between wireless access to the PSTN and the Internet is that wireless access to the PSTN, shown in Figure 1.4, is a connection-based voice-oriented network and wireless access to the Internet, shown in Figure 1.5, is a connectionless data-oriented network. A connection-based network needs a dialing process and, after dialing, a minimum quality of service is guaranteed to the user during the communication session. In connectionless networks, there is no dialing and the terminals are always connected to the network, but a uniform quality of service is not guaranteed. Figure 1.6 illustrates the basic difference between a packet-switched and a circuit-switched network in the handling and delivery of packets from a source to a destination terminal. In a connectionless

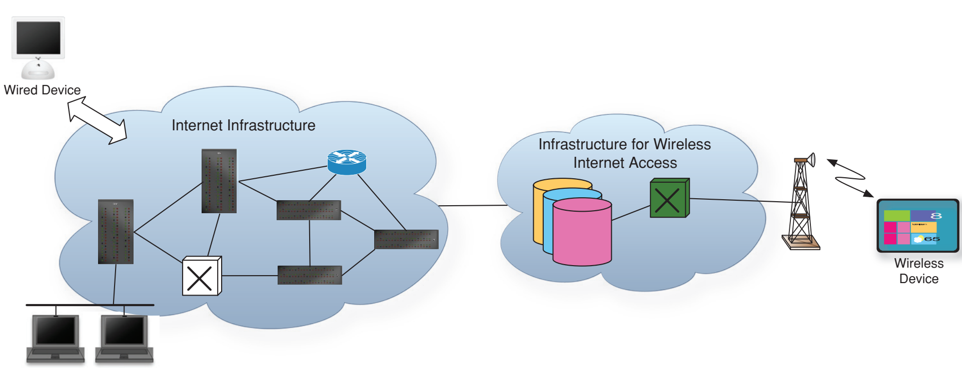

Figure 1.5 The Internet and its extension to cellular telephone services.

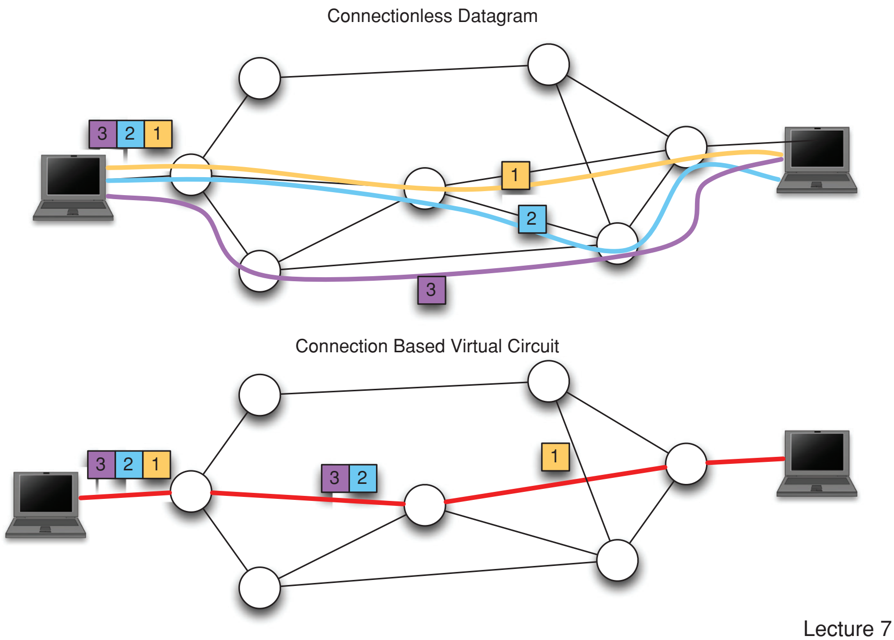

Figure 1.6 Connection-less packet-switched Internet versus connection-based circuit-switched PSTN.

data gram network, information packets takes routes that are determined by the routers, hub-by-hub, as based on the traffic and resources arriving and leaving the hub. As a result, consequent packets from a single information source may take different paths to arrive at the receiver. This approach provides a more efficient method to utilize the transmission line capabilities but has no guarantee for the delay of the arriving packets with respect to one another, which challenges support to maintain a prescribed quality of service for the user. In connection-based networks a virtual path is established between the source and destination, and the consecutive data packets take the same route. This formation allows more control on the delay and consequently the quality of service provided to the user.

1.2.3 Connection Between Wireless Access and Localization

Wireless localization is tied with wireless access through two connections. First, popular wireless localization techniques, such as Wi-Fi localization and cell tower localization, use the existing infrastructure and the transmitted signals originally established for wireless access and communications, to localize a mobile terminal. The data base of the location of the Wi-Fi access points or cell tower base stations is used as the landmark and the received signal strength or the time of flight of the signal between the landmark and the mobile terminal is used to estimate the distance of the terminal from the landmarks. The distances from several landmarks are used to estimate the location of the terminal. Using the existing infrastructure and the received signal strength is the most inexpensive and commercially popular method currently used for wireless localization of smart devices.

The second tie between wireless access and localization lies in understanding the multipath channel characteristics that cause deformation of the transmitted waveforms due to multipath effects. As we will describe later in this book, this deformation of the transmitted waveform by the multipath characteristics of indoor and urban areas for wireless communications imposes restrictions on the highest symbol transmission rate for communication applications. In localization application using the time of flight of the transmitted waveform, which provides a more precise measure for ranging the distance from a landmark, deformation of the waveform caused by multipath causes errors in estimations of the time of flight. The time of flight of the signal is often calculated from a reference location of a feature of a waveform, for example, the peak of the transmitted waveform. In the multipath environment the peak of the received signal is dislocated by the effects of the multipath causing an unwanted error in estimations of the distances using the time of flight estimation. Therefore, both high-speed wireless access and precise localization techniques need a careful understanding of the nature of the multipath arrivals in wireless media that is one of the important subjects addressed in this book.

1.2.4 Standards Organizations for Information Networking

The increasing number of portable and mobile applications on different communication devices demands a variety of standardized wireless access technologies operating on different frequency bands. Frequency bands are regulated by national agencies such as the Federal Communication Commission (FCC) in the United States. Wireless technologies that are discussed in this book include cellular telephone and personal communication systems that are operating within licensed bands and WLAN and WPAN technologies that are operating in unlicensed bands. Licensed bands are like a privately owned backyard. The owner of the band needs to invest a substantial amount of money and effort to obtain permission for using that band in a certain geographical area. These bands usually allow higher transmission power but they are more restricted in the size of the bandwidth. Unlicensed bands are similar to public gardens; users of these bands have access to a wider bandwidth but with restrictions on their transmission power. Figure 1.7 illustrates several licensed and unlicensed bands in the United States that are used both for different generations of cellular networks and for cordless telephones and several unlicensed bands used for WLAN and WPAN applications.

Standards define interface specifications between elements of a wireless network infrastructure allowing a global multivendor operation, which facilitates the growth of the industry. Figure 1.8 provides an overview of the standardization process in information networking. The standardization process starts in a special interest group of a standards developing body such as the Institute of Electrical and Electronics Engineers (IEEE 802.11) or Global System for Mobile (GSM) communications, which defines the technical details of a networking technology as a standard for operation. The defined standard for implementation of the desired network is then moved for approval by a regional organization such as the European Telecommunication Standards Institute (ETSI) or the American National Standards Institute (ANSI). The regional recommendation is finally submitted to world-level organizations, such as the International Telecommunications Union (ITU), International Standards Organization (ISO), or International Electrotechnical Commission (IEC), for final approval as an international standard. There are a number of standards organizations involved in information networking. Table 1.1 provides a summary of the important standards playing major roles in shaping the information networking industry, which are also mentioned in this book.

The most important standard developing organizations for technologies described in this book are the IEEE 802-series standards for personal, local, and metropolitan area networking. The IEEE