NETWORKING FUNDAMENTALS

Wide, Local and Personal Area Communications

KAVEH PAHLAVAN

Worcester Polytechnic Institute, USA

PRASHANT KRISHNAMURTHY

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ABOUT THE AUTHORS

Kaveh Pahlavan, is a Professor of Electrical and Computer Engineering (ECE), a Professor of Computer Science (CS), and Director of the Center for Wireless Information Network Studies, Worcester Polytechnic Institute (WPI), Worcester, MA. He is also a visiting Professor of Telecommunication Laboratory and CWC, University of Oulu, Finland. His area of research is location-aware broadband wireless indoor networks. He has contributed to numerous seminal technical publications and patents in this field. He is the principal author of the *Wireless Information Networks* (with Allen Levesque), John Wiley and Sons, 1995 and *Principles of Wireless Networks – A Unified Approach* (with P. Krishnamurthy), Prentice Hall, 2002. He has been a consultant to a number of companies, including CNR Inc., GTE Laboratories, Steinbrecher Corp., Simplex, Mercury Computers, WINDATA, SieraComm, 3COM, and Codex/Motorola in Massachusetts; JPL, Savi Technologies, RadioLAN in California; Aironet in Ohio; United Technology Research Center in Connecticut; Honeywell in Arizona; Nokia, LK-Products, Elektrobit, TEKES, the Finnish Academy in Finland; and NTT in Japan. Before joining WPI, he was the director of advanced development at Infinite Inc., Andover, MA, working on data communications. He started his career as an assistant professor at Northeastern University, Boston, MA. He is the Editor-in-Chief of the *International Journal on Wireless Information Networks*. He was the founder, the program chairman, and organizer of the IEEE Wireless LAN Workshop, Worcester, in 1991 and 1996 and the organizer and technical program chairman of the IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications, Boston, MA, 1992 and 1998. He has also been selected as a member of the Committee on Evolution of Untethered Communication, US National Research Council, 1997 and has led the US review team for the Finnish R&D Programs in Electronic and Telecommunication in 1999 and NETs project in 2003. For his contributions to the wireless networks he was the Westin Hadden Professor of Electrical and Computer Engineering at WPI during 1993–1996, was elected as a fellow of the IEEE in 1996 and became a fellow of Nokia in 1999. From May to December of 2000 he was the first Fulbright–Nokia scholar at the University of Oulu, Finland. Because of his inspiring visionary publications and his international conference activities for the growth of the wireless LAN industry, he is referred to as one of the founding fathers of the wireless LAN industry. In the past few years his research work has been the core for more than 25 patents by Skyhook Wireless, where he acts as the chief technical advisor. In January 2008 Steve Jobs announced that Skyhook Wireless's WiFi localization technology is used in iPhone. Details of his contributions to this field are available at www.cwins.wpi.edu.

Prashant Krishnamurthy is an associate professor with the graduate program in Telecommunications and Networking at the University of Pittsburgh. At Pitt, he regularly teaches courses on cryptography, network security, and wireless communications and networks. His research interests are wireless network security, wireless data networks, and position location in indoor wireless networks. He is the coauthor of the books *Principles of Wireless Networks – A Unified Approach* and *Physical Layer of Communication Systems* and is a co-editor of *Information Assurance: Dependability and Security in Networked Systems*. He served as the chair of the IEEE Communications Society Pittsburgh Chapter from 2000 to 2005. He obtained his PhD from Worcester Polytechnic Institute, Worcester, MA, in 1999.

PREFACE

Information networking has emerged as a multidisciplinary diversified area of research over the past few decades. From traditional wired telephony to cellular voice telephony and from wired access to wireless access to the Internet, information networks have profoundly impacted our lifestyle. At the time of writing, over 3 billion people are subscribed to cellular services and close to a billion residences have Internet connections. More recently, the popularity of smartphones enabling the fusion of computers, networking, and navigation for location-aware multimedia mobile networking has opened a new way of attachment between the human being and information networking gadgets. In response to this growth, universities and other educational institutions have to prepare their students in understanding these technologies.

Information networking is a multidisciplinary technology. To understand this industry and its technology, we need to learn a number of disciplines and develop an intuitive feeling for how these disciplines interact with one another. To achieve this goal, we describe important networking standards, classify their underlying technologies in a logical manner, and give detailed examples of successful technologies. The selection of detailed technical material for teaching in such a large and multidisciplinary field is very challenging, because the emphasis of the technology shifts in time. In the 1970s and 1980s the emphasis of industry and, subsequently, the interest in teaching networks were primarily based on queuing techniques [Kle75, Sch87, Ber87] because, at that time, medium access control was playing an important role in differentiating local-area network (LAN) technologies such as Ethernet, token ring and token bus. At that time, researchers and educators were interested in understanding the random behavior of traffic in contention access on computer resources and performance issues such as throughput and delay. The next generation of textbooks in the 1990s was around details of protocols used in the seven-layer ISO model, and they were written mostly by professors of computer science [Tan03, Pet07, Kur01]. During this period, authors with an electrical engineering education would introduce similar material with more emphasis on physical channels [e.g. Sta00]. These books described the Internet and asynchronous transfer mode as examples for wide-area networks (WANs) and provided details of a variety of LAN technologies at different levels of depth. They lacked adequate details in describing the cellular and other wireless networks that have been the center of attention in recent years for innovative networking.

The success of wireless information networks in the 1990s was a motivation behind another 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 networks and local wireless networks. These books were written by professors of electrical engineering and computer engineering with different levels of emphasis on detailed descriptions of the lower layers issues and system engineering aspects describing details of implementation of wireless networks. These books do not cover the description of local wired technologies such as Ethernet or details of the implementation of bridges, switches, and routers which are used to form the Internet.

The emergence of wireless access and the dominance of the Ethernet in LAN technologies have shifted the innovations in networking towards the physical layer and characteristics of the medium. Currently, there is no single textbook that integrates all the aspects of current popular information networks together and places an emphasis on the details of physical layer aspects. In this book we pay attention to the physical layer while we provide fundamentals of information networking technologies which are used in wired and wireless networks designed for local- and wide-area operations. The book provides a comprehensive treatment of the wired Ethernet and Internet, as well as of cellular networks, wireless LANs (WLANs), and wireless personal area network (WPAN) technologies. The novelty of the book is that it places emphasis on physical layer issues related to formation and transmission of packets 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 "Introduction to WANs and LANs." The principal author also taught shorter versions of the course at the University of Oulu, Finland, focused on the wired LANs and WLANs. The co-author of the book has taught material from this book at the University of Pittsburgh in several courses, such as "Mobile data networks," "Network security," and "Foundations of wireless communications." These courses were taught for students with electrical engineering, computer science, information science, and networking backgrounds, both from academia and industry.

We have organized the book as follows: we start with an overview of telecommunications followed by four parts each including several chapters. Part I contains Chapters 2–5 and explains the principles of design and analysis of information networks at the lowest layers. In particular, this part is devoted to the characteristics of the transmission media, applied transmission and coding, and medium access control. Part II and Part III are devoted to detailed descriptions of important WANs and LANs respectively. Part II describes the Internet and cellular networks and Part III covers popular wired LANs and WLANs, as well as WPAN technologies. Part IV describes security, localization, and sensor networking as other important aspects of information networks that have been important topics for fundamental research in recent years. The partitioned structure of the book allows flexibility in teaching the material. We believe that the most difficult part of the book for the students is Chapters 2–5, which provide a summary through mathematical descriptions of numerous technologies. Parts II and III 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 5) before describing time-division multiple access cellular networks (Chapter 7). Then he introduces spread-spectrum coding techniques (Chapters 3 and 4) and code-division multiple access cellular networks (Chapter 7), and finally covers multidimensional constellations (Chapter 3) before discussing WLANs (Chapter 9). In fact, we believe that this is an effective approach for enabling the understanding of the fundamental concepts in students. Therefore, depending on the selection of the material, depth of the coverage, and background of the students, this book can be used for senior undergraduate or first- or second-year graduate courses in computer science, telecommunications, electrical and computer engineering, or electrical engineering departments as one course or a sequence of two courses.

The idea of writing this book and the first table of contents was developed between the lead author and Professor Mika Ylianttila of the University of Oulu, Finland, during the late summer of 2006 in Helsinki and Oulu, Finland, with some input from Dr. Sassan Iraji of Nokia. The basic idea was that the most interesting parts of the current networking issues evolve around physical layer aspects of wireless networks. Therefore, it is a good idea to write a new book describing the fundamentals of networks with emphasis on lower layers of communication protocols and technologies. To have a practical model, we started using the structure of the current authors' previous book, *Principles of Wireless Network – A Unified Approach*, and expanded that to include physical layer aspects of the wired medium as it is applied to the Ethernet and the Internet. Initially, we had the entire modulation and coding aspects of transmission in one chapter. Dr. Mohammad Heidari of the Center for Wireless Information Network Studies at WPI helped us to extract the coding parts from that chapter and prepare a first draft of a new chapter on coding based on class notes of the lead author for a similar lecture at the LANs and WANs course in WPI for which he had served as a teaching assistant. Dr. Heidari also committed to prepare the solutions for the book. The authors thank Dr. Heidari for his contribution in preparing Chapter 4 and editing Chapter 3 of the book and Dr. Ylianttila for his help in preparing the original proposal. In addition, the authors 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 Professor Jacques Beneat, 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. The lead author also thanks Dr. Siamak Ayandeh and Brian Sylvester for their lectures in his classes on the Internet and Ethernet which has affected formation of material in Chapters 6 and 8 of the book, Ferit Akgul for his careful editing of the example and problems in the manuscript, and students of his Introduction to WANs and LANs course in Spring 2009 at WPI for their editorial comments on the first draft of the book. The second author expresses his gratitude to Dr. Richard Thompson, Dr. David Tipper, Dr. Martin Weiss, Dr. Sujata Banerjee, Dr. Taieb Znati, and Dr. Joseph Kabara 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. Similarly, we would like to express our appreciation to all graduates and affiliates of the 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 on material presented in this book.

We have not directly referenced our referral to several resources on the Internet, notably Wikipedia. While there are people that 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 and usage of these resources.

In particular, we have used numerous articles in Wikipedia in many ways, as a quick check of facts and for links to references in many chapters of the book. We believe that such resources also benefit students tremendously.

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1

INTRODUCTION TO INFORMATION NETWORKS

1.1 INTRODUCTION

In the eyes of an engineer, the complexity of an industry relates to the challenges in implementation, size of the market for the industry, and the impact of the technology in this industry on human life. Everyday we use information networks and information technology more than any other technology – for social networking in both professional and personal aspects of our lives. The heart and the enabler of this technology is the *information networking industry*, which brings us mobile and fixed telephone services and connects us to the Internet in the home, office, and on the road, wherever we are. Although the infrastructure of the information networking industry is not seen by the public because it is mostly buried under the ground or it is propagating in the air invisibly, it is the most complex technology to implement, it owns the largest market size by far among all

Networking Fundamentals: Wide, Local and Personal Area Communications, by Kaveh Pahlavan and Prashant Krishnamurthy

industries, and it has enabled us to change our lifestyle to the extent that we often refer to our era as “the age of information technology.”

To have an intuitive understanding of the size of the information networking industry it is good to know that the size of the budget of AT&T in the early 1980s, before its divestiture, was close to the budget of the fifth largest economy of the world. AT&T was the largest public switched telephone network (PSTN) company in the world and its core revenue at that time was generated from the plain old telephone service (POTS) that was first introduced in 1867. During the past two decades, the cellular telephone industry has augmented the income of the prosperous voice-oriented POTS with subscriber fees from more than 3 billion cellular telephone users worldwide. Today, the income of the wireless industry dominates the income of the wired telephone industry. While this income is still by far dominated by the revenue of the cellular phones, smart mobile terminals are gradually changing this characteristic by bringing more Internet-oriented applications into the terminal. In the mid 1990s, the Internet brought the computer and data communications and networking industry from a relatively smaller business-oriented office industry to an “everyday and everybody” use home-oriented industry that soon generated an income comparable to that of a voice-oriented POTS and the wireless industry. At the time of writing, the revenue of the information networking *industry* is dominated by the combined income of the wired and wireless telephone services over the PSTN and the Internet access industries, with total annual revenue of a few trillion dollars, which makes it one of the largest industries in the world.

At the start of the year 2008, the number of mobile phone subscriptions in the world had already passed 3 billion, with a worldwide average penetration rate of close to 50%, making the mobile phone the most widespread and adopted technology in the world. At the same time, close to a billion people around the world have access to the Internet or equivalent mobile Internet services using a mobile phone, a laptop, or a personal computer. In June 2007, Apple lunched the iPhone, which opened a new dimension in the integration of computer, communication, and navigation devices in a mobile handheld terminal. Around 4 million devices were sold during the first 200 days [MOB08], and in the first quarter of business it turned in to the third best-selling smartphone in the world [ARS08]. The third-generation (3G) iPhone introduced in July 2008 sold 1 million in the first 3 days [WAC08]. The iPhone provides built-in mobile user-friendly applications for video streaming, audio storage, and localization, as well as a number of popular applications, such as e-mail access, stock market reports, weather condition reports, calendar, and notebooks, on top of the traditional mobile phone and short messaging. This range of applications uses location-aware and secure broadband wireless access technologies provided through cellular networks, WiFi wireless local area networks (WLANs), and Bluetooth-based wireless personal-area networks (WPANs) to connect to the Internet and the PSTN backbones.

The authors believe that the information network technologies which enable smartphones to integrate traditional communication and Internet applications provide a suitable framework for teaching a basic course to introduce the fundamentals of modern information networks to students. The objective of this book is to provide a text for teaching these fundamentals at a senior undergraduate or first-year graduate-level course. In the rest of Section 1.1 we describe the elements of the information networks, a brief history of major events since the inception of the industry, a summary of the important standards, and a short description of long-haul standards to interconnect networks worldwide. The rest of this chapter provides a more detailed overview of evolution of important wide-area networks

(WANs) and local-area networks (LANs) followed by a brief description of the material presented in the rest of this book.

1.1.1 Elements of Information Networks

Figure 1.1 illustrates the fundamental elements of information networking. A network infrastructure interconnects user applications through telecommunication devices using network adaptors to provide them with means for exchanging information. Users are human beings, computers, or "things" such as a light bulb. Applications could be a simple telephone call, sending a short message, downloading a file, or listening to audio or video streams. The telecommunication devices range from a simple dumb terminal only translating user's message to an electrical signal used for communication, up to a smart terminal enabling multiple applications through a number of networking options. The network adaptor could be a connector to a pair of wires for a plain old telephone, a cellular phone, or a wireless local network chip set for a personal computer, a laptop or a smartphone, a low-power personal communication chip set for a light bulb, or a reader for a smart card. The information network infrastructure consists of a number of interconnecting elements that are connected primarily through point-to-point links. Switches include fixed and variable-rate connection-based circuit switches or connectionless packet-switching routers. The point-to-point links include a variety of fibers, coaxial cables, twisted-pair wires, and wireless technologies.

Figure 1.2 shows a view of the evolution of telecommunication devices and the networking concepts which have allowed these devices to interconnect with one another. The first communication device was the Morse pad invented for telegraph application in the nineteenth century to transfer coded short messages using Morse code. This was followed by the telephones devices used for voice communications. Both terminals were dumb and used for human-to-human communications. Shortly after the Second World War, the first dumb computer terminals were networked to start the era of computer-to-computer and human-to-computer networking which finally emerged into the Internet. Simplicity, flexibility, and lower cost of implementation of Internet technology opened a new frontier for the emergence of numerous popular applications and computer networking devices.

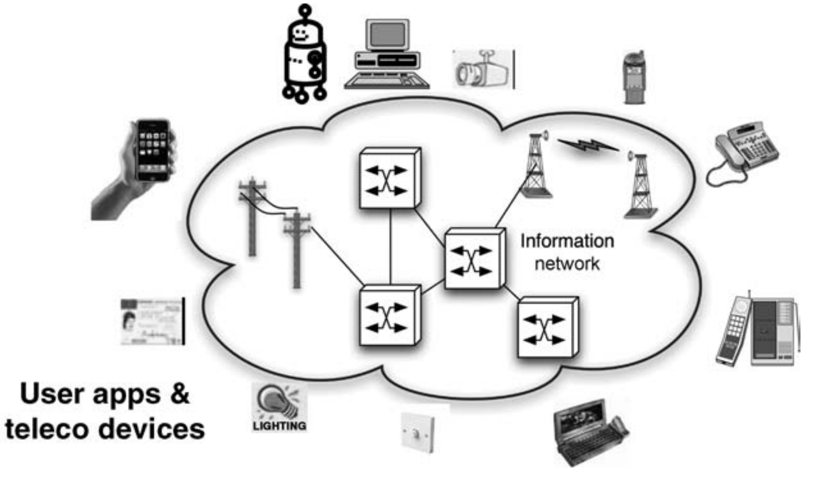

FIGURE 1.1 Elements of information networks.

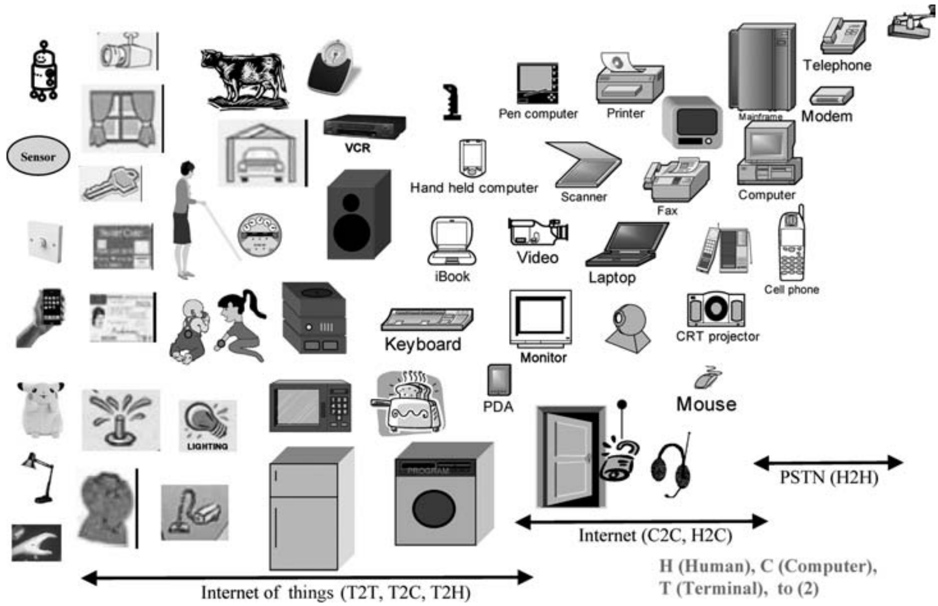

FIGURE 1.2 Evolution of telecommunication devices and information networks.

More recently, with the introduction of mobile wireless access to the PSTN and the Internet, a new window of opportunity for connecting "things" with the Internet and the so-called the "Internet of Things" has become popular. The Internet of Things allows things-to-human, things-to-computer and things-to-things networking, turning virtually everything to a communication device. Since these new devices have different data rates, power consumption, and cost requirements, a number of networking technologies have evolved in their support.

To support the evolution of telecommunication devices and applications, several information network infrastructures have evolved throughout the past 150 years. The largest of the existing backbone information networks are the PSTN, the Internet and the hybrid fiber cable (HFC). The PSTN was designed for the telephony application and it is also the backbone for popular cellular telephone networks. Cell phones are connecting to the PSTN using different cellular technologies. The Internet supports all computer communication data applications, and HFC was designed for cable TV distribution. To connect to the backbone networks, terminals are usually clustered in a local area to form a local network and the local network is connected to the backbone using another technology, which we can refer to as the access network. In this way, networking technologies are divided into core or backbone, access, and distribution or local networks.

In the PSTN industry, the local network is a private box exchange (PBX) used in office environments. It is a private switch allowing internal telephones of a company to talk with one another without the intervention of the core network. In the home, the local network for PSTN is the random tree wiring distribution in a residence which connects all rooms to the main line connected to the PSTN. Cordless telephones allow portable phones to connect to the home network. Cellular telephone companies add smaller base stations (BSs) called picocells inside large buildings, such as airports and shopping malls, and they are designing femtocell technologies for home applications to help cellular technologies to penetrate to indoor areas. In the case of the Internet, the local distribution network is a LAN. The Ethernet technology is dominating the wired LAN technology in offices, and WLANs complement them for mobile wireless access. In homes, the most popular Internet distribution network is the WLAN.

An access network is something between a WAN and a LAN. The infrastructure for the access network is a twisted-pair wire, a coaxial cable, a fiber line, a wireless terrestrial, or a satellite connection which connects the office or home to the backbone network. In the PSTN industry, this access network for the home is sometimes referred to as the last mile network. In the Internet industry it is sometimes referred to as metropolitan area networks (MANs). Home network access technologies are very important for the service providers because the high cost of the wiring to the home needs to be recuperated through the income of a single private subscriber.

1.1.2 Chronology of Information Networks

In the same way that the Greek philosophers of antiquity addressed the basic challenges in philosophy which laid the foundation for modern civilization, the emergence of the telegraph and the telephone in the early days of the information networking industry addressed the basic challenges facing information networking which have been carried on until modern times. Connection-based telephone conversations versus datagram-based connectionless messaging, digital versus analog, local versus wide area networking, wired versus wireless communications, and home versus office markets were all introduced in those early days. Over a century, engineers have discovered a number of technologies to enable these two services to adapt to the evolution of the terminals and to support ubiquitous operation.

To understand the sequence of events resulting in the evolution of information networks, it is useful to have a quick overview of the chronology of the events, which is presented in Table 1.1. Five years after Gauss and Weber's experiment to introduce wired telegraph for manually digitized data in 1834,[1] information networking started with the simple wired telegraph that used Morse code for digital data communication over long-distance wires between the two neighboring cities of Washington DC and Baltimore in 1839. It took 27 years, until 1866, for engineers to successfully extend this network over the ocean to make it a worldwide service. In 1900, 34 years after the challenging task of deploying cables in the ocean and 3 years after the first trial of the wireless telegraph, Marconi demonstrated *wireless* transoceanic telegraphy as the first wireless data application. It took over 150 years for this industry to grow into the wireless Internet. Bell started the telephone industry in 1867,[2] the first wired analog voice telecommunication service. It took 47 years for the telephone to become a transoceanic service in 1915, and it took almost 100 years for this industry to flourish into the wireless cellular telephone networks in the 1990s. The wireless telegraph was a point-to-point solution that eliminated the tedious task of laying very long wires in harsh environments. The telegraph was indeed a manual short messaging system (SMS) that

[1] Although focused on civil engineering, Rensselaer Polytechnic Institute (RPI), Troy, NY, the first engineering school in the USA, was established in 1824 as well. These events are indicators of the start of the industrial revolution and dominance of the engineers in shaping the future of the world.

[2] In the 1860s, in the dusts of the closing of the Civil War in the USA, a new wave of engineering and science schools mushroomed in the USA, starting with MIT (1862) in Boston and Worcester Polytechnic Institute (WPI; 1865) in Worcester, MA.

TABLE 1.1 A Brief History of Telecommunications

	Chronology of information networks
1839	First demonstration of telegraph between DC and Baltimore (Morse)
1876	Manually switched telephone for analog voice (Bell)
1900	Transoceanic wireless telegraph (Marconi)
1915	Transcontinental telephone (by Bell)
1946	First computer (U Penn)
1950	Voice-band modems for first computer networks using PSTN infrastructure
1968	Cable TV development and introduction of HFC
1969	ARPANET packet-switched network started (first node at UCLA)
1972	Demonstration of cellular systems (Motorola)
1973	Ethernet was invented (Metcalfe)
1980	IPv4 was released, fiber-optic systems were applied to the PSTN
1981	IEEE 802.3 adopted Ethernet
1986	IETF was formed
1990	GSM standard for TDMA cellular
1991	ATM Forum was founded
1994	Netscape was introduced and Internet became popular
1995	IS-95 standard for CDMA cellular, fast Ethernet at 100 Mb/s, first ATM specification
1996	IPv6 was defined by IETF
1997	IEEE 802.11 completed
1998	IEEE 802.1D MAC bridges and STA, gigabit Ethernet, 802.16 WMAN, IEEE 802.15.1 Bluetooth for WPAN
1999	IEEE 802.11b at 11 Mb/s
2000	3G IMT-2000 for wireless Internet access was introduced
2001	IEEE 802.11a for 54 Mb/s at 5 GHz using OFDM
2002	Mobile IP standard completed, UWB was used for high-speed WPAN
2003	IEEE 802.1Q virtual LAN, IEEE 802.11g using OFDM at 2.4 GHz, IEEE 802.15.4 ZigBee, 10 Gb/s Ethernet
2004	IEEE 802.1w rapid spanning tree algorithm for switches, IEEE 802.11d WiMAX for WMAN
2005	IEEE 802.11e mobile WiMAX
2006	RFID, sensor networks, "Internet of Things"
2007	IEEE 802.11n for 100 Mb/s
2008	iPhone, 100 Gb/s Ethernet

needed a skilled worker to decode the transmitted message. The wireless telephone network had to support numerous mobile users. While the challenge for wireless point-to-point communications is the design of the radio, the challenge for a wireless network is the design of a *system* that allows many mobile radios to work together.

The computer era started with the demonstration of the first digital computer at the University of Pennsylvania in 1946. Computers have revolutionized the traditional methods for information storage and processing that were in use since the dawn of literacy some 3000 years ago. The massive information stored and processed by computers needed communication networking. The first computer communication networks started after the Second World War by using voice-band modems operating over the PSTN infrastructure to exchange large amounts of data among computers located at great distances from one another. The need of the computer communication industry for massive information transfer and the high cost of leased lines provided by PSTN service providers to be used for voice-band data communications stimulated the evolution of sophisticated modem design technologies. By the late 1980s a number of modem design techniques were introduced which could achieve higher data rates over a fixed bandwidth channel [Pah88]]. These technologies laid the foundation for the design of the different physical layers that have been at the core of advancements in evolution of broadband access using cable modems and digital subscriber line (DSL), as well as LAN, WLAN, and WPAN technologies, in the 1990s and 2000s. In parallel with the growth of information theory to support higher data transmission rates, networking protocols emerged first for reliable transmission of data and later to facilitate the implementation of ever-growing computer applications.

About two decades after the emergence of circuit-switched computer communication networks, in 1969, the first wide-area packet-switched network called *Defense Advanced Research Projects Agency* Department Network (DARPAnet) was introduced, which later on became the Internet and gained popularity in the mid 1990s. A few years after the introduction of DARPAnet, in 1973, the first wired LAN, Ethernet, was invented, which dominated the LAN industry again in the mid 1990s. The Internet/Ethernet network core has dominated the networking industry, and numerous other technologies and applications have emerged around them. These technologies include a variety of Institute of Electrical and Electronics Engineers (IEEE) 802.11 WLANs, a number of IEEE 802.15 WPANs, several IEEE 802.16 wireless MANs (WMANs), a few IEEE 802.1 bridging technologies, and a number of transport control protocol (TCP)- and Internet protocol (IP)-based protocols defined by the Internet Engineering Task Force (IETF) which are highlighted in Table 1.1.

1.1.3 Standards Organizations for Information Networking

The increasing number of applications, and the information networking technologies to support them, has demanded standardization to facilitate the growth of the industry. Standards define specifications for the design of networks allowing multi-vendor operation which is essential for the growth of the industry. Figure 1.3 provides an overview of the standardization process in information networking. The standardization process starts in a special interest group of a standard developing body such as the IETF or IEEE 802.3, 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

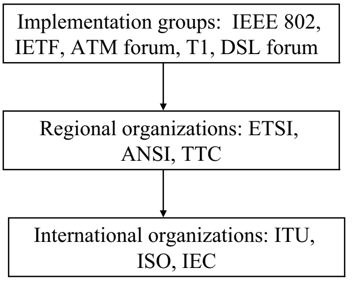

FIGURE 1.3 Standard development process.

TABLE 1.2 Summary of Important Standard Organizations for Information Networking

Important Standards Organizations	
IEEE (Institute of Electrical and Electronics Engineers)	Publishes 802 series standards for LANs and 802.11, 802.15, and 802.16 for wireless applications
T1	Sponsored by Alliance for Telecommunications Information Solutions (ATIS) telecommunication standards body working on North American standards
ATM (Asynchronous Transfer Mode) Forum	An industrial group working on a standard for ATM networks
DSL (Digital Subscriber Loop) Forum	An industrial group working on xDSL services
CableLab	Industrial alliance in the USA to certify DOCSIS-compatible cable modems
IETF (Internet Engineering Task Force)	Publishes Internet standards that include TCP/IP and SNMP. It is not an accredited standards organization
FCC (Federal Communication Commission)	The frequency administration authority in the USA.
EIA/TIA (Electronic/ Telecommunication Industry Association)	US national standard for North American wireless systems
ANSI (American National Standards Institute)	Accepted 802 series and forwarded to ISO. Also published FDDI, HIPPI, SCSI, and Fiber Channel. Developed JTC models for wireless channels
ETSI (European Telecommunication Standards Institute)	Published GSM, HIPERLAN/1, and UMTS
CEPT (Committee of the European Post and Telecommunication)	Standardization body of the European Posts Telegraph and Telephone (PTT) ministries. Co-published GSM with ETSI
IEC (International Electrotechnical Commission)	Publishes jointly with ISO
ISO (International Standards Organization)	Ultimate international authority for approval of standards
ITU (International Telecommunication Union formerly CCITT)	International advisory committee under United Nations. The Telecommunication Sector, UTU-T, published ISDN and wide-area ATM standards. Also works on IMT-2000

(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 1.2 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 of the standard development organizations for technologies described in this book produces the IEEE 802-series standards for personal, local, and metropolitan area networking. The IEEE, the largest engineering organization in the world, publishes a number of technical journals and magazines and organizes numerous conferences worldwide. The IEEE 802 community is involved in defining standard specifications for information networks. The number 802 was simply the next free number that the IEEE could assign to a committee at the inception of the group on February 1980, although "80-2" is sometimes associated with the date of the first meeting. Regardless of the ambiguity of the name, the IEEE 802 community has played a major role in the evolution of information networks by introducing IEEE 802.3 Ethernet, IEEE 802.11 WLANs, IEEE 802.15 WPAN, and IEEE 802.16 WMAN and other standards which are discussed in detail in this book.

Another important standard development organization is the IETF, which was established in January 1986 to develop and promote Internet standard protocols around the TCP/IP suite for a variety of popular applications. In the 1990s, the Asynchronous Transfer Mode (ATM) Forum was an important standard development group trying to develop standards for connection-based fixed packet-length communications for the integration of all services. This philosophy was in contrast with Internet/Ethernet networking using connectionless communications with variable and long-length packets.

Telecommunication/Electronic Industry Association (TIA/EIA) is a US national standards body defining a variety of wire specifications used in LANs, MANs, and WANs. The TIA/EIA are trade associations in the USA representing several hundred telecommunications companies. The TIA/EIA has cooperated with the IEEE 802 community to define the media for most of the wired LANs used in fast and gigabit Ethernet. TIA/EIA also defines cellular telephone standards such as Interim Standard (IS-95) or cdmaOne and the IS-2000 or CDMA-2000 (respectively the second and third generation) cellular networks. ETSI and the Committee of the European Post and Telecommunications (CEPT) were the European standardization bodies publishing wireless networking standards, such as the global system for mobile communications (GSM) and the universal mobile telecommunications system (UMTS), in the EU.

The most important international standards organizations are the ITU, the ISO, and the IEC, which are all based in Geneva, Switzerland. Established in 1865, the ITU is an international advisory committee under the United Nations and its main charter includes telecommunication standardization and allocation of the radio spectrum. The telecommunication sector, ITU-T, has published for instance the integrated service data network (ISDN) and wide-area ATM standards, as well as International Mobile Telephone (IMT-2000) for 3G cellular networks. The World Administrative Radio Conference (WARC) was a technical conference of the ITU where delegates from member nations of the ITU met to revise or amend the entire international radio regulations pertaining to all telecommunication services throughout the world. The ISO and IEC are composed of the national standards bodies, one per member economy. These two standards often work with one another as the ultimate world standard organization. Established in 1947, the ISO nurtures worldwide proprietary industrial and commercial standards that often become law, either through treaties or national standards. The ISO seven-layer model for computer networking is one of the prominent examples of ISO standards. IEC, which started in 1906, is a nongovernmental international standards organization for "electrotechnology," which includes a vast number of standards from power generation, transmission and distribution to home appliances and office equipment, to telecommunication standards. The IEC publishes standards with the IEEE and develops standards jointly with the ISO and the ITU.

1.1.4 Evolution of Long-Haul Multiplexing Standards

In telecommunications and computer networks, multiplexing is used where multiple data streams are combined into one signal to share the expensive long-haul transmission resources. From a different perspective, multiplexing divides the physical capacity of the transmission medium into several logical channels, each carrying a data stream. The two most basic forms of multiplexing over point-to-point connections are time-division multiplexing (TDM) and frequency-division multiplexing (FDM). In optical communications, FDM is referred to as wavelength-division multiplexing (WDM). Multiple streams of digital data can also use code-division multiplexing (CDM), which has not been commercially successful over wired networks. Variable bit-rate digital bit streams may be transferred efficiently over a fixed-bandwidth channel similar to TDM by means of statistical multiplexing techniques such as ATM. If multiplexing is used for channel access then it is referred to as medium access control (MAC), in which case TDM becomes time-division multiple access (TDMA), FDM becomes frequency-division multiple access (FDMA), CDM becomes code-division multiple access (CDMA), and statistical multiplexing into something like carrier sense multiple access (CSMA). Multiplexing techniques are simple and they are part of the physical layer of the network. We discuss them in this section. MAC protocols are more complex and we describe them in Chapter 5.

In PSTN, the home user's telephone line carrying telephone or DSL data typically ends at the remote concentrator boxes distributed in the streets, where these lines are multiplexed and carried to the central switching office on significantly fewer numbers of wires and for much further distances than a customer's line can practically go. Fiber multiplexing lines, mostly using ATM protocols, are commonly used as the backbone of the network which connects POTS lines with the rest of the PSTN and carry data provided by DSLs. As a result, PSTN has been the driver for the development and standardization of most multiplexing techniques. In the early 1960s, the first multiplexing system used for telephony was FDM. Figure 1.4 illustrates this early multiplexing system. This system multiplexed 12 subscribers, each with a 4 kHz bandwidth signal in frequencies between 60 and 108 kHz. Figure 1.4 shows the original bandwidths for each subscriber, the bandwidths raised in frequency, and the multiplexed channel. In PSTN connection to the home, as shown in Figure 1.5, FDM is also used to multiplex DSL data services with POTS and the so called Home Phone Network Alliance (HPNA) signal for Ethernet-like networking over home telephone wires. The POTSs use the frequency range between 20 Hz and 3.4 kHz, DSL uses

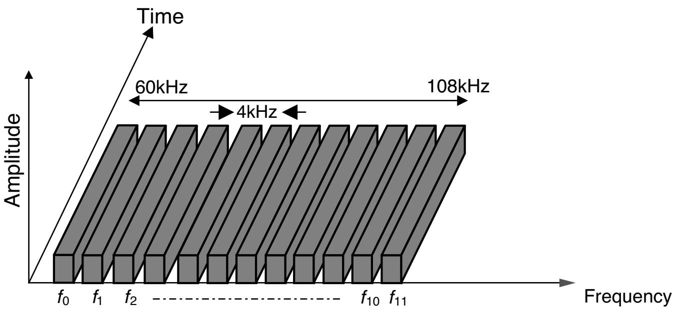

FIGURE 1.4 FDM used in telephone networks multiplexing 12 subscribers each with 4 kHz bandwidth in frequencies between 60–108 kHz.