universal personal communications

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simulation and software radio

for mobile communications

CD-ROM INCLUDED

Contents

Preface

ज्ञानं ज्ञेयं परिज्ञाता त्रिविधा कर्मचोदना ।
करणं कर्म कर्तेति त्रिविधः कर्मसंग्रहः ॥

jñānaṁ jñeyaṁ parijñātā
tri-vidhā karma-codanā
karaṇaṁ karma karteti
tri-vidhaḥ karma-saṅgrahaḥ

> Knowledge, the object of knowledge, and the knower are the three factors that motivate the action; the senses, the work, and the doer are the three constituents of action.
>
> —*The Bhagvad Gita (18.18)*

From September 1996 to August 1997, we worked together at the Delft University of Technology, The Netherlands, in order to realize future wireless personal multimedia communications (WPMC). During our joint research period, research and development were done on higher layers such as the media access control (MAC) layer and the physical layer, and many researchers came from Europe, Asia, the United States, and The Netherlands to work with us. We also started new projects and established a joint cooperation with several research institutes, companies, and universities.

Once a project is defined, many new researchers are allocated. Among the researchers, some newcomers are occasionally involved. Moreover, most projects are time-limited. In this situation, the answer to the question of how newcomers prepare to evaluate the target is one of key issues to success in the time-limited project. We considered the answer carefully.

When we instructed the newcomers on how to evaluate a communication system, we used the following procedure. First, the newcomers read some books about a basic communication theory for the target topic to obtain basic knowledge for the target topic on the project. Then they read many writings about the target topic to understand the state-of-the-art technology, defined the remaining problems, and found new solutions suitable for the target topic. Then, once the newcomers set their research direction, by using references on how to use computer languages, they began their own programs to design and evaluate the target communication system.

This procedure may seem quite logical. However, during the procedure, newcomers have many questions, which take too long to discuss. Moreover, when we viewed our research field, we found many excellent books on the basic communication theory. However, there are few books on how to design a telecommunications system using computer simulation. There is currently no single book on how to design and evaluate a telecommunications system from the physical to the upper layer.

It is too time-consuming to prepare the newcomers to design and evaluate their own communication system. We therefore decided to write a new book to describe how to design telecommunications systems and evaluate them from the physical layer to the upper layer. In writing this book, we have attempted to set our concept as follows. In each chapter, we have described a simple explanation for a target telecommunications system, before showing programs. The explanation is quite simple. If you need more concrete explanation, you can find many excellent books on the subject. We chose MATLAB, one of the most popular computer simulation languages in the world, as the computer language to design the telecommunications systems. Moreover, we showed source programs in this book and included them on the accompanying CD-ROM. The users can customize our programs to their favorite systems. We believe that this book and accompanying CD-ROM are a must-have for all engineers, researchers, academics, and students of telecommunications technology.

Chapter 1 presents a general introduction to the history of the wireless communication system and the latest information on WPMC. This chapter also describes why we need to evaluate the performance of telecommunications system by computer simulation and why we can realize the simulation.

Chapter 2 describes several key parameters to perform computer simulations smoothly. MATLAB, a good software simulation tool, is mainly used in this book. Therefore, we first describe how to use the MATLAB language. We summarize frequently used commands and functions and the methods of creating a hierarchical program, in addition to the methods of programming function blocks, which are commonly used to evaluate all communication systems.

Chapter 3 explains the basic configurations of the phase shift keying (PSK)–based digital radio transmission scheme and describes the method of evaluating transmission performance by computer simulation. The PSK-based digital radio transmission schemes—binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), offset QPSK (OQPSK), minimum shift keying (MSK), and Gaussian-filtered minimum shift keying (GMSK)—and quadrature amplitude modulation (QAM) are introduced and their performances are evaluated by creating computer simulation programs. Parts of the programs are based on contributions from Takako Yamamura of the National Police Agency in Tokyo, Japan, and Ryo Sawai and Ryuhei Funada of Chuo University, also in Tokyo, Japan.

Chapter 4 presents the configuration of the orthogonal frequency division multiplexing (OFDM) transmission scheme, which can reduce the influence of multipath fading and realize broadband communication while retaining high-frequency utilization efficiency. This chapter also describes the method of simulating transmission performance using computer simulation programs. Takako Yamamura has also contributed to parts of the programs in this chapter.

Chapter 5 presents the configuration of code division multiplexing (CDM), which can retain robustness against multipath fading and is used in third-generation mobile communication systems. As did Chapter 4, this chapter also describes the method of simulating transmission performance using computer simulation programs. Makoto Okita from the National Police Agency in Tokyo also contributed to parts of the programs in this chapter.

Chapter 6 evaluates the transmission performance of a point-to-multipoint communication system with multiple-access protocols by computer simulation. Pure ALOHA, slotted ALOHA, nonpersistent carrier-sense multiple access (CSMA), and slotted nonpersistent inhibit sense multiple access (ISMA) are explained as examples of multiple-access protocols. In this chapter, the methods of simulating throughput and average delay time are described using computer simulation programs. This chapter and its programs contain contributions and suggestions from Makoto Okita.

Chapter 7 describes the basic simulation method for a multipoint-to-multipoint communication system based on a cellular telecommunications system. The dynamic channel assignment (DCA), fixed channel assignment (FCA), and adaptive cellular zone configuration (AZC) algorithms using an adaptive antenna are introduced. In this chapter, the method used to simulate call-blocking probability is described by using computer simulation programs. This chapter and all of its programs contain contributions from Fumihide Kojima and Ami Harada from the Communication Research Laboratory, Independent Administrative Institution, in Japan.

Chapter 8 describes a software radio communication system as a future application of the software programming method presented in this book. Computer simulation languages have a good relationship with software languages that configure digital signal processing hardware (DSPH) such as a digital signal processor (DSP) and/or field programmable gate array (FPGA) and/or application-specific integrated circuit (ASIC). The concept of software radio bridges the software programming examined in this book and real hardware implementation.

To make the learning process fast and easy, MATLAB code is provided at the end of each chapter and on the accompanying CD-ROM. This CD-ROM will allow users to exercise the simulations for real without having to write their own programs, which is always a barrier and prone to error. One of the main strengths of this book is that the learning process can be hands-on, allowing the readers to see the effects of varying parameters on the output of the simulation, a great aid to learning. Providing the MATLAB code at the end of each chapter is very helpful for readers. This book has a great deal to offer to researchers, practicing engineers, and to everyone in the field of wireless information and multimedia communication.

Finally, we would like to state that this book is a work in progress. We wish to develop new discussions about evaluating the communication system through worldwide computer simulations. If you have any comments or questions, please let us know. Through your comments, this book will evolve with the future. Please enjoy this book.

Acknowledgments

The material in this book is based on Dr. Harada's work during his post- doctoral fellowship at the Delft University of Technology, The Netherlands, supervised by Dr. Prasad. Based on Dr. Harada's work, the material developed into a book by adding comments and new computer simulation programs from many researchers in the Communications Research Laboratory, Independent Administrative Institution in Japan, and several other institutions.

We wish to thank Takako Yamamura and Makoto Okita from the National Police Agency in Tokyo, Japan; Fumihide Kojima and Ami Harada, from the Communications Research Laboratory, Independent Administrative Institution; and Ryo Sawai and Ryuhei Funada from Chuo University in Tokyo, Japan, for their valuable contributions to this book.

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We believe that exploiting this book removes the technical borders and technical differences in the research area of wireless telecommunication engineering among all over the world.

1

Introduction

This book describes a method for evaluating the wireless communication systems by computer simulation. This chapter shows how evaluations by computer simulation are beneficial in wireless communication research by reviewing the history of a mobile communication system that is representative of wireless communication systems. Then, the significance of evaluation by computer simulation is described. Finally, this chapter describes the scope of this book and presents some figures that describe the process of evaluation by computer simulation for wireless communication systems.

1.1 History of Mobile Communications

The prosperous progress of mobile communication has built the main road of the history of wireless communication. Historically, when a mobile communication system was to be standardized, many system proposals were submitted to standardization bodies. Then, these proposals were equally evaluated by using computer simulations or developed prototypes. Finally, one or a few standardized systems were chosen. The standardized mobile communication systems included many important concepts, and thus, a historical survey is the best way to understand the key points of recent mobile communication systems.

The history of mobile communications can be categorized into three periods: (1) the pioneer era, (2) the precellular era, and (3) the cellular era [1]. Table 1.1 summarizes several representative events in each era.

Table 1.1
History of Mobile Communications

Time	Significant Event
Pioneer Era	
1860s	James Clark Maxwell's *electromagnetic* (EM) wave postulates
1880s	Proof of the existence of EM waves by Heinrich Rudolf Hertz
1890s	First use of wireless and first patent of wireless communications by Gugliemo Marconi
1905	First transmission of speech and music via a wireless link by Reginald Fessenden
1912	Sinking of the *Titanic* highlights the importance of wireless communication on the seaways; in the following years marine radio telegraphy is established
Precellular Era	
1921	Detroit Police Department conducts field tests with mobile radio
1933	In the United States, four channels in the 30–40-MHz range
1938	In the United States, rules for regular services
1940	Wireless communication is stimulated by World War II
1946	First commercial mobile telephone system operated by the Bell system and deployed in St. Louis
1948	First commercial fully automatic mobile telephone system is deployed in Richmond, Virginia, in the United States
1950s	Microwave telephone and communication links are developed
1960s	Introduction of trunked radio systems with automatic channel allocation capabilities in the United States
1970	Commercial mobile telephone system operated in many countries (e.g., 100 million moving vehicles on U.S. highways, "B-Netz" in West Germany)
Cellular Era	
1980s	Deployment of analog cellular systems
1990s	Digital cellular deployment and dual-mode operation of digital systems
2000s	*Future public land mobile telecommunication systems* (FPLMTSs)/*international mobile telecommunications-2000* (IMT-2000)/*universal mobile telecommunication systems* (UMTS) will be deployed with multimedia services
2010s	*Fixed-point* (FP)–based wireless broadband communications and software radio will be available over the Internet
2010s+	Radio over fiber (such as fiber-optic microcells) will be available

In the pioneer era, a great deal of the fundamental research and development in the field of wireless communications took place. The postulates of *electromagnetic* (EM) waves by James Clark Maxwell during the 1860s in England, the demonstration of the existence of these waves by Heinrich Rudolf Hertz in the 1880s in Germany, and the invention and first demonstration of wireless telegraphy by Guglielmo Marconi during the 1890s in Italy were representative examples from Europe [2, 3]. Moreover, in Japan, the Radio Telegraph Research Division was established as a part of the Electrotechnical Laboratory at the Ministry of Communications and started to research wireless telegraphy in 1896.

From the above fundamental research and the resultant developments in wireless telegraphy, the application of wireless telegraphy to mobile communication systems started from the 1920s. The period, which is called the precellular era, began with the first land-based mobile wireless telephone system installed in 1921 by the Detroit Police Department to dispatch patrol cars, followed in 1932 by the New York City Police Department [4]. These systems were operated in the 2-MHz frequency band [4]. Unfortunately, during World War II, the progress of radio communication technologies was drastically stimulated.

In 1946, however, the first commercial mobile telephone system, which operated in the 150-MHz frequency band, was set up by Bell Telephone Laboratories in St. Louis [1, 4]. The demonstration system was a simple analog communication system with a manually operated telephone exchange.

Subsequently, in 1969, a mobile duplex communication system was realized in the 450-MHz frequency band. The telephone exchange of this modified system was operated automatically [5]. The new system, called the *improved mobile telephone system* (IMTS), was widely installed in the United States. However, because of its large coverage area, the system could not manage a large number of users or allocate the available frequency bands efficiently.

The cellular zone concept was developed to overcome this problem by using the propagation characteristics of radio waves. The concept is shown in Figure 1.1. A frequency channel in one cellular zone is used in another zone. However, the distance between the cellular zones that use the same frequency channels is sufficiently long to ensure that the probability of interference is quite low. The use of the new cellular zone concept launched the third era, known as the cellular era.

The first generation of cellular mobile communication was developed from 1980 to 1990. In this period, research and development (R&D) centered around analog cellular communication systems. Table 1.2 summarizes these analog cellular communication systems.

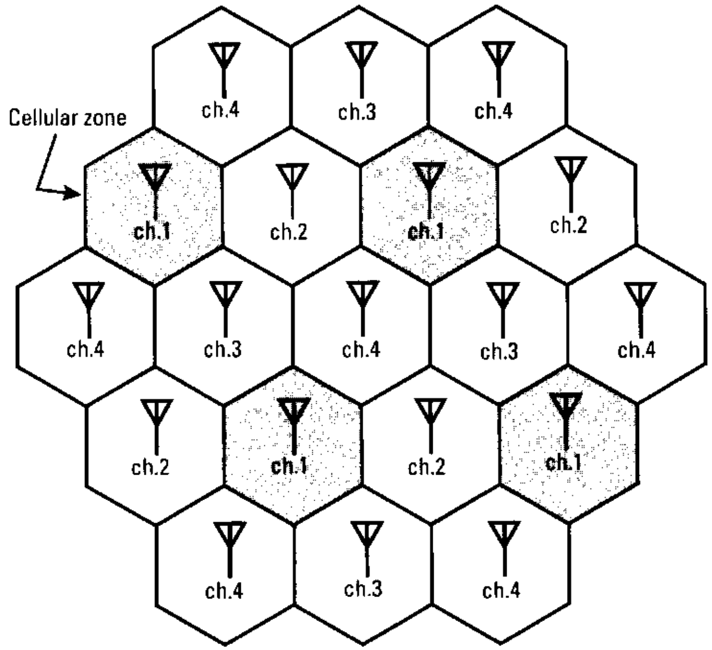

Figure 1.1 Cellular zone concept.

In the United States, an analog cellular mobile communication service called advanced mobile phone service (AMPS) was started in October 1983 in Chicago [6].

In Europe, several cellular mobile communication services were started. In Norway, *Nordic Mobile Telephones* (NMT) succeeded in the development of an analog cellular mobile communication system: NMT-450 [7].

In the United Kingdom, Motorola developed an analog cellular mobile communication system called the *total access communication system* (TACS) based on AMPS in the 1984–1985 period. In 1983, NMT started a modified NMT-450 called NMT-900. Moreover, C-450, RTMS, and Radiocom-2000 were, respectively, introduced in Germany, Italy, and France.

Meanwhile, in Japan, *Nippon Telephone and Telegraph* (NTT) developed a cellular mobile communication system in the 800-MHz frequency band and started service in Tokyo in December 1979. Furthermore, a modified TACS that changed the frequency band to adjust for Japanese frequency planning and was called JTACS was also introduced in July 1989. Subsequently, *narrowband TACS* (NTACS), which reduced the required frequency band in half, started service in October 1991.

Table 1.2
Summary of Analog Cellular Radio Systems

System	**AMPS**	**NMT-450**	**NMT-900**	**TACS**	**ETACS**
Frequency range (mobile Tx/base Tx) (MHz)	824–849/ 869–894	453–457.5/ 463–467.5	890–915/ 463–467.5	890–915/ 935–960	872–905/ 917–950
Channel spacing (kHz)	30	25	12.5*	25	25
Number of channels	832	180	1,999	1,000	1,240
Region	The Americas, Australia, China, Southeast Asia	Europe	Europe, China, India, Africa	United Kingdom	Europe, Africa

System	**C-450**	**RTMS**	**Radiocom-2000**	**JTACS/ NTACS**	**NTT**
Frequency range (mobile Tx/base) (MHz)	450–455.74/ 460–465.74	450–455/ 460–465	165.2–168.4/ 169.8–173 192.5–199.5/ 200.5–207.5 215.5–233.5/ 207.5–215.5 414.8–418/ 424.8–428	915–925/ 860–870 898–901/ 843–846 918.5–922/ 863.5–867	925–940/ 870–855 915–918.5/ 860–863.5 922–925/ 867–870
Channel spacing (kHz)	10*	25	12.5	25/12.5* 25/12.5* 12.5*	25/6.25* 6.25* 6.25*
Number of channels	573	200	256 560 640 256	400/800 120/240 280	600/2400 560 480
Region	Germany, Portugal	Italy	France	Japan	Japan

*Frequency interleaving using overlapping or "interstitial" channels; the channel spacing is half the nominal channel bandwidth.

So far, we have described the evolution of the analog cellular mobile communication system. However, the incompatibility of the various systems precluded roaming. This meant that users had to change their mobile ter- minals when they moved to another country. In addition, analog cellular mobile communication systems were unable to ensure sufficient capacity for the increasing number of users, and the speech quality was not good.

To solve these problems, the R&D of cellular mobile communication systems based on the digital radio transmission scheme was initiated. These new mobile communication systems became known as the second generation of mobile communication systems, and the analog cellular era thus is regarded as the first generation of mobile communication systems. Table 1.3 summarizes digital cellular radio systems.

In Europe, the global system for mobile communication (GSM), a new digital cellular communication system that allowed international roaming and used the 900-MHz frequency band, started service in 1992. In 1994, DCS-1800, a modified GSM that used the 1.8-GHz frequency band, was launched.

In North America, the IS-54 digital cellular communication system was standardized in 1989. Subsequently, the standard was revised to include dual-mode services between analog and digital cellular communication systems and reintroduced in 1993 with the title DAMPS, or IS-136. In addition, IS-95, which was the first standardized system based on *code-division multiple access* (CDMA), started service in 1993.

In Japan, the digital cellular communication or *personal digital cellular* (PDC) systems using the 800- and 1.5-GHz frequency bands started service in 1993 and 1994, respectively.

In addition to the above digital systems, the development of new digital cordless technologies gave birth to the second-supplement-generation systems, namely, the *personal handy-phone systems* (PHSs)—formerly PHPs—in Japan, the *digital enhanced* (formerly European) *cordless telephone* (DECT) in Europe, and *personal access communication services* (PACSs) in North America. Table 1.4 summarizes the second-supplement-generation systems [8, 9] and shows the *cordless telecommunications, second generation* (CT2) and CT2+. A detailed description of CT2 can be found in [10, 11], where CT2+ is a Canadian enhancement of the CT2 common air interface.

In the second generation of mobile communication systems, the common standardizations of some regions, such as in Europe and North America, enabled the realization of partial roaming. This feature was a unique point of the second-generation systems in comparison with the first-generation systems. The advent of common standard gave users a sense of ease of international roaming. Users have been eager to see worldwide standardization.

Table 1.3
Summary of Digital Cellular Radio Systems

Systems	GSM DCS-1800	IS-54	IS-95	PDC
Frequency range (base Rx/Tx, MHz)	GSM: Tx: 935–960; Rx: 890–915 DCS-1800: Tx: 1,805–1,880; Rx: 1,710–1785	Tx: 869–894; Rx: 824–849	Tx: 869–894; Rx: 824–849	Tx: 810–826; Rx: 940–956; Tx: 1,429–1,453; Rx: 1,477–1,501
Channel spacing (kHz)	200	30	1,250	25
Number of channels	GSM: 124; DCS-1800: 375	832	20	1,600
Number of users per channel	GSM: 8 DCS-1800: 16	3	63	3
Multiple access	TDMA/FDMA	TDMA/FDMA	CDMA/FDMA	TDMA/FDMA
Duplex	FDD	FDD	FDD	FDD
Modulation	GMSK	$\pi/4$ DQPSK	BPSK/QPSK	$\pi/4$ DQPSK
Speech coding and its rate (Kbps)	RPE-LTP 13	VSELP 7.95	QCELP 8	VSELP 6.7
Channel coding	1/2 Convolutional	1/2 Convolutional	Uplink 1/3 Downlink 1/2 Convolutional	9/17 Convolutional
Region	Europe, China, Australia, Southeast Asia	North America, Indonesia	North America, Australia, Southeast Asia	Japan

Notes: RPE-LTP: regular pulse-exciting long-term predictive coding; VSELP: vector-sum–excited linear predictive coding; GSM: global system for mobile communication.

During the period 1990–2000, the styles of wired communication as well as wireless communication were both changed by the innovation of digital signal processing. During the period, all information such as voice, data, images, and moving images could be digitized, and the digitized data could be transmitted through a worldwide computer network such as the Internet. Mobile users were also eager to be able to transmit such digitized data in a mobile communication network. However, in the second-generation mobile communication systems, the data transmission speeds were limited, creating the need for new

Table 1.4
Summary of Digital Cordless Systems

System	CT2/CT2+	DECT	PHS	PACS
Frequency range (Base Rx/Tx, MHz)	CT2: 864–868 CT2+: 944–948	1,880–1,990	1,895–1,918	Tx: 1,850–1,910 Rx: 1,930–1,990
Channel spacing (kHz)	100	1,728	300	300
Number of channels	40	10	77	96
Number of users per channel	1	12	4	8
Multiple access	FDMA	TDMA/FDMA	TDMA/FDMA	TDMA/FDMA
Duplex	TDD	TDD	TDD	TDD
Modulation	GFSK	GFSK	$\pi/4$ DQPSK	$\pi/4$ DQPSK
Speech coding	ADPCM	ADPCM	ADPCM	ADPCM
	32	32	32	32
Channel coding	None	CRC	CRC	CRC
Region	Europe, Canada, China, Southeast Asia	Europe	Japan, Hong Kong	United States

high-speed mobile communication systems. Based on this objective, R&D into third-generation mobile communication systems was started in 1995. The R&D that occurred in the 1995–2000 period can be categorized into two areas: (1) international standardized high-speed digital cellular systems with mobility as the second generation and (2) international standardized broadband mobile-access systems with low mobility.

In the first area, IMT-2000 has become the standard. IMT-2000 aims to realize 144 Kbps, 384 Kbps, and 2 Mbps under high-mobility, low-mobility, and stationary environments, respectively. Figure 1.2 shows an image of the IMT-2000 concept.

In IMT-2000, on the basis of CDMA, three radio-access schemes have been standardized: (1) *direct-sequence CDMA* (DSCDMA)-*frequency division duplex* (FDD) (DSCDMA-FDD), (2) *multicarrier CDMA* (MCCDMA)- *FDD* (MCCDMA-FDD), and (3) *direct-sequence CDMA* (DSCDMA)-*time division duplex* (TDD) (DSCDMA-TDD). WCDMA by NTT Docomo and Ericsson and CDMA2000 by Qualcomm were submitted to the ITU [12, 13]. Their basic requirements are shown in Table 1.5. IMT-2000 adopted a CDMA-based system that, by fixing the code transmission rate (chip rate), brought

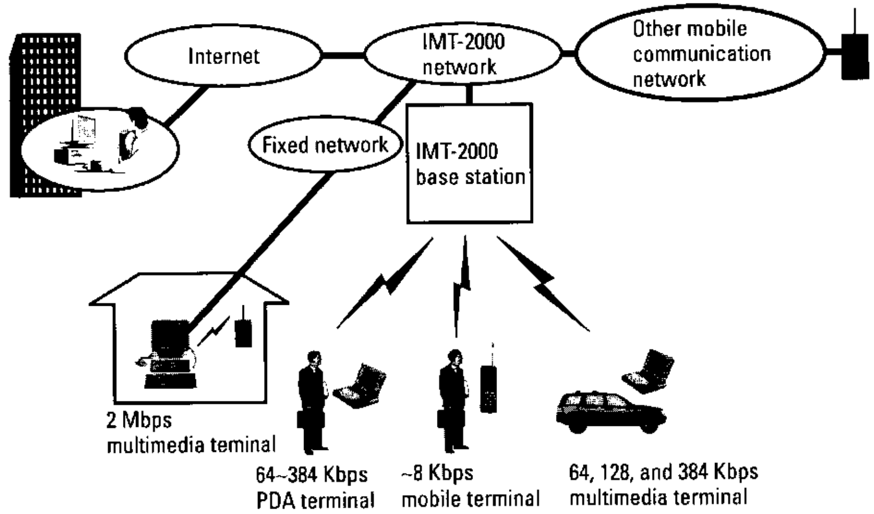

Figure 1.2 Image of IMT-2000.

Table 1.5
Summary of IMT-2000

	WCDMA	CDMA2000
Frequency	2-GHz band	—
Bandwidth	1.25/5/10/20-MHz (DSCDMA)	1.25/5/10/20-MHz (DSCDMA) 3.75/5-MHz (MCCDMA)
Chip rate	3.84-Mcps (DSCDMA-FDD, DSCDMA-TDD)	3.84-Mcps (DSCDMA-FDD) 3.6864-Mcps (MCCDMA-FDD)
Data rate	144-Kbps (high-mobility environment) 384-Kbps (low-mobility environment) 2-Mbps (stationary environment)	—
Synchronization between base stations	Asynchronous Synchronous	Asynchronous synchronous (DSCDMA-TDD) Synchronous (MCCDMA-FDD)
Exchange	GSM network	ANSI-41

about the capability of offering worldwide roaming. Moreover, since the data transmission rates of third-generation mobile communication systems (144 Kbps–2 Mbps) are much higher than those of the second-generation systems (less than 64 Kbps), users can realize moving-image-based communication as well as voice and data communication using a mobile terminal.

Several high-speed wireless-access systems have been standardized [14]. These basic requirements are shown in Table 1.6. Figure 1.3 shows an image of a high-speed wireless access system. As stated in Table 1.6, most standardized systems can realize transmissions of more than 10 Mbps. It is especially so in the 5-GHz frequency band: An *orthogonal frequency-division multiplexing* (OFDM)–based high-speed wireless access system can realize several tens of megabits per second transmission rates [14]. By using such a mobile-access scheme, broadband data transmission rates, such as several tens of megabits per second, can be realized in a wireless communication network as well as a wired network.

Ultra-high-speed wireless access systems that can realize several tens of megabits per second to hundreds of megabits per second as supported data transmission rates are targets of new R&D.

Within the European *Advanced Communication Technologies and Services* (ACTS) program, there were four European Union–funded R&D projects

Table 1.6
Summary of Broadband Mobile-Access Systems

	IEEE802.11 2 GHz	**IEEE802.11 5 GHz**	**HiperLAN2**	**MMAC**
Frequency	2.40–2.4835 GHz	5.150–5.350 GHz 5.725–5.825 GHz	5.150–5.350 GHz 5.470–5.725 GHz	5.150–5.25 GHz
Modulation scheme	CDM (DBPSK/DQPSK/CCK)	OFDM (BPSK/QPSK/16-QAM/64-QAM)	OFDM (BPSK/QPSK/16-QAM/64-QAM)	OFDM (BPSK/QPSK/16-QAM/64-QAM)
Channel access	CSMA/CA	CSMA/CA	Scheduled TDMA	DSA
Duplexing	TDD	TDD	TDD	TDD
Data rate	1, 2 Mbps, DBSK, DQSK, 5.5, 11 Mbps (CCK)	6, 9 Mbps BPSK 12, 18 Mbps QPSK 24, 36 Mbps 16-QAM 54 Mbps 64-QAM	6, 9 Mbps BPSK 12, 18 Mbps QPSK 27, 36 Mbps, 16-QAM 54 Mbps 64-QAM	6, 9 Mbps BPSK 12, 18 Mbps QPSK 27, 36 Mbps 16-QAM 54 Mbps 64-QAM
Organization	IEEE	IEEE	ETSI BRAN	ARIB MMAC

Notes: CCK: complimentary code keying; DSA: dynamic slot assignment; BRAN: broadband radio access networks; MMAC: Multimedia Mobile Project Access Communication Systems Promotion Council; IEEE: Institute of Electrical and Electronics Engineers; ETSI: European Telecommunications Standards Institute; ARIB: Association of Radio Industries and Businesses.

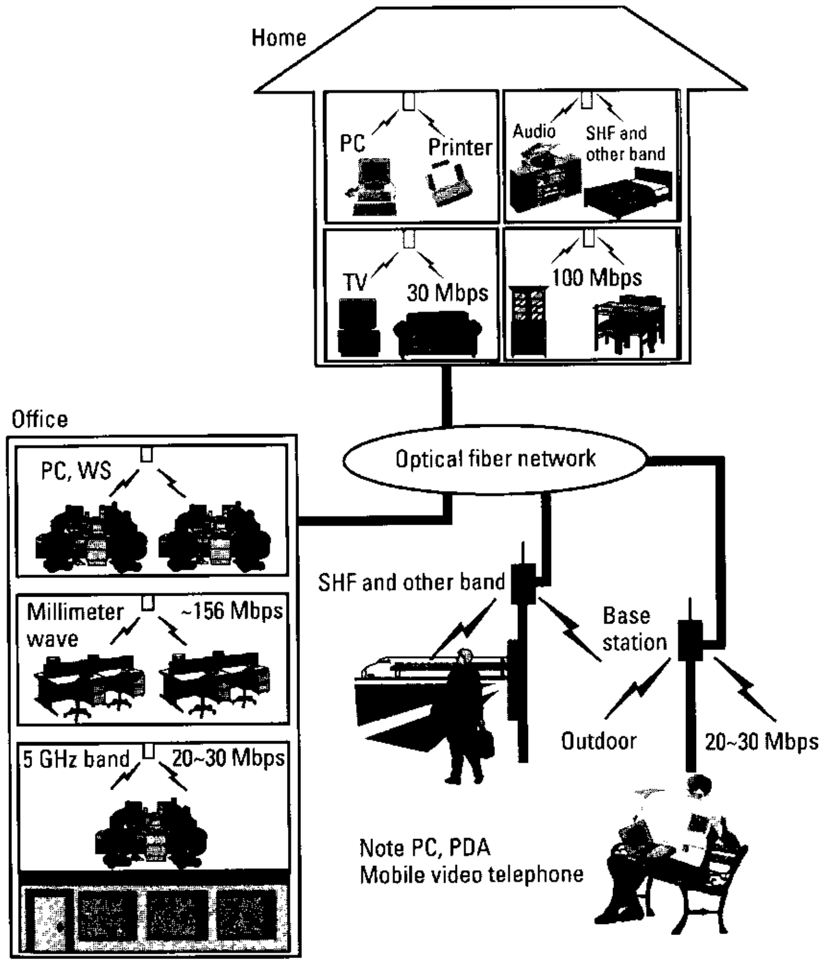

Figure 1.3 Image of a high-speed wireless access system.

ongoing, namely the Magic Wand [*wireless ATM* (WATM) network demonstration], the *ATM wireless access communication system* (AWACS), the *system for advanced mobile broadband applications* (SAMBA), and the wireless broadband *customer premises local area network* (CPN/LAN) for professional and residential *multimedia applications* (MEDIAN) [14–23].

In the United States, a *seamless wireless network* (SWAN) and a *broadband adaptive homing ATM architecture* (BAHAMA) along with two major projects at Bell Laboratories and the *WATM network* (WATMnet) are being developed in the *computer and communication* (C&C) research laboratories of *Nippon Electric Company* (NEC) in the United States [15–19].

In Japan, the *Communications Research Laboratory* (CRL) in the Ministry of Posts and Telecommunications is busy with several R&D projects, such as a broadband mobile communication system [24] in the *super high-frequency* (SHF) band (from 3 to 10 GHz) with a channel bit rate of up to 10 Mbps that achieves 5-Mbps transmission in a high-mobility environment where the vehicle speed is 80 km/hr [25, 26]. Moreover, an indoor high-speed wireless LAN in the millimeter-wave band with a target bit rate of up to 155 Mbps [27, 28] has also been researched, and a point-to-multipoint wireless LAN was developed that can achieve a transmission rate of 156 Mbps by using an original protocol named *reservation-based slotted idle signal multiple access* (RS-ISMA) [29].

As a mobile communication system that requires broadband transmission capability, such as several megabits per second to 10 Mbps, in a high-mobility environment, the *intelligent transport system* (ITS) is the most representative example [30–34].

In the ITS, there are many communication schemes, of which the *global positioning service* (GPS) is the most famous application. However, nowadays, the standardization of the *dedicated short-range communication* (DSRC) system has progressed. The DSRC system uses an *industrial, scientific, and medical* (ISM) band (5.725–5.875 GHz) to realize a short-distance (about up to 30m), vehicle-to-roadside communication system. The image, the applications, and the spectrum allocations for DSRC are shown in Figures 1.4–1.6, respectively [31].

To realize the DSRC, the *Comité Européen de Normalisation* (CEN) in Europe, the *American Society for Testing and Materials* (ASTM) and the IEEE in North America, and ARIB in Japan organized standardization committees for DSRC. As for the data transmission scheme, the *International Telecommunication Union-Radiocommunication* (ITU-R) recommendation M.1453 suggests two methods: the active and backscatter methods [31]. The requirements are shown in Table 1.7 [31]. Based on the recommendation, several applications are being considered. Figure 1.5 shows some examples of the intended applications. Furthermore, a full-mobility and a quasi-mobile communication system are also being considered.

There are many modulation and demodulation schemes, as well as access protocols used in mobile communication as described earlier in this section. The relationship between the first-, second-, and third-generation mobile communication systems, high-speed and ultra-high-speed wireless-access systems, and ITS is shown in Figure 1.7.

We, therefore, sometimes compare the performance of a new system with that of an old one in a common environment. Computer simulation is one of

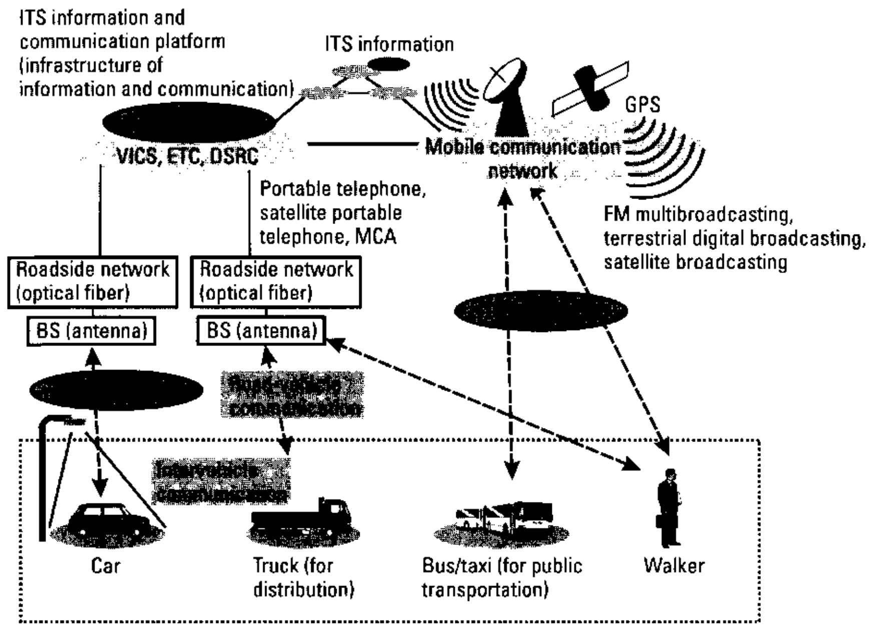

Figure 1.4 Image of the DSRC system. (BS: base station.)

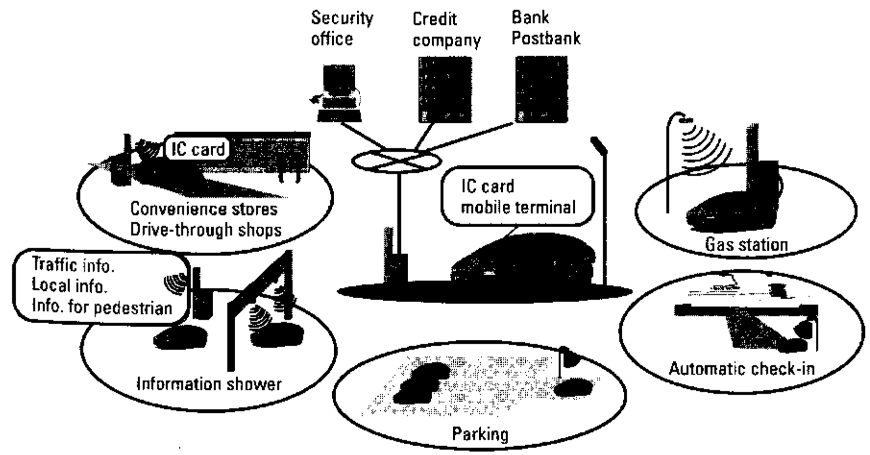

Figure 1.5 Applications of the DSRC system.

methods used to evaluate the performance of different systems in a common environment.

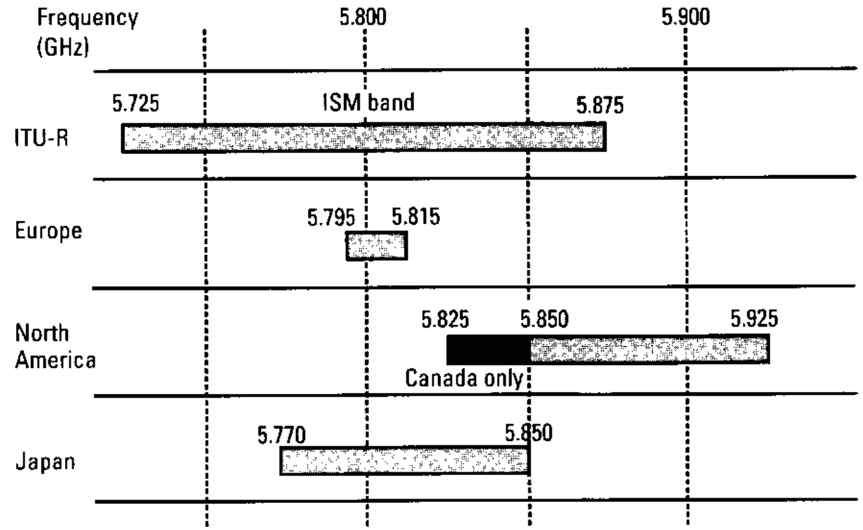

Figure 1.6 Spectrum allocations for the DSRC system.

Table 1.7
Standardized DSRC System

	Active	**Backscatter**
Organization	ARIB	CEN
RF carrier spacing	10 MHz	1.5, 12 MHz (medium data rate) 10.7 MHz (high data rate)
Allowable occupied bandwidth	Less than 8 MHz	5 MHz (medium data rate) 10 MHz (high data rate)
Modulation method	ASK (UL/DL)	ASK (DL)/PSK (UL)
Data coding	Manchester code	FMO (DL)/NRZI (UL)

Notes: DL: downlink; UL: uplink.

1.2 Evaluation by Computer Simulation

The performances of several wireless communication systems can be evaluated by computer simulation without the need to develop prototypes and perform field experiments. This book focuses on the evaluation of digital wireless communication systems. The typical models of a digital wireless communication system are categorized into three types: (1) point-to-point communication,

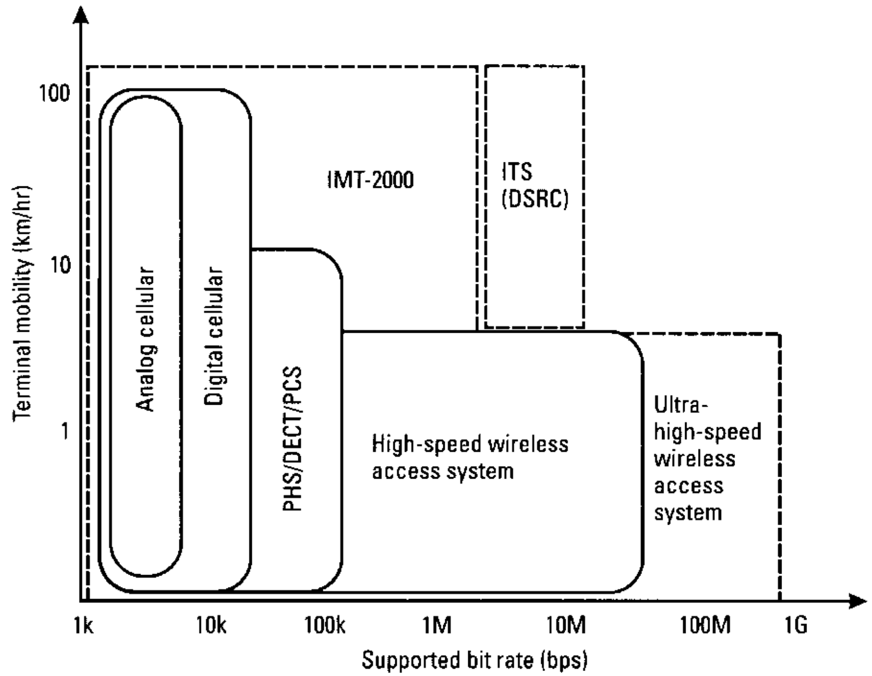

Figure 1.7 Classification of mobile communication systems.

(2) point-to-multipoint communication, and (3) multipoint-to-multipoint communication. Sections 1.2.1–1.2.3 detail these three models.

1.2.1 Point-to-Point Communication

The concept of point-to-point communication is shown in Figure 1.8 [35]. In point-to-point communication, information data is first fed into a source encoder. In this encoder, the information data is digitized if it is analog data. If the volume of digitized data is large, the data is compressed by one of several encoding methods. *Motion Picture Experts Group* (MPEG) and *adaptive differential code modulation* (ADPCM) are examples of the encoding methods used for moving-image and voice-information data. Then, the source-encoded digital data is fed into a channel encoder to reduce the occurrence of bit errors under severe radio communication channels. For example, encoding techniques that use an *error-correction code* (ECC), such as a convolutional code, *Bose-Chaudhuri-Hocquenghem* (BCH) code, or Reed-Solomon code; a pilot data insertion technique; and a frame construction to estimate radio propagation characteristics are the representative examples.

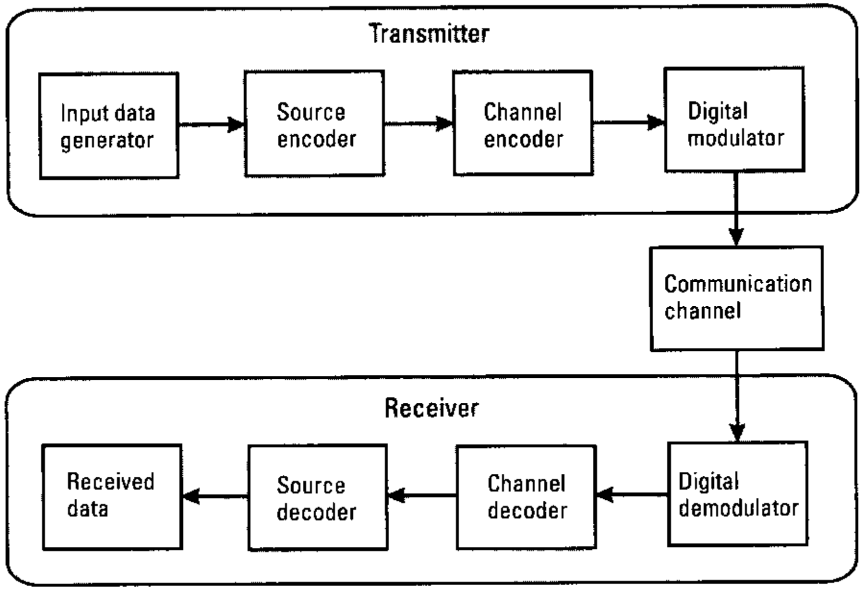

Figure 1.8 Point-to-point communication.

Next, the channel-encoded digital data is fed into a digital modulator and converted to a radio signal. The meaning of "modulation" is to vary the peculiar components that are included in carrier signal wave. The carrier signal is generally written as follows.

$$S(t) = A(t)\exp\left(2\pi f_c t + \theta(t)\right) \tag{1.1}$$

where $A(t)$, f_c, and $\theta(t)$ are the time-variant amplitude, the radio carrier frequency, and the time-variant phase of the carrier wave signal, respectively. In (1.1), we have three peculiar components by which users can change the value. These are amplitude, frequency, and phase. If we change the amplitude of (1.1) in accordance with the digital information data, we call the modulation scheme *amplitude modulation* (AM). If we change the frequency of (1.1) with information data, then we call the modulation scheme *frequency modulation* (FM). Finally, if we change the phase of (1.1) in accordance with the digital information data, we call the scheme *phase modulation* (PM). The modulated signals are shown in Figure 1.9.

The process of modulation is performed in the lower frequency band as well as the carrier *radio frequency* (RF) band. In some cases, we use a quite low-frequency band in which digital signal processing can be performed. The

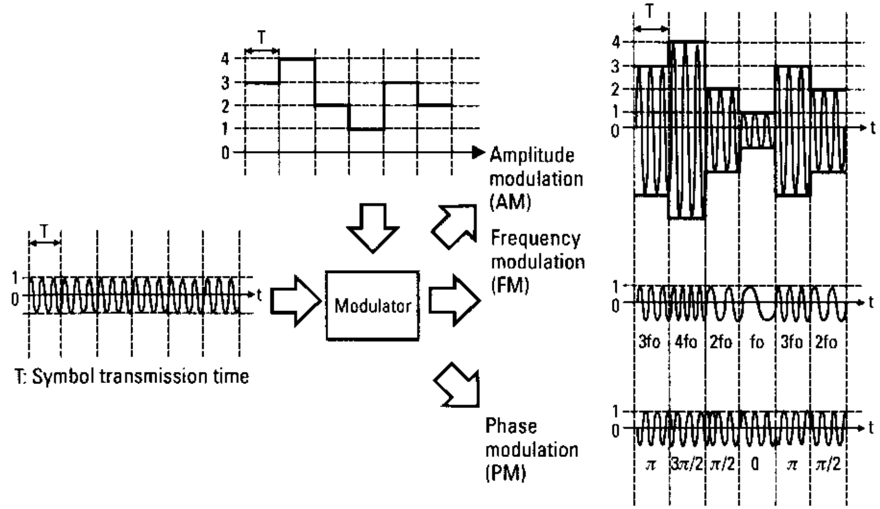

Figure 1.9 Examples of modulated signals.

frequency band is called the "baseband." If used in the baseband, we need an upconversion to the carrier RF band to make a modulated signal. If the direct conversion is difficult, we first upconvert the signal via an *intermediate frequency* (IF) band. Then, the digital modulated signal is transmitted to the receiver through a radio channel.

In the receiver, the received signal is fed into the digital demodulator and downconverted to baseband digital data. For conversion, the method where the received signal on the carrier frequency band is converted to the IF band, and then converted to the baseband is popular. Then, on the baseband, the level of amplitude, frequency, or phase is detected for the AM, FM, and PM schemes, respectively, and finally the transmitted digital data is recovered.

Next, the detected digital data is fed into the channel decoder, the various amplitudes and phases caused by the radio channel are compensated, and the ECC used in the transmitter is decoded. Finally, the channel-decoded data is fed into the source decoder, and the transmitted information data is recovered.

This book considers the model shown in Figure 1.8. Details of the shaded areas in Figure 1.8 are shown in Figure 1.10, in which the following elements are evaluated:

1. *Bit error rate* (BER);
2. *Frame-error rate* (FER)—if frame construction is used;
3. *Packet-error rate* (PER)—if packet construction is used.