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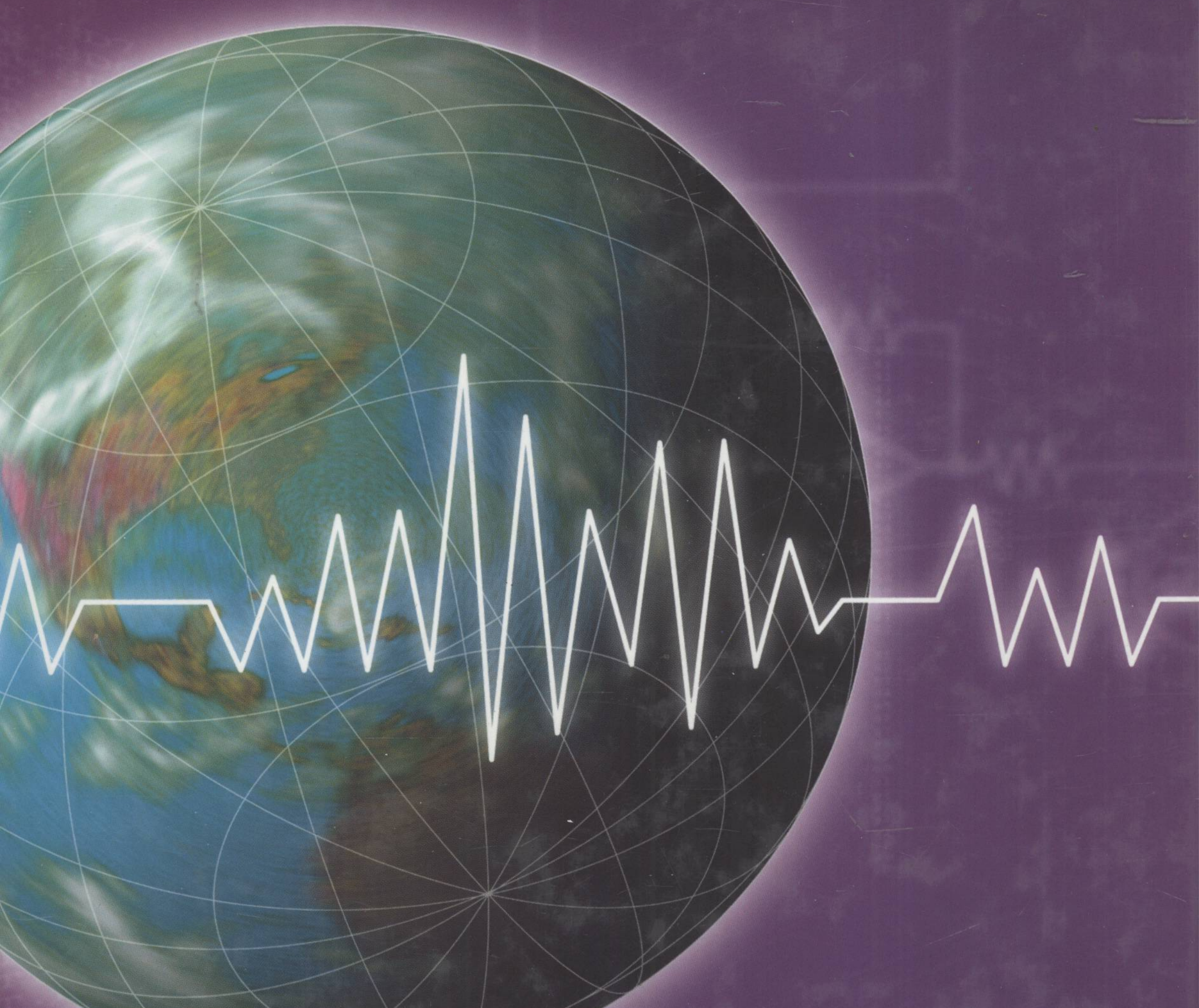
W-CDMA

MOBILE COMMUNICATIONS SYSTEM



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Editorial Board

Supervisor's Note

The progress of the IT revolution is about to change not only the ways in which business is done but also people's lifestyles. The *mobile*, *wireless* and *personal* features of mobile communications will have unprecedented importance in building a mobile multimedia society for the future. Mobile communications is expected to undergo dramatic progress through the development of a wide range of terminals, the advancement of network and gateway functions and the supply of various content and applications. An example is *i-mode*, the world's first wireless Internet access service on cellular phones. Since its commercial launch in February 1999, *i-mode* has acquired more than 21.5 million subscribers as of the end of March 2001. As demonstrated by this example, mobile communication is expected to form the core of information and communications networks in the twenty-first century, in line with the progress of the IT revolution.

Mobile multimedia services in the twenty-first century are expected to move on from "person-to-person" communications (as was the case in the twentieth century) to "person-to-machine" communications (as in *i-mode*, in which mobile terminals are used to access servers over the Internet) and "machine-to-machine" communications (aka machine communications using mobile terminals, which is a form of communications in a broader sense that targets all objects in motion). While progress in this area hitherto has largely been due to technologies that helped digitize mobile networks, Internet protocols will have to be incorporated into mobile communications in the future so as to further integrate mobile communications with the Internet. This should enable the provision of cheaper and more efficient services.

In Japan, a digital mobile phone system referred to as the *second-generation mobile communications system* and built in compliance with Japan's domestic standard was put to practical use in 1993. Today's progress is attributable to this system, which increased subscriber capacity through highly efficient frequency usage and led to the development of new services and various types of terminals. By the end of May 2001, the world's first service based on the third-generation mobile communications system (IMT-2000) using W-CDMA was launched under a service brand *FOMA*. This new system is expected to further facilitate the market penetration of mobile multimedia, as various types of content can be transmitted at speeds faster than the existing system by more than a digit and processed smoothly without sacrificing their high quality.

This volume consists of detailed articles written by leading engineers for readers who wish to learn about the basic technologies, systems, networks, services and operations of

W-CDMA in a systematic manner. We hope that it will help deepen your interest in, and understanding of, mobile communication technologies.

Keiji Tachikawa, Doctor of Engineering

President and CEO
NTT DoCoMo, Inc.

Preface

The remarkable progress in information technology (IT) since the late 1990s continues to facilitate faster communications, broadband access and lower communication costs in the information and communications sector. Consequently, communications has penetrated not only the business scene but also every aspect in personal life, to the extent of dramatically changing people's lifestyles. The widespread use of the Internet, which appeared in the 1990s, is also contributing to the advent of a wide range of multimedia services that undermine the barriers of time and place.

In Japan, the automobile phone service based on cellular technology was commercially launched in 1979, followed by the portable mobile phone system in 1987. Since 1994, the number of subscribers has skyrocketed at a rate of 10 million per year, owing to improved and enhanced network coverage and quality, liberation of terminal sales and continuous tariff reductions. As of March 2000, the number of mobile phone subscribers reached 56.8 million, accounting for approximately 50% of the Japanese population. In February 1999, the commercial service of *i-mode*, a mobile communications service enabling Internet access, was started. As of the end of March 2001, *i-mode* subscribers totaled about 21.5 million in number. *i-mode*, which enables subscribers to access the Internet by using a packet-switched network overlaid on the existing mobile phone network, has been successful in winning the hearts of mobile Internet users by lowering communication costs through data-volume-based billing, developing easy-to-use handsets, and establishing new business models including the bill collection service on behalf of the content providers. The evolution of cellular-based mobile communication systems from the first-generation (analog) to the second-generation (digital), as described above, has been made possible by solving many technical issues along the way. Efforts to develop a global standard for providing high-speed, high-quality multimedia services have crystallized in the form of the third-generation (3G) systems, under the IMT-2000 standard. The world's first 3G system was implemented by Japan in 2001 on the basis of the latest research results, and other countries are expected to follow suit. 3G systems are expected to bring about radical socioeconomic and cultural changes that would affect people around the world.

As explained above, recent mobile communication systems are based on the wealth of an extremely wide range of advanced technologies, including radio transmission technologies, radio link control technologies, network technologies, operation technologies, terminal equipment technologies and other multimedia processing technologies. The cellular phone system together with the Personal Handyphone System (PHS) and other information infrastructure provide a vital means for communication in our everyday life.

In light of these facts, this volume reviews in detail the basic technologies applied to W-CDMA, a standard 3G mobile communications technology. The focus is to explain the technologies that will play an important part in future developments, with reference to the latest research results.

Chapter 1 "Overview" briefly reviews various cellular systems, ranging from analog to digital, describes their characteristics and discusses the objectives of IMT-2000 and the status of standardization. *Chapter 2 "Radio Transmission Systems"* explains, in an easy-to-understand manner, the mechanism and the characteristics of CDMA as discussed in this volume with respect to radio access systems, a basic technology that is vital for mobile communications. It also describes basic transmission technologies such as cell search technologies, transmission power control technologies and diversity technologies, in addition to capacity-enhancement technologies based on adaptive array antennas. *Chapter 3 "Radio Systems"* provides a detailed explanation of radio access interfaces and radio system designs that form the basis of W-CDMA technology, as well as an introduction to mobile terminals. *Chapter 4 "Network Technologies"* reviews in detail ATM technologies, packet communication systems and other types of network systems. *Chapter 5 "Operation System"* gives an outline of network monitoring/control and equipment monitoring/administration. *Chapter 6 "Multimedia Processing Methods"* describes in detail the processing schemes for multimedia signals including audio and video adopted in radio systems, information distribution schemes, location information processing and electronic authentication systems. *Chapter 7 "Future Prospects"* provides an outlook on the future directions of radio technologies, network technologies and signal processing technologies.

This volume was written by NTT DoCoMo's engineers working at the forefront of research and development of W-CDMA. Much consideration was given to ensure that the descriptions are sufficiently covered and consistent. It was written to enable a wide range of readers to gain a general understanding of W-CDMA, with researchers, developers and operators in the mobile communications sector in mind, as well as students and end users.

The editors are immensely grateful to Professor Fumiyuki Adachi at Tohoku University, for his pioneering research findings, and Teruaki Kuwabara at Maruzen Co., Ltd, for his cooperation in planning and publishing this work.

Editors

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1

Overview

Keisuke Suwa, Yoshiyuki Yasuda and Hitoshi Yoshino

1.1 Generation Change in Cellular Systems

In Japan, mobile communications systems based on cellular technology have evolved, as illustrated in Figure 1.1. The first-generation analog car phones were first introduced in 1979, followed by the commercialization of the second-generation digital phones in 1993. Mobile phone subscribers have rapidly increased in number since then, owing to the liberation of terminal sales and continuous price reductions. In March 2000, the number of mobile phone subscribers outnumbered those of fixed telephones. Meanwhile, the expansion of data communications on a global scale – spearheaded by the Internet – is promoting the introduction of Packet-Switched (PS) communication systems that are suitable for data communications in a mobile environment.

The standardization and system development of the next-generation mobile communications system, known as the Third-Generation (3G) International Mobile Telecommunications-2000 (IMT-2000), began in response to the rising need in recent years to achieve high-speed data communications capable of supporting mobile multimedia services and developing a common platform that would enable mobile phone subscribers to use their mobile terminals in any country across the world. From 2001 onwards, IMT-2000 systems using Wideband Code Division Multiple Access (W-CDMA) technology are due to be introduced.

The following is a rundown of mobile phone and car phone systems that have been commercialized to date.

1.1.1 Analog Cellular Systems

Analog cellular systems were studied by Bell Laboratories in the United States and the Nippon Telegraph and Telephone Public Corporation (predecessor of NTT) in Japan. The American and Japanese systems are referred to as the Advanced Mobile Phone Service (AMPS) and the NTT system, respectively. Both systems are called *cellular systems* because they subdivide the service area into multiple "cells".

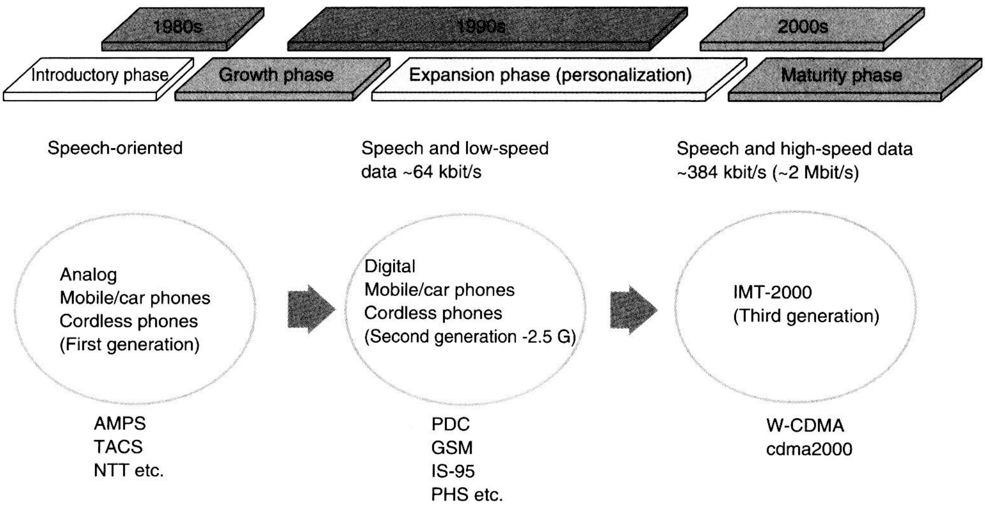

Figure 1.1 Progress in networks

The NTT system embraced the following cellular system element technologies:

1. Use of the new 800-MHz frequency band,
2. small-zone configuration (radius: several kilometers) and iterative use of the same frequency,
3. allocation of a radio channel for control signal transmission separate from speech transmission,
4. development of a mobile terminal that can switch hundreds of radio channels by a frequency synthesizer, and
5. establishment of new mobile-switching technologies to track and access mobile terminals.

The NTT system became commercially available as the Large-Capacity Land Mobile Telephone System in 1979, initially targeting the Tokyo metropolitan area. Later, the service area was gradually expanded to accommodate other major cities nationwide [1].

Moreover, on the basis of this system, efforts were made to improve the adaptability to small and medium-sized cities and to make smaller, more economical mobile terminals. This led to the development of the Medium-Capacity Land Mobile Telephone System, which was rolled out on a nationwide scale.

Subsequently, the further increase in demand for the NTT system prompted the development of a car phone system that would allow the continuous use of legacy mobile phones aimed at dealing with the increasing number of subscribers, improving service quality and miniaturizing the terminals. This resulted in the so-called *large-capacity system*, characterized by one of the narrowest frequency spacings among analog cellular systems worldwide. The system achieved a radical increase in capacity, smaller radio base station (BSs), advanced functions and a wider range of services [2]. Table 1.1 shows the basic specifications of the NTT system.

Table 1.1 Specifications of the NTT system

		NTT system	
		Large city system	Large-capacity system
Frequency band	Base station transmission	870 ~ 885 MHz	8 70 ~ 885 MHz 860 ~ 870 MHz[a]
	Base station reception	925 ~ 940 MHz	925 ~ 940 MHz 915 ~ 925 MHz[a]
Transmission/Reception (TX/RX) frequency spacing		55 MHz	55 MHz
Channel spacing interleave		25 kHz	12.5 kHz 6.25 kHz
Number of channels		600	1199 800

[a]Used by IDO Corporation (predecessor of au Corporation).

On the basis of the American analog cellular standard AMPS, Motorola, Inc. developed a system customized for Britain called the *Total Access Communication System* (TACS). A version of TACS with a frequency allocation adapted to Japan is called *J-TACS*. Another version that achieves greater subscriber capacity by halving the bandwidth of radio channels is called *N-TACS*. Table 1.2 shows the basic specifications of TACS. TACS is characterized by increasing the subscriber capacity, by securing a wider frequency carrier spacing for voice channels to improve the tolerance against radio interference and by subdividing each zone into a maximum of six sectors to shorten the distance for frequency reuse.

1.1.2 Digital Cellular Systems

Digital cellular systems have many features, such as improved communication quality due to various digital signal processing technologies, new services (e.g. nontelephony services), improved ciphering, greater conformity with digital networks and efficient utilization of the radio spectrum.

The development of digital cellular systems was triggered by standardization efforts in Europe, which was home to many competing analog systems. In Europe, analog cellular systems in each country used different frequency bands and schemes, which made interconnection impossible across national borders. In 1982, the European Conference of Postal and Telecommunications Administrations (CEPT) established the Group Spécial Mobile (GSM), and development efforts were carried out under the leadership of the European Telecommunications Standards Institute (ETSI). GSM-based services were launched in 1992.

In the United States, the IS-54 standard was developed under the Electronic Industries Association (EIA) and the Telecommunications Industry Association (TIA). IS-54 services, launched in 1993, were required to satisfy dual-mode (both analog and digital cellular) operations and adopted Time-Division Multiple Access (TDMA). Studies on