# Overview of the Fourth-generation Mobile Communication System

*Narumi Umeda*†, *Toru Otsu, and Tatsuro Masamura*

**Abstract**

NTT DoCoMo is conducting research on the fourth-generation (4G) mobile communication system. This article outlines the technical issues involved in establishing such a system taking into consideration the capability and performance expected from future mobile communication systems. It also overviews the system configuration and discusses activities related to the standardization of 4G mobile communication systems.

## 1. Introduction

The third-generation (3G) of mobile communication services, standardized as IMT-2000 (international mobile telecommunications 2000) [1], which began in October 2001 in Japan, have generated much anticipation regarding the development of a variety of multimedia services such as video communications. We believe that this will lead to mobile communications taking a more central role in our daily lives and to the expansion of this role as our lifestyles use mobile communications as a stepping stone to improve the quality of life over the next ten years. Such an era will require a fourth-generation (4G) mobile communication system that far surpasses the capability of IMT-2000. Providing mobile communication services based on new technology involves more than simply proposing and proving technology—it also requires field-testing of functions and performance, standardization of technical specifications, development of mobile terminals, and construction of network facilities. New mobile communication services will require more time and effort to establish than other types of communication services do. Research and development for the timely introduction of a 4G system that has the performance required to serve as a part of the future foundation for our society and lifestyle is in progress in NTT DoCoMo.

† NTT DoCoMo, Inc.
Yokosuka-shi, 239-8536 Japan
E-mail: umedan@nttdocomo.co.jp

In this article, we describe a basic approach to the technical issues and system configuration involved in achieving the capabilities and performance required of the 4G system based on the research at NTT DoCoMo. We also describe the trends in standardization concerning future mobile communication systems.

## 2. System objectives

### 2.1 Requirements

(1) Broadband communications

Up until now, the traffic carried by mobile communication systems has mainly been voice communications. The second-generation (2G) system, the personal digital cellular (PDC) system, introduced i-mode services [2] that have brought about the currently popular form of Internet access, electronic commerce, and e-mail, which are mainly text-based data communications via a cellular phone. The IMT-2000 system offers high bit-rate transmission services from 64 to 384 kbit/s, and the proportion of data to voice traffic is expected to increase. Moreover, the rising popularity of broadband services such as ADSL (asymmetric digital subscriber line) and optical fiber access systems and office and home LANs is likely to lead to a demand for comparable services in the mobile communications environment.

(2) Low cost

To make broadband services available so that users can exchange various kinds of information, it is necessary to lower charges dramatically to keep the cost

at or below that of existing services. The IMT-2000 system aimed at lowering the bit cost and establishing economical rates, but the 4G system requires a broadband channel and an even lower bit cost.

(3) Wide service area

One feature of mobile communications is that it is available for use anytime and anywhere. These capabilities are also important for future mobile communications. When a new system is first introduced, it is generally difficult to provide such an extensive service area as the existing system, but customers will not buy the new terminals if they have restricted service areas. Moreover, to support terminals that have relatively large display screens, such as personal digital assistants (PDAs) and personal computers with wireless capability, especially ones used with advanced services, which will often be used indoors, we need to provide better coverage of indoor service areas.

(4) Diversified services and ease of use

The target subscriber base for mobile communications comprises various types of users. In the future, we expect to enhance the system performance and functionality to introduce a variety of services that include not only ordinary telephone services, but also services that transfer information utilizing all five senses. These services must be made easier for anyone to use.

### 2.2 Design objectives

The design objectives for meeting the above requirements are shown in **Fig. 1**. Considering that video and data communications will be the main features, the 4G system must provide even higher transmission rates and larger capacity (i.e., both number of users and traffic volume) than IMT-2000. Also, considering that the video transmission quality in current broadcasting is achieved by a transmission rate of several megabits per second, that LAN transmission rates are from 10 to 100 Mbit/s, and that the rate of ADSL is several megabits per second, the design objective is a transfer rate of approximately 100 Mbit/s in an outdoor mobile environment and gigabit-class rates indoors. It will not be possible to accommodate future mobile communication traffic unless a transmission capacity of at least ten times that of the IMT-2000 is achieved. To ensure throughput for communications between terminals and achieve high-level realtime communications, it is necessary to achieve a low transfer delay time of 50 ms. Also, assuming that future services will be based on Internet protocol (IP) networks, efficient transmission of IP packets over wireless connections is also a necessity. While increased capacity is also effective in lowering the bit cost, the cost per bit must be reduced to between 1/10 and 1/100 of the current levels by reducing the infrastructure equipment, operation, and construction costs. The design objectives described above focus on services that have higher performance than existing services, yet are easy to use. It is necessary to pioneer new markets by making use of the capabilities and performance of the 4G system, such as integration with indoor wireless LAN and wired systems, and by implementing a mechanism for introducing new services in a short time.

## 3. Basic approach to 4G system configuration

### 3.1 Technical issues

The technical issues concerning wireless technolo-

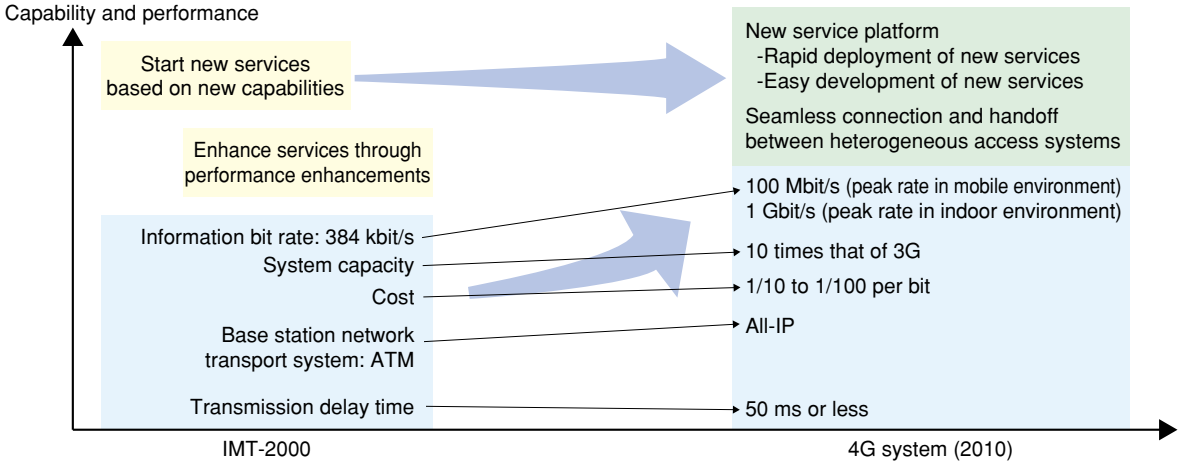


Fig. 1. Design objectives.

gy that need to be addressed to achieve the system objectives described above are shown in **Fig. 2**.

(1) High-capacity and high-rate transmission

IMT-2000, which employs wideband code division multiple access (W-CDMA), achieves a transmission rate of 2 Mbit/s with a 5-MHz frequency bandwidth. Furthermore, technology for transmission at approximately 10 Mbit/s with the same frequency bandwidth using multi-level adaptive modulation and demodulation is under development [3]. To achieve rates of 100 Mbit/s to 1 Gbit/s, we must use a larger frequency bandwidth and new transmission systems that are suited to high-rate transmission. For data communications, we will need a radio access system that can transmit packets efficiently. Considering the importance of indoor area coverage in the future, technologies that allow use both indoors and outdoors must also be developed. To obtain the broadband frequencies for achieving high-rate transmission and meet the expected large increase in data traffic demand, we must consider new frequency bands and we must develop the circuit technology needed to make amplifiers and filters and understand radio wave propagation in these bands. At the same time, technology for making efficient use of limited spectrum resources is also important.

(2) Lower costs

With conventional system configuration technology, using a higher frequency band to achieve a higher transmission rate generally reduces the area of the cell that one base station can cover. Retaining the original coverage area requires more base stations and increases the network cost. To avoid that problem, it is necessary to expand the cell radius by using higher performance radio transmission and circuit technology such as improved modulation/demodulation techniques that can cope with a low signal-to-noise ratio, adaptive array antennas, and low-noise receivers. To further reduce the system construction and operating costs, we must study diversified entrance links that connect base stations to the backbone network, autonomous base station control technology, and multi-hop radio connection technology employing simple relay stations.

(3) Interconnection based on IP networking

One way to ensure that users of the new system do not have restricted service areas is to ensure that new terminals can handle the existing system as well as the new one. Moreover, considering the demand for international roaming, a terminal that can be configured to work with multiple systems based on software defined radio (SDR) technology [4] is an effective way to cope with introductory periods and differences in operating frequency bands among different countries and regions. Furthermore, future mobile communication networks will be integrated with heterogeneous access methods and various kinds of cells with interconnection capabilities based on IP net-

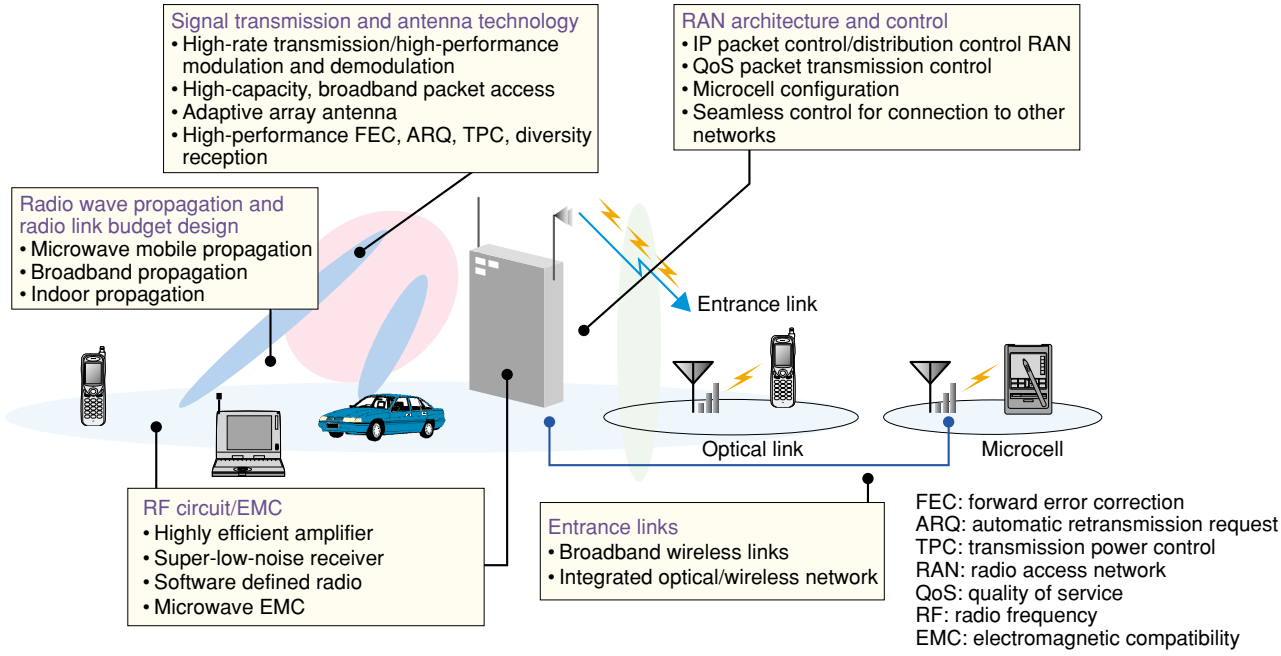


Fig. 2. Technical issues concerning wireless technology.

working. Accordingly, interconnection and handover between such various access systems are required in addition to handover and roaming within one mobile communication system.

### 3.2 System configuration

(1) IP-based connection configuration

The 4G system will be configured for connection to IP networks, considering efficient transmission of IP packets, co-existence with other access systems, ease of system introduction, expandability, and other such factors. IP networks can also connect with or accommodate wireless access systems other than 4G systems. The 4G wireless access point (hereinafter 4G-AP) will be connected to an access router (AR) as shown in **Fig. 3** and will have wireless control functions for wireless transmission, handover, etc., allowing communication with mobile nodes operating on IP. The 4G-APs will form their respective cells. When a mobile node moves between cells, handover will be accomplished by simply switching access points and wireless areas if the two 4G-APs are connected to the same AR. If the 4G-APs belong to different ARs, then the packet transmission route on the IP network must be changed rapidly. The cooperative operation of 4G-AP switching and IP routing is important for smooth handover. For handover between a 4G-AP and an AP of another system, the mobile node must have functions for accessing both systems. Handover will be performed by monitoring and comparing different systems to select the one that is more suitable.

(2) Cell classification and configuration according to communication environment

The 4G system has cells for outdoors, indoors, and inside moving vehicles, as shown in Fig. 3. Outdoor cells cover a wide area, unlike the hotspot areas of wireless LANs, and allow high-rate packet transfer for fast-moving terminals. Indoor areas are covered by indoor APs, because the radio waves to/from outdoor base stations suffer large attenuation. Indoor APs are designed not only to provide a high rate transfer and simple operation, but also to compete with expected future wireless LANs. Furthermore, cells within moving vehicles such as buses and trains (moving cells/networks) are served by a mobile router (MR) that has wireless functions and relays signals between a base station and each terminal in the vehicle, rather than the terminals individually communicating directly with the base station in the conventional method. This configuration is designed to achieve efficiency in terms of terminal transmission power, transmission rate, control signal volume, etc. A multi-hop connection, which is effective in expanding the cell size, is being investigated as a way to overcome dead spots caused by shadowing. Data transmission via relay stations is expected to allow communications even when the effects of limited terminal transmitting power and radio wave propagation attenuation are large, as shown in **Fig. 4** [5].

(3) Multimedia communications

Conventional IP networks have provided mainly best-effort services, but with realtime applications expected to increase as multimedia communication

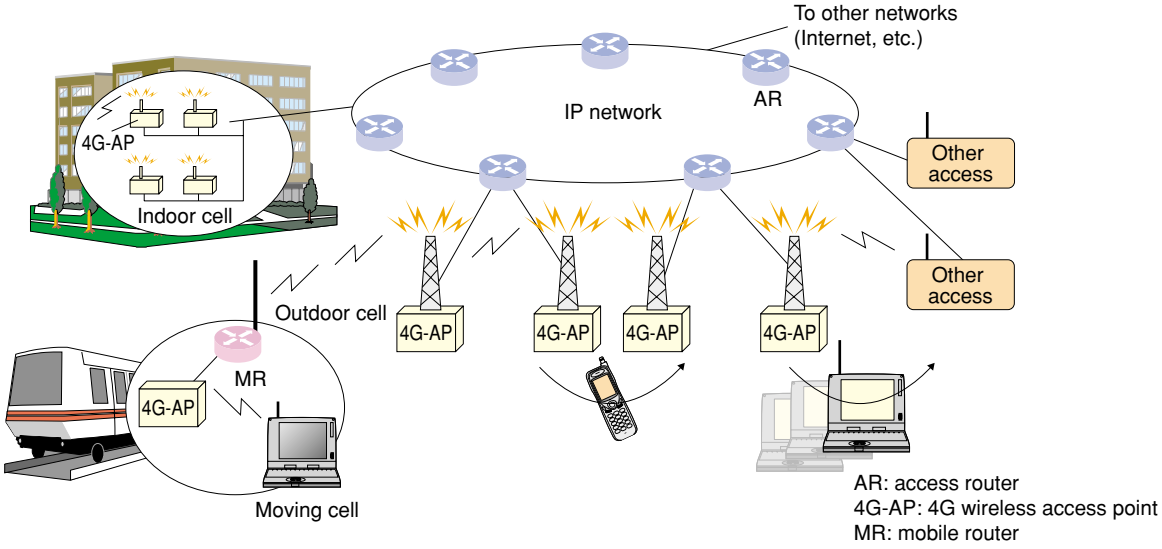


Fig. 3. 4G system configuration.

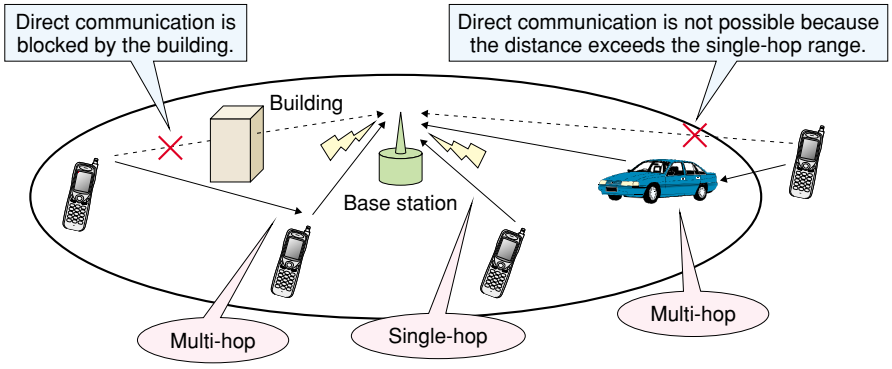


Fig. 4. Communication problems overcome by multi-hop connection.

diversifies, the importance of services that take into account quality of service (QoS) is also expected to increase. The 4G system configuration allows for a mechanism that guarantees the transmission rate to some extent and that prioritizes packet transfer by the packet type in cooperation with the IP network for QoS-aware packet transmission on a mobile radio link, which is the bottleneck.

## 4. Trends in standardization

### 4.1 ITU-R activities

In 2000, the year in which the prospect of introducing the IMT-2000 system came into view, the international telecommunication union (ITU) began research on future development of IMT-2000 and other systems. In the ITU radiocommunication sector (ITU-R), investigation of Q.229/8 on future development of IMT-2000 and systems beyond IMT-2000 was assigned to study group 8 (SG8) working party 8F (WP8F), which was established in November 1999, and work on this topic began in March 2000. At the world radiocommunication conference held in June 2000 (WRC-2000), ITU-R resolved to conduct research on future systems, including spectrum requirements, to investigate the research situation at WRC-2003, and to review spectrum requirements at subsequent WRCs. ITU-R WP8F formulated a recommendation regarding a future vision to give direction to future technological development. The recommendation was approved at the February 2003 meeting of SG8 and forwarded to a higher-level organization, the radiocommunication assembly (RA). In RA, it was approved as the framework recommendation in June 2003. In WRC-2003 held in July, approval was given for the agenda items of WRC-2007 to include the frequency assignment for systems beyond IMT-2000. In that recommendation, “systems beyond IMT-2000” is considered to cover all future mobile communication systems, including the current IMT-2000 and its enhanced versions. The various wireless access systems will need to cooperate via the network so that users can use the full range of capabilities of the systems beyond IMT-2000 without being aware of individual wireless access systems. Furthermore, there is now recognition of the need for a new wireless access system and a frequency band for it to operate in to cover the performance region that cannot be achieved by advanced IMT-2000 systems (transmission rates of approximately 100 Mbit/s during high-speed movement and approximately 1 Gbit/s when not moving, although these bit rates assume sharing by users and the specific values are research targets). Furthermore, the target time for implementation of the new wireless access system is 2010 [6]. In the future, the study of spectrum requirements and research on specific technological issues are expected to make progress.

### 4.2 Activities in Japan

In Japan, the New Generation Mobile Communication Committee was established in the Information and Telecom Council of the Ministry of Public Management, Home Affairs, Posts and Telecommunications between October 2000 and June 2001, the same period during which ITU began research, and it formulated a vision for future mobile communications [7]. The results were reflected in ITU-R’s vision recommendation described above. Furthermore, based on the committee’s findings, the mobile IT Forum (mITF) was established in June 2001 to investigate and research the early implementation of the 4G system, mobile commerce, and other topics. [8].

### 4.3 Activities in other organizations

The Wireless World Research Forum (WWRF), an

organization of mainly European vendors, is also conducting research concerning a future vision for wireless communications [9], and new research projects are being organized on the basis of the results. In Europe, the 6th Framework Programme is being promoted. It established "Ambient Network" [10] and "WINNER" [11] this January and initiated research on future systems.

### 4.4 Future plans

The vision for systems beyond IMT-2000 proposed so far by ITU-R coincides with the research objectives of NTT DoCoMo. We will continue to contribute to the standardization work being accomplished by ITU-R in coordination with future progress in research. It is also important to make global standards through cooperation with other research organizations. IEEE, which has established wireless LAN standards, has begun to study next-generation wireless LANs. Considering the expected increase in indoor use of the 4G system and the growing affinity for the Internet, further cooperation with IEEE standardization is necessary.

## 5. Conclusion

We outlined research projects toward the 4G system. We described system requirements, topics for study, and a basic approach to the system configuration. We also presented trends related to standardization in this field.

## References


[1] http://www.itu.int/home/imt.html
[2] http://www.nttdocomo.com/corebiz/imode/index.html
[3] F. Adachi and M. Uesugi, "Latest Trends in CDMA Technology," IEICE Journal, Vol. 86, No. 2, pp. 96-102, 2003.
[4] K. Uehara, K. Araki, and M. Umehira, "Trends in Research and Development of Software Defined Radio," NTT Technical Review, Vol. 1, No. 4. pp. 10-14, 2003.
[5] A. Fujiwara, S. Takeda, H. Yoshino, T. Otsu, and Y. Yamao, "System Capacity Expansion Effect of Multi-hop Access in a Broadband CDMA Cellular System," IEICE Trans. B, Vol. J85-B, No. 12, pp. 2073-2079, 2002.
[6] T. Otsu, "The Challenge of Systems beyond IMT-2000—approach from wireless," ITU Journal, Vol. 33, No. 3, pp. 26-30, 2003.
[7] http://www.soumu.go.jp/joho_tsusin/policyreports/joho_tsusin/bunkakai/abstract.pdf
[8] http://www.mitf.org/index_e.html
[9] http://www.wireless-world-research.org/
[10] http://www.ambient-networks.org/
[11] https://www.ist-winner.org/



**Narumi Umeda**
Director, Communication Systems Laboratory, Wireless Laboratories, NTT DoCoMo, Inc.
He received the B.E. and M.E. degrees in electronic engineering from Hokkaido University, Sapporo, Hokkaido in 1985 and 1987, respectively. He joined NTT Laboratories in 1987. In 1992, he transferred to NTT Mobile Communications Network, Inc. (now NTT DoCoMo, Inc.). He has been engaged in research on the radio link control for the personal digital cellular (PDC) system and IMT-2000. His current research interests are in the radio control for 4G mobile communications systems (beyond 3G). He was a co-recipient of the Japan Institute of Invention and Innovation (JIII) Imperial Invention Prize in 1998 and the best paper award of the International Conference on Telecommunications at ICT2002. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) and IEEE.



**Toru Otsu**
Director, Global Business Department, NTT DoCoMo, Inc. (Formerly with the Wireless Laboratories)
He received the B.E., M.E., and Ph.D. degrees in global information and telecommunications from Waseda University, Tokyo in 1983, 1985, and 2002, respectively. In 1985, he joined NTT and in 2000 he transferred to NTT DoCoMo, Inc. From 1992 to 1993, he was a visiting researcher at ENST (Ecole Nationale Superieure des Telecommunications), France. Since joining NTT DoCoMo, he has been involved in research projects on 4G mobile communications systems and related standardization activities. His research interests are network architectures, network control protocols, and resource management in mobile and satellite networks. He is a member of IEICE and IEEE.



**Tatsuro Masamura**
Associate Senior Vice President, Managing Director of Wireless Laboratories, NTT DoCoMo, Inc.
He received the B.E. and M.E. degrees in electrical engineering from the University of Tokyo, Tokyo in 1974 and 1976, respectively. He joined the Electrical Communication Laboratories, Nippon Telegraph and Telephone Public Corporation (now NTT) in 1976. Since then he has been engaged in R&D of satellite communication systems based on CDMA and TDMA. He worked at the Communication Research Center, Department of Communication of Canada as an exchange scientist from 1983 to 1984. From 1992 to 1994, he was a manager of satellite communications systems at NTT Network Development Center. From 1994 to 1999, he was engaged in the development of multimedia services using satellite communications. From 1999 to 2002, he was the executive manager of NTT Network Innovation Laboratories. Since April 2002, he has been with NTT DoCoMo as the Managing Director of Wireless Laboratories responsible for R&D activities for next-generation mobile communications.