(1) The Fourth-Generation Mobile Communication System

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Research on the Fourth-Generation (4G) mobile communication system is being performed in the Wireless Laboratories. We outline the technical issues involved in realizing such a system, considering the capability and performance expected of future mobile communication systems. We also discuss activities related to standardization of the 4G mobile communication system.

1. Introduction

The offering of Third-Generation (3G) International Mobile Telecommunications-2000 (IMT-2000) mobile communication services which began in October 2001, and the development of a variety of multimedia services such as video communication are expected. We believe that this will lead to mobile communication more important to our daily lives and expand the role as a lifestyle basis in the next ten years. Such an era requires a new 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 just proposing and proving technology; field-testing of function and performance, standardization of technical specifications, development of mobile terminals, and construction of network facilities are also required. New mobile communication services thus require more time and effort to establish than do other types of communication services. Research and development for a timely introduction of a 4G system that has the performance required to serve as a future foundation for society and lifestyle is already in progress in the Wireless Laboratories, and results are accumulating.

In this article, we describe a basic approach to the technical issues and system configuration involved in achieving the capability and performance required of the 4G system. We also describe the trends in standardization concerning mobile communication systems.

2. System Objectives

2.1 Requirements for 4G System

(1) Broadband Communication

The traffic carried by mobile communication systems until today was mainly voice communication. The Second-Generation (2G) system, the Personal Digital Cellular (PDC) system introduced the i-mode services, which enabled the currently popular Internet access, electronic commerce and e-mail, which are mainly the text-based data communications via the cellular phone. The IMT-2000 system offers high bit rate transmission service from 64 kbit/s to 384 kbit/s, and it is expected that the proportion of data traffic would continue to increase. Moreover, the rising popularity of broadband services such as ADSL or optical fiber access systems and office or home LANs is likely to lead to a demand for comparable services in the mobile communication environment.

(2) Low Cost

To make broadband services available to the user to exchange various kinds of information, it is necessary to lower charges dramatically in order to keep the cost at or below the cost of existing service. The IMT-2000 system aimed at lower bit cost and economical charge rates, but for the 4G system, a broadband channel and an even lower bit cost are both required.

(3) Wide Service Area

One feature of mobile communication is that it is available for use anytime and anywhere. That advantage is important for future mobile communication as well. In particular, it is important to maintain the service area in which the terminals of the new system can be used during the transition from the existing system to a new system. It can be assumed that terminals that have relatively large display screens, such as Personal Digital Assistants (PDAs) or personal computers are used indoors rather than outdoors. Accordingly, better coverage of indoor service areas is needed.

(4) Diversified Services and Ease of Use

Mobile communication is for various types of users. In the future, we expect to make the advanced system performance and functionality to introduce a variety of services not only the ordinary telephone service but to transfer information about the five sensual modes. Those services must be made easier for anyone to use.

2.2 System Design Objectives

The system design objectives for meeting the requirements described above are shown in **Figure 1**.

Considering that video communication and data communication will be the main features, the 4G system must provide even higher transmission rate and higher capacity than IMT-2000. Also, considering that video transmission quality in current broadcasting is achieved by a transmission rate of several megabits per second, LAN transmission rates are from 10 Mbit/s to 100 Mbit/s, and the rate of ADSL is several megabits per second, the design objective is a transfer rate of about 100 Mbit/s for the outdoor mobile environment and gigabit class rates for indoors. It will not be possible to accommodate future mobile communication traffic unless a transmission capacity of at least ten times that IMT-2000 does attain. To ensure throughput for communication between terminals and achieve highly real-time communication, it is necessary to realize the low transfer delay time of 50 ms and low connection set up delay time of 500 ms or less. Also, assuming that future services will be based on IP (Internet Protocol) networks, the efficient transmission of IP packets between wireless terminals is also a necessity. While increased capacity is also effective in lowering bit cost, the cost per bit must be reduced to from 1/10 to 1/100 of the current levels by reduction of infrastructure equipment costs, operation costs and construction costs as well.

The design objectives described above aim at services that have higher performance than existing services, yet are easy to use. It is necessary to pioneer new markets, making use of the capabilities and performance of the 4G system such as integration with indoor wireless LAN and wired systems, and the implementation of a mechanism for introducing new services in a short time, etc.

3. Basic Approach to 4G System Configuration

3.1 Technical Issues

The technical issues to be addressed for achieving the system objectives described above, particularly concerning the wireless technology aspect, are shown in **Figure 2**.

(1) Technology for Implementing 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 under stand-still conditions. Furthermore, technology for transmission at about 10 Mbit/s with the same frequency bandwidth using multi-level adaptive modulation and demodulation is under development [1]. To achieve rates that are several times to several tens of times higher than that, it requires the use of greater frequency bandwidth and new transmission systems that are suited to high-rate transmission. Turning attention to the characteristics of data communication, we can see the need for an radio access system that can transmit packets efficiently. Furthermore, considering the importance of indoor area coverage for the future, technologies that allow to use both indoors and outdoors must also be developed. Moreover, to ensure the broadband frequencies for realizing high-rate transmission and to meet the anticipated great increase in data traffic demand, it is necessary to consider

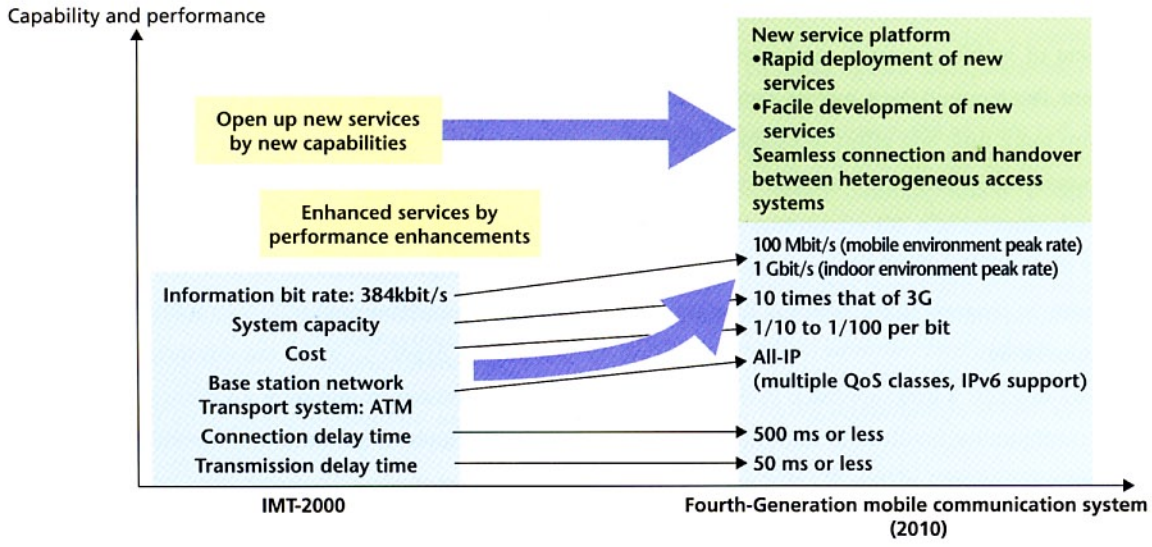

Figure 1 Main targets for capability and performance

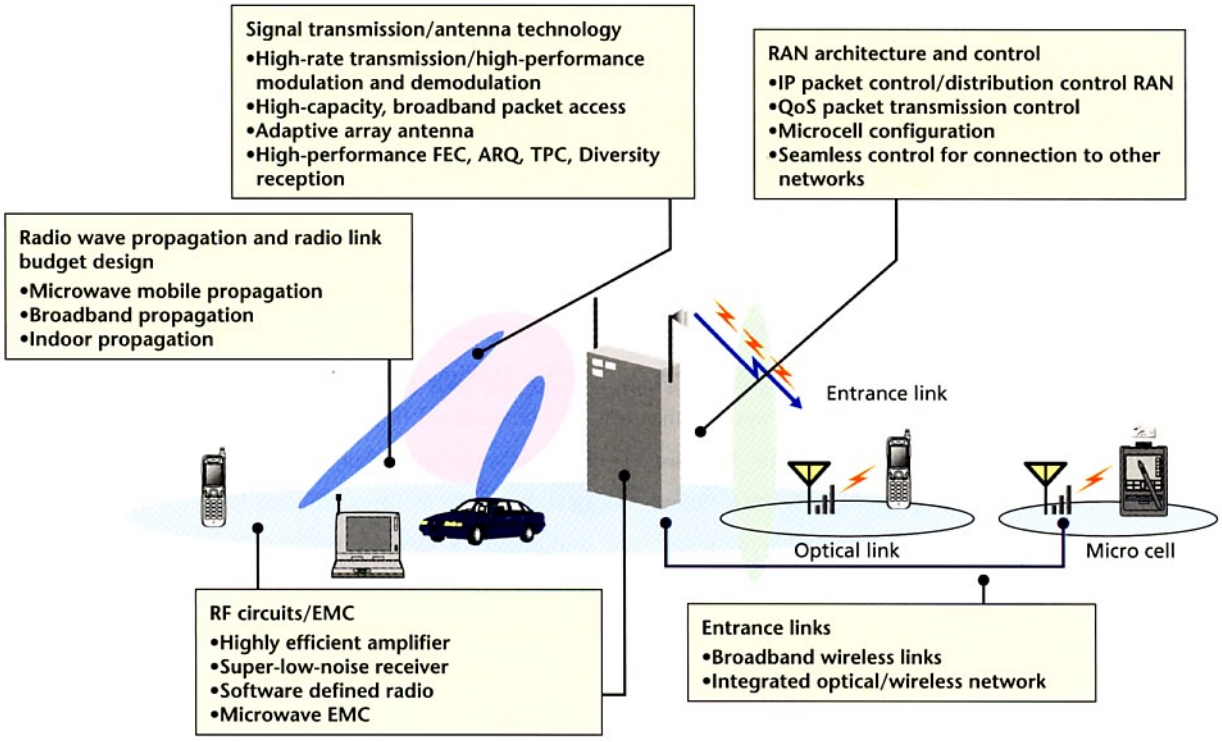

Figure 2 Research issues concerning wireless technology

new frequency bands. Along with that comes the need for circuit technology to implement amplifiers and filters for the new frequency bands and for elucidation of radio wave propagation in those bands. At the same time, technology for efficient use of limited spectrum resources is also important.

(2) Cost Reduction Technology

The use of higher frequency band to achieve higher transmission rate with conventional system configuration technology generally reduces the radius of the cell that one base station can cover. To retain the original coverage area, more base stations are required and network cost is increased. To avert that problem, it is necessary to expand cell radii by means of higher performance radio transmission and circuit technology, such as improved modulation/demodulation techniques that can cope with low S/N, the use of adaptive array antennas, and low noise receivers. There is also a need to study diversified entrance links that connect base stations to the backbone network, autonomous base station control technology and multi-hop radio connection technology that employs simple relay stations, for further reduction in the costs of system construction and operation.

(3) System Interconnection Technology Based on IP Networking

When a new system is first introduced, it is generally difficult to fulfill the service area to the extent of the existing system. However, by implementing a terminal that has the capabilities of both the new system and the existing system, it is possible to cover both areas. Also, giving consideration to international roaming, a terminal that can be configured to work with multiple systems based on Software Defined Radio (SDR) technology is an effective way to cope with periods of system introduction and operating frequency bands that differ from country to country and region to region. Furthermore, future mobile communication services will be provided with interconnection and integrated with heterogeneous access technologies, including wired and indoor area, access based on IP networks. 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) is connected to a router and has wireless control functions for

wireless transmission, handover, etc., allowing communication with mobile nodes operating on IP.

The router is connected to multiple 4G-APs which form their respective cells. When a mobile node moves between cells, handover is accomplished by simply switching access points and wireless areas if the two 4G-APs are connected to the same router. If the 4G-APs belong to different routers, it is necessary to rapidly change the packet transmission route on the IP network, as well. The cooperative operation of 4G-AP switching and IP routing is important for smooth handover. For handover between a 4G-AP and an access point of the other system, the mobile node must have functions to access both systems. Handover is performed by monitoring and comparing different systems to select one that is suitable.

(2) Cell Classification and Configuration According to Communication Environment

The 4G system has cells for outdoors, indoors and within mass transportation vehicles, as shown in **Figure 3**. Outdoors cells cover a wide area, unlike the spot areas of wireless LANs, and allow high-rate packet transfer for fast-moving terminals. Indoor areas are covered by indoor access points, rather than by outdoor base stations for which radio wave attenuation is large, aiming at competitiveness with respect to future wireless LANs as well as high rate transfer and simplicity of function. Furthermore, cells within moving vehicles such as buses and trains (moving cells/ moving networks) will be served by a Mobile Router (MR) that has wireless functions and relays the signal between a base station and each terminal in the vehicle, rather than the terminals individually communicating directly with the base station in the conventional way. That configuration is designed to achieve efficiency in terms of terminal transmission power, transmission rate, control signal volume, etc.

Multi-hop connection, which is effective for expanding cell size and as a measure against dead area caused by shadowing, is also being investigated. Data transmission via relay stations is expected to allow communication even when the effects of limited terminal transmitting power and radio wave propagation attenuation are large, as shown in **Figure 4** [2].

(3) For Multimedia Communication

Conventional IP networks have provided mainly best-effort services, but, anticipating an increase in real-time applications in response to the diversified multimedia communication, the importance of services that take Quality of Service (QoS) into account is also expected to increase. The configuration allows a mechanism that guarantees transmission rate to some extent and prioritizing packet transfer by packet type in cooperation with IP network for QoS aware packet transmission on the mobile radio link, 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 future system. In the ITU Radiocommunication sector (ITU-R), investigation on the new Q.229/8 research topic, future development of IMT-2000 and Systems beyond IMT-2000, posed for the Study Group 8 (SG8)

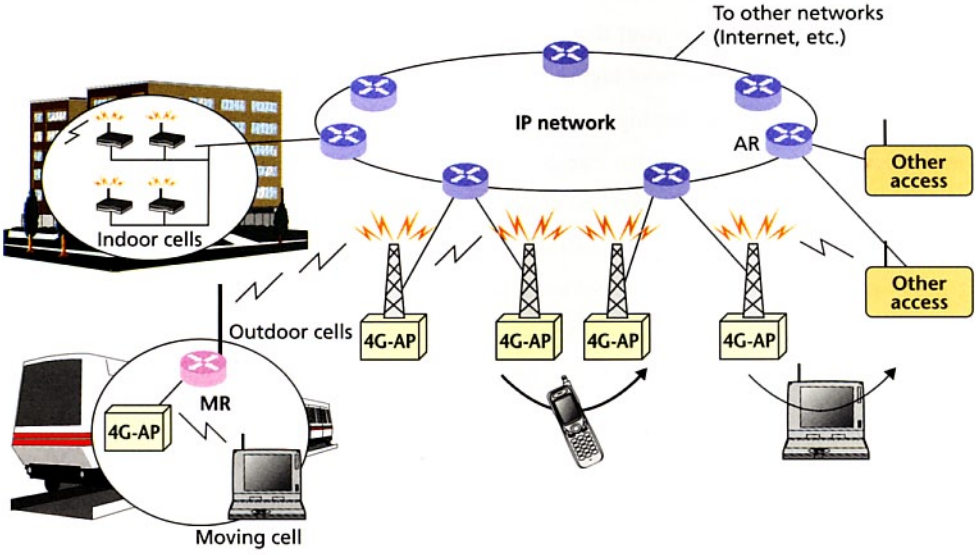

Figure 3 4G system configuration image

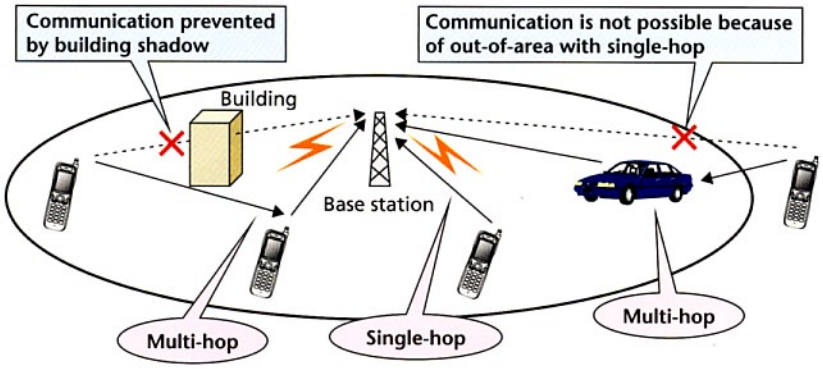

Figure 4 Area complementation by multi-hop connection

Working Party 8F (WP8F) established in November 1999 began in March 2000. At the World Radiocommunication Conference -2000 (WRC-2000) held in Istanbul in June 2000, ITU-R resolved to do research on future systems, including spectrum requirements, to investigate the research situation at WRC-2003 and to review spectrum requirements at subsequent WRCs. As the first step, the ITU-R WP8F has 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 sent on to the higher level organization, the Radiocommunication Assembly (RA). In that recommendation, 'Systems beyond IMT-2000' is considered to be the whole of future mobile communication systems, including the current IMT-2000 and its enhanced versions. Cooperation of the various wireless access systems that constitute 'Systems beyond IMT-2000' via the network will be required so that users will be able to use the full range of capabilities of Systems beyond IMT-2000 without awareness of individual wireless access systems. Also, there is now recognition that a new wireless access system and a frequency band for that system to operate in are needed to cover the performance region that cannot be achieved by advanced IMT-2000 systems (transmission rates of about 100 Mbit/s during high-speed movement and about 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 period for implementation of the new wireless access system is the year 2010 [3]. In the future, the study of requirements concerning spectrum and research on specific technological issues are expected to move forward.

4.2 Activities in Japan

In Japan, the New Generation Mobile Communication Committee was set up 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 formulated a vision for future mobile communication [4]. The result was reflected in the ITU-R vision recommendation described above. Furthermore, according to the findings of the New Generation Mobile Communication Committee, the mobile IT Forum (mITF) was established in June 2001, for investigation, research and early implementation of the 4G system and mobile commerce etc. [5]

4.3 Activities in Other Organizations

The Wireless World Research Forum (WWRF), an organization of mainly European vendors, is also producing research results concerning a future vision for wireless communication [6], and new research projects are being organized on the basis of those results. Also, the 3rd Generation Partnership Project (3GPP), which created the IMT-2000 standard specifications through international cooperation, has produced a road map for future functional extension of IMT-2000. That road map includes study of a schedule for functional extension according to the ITU-R vision recommendation.

4.4 Future Plans

The vision for Systems beyond IMT-2000 as it has been completed up to now by ITU-R coincides with the research objectives of the Wireless Laboratories. We will continuously contribute to the standardization work being done by ITU-R in coordination with future progress in research. To make global standards through cooperation with other research organizations is also important. The Institute of Electrical and Electronic Engineers (IEEE), which has established wireless LAN stan-

dards, has begun study of the next-generation wireless LAN. Considering the increasing indoor use of the 4G system and growing affinity for the Internet, further cooperation with IEEE standardization is necessary.

5. Conclusion

We reported on research that is directed toward implementation of the 4G system and described system requirements, topics for study, and a basic approach to system configuration. We also explained trends related to standardization in this field.

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ABBREVIATIONS

3GPP: 3rd Generation Partnership Project
ADSL: Asymmetrical Digital Subscriber Line
AP: Access Point
AR: Access Router
ARQ: Automatic Repeat reQuest
ATM: Asynchronous Transfer Mode
EMC: Electro-Magnetic Compatibility
FEC: Forward Error Correction
IEEE: Institute of Electrical and Electronic Engineers
IMT-2000: International Mobile Telecommunications-2000
IP: Internet Protocol
IPv6: IP version 6
ITU: International Telecommunication Union
ITU-R: ITU-Radiocommunication sector
LAN: Local Area Network
mITF: mobile IT Forum
MR: Mobile Router
PDA: Personal Digital Assistant
PDC: Personal Digital Cellular
QoS: Quality of Service
RA: Radiocommunication Assembly
RAN: Radio Access Network
RF: Radio Frequency
SDR: Software Defined Radio
SG8: Study Group 8
TPC: Transmit Power Control
W-CDMA: Wideband Code Division Multiple Access
WP8F: Working Party 8F
WRC: World Radiocommunication Conference
WWRF: Wireless World Research Forum