A Perspective on the Evolution of Mobile Communications

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ABSTRACT

This essay outlines the current state of mobile communications and presents some of the future directions in research and development from the perspective of NTT DoCoMo with special emphasis on the market in Japan. The essay will first describe the directions in which mobile communications are expected to forge ahead in the future, and the service implementation strategies they could employ. Then it will describe an example of mobile multimedia services and present an outline of Freedom of Mobile Multimedia Access (FOMA), which is a service based on the 3G mobile communications system called International Mobile Telecommunications-2000 (IMT-2000). This will be followed by an overview of our R&D approach to 4G systems, which constitute mobile communications systems of the future, and the profile of technologies to make these happen. Finally, it will review our approach to future technologies that are expected to be realized in 4G and subsequent systems, and illustrate with an example of a research project.

INTRODUCTION

Currently, Japan is the world's third largest mobile communications market, behind China and the United States. In Japan, the number of mobile phone subscribers increased by 10 million annually over the five-year period between 1995 and 2000. As a result, by 2000 the number of mobile phone subscribers exceeded the number of subscribers to fixed-line phones, which have a history of more than 100 years. Currently, the number of mobile phone subscribers is 82.2 million, and the national penetration rate was 69 percent at the end of May 2003.

The other significant trend in the telecom market is the growth of the Internet and broadband services. In the late 1990s, the number of Internet users rapidly increased worldwide. Nowadays, broadband access based on asymmetric digital subscriber line (ADSL), CATV, fiber to the home (FTTH), and other such technologies is gaining momentum, and various multimedia services are being implemented harnessing their high-speed broadband characteristics.

Mobile communications services in Japan are distinctive in that the number of wireless Internet users, through mobile phones, has exploded since the launch of i-mode by NTT DoCoMo. Today, more than 60 million people access the Internet using mobile phones: wireless mobile Internet has become widely accepted in Japan. While the mobile communications market has rapidly grown in recent years as such, the rate of increase in the number of subscribers has started to slow down as the penetration rate of mobile phones has risen and is about to reach the saturation point. For further progress, new mobile service frontiers need to be explored.

By October 2001, the third-generation (3G) mobile communications system IMT-2000, an international standard, was implemented in Japan before any other country in the world. This is expected to facilitate widescale penetration of non-voice mobile multimedia services.

Furthermore, NTT DoCoMo is working on the research and development of a 4G system that supports faster and larger-capacity transmissions, in order to provide high-resolution video and other applications seamlessly in a mobile environment.

This essay outlines the current state of mobile communications and presents some of the future directions in research and development from the perspective of NTT DoCoMo and with special emphasis on the market in Japan. In the following sections, we will discuss the nature of various mobile multimedia services and provide an outline of the 3G mobile communications system. This will be followed by a description of our R&D approach to 4G mobile communication systems, which are regarded as one of the systems beyond IMT-2000, and the present state of research and development. The final section will provide a forecast of future technologies in 4G and subsequent systems.

OBJECTIVES OF MOBILE COMMUNICATIONS AND SERVICE IMPLEMENTATION

Mobile communications services originated from voice telephony. However, even if every person in the country owns a mobile terminal, we can

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neither expect the number of subscribers to exceed the population nor hope for an increase in traffic merely through voice telephony. Therefore, in light of exploring new service frontiers for mobile communications in the 21st century, there are three cornerstones in the strategies to achieve growth in mobile communications, as shown in Fig. 1: the implementation of multimedia services, ubiquitous services, and global services.

Multimedia services are expected to diversify services and increase the volume of traffic by migrating traditional voice-oriented services over to services centering on text data, image (still pictures, video), and other non-voice services.

Ubiquitous services aim to expand the object of communications services, which has been limited to human so far, to everything and anything. In principle, a wireless terminal may be attached to anything we would find convenient if traceable. For example, an extremely small wireless chip may be attached to a bag being delivered to execute delivery management. As such, if everything or anything other than human that moves becomes an object of mobile communications, the number of mobile terminals will increase dramatically and lead to much greater traffic.

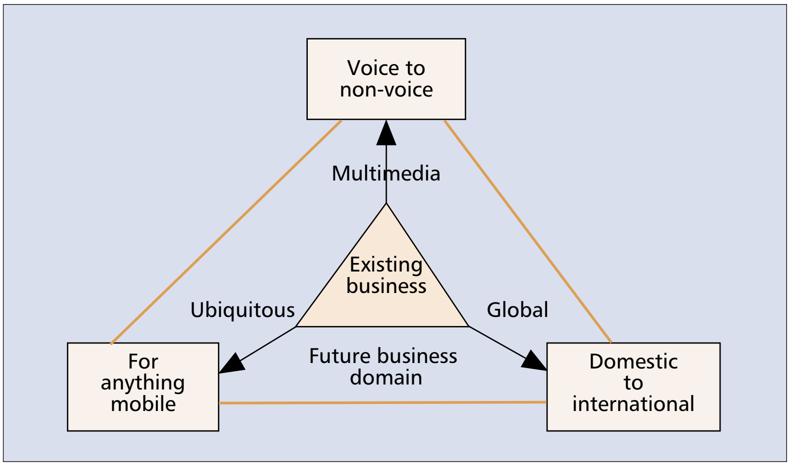
Globalization is about implementing multimedia services that are standardized on a worldwide scale. The aim is to achieve global mobility.

In order to achieve progress based on these three cornerstones, there are many technological and management issues that need to be resolved, particularly on the technology front, where it is necessary to put additional focus on multimedia and ubiquity.

In a society with advanced multimedia and ubiquitous communications services, computers and communication equipment will be all over the place, and communications will take place in all forms centering on mobile networks, not only between people, but also between a person and a machine (computer), and even between a machine and another machine. Under these circumstances, a huge increase in non-voice traffic will be expected in person-person, person-machine, and machine-machine communications. In order for mobile multimedia services to make progress in an ubiquitous environment, the execution of the following three policies appears to be a prerequisite:

- Give wireless communications functions to all moving objects.
- Give wireless communications functions to places where fixed lines are hard to install.
- Give wireless communications functions to objects that take orders, make confirmation, and execute control functions, assuming that they will be worn by users.

NTT DoCoMo has bold forecasts on the future demand for communications. Currently, we experience an increasing role being played by the computerization and networking of home electrical appliances and delivery services. Assuming that mobile communications terminals will be attached to everything and anything that moves, taking into account home electrical appliances and parcels whose movements need to be tracked, we estimate that the total number of mobile communications terminals connected to mobile networks around 2010 will exceed 500 million units in Japan alone.



■ **Figure 1.** *Directions of mobile communications.*

It will be possible to increase the number of terminals if a subscriber starts using more than one terminal, each for a different purpose and occasion, in the same manner as a person changing into a different outfit according to a specific occasion. It will also be possible to accommodate a huge number of terminals without being capped by the population size if home information appliances, wireless tags, sensors, and other wireless terminals are broadly used in a ubiquitous environment. A profitable business model will be required for each service contract, based on the growing number of terminals and the increasing types of services available to them. It is important for future mobile networks to have enhanced platform functions that can offer diverse services to such ubiquitous terminals in massive numbers.

Mobile Multimedia Services and 3G Systems

In Japan, various mobile multimedia services have been offered as a priority since the early days of the second-generation (2G: digital) cellular systems to spur demand for new mobile multimedia services and increase traffic, anticipating the saturation of voice-oriented telephony demand.

Specifically, efforts to develop various new services are being made in five categories: the Internet, location information, information distribution, remote sensing/control, and settlement.

Internet services include i-mode, which is one of the most successful services, having gained as many as 36.5 million users as of the end of January 2003 since its launch in February 1999. The i-mode service was initially limited to email and text-based Web browsing, but subsequently incorporated intranet packages for corporate users. In i-mode-enabled mobile terminals, the adoption of color liquid crystal display (LCD) and the diversification of ringtones underwent rapid progress. In the beginning of 2001, i-mode

i-mode	• Fast-speed access at up to 384 kb/s (downlink) • Still pictures and music attachable to i-mode mail • Supports mail size up to 5000 full Japanese characters • Supports i-appli applications
Video phone	• Comfortable video transmission with 64 kb/s digital connection
High-speed data access	• High-speed packet access at up to 384 kb/s (downlink)/64 kb/s (uplink) • 64 kb/s digital communications • LAN service (dedicated line connection service)
Multiple access	• Simultaneous packet transmission while talking over the phone is enabled
Voice	• Voice quality equivalent to landline network

Table 1. *FOMA services.*

Figure 2. *The FOMA handset line-up.*

was powered by Java, and the service enabled terminals to download application programs named i-appli. In May 2002, we accelerated its packet communications speed to 28.8 kb/s and equipped the terminals with infrared communication functions, offering new ways to use them by interacting with various machines, including vending machines.

Location services include services that offer location information to users and car navigation applications based on location information, which is a distinctive feature of mobile communications.

Information distributing services include content distribution (e.g., games), video distribution (e.g., advertisements, promotion videos), and music distribution, which can be customized according to individual preferences.

Remote monitoring/control services involve the management of the stock status of vending machines with built-in wireless terminals and the remote control of home information appliances.

Settlement services relate to mobile e-commerce, in which mobile terminals are used in place of wallets to buy bus/train tickets, concert tickets, and even merchandise.

In order to offer these mobile multimedia services, a more advanced mobile communication system will have to be put in place as massive volumes of information will have to be provided at low cost.

The 3G system IMT-2000 was developed and implemented for the purpose of offering various high-quality multimedia services including voice and image that can be seamlessly received anywhere in the world by a single phone across diverse user environments, both indoors and outdoors.

In Japan, IMT-2000 was commercialized before any other carrier in the world in a service called FOMA, which is based on wideband code-division multiple access (W-CDMA), a wireless access technology adopted as one of the global standards in October 2001.

FOMA is capable of offering a wide range of high-speed data communications services as shown in Table 1, due to its radically improved circuit- and packet-switched communication speed. In circuit-switched communications, FOMA adopts adaptive multirate (AMR, max. 12.2 kb/s) for encoding and decoding voice communications, in order to achieve quality of calls as high as those over fixed networks. For data communications based on circuit-switching, users can communicate with integrated services digital network (ISDN) lines, mobile terminals, and videophone terminals at a transmission speed of 64 kb/s. In high-speed data communications based on packet switching, users can access i-mode and so forth through best-effort-type service with maximum transmission speeds of 64 kb/s uplink and 384 kb/s downlink, and even access corporate local area networks (LANs) and Internet service providers (ISPs). FOMA users can also use advanced i-mode, which takes advantage of the high-speed transmission capabilities and features applications like Short Message Service (SMS) and multi-access (which enables users to make voice calls and view pictures simultaneously), as well as visual communication services such as video distribution on videophones.

Figure 2 shows an example of FOMA terminals. Broadly speaking, there are four types of FOMA terminals. The first is the standard type, referring to i-motion-enabled terminals on which video clips can be viewed based on i-mode. Also, i-mode can send and receive still pictures and music files as attachments, and supports the transmission of email consisting of up to 5000 full-sized Japanese characters. Visual-type terminals are videophone terminals, with videophone capabilities. The third is the data card type, which enables data communications at 384 kb/s downlink. The fourth is the PDA type, which has a relatively large screen and supports videophone and advanced data processing. The connection between the main unit and the wireless handset is established via Bluetooth for user convenience.

To expand FOMA services in the future, we are examining the possibility of interaction between wireless LAN and FOMA, global roaming, mobile e-commerce, and so on. We plan to offer diverse services as shown in Table 1, and introduce high-functionality high-performance terminals adapted to these services.

AN APPROACH TO FOURTH-GENERATION SYSTEMS

The number of Internet users has rapidly increased worldwide since the late 1990s. Nowadays, broadband access is gaining momentum, using technologies such as ADSL, CATV, and FTTH, and their communications charges are falling. Consequently, the market penetration rate of broadband services is increasing dramatically. In terms of services, the demand for high-resolution video services is expected to increase in mobile communications, as indicated by the high popularity of Hi-Vision images.

It is important that communications carriers reduce their communications charges on a sound management basis, rather than engage in a cutthroat price war. This requires reduction of capital investment costs by expanding system capacity. 4G systems hold an extremely important position as a wireless infrastructure in the broadband multimedia information society. The reduction of system costs resulting in the construction of an economical system is a top-priority issue. Other important themes in light of making services seamless include not only accelerated radio transmission speed but also improved user convenience, by constructing and operating a system that integrates IMT-2000 networks, fixed wireless access networks, wireless LAN, and so forth. Therefore, R&D must be promoted strenuously with the aim of resolving these major issues.

The key to providing mobile services is not limited to the concept of each and every subscriber having his or her own terminal to communicate. Another key issue is to build a ubiquitous information environment surrounding humans at home, in the office, or at hot spots so that information can be obtained in various forms according to individual need. We need to examine different scenarios such that a value may be attached to the content of information or the timeliness with which it is provided. Accordingly, a new business model will probably be required, and coming up with such a model is a major challenge.

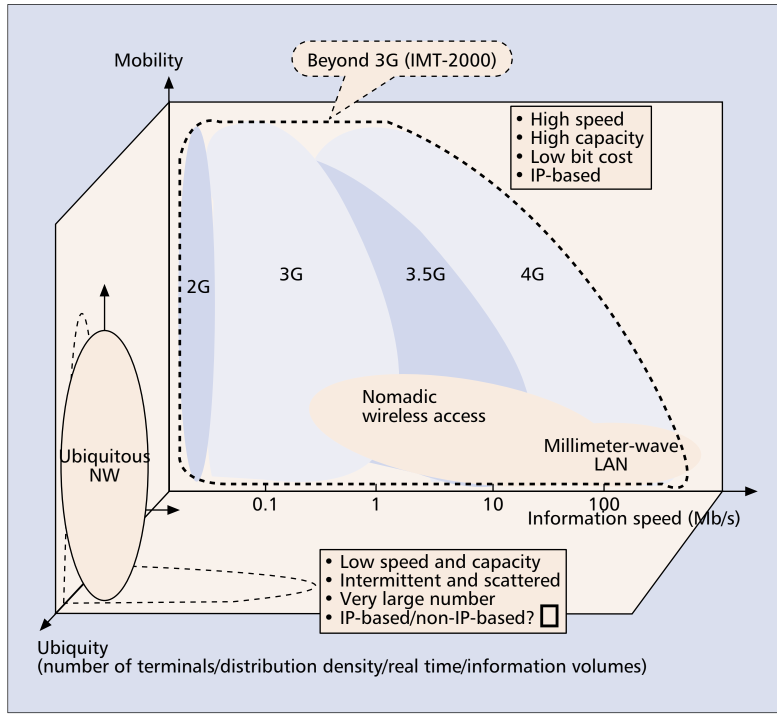


Figure 3. *Mobile systems beyond 3G (IMT-2000).*

Figure 3 shows the positioning of the 4G system, which is one of the post-3G systems (systems beyond IMT-2000). In the figure, the vertical axis represents mobility, whereas the horizontal axis indicates the information speed in megabits per second. As the 4G system is an evolved version of the 3G one, the service scope and mobility of the 4G system must be compatible with those of the 3G system. Thus, 4G will be based on a cellular system, and in limited-mobility areas (e.g., indoors, hot spots), it will have to incorporate systems that accommodate wireless LAN technologies to achieve higher speed. On the other hand, another axis called ubiquity will be added anew in the age of 4G systems. In order to offer the capabilities represented along this axis, networks will be required to handle traffic patterns that are entirely different from those in existing communications. For example, a network may be required to efficiently handle intermittent signals transmitted at low speed, each being small in volume but generated by a huge number of terminals. In some cases, connections between terminals may primarily be based on local networks in an ad hoc fashion. Therefore, an extremely broad range of access and networking capabilities will be required in the age of 4G systems.

The implementation and penetration of 4G systems is expected to help close the gap in medical care, education, information, and other areas, and substantially contribute to environmental problems and an aging society. Specifically, in a society penetrated by 4G systems, home medical care and remote diagnosis will become common, checkup by specialists and prescription of drugs will be enabled at home and in underpopulated areas based on high-resolution image transmission technologies and

- High-speed transmission (peak 50–100 Mb/s, average 200 Mb/s)
- Larger capacity (~10 times greater than 3G systems)
- Next-generation Internet support (IPv6, QoS)
- Seamless services
- Flexible network architecture
- Use of microwave band (3~6 GHz)
- Low system costs (1/10~1/100 of 3G systems)

Table 2. *The 4G system objectives.*

remote surgery, and virtual hospitals with no resident doctors will be realized. Preventive medical care will also be emphasized: for individual health management, data will constantly be transmitted to the hospital through a built-in sensor in the individual's watch, accessories, or other items worn daily, and diagnosis results will be fed back to the individual. In education, multimedia education using video between remote places and big cities, and field work using mobile terminals outdoors are expected to thrive. Also, the interface of various information terminals will be simplified, so no special operation will be required on the part of children or elderly people. Furthermore, regardless of differences in the languages used, use of these terminals may make everyday life more convenient. Sensors and control chips equipped with wireless communication functions will be attached to objects, fauna and flora rather than humans, which can make social contributions in areas such as improving logistics efficiency, protecting the global environment, and preventing disasters.

The Technology Profile of 4G Systems

Table 2 shows the main technological requirements of 4G systems. The system capacity must be at least 10 times greater than its 3G counterpart, and the cost per bit must be decreased to 1/10 to 1/100 of 3G, in order to avoid imposing a heavier burden on users associated with the expansion of information volume. Additionally, 4G must introduce various quality of service (QoS) levels in order to provide many kinds of best effort multimedia services corresponding to users' demand. Furthermore, Internet Protocol version 6 (IPv6) should be supported in IP networks so that a huge number of IP addresses of mobile terminals, especially in person-machine and machine-machine communications, can be accommodated. In terms of user friendliness, the issue will be to offer seamless services by radically shortening the time consumed in accessing servers, which is slightly not enough in 3G systems.

In the area of networking, the key will be to provide an IP network with sufficient reliability, and construct a flexible network configuration that enables seamless connections with the use of various accessing methods, the number of which will increase further in the future. Figure 4 shows the configuration of a next-generation mobile network. *IP over everything* is believed to make progress, in which IP packets are processed based on various transport technologies (from asynchronous transfer mode, ATM, to optical routers). In the next-generation IP network, the control and packet forwarding functions will evolve independent of each other, and the functional configuration of the IP transport

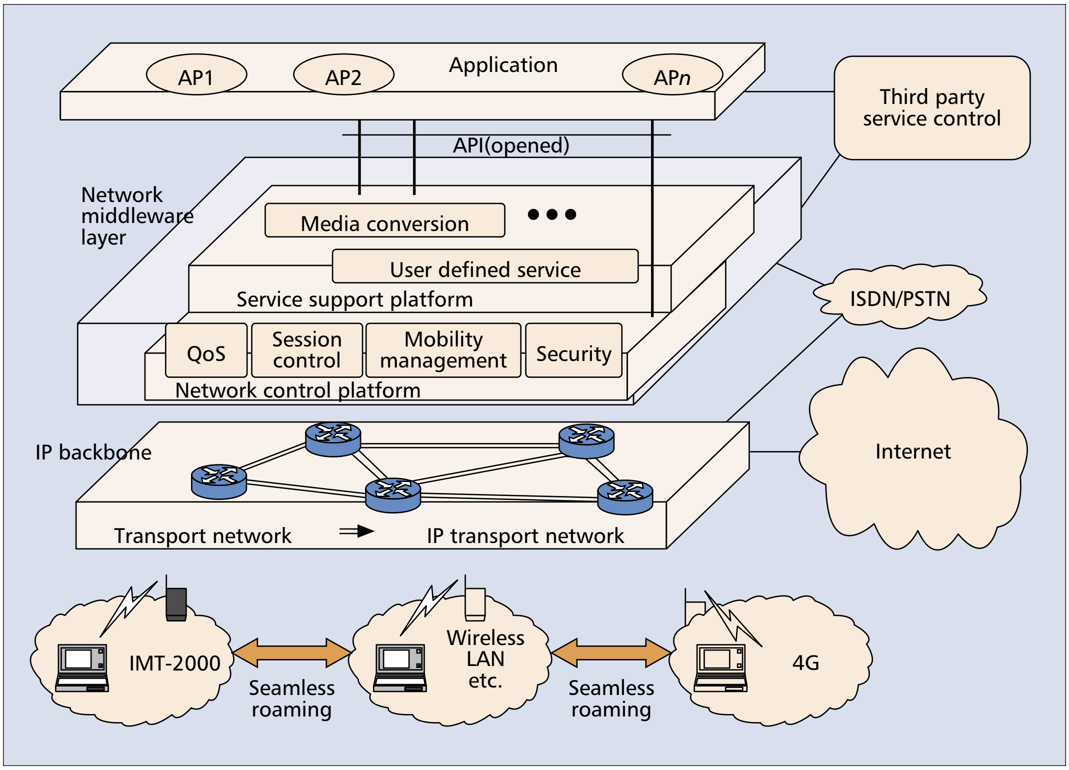


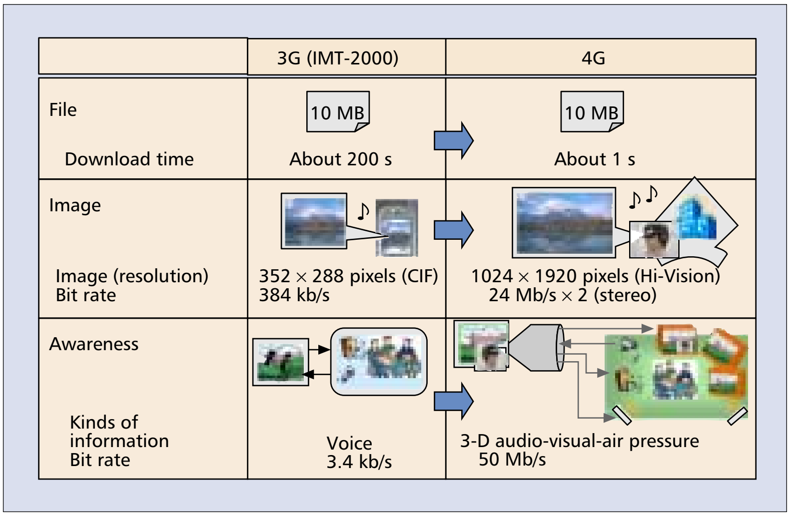
Figure 4. *A 4G mobile network.*

network and middleware will be separated logically. The middleware will consist of two platforms: the network control platform (NCPF) and the service support platform (SSPF). NCPF functions include mobility management, session management, QoS management, authentication/admission, and common radio resource management required for mobile communications management. NTT DoCoMo is considering an architecture for common mobility management that does not depend on a radio system, so services can be sustained seamlessly across different types of access systems. SSPF consists of service function groups exemplified by content conversion/distribution. SSPF functions include the provision of services unique to mobile communications, such as location services support.

As for terminals, limited-functionality chip-type terminals (so small that they cannot provide any services by themselves) are expected to emerge and form a ubiquitous environment, in addition to the generic all-in-one mobile terminals serving as the evolved version of existing terminals. Furthermore, connections between terminals are expected to be based primarily on local networks, such as ad hoc networks. In this manner, an extremely broad range of access and networking capabilities will be required in the age of 4G systems.

Figure 5 shows an example of 4G service scenarios in contrast with its 3G counterparts. The illustration in the top row indicates that file transfer will be smoother than in the 3G system. For example, 4G mobile phones will enable faster downloading of application program files from servers and fulfill multimedia applications, harnessing the high-speed high-capacity data rate. The second row relates to the high-speed transmission of bulky image information. For example, 4G mobile terminals will be able to display, virtually and three-dimensionally, high-quality images equivalent to Hi-Vision, based on terminals like head-mounted displays that are constantly carried around. This will enable parents to check how their children are doing at nurseries, scientists to remotely monitor the life of wild animals, people to watch a movie when they are out, and so on. The third row is the service scenario of communications with realistic sensations, in which 3D sound, light, and pressure fields are sent to another party to reproduce a situation. Thus, virtual reality can be generated, letting you experience things as if you are “actually there.” For example, if you can feel the atmosphere of the place the other person is visiting, you can perceive how he/she is doing “with realistic sensations,” which are not easily identifiable just by 2D images and voice. This will not only enhance videoconference calls, but also make it possible to execute advanced surgery in remote places and developing countries, and install distributed/coordinated production lines by offering a workspace in harmony with remotely controlled robots and workers.

4G wireless access is expected to support cellular systems and environments such as hot spots and indoor offices based on the same radio interface, as shown in Fig. 6. It will realize a wireless access system optimized for each environment by controlling radio parameters in an adaptive manner. The downlink uses a wireless access technology called variable spreading factor (VSF) and orthogonal frequency- and code-division multiplexing (OFCDM). The frequency of OFCDM and the spreading factor (SF) in the temporal domain are updated adaptively according to the radio propagation conditions, such as the cell environment (multicell or isolated-cell), the delay spread, and the maximum Doppler frequency. In a multicell environment, as in a cellular system, SF is set at larger than 1 to avoid intercell interference. In an isolated cell, as in hot spots and indoor areas, SF is set at 1 in OFDM mode to achieve maximum throughput in the absence of intercell interference. As a result, VSF-OFCDM can fulfill the maximum system capacity according to the cell composition and radio propagation conditions. In October 2002, NTT DoCoMo successfully demonstrated an indoor signal transmission experiment of packet data at extremely high speeds, up to 100Mb/s downlink and 20 Mb/s uplink. This has given NTT DoCoMo the potential to expand service areas and implement services flexibly at low cost, just by changing the radio parameters using the radio frequency, frequency bandwidth, radio frame composition, and so on as the common air interface.



■ **Figure 5.** *Service evolution from 3G to 4G.*

FUTURE TECHNOLOGIES

The 21st century, which may be signified by such keywords as *humanity*, *environment*, and *information*, is believed to migrate from a materialistic society to a human-oriented society that will bring about spiritual affluence.

With this in the backdrop, it will be important for information and communications in the 21st century to conduct research on human-oriented, human-friendly communication systems. Potential research directions include *pursuing humanness*, utilizing the five senses (touch, taste, hearing, sight, and smell) and artificial intelligence; *complementing human abilities*, based on

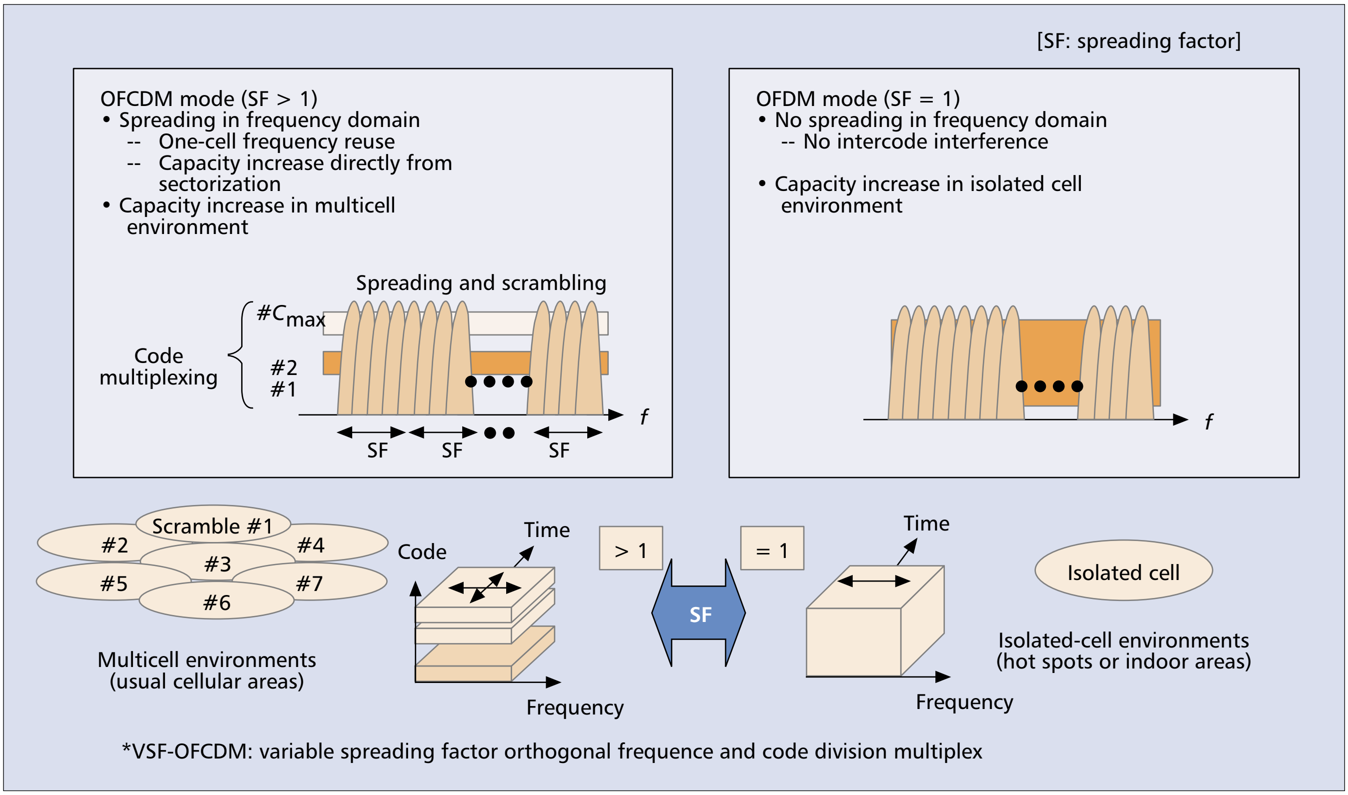


Figure 6. *4G broadband packet wireless access employing VSF-OFCDM.*

intelligence; *pursuing new forms of communication*, through robots and wearable models; and *expanding the human space*, by pushing the limits of communication quality. The approach to future technologies is described below, with reference to research on new mobile communications as an example.

In human communications, it is important to convey feelings to communicate smoothly. Although videophones featuring images and virtual reality (VR) have accomplished visual communication of the user's appearance and the senses of virtual movement of the user in cyberspace, they alone are not enough to help convey feelings. If we can add voice, image, or data, and import the real physical sensations that complement feelings, the atmosphere around the user, and his/her physical movements in communication, it should be possible to establish a more empathetic physical communication style. NTT DoCoMo is conducting research to introduce a wide range of previously unused information into this new kind of communications. As an example of new communication styles being pursued, we are exploring a future technology called Avatar Interface that pursues these advanced forms of communications. This interface is a communication technology for transmitting your own physical sensations to an embodied robot, and communicating with another party by remotely controlling the robot by gestures, and by vision through the robot's camera serving as your alter ego. Figure 7 shows an example of a service that uses a humanoid robot to share the same space as an avatar interface in various circumstances. Brain waves, myoelectric potential, and other biological information that represent the operator's expressions and movement, and information on the operator's body extracted by measuring the human body are transmitted to the avatar humanoid robot via a wireless network, and the robot functions not as a virtual avatar but as a real avatar with size and weight. Such a communication style may be applied to a wide range of fields, including the public sector, home, and entertainment, and shows a new way to use wireless communications.

Conclusion

In the 21st century, mobile communications is expected to experience the highest growth in the information and communications sector. The number of subscribers is steadily increasing in countries around the world. In order for mobile multimedia to make further progress in the future, it is necessary to promptly introduce and spread the IMT-2000 system (the international standard) in every country. To achieve this, it is important to improve on current wireless systems and core networks, explore new service applications, and develop small and highly functional terminals.

This article first clarifies the directions in which mobile communications should forge ahead in the future and the service implementation policies. Then it describes an example of mobile multimedia services and the IMT-2000 service FOMA. Furthermore, it presents the R&D approach to 4G systems — the mobile communication systems of the future— and the profile of the associated new technologies. It also reviews the approach to future technologies that are expected to be realized in 4G and subsequent systems, and outlines an example of research.

Mobile communications is the enabler in broadband information and communications to make ubiquitous communications into a reality by harnessing mobile characteristics. Technological innovation and challenges must therefore continue in the future. For the creation of innovative technologies, it will be crucial to interact with researchers and engineers in universities and companies worldwide, and desirable to exchange information and conduct joint experiments with open minds. It is hoped that mobile communications technologies and mobile multimedia services will enjoy further progress through R&D and standardization activities on a global scale.

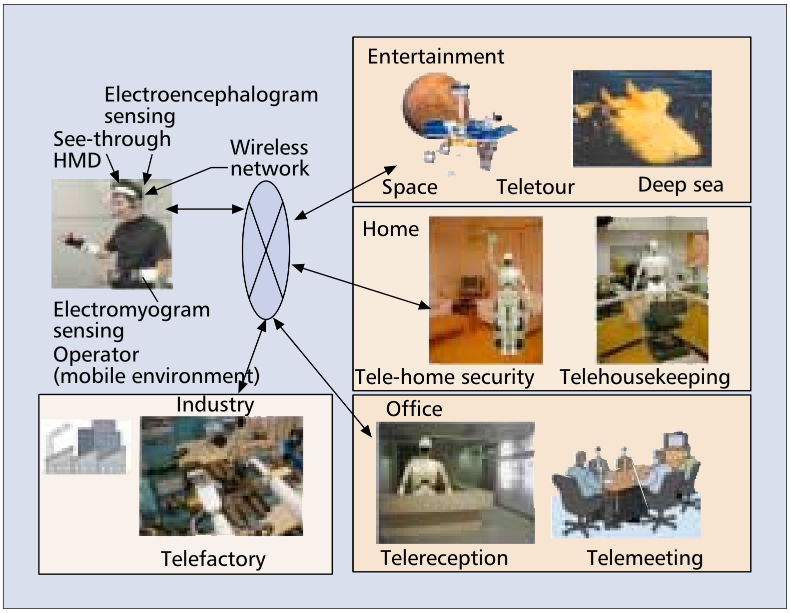


Figure 7. *Alter-ego-robot application service images.*

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BIOGRAPHY

KEIJI TACHIKAWA [F] received his M.B.A. from MIT in 1978 and his doctorate in engineering from the University of Tokyo in 1981. In 1987 he was director of NTT's American representative office in New York for two years, founding NTT America, Inc. and becoming its first chief executive officer. From 1989 to1990 he was a senior manager of Business Strategy Planning Headquarters, where he was responsible for the preparation of NTT's Twenty-First Century Service Vision. From 1990 to 1991 he was a senior executive overseeing NTT's mobile communications business, as well as its packet network and visual communications business. From 1991 to 1992 he was executive manager of the Technology Research Department, working on the development of NTT's General Planning Headquarters, and from 1992 to 1995 he was senior vice president and general manager of the Kanto Regional Communications Sector. Between 1995 and 1996 he was executive vice president of the Service Engineering Headquarters. During 1996 and 1997 he was senior executive vice president of NTT's Business Communications Headquarters. From 1997 to 1998 he served as senior executive vice president of NTT Mobile Communications Network, Inc. At the present, he is president and chief executive officer of NTT DoCoMo, Inc.