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PROSPECTS FOR MOBILE COMMUNICATION SYSTEMS AND KEY TECHNOLOGIES CAPABLE OF SUPPORTING EXPANDING MOBILE MULTIMEDIA SERVICES

MASAHIRO MINOMO

Research and Development Planning Department, NTT DoCoMo, Inc.,
2-11-1, Nagata-cho, Chiyoda-ku, Tokyo, 100-6150 Japan
minomom@nttdocomo.co.jp

TATSURO MASAMURA

Wireless Laboratories, NTT DoCoMo, Inc.,
3-5, Hikarino-oka, Yokosuka-shi, Kanagawa, 238-8536 Japan
masamura@nttdocomo.co.jp

The first commercial service of the 3rd generation (3G) mobile communication system, IMT-2000 (International Mobile Telecommunications), was launched in October 2001 in Japan. This is the first 3G service employing Wideband Code Division Multiple Access (W-CDMA) as its air interface between mobile terminals and base stations. This new system, 3G, is expected to accelerate the deployment of future mobile multimedia services, which substantially got started with the "i-mode" service in February 1999 in Japan. Research activities into future mobile communication systems capable of supporting a vastly expanded market for mobile multimedia services are underway worldwide. This paper describes the vision, service trends, and technical challenges of such future systems. Broadband packet wireless access, Variable Spreading Factor Orthogonal Frequency and Code Division Multiplexing (VSF-OFCDM), are promising candidates for realizing future mobile communication systems that provide higher transmission rates and capacity than 3G systems.

Keywords: IMT-2000; beyond 3G; VSF-OFCDM.

1. Introduction

In year 2002, the number of mobile phone subscribers exceeded one billion worldwide. The growth was especially remarkable in the Asian nations such as China. However, in the advanced mobile communication markets of Europe, such as in Nordic countries, Singapore, Taiwan, Hong Kong, South Korea and Japan, mobile phones are already used by a large percentage of people. Thus the growth in the number of subscribers has slowed down, and as such, more advanced and diversified services are expected.

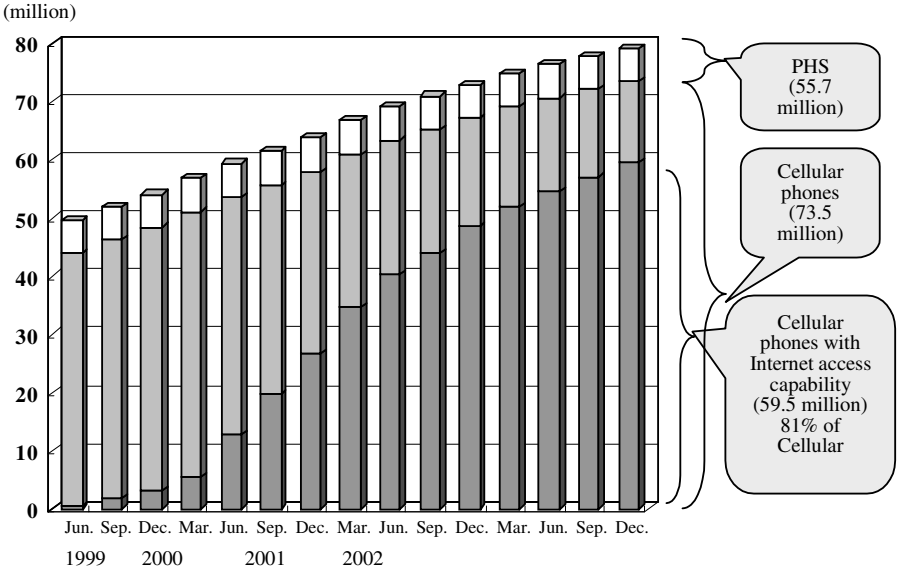


Fig. 1. Number of mobile phone subscribers and mobile Internet users in Japan.

The situation in Japan, for example, is that the number of mobile phone subscribers exceeded that of fixed phone at the end of March 2000, and at the end of December 2001, it reached 79 million subscribers including Personal Handy Phone (PHS; personal Communications System in Japan) as shown in Fig. 1, which accounts for 62% of the total population. Although the number of subscribers had increased by approximately 9 million to 10 million people each year in the past five years up to 2001, this figure decreased to 6.4 million in 2002, which suggests that the market has become saturated. There is one aspect of the recent mobile communications that need our attention, that is the substantial spread of mobile Internet access services. Of the 73.5 million cellular users, as of the end of December 2002, 59.5 million (81%) are the mobile Internet users supported by the 2nd generation mobile communication systems.

The commercial launch of the first 3rd generation (3G) mobile communication system (IMT-2000) in the world, which employs the W-CDMA wireless access scheme, was occurred in Japan in 2001 under the name of FOMA (Freedom Of Mobile multimedia Access), in order to satisfy the market demand for mobile multimedia services.[1] The services were started in densely-populated Tokyo metropolitan areas, and now cover all the major cities in Japan with a population cover rate of 90%. The 3G system has started to offer high data rates such as 384 kbit/s, even with high levels of mobility, as well as new communication services centered on moving pictures. Looking at 10 years ahead, however, it is certain that infrastructure of enhanced capacity will be required to support multimedia services that are with constant demand, and we think that the next generation of mobile

communication systems will make this possible.[2] Their aim is to provide larger capacity, enhanced services, and higher bit rates than 3G at high levels of mobility. This paper provides a general view on the prospects of the new generation of mobile communication systems.

First, we survey the current situation, future trends, and prospects for the development of new mobile multimedia services.[2–6] Next, we introduce the vision of systems beyond IMT-2000 developed at International Telecommunication Union, Radiocommunication Sector (ITU-R), Study Group 8 (SG8), Working Party 8F (WP8F).[7] Deliberations have gone forward at WP8F on draft recommendations to define the future enhancement of IMT-2000, a vision on systems beyond IMT-2000 (or Beyond 3G) wireless access networks, its framework, and targets. The vision is important in forming a common understanding with which to carry out research and development activities.[7–9] Next, we examine actual service deployment based on these trends and vision, and requirements on mobile communication systems; we then define the new generation system research targets. Further, we describe strategies for the new generation system deployment and approaches for realizing such systems. Finally, we survey the techniques required for realizing such systems, present key technologies, and introduce a promising candidate for a broadband wireless access scheme to realize higher data rates: VSF-OFCDM (Variable Frequency Code Division Multiplexing).[3–5,10–16]

2. Mobile Multimedia Service Trend

2.1. *Current mobile multimedia services*

We introduce the major mobile multimedia services in Japan in the guide of i-mode.

(i) Mobile internet access service

In NTT DoCoMo's 2G digital mobile communications system, voice traffic is transmitted through a Personal Digital Cellular (PDC) network and data is transmitted through PDC and PDC-Packet (PDC-P) networks. The PDC-P network supports the mobile Internet access service "i-mode", which provides cellular phone customers with direct and easy Internet access.[6] The basic monthly charge for i-mode is only 300 yen, and a tariff is charged for the number of packets transmitted, not for the connection time. The i-mode service opened the door to easy Internet access for many people who had been unfamiliar with the Internet. It had more than 36.2 million subscribers, which corresponds to 84% of NTT DoCoMo's 42.9 million cellular subscribers, as of the end of December 2002.

Among i-mode services, e-mail accounts for about 40%, while access to web sites accounts for the remaining 60%. Sites providing entertainment services, such as novel ringing tones, standby screens, games, horoscopes, and music, account for 45% of the total. Sites offering communication services such as bulletin boards, chat, and mail-friend search account for approximately 30%. The remaining 25% are sites providing news, sports, and corporate information.

(ii) Services by downloading application programs

In January 2001, we started "i-appli" service which enables application program downloading from Internet Service Provider (ISP) servers on the Internet as an i-mode service. Using i-appli, one can easily enjoy a variety of games, entertainment, and transactions. Similar services are also provided by other operators in Japan.

(iii) Mobile e-commerce

Some examples of electronic settlement that are possible while on the move are:

(a) Transaction/settlement for mobile shopping,
(b) Mobile banking,
(c) e-ticket.

Considering the strengths of mobile communication such as mobility, immediacy, remote capability, and ease of use, we foresee continued growth in the mobile commerce market.

(iv) Location services

Location information services are very promising. Some systems employ Global Positioning System (GPS) data while others utilize cellular base station location data. Local area-oriented information services, such as the i-mode service "i-area", are also offered to customers. This kind of service offers various conveniences and is being widely accepted.

(v) Music/video distribution services

In May 2000, NTT DoCoMo started a mobile music distribution service as a pilot project. Commercially introduced in January 2001, it uses the PHS platform, which offers a transmission rate of 64 kbit/s. Customers can download and enjoy music anywhere and anytime they like. A video preview service was also offered in November 2000, using the 64 kbit/s transmission capability of PHS. After the customer selects a movie, a short clip of the video is shown on the screen of the PHS terminal. With the diffusion of the 3G systems, these services, i.e., content delivery services, can be provided at lower charges and so will enjoy greater popularity.

2.2. *Future mobile communication service trend and perspective*

Let us take a brief look at service evolution from 2G to 3G and future systems; please refer to Fig. 2.

Until recently, the development of mobile communications was driven by the growth of voice traffic. However, as shown above, this voice service growth, which depends on the spread of mobile phones, is reaching saturation. On the other hand, the convenience offered by 2G systems to customers has improved significantly with the introduction of mobile Internet access, such as the i-mode service. Today, customers can obtain information anywhere, anytime. In addition, various new services

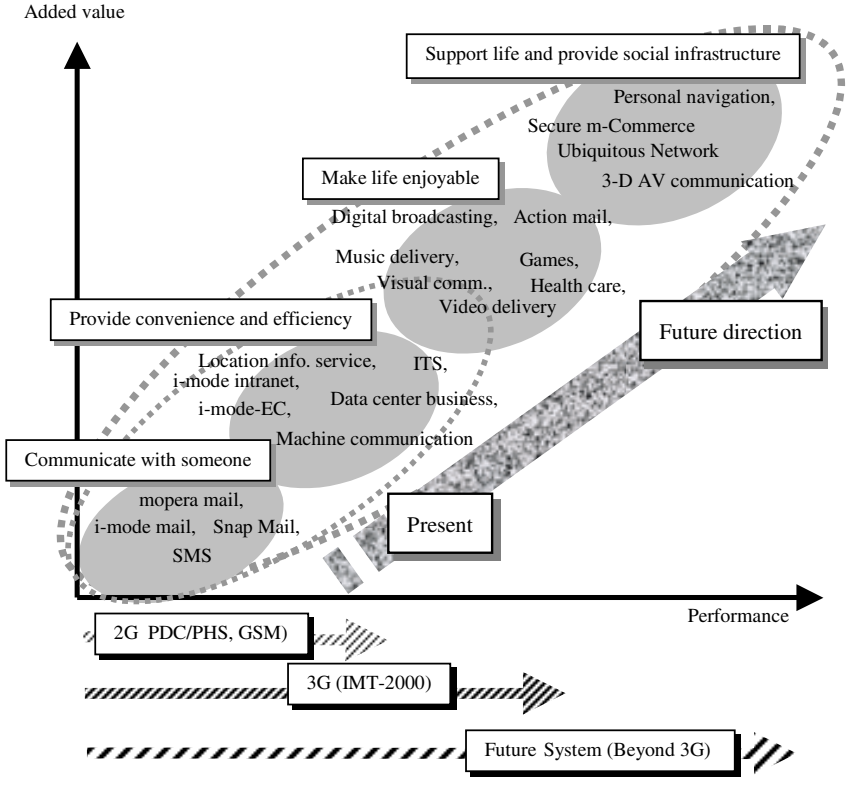


Fig. 2. Trend of mobile communication services.

that take advantage of location information are being implemented. Multimedia traffic is expected to grow enormously.

3G (IMT-2000) systems were developed in order to support the increasing demand for mobile multimedia services. Requirements for such systems include high voice quality (telephony level), high transmission rates, high spectrum utilization efficiency, and the individualization/globalization of communication. From the perspective of the air interface transmission rate, the platform must support 2 Mbit/s for stationary use, 384 kbit/s for pedestrian use, and 144 kbit/s for use at high levels of mobility. This makes it possible to offer, in addition to the existing services of the 2G systems, services based on packet data transmission, asymmetric data rates, and variable rates; mobile communication operators will be able to provide services with high added value that cater to the needs of each customer who wants to make the most of mobility. NTT DoCoMo's 3G system "FOMA" provides advanced i-mode services such as a video clipping service (i-motion), multi-access service, video phone service, video distribution service, high data rate transmission service, and high speed internet access employing 384 kbit/s capability. A live video distribution service is also being provided.

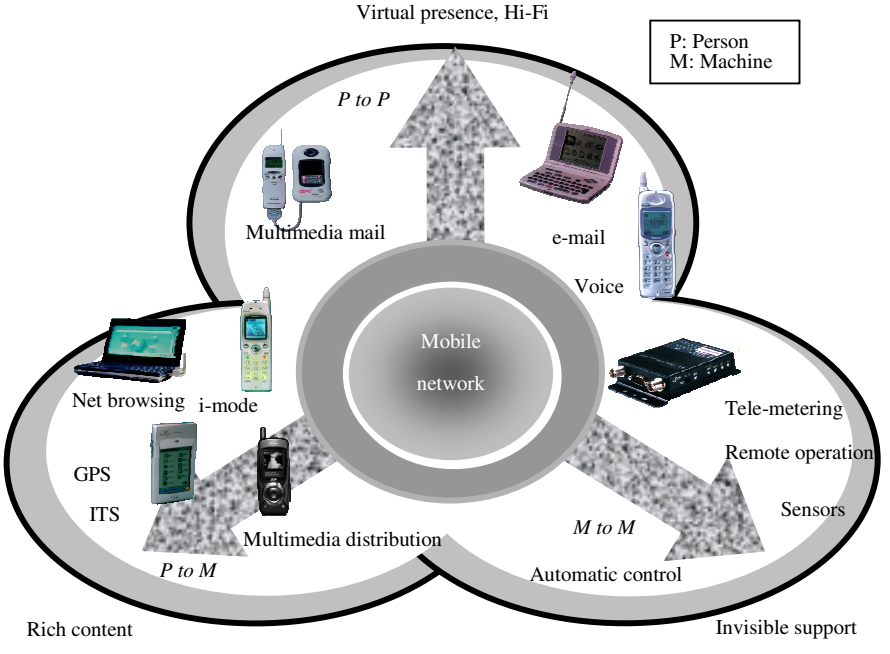
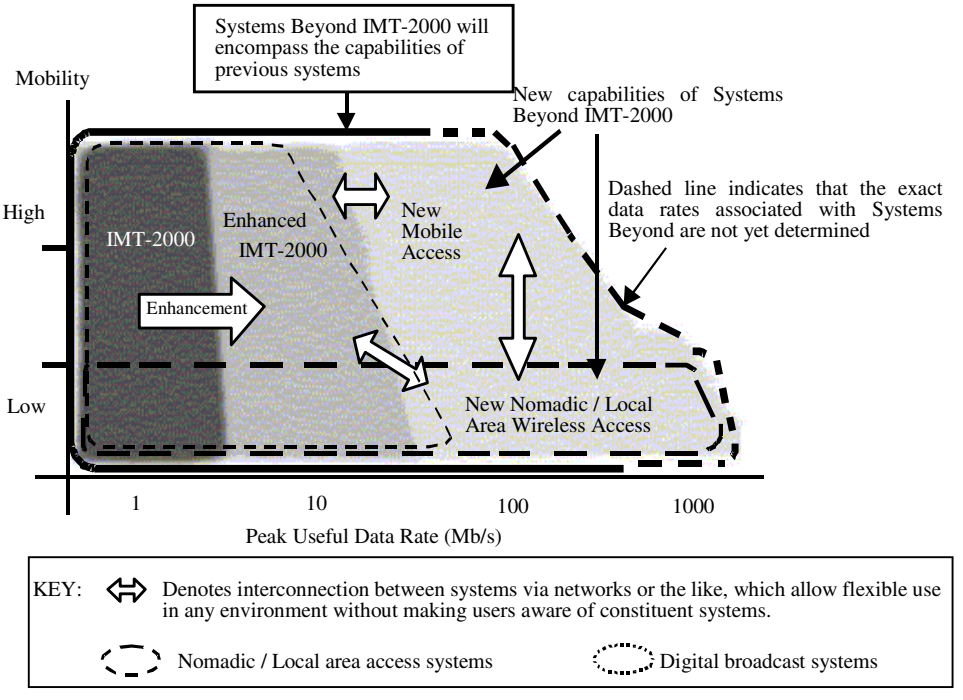


Fig. 3. Multimedia and ubiquitous services.

As indicated in Fig. 3, the keywords for future mobile communication services are "Multimedia", "Ubiquitous", and "Global". Future communication services will not only be provided to people, but also to many forms of machinery and moving objects. When speaking of "multimedia" and "ubiquitous", one should think of all moving objects as users and all the media as being applicable. In other words, it is expected that any object will be able to generate communication traffic, and this traffic will generate a further increase in traffic. In addition to person-to-person communication, in other words, person-to-machinery and machinery-to-machinery communications are expected to be supported by the mobile communication networks. This is an important consideration when forecasting traffic increases in the future. It is evident that mobile multimedia services have enormous potential demand. We predict that nonvoice traffic will account for 70–80% of the total mobile communication traffic in Japan by 2010. In order to cope with changes in quality and quantity in the future mobile communication services in 10 years and onwards, systems with capacities beyond those of 3G are necessary.

3. How We Envision Future Systems

In the year 2000, when the introduction of the 3rd generation mobile communication systems took shape, ITU started research into the enhancement of IMT-2000 and future systems. As a first step, ITU-R SG8 WP8F worked on creating a recommendation for a future scenario that would show the direction of future



- Dark gray color indicates existing capabilities, medium gray color indicates enhancements to IMT-2000, and the lighter gray indicates new capabilities of systems beyond IMT-2000.
- The degree of mobility as used in this figure is described as follows: Low mobility covers pedestrian speed, and high mobility covers high speed on highways or fast trains (60 km/h to ~250 km/h, or more).

Fig. 4. Capabilities of systems beyond IMT-2000.[7]

technological development. Nine meetings were held within three years, and the 9th WP8F meeting, which took place from September to October 2002, completed a draft recommendation DNR [IMT.VIS] "Vision, Framework and Overall Objectives for the Future Development of IMT-2000 and Systems Beyond IMT 2000".[7]

As indicated in Fig. 4, the vision defines systems beyond IMT-2000 as being seamlessly interworked; these systems include existing systems and their enhancements as well as cellular systems, nomadic wireless access systems and other wireless access systems that remain to be developed. As research targets, it is also predicted that by 2010 new wireless access systems and the spectrum to support them will be needed that can provide up to 100 Mbit/s in high mobility environments (i.e., mobile access) and approximately 1 Gbit/s in low mobility environments (i.e., nomadic and local wireless access).

Furthermore, Fig. 5 indicates that different wireless access systems will be connected via a flexible core network, and that horizontal and vertical interworking will be realized seamlessly with mobility, security and QoS.

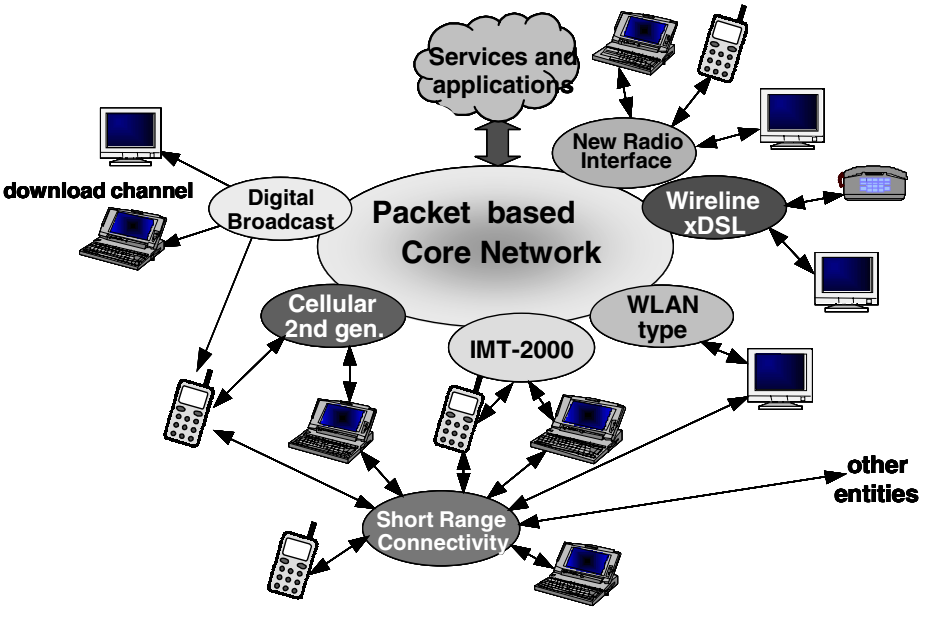


Fig. 5. Seamless interworking of systems beyond IMT-2000.[7]

4. Future Mobile Multimedia Services and New Generation Mobile Communication System Infrastructure Capability

What kind of services will satisfy customers' needs in the future mobile communication systems realized in accordance with the vision introduced above? What can operators provide and how can they evolve together with such new systems? We do not think it is possible to fully satisfy future customer needs simply by extending the existing services. Nor will it be easy to expand revenues as mobile communication operators. Therefore, it is necessary to carry out research on a wide range of services, enabling us to anticipate potential customer needs. We think that significant improvements in network performance will be crucial for realizing new services. Further, by finding new directions for creating new services in addition to existing performance indices, and by improving their performance, we should be able to engender more possibilities for developing new services.

Improvement is expected in the transition from 3G systems to the new generation systems. Frustration arising from the transfer and download of very large files in 3G will be eased, and the new generation mobile terminals will be able to display high resolution and high quality images on portable head-mount type displays as one example. Such devices will allow children at kindergarten or even wild animals to be monitored remotely and movies watched when away from home. Delay plays an important role in sophisticated remote operation, especially when interaction is frequent, and certain operations require delay values under 100 ms.

New services, such as high presence communications, realized by transmitting a three-dimensional sound field and pressure field to a different location, may be provided. This will enable the creation of a virtual reality with a sense of actual presence.

4.1. *Technical targets of the new generation systems: Capabilities and performance*

Conversing communications and computing is also an obvious trend in multimedia communication. Packet switching is more suitable than circuit switching for supporting new services and systems, because it packetizes all information and multiplexes it on high data rate shared channels. The new generation systems can also be called a form of broadband packet mobile communication.

Research targets on the new generation systems with regard to capabilities and performance are assumed. The basic target for the down link is over 100 Mbit/s peak data rate. Variable data rate transmission is also likely to be adopted in order to maximize throughput and system capacity. High system capacity is also required. The system capacity will have to be more than 10 times that of 3G and bit cost will have to be 90% to 99% lower so that the increase in data volume does not place an excessive burden on the customer. Significant system cost reductions can be expected by applying Internet Protocol (IP) technologies more fully. Packet multiplexing and best effort service are expected to become the basic approach toward network design. Further, in order to guarantee various service quality levels on best effort networks, quality of service (QoS) controls on the radio links will be a key element, and as such, various QoS levels need to be provided in addition to IP version 6 (IPv6).[10] For ease of use, server connection time has to be reduced significantly from several seconds to 500 ms, and end-to-end delay from several hundreds of milli-seconds to 50 ms; a significant improvement over 3G.

Seamless service provision with other networks such as 3G, private networks using wireless LAN and fixed networks is another requirement. Open-ended transformation of the next generation Internet such as QoS, IPv6 and IP multi-cast should be supported. During the 2010's, all personal electronic devices and electric home appliances will be connected to the Internet and controlled by the new generation handsets.

4.2. *Consideration to the new generation system deployment and approaches to realization*

For us as a mobile communication operator, the following ideas for and approaches to establishing and deploying the new generation system are important issues. Current external environment has three main characteristics: the wide use of alternative wireless access systems such as wireless LANs, the demand for broadband and flat rates, and the rapid development of IP-related technologies.

In order to continue to provide networks to mobile customers competitively in this situation, it is important to provide systems that satisfy the following requirements: securing efficient area coverage, support of various access schemes, supporting the spread of IP applications, always-on, low cost, and reinforcement of competitiveness with regard to service provision. This analysis indicates that wireless systems will have to be deployed aggressively indoors where the majority of future traffic can be assumed to be generated. One should also note the importance of providing the same air interface both indoors and outdoors to realize seamless communication.[14] As for network, all-IP is necessary in order to support various access systems such as 3G and wireless LAN, to provide seamless connection between systems gradually, and to carry multimedia traffic efficiently and with high quality.

4.3. *Service platform to support new business*

Another technical trend is separating applications from networks. In the existing communication infrastructure, many of the basic services and supplementary services are dependent upon the intelligence of the networks themselves. In the future, however, various multimedia applications will be created by independent providers and implemented on servers that will be accessed by network users. As a result, communication operators will face competition in the area of developing new, convenient and innovative services.

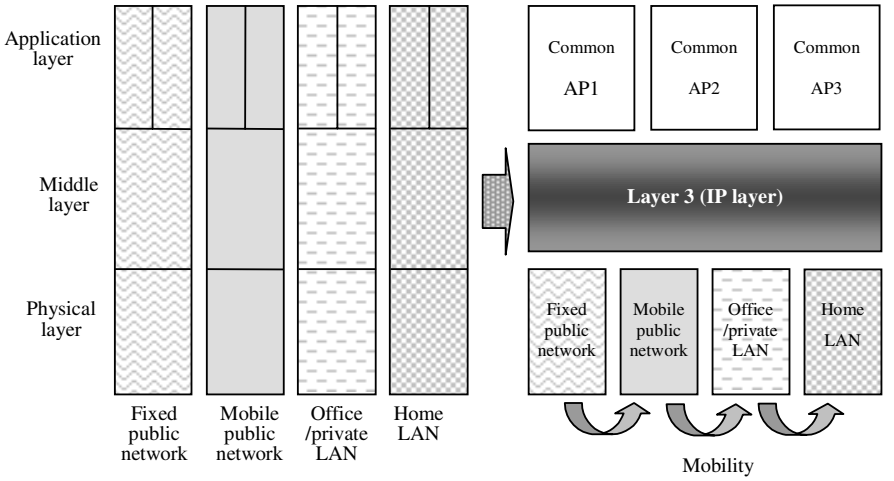
In order for the future services to be employed widely, data volume should increase, but customers can bear only reasonable burdens. In other words, always-on connections and flat rates are desirable. This suggests that operators will not be able to survive on the revenues from just network traffic, thus deployment of the service platform, which enables services to be created on the network, will be important to create new revenue sources.

4.4. *Key technologies to realize the new generation systems*

The following are important requirements for the realization of new generation systems.

First, to enable seamless services among heterogeneous networks, it is necessary to integrate layer 3 protocols. Since all existing telecommunication systems have independent layered structure from physical to application layers, there is not enough flexibility or mobility. By integrating the layer 3 protocols, common application and network interfaces can be provided as shown in Fig. 6. In order to do this, an integrated mobility management function needs to be added to the networks to support both macro mobility such as handover between access networks, and micro mobility between cells within a network.

Second, it is important to establish innovative IP-based wireless access networks. Packet switching will require new schemes for routing, handover and transmission protocols, etc. As the cell sizes becoming smaller, more base stations will be needed.



IP integration in Layer 3 enables seamless services across heterogeneous networks.
- Unified mobility management (both macro- and micro-mobility) will be provided.
- Security measures will become more important.

Fig. 6. Integration of layer 3.

Therefore, in order to allow flexible deployment of base stations, plug-and-play operation and multi-hop links will become essential. Clustering base stations is one way of realizing high mobility in micro cell systems; several base stations are formed into one group that functions as if it was a single base station.[5]

The third key technology this paper emphasizes is an air interface to realize broadband packet wireless access. Multiple access schemes have always been key to existing systems. Frequency Division Multiple Access (FDMA) was employed in the 1st generation systems, Time Division Multiple Access (TDMA) in the 2nd generation (2G) systems, and Code Division Multiple Access (CDMA) in the 2G and 3G systems. Space Division Multiple Access (SDMA) is a multiplexing technique that exploits the interference suppression capability of an adaptive antenna array. We think that the new generation mobile communications systems will use a combination of all the possible dimensions: frequency, time, code, and space.

5. The New Generation Air Interface

There are three basic approaches to realizing Radio Access Networks (RANs) depicted in the New Capabilities par of the ITU-R WP8F's vision [Fig. 4].

(i) Using the same air interface both indoors and outdoors.
(ii) Changing the air interface based on mobility.
(iii) Supporting outdoor use by extending IMT-2000 and developing an indoor-specific air interface.

We think that (i), which provides high data rate services with the same air interface in different environments, indoors and outdoors, is most desirable both for customers and operators. To realize this, a new broadband wireless access scheme is needed that can adaptively support both multi-cell environments (i.e., outdoor cellular systems) and isolated cell environments (indoor, such as offices), while providing robustness against multi path fading and efficient frequency utilization.

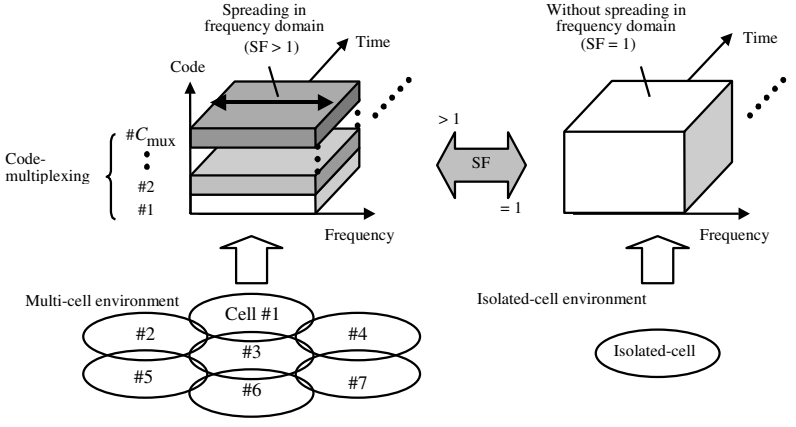
6. Broadband Packet Wireless Access: VSF-OFCDM

For realizing high transmission rates, we require robustness against multi path fading and high spectrum efficiency. The multi-cell configuration can be employed to realize seamless coverage. In this sense, CDMA is a good candidate because CDMA can achieve high radio wave utilization without the rigid frequency channel allocation required in 2G. On the other hand, if service conditions allow, isolated cell condition is desirable to achieve high throughput because adjacent cell interference does not have to be considered. In this case, OFDM is a good candidate for the down link. Actually, IEEE 802.11a, High Speed Wireless LAN, has adopted OFDM.

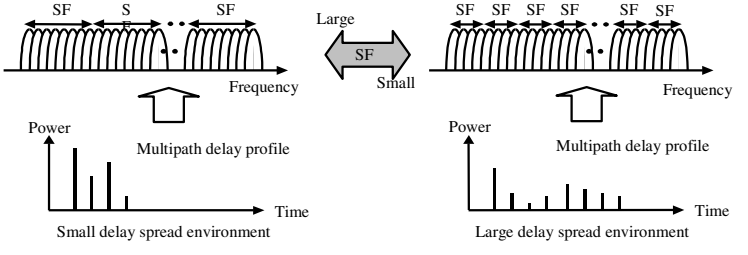
For the new generation system we are aiming at, one new wireless access scheme that can cover both the cell configurations is desirable. In other words, an optimal broadband access scheme is sought to realize high data rate packet transmission, high capacity packet transmission, and support of different variable data rate services; all with 50–100 MHz bandwidth. Recent research results show that Variable Spreading Factor Orthogonal Frequency and Code Division Multiplexing, VSF-OFCDM, is a promising down link wireless access scheme for broadband packet radio. The origin of OFCDM is multi-carrier CDMA.[11−13] As indicated in Fig. 7, VSF allows the spreading factors to be changed adaptively in the frequency domain, according to wireless link conditions such as cell structure and delay spread, thus wireless access close to optimum can be flexibly-realized with higher link capacity.[14−16]

The new generation broadband access scheme in the down link supports both cellular systems and indoor isolated cell environments with the same air interface by changing radio parameters. The spreading factors in the frequency and time domains are adaptively-updated based on conditions such as cell structure (multi-cell or isolated cell), radio parameters (data modulation), and propagation conditions (delay spread and maximum Doppler frequency). By controlling the radio parameters adaptively, maximum system capacity can be achieved for each cell environment. In the multi-cell environments, the spreading factors will be set to greater than 1 to avoid inter-cell interference; for isolated cells, where there is no inter-cell interference, the spreading factor will be set to 1, OFDM mode, in order to achieve maximum throughput. This yields flexible and low cost area deployment and service deployment.

If the same air interface is used both outdoors and indoors, indoor base station cost can be reduced by removing functions such as power control and hand-off,



(a) Variable spreading factor based on cell structure



(b) Variable spreading factor based on channel conditions

Fig. 7. Concept of VSF-OFCDM.[14]

and by selecting parameters tuned to isolated cells. Outdoor base stations will provide robustness against interference. Their cost can be reduced since indoor radio penetration margin does not have to be taken into account.

Figure 8 shows the external view of the VSF-OFCDM test-bed. On the left is the base station equipment and on the right is the mobile station equipment. The main purposes of the experiment are as follows:

- To demonstrate maximum throughput of more than 100 Mbit/s and 20 Mbit/s in the forward and reverse links.
- To clarify key technologies essential for broadband packet wireless access.
- To evaluate real broadband channel conditions.
- To evaluate IP packet transmission via real wireless channels.

In the laboratory, this equipment has achieved forward link and reverse link throughputs of more than 100 Mbit/s and 20 Mbit/s, respectively, even in the presence of interference.[17]

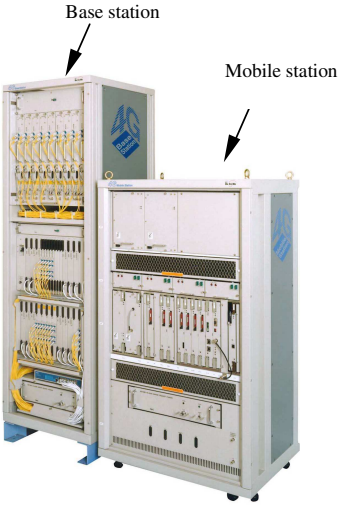


Fig. 8. Broadband packet wireless access test-bed for a new generation mobile communication system.

7. Conclusion

In this paper, we have focused on the current situation and future expansion of mobile multimedia services in the mobile communication systems and have surveyed the vision of future systems, service trends, system requirements, research targets, and key technologies. The paper introduced VSF-OFCDM as a promising candidate for the forward link air interface for realizing mobile communication with higher data rates in broader bandwidth, not only from the perspective of high data rate transmission but also from the perspective of adaptive optimization based on cell structure and radio conditions.

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