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# Wireless Past and Future—Evolving Mobile Communications Systems—

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**SUMMARY** Nowadays, when people colloquially use the word "wireless," they almost always mean a portable telephone. Over the last 10 years, there has been tremendous growth in the mobile communications markets not only in Japan but also worldwide. For these 10 years, the most popular service has been dominated by voice communication. However, modern mobile communications systems are shifting their focus from solely voice communication to electronic mailing and Internet access. From now, we will evolve into a wireless multimedia society, where a combination of mobile communications and the Internet will play an important role. Wireless technology is the core of mobile communications systems. This article, which focuses on wireless technology, looks at how mobile communications systems have evolved over the last 10 years and looks to the future of advanced wireless technologies that will be necessary to realize a true wireless multimedia society in the coming decade.

***key words:*** *mobile communications systems, wireless techniques, multimedia communications, wireless Internet*

## 1. Introduction

Our ultimate goal is to communicate any information with anyone, at anytime, from anywhere. This is only possible through the aid of wireless technology. For the decade, mobile communications have enhanced our communications networks by providing an important capability, i.e., mobility. Before the introduction of mobile communications systems, communications were only possible from/to fixed places, i.e., houses, offices, and public phones. It was December 1979 when the first public mobile communications services started in Japan. For the first 10 years, its growth rate was very low. However, through the liberalization of mobile communications services in 1988 and terminal markets in 1994, the growth rate of mobile communications services accelerated over the last 10 years. In Japan, the number of subscribers to cellular and Personal Handyphone System (PHS) services has reached close to 57 million by March 2000; this number is equivalent to a penetration rate of around 45% in the population. One of the most important technical factors for this success is the increased utilization efficiency of portable phones (lighter weight and longer talk time [1], made possible by advanced LSI technology) and easier-to-use portable phones. Similar rapid growth rates in mobile communications services are evident worldwide. On the other hand, the number of fixed analog telephone users has been continuously declining from its peak of 61 million at the end of March 1997 to 55.4 million at the end of March 2000 and was overtaken by the number of mobile communications users. This clearly shows that people want to communicate with people, not with places. Mobile communications systems have now become an important infrastructure of our society. Mobile communications systems have now just started to evolve from simply providing traditional voice and fax communications services to providing Internet services that can exchange a mixture of voice, text, and images. Wireless technology is the core of mobile communications systems. This article, which focuses on wireless technology, looks at how mobile communications systems have evolved over the last decade and takes a look at the future of advanced wireless technology that will be necessary to realize a true wireless multimedia society in the coming 10 years.

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## 2. Wireless Internet Society is Our Future

In fixed networks, voice conversation was a long-time dominant service, but the introduction of Internet communications services has been changing our society at a very rapid pace. Figure 1 shows just how fast mobile communications, personal computers, and the Internet have grown in Japan [2]. It is evident that Internet services have spread throughout our society at a much faster rate than other services. Through the Internet, users can easily browse WWW sites to retrieve vari-

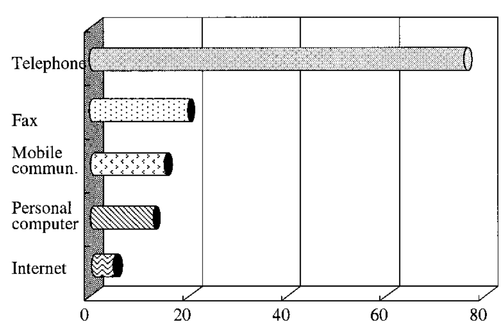


**Fig. 1** Time taken to arrive at 10% penetration (household) point.

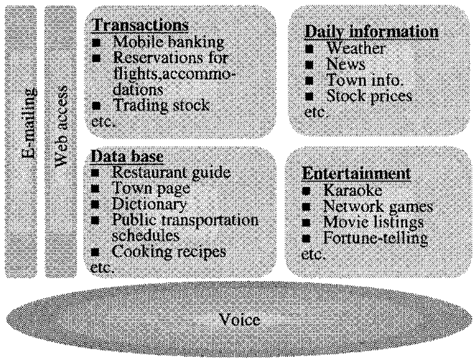


**Fig. 2** "i-mode services" available with 2G systems.

ous types of information including images, enjoy on-line shopping and trading services, and almost instantly exchange electronic mail messages instead of using traditional postal services. In line with the increasing popularity of Internet communications in fixed networks, mobile communications services have shifted their focus from solely voice conversation to electronic mailing and Internet access. One good example is the success of the mobile Internet access services called "i-mode services" provided through the 2nd generation (2G) cellular systems using the Japan standard PDC-Packet technology [3]. A variety of services are available, including e-mail, Web access, and on-line services ranging from bank transactions to entertainment, in addition to conventional voice conversation (Fig. 2).

Now, it seems that a mobile phone is not just for voice conversation, but is a communication tool that enables various types of electronic communications for private as well as business use. Present 2G systems allow access to only text information due to their slow data transfer rates, e.g., 9.6 kbps, and small displays on the portable phones. However, the 3rd generation (3G) systems, called the International Mobile Telecommunication Systems (IMT)-2000 in the International Telecommunication Union (ITU) [4], will be deployed starting around 2001–2002 with much better representation compared to present 2G systems. Up to a 2-Mbps data transfer rate will be available.

## 3. Past 10 Years of Wireless

### 3.1 Basics of Wireless Techniques

Today's 2G systems are designed based on the well-known cellular concept. Multiple base stations are distributed uniformly as much as possible over a wide geographical area to communicate with users. All the wireless channels in the available frequency bandwidth are grouped into $F$ groups and each base station is assigned a different channel group (an example of $F = 7$ is illustrated in Fig. 3). The same channel groups are reused in different clusters ($F$ cells that are assigned different channel groups form a cluster). In this way, a wide geographical area can be covered using a limited frequency bandwidth. To enable as many mobile users as possible to communicate with the same base station, wireless multiple access techniques must be adopted. There are a number of multiple access techniques (see Fig. 4); the type that is used depends on the type of traffic. If there is continuous traffic requiring a very short transmission delay, e.g., voice conversation, demand-assign based multiple access is applied, in which the channels are divided in a static fashion and each user is allocated one or more channels by a base station during its communication, irrespective of whether or not transmitted data is generated. The demand-assign based multiple access includes frequency division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA). Channels are configured using the available bandwidth either in frequency, time, or code space (see Fig. 5). In CDMA, unlike in FDMA and TDMA, all the base stations use the same frequency bandwidth, i.e. $F = 1$, and all users share the same frequency bandwidth and time, but use different spreading code sequences to separate each user.

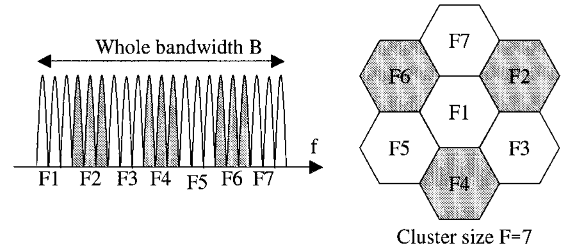


**Fig. 3** Cellular concept.

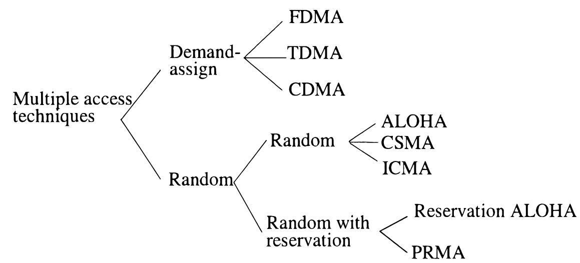


**Fig. 4** Multiple access techniques.

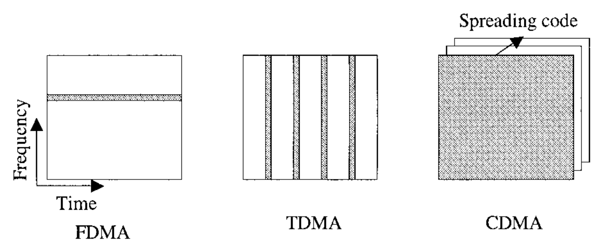


**Fig. 5** FDMA, TDMA, and CDMA.

On the other hand, if data generation is random and has a high peak-to-average rate ratio, random multiple access is used, in which many users share one communication channel and users transmit their packets in a random or partially coordinated way. The most popular examples are ALOHA, carrier sense multiple access (CSMA), and idle signal casting multiple access (ICMA) [5]. Any random multiple access technique can be combined with any demand-assign based multiple access technique. When a portable phone enters an active state, it requests a channel from a base station. The base station assigns one of multiple channels based either on FDMA, TDMA, or CDMA. The assigned channel is shared by a group of active portable phones. The portable phone stays in the group until it leaves the active state. The channel assignment acts as admission control so that the channel does not become overloaded. During the active state, portable phones in the same group access a base station based on a random multiple-access technique. This type of wireless access will be important for the 4th generation (4G) systems that provide advanced Internet access services to mobile users.

## 3.2 Evolution Path

Figure 6 summarizes the evolution path of cellular mobile communications systems. Interestingly, every decade, new technology has emerged that enhances the communications capability. We will look back through the evolution of wireless multiple access techniques in mobile communications history.

### 3.2.1 From 1G to 2G

The 1st generation (1G) mobile communications systems, i.e., AMPS, TACS, and NTT, were deployed around 1980. These systems employed analog FM wireless access using narrowband FDMA with the channel spacing of around 25–30 kHz [6]. Then, the 2G systems, i.e., North American standards IS54/136, European standard Global System for Mobile (GSM), and Japan standard Personal Digital Cellular (PDC), were deployed in the 1990's, all of which adopted TDMA with the channel spacing ranging from 25 to 200 kHz. Later, a wireless access technique based on narrowband direct sequence CDMA (DS-CDMA) was developed and IS-95 started its deployment [7]. Its channel spacing is 1250 kHz, which is much wider compared to other 2G systems.

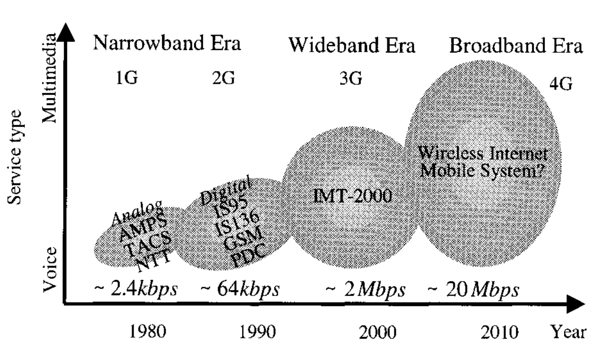


**Fig. 6** Evolution path.

As mentioned earlier, major services provided by the present 2G systems are shifting from voice conversation to multimedia communications over the Internet, as indicated by the "i-mode services." However, all of the 1G and 2G systems were designed so that they can be optimized for basic services, i.e., voice, facsimile, and low-speed voice-band data. It is expected that the coming 3G systems can provide advanced "i-mode" like services with much higher transfer rates and much better representation.

### 3.2.2 From 2G to 3G

There are three strong reasons for developing 3G systems: multimedia, higher capacity, and a global standard. In 2G systems, the data transfer rate is only around 9.6 kbps, which is far too slow for retrieving rich information comprising text and images. A significantly wide data-rate range will be in demand, e.g., from as low as 8 kbps to a couple of megabits per second. Next, in order to cope with the still-continuing rapid growth of mobile communications, the issue of link capacity must also be addressed. Finally, establishing a global standard is becoming increasingly important in the 21st century, when more and more people will travel around the world for businesses and leisure (2G system standards are, more or less, regional standards).

Data transfer rates of up to 2 Mbps and the same quality as fixed networks are the targets. Minimum requirements in terms of data transfer rates and quality for different environments are summarized below.

- Indoor: 2.048 Mbps and bit error rate $BER = 10^{-6}$
- Pedestrian: 384 kbps and $BER = 10^{-6}$
- Vehicular: 144 kbps and $BER = 10^{-6}$

For the transfer of image information of 1 Mbyte, 14 min. is necessary at a 9.6 kbps user rate in 2G systems, but the transmission time will be significantly shortened (to 4 sec.) with a 2 Mbps transfer rate.

The 3G system standardization process is in the final stage in the ITU. Wideband DS-CDMA has been adopted as the wireless access technique [8]. As shown in Fig. 7, there are three operation modes: Frequency division duplex (FDD) single-carrier, FDD multi-carrier, and time division duplex (TDD) [9]. They will use the 2-GHz band. There are two fully globally established core networks presently used for the 2G systems: GSM-MAP for GSM systems and ANSI-41 for AMPS and IS-95 systems. Both core net-

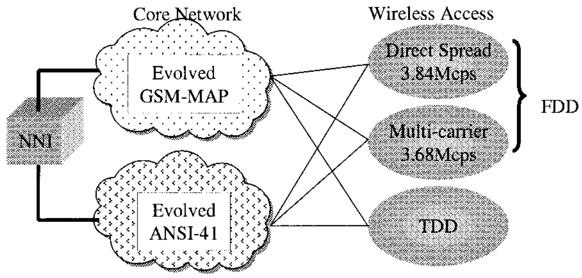


**Fig. 7** 3G system.

works will evolve into 3G core networks and the above-mentioned air-interfaces will connect to both GSM-MAP and ANSI-41 core networks.

3G systems will be deployed worldwide starting around 2001–2002.

### 3.2.3 Coming 10 Years of Wireless Technology

Figure 6 shows that the 4G systems should emerge around 2010. A major objective is to offer mobile users broadband multimedia services, which will soon be in full force in fixed networks based on next generation Internet technology. Information transferred over the Internet will become increasingly rich. Most of the information may contain high-quality still and moving images.

## 3.3 What is 4G?

As mentioned earlier in this article, the 3G systems have a much higher data transfer capability and can handle Transmission Control Protocol and Internet Protocol (TCP/IP) traffic more efficiently than any other 2G system. However, the 3G core networks will slowly evolve from 2G by taking advantage of their legacy and therefore, the 3G core networks may not be fully optimized to the TCP/IP packet traffic. Therefore, it is the 4G system core network that must be fully optimized to TCP/IP traffic. Data transfer rates of 3G systems may not be sufficiently high to handle a variety of information comprising rich images. Completely different wireless and network architectures from 2G and 3G systems are thus, necessary.

Figure 8 illustrates a conceptual configuration of 4G systems and Table 1 shows how 1G to 4G systems are differentiated. The wireless part will become closer to a wireless LAN, but with wide area mobility management as in the 2G and 3G systems. Mobile communications systems require many call control functions and a distributed database, and quick and stable connections between these are necessary. These will be embedded in the TCP/IP based core networks based on a virtual leased line concept. Voice traffic can be transferred as TCP/IP packets, i.e., voice over IP, but how to guarantee QoS and reduce latency is a major technical problem (this may be much easier to realize if TCP/IP over asynchronous transfer mode (ATM) networks are used).

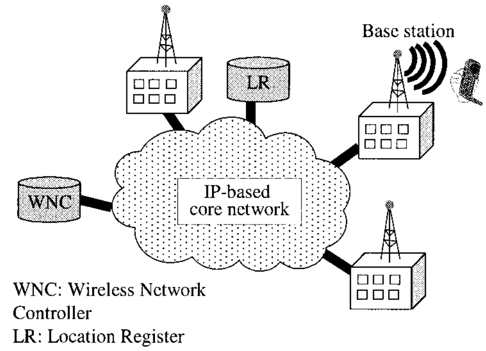


**Fig. 8** Conceptual configuration of TCP/IP-based 4G systems.

**Table 1** Comparison of 1G to 4G systems.

| Generation | 1G | 2G | 3G | 4G |
|---|---|---|---|---|
| Wireless Access | Analog | *Digital* | *Digital* | *Digital* |
| | FDMA | TDMA, *CDMA* | *CDMA* | *?* |
| Major Services | Voice | Voice | Voice | *Voice over IP* |
| | | *Internet (text only)* | *Internet (text, images)* | *Rich Internet* |
| Core-network | Circuit-based | Circuit-based | Circuit- and *Packet-based* | *Fully IP-based* |

With respect to the wireless part, wireless Internet access will be the core:

- TCP/IP packet over the air
- Broadband random multiple access
- Significantly asymmetric traffic between forward and reverse links.

We need to develop an efficient wireless random multiple access technique. Probably, there will be demand for peak throughput of more than 2 Mbps in a vehicular environment and more than 10–20 Mbps in stationary-to-pedestrian environments on the forward links [10]. Due to asymmetric traffic between the forward and reverse links, wireless access networks must be completely redesigned from the 3G systems.

There are other approaches to provide multimedia services to mobile users with the aide of wireless technologies [11]; they are wireless LAN and wireless ATM. It is highly probable that cellular core network architectures will migrate to packet/cell-based architectures and will converge with wireless LAN/wireless ATM architectures in the 4G era (or inter-technology mobility management will be introduced among cellular, wireless LAN and wireless ATM networks). As one may expect, TCP/IP traffic will dominate over the circuit switched type traffic in the near future, e.g., voice, and thus, TCP/IP-based core networks are highly desirable for 4G services. Note that there are also many development activities to accommodate TCP/IP traffic over ATM networks [12]. One advantage of the ATM network is that it can transfer efficiently different types of traffic, e.g., the delay sensitive voice traffic and best effort type TCP/IP traffic, while guaranteeing their respective QoS requirements.

### 3.4 Will the Cellular Concept Disappear?

The frequency bands for the 4G systems will most likely lie above 5 GHz. We must remember that propagation loss is in proportion to 2.6th power to the carrier frequency [13], resulting in increased propagation loss. The wireless channel links are not only interference-limited but also severely power-limited. This suggests that a nano-cell or even a pico-cell structure must be adopted and there is no doubt that an adaptive antenna array will play a key role in abating this power problem.

Due to the nano/pico-cell structure, propagation statistics are strongly influenced by microscopic structure of nearby propagation environments and dynamically change from cell to cell. Also, it is almost impossible for 4G systems to provide nationwide coverage. Only high multimedia traffic areas may be covered. These suggest that 4G systems may need to be designed apart from the cellular concept that relies on the statistical properties of propagation channels. An interesting question is: based on which concept should 4G systems be designed? One solution may be an ad hoc wireless network. Base stations are installed where they are needed and are added or deleted; they are connected to each other in a self-configuring way to transfer TCP/IP traffic. This is similar to the present Internet architecture in fixed networks. Of course, a dynamic TCP/IP routing algorithm over ad hoc wireless networks according to user movement is necessary. With very short-range coverage, coverage areas of ad hoc network base stations cannot overlap. So, close cooperation with 3G systems is necessary. The 3G cellular network will be the primary network, which can be overlaid with the above ad hoc networks in the areas such as business centers, shopping areas, airports, etc. Inter-technology mobility management between the 3G and 4G ad hoc networks is one of the important issues. This requires so-called software radio technology to enable a single mobile terminal to access both 3G and 4G systems.

One idea to reduce the portable phone's transmit power is to distribute many receive stations; transmit base stations with large transmit powers can be co-located with the base stations of 3G systems. This is illustrated in Fig. 9. This concept is particularly suitable to non-real time TCP/IP packet transfer, which obviously does not require transmit and receive functions at the same base station.

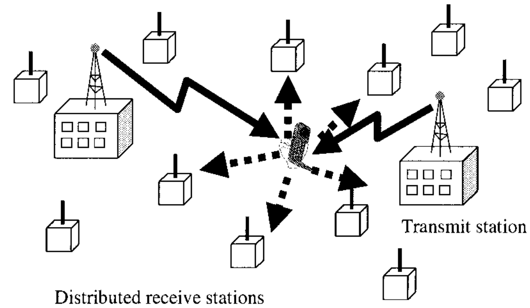


**Fig. 9** Distributed receive stations.

### 3.5 Which Wireless Access Technique?

A debate similar to that concerning 3G wireless multiple access will undoubtedly occur again. When deciding on multiple access techniques, we must remember that the propagation channel becomes a severe frequency selective channel; it is a difficult challenge to realize a high rate and high-quality transmission. Advanced wireless techniques must be developed. The significant difference between traffic in the forward and reverse links may lead to different wireless access techniques to be adopted in the forward and reverse links.

One promising candidate is a hybrid random multiple access technique using orthogonal frequency division multiplex (OFDM) and CDMA, because both provide a good degree of robustness against multipath fading while ensuring flexibility in the multi-rate and high-speed services. It should be emphasized that multiple access may not be necessary in the same way on the forward and reverse links, e.g., DS-CDMA or OFDM-CDMA on the reverse link and OFDM-CDM on the forward link. Furthermore, the frequency bandwidth can be different between the forward and reverse links. In this respect, for the duplex scheme, TDD may be more suitable than its counter part, i.e., FDD. Another promising technique is adaptive transmission according to the varying channel conditions; higher throughput is offered for better channel conditions. This can be easily achieved by random access with retransmission; however, minimum throughput must be guaranteed. For this, the modulation level can be adapted to the channel condition.

## 4. Conclusion

Mobile communications systems have now become an important infrastructure of our society and now, are about to evolve into wireless multimedia communications systems that can flexibly offer various types of Internet services to mobile users. This article reviewed the past 10 years of wireless technology and took a look back over the evolution path of mobile communications systems. In almost every decade, a new generation system appeared. Wireless access techniques evolved from FDMA (1G) to TDMA (2G) and to CDMA (3G) so that digital technology can be fully utilized to improve quality and frequency efficiency. The 4G systems will emerge around 2010. We discussed the technical issues for the 4G systems. Its core network will be TCP/IP-based. Since the expected frequency bands are above several GHz and data throughput over the air will be more than several Mbps, wireless links are severely power-limited. A hybrid random multiple access technique using OFDM and CDMA may be a promising technique. Adoption of the well-known and long-time used cellular concept may not be a good idea. The use of wireless ad hoc networks that allow flexible installation of base stations may be a better solution. Furthermore, the receive functions can be separated from the base station and can be geographically distributed to make it possible to reduce the transmit power of portable phones.

Finally, the 21st century will be a wireless multimedia society, in which a combination of mobile communications and the Internet will play an important role. Before the realization of this society, very difficult but interesting technical challenges are waiting for us.

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