REALIZING MOBILE MULTIMEDIA SYSTEMS OVER EMERGING FOURTH-GENERATION WIRELESS TECHNOLOGIES

by

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ABSTRACT

Fourth Generation Network is an emerging concept envisioned to be a converged access platform for both broadband wireless and wired systems. It is designed to enable high-performance streaming multimedia content to mobile users, optimal use of network resources and scalable media coding methods. Besides opening up new spectrum frequencies and providing higher transmission data rates, Fourth Generation Network will also include a variety of communication networks such as high-speed wireless LAN, Intelligent Transport System (ITS) and fixed infrastructures in addtion to cellular phone systems.

The wireless domain is facing unprecedented growth. In this thesis, the evolution of wireless communication systems from its beginnings in radio through First Generation analog systems and Second Generation digital systems, to current Third Generation broadband wireless systems is presented. Location and culture aspects are also discussed. Fourth Generation is expected to provide higher data rate, higher mobility and high performance multimedia services. It will also be a highly integrated system with seamless global roaming capability. Several key enabling technologies in the upcoming mobile multimedia revolution such as Mobile IP based network, Software-Defined Radio, Intelligent Transport System, smart antenna and high-speed wireless LANs are described in this thesis work.

Thesis Supervisor: Feniosky Peña-Mora

Title: Associate Professor of Civil and Environmental Engineering

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TABLE OF CONTENTS

#Page

LIST OF FIGURES

LIST OF TABLES

Page #

CHAPTER 1

INTRODUCTION

Third generation wireless network will new network architecture and include new IP-based mobility supported features, however, it still suffers from divergent standards as several IMT-2000 (International Mobile Communication 2000) standards are being implemented in different regions of the world. The targeted data rate of IMT-2000 for limited mobility applications is 384 kbps, which is enough for compressed video transmission on the way, but still cannot achieve the goal of providing high performance mobile multimedia services.

In mobile communication systems, there has been an evolutionary change every decade. In the 1980s, First Generation cellular telephone was an analog system, which provided voice services with limited capacity. In the 1990s, Second Generation digital cellular system provided more capacity and better voice quality. In the 2000s, Third Generation Wireless Technology are aiming for broadband access for applications of wireless mobile Internet and e-commerce. In the 2010s, Fourth Generation Systems are envisioned to be a converged platform for broadband wireless as well as fixed access. The concept of Fourth Generation, in a broad sense, will contain several systems and provide global seamless roaming between heterogeneous wireless and wired networks. In this introductory chapter, brief descriptions of the various mobile communication generations and key emerging Fourth Generation technologies will be presented.

1.1 MOBILE COMMUNICATION GENERATIONS

1.1.1 First Generation Analog System

Analog systems are considered to be in the category of first generation mobile telephony systems. They use frequency modulation technique to transmit voice on radio signal using all of the available bandwidth; consequently, channel capacity is limited. Several analog systems have been implemented in many countries since 1979, such as MCS in Japan, NMT 450 in Scandinavia, AMPS in United States and TACS in Britain. Details of these standards can be found in section 2.3.3. There are still analog systems in the world, but many are gradually being phased out or transferred into digital systems.

1.1.2 Second Generation Digital System

Digital cellular telephony systems are generally referred to as Second Generation systems. Digital radio technology uses a combination of multiple access mechanisms, such as FDMA which divides channels by frequency, TDMA which divides channels by time and CDMA which divides channels by spread code to enhance spectrum efficiency and system capacity. Digital Second Generation systems came out on the market in the 1990s. In Europe, GSM is the single harmonized standard adopted for second generation digital cellular services. In Japan, PDC is the dominant system developed and used exclusively there. In the United States, however, three major competing standards coexist: GSM which operates on PCS 1900 frequency, IS-95 CDMA, and D-AMPS which is a modification of analog AMPS system. Detail descriptions on second generation systems can be found in section 2.3.4.

1.1.3 Third Generation Broadband Mobile System

Spectrum limitation and various technical deficiencies of second generation systems have led to the development of Third Generation systems. Third Generation systems are designed for broadband multimedia communications that integrate voice and high data rate services. Research on third generation systems has focused on standardization of a single global platform. The result is the concept of a family of systems called International mobile Telecommunication 2000 (IMT-2000).

Within this framework, Universal Mobile Telecommunication Systems (UMTS) is the main standard being developed. The air interfaces and spectrum allocations of IMT-2000/ UMTS still differ between regions. In addition, existing second generation standards in different regions have several expected migration paths. In Europe, the 2GHz spectrum allocated for IMT-2000 is mostly available. While W-CDMA is expected to be the air interface for 3G in Europe, transition from current GSM system via a so-called 2.5 G GPRS system to W-CDMA is anticipated. In Japan, as PDC is a local system, transition will jump directly from 2G PDC system to 3G W-CDMA system. With NTT DoCoMo's planned initial launch on May 2001, Japan will be the first place in the world to provide commercialized 3G services. In US, diversified 2G technologies are used including PCS-19900, D-AMPS, and IS-95 CDMA. In addition, the PCS system regulated in US has occupied most of the IMT-2000 spectrum. Therefore, the convergence of the 3G market in the US is not likely to occur in the near future. Detailed description of Third Generation systems can be found in Chapter 3.

1.2 EMERGING FOURTH GENERATAION SYSTEM

Fourth Generation Network is an emerging concept, envisioned to be a converged access platform for both broadband wireless and wired systems. Besides opening up new spectrum and providing higher transfer data rates, Fourth generation network will include not only cellular phone systems but also a broader variety of communication systems such as Intelligent Transport System, discussed in Chapter 6 and high-speed Wireless LAN system, discussed in Chapter 7. Key technologies the would enable fourth generation global seamless interworking include Mobile IP, discussed in Chapter 4, and Software-Defined Radio, discussed in Chapter 5.

The Fourth Generation (4G) multimedia architecture has been dubbed "MOTO-Media," and is designed to enable high-performance streaming of multimedia content to mobile users based on agent technology, optimal use of network resources and scalable media coding methods. (NTT DoCoMo, 2000) While most companies are now targeting on their Third Generation (3G) wireless technology approach, two major companies, NTT DoCoMo and Hewlett-Packard Co (HP), formed the first alliance to conduct joint research on 4G technologies between Japan and United States. This joint effort is expected to be complete by 2003, with a release scheduled for 2007. Besides this joint study by NTT DoCoMo and HP, industry researches and forums have come up with proposals for the fourth generation networks. While wireless industry has experienced generational changes every decade, Fourth Generation network is expected to become the next revolution in year 2010s.

Figure 1-1 summarizes the evolutionary path of mobile communication generations:

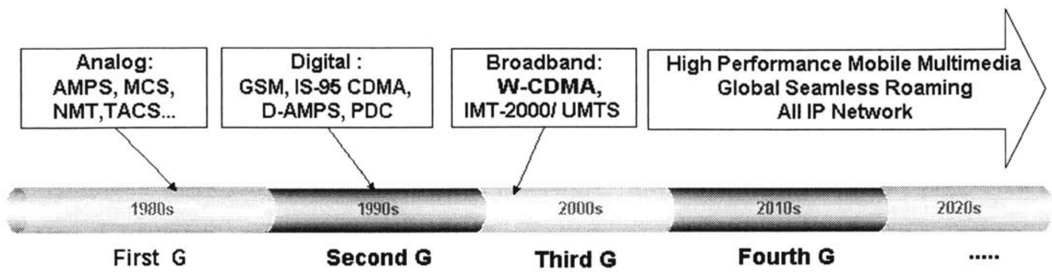

Figure 1-1 Evolutionary Path of Wireless Communication Generations

Fourth Generation network is envisioned to provide:

- **Higher Data Rate**: the 5 GHz band wireless LAN and wireless broadband access system MMAC (Multimedia Mobile Access Communication System) developed in Japan, HiperLAN/2 in Europe and IEEE 802.11 in US reach a data rate of about 20-30 Mbps. The 4G cellular system is expected to provide at least 2~20 Mbps data rate.

- **Higher Mobility:** The use of Mobile IP or evolving protocols is aiming for the future systems with higher mobility. Also, the realization of Intelligent Transport System (ITS) becomes important in facilitating higher mobility system.

- **High Performance Mobile Multimedia Service**: By using higher data rates and IP-based system, it is possible to provide high performance mobile multimedia services. However, since wireless systems have limited radio resources, wireless quality of service (QoS) resource control is an important issue to be addressed.

- **Highly Integrated:** The interoperability and interconnection between heterogeneous networks is the biggest challenge for Fourth Generation Networks, often regarded as a Fixed-Mobile Convergent network.

1.3 FOURTH GENERATION KEY TECHNOLOGIES

The emerging key technologies that enable Fourth Generation Networks, which are discussed in this thesis, are follows:

1.3.1 Mobile IP

The existing IP routing protocols were designed for stationary network systems, where routers identify the designations of transmitted packets and route them according to their specific IP addresses. This manner requires the destination device maintains physical attachment to its specific network; otherwise, a change of IP address is needed. Mobile IP, on the other hand, permits a mobile host to use a permanent IP address regardless of the point of attachment to the network. Thus, a mobile host can maintain continuous connection while moving. Mechanisms of Mobile IP include Mobile IPv4, Mobile Ipv4 with routing optimization, and Mobile IPv6. Mobile IP protocols has been designed to be independent of the access interface, therefore, it is possible for existing or future wireless service providers to incorporate their data network with Mobile IP functions at appropriate network nodes. As a result, it is essential to design protocols, which enable interworking between Mobile IP protocol and wireless mobility management protocols. The third generation wireless network is envisioned to evolve into an IP based network, and in the fourth generation network, IP mobility capability becomes an essential part for future high-speed wireless multimedia services. Details of Mobile IP are described in Chapter 4.

1.3.2 Software-Defined Radio

The rapid improvement of silicon technology makes it possible to develop general purpose Digital Signal Processors (DSP) instead of dedicated hardware. By reprogramming software, the DSP could easily be adapted to the existing multiple radio standards and accommodate the rapid evolving new features and higher data rates. This provides a single hardware platform with software control of a variety of modulation techniques, wide-band or narrow-band operations, and waveform requirements over a broader frequency range. By migrating processing functions from dedicated ASIC implementations to software implementations, users can enjoy a scalable hardware that can be used globally without the need for different handsets when changing to another operator who uses different standard. From the operator's point of view, they would provide services without having to support a myriad number of handheld devices. For infrastructure suppliers, they could lower the cost and secure investment without frequent change hardware components. As for terminal manufacturers, add on capabilities could be done with software patches without needing to design new terminals. For application developers, programs could be developed without concern for hardware types.

The concept of 4th generation networks includes not only cellular telephony, but also a broad range of wireless access systems like Wireless LAN and ITS. Software-Defined Radio can realize the integration of different systems and connection between wireless areas. SDR technology increases hardware lifetime, reducing the obsolescence risk. This phenomenon is likely to be similar as the PC market where software upgrade is possible for newer operating systems or peripheries. Details of SDR are explained in Chapter 5.

1.3.3 Intelligent Communication Technologies

Intelligent Communication Technologies include Intelligent Network (IN), Common Object Request Broker Architecture (CORBA), Mobile Agent Technology (MAT), Intelligent Transport Systems (ITS) and Smart Antenna systems. As mobile communication becomes more global, heterogeneous, and distributed, traditional IN used for PSTN to conduct communications between service logic and switch systems need to evolve into a hardware/software/technology/protocol independent mechanism in order to facilitate today's service implementation. CORBA and MAT are both based on distributed object –orient concept and are believed to be two important key technologies in the IN migration path. ITS contains a series of research activities that aim on adding intelligence into traditional transportation system and has a huge market potential in terms of providing multimedia localized services. While the above four technologies provide intelligent mechanism for future mobile multimedia services, adaptive smart antenna is considered to be a solution for accommodating the crowded air spectrum and increased radio interference from the increasing demand of those services. Detail descriptions of these technologies are in Chapter 6.

1.3.4 High-Speed Wireless LANs

Wireless LAN, as its name suggests, provides users a local area network, which includes functions such and file sharing, peripheral sharing and Internet access, without wire. Wireless LAN adds mobility compares to the fixed LAN, for example, managers in an office environment do not need to unplug and plug again their network cable while doing presentations with their laptop from conference room one to conference room two. WLAN products for ISM bands have appeared in the market since the 90s. IEEE 802.11 standardized for 2.4 GHz band supports 1 Mbps and optionally 2 Mbps. A higher speed version of 802.11, 802.11b provides 11 Mbps throughput., which is currently the main stream of WLAN in corporate environment. A newer version, 802.11a, which moves from the 2.4 GHz spectrum to the U-NII 5 GHz bands and provides physical layer data rate as high as 54 Mbps, is expected to substitute 802.11b as enterprise networking solution by 2002. Similarly, HIPERLAN/2, developed by ETSI, also aims on 54 Mbps of physical layer data rate at the 5 GHz frequency band. HomeRF focuses on the fast growing home networking market with a vision to bring together electronic devices anywhere in and around the home. Bluetooth technology supports ad hoc wireless networks for electronic devices and provides 1 Mbps communication data rate and around 10 to 100 meters short-range communication capacity. The main vision of Bluetooth is to replace cables between diversified devices at home and overcome the light-of-sight limitation of infrared links used nowadays. A detailed description of these standards can be found in Chapter 7.

1.4 THESIS ROADMAP

This thesis work is an evaluation on the upcoming wireless revolution. It begins with an overview of mobile communication status in Chapter 2. The history of radio communication, first generation analog systems and second generation digital systems are laid out. In Chapter 3, Third generation mobile communication systems are introduced. Discussion will focus on both existing and evolving technologies based on their expected time frames as well as their location specifications. From Chapter 4 to Chapter 7, emerging technologies towards Fourth Generation Network are explained. They include Mobile IP in Chapter 4, Software-Defined Radio in Chapter 5, Intelligent Communication Technologies in Chapter 6 and High-Speed Wireless LANs in Chapter 7. Lastly, Chapter 8 concludes this thesis.

PART I

THE DEVELOPMENT

CHAPTER 2

OVERVIEW OF MOBILE COMMUNICATION

Today, the word telecommunication draws an enormous amount of media attention. Numerous books and articles can be found addressing the different technologies, protocols and standards in the broad telecommunication domain. In this chapter, fundamental concepts of telecommunication are discussed, including the definition of telecommunication and one specific form that makes wireless communication possible: Radio communication. As the focus of this thesis is on mobile communication, a brief introduction of cellular technology is described in the second section. In the third section, the history of mobile communication development will be reviewed.

2.1 TELECOMMUNICATION FORMS

Telecommunication systems include a variety of communication subsystems. The transmission of information may go through a hybrid of systems including copper-based cable, fiber optics, coaxial cable, Radio-base systems and light-based systems. (Bates, 2000) Before we start discussing the various standards and development in wireless communication, it is worthwhile to evaluate how this form of telecommunication behaves in relation to the other forms.

2.1.1 Telecommunications

Adopted by the International Telecommunication Union (ITU), the term *telecommunication* is defined as:

> *"Any transmission, emission or reception of signs, signals, writing, images and sounds or intelligence of any nature by wire, radio, optical or other electromagnetic systems."*

Everyday human activities such as telephony, TV, Internet and radio are all covered by this definition of telecommunications.

Telecommunication is divided into two specific forms, *wireline* communication and *wireless* communications. Wireline communication, in which an electrical conductor or glass fiber such as copper, coax cable, fiber optics are used (Bekkers and Smits, 1999), has been the most common method of transferring information. In contrast, wireless communication uses radio waves to transfer information. This thesis will focus on *wireless* communications.

2.1.2 Radio Communications

Wireless communications is defined by ITU as " telecommunication by means of radio waves" (Bekkers and Smits, 1999). Radio waves are *electromagnetic waves.* The radio frequency spectrum or radio spectrum is a part of the electromagnetic spectrum. Electromagnetic waves include ordinary light, radar, and x-rays. These different types of electromagnetic waves are characterized by their frequency (i.e., the rate at which the electrical and magnetic fields vary with time). For example, light waves have higher frequencies than radio waves, and x-rays have higher frequencies than light waves. (See Figure 2-1)

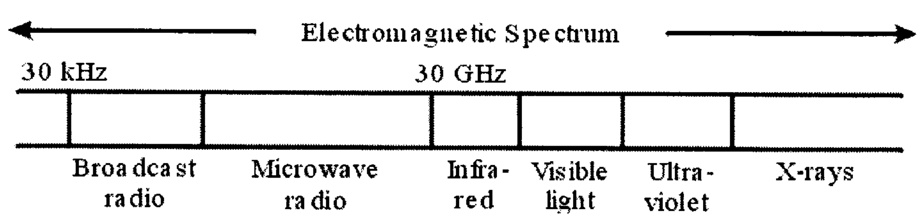

Figure 2-1 Radio spectrum forms part of the electromagnetic spectrum

(Adopted from Downey et al., 1998)

Hertz (Hz) is the unit used for measuring frequency, where 1 Hz is equal to one cycle per second. For example, a pendulum swinging with a frequency of 1 Hz takes 1 second to swing back and forth. Radio waves have very high frequencies—ranging from 30 kHz to 30 GHz. At present, mobile phones use frequencies close to 450, 800, 900, 1,500, 1,800, and 1,900 MHz. (Downey et al., 1998) Figure 2-2 shows that all of these frequencies lie within the *ultrahigh frequency* (UHF) band, which is often referred to as microwaves. The term *spectrum* refers to a broad range of frequencies, for example, the whole electromagnetic spectrum or a particular portion, such as the radio spectrum. A variety of services share the whole radio spectrum; satellite communication, point-to-point radio links, TV broadcasting and mobile radio all use different portions of the radio spectrum. (See Figure 2-2) As the spectrum is limited, maximum use must be made of the available spectrum if mobile phone systems are to be able to support millions of users.

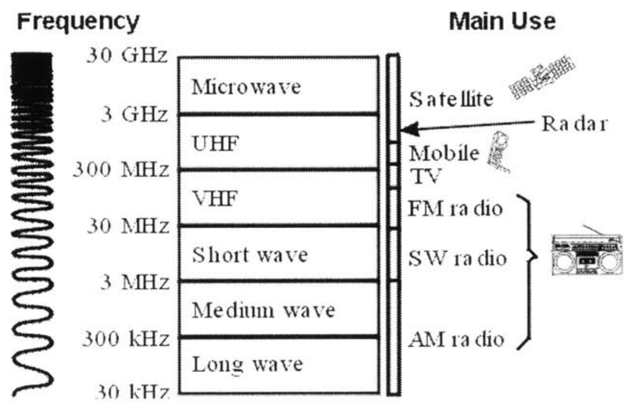

Figure 2-2 Radio band

(Adopted from Downey et al., 1998)

Radio communications using frequencies up to 60GHz are currently considered to be operationally feasible, although frequencies up to 300GH has been realized in the laboratory. (Bekkers and Smits, 1999) In Figure 2-2, the similar size of the blocks used to present the radio spectrum does not mean that the same amount of bandwidth is available in both the Ultra high frequencies (UHF) and the Short Wave Frequencies. In fact, the UHF frequencies contain almost 100 times more bandwidth as Short Wave Frequencies.

There are many issues in determining suitable frequencies for mobile communication systems; for example, component costs increases as communications frequencies become higher. Also, the signal losses in open space increase quadratically with the communication frequency used. This means the higher the communication frequency, the lower the received signal. (Bekkers and Smits, 1999) One the other hand, at lower frequencies, communications are easily disrupted by *man-made noise*, such as electrical motors and car ignitions. (Bekkers and Smits, 1999) A suitable frequency range for mobile communication must find a balance between these competing issues.

2.1.3 Mobile Communications

The term *Mobile Communications* refers to a form of radio communications, which includes various radio communication applications. Generally, we could define mobile communication as a communication form that transmits, receives, or transmits/receives signals between a communication station whose location is not restricted and another communication station whose location is either fixed or mobile. (Bekkers and Smits, 1999) In this thesis, the term *mobile terminal* refers to a communication station that can move around and can communication while it is moving such as mobile phones. Alternatively, in remote locations where conventional fixed line phone networks are relatively expensive, instead of using fixed wires, mobile terminals can be installed in a fixed location, for example in the form of a telephone plus a rooftop antenna. The term *wireless local loop (WLL)* – a wireless connection from telephone wall socket to local switch - is used to describe this way of accessing public phone network.

Normally, a fixed mobile network transceiver station covers only a small geographical area. Therefore, a mobile communication network consists of several communication stations – called as *base station* – to make complete coverage of a wide area possible. When the signal of a mobile terminal reaches nearby base stations, the base stations are in turn connected to switching centers where wired communications is normally used. A complete mobile communication system comprises both the infrastructure for radio connections and the entire fixed network backbone. Figure 2-3 illustrates the integration of radio connections and fixed network backbone.

Mobile communication is a fast growing area. During the last 10 years, more than 400 million wireless phones have been added to the world. In contrast, it took 100 years for current wire line telephones to accumulate about a billion customers. It is expected that by year 2004 the number of wireless telephones will be more than a billion. The number of wireless phone will quickly surpass the number of wireline phones.

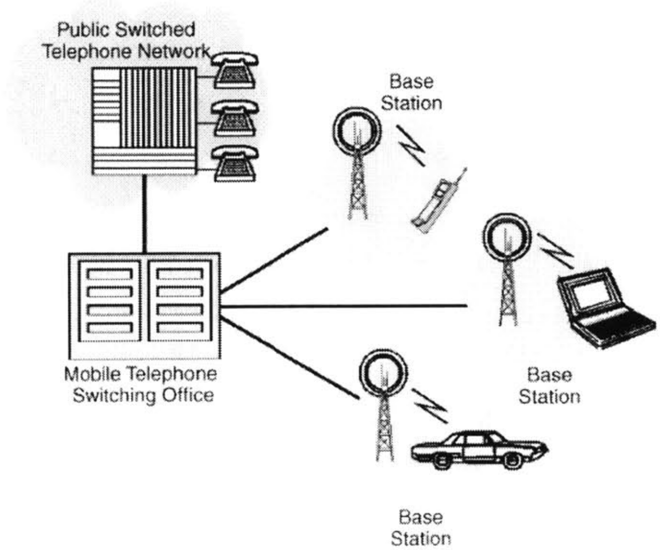

Figure 2-3 Radio connection and fixed network backbone

(Adopted from Muller., 2000)

Mobile computers and the Internet technologies have created the need for an integrated network, which allows for the transmission of voice, image, text message, audio and video through united networks based on IP technologies. As computer scientists have observed that the computing power growth during the last 60 years closely follows the exponential growth curve, we are now heading toward an electronic future where information will be accessible at our fingertips, whenever and wherever needed. Some of the computing and communication equipment required to provide this personal and immediate access to information will be incorporated into smaller and more distributed devices such as mobile phones.

In this information age, many people are carrying devices such as mobile phone, laptop computer, personal digital assistant and digital stereo players at the same time. With the emergence of new generation wireless technologies, we are now at a crossroad where diversified information is about to be integrated into a single mobile terminal unit in a unified mobility network. It is worthwhile to focus on the fundamental *cellular phone technology* structure upon which the future unified mobility network is based.

2.2 CELLULAR PHONE TECHNOLOGY

2.2.1 Concept of Cellular System

Radio waves carry voice or data information via channels. A radio channel contains a range of frequencies within the whole spectrum. The range between the highest and lowest frequencies in a radio channel is called its *bandwidth.* The first analog mobile phone system used in the United States, AMPS, for example, uses 30kHz for a channel. In a radio communication system, the receiving stations should have their channel positioned within the interval along with transmitting stations. Figure 2-4 shows the 800-MHz band used by AMPS system and its relation with divided channels. Downey et al., 1998)

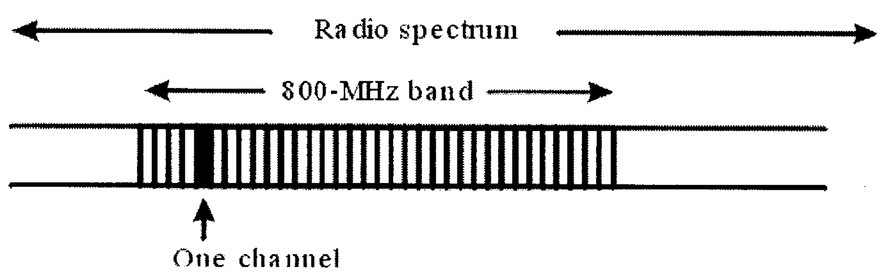

Figure 2-4 Radio band and divided channels

(Adopted from Downey et al., 1998)

The demand for mobile services has grown very fast in spite of the limited amount of available radio spectrum. Congestion of radio channels increased rapidly and has become a serious problem. As early as 1953 and 1960, K. Bullington and H.J. Shulte in AT&T Bell Laboratories presented a concept that resulted in a giant leap forward: *cellular mobile telephony.* The concept was to divide the coverage area into smaller areas called *cells.* Each cell uses several channels (frequencies) and owns antenna for transmitting to and receiving from the mobile phones. Different channels are used on adjacent cells, and due to the low output, channels can be reused in cells that are far apart, greatly increasing the communication capacity. Figure 2-5 shows the concept. (NTT DoCoMo, 2000)

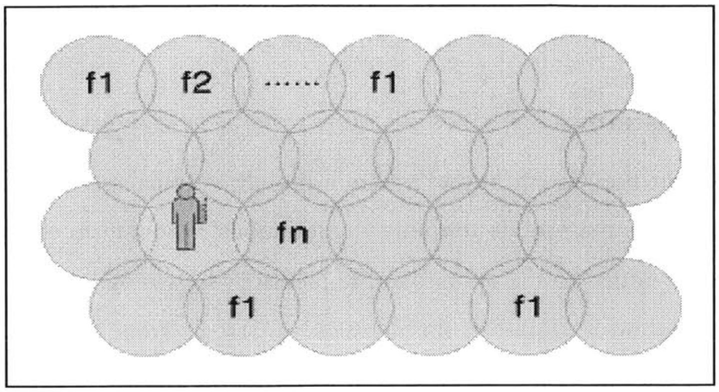

Figure 2-5 The Concept of Cellular Systems

(Adopt from NTT DoCoMo, 2000)

Depending on the anticipated traffic volume, cell sizes could vary. For example, cells in towns and cities would be much smaller than in rural areas to accommodate the higher usage. This concept is called *cell splitting* and was introduced by V.H. McDonald in AT&T Bell Laboratories in 1978. (NTT DoCoMo, 2000) The concept is illustrated in Figure 2-6.

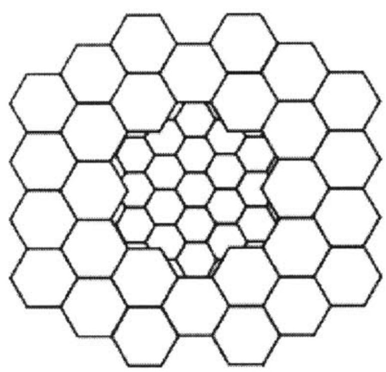

Figure 2-6 Concept of cell splitting

(Adopted from Downey et al., 1998)

As the service area is divided into small cells, a mobile user can move from one cell to another. Therefore, it is important for the system to identify the cell in which the user is located. Two essential technologies -*location registration* and *handoff* were introduced to ensure smooth transition between different cells. The following sections will describe these two technologies.

2.2.2 Location Registration

It is necessary that the system knows where a mobile terminal is located in order to send the communication data. As the mobile terminal is continuously moving in space, a technology called location registration is added to the system and immediately logs mobile terminal onto the network. First, location information is stored in the network via signals from the cell station to the mobile terminal. Then, the mobile terminal sends a message to the Mobile Telephone Switching Office (MTSO). The information sent to the MTSO includes the electronic serial number and telephone number from the handset. Using the above two information and location registration information between base station and mobile terminals, MTSO can identify individual device. (See Figure 2-7, Bates, 2000)

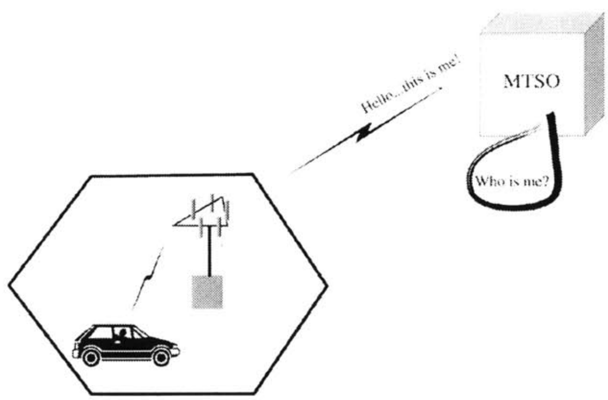

Figure 2-7 Mobile terminal logs on to MTSO

(Adopted from Bates, 2000)

When the mobile terminal gets closer to the cell boundary, the signal from original base station becomes weaker and signal from base station in adjunct cell gets detected. When the mobile terminal receives different location information sent from another base station, it updates its internal location registration immediately and notifies the network. (NTT DoCoMo, 2000)

Overlapping coverage, the method that allows an overlap between adjoining cells, is used to reduce location registration traffic while mobile terminal is around the boundary between cells and to ensure a complete coverage. Figure 2-8 is an illustration of overlapping coverage concept.

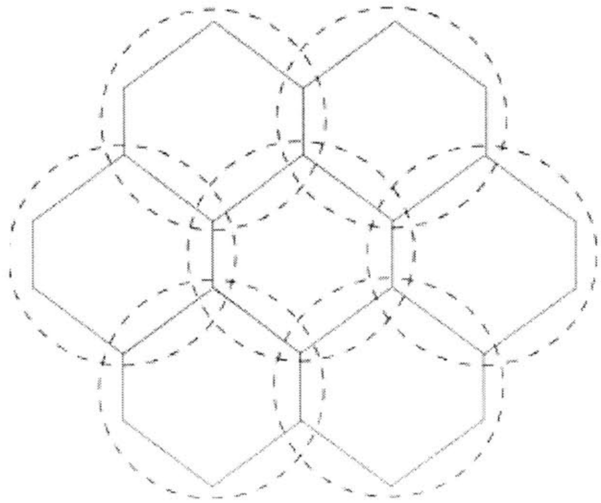

Figure 2-8 Overlapping Coverage

(Adopted from Bates, 2000)

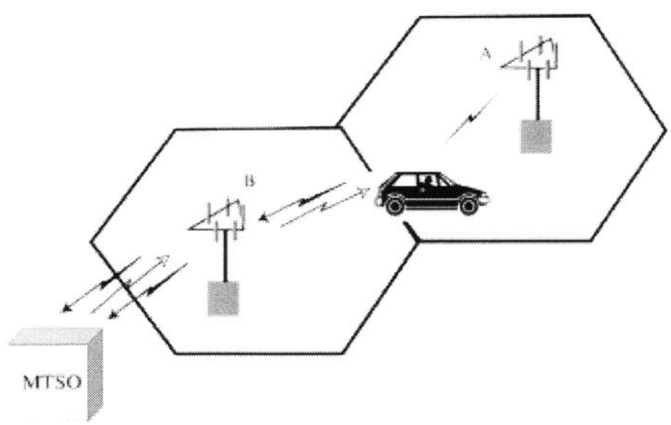

Figure 2-9 Hand-Over process

(Adopted from Bates, 2000)

2.2.3 Handoff

When a cellular user moves cross cell boundary during a call, handoff is needed to switch the service from original cell to the new cell. (See Figure 2-9) Here, the base station plays an active role in handling handoffs. When the signal received by a base station gets weaker as mobile terminal moves toward cell boundary, each base station in adjacent cells will try to identify which cell covering the mobile terminal's new location by measuring the quality of received signals. After the identification of new location is received by MTSO, it will select a channel and direct the new base station to set up call path for the call. (Figure 2-9)

2.3 THE DEVELOPMENT OF MOBILE COMMUNICATION SYSTEM

2.3.1 Development of Radio Communications

At the end of the 19th century, a young German Scientist Heinrich Rudolf Hertz discovered the electromagnetic wave: An electrical spark with sufficient energy can cause invisible waves that can be received by a specially constructed device close by. In 1886, he had demonstrated a practical radio communication system, which is the origin of the term, *Hertz*, the unit for measuring frequency.

Several years after Hertz's experiments, Gugliemo Marconi developed the world's first commercial radio service in 1898. He successfully transmitted waves over several kilometers and called that "radio". Many Entrepreneurs like Marconi built their companies providing communications between ships. At that time, the signals are limited to series of pulses using Morse code[1].

In December 1990, Reginald Fessenden accomplished the first human voice transmission via radio in Maryland, which is marked as the beginning of radiotelephony. It is 79 years earlier than the first *cellular* telephony system opened in December 1979 at Japan.

After two ship sinking disasters -the *Republic* in 1909 and the *Titanic* in 1912, the United States, Great Britain, and other maritime nations established the *mandatory* 24- hours ship-to-shore

[1] Morse code is one of the oldest forms of long distance communication ever invented. A Morse code transmission consists of a number of dashes and dots that can be sent as long or short pulses using any form of media – lights, electrical signals, or sound.

communications from 1910 to 1912. This requirement was derived from the first attempt at regulation of the radio industry: the Radio Act of 1912. By the year of 1918, 5700 ships worldwide had wireless telegraphy installations. (Bekkers and Smits, 1999; Bedell, 1999; Bates, 2000)

2.3.2 Early History of Mobile Telephony

Mobile Telephone Service (MTS)

The value of communications using radio was recognized early by public-service organizations. The first system in 1921 used mobile radio in an automobile instead of a ship in the Detroit Police Department in the Untied States. It was initially an unidirectional communication system from its home base to its patrol cars using a frequency band near 2 MHz. This service proved so successful that by 1934, 194 police forces in the United States had implemented them. (Bekkers and Smits, 1999; Bedell, 1999)

In 1946, AT&T Bell Labs implemented the world's first car phone system in St. Louis, Missouri, US. This system was known as Mobile Telephone Service (MTS). At that time, AT&T was the fixed wire telephone provider in the United States. The systems used only one transceiver station with six FM channels. Each channel permitted only one simultaneous communications session; therefore the maximal number of subscribers was particularly limited. MTS transmissions (from radio towers) were designed to cover a very large area, using high-power radio transmitters. Often the towers were placed at geographically high locations. Because they served a large area, they were subject to noise, interference, and signal blocking. MTS was a half-duplex, "push-to-talk" system; therefore MTS offered communications that were only one way at a time. In spite of the limited capacity and the unsatisfactory voice quality, the demand for these mobile telephony services was still large and increased very rapidly. At peak hours, almost all channels were engaged continuously.

Improved Mobile Telephone Service (IMTS)

Two developments took place in order to improve the capacity of MTS. The first was to decrease the required channel width from 120 to 25 kHz, which was possible because of the improvement of FM equipment. The second development was called trunking.

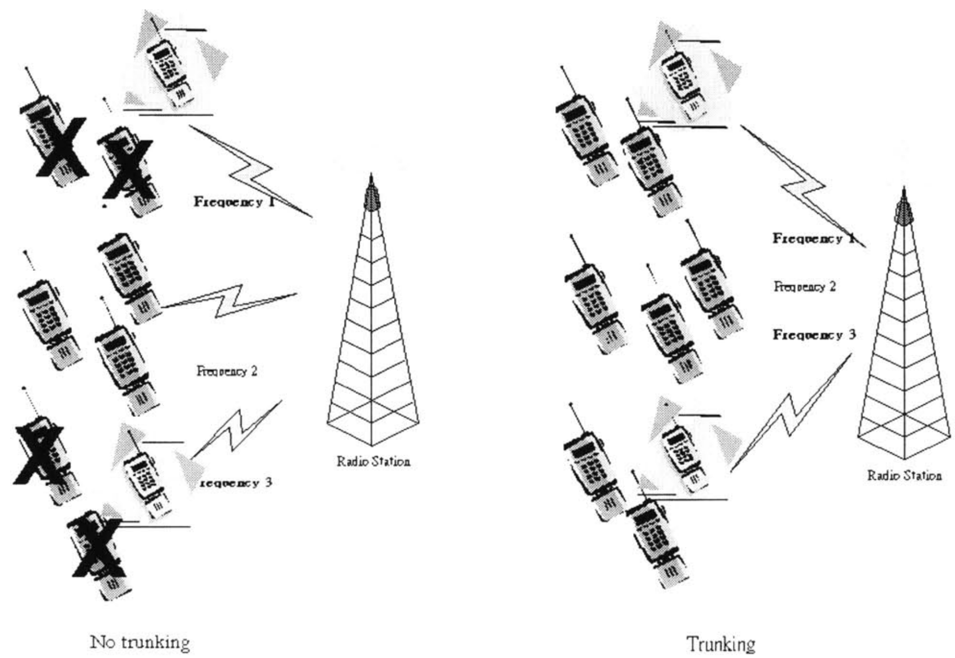

Figure 2-10 Concept of trunking

A trunking system allows mobile stations to use any free channel, instead of communicating only on one specific frequency. As we can see from Figure 2.5, as described by Bekkers and Smits, the two highlighted mobile terminals on the left are communicating without trunking, in which case the four terminals indicated by a cross are blocked. With trunking technology illustrated at the right side, any other terminals can still establish a session with using the remaining free frequency.

In, 1965, the Improved Mobile Telephone Service (IMTS) was introduced with automatic trunking and automatic dialing ability. Also, IMTS is a full-duplex system, which allows simultaneous two-way conversation.

2.3.3 First –Generation Analog Mobile Systems

Analog systems are considered to be in the category of first generation mobile telephony systems. Analog systems use amplitude or frequency modulation techniques to transmit voice on the radio signal uses all of the available bandwidth. The first generation systems have many similarities, such as analog transmission and an FDMA access mechanism, which we will discuss in the next section. This means that the cellular carriers can support a single call today on a single frequency. The limitations of the systems include limited channel availability.

As described in the above sections, the vest majority of mobile networks before 1980s were not automatic; those systems operated with different call areas had a low capacity and were expensive to use. A breakthrough came at the beginning of 1980s, at which time the capacity problems were solved by the cellular technique and mobile telephony become attainable for a much larger group of users.

Analog Mobile Standards

Several standards were implemented in many countries throughout the world. For example, Japan's world first cellular phone system Mobile Control Station (MCS) launched in 1979, Nordic Mobile Telephone at 450MHz (NMT 450) launched in Scandinavia in 1981, Advanced Mobile Phone System (AMPS) launched in the United States in 1983, and Total Access Communication System (TACS) launched in Britain in 1985. However, applications based each standards were almost exclusively limited to their specific country or regions. Table 2-1 summaries different analog systems and their approximate subscribers until 1996. (Source: Downey, Boland and Walsh, 1998)

Phasing Out

The analog system was designed for quick communication while on the road. Because this service could meet the needs of users on the go, the thought process regarding heavy penetration was only minimally addressed. However, as the major *Metropolitan Service Areas* (MSA) began expanding, the carriers realized that the analog systems were going to be too limiting. With only a single user on a frequency, congestion in the MSA became a tremendous problem.

As a result, many analog systems are likely to be phased out over time, particularly in areas of high population densities. Some countries have already announced closure of their analog networks. The AMPS network in Australia, which had 2 million connections in mid 1995, was discontinued after the year 2000. An NMT450 network (30,000 connections) in Belgium was discontinued after 2000. In Spain, the NMT450 network was closed in January 1998, and the Spanish TACS network (1.4 million connections in 1996) is scheduled to close in 2006. Some handset manufacturers have already ceased production of analog handsets. (Bekkers and Smits, 1999)

Name	**Started**	**Main Countries of Operation**	**Approximate Number of Subscribers (1996)**
Mobile Control Station (MCS)	1979	Japan	2M
Nordic Mobile Telephone at 450 MHz (NMT450)	1981	Europe (especially Nordic countries)	2M
Advanced Mobile Phone System (AMPS)	1983	North and South America, Canada, Australia	48M
Narrowband AMPS (NAMPS)	1992	South America and Asia	2M
Total Access Communication System (TACS)	1985	Europe (especially U.K. and Italy)	14M
Nordic Mobile Telephone at 900 MHz (NMT900)	1986	Europe	3M
Japanese Total Access Communication System (JTACS)	1989	Japan	2M
Narrowband Total Access Communication System (NTACS)	1991	Japan	2M

Table 2-1 Analog Mobile Phone Systems

(Source: Downey, Boland and Walsh, 1998)

The phasing out of an analog network will in general require a number change and a handset change for the customers. In the United States, the first digital system called D-AMPS was then introducing to smoother the transition. D-AMPS has downward compatibility with analog AMPS standard.

Technical Parameters of Analog Mobile Phone Systems

Table 2-2 gives an overview of technical Parameters of some major analog mobile phone systems.

Name	Frequency Band	Mobile Terminal Transmission Frequency	Base Station Transmission Frequency	Available Bandwidth	Channel Spacing
Mobile Control Station (MCS)	800MHz	860-885MHz	915-940MHz	2 x 15 MHz	25kHz & 12.5kHz
Nordic Mobile Telephone at 450 MHz (NMT450)	450MHz	450MHz band	460MHz band	2 x 4.5 MHz	25kHz
Advanced Mobile Phone System (AMPS)	800MHz	824-849MHz	869-894 MHz	2 x 25 MHz	30kHz (NAPMS: 10kHz)
Total Access Communication System (TACS)	900MHz	890-915MHz	935-960MHz	2 x 15 MHz	25kHz
Nordic Mobile Telephone at 900 MHz (NMT900)	900MHz	890MHz band	935 MHz band	2 x 25 MHz	12.5kHz
German C-NETZ (C-450)	450MHz	461-465MHz	451-455MHz	2 x 4.5 MHz	20kHz

Table 2-2 Technical Parameters of Analog Mobile Phone Systems

(Source Bekkers and Smits, 1999)

2.3.4 Second-Generation Digital Mobile Systems

Digital cellular telephony systems are generally referred to as *second-generation* systems. Using conventional analog technology, ways to accommodate spectacular growth in cellular customers are limited to using cell splitting technology to reduce cell sizes, or introducing additional base stations. However, in most large cities (MSAs), it has become increasingly difficult and costly to obtain the necessary permits to erect base stations and antennas. Digital radio technology was introduced as a solution that made it possible to increase system capacity significantly without requiring more base stations. Digital radio technology has higher spectrum efficiency and higher system capacity in relation to costs. In March 1988, the Telecom Industry Association (TIA) set up a subcommittee to produce a digital mobile system standard. By the early 1990s IS-54 systems, the so-called D-AMPS system was deployed.

Multiple Access

In mobile communications, it is important and necessary to utilize the limited frequency spectrum effectively. A technology that is used for enabling multiple users to share radio communication channels and conduct communications simultaneously is called *multiple access*. Three systems have been adopted to realize multiple access depending on way in which radio channels are separated. They are *Frequency Division Multiple Access (FDMA)* which divides channels by frequency, *Time Division Multiple Access (TDMA)* which divides channels by time, and *Code Division Multiple Access (CDMA)* which divides channels by spectrum spread coding technology.

Also, for conducting two-way communications (duplex), two channels are needed. One is for a downlink channel from the base station to the mobile station and the other is an uplink channel from the mobile station to the base station. There are two types of duplex systems: Frequency Division Duplex (FDD) divides by the frequency used and Time Division Duplex (TDD) divides the same frequency by time. FDMA systems mainly use FDD and the TDMA and CDMA systems use both FDD and TDD. (NTT DoCoMo, 2000)

Figure 2-6 depicts the three types of multiple access systems, how they compare functionally, and how they utilize spectrum: FDMA, users are assigned with different frequencies within a given band. TDMA, users are assigned different frequencies and different time slots within a given band.

CDMA, users are channeled by specified codes within a frequency band.

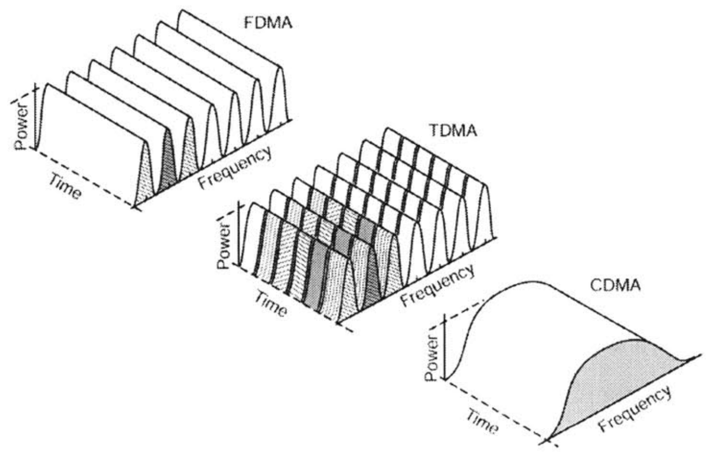

Figure 2-11 Multiple access technologies

(Adopted from Bedell, 1999)

FDMA

FDMA is widely adopted in the analog mobile telephone systems. It assigns a different frequency to each active user; therefore, the same number of transceivers is required for the base station as the maximum desired number of simultaneous sessions. Each session is allocated its own frequency; no particular efficient method is used for available frequency. FDMA requires only limited computing power; a frequency synthesizer is used to set the transmission and receiving frequencies.

TDMA

TDMA splits a single carrier wave into time slots and distributes the slots among multiple users. In TDMA, communication channels consist of many units called time slots over a certain time cycle; in one time slot, different frequencies are given to multiple users, therefore, it's possible for one frequency channel to be effectively utilized by multiple users as each uses a different time slot. If this technique is used simultaneously on several frequencies, it is called TDMA/FDMA. TDMA is the generic name for this *air interface* technology and is used by a variety of digital mobile communication systems, such as IS-54 (D-AMPS), IS-136, and GSM[2]. (Bedell, 1999)

TDMA involves fairly complicated timing technology, as the transmission speed is high if many sessions are to be processed on one frequency. Also, all kinds of delays occur between the users' radio signals on one frequency as each of them are situated in different locations. The earliest standard to use TDMA technology is IS-54; also know as D-AMPS (digital AMPS). IS-54 is a standard used for the migration from analog AMPS to digital cellular systems and is referred as TDMA in very generic terms. In fact, it contained few references to digital radio features. IS-136 is the updated standard for TDMA and uses full TDMA digital features such as caller ID and Short Message Service (SMS).

In FDMA and TDMA, two methods called *Fixed Channel Assignment (FCA)* and *Dynamic Channel Assignment (DCA)* are normally used either individually or in combination, according to the situation. FCA assigns the channels to be used to each cell on a fixed manner, whereas DCA assigns each channel according to actual situation. In CDMA, FCA is normally used since CDMA can flexibly deal with traffic fluctuations by code processing. (NTT DoCoMo, 2000)

CDMA

CDMA multiplying the transmitted data of each session with a certain unique code, then the receiver can reconstruct the corresponding information signal. It is like each CDMA mobile phone speaks its own language and the base station then interprets the information receives. All communication sessions take place simultaneously in the available frequency area. CDMA employs a technology called *spread spectrum* to carry digitized voice and digital code. The term spread spectrum is refers to the relatively broad frequency band between 1 and 20 MHz, which each session communicates. In CDMA system, code is assigned as a pseudorandom noise code that's generated by the digital radio. At this point, the voice transmission has been encoded. This code is then transmitted back to the cell base station, where the voice is decoded, and regular call processing is

[2] GSM uses TDMA as its air interface technology. However, since GSM has its special features and attributes which make it a distinct radio technology. (Bedell, 1999)

completed. This mechanism makes CDMA less susceptible to the impact of noise and interference by substantially spreading the bandwidth range of signals after modulation. Spread spectrum also offers the advantage in providing excellent privacy functions against third-party interception. In fact, CDMA comes from the field of defense and has become commercial in the second half of 1990s. Qualcomm in the United States started using CDMA in the defense-orient field since it is very hard if not completely impossible to intercept CDMA transmissions. They are lobbying vigorously for the application of CDMA in cellular networks.

Different forms for CDMA implementation are Frequency Hopping Spread Spectrum (FH/SS, FH-CDMA) and Direct Sequence Spread Spectrum (DS/SS, DS-CDMA). As FH requires super-fast synthesizer, it is difficult to use on a practical basis. DS system is seen in commercial networks for mobile communications. In DS-CDMA system, transmission and reception process both conduct a two-way system modulation and demodulation. The transmission side firstly conducts the primary signal modulation and creates special waveforms, which is then transmitted via broadband spectrum spread. The reception side also receives communication signals other than the required signals; it then restores the base-band waveform by restoring only the required signals to the original primary modulated signals by reserve-spread using the same spread codes as those on the transmission side. (Bekkers and Smits, 1999; NTT DoCoMo, 2000; BeDell, 1999)

Advantages of Digital Systems

The implementation and use of digital wireless systems result in better use of available radio spectrum and cleaner, quieter signals than the analog systems. Digital transmission all provides for greater security against eavesdropping and cloning fraud. There are some basic differences between digital mobile radio systems and analog mobile radio systems:

- Digital mobile technologies allow for the increased use of radio spectrum, compared to analog systems. The basic intention of deploying digital radio technologies is to overcome the limitation of radio spectrum. Therefore, all of the digital radio technologies allow for a substantially larger amount of radio channels than analog AMPS systems hence can accommodate the increasing traffic.

- Digital radio base stations cost significantly less than analog base stations. The infrastructure and terminals use highly integrated chips to reduce the cost. Also, time slots enabling users to share a channel with associated transceivers, which reduce the number of transceivers needed.

- Digital systems can employ handoff techniques in which the mobile handset has more of a role in determining if and when a handoff is required.

Digital Mobile Standards

Different second-generation digital systems were developed in three most important regions: the United States, Europe, and Japan. Table 2-3 gives an overview of those standards in the three regions. And Table 2-4 gives an overview of the evolving of specific standards from a time series.

Region	Standard	Remark	Developed By
Europe	GSM	Harmonized European standard	ETSI[3]
	DCS-1800	GSM variant for 1800 MHz band	
United States	D-AMPS PCS 1900	Downward compatible with analog AMS standard, later made suitable for 1900 MHz band	TIA (IS-54B, IS-136)
	IS-95 CDMA	Downward compatible with analog AMS standard, later made suitable for 1900 MHz band	Qualcomm/ TIA (IS-95)
Japan	PCS	GSM variant for 1900 MHz band	ETSI
	PDC	Both for 800 MHz and the 1500 MHz band	NTT

Table 2-3 Overview of Second-Generation Standards

[3] ETSI, European Telecommunications Standardization Institute

Name	Started	Main Countries of Operation	Further Details
Global System for Mobile Communication (GSM)	1992	Europe, Australia, others	140 million users in mid-1997
Digital AMPS (D-AMPS)	1992	U.S., others	4 million users in 1996
Digital Communication System at 1800 MHz (DCS1800)	1993	Europe	Also known as PCN
Personal Communication System at 1900 MHz (PCS1900)	1995	U.S.	Based on GSM
Personal Digital Cellular (PDC)	1993	Japan	Was called JDC, 10 million users in late 1996
Personal Handyphone System (PHS)	1995	Japan	Telepoint, 5 million users in early 1997
Code-division multiple access (CDMA)	1995	U.S., others	First used in Hong Kong

Table 2-4 Digital Mobile Phone Systems

(Source: Downey, Boland and Walsh, 1998)

It is remarkable that Europe came up with a single harmonized digital system standard after its many different analog systems. However in the United States, a single harmonized analog standard was implemented in the past. For the second-generation systems, more technologies are developing simultaneously and result in diversified digital standards.

2.4 SUMMERY

Telecommunication systems include a variety of communication subsystems such as copper-based cable, fiber optics, coaxial cable, and radio based systems. Two specific forms of telecommunication systems are wireline communications and wireless communications. In this chapter, discussion is focus on the radio based wireless mobile communication system. Mobile communication is a fast growing area; it is based on a fundamental structure called cellular phone technology. Cellular phone system divides the radio coverage area into smaller areas called cell that uses several frequency channels for transmitting and receiving signals. As adjacent cells use different channels, frequencies can be reused for cells that are far apart and hence increase the capacity. Radio communication technology started at the end of 19^{th} century after Heinrich Hertz discovered the electromagnetic wave. It was firstly used for communication between ship and shore to ensure safeness and then used for police patrol cars. First generation analog mobile systems started around 1980s. In US, AMPS is the only analog systems used where as in Europe and other countries in the world, diversified analog systems such as TACS, NMT 900 and MCS have been developed in different regions. Starting from early 1990s, digital mobile system, also referred as second-generation mobile system, started to emerge on the market. Digital mobile systems use multiple access technologies such as TDMA or CDMA to increase capacity and provide better voice quality. Different second-generation digital systems were developed in three major regions: United States, Europe and Japan. In Europe, GSM is chosen as a unified digital system. In Japan, PDC is the major digital system used. In the United States, however, three competing standards are developed:, they are D-AMPS, PCS-1900 and IS95-CDMA. Detailed evolvement of these systems will be described in Chapter 3.

CHAPTER 3

THIRD GENERATION MOBILE COMMUNICATION

Digital mobile communication systems enable higher capacity by using air interface technologies such as TDMA and CDMA. The number of mobile phone users is exceeding fixed line users, and in countries with the most advanced wireless markets, the mobile phone penetration is as high as around 70% of the overall population. The first generation of analog mobile communication systems adopted various formats such as AMPS, NMT and TACS. These formats were mostly incompatible with each other, which limited the market and accessibility outside their original countries. In second-generation mobile communication systems, the three most important regions: Europe, Unities States, and Japan still have different standards. In particular, GSM is used in Europe, D-AMPS in the United States, and PDC in Japan. Both first- and second -generation systems were designed primarily for carrying speech information and basic data services; therefore, they support only limited data handling capability.

Spectrum limitations and various technical deficiencies of second-generation systems have let to the development of third-generation (3G) systems. Third-generation systems are designed for multimedia communications; hence, high bit rate services that enable high quality images and video to be transmitted and received are needed. To avoid the problem of fragmentation of standards which first- and second-generation systems had, research has been focused on developing and standardizing of a single global 3G platform. The concept proposed up by ITU and regional standards bodies is a "family of systems" that would be capable of unifying the various technologies at a higher level to provide users with seamless global roaming and voice-data convergence. The resulting system is called International Mobile Telecommunications 2000 (IMT-2000), which is a modular concept that takes full account of the trends toward convergence of fixed and mobile networks and voice and data services. Third generation networks represent an evolution and extension of current wireless systems, which provide multimedia delivery services with enhanced capacity, robustness, and flexibility.

In scope, IMT-2000 service environments will address a full range of mobile and personal communication as shown in Figure 3-1.

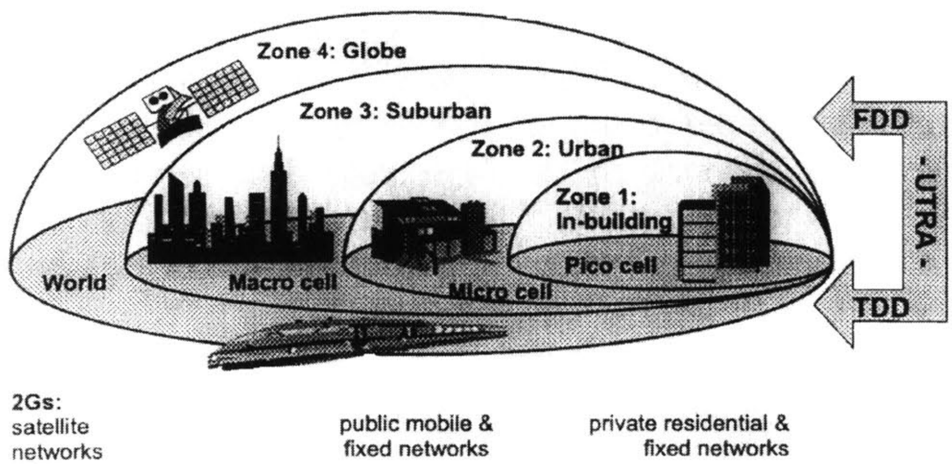

Figure 3-1 IMT-2000 Service Environments Scope

(Source: UMTS Forum)

3.1 TRANSITION FROM SECOND GENERATION TO THIRD GENERATION

Third generation networks has been widely discussed and developed all over the world, especially in the United States, Europe and Japan, and it is expected that the first 3G networks will become commercially available in mid-2001 in Japan. In Europe and Asia, commercial operation of 3G networks will not phase in until the year 2002. Before truly third generation networks arrive, more and more value-added services are emerging in e current 2G digital mobile services. First generation systems are still co-existing with second -generation systems today; therefore, a smooth transition and integration of emerging third generation networks and existing systems is an important consideration. In this regard, it is important to understand the technical aspects and limitations of the current standards developed in different regions of the world. In the following sections, developments in the United States, Europe, and Asia will be discussed respectively.

3.1.1 Developments in the United States

In the United States, competition between second-generation standards has been surprisingly complex. Network operators adopted different standards and the situation is opposite to the development of second-generation network in Europe, where a unified standard GSM was chosen in the whole Europe market. Discussion on the GSM standard will be found in the next section.

Technology	Population in Awarded License Area	Number of Licenses	Network Operators
CDMA	258,000,000	48	Sprint/Wireless Co, PCS PrimeCo, Cox Cable, GTE, Ameritech
D-AMPS	118,000,000	24	AT&T Wireless PCS, SBC Communications
GSM	101,000,000	20	Pacific Telesis, American Portable Tel, Wiestern Wireless, BellSouth, Powertel PCS, American Personal Communications

Table 3-1 PCS Standatds

(Source: Bekkers and Smits, 1999)

Three major technologies were selected by network operators in a series of auction conducted in the United States form 1993 to 1997. They are called Personal Communication Service (PCS) and consist of D-AMPS, CDMA, and GSM. Table 3-1 is a summary of these three standards and their related information according to 92 of the total 102 licenses. (Source: Bekkers and Smits, 1999)

D-AMPS (IS-54, IS-136, D-AMPS-1900)

D-AMPS is often referred as TDMA since it is based on TDMA technology mentioned in Chapter 2. In fact, TDMA is the general name of digital air interface technology. The United States actually had only one first-generation standard - AMPS. At the end of the 1980s, network operators predicted that there would be a capacity shortage in their AMPS networks, especially in urban areas. AMPS standard divides the 12.5 MHz of available bandwidth into 30-kHz channels and only one user could be assigned to each channel. TDMA increases the call handling capacity of AMPS by dividing the available 30-kHz channels into three time slots and hence increase the capacity by a factor of three.

The original TDMA was called IS-54, which was based on the technology available in the 1970s and had limited system performance. IS-136 is the updated TDMA standard and took into account later developments in digital mobile systems. Both IS-54 and IS-136 are operated using the 800 MHz frequency band with the AMPS standard. A variant of D-AMPS was developed for the new 1900 MHz band later on and is sometimes referred as D-AMPS 1900, PCS 1900 or just TDMA.

D-AMPS is implemented within an existing AMPS system- in which a certain number of channels are digitized. In view of the fact that implementation within the existing infrastructure is proceeding gradually, and many users still own analog terminals, the standard makes a dual mode (AMPS/D-AMPS) terminal mandatory so that calls can also be made in cells or networks without digital channels. (Bekkers and Smits, 1999; Muller, 2000)

CDMA (IS-95)

CDMA uses spread- spectrum technology to separate users by assigning them digital codes within a much broader spectrum. Basic idea of CDMA can be found in section 2.3.4. Like TDMA, IS-95 CDMA operates in both 1900-MHz band and 800-MHz band. With spread-spectrum technology the information contained in a particular signal is spread over a much greater bandwidth than the original signal. As CDMA assigns unique codes to each user and spreads the transmissions of all users in parallel across a wide band of frequencies, the respective mobile terminals based on their assigned code recover conversations, and other conversation will look like random noise and are ignored.

Qualcomm in the United States was the pioneer of CDMA since this company was formerly active in the defense sector where CDMA has been in use since the 1950s. Since the mid-1990s, Motorola, Lucent, Nortel, OKI and Samsung also joined the CDMA camp. Sony established a joint venture with Qualcomm to produce terminals for CDMA services, and several other Japanese companies have also licensed the technology. (Bekkers and Smits)

Many European suppliers also actively focus on IS-95 CDMA. Nokia has achieved a considerable market share of CDMA terminals, and Alcatel is cooperating with Motorola in the supply of CDMA infrastructure and terminals. In contrast, Ericsson, supports GSM and D-AMPS, but has since realized that CDMA will be the access system for third generation mobile systems. As Qualcomm owns most of the intellectual property relates to CDMA technology, infrastructure and terminal suppliers have to enter into license agreements with Qualcomm. In the past few years, Ericsson and Qualcomm have been in various lawsuits in which they accused each other of patent infringement in the field of CDMA.

The First commercial IS-95 CDMA networks were opened in 1996 in South Korea, Hong Kong, and Singapore. The first 800 and 1900 MHz CDMA networks also started in the United States during 1996 and are scheduled in Canada, Japan and other countries. Many European operators such as Deutsche TeleKom and British Vodafone have constructed experimental CDMA networks in spite of the mandatory GSM and DCS-1800 standards there.

The channels used for IS-95 CDMA are 1.8MHz wide, contain a voice channel of 1.25MHz plus two *guard bands* of 275kHz. A license of two 1.25MHz (or say, 1.8MHz with *guard band*) can form a working network. The duplex separation must be at least 45 MHz. A CDMA channel can handle between 25 to 40 calls simultaneously. However, the greater the number of users, the greater the potential interference from other terminals could be, and therefore the greater the likelihood of transmission errors could happen. The network operator is responsible for the selection of a maximum number of users per channel. Beside speech, IS-95 also support data, fax and short message services, the maximum transmission speed is up to 14.4 kbps.

GSM

It is worth noticing that variants of D-AMPS and CDMA use the spectrum in the 1900 MHz band, due to the announcement of Personal Communications Services (PCS) networks. PCS are telecommunication services described by FCC as a broad range of radio communications services that free individuals from the constraints of wireline PSTN and enable them to communicate when whey are away from their home or office telephone.[4] The 1900 MHz band licenses are awarded to both broadband PCS[5] for mobile telephony and narrowband PCS for other applications such as paging and two-way data communications. This resulted in the emergence of PCS-1900 derived from GSM.

PCS-1900 targets primarily for network operators who have won license in the PCS auction in the United States. Several changes have been made with respect to the DCS-1800, 1800 band standard for GSM, used in mainly in Europe to adapt the system to the North American market. Detailed description on GSM will be in next section.

However, it should be noted that later on the third generation network initiative IMT-2000 allocated the frequency bands around 2 GHz to be used for the third generation systems. Thus in the United States, third generation services must be implemented within the existing bands by replacing part of the spectrum with third generation systems.

3.1.2 Developments in Europe

As mentioned earlier, many different mobile systems were developed in Europe, the incompatible standards and uncoordinated national systems inevitably caused many problems. As each country developed its own standard, users traveling throughout Europe cannot use the same mobile terminal. Not only is this inconvenient for the subscriber, the market of related equipment was also limited as a result. It is thus hard to realize the hope of reducing cost by scaling up the market. Furthermore, government officials realized that this situation could hinder the progress of

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[4] Bekkers and Smits, 1999, P.33. Originally come from *Mobile Communications Internationa,* Oct. 1994, P.S10.

[5] The term *broadband* here refers to as the contrast to the narrowband licenses for paging and the like. It's not referred to as the term broadband used for third generation networks.

building an economically unified Europe. Consequently, the Conférence Européenne des Postes et des Télécommunications (CEPT) decided to set up a working group to develop a Pan-European mobile system in 1982.

Global System for Mobile Communications (GSM)

The name of this working group was Group Spéciale Mobile, abbreviated to GSM. Now, the developed system is called Global System for Mobile Communications and the same abbreviation is used. An important objective of this working group is to form a united mobile system where the same mobile phone could be used in different countries. With a strong European mobile system, the whole telecommunication industry in Europe could scale up and play an important role in the world. GSM in Europe operates at the 900-MHz frequency and 1800-MHz frequency. However, as mentioned in the above section, in the United States, GSM is used for PCS 1900 service available mostly in the Northeast and in California and Nevada. As a result, the phones that operate on the 1900-MHz frequency in the US cannot interoperable with those GSM phones that operate on the 900-MHz or 1800-MHz networks. Introducing triple band GSM phones that can operate in 900-MHz, 1800-MHz, and 1900-MHz frequencies could solve this problem and eliminate the need for renting phones while traveling. CEPT recommended reserving two blocks of frequencies in the 900-MHz band for the new system. In 1986, the European Commission decided to reserve the two 25 MHz frequency blocks 890 to 915-MHz and 935 to 960-Mhz for GSM uplink band and downlink band respectively. Each of the 25 MHz band was divided up into 200-kHz channels.

Several criteria was envisioned by CEPT for the new system:

- Offer high quality speech;
- Support international roaming;
- Support hand-held terminals;
- Support a range of new services and facilities;
- Provide special efficiency
- Offer compatibility with ISDN;
- Offer low terminal and service cost. (Mullar, 1999)

In 1989, the development of GSM specification was transferred from CEPT to the European

Telecommunication standards Institute (ETSI), which was set up in 1998 to set telecommunication standards for Europe and related fields of broadcasting and office information technology.

GSM Phase I specification was published by ETSI in 1990, which contains functions such as voice and data transmission, short message Service, fax and alarm numbers. In 1993, 36 networks were operational in 22 countries, signifying the rapid acceptance and development of a single, standards-based network. Now over 300 operators in 133 countries have already endorsed and accepted the GSM specification for their local and national wireless networking standard. (Bekkers and Smits, 1999)

GSM Network Architecture

GSM has a hierarchical architecture and was designed for reasonably large traffic volumes - at least several hundred thousand users per network. The functionality of each of the components describes the overall complexity and the degree of robustness built into the network. In GSM, spectrum efficiency is much better than the existing analog networks due to speech compression as well as the digital cellular cluster design.

A GEM network consists of the following subsystems: Mobile Terminals, Switching subsystem, Base Station subsystem, and Operation and Support System. (See Figure 3-2)

- *Mobile Terminal (MS: Mobile Station):* The mobile station, or mobile terminal is the hand –held device carried by the subscriber. It consists of a mobile telephone unit and a removable smart card called the *subscriber Identity Module (SIM).* The SIM provides mobility for the individual so that a user can roam seamlessly and have all the services contracted for, regardless of the end user terminal device. SIM contains subscriber and authentication information, and by inserting the SIM into the set, the set takes on the personality of the end user. The user is then able to make and receive calls and receive the features allowed by contract, even if the set is a temporary one.

- *Base Station (BS):* The base station subsystem comprises of two parts, *Base Transceiver Station (BTS)* and the *Base Station Controller (BSC)*, and controls the radio link with the mobile station and monitors call status for handoff purposes. BTS is where the radio system is located for the air interfaces to the subscriber mobile unit, and BSC controls several dozen of BTS and is the interface between the mobile unit and the Mobile Switching Center (MSC), which will be discussed next. The first generation GSM base station can communicate on three to five frequencies and support 24 to 40 simultaneous calls. (Bekkers and Smit, 1999)

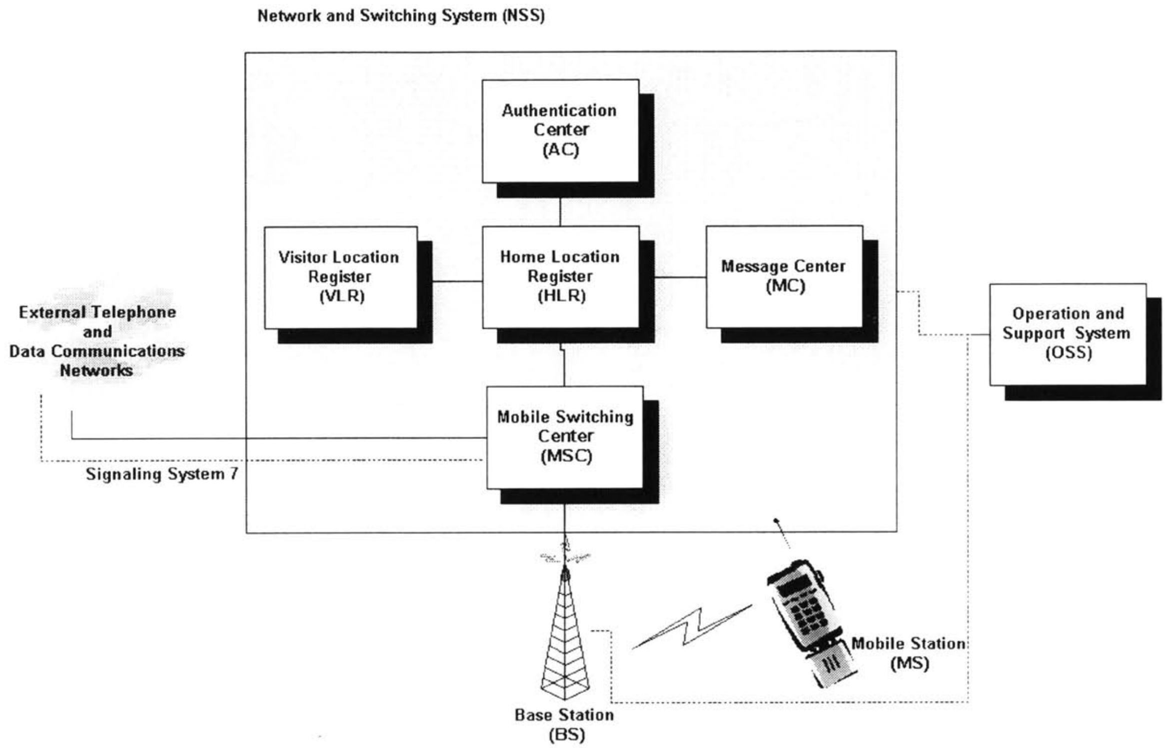

Figure 3-2 GSM Architecture

- *Switching System (NSS: Network and Switching Subsystem):* The BTS mentioned above is linked to the switching subsystems, which also contain several components. *Mobile Switching Center (MSC)* provides all the necessary switching and call capacity as well as functions like authentication, mobile handoff, registration and a group of database functions. A MSC controls several BSCs and can usually cover an area up to approximately one million inhabitants. The switching system usually uses the *Signaling System 7 (SS-7)* as an interface for communication with external communication network. Two registers *Home Location Register (HLR)* and *Visitor Location Register (VLR)* are contained in the subsystem, HLR stores its own subscribers and VLR stores temporarily data of guests on the network. When a mobile terminal is moving, HLR and VLR are updated continuously. *Authentication Center (AC)* manages subscribers' authentication and encryption data and *Message Center (MC)* handles all the messages.

- *Operation and Support System (OSS):* The Operation and Support System is in charge of fault management, cost management, configuration management, performance management and security management. Hence, OSS is directly or indirectly connected to all other systems in the network. Several interfaces between GSM components in the architecture are as following:

    - *Radio Interface,* Um, is a radio link over which the mobile station and the base station subsystem communicate.

    - *Abis Interface,* which describes the communications between base station and BSC. This interface makes it possible to compose a network using equipments from various providers.

    - *A Interface,* is a radio link over which the base station subsystem communicates with the MSC.

GSM Technical Information

GSM uses a combination of TDMA and FDMA. The full allocated 25 MHz band was broken down into a total of 124 carrier frequencies spaced 200 kHz apart using FDMA. One or more of these frequencies are then assigned to each base station. From there, each of the carrier frequencies is subdivided in time - using the TDMA scheme into eight time slots. Then, the mobile unit uses temporally separated time slots for transmitting and receiving data.

Phase I GSM implemented functions such as voice and data transmission, short message service (SMS), fax and alarm numbers. In 1994, ETSI concludes the core of phase II GSM specification, which includes functions such as call waiting, call charge, call hold, conference call and cell broadcast. Phase II+ of GSM provides support allows a user to adopt different roles using a single handset.

Also, with the introduction of private numbering pan, users can internetwork with other staffs in an organization as if they were on the same PBX.

Two new data communication over GSM developments came up recently: General Packet Radio Service (GPRS), which is a packet-switched mode and High-Speed Circuit Switched Data (HSCSD), which is a circuit-switched mode. Originally, the Phase II+ GSM standard added an addition to offer packet-switched data communication since it has several advantages over circuit-switched system. However, to introduce GPRS, fairly large-scale modifications of both the infrastructure and the terminal of GSM network are necessary. Therefore, the development schedule of GPRS has become seriously delayed. Several suppliers, such as Nokia in particular, have put forward proposals to introduce a simpler data mode the does not require far reaching modifications. This proposal is called HSCSD. Next two sections are brief descriptions on each of them.

High-Speed Circuit Switched Data (HSCSD)

HSCSD was introduced in 1998. It uses several time slots for a single communication session to achieve a higher speed. 14.4 Kbps channel coding replaced the original 9.6 Kbps coding, and four channels of 14.4 Kbps are combined into a single cannel of 57.6 Kbps, which is almost the speed of a fixed ISDN channel of 64 Kbps.

Multiple time slot assignment means that fewer customers can share the GSM services if more radio resources are assigned to individual customers. However, this problem can be reduced by flexible resource assignment such that integral bandwidth on demand capability allows the service to provide what ever speed the customer require between the maximum and the minimum capacities.

General Packet Radio Service (GPRS): 2.5 Generation Network

GRPS is a packet-switched protocol developed in 1999, which provides higher speed data services for mobile users. By using packet-switched technology, GPRS is ideal for services that involve short data transmissions (compare to voice data), like e-mail or database access, for example, where users do not want to pay high call charges. Also, GPRS permits the user to receive voice calls while sending or receiving data calls and offers faster call setup time than HSCSD with in 0.5 to 1 second. To accommodate GPRS, new radio channels are defined. The allocation of these channels is flexible such that from one to eight time slots can be allocated to a signal user, and the uplink and downlink are allocated separately. (Lin and Chlamtac, 2001) With circuit switched technology, a channel is allocated to a single user for the duration of the entire call, even though conversations consist of many silence periods. With a packet switched network like GPRS, all types of transmission from slow-speed short messages to higher speed web browsing, could be handled where radio resources can be shared dynamically between speech and data services as a function of traffic load and operator preference. The spectrum is used only when there is something to send, voice or data. When there is no data to be transmitted, the spectrum can be assigned to another user.

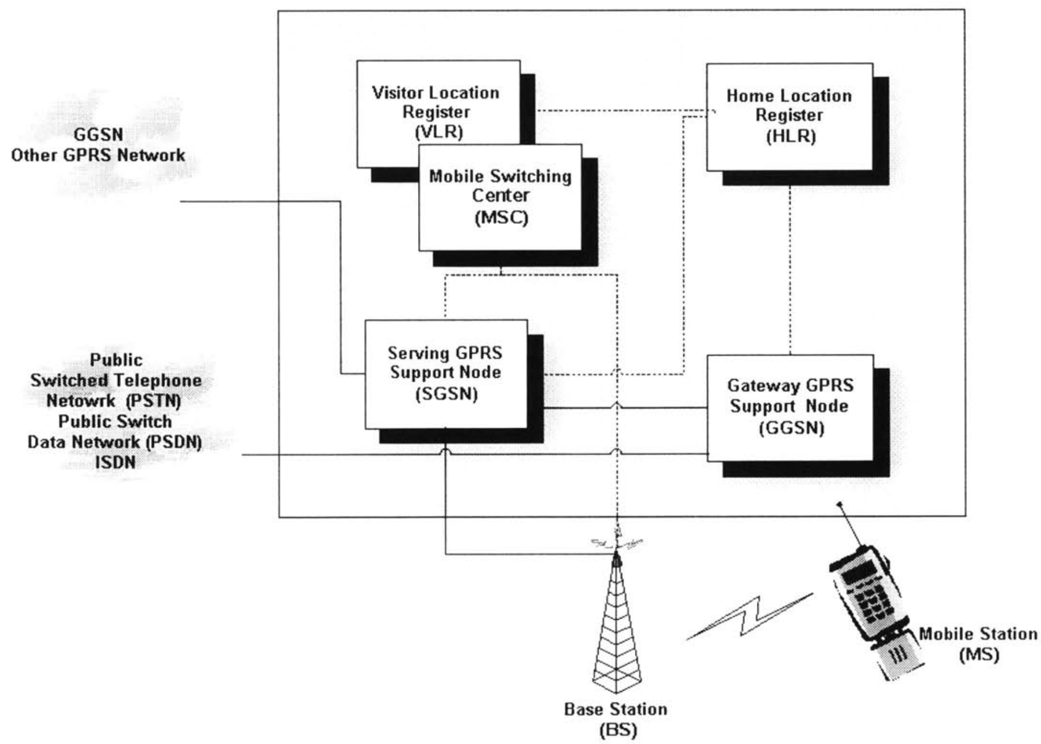

Figure 3-3 GPRS Architecture

GPRS will enhance GSM to deliver data services at 40-45 Kbps data rates, around 4 times to original GSM data rate. Also, GPRS provides transparent IP support from the end user terminal to the Internet. With EDGE (Enhanced Data for GSM Evolution), which will be mentioned next, further enhances GPRS, and can reach user data rates of 384 Kbps. In reality, 3G networks still have a long way to go, and GPRS, of referred as 2.5 G service, is viewed as the first stepping –stone to fully-fledged mobile multimedia networks on 3G broadband wireless technologies. Some operators might decide to focus their mobile data efforts on adding the GPRS base on their existing second-generation investment due to the high auction price of 3G licenses.

Figure 3-3 illustrates the GPRS network architecture. Implementing GPRS, operators have to deploy a packet based core network to carry packet-switched data traffic on top of the GSM infrastructure. In GPRS architecture, Mobile Station (MS), Base Station (BS), Mobile Switching Center (MSC), Visitor Location Register (VLR) and Home Location Register (HLR) in the existing GSM network are modified. And two new network nodes are introduced in GPRS. *Serving GPRS Support Node (SGSN)* is equivalent to MSC in the packet-switched GPRS network, and *Gateway GPRS Support Node (GGSN)* is interworking with external packet-switched networks and is connected with SGSNs via IP based GPRS backbone network. Data traffic together with voice traffic will be carried over the modified access infrastructure from the Base Transceiver Station (BTS) to Base Station Controller (BSC), from where it would be branched off to the data network SGSN).

By reusing GSM infrastructure, most GPRS implementation costs in existing GSM architecture will be software –related, except for SGSN and GGSN. Therefore, GPRS provides a smooth path from second-generation GSM technology to third generation network by reusing the GSM investment so that both circuit-switched and packet-switched services coexist in one subscription. Also, the GPRS IP backbone could be used by third generation mobile network. The limitation of GPRS is that the data rate is still too low for truly multimedia applications. This could be solved by the introduction of EDGE as a temporary method before the launch of third generation radio technology.

Enhanced Data for GSM Evolution (EDGE)

GPRS provides only limited data capacity with GSM radio technology. To solve this problem, Enhanced Data for GSM Evolution (EDGE) was introduced using the standard GSM 200 KHz carrier and an alternative modulation scheme to provide data rates up to 384 Kbps. The enhanced modulation scheme can automatically adapt to the current radio environment to provide the highest data rate depending on the propagation conditions an ensuring wider area coverage using lower data speeds. EDGE can also be implemented over TDMA IS-136 networks.

Based on EDGE, *enhanced GPRS (EGPRS)* can reach a data rate up to 470 Kbps indoors and 133

Kbps outdoor and its spectrum efficiency is two to six times higher than GPRS.

3.1.3 Developments in Japan

Japan plays a leading role in mobile communication in Asia. PDC, Pacific Digital Cellular, also referred as Personal Digital Cellular, is a digital cellular system developed in Japan at the beginning of 1990s to succeed the analog NTT standard. PDC was initially referred to as Japanese Digital Cellular (JDC).

PDC is a digital cellular telephony standard using TDMA. It was developed by NTT in collaboration with NEC, AT&T, Ericsson and Motorola; however, this standard is only implemented in Japan. The first PDC network came into operation in April 1994

3.1.4 CDMA V.S GSM

Table 3-2 is a comparison between CDMA and GSM network. The advantages and disadvantages of each technology are crucial considerations for parties to initiate migration from second-generation to third generation networks.

CDMA	**GSM**
Advantages: • High frequency efficiency • Simple network planning • Fewer base stations required for same coverage • Flexible capacity • Simple insertion of microcells • Increasing support by supplier, also in Asia	Advantages: • Tried and tested, efficiently operating technology • Adopted by many countries • Relatively low prices

Disadvantages:	Disadvantages:
• Still relatively limited experience in large, operational networks • Critical power control of terminals required • Intellectual property rights lie mainly with one party (Qualcomm)	• Large number of base stations required • Critical network planning • Slow further development • Intellectual Property rights (IPR) lie mainly with several parties (Motorola, Lucent, Philips, etc.). Closed supplier market. Permission of IPR owners required to use GSM outside Europe

Table 3-2 Comparison of CDMA and GSM

3.1.5 Technical Comparison of Current 2G Standards

Table 3-3 contains technical parameters for major digital 2G standards. The comparison serves as reference while progress to discussion among third generation networks.

Standard	GSM/DCS-1800/PCS-1900	D-AMPS	IS-95 CDMA	PDC
Frequency band (MHz)	900/1800/1900	800/1900	800/1900	800/1500
Mobile to base station (MHz)	890-915/1710-1785/1850-1890	824-849/1850-1890	824-849/1850-1890	940-956/1429-1441 and 1453-1465
Base station to mobile (MHz)	935-960/1805-1880/1930-1970	869-894/1930-1970	869-894/1930-1970	810-826/1477-1489 and 1501-1513
Duplex separation (MHz)	45/95/80	45/80	45/80	130/48

Access	TDMA, 8 time slots (later 16)	TDMA, 3 time slots	CDMA	TDMA, 3 time slots (later 6)
Channel width	200 kHz	30 kHz	1.25 MHz	25 kHz
Available spectrum in domestic market	2 x25 MHz/ 2x 75 MHz/ 2x 80 MHz (US)	2 x 25 MHz/ 2 x 80 MHz	2 X 25 MHz/ 2 / 80 MHz	2 x 16 MHz/ 2 x 24 MHz
Modulation speed	271 kbps	48.6 kbps	1.2 to 14.4 kbps	42 kbps
Speech encoding	LPC, 13 kbps	VSELP, 7.95 kbps	QSELP, 1.2 to 8 kbps	VSELP, 11.2 kbps
Important Suppliers	Ericsson, NOKIA, Siemens, Alcatel, Motorola	Ericsson, Nokia, Northern Telecom, Motorola, Lucent	Qualcomm, Motorola, Lucent, Nortel, OKI, NEC, Samsung, Alcatel, Nokia, Sony	NEC, Lucent, Ericsson, Motorola

Table 3-3 Technical Parameters of Digital Cellular Standards

(Source: Bekkers and Smit, 1999)

3.2 INTRODUCTION TO THIRD GENERATION STSTEMS

First generation analog and second generation digital cellular communication systems have enabled voice communications and some data services such as information browsing and text messaging to go wireless. The penetration of cellular phone services at various countries can be seen from Figure 3-4. We can see that by the year 2000, countries in North Europe such as Finland, Norway, Sweden, Denmark, and Iceland have reached a penetration rates as high around 60~70 percent of their population. And countries such as Italy, HK, Taiwan, Korea, and Luxembourg have a cellular penetration of more than 50 percent in regard of their total population. The above statistics are growing rapidly, and huge potential markets in the United States and China are also catching up.

However, as described in above sections, current cellular phone users are mostly using a combination of analog and digital networks provided by operators in their specific countries. Major second generation cellular systems are GSM used in Europe and in much of Asia, PDC used in Japan, IS-95 (also referred as cdmaOne) used primarily in North America and IS-136 (also referred as US-TDMA. As second generation systems are still not smoothly integrated with each others, and the spectrum limitations of above systems become potential problems while subscriber number are increasing tremendously, many are the anticipating a newer generation of mobile systems. These all led to the development of a third generation system.

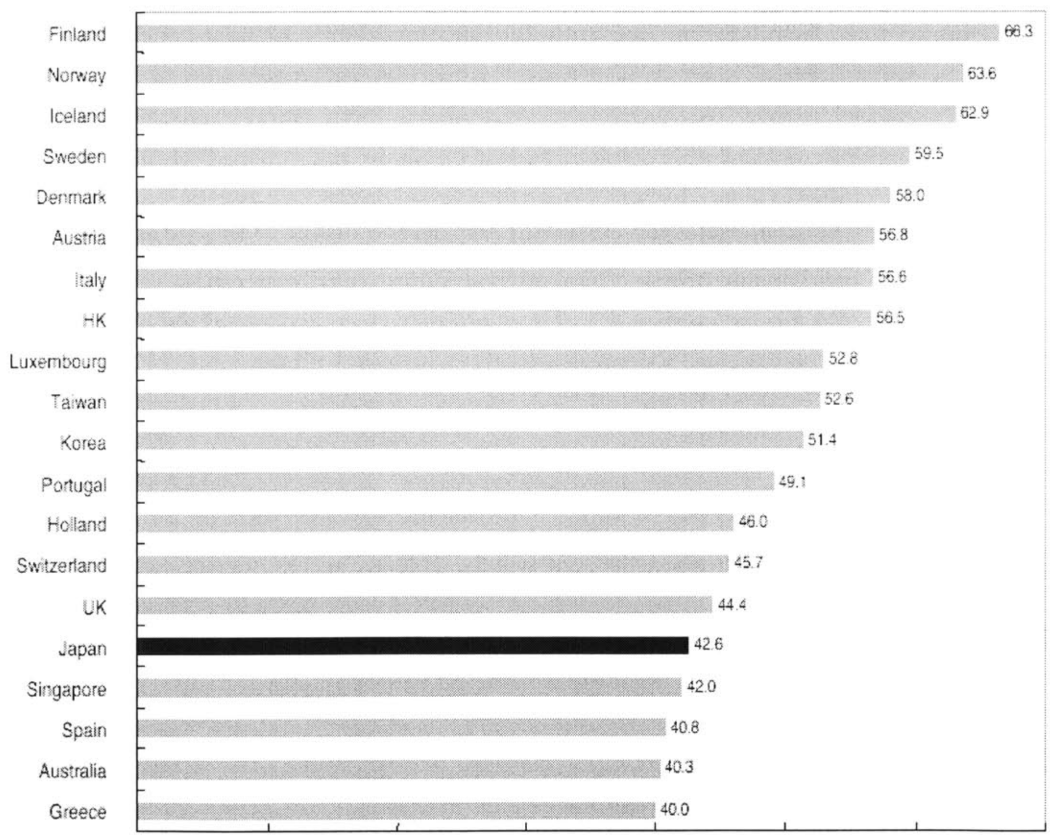

Figure 3-4 Cellular Service Penetration in Various Countries

(Source: Nikko Salomon Smith Barney)

While the transition from first generation to second generation systems focused on solving the problem of limited capacity, third generation systems primarily concerns the addition of new functionalities in the field of high-speed data transport, enabling video, audio data information and multimedia applications. It is anticipated to become the mobile extension of existing fixed telecommunication infrastructure, providing seamless connection in the new millennium.

3.3 GLOBAL 3G INITIATIVE

3.3.1 IMT-2000 (International Mobile Telecommunications 2000)

One of the most ambitious projects launched by the International Telecommunications Union (ITU) was to unify standards in line with the upcoming shift to next-generation digital cellular technology, which will provide wireless access to the global telecommunication infrastructure at anytime and anywhere. The generic name of this framework of standard is called International Mobile Telecommunications 2000, with an abbreviation of IMT-2000. The word 2000 here represents ITU's important achievement in the last decade of the 20th century and also the 2,000 MHz frequency band being proposed to use for future third generation mobile systems. This proposal was identified by the World Administrative Radio Conference (WARC) at its 1992 meeting. The IMT-2000 framework identifies some key factors for next-generation mobile communications as following:

- **High-speed,** access to support broadband services such as image, video, and other multimedia applications. Users will be able to access services as easy as in wireline equipment.

- **Flexibility,** enough to support all kinds of services such as universal personal numbering and satellite telephony, while providing seamless roaming to and from IMT-2000 compatible terrestrial wireless networks.

- **Affordability**, such that the services can reach a wide range of customers. Affordability is vital for quick penetration of services, the initial cost must be at least as affordable as today's mobile communication services.

- **Compatibility** to the existing standards and provide an evolutionary path for migrating from current systems to the new networks. (Prasad, Mohr et al., 2000; Mullar, 2000)

IMT-2000 will access to the global telecommunication infrastructure through both satellite and terrestrial systems, and serving fixed and mobile users in both publics and private networks. A generic concept of IMT-2000 is illustrated in Figure 3-5.

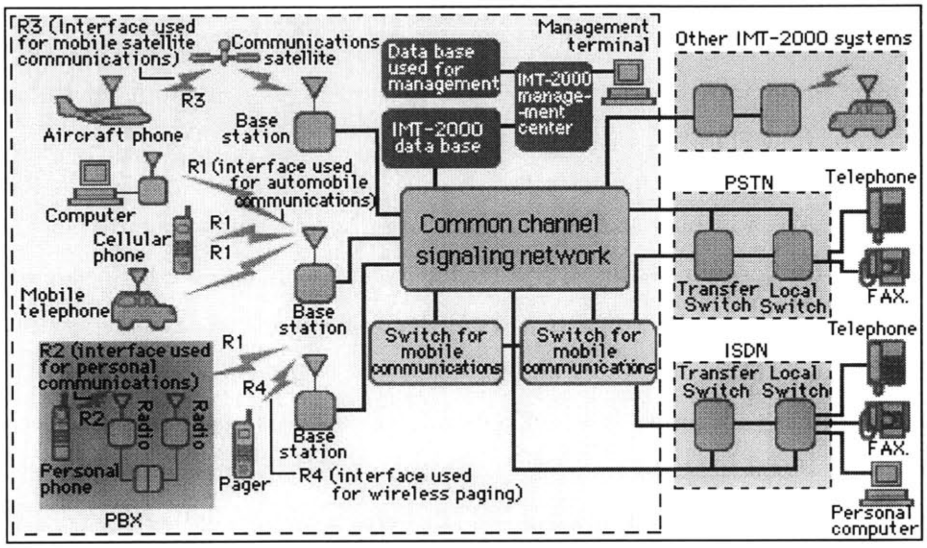

Figure 3-5 IMT-2000 Concept

(Adopted from NTT DoCoMo, 2001)

In short, the IMT-2000 model provides common standardized flexible platforms instead of a range of market-specific products for mobile telephony. Which could meet basic needs of major public, private, fixed, and mobile markets around the world. (Mullar, 2000)

3.3.2 Standard Developments

The frequency bands identified by WRC for IMT-2000 are 1,885-2025 MHz and 2,110-2,200 MHz, where the bands 1,980-2,010 MHz and 2,170-2,200 MHZ were intended for the satellite part of these future systems. And the role of ITU is to coordinate many related technology developments and to assist competing national and regional access technologies to converge. 15 proposals for the radio interface technology from different countries and regions were considered by ITU and the final evaluation reports from special independent evaluation groups cam back to ITU in

September 1998, and in March 1999, key characteristics for the IMT-2000 radio interfaces were selected.

ITU decided to provide essentially a single flexible standard with multiple access technology choices, which include TDMA, TDMA, combined TDMA/CDMA and *Space Division Multiple Access (SDMA).* SDMA, which currently has little usage, is expected to use adaptive antenna technology with systems to optimized performance in the space dimension for future systems. (Mullar, 2000) Description on how SDMA works is provided at Chapter 6.

IMT-2000 try to minimize the impacts on existing infrastructures by organizing most characteristics for both the terrestrial and satellite components into the RF part. Such that the base band part is largely defined in software and only hardware part of the mobile terminals have to make some modification. ITU anticipates that the usage of common components for the RF part of the terminals, together with primarily software defined flexible base band processing capabilities, could allow the same mobile terminal to be used for various radio interfaces in the new global network. So that terminal providers can take advantage of the economic scale and reduce the overall price. This flexible approach allows operators to select their choices among multiple access methods which best address their specific regulatory, financial, and customer needs, while minimizing the impact of this flexibility on end users. (Mullar, 2000) The goal of IMT-2000 is to provide a single standard that could serve the needs from a variety of worldwide wireless parties.

3.3.3 Third Generation Air Interfaces and Spectrum Allocations

WARC of the ITU, in their 1992 meeting, identified frequencies around 2 GHz to be used for future third generation terrestrial and satellite mobile systems. The frequency bands identified by WRC for IMT-2000 are 1,885-2025 MHz and 2,110-2,200 MHz, where the bands 1,980-2,010 MHz and 2,170-2,200 MHZ were intended for the satellite part of these future systems. However, these frequency bands are currently not available worldwide. Figure 3-6 shows the spectrum allocation of ITU and current availability of spectrum in Europe, China, Japan/Korea and the North America. In Europe, DECT (Digital European Cordless Telephony) operates at 1,880-1,900 MHz, and in Japan, PHS (Personal Handyphone System) operates at 1,895-1918.1 MHz. Further, in some countries, the existing terrestrial fixed services such as microwave communication systems for utilities are currently using the bands that are allocated for IMT-2000.

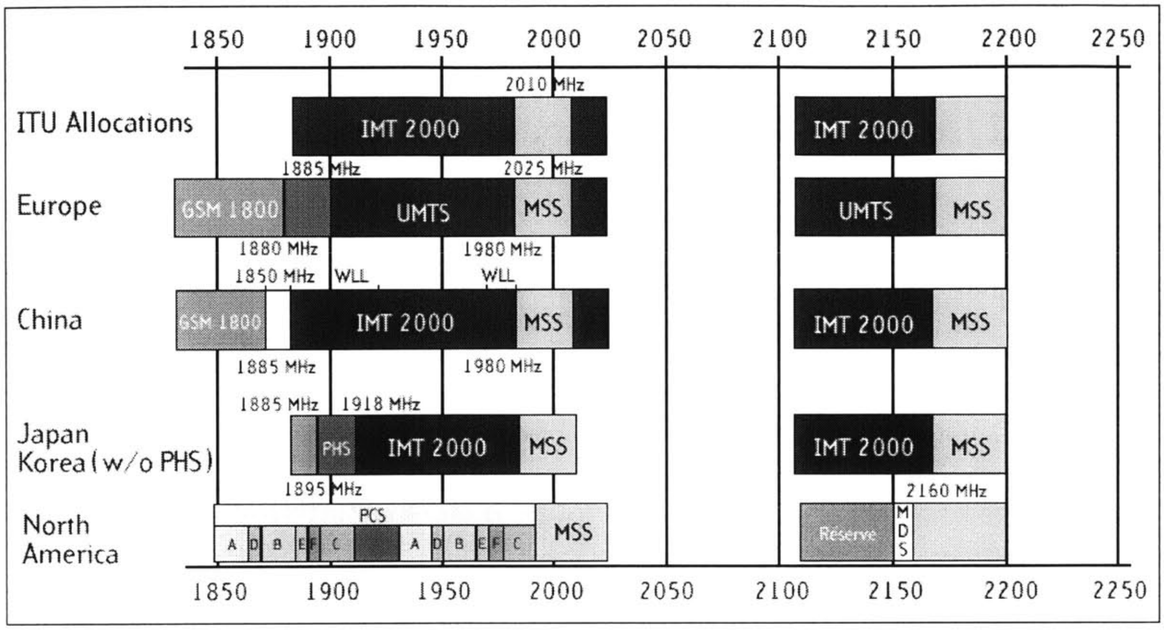

Figure 3-6 Spectrum Allocation in ITU, Europe, China, Japan, Korea, and America

(Source: UMTS Forum)

The worst case is in North America and countries that follow the US PCS spectrum allocation, where 1,850-1,890 MHz 1,930-19,70 MHz frequency bands are used for PCS uplink and downlink operations, and most spectrum has already been auctioned for operators using second generation systems. As there is no new spectrum available in the America for IMT-2000 systems, third generation services there much be implemented within the existing bands by replacing part of the spectrum with third generation systems. A term *refarming* is used for this approach. This involves replacing existing second generation frequencies with third generation alternatives for the US PCS band such as EDGE, Multicarrier CDMA (cdma 2000) and WCDMA. Following is a summary of spectrum availability in different regions (UMTS Forum, 1999):

Europe

In general, all UMTS/IMT-2000 spectrums are available except 15 MHz that is already used form DECT. Terrestrial UMTS are 1,900-1,980 MHz, 2,010-2,025 MHz, and 2,110-2,170 MHz, a total of 155 MHz. MSS allocations at 2GHz frequency band for UMTS/IMT-2000 satellite component are 1,980-2,010 MHz and 2,170-2,200 MHz, a total of 60 MHz. By the beginning of year 2002, 2 X 40 MHz should be made available to operators and by year 2005, all 155 MHz terrestrial UMTS/IMT-2000 spectrums should be available subject to market demand.

North America

In North America, PCS services and the auctioning occupied most of the frequency bands between 1,850-1,990 MHz. As seen in Figure 3-6, only 5 or 15 MHz frequency blocks can be used in the PCS bands. As a result, the 5 MHz minimum bandwidth per operator is important for this standard. In Canada, C and E blocks are reserved for future allocations, therefore, 2 X 15 MHz and 2 X 5 MHz, a total of 40 MHz frequency blocks are available for 3G services.

Asia/Pacific

Most Asia Pacific countries are expected to make ITU spectrum available for IMT-2000.

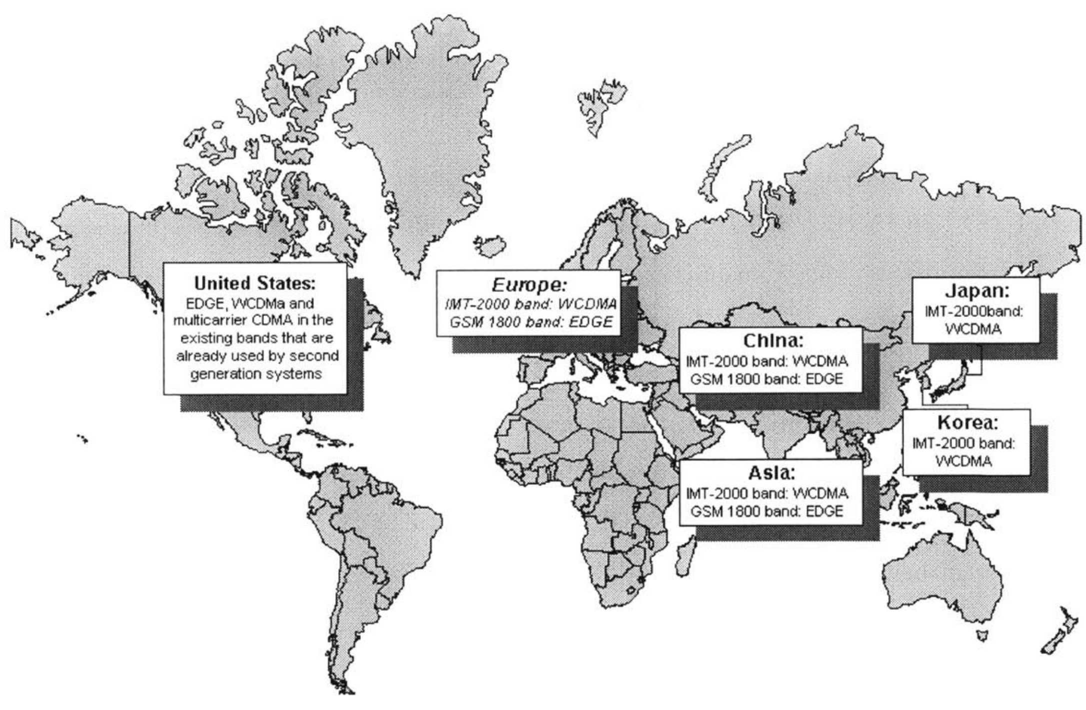

Figure 3-7 Expected 3G Air Interfaces and Spectrum in Different Regions

(Source: Holma and Toskala, 2000)

In Japan, the Ministry of Post and Telecommunications (MPT) planned to allocate the spectrum the same way as European except that the frequency band 1,895-1918.1 MHz has been used for PHS services. Therefore, Japan has 2 X 60 MHz + 15 MHz, a total of 135 MHz band available for IMT-2000 usage.

In Korea, a total of 170 MHz spectrums for terrestrial and 60 MHz for satellite services will be available.

In China, some of the IMT-2000 bands have been reserved for codeless and wireless local loop (WLL) applications. Detailed studies are still on going, however, up to 2 X 60 MHz of IMT-2000 spectrum will be available for 3G services.

As mentioned above, IMT-2000 framework provides flexible choices between different air interfaces based mainly on CDMA, TDMA, or a combination of both. Currently, WCDMA technology has emerged as the most widely adopted air interface for third generation systems, and will likely to be used in Europe and Asia, including Japan and Korea. In addition to WCDMA, other air interfaces that can be used for third generation systems are EDGE, which is described above, Multicarrier CDMA (cdma200), which will be described later. EDGE can provided services with bit rates up to 500kbps within a GSM carrier spacing of 200 kHz and includes advanced features to improve spectrum efficiency. Multicarrier CDMA could be a migration plan for existing IS-95 (cdmaOne) operators. Figure 3-7 summaries the expected air interfaces and spectrums to be used in different regions for third generation services.

3.3.4 UMTS (Universal Mobile Telecommunications Systems)

Universal Mobile Telecommunications System (UMTS) is one of the major new 3G mobile communications systems being developed within the IMT-2000 framework, which has been standardized by ETSI. UMTS supports the creation of a flexible service rather than standardizing the implementations of services in detail. This separates the roles of service provider, network operator, subscriber, and user, and makes it possible to develop innovative new services without requiring additional network investment from service providers. Sometimes, UMTS is referred as third generation network system.

UMTS Objectives

The objective of UMTS is to mark a wild variety of mobile services possible, such as video telephone and interactive multimedia applications. The target data transmission rate 2 Mbps will enable the vision of voice and data convergence.

To be a successful system, UMTS has to support a variety of applications that possess different quality of service (QoS) requirements. Applications and services can be divided into different groups depending on how are they considered, hence, the QoS requirements are different between application groups. One unique feature is that UMTS allows a user/application to negotiate bearer characteristics that are most appropriate for carrying information. For example, an application may request an UMTS bearer according to its need, and the network checks the available resources and the user's subscription and then responds. The price of the service is changed according to the property of a bearer. Four traffic classes have been identified in UMTS:

- **Conversational Classes** such as speech service over circuit-switched bearers. Voice over IP or video telephony also require this type, where real-time conversation allows less than 4000 ms end-to-end delay; otherwise the quality will be unacceptable. In conversational classes, the traffic is symmetric or nearly symmetric.

- **Streaming Classes** such as streaming video/audio. Streaming technique are used to transfer a steady and continuous stream of data. It has become increasingly important because most users do not have enough multimedia downloading data rate. Streaming applications are very asymmetric and thus can allow more delay than conversational services.

- **Interactive Classes** such as web browsing, database retrieval and game playing. Interactive traffic is characterized by the request response pattern of end-user, thus round-trip delay time if the key consideration. Another characteristic is that the content data packets should be transferred with low bit error rate.

- **Background Classes** such as email delivery, SMS, downloading and reception of measurement recodes. Those data traffic can be delivered in background since those applications normally do need immediate response. In background traffic, the destination is not expecting the data within a certain time and thus more or less insensitive to delivery time. (Sakinen, 2000)

Technological Approaches

Since the beginning of UMTS development, whether for TD-CDMA (time division) or W-CDMA (Wideband), there has been disagreement within the UMTS Forum. In January 1998, ETSI decided to combine two technologies –W-CDMA for paired spectrum bands and TD-CDMA for unpaired bands into one common standard for UMTS radio access technique. TD-CDMA uses CDMA signal–spreading techniques to enhance the capacity offered by conventional TDMA technology. Each time slot of the TDMA channel could be coded using CDMA and support multiple users per time slot. TD-CDMA provides an economical and smooth transition from GSM network to the 3G services such that current GSM operators can protect their current and future investment. W-CDMA (See next section), on the other hand, had emerged as the most widely adopted third generation air interfaces. Thus, this approach ensures an optimum solution for all the different operating environments and services.

UMTS use UTRA (UMTS Terrestrial Radio Access) as the basis for a global terrestrial radio access network, the transmission rate capacity are summarized in Table 3-4, where full mobility application apply to all environments, limited mobility applications apply to macro and micro cellular environment, and the low mobility applications apply particularly in the micro and pico cellular environments.

Environment	Data Transmission Rate
Full Mobility Applications	144 kbps
Limited Mobility Applications	384 kbps
Low Mobility Applications	2M kbps

Table 3-4 UTRA transmission Rate for Different Mobility Environment

From physical point of view, UMTS will comprise new air interface technologies and new radio components. Those components should be able to put together in a modular way such that pe-UMTS fixed or mobile networks can have a smooth evolutionary process. For the users, UMTS will provide adaptive multimode/multiband terminals or terminals with a flexible air interface to enable global roaming across location and generations.

3.4 W-CDMA

W-CDMA appears to be the strongest candidate for IMT-2000 air interface. It uses bandwidth of 5 MHz, which is much wider than the 1.25 MHz bandwidth of cdmaOne, to enhance data transmission capacity to the required level of third generation standard. Its specification has been created in 3GPP (the 3rd Generation Partnership Project), which is the joint standardization project of standardization bodies from Europe, Japan, Korea, USA and China. European research work on W-CDMA was initiated in the European Union research projects CODIT and FRAMES in 1990s. In Japan, the Association of Radio Industries and Businesses (ARIB) and the Telecommunication Technology Committee (TTC) are conducting coordination and liaison work in Japan.

Figure 3-8 NTT DoCoMo's 3G Concept Phone

By using much wider bandwidth then cdmaOne, NTT DoCoMo is the first company in the world that can achieve the data transmission capacity required by the IMT-2000 standard. In 1997, ARIB focused on the standardization of W-CDMA, and because it was before the completion of ETSI's selection process, ETSI decided to use W-CDMA as their third generation air interface in January 1998. NTT DoCoMo scheduled to introduce the world's first commercial W-CDMA services called FOMA in Oct 2001. FOMA (Freedom Of Mobile multimedia Access), by its name, describes the vision of this revolutionary service. Figure 3-8 shows a W-CDMA concept phone from NTT DoCoMo. In Europe and other countries in Asia, W-CDMA based third generation services are also expected to launch in the beginning of 2002. With the full support of the European market and an initial launch in Japan, W-CDMA is believed to be the most important air interface for third generation networks. Figure 3-9 summarizes the standardization schedule and expected time line for the commercial launch of W-CDMA.

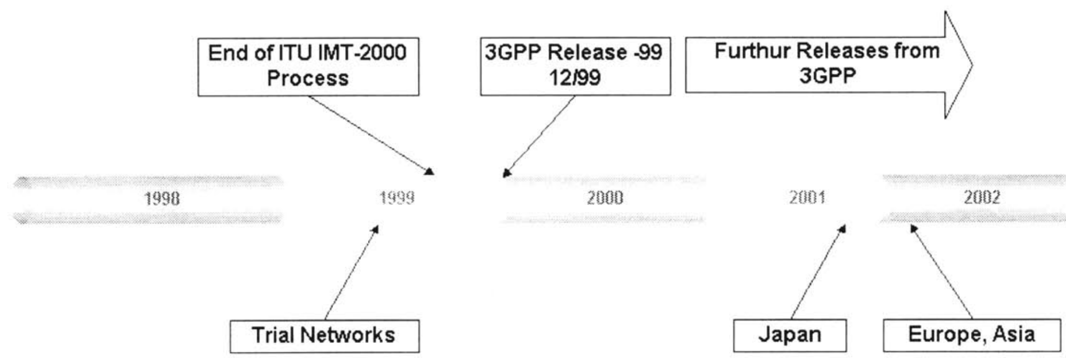

Figure 3-9 Commercial Operation and Standardization schedule for W-CDMA

(Source: Halma and Toskala, 2000)

3.4.1 Main Characteristics of W-CDMA

W-CDMA has the following characteristics (Halma and Toskala, 2000):

- **DS-CDMA as Multiple Access Method:** W-CDMA uses Direct-Sequence Code Division Multiple Access (DS-CDMA) such that user information bits are multiplied with quasi-random bits (called chips) derived from CDMA spreading codes and are distributed over a wide bandwidth.

- **FDD and TDD:** Two basic operation modes are supported by W-CDMA: Frequency Division Duplex (FDD) and Time Division Duplex (TDD). The FDD mode uses two 5 MHz paired carrier frequencies for uplink and downlink traffic. TDD is used for unpaired spectrum allocation for the IMT-2000 systems. Uplink and downlink traffic use different time slots.

- **Asynchronous Base Station Operation:** In W-CDMA, base stations are operating asynchronously so that GPS reference of global time is not required. It is simpler than the synchronous IS-95 system and thus is easier to implement in indoor or micro base stations.

- **Multiple Services with Different Quality of Service Requirements Multiplexed on One Connection:** W-CDMA used the concept of Bandwidth on Demand (BoD) to support highly variable user data rates. Frames of 10 ms duration are allocated to each user, and the data rate in each frame is the same. The date capacity among the users can change from frame to frame and the network will control this fast radio capacity allocation in order to have an optimum usage of available bandwidth. (See Figure 3-10)

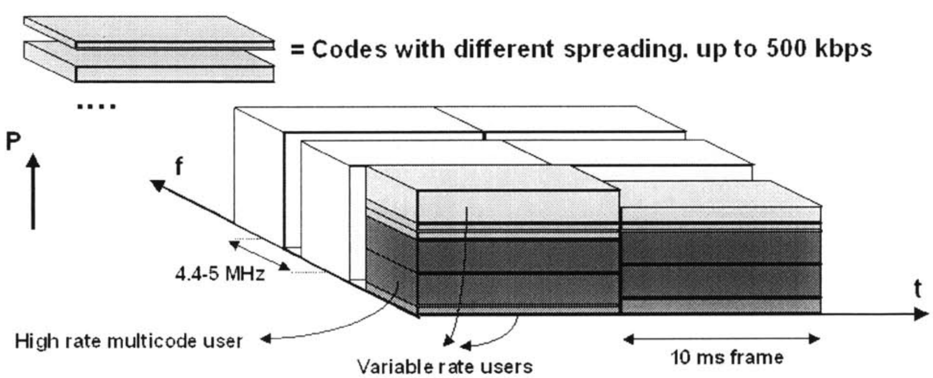

Figure 3-10 W-CDMA Bandwidth Allocation in Time-Frequency-Code Space

- **3.84 Mcps Chip Rate:** W-CDMA uses chip rate of 3.84 Mcps to lead carrier bandwidth of approximately 5 MHz. DS-CDMA system such ass IS-95 that uses about 1 MHz bandwidth are commonly referred to as narrowband CDMA systems. A wider bandwidth can support higher bits rate, and the actual carrier spacing are selected on a 200 kHz grid between approximately 4.4 to 5 MHz, depending on interference factors.

- **Multiuser Detections, Smart Antennas:** In W-CDMA air interface, network operators can deploy advanced CDMA receiver concepts such as multiuser detection and smart adaptive antennas. Operators have options to increase capacity and coverage area.

- **Variable Spreading Factor and Multicode:** Inter-frequency handovers are considered important in W-CDMA. Based on this feature, a base station can be used for several carriers. This is not specified in IS-95.

- **Deployed in Conjunction with GSM:** W-CDMA is designed to be deployed in conjunction with GSM. Therefore, handovers between GSM and W-CDMA could be supported.

3.4.2 Difference between W-CDMA and IS-95, GSM Air Interfaces

W-CDMA is often compared with second generation GSM and IS-95 (the standard for cdmaOne) systems. Other systems are PDC in Japan and US-TDMA (D-AMPS) in US. Table 3-5 and Table 3-6 summarized the differences between W-CDMA, GSM and IS-95.

	W-CDMA	**GSM**
Carrier Spacing	5 MHz	200 kHz
Frequency Reuse Factor	1	1-18
Power Control Frequency	1500 Hz	2 Hz or lower
Quality Control	Radio resource management algorithms	Network planning
Packet Data	Load-based packet scheduling	Time slot based scheduling with GPRS
Frequency Diversity	5 MHz bandwidth gives multipath diversity with Rake receiver	Frequency hopping
Downlink Transmit Diversity	Supported for improving downlink capacity	Not supported by the standard, but can be applied

Table 3-5 Differences between W-CDMA and GSM Air Interfaces

(Source: Halma and Toskala, 2000)

	W-CDMA	IS-95
Carrier Spacing	5 MHz	1.25 MHz
Chip Rate	3.84 Mcps	1.2288 Mcps
Power Control Frequency	1500 Hz, uplink and downlink	Uplink: 800 Hz, downlink: slow power control
Base Station Synchronization	Not needed	Yes, typically obtained via GPS
Inter-frequency Handovers	Yes, measurements with slotted mode	Possible, but measurement method not specified
Efficient Radio Resource Management Algorithms	Yes, provides required quality of service	Not needed for speech only networks
Packet Data	Load-base packet scheduling	Packet data transmitted as short circuit switched calls
Downlink Transmit Diversity	Supported for improving downlink capacity	Not supported by the standard

Table 3-6 Differences between W-CDMA and IS-95 Air Interfaces

(Source: Halma and Toskala, 2000)

3.4.3 US Proposals

In North America, there are three competing wideband CDMA standards: wideband cdmaOne, WIM W-CDMA (Wireless Multimedia and Messaging Services.), and WCDMA/NA (W-CDMA North America). They all evolve from second-generation digital wireless technologies. WIMS W-CDMA and WCDMA/NA later merged into a single proposal. This and wideband cdmaOne have been submitted to the ITU's IMT-2000 " family of systems". A US TDMA solution also submitted to ITU by the Universal Wireless Communication consortium (UWCC).

cdma2000 (Wideband cdmaOne)

Wideband cdmaOne technology was submitted to the ITU by the CDMA Development Group (CDG) and is called cdma2000. cdma2000 uses CDMA air-interface to provide wireline-quality voice service and high-speed data services, ranging from 144 Kbps for mobile users to 2 Mbps for stationary users. It supports both packet and circuit –switched communications. Other than the US, Korea carriers also contributed to the developement of cdma2000. Korea's CDMA1 ITU proposal from the Telecommunication Technology Association (TTA) has a high degree of commonalty with cdma2000.

The cdma2000 proposal is based partly on IS-95 principles with synchronous network operation, but with a bandwidth of 3.75 MHz, three times of the IS-95 1.25 MHz bandwidth.

Enhanced W-CDMA/NA

Enhanced W-CDMA/NA is the result of a merger of WIMS, W-CDMA, and W-CDMA/NA. AT&T Wireless, Hughes Networks, and InterDigital Communications Corporation, among others, proposed WIMS. The WCDMA/NA technology was proposed by the North American GSM Alliance, a group of 12 US and one Canadian digital wireless PCS carriers. (Mullar, 2000)

This third generation GSM will be an evolution and extension of current GSM network systems. Because of the common hip rate, frame length, asynchronous base station operation, and vocoders, the GSM Alliance strongly support the merging of the above two technologies as a migration solution toward third generation services.

UWC-136 (TDMA Proposal)

UWC-136 is a pure TDMA digital solution that provides an evolutionary path from IS-136 to the new generation services. This proposal was developed by the Global TDMA Forum of the UWCC and is a market-driven solution from TDMA IS-136 used in the US. With UWC-136, carriers can retain their infrastructure investments for IS-136 systems, also, it increases capacity to 10 times of AMPS capacity which maintaining high voice quality. It also includes in-building coverage and tightly integrated voice and data services.

3.5 SUMMARY

The original vision of Third Generation Communication was studied before the implementation of second generation. The goal was to be a global standard, which integrate voice and high data rate services and facilitating international roaming. Now, second generation has been deployed for almost a decade, and the concept of 3G has had to be modified.

3.5.1 3G Means Different Things in Different Parts of the World

The success of 2G cellular services expanded the wireless market beyond all expectations. Figure 3-11 shows the expected growth in subscribers of three major 2G technologies: GSM, TDMA, and CDMA.

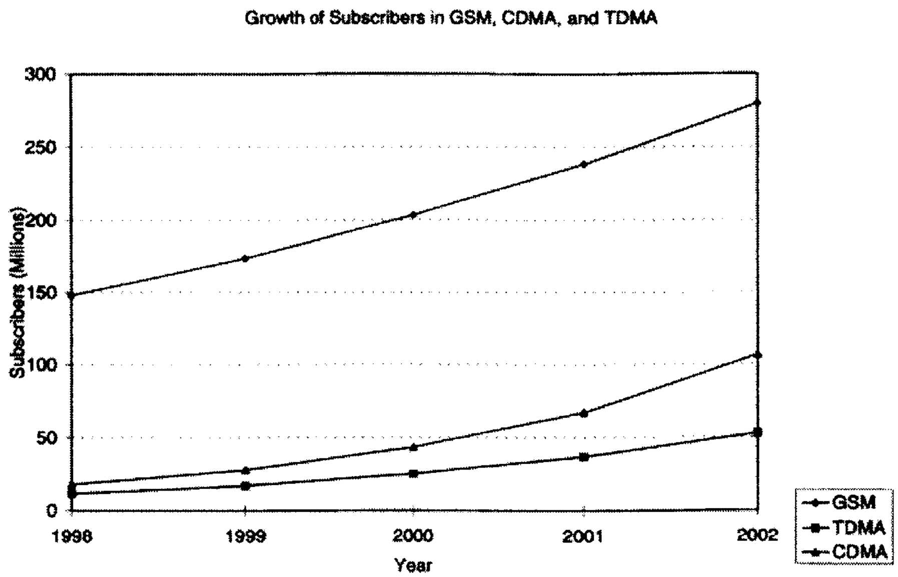

Figure 3-11   Growth Subscription in GSM, CDMA, and TDMA

(Source: Harte,, Hoenig, et al..,1999)

GSM is a successful standard that fundamentally altered the market characteristics; it reached a 65% of penetration of the cellular market until the end of 2000 and is estimated to continue growing in the near future. GSM is a near-global system, which provides widespread international roaming between all continents and delivers both voice and data services to mobile terminals. GSM is used in almost all of the European market and a large portion in the Asia market. In the large North American market, GSM was challenged by two major alternative 2G technologies: US-TDMA (IS-

136) and cdmaOne(IS-95). In Japan, PDC is its own standard. Figure 3-12 is the market penetration of above four 2G technologies at the end of year 2000.

Since huge investments have been made in building 2G infrastructures worldwide, operators, manufactures and regulators are seeking solutions for smoothing the transitions from 2G to 3G. This transition involves not only higher data rate and new technologies, but also complicated regional policies and regulations.

As a result, the solution was the introduction of IMT-2000 family of systems concept for 3G. In other words, the vision of building a single global standard is still not possible in the near future. However, the convergence of technologies, market requirements, regional standards, voice and data is happening. In market perspectives, that means 3G will refer to different things in different parts of the world. (UMTS Forum, 2000)

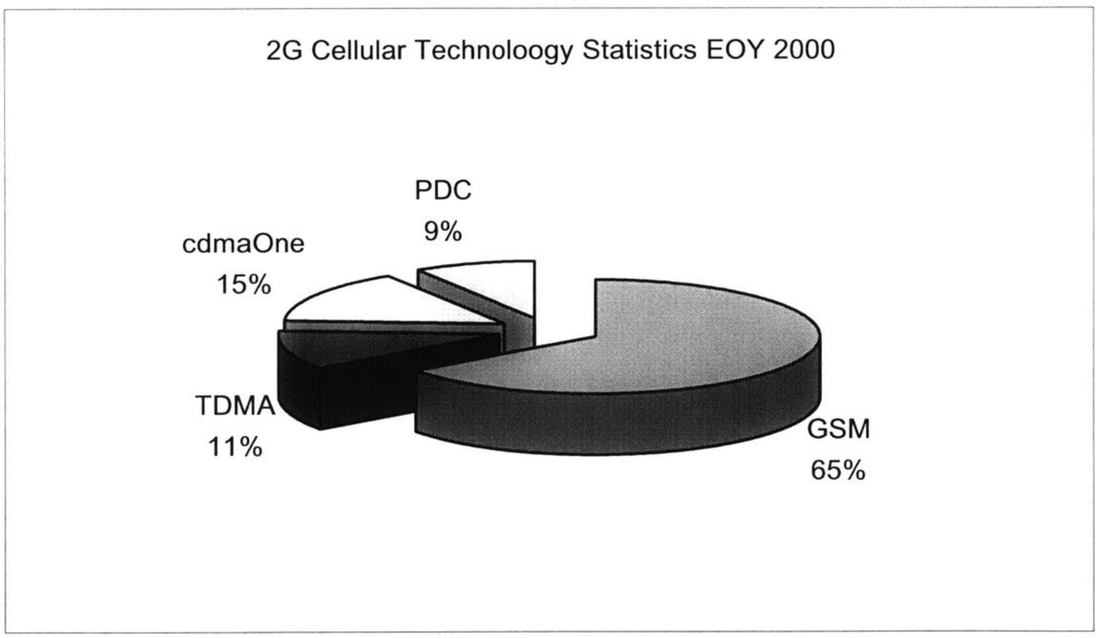

Figure 3-12 2G Cellular Technology Statistics -EOY 2000

(Source: EMC, August 2000)

3.5.2 Japan: Transition from PDC to W-CDMA

In Japan, NTT DoCoMo will be the first provider of commercial 3G services, which DoCoMo named FOMA. Because the current dominant standard PDC is only used within Japan, migration plan is not economically practical considering the limited market potential and the anticipated cost. Therefore, Japan is going to jump directly from the 2G PCD to the 3G W-CDMA standard. For Japan, 3G means an opportunity to step into the world market.

3.5.3 Europe and Asia: Transition from GSM to UMTS

In Europe, 3G refers to the UMTS technology members of the IMT-2000 family, which is derived from GSM and deployed on a new spectrum. The potential economics scale and the fact of existing common standard deployed across many countries have led a strong focus within the UMTS community on international roaming capabilities. A number of phases of this transition are ongoing and might be taken as post 2G strategies for different GSM carriers. Table 3-5 summarized the different phases of transition between GSM to 3G. The steps are GSM -> HSCSD -> GPRS -> EDGE ->W-CDMA.

System	Theoretical Data Speed	Channel Width	Network
GSM	9.6 kbps	200 kHz	Circuit Switching
HSCSD	57.6 kbps	200 kHz	Circuit Switching
GPRS	115 kbps	200 kHz	Circuit/Packet Switching
EDGE	384 kbps	200 kHz	Circuit/Packet Switching
W-CDMA	2 Mbps	5 MHz	Packet Switching

Table 3-7 Transition from GSM to 3G

(Source: Nikko Salomon Smith Barney, 2000)

GSM has channel width 200 KHz, which is eight times comparing to PDC's 25 KHz, and is scalable to a maximum data transmission speed of 384 Kbps. For carriers who want to secure their existing investment or lack of financial resources, GPRS, so called 2.5 G technology will be used before the truly launch of 3G services. For carriers who failed to win 3G bandwidth allocation will probably opt to EDGE. HSCSD, however, uses a witching format that takes up four GSM time slots (thereby reducing capacity) and has only one infrastructure vender Nokia, might not be implemented by most of the carriers. (Nikko Solomon Smith Barney) UMTS technology members are also used in South Korea, China and most of the Asian Regions.

3.5.4 U.S.: Transition from TDMA and cdmaOne to 2.5 G and 3G

In US, diversified 2G technologies are used, including PCS-1900 using GSM, D-AMPS (IS-136) using TDMA, and cdmaOne (IS-95) using CDMA. According to this fact, immediate convergence is not possible to occur in the near future. In addition, PCS system regulated in US occupied most of the 3G spectrum allocation specified by IMT-2000, which makes it harder to find bandwidth for new services in US. As a result, 3G in US refers to derivatives of existing 2G technologies, mainly deployed on occupied spectrum. The focuses will be providing high data rates instead of international roaming. (UMTS Forum)

TDMA to 2.5G

AT&T Wireless and SBS-Bell South let the TDMA GROUP in North America. The plan for migrating to higher data rates is: TDMA-> CDPD-> IS-136 -> EDGE. Table 3-8 summarizes the transition path. As PDC, TDMA has smaller channel width, 30 KHz, compare to GSM. IS-136 is US's migration standard from 1G to 2G, which provided subscribers of analog AMPS a smooth way to step into 2G digital cellular technologies. Later version of IS-136 is similar to GPRS, and another high-speed modification of IS-136+ provides EDGE. This pattern will end at 2.5 G and have no ultimate plan to move to IMT-2000 technology.

System	Theoretical Data Speed	Channel Width	Network
TDMA	9.6 kbps	30 kHz	Circuit Switching
CDPD	19.2 kbps	30 kHz	Packet Switching
IS-136	64 kbps	200 kHz	Circuit/Packet Switching
EDGE	384 kbps	200 kHz	Circuit/Packet Switching

Table 3-8 Transition from TDMA to 2.5 G

(Source: Nikko Salomon Smith Barney, 2000)

cdmaOne to 3G

cdmaOne camp includes Version, which is formed by Vodafon Air Touch, Bell Atlantic, and GTE, and Sprint. Table 3-9 is the roadmap suggested by Qualcomm that migrates cdmaOne to 3G cdma2000. cdma2000 offers channel widths in multiples of 1.25 MHz and is designed for use in scaleable network processing.

System	Theoretical Data Speed	Channel Width	Network
cdmaOne Release A	14.4 kbps	1.25 MHz	Circuit Switching
cdmaOne Release B	64 kbps	1.25 MHz	Packet Switching
cdma2000 (MC-1X)	144 kbps	1.25 MHz	Packet Switching
cdma2000 (MC-3X)	2M kbps	3.75 MHz	Circuit/Packet Switching

Table 3-9 Transition from cdmaOne to 3G

(Source: Nikko Salomon Smith Barney, 2000)

In short, the US has lagged behind other regions in the deployment of 2G digital cellular, and it is anticipated that US will continue to lag behind in the implementation of 3G technology.

3.5.5 Market Expectations

Culture differences influence the approach to standardization of above technologies. The US celebrates diversity and hence lets the large domestic market determine which standards will succeed for future 3G services. In contrast, the rest of the world is sees standards as a way to create markets. GSM is a successful example of this approach.

Figure 3-13 summarized the chronological evolution of cellular telephony technologies and their referred generations. The world is waiting for the first launch of 3G W-CDMA service in Japan; the original planned launch time on May, 2001 has just been delayed to Oct, 2001 by NTT DoCoMo due to worries of technological glitches. The delay disappointed many of the expecting eyes, however, this cannot cease the eager market expectations.

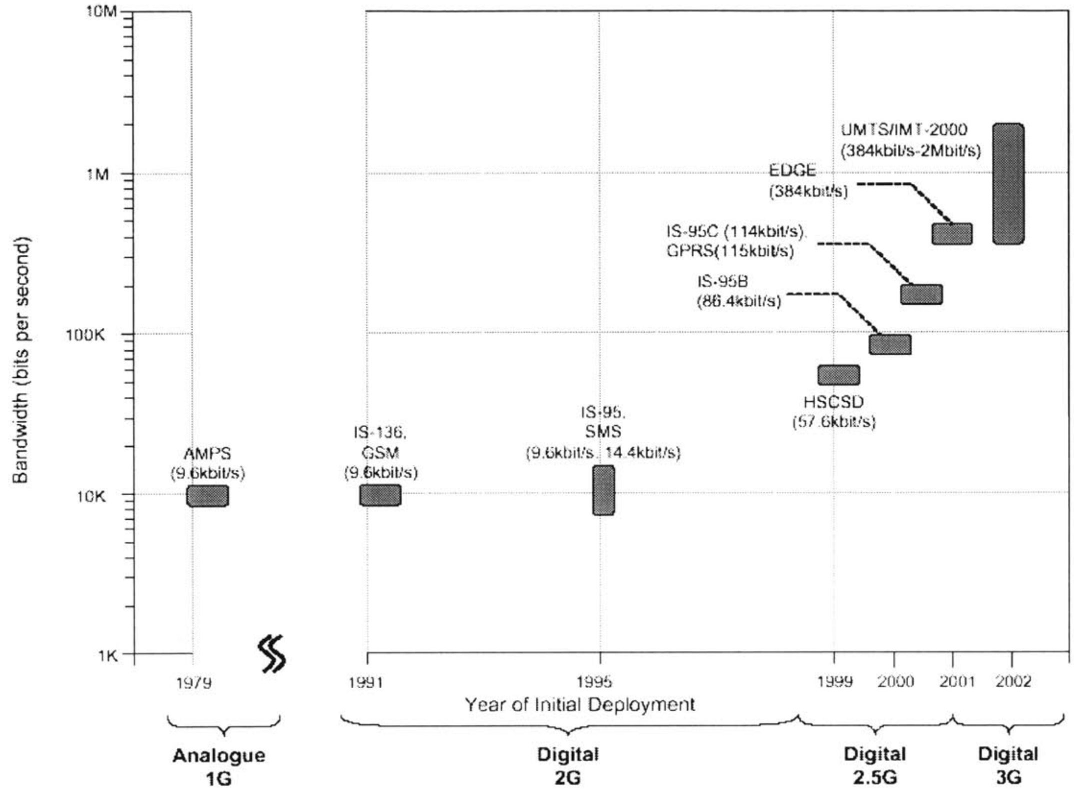

Figure 3-13 Cellular Telephony Technologies Chronology

(Source: PricewaterhouseCoopers, 2000)

Market needs will determine which combinations the majority of the operators will use. Because of the different technologies and frequency allocations, global roaming will still need specific arrangements between operators. In this case, multi-mode or multi-band handsets are still needed when go across different core networks. Assuming that 3G technologies deployment will follow the migration paths from 2G, UMTS will most likely take advantage of the economic scale worldwide. However, the transition still needs some time to be realized. While Japan's world leading 3G launch of W-CDMA service FOMA is now scheduled on Oct 2001, Europe and other Asia countries are expected to start their 3G services sometimes in 2002. In the US, 3G services might not appear for another two years. Before that, migration plans described above will take place in different regions according to various considerations and operator arrangements. For the end uses, terminal manufacturers and network operators are working to make the transition behind the scene to establish the picture of real high speed "global voice-data communication services".

PART II:

EMERGING FOURTH GENERATION TECHNOLOGIES

CHAPTER 4

MOBILE IP

IP (Internet Protocol) is the protocol suite upon which a large portion of the Internet is built. The existing IP routing protocols were designed for stationary network systems, where routers identify the designations of transmitted packets and route them according to their specific IP addresses. This manner requires the destination device maintains physical attachment to its specific network; otherwise, a change of IP address is needed. Mobile IP, on the other hand, permits a mobile host to use a permanent IP address regardless of the point of attachment to the network. Thus, a mobile host can maintain continuous connection while moving. The advances of IP technology such as IP telephony and Voice over IP make IP a logical network protocol choice for future wireless data networks. Moving telephone numbers into IP addresses enables seamless connectivity between wireless and current IP-based wired networks. Also, it is clear that Mobile IP protocol will play an important role in future IP-based access networks to support macro-mobility of mobile hosts. Efforts towards all IP based 3rd Generation networks has been intensified after both the 3rd Generation Partnership Project (3GPP) and 3GPP2 accepted this topic as a work item. IP convergence is generally believed to be the next revolution in telecommunications. The 3rd generation network will migrate towards all IP-based network, which will also be one of the key features of the 4th generation wireless network.

This chapter will start with a brief introduction to Internet Protocol (IP), then the concept of Mobile IP will be explained, including basic Mobile IP, Mobile IPv4 with rout optimization and the newest Mobile IPv6. Also, discussions of the IP core network evolution will be presented.

4.1 IP (INTERNET PROTOCOL)

Internet Protocol (IP) allows data to flow across computer networks such as Intranet or the Intranet. Packets that carrying information such as traditional data, voice, video, image and other multimedia contents are routed from the source network to the destination network according to the IP address information in the packets and the network information in the routers. An IP address is structured as Figure 4-1, where the networkID is the network on which the computer resides and hostID is a specific computer. The design of this structure assumes that the network consist of computer physically connected by wire, or bigger networks connected by repeaters or bridges. (Perkins, 1998) A single network with computers connected by cables, repeaters and bridges is considered as being located in a nearby physical space as far as routers are concerned. Based on the IP, these computers will have the same networkID in their IP addresses, for example, computers connected in the same school or office. When two computers in the same network send information to each other, the data will be sent directly to the destination device without using these routing services.

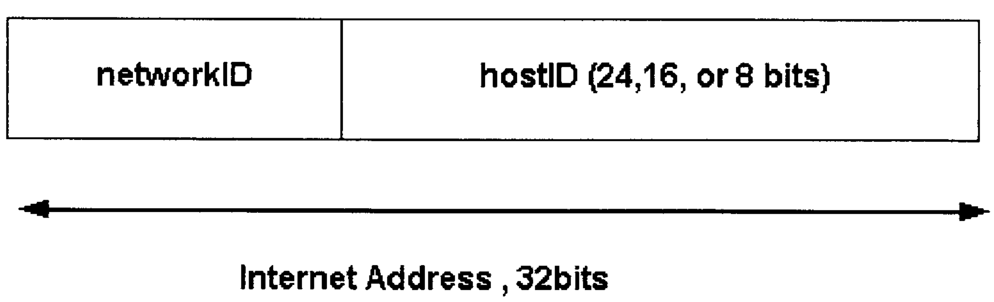

Figure 4-1 IP Address Structure

However, in the current world where laptop computers are prevailing, the requirement of a physical connection means whenever the laptop moves, even within the same network, a change of IP address is necessary. Dynamic Host Configuration Protocol (DHCP) eliminates some of these cumbersome operations by automatically providing necessary configuration information that a stationary system needs. But, DHCP still limits the computer devices to be physically inside the network. Once the computer moves outside of the network, outside an office building for example, reconfiguration is needed.

4.2 MOBILE IP

Mobile IP is a protocol that was standardized by the Internet Engineering Task Force (IEFT) to allow terminal devices to maintain continuous connection via the same IP address while changing their point of attachment to the network. Mobile IP works at the network layer that influences the routing of datagrams and can easily handle mobility among different media such as LAN, WLAN, dial-ups and wireless channels. Because the transport layer uses IP addresses as an identifier and correlate IP packets to transport sessions, an IP node that moves to a new subnet needs either change its IP address to reflect its current point of attachment or the router to have a mechanism for build host-specific route. Otherwise, the packet may be lost before reaching its destination. Mobile IP solves this problem by managing the correlation between a changing IP address (Care-of Address, COA) and the static home address. The upper layers, transport and application layers, use the static home address while sending information and leave the mobility problem to lower layers.

Mobile IP was originally defined in RFC2002 for IPv4 and is normally called basic mobile IP. However, IPv4 doesn't initially have mobility support, and the majority of IPv4 nodes do not support Mobile IP. Two modifications called Mobile IPv4 with rout optimization and a newer version called Mobile IPv6 have also been proposed to IETF. As IPv6 has mobility support as a required feature, it is expect that future IPv6 deployments will include at least minimal mobile IP support.

4.2.1 Mobile IP Entities

Mobile IP architecture consists of several entities:

Mobile Host (MH)

A mobile host is a host that can change its point of attachment from one network to another. It can maintain connection while moving to another network attachment using the same IP address, called *Home Address.*

Correspondent Host (CH)

A Correspondent Host (CH) is a host that communicates with a MH.

Home Agent(HA)

Home Agent is a router that is located in MH's home network. Home Agent maintains current location information for MH and *tunnels* the datagrams originally destined to the MH to the current location of MH when it is away from original home network.

Foreign Agent (FA)

Foreign Agent is located in MH's visited network and is a router that provides routing services to the MH while it is registered there. It can serve as the default router for outgoing datagram from MH. The Foreign Agent detunnels and delivers datagrams to the MH that were tunneled by the MH's home agent. (Perkins, 1998)

In this mechanism, a MH has a permanent IP address on a home network and is treated as a stationary host. When it moves out of its home network, HA will keep record of the associated Care of Address and forward the datagrams originally sent for MH's home address to its COA. Then FA will help the MH in foreign network sending and receiving datagrams.

4.2.2 Mobile IP Procedures

In general, Mobile IP protocol consists of the following functions: agent discovery via advertisement or solicitation, MH registration of COA with its HA, and packet tunneling to the COA. These main processes of Mobile IP are described as following:

Agent Discovery

Agent Discovery consists of two messages, *Agent Advertisements* and *Agent Solicitations.* Home Agent and Foreign Agents that are available will send agent advertisement messages to Mobile Hosts. Agent advertisements are periodically transmitted as multicasts of broadcasts to each link on which a node is configured to perform as a HA, FA or both. In this way, Mobile Host can know whether there is an agent around and the respective information of that agent. If there is no agent advertisement received by the Mobile Host, it can force any agent on the link to immediately transmit an Agent advertisement, this is called Agent Solicitation. This happens when the Mobile Host moves too fast from link to link to receive the periodically transmitted agent advertisements. The agent advertisements sent back by agent in respond to solicitations are uni-casted.

Registration

A Mobile Host *registers* whenever it detects that its point-of –attachment to the network has changed from one link to another. A Home Agent is then aware of the current location of the Mobile Host by its Care of Address. When receiving an agent advertisement, the Mobile Host will obtain its Care of Address at the Foreign Network; it could be the IP address of the Foreign Agent or a temporary address assigned to Mobile Host via other means such as DHCP. MH then requests routing services from a FA on a foreign link and informs its HA of its current COA. When the MH detects via the agent advertisement message that it has returned to its home network, it then de-registers with its HA and acts as if it is a stationary IP host. (Chang, 2000; Perkins, 1998)

Tunneling

Figure 4-2 illustrates the datagram flow to a MH locates in a foreign network:

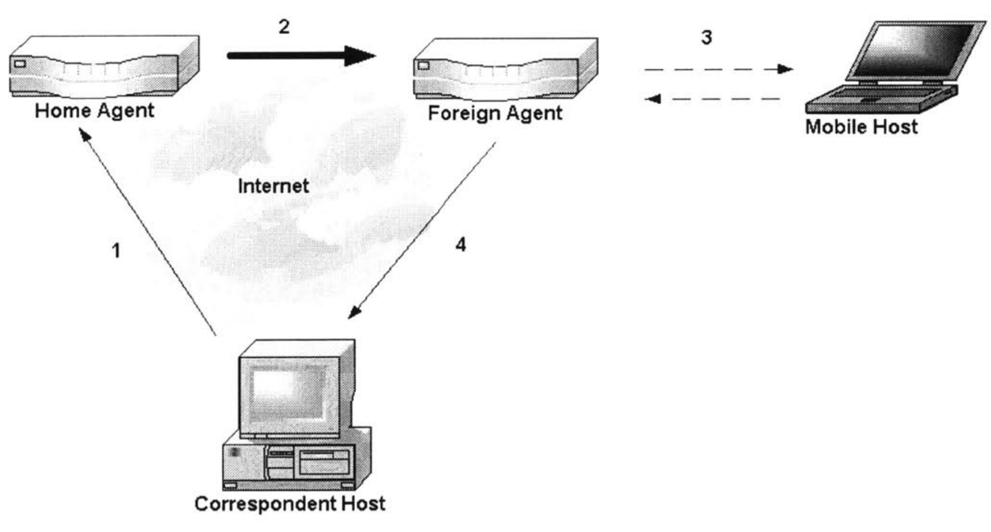

Figure 4-2 Mobile IP Datagram Flow

The routing procedures are as follows:

1. Datagrams destined to the Mobile Host's home address are routed to its home network as if to a stationary host. A Correspondent Host (CH) originates the datagram that includes MH's IP address in the IP packet header.

2. When the datagram arrives the home network, it will be intercepted by the home agent and tunneled to the Care of Address (COA).

3. When the datagram arrives the foreign network of the COA, it is detunneled and delivered to the MH.

4. Datagrams originated by the MH will be routed directly to the destination using standard IP routing. Normally, the FA will be the MH's default router.

4.3 MOBILE IPV4 WITH ROUTING OPTIMIZATION

In the basic Mobile IP routing procedure as shown in Figure 4-2, Correspondent Host sends IP datagrams to a MH's home address in the same way as with any other destination. This mechanism allows transparent interoperation between MH and their CH, but the datagrams to the MH are often routed along paths that are much longer than optimal. This does not only create additional load to the Home Network but also adds delay to the datagram delivery. For example, if a datagram was sent to the MH from the foreign network that the MH is visiting, it still needs to be routed to MH's HA and routed back according to the basic Mobile IP protocol.

In this regard, an extension of basic Mobile IP is proposed in the IETF for IPv4 with routing optimization. The mechanism is as follows: (Figure 4-3) the HA tunnels the datagram to MH that is out from its home network the same way as basic Mobile IP routing procedure shown in figure 4-2. In addition to that, HA sends an *Binding Update* message to the CH, which includes MH's current COA. After that, as shown in Figure 4-4, the CH caches the binding association between MH's home address and COA and then tunnel the datagrams directly to the COA indicated in that binding, bypassing the original longer rout going through MH's HA. With this extension, when a MH moves from one COA to a new COA, the CH can send the datagrams to MH using out-of-date COA, then the previous FA will be able to tunnel these datagrams to the MH's new FA and minimize datagram loss rate while MH is moving. This routing optimization extension can use the same type of authentication mechanism as basic Mobile IP protocol, which generally replies on a mobility security association established before message transmission.

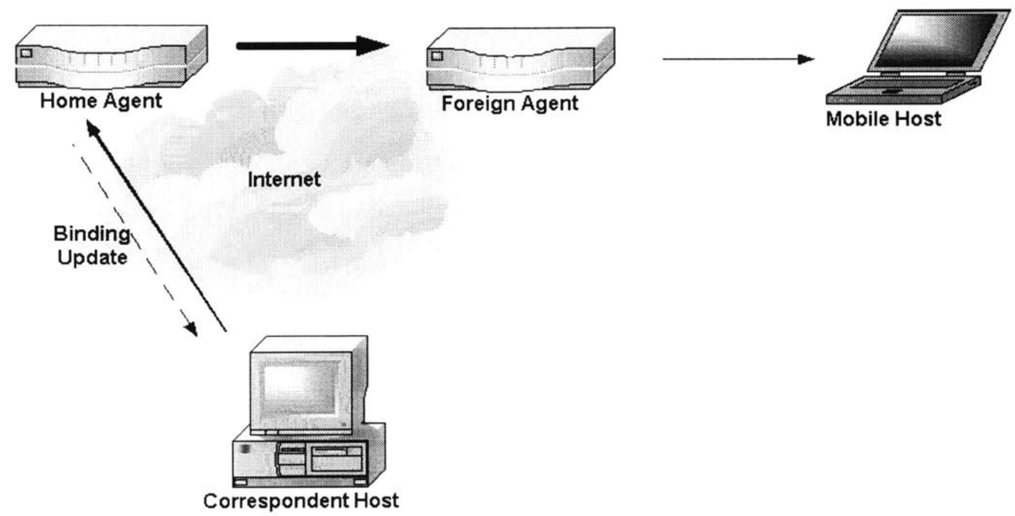

Figure 4-3 Mobile IPv4 with Route Optimization Before Binding Update

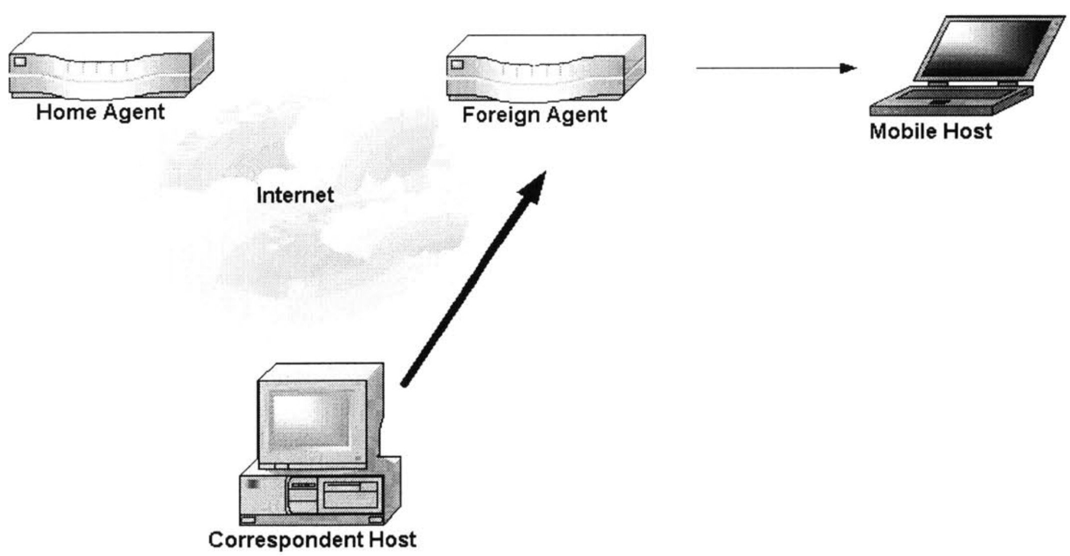

Figure 4-4 Mobile IPv4 with Route Optimization After Binding Update

4.4 MOBILE IPV6

4.4.1 IPv6

As we described above, the advanced network of high-speed data transfer are enabled by Internet Protocol (IP), the IP version 4, IPv4 which we are using now is going to be limited while facing the growing demand of IP address. In the envisioned IP network, not only personal computers require IP addresses, but also mobile phones, cars, vending machines home electronics. Devices will exchange information over the Internet, i.e., they also need IP addresses.

To solve this problem, a new version of IP has been designed, and is called IP version 6 (IPv6). The address of IPv6 has expanded the 32 bits address space for IPv4 to 128 bits. This amount of address space is enough for assigning a separate address for every grain of sand on the planet! (Nokia, 2000; Perkins, 1998)

IPv6 is has special emphasis on future Mobile Internet where people are carting a variety of mobile devices. The address space makes it possible for each device to have its own unique IP address.

4.4.2 Mobile IPv6 Implementation

The Mobility support for IPv6 contains the general ideas of Mobile IPv4. but with different implementations. Figure 4-5 shows the basic mechanism of Mobile IPv6, the protocol specified to support IPv6 systems.

In Ipv6, the mobility signaling and security features are integrated in the header extensions. In its stateless address autoconfiguration, addresses can be generated with networked of a visited network and an interface identifier of the MH. That means, when MH moves to a different network, MH will have a new COA and registers this COA with its HA by sending a binding update message to its HA. The packets send to MH using its home IP address will be routed to the HA and then tunneled to MH's COA. In this case, MH assumes the CH does not have any binding cache for the MH. So it sends a binding update to the CH for future datagram delivery. After having a binding cache for the MH, the CH will use a routing header to route the packet to MH. This is one feature of IPv6 that the datagram's header contains MH's COA. At the initiation, the address was set to the MH's home address. (Chang, 2000)

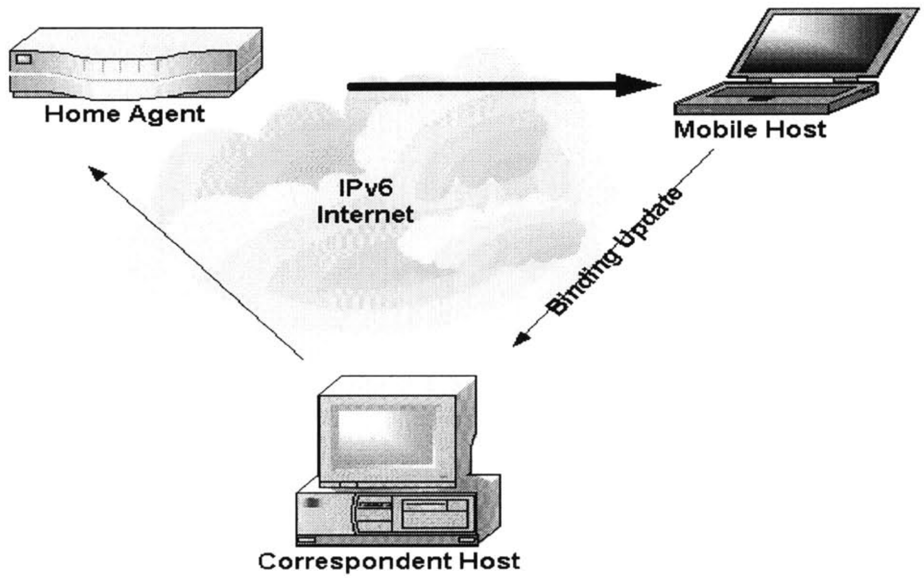

Figure 4-5 Mobile IPv6 Datagram Delivery Before Binding Update

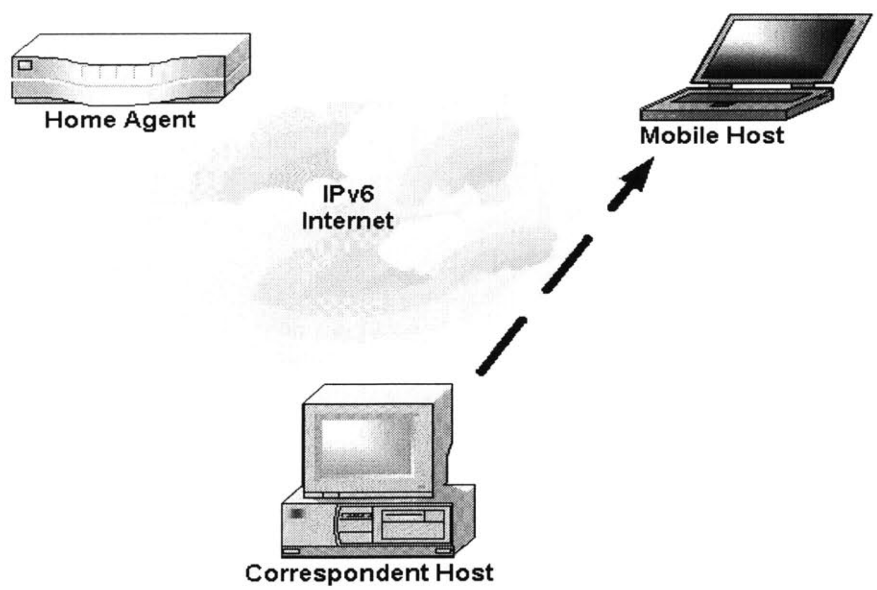

Figure 4-6 Mobile IPv6 Datagram Delivery After Binding Update

As seen from above figures, FA is eliminated in Mobile IPv6. In Mobile IPv6, MH uses IPv6 routing header to tunnel the datagrams instead of the encapsulation method used for Mobile IPv4.. The routing optimization is integrated into Mobile IPv6 and is performed in the registration process by a single process.

4.5 ENVOLVEING TO IP MOBILE NETWORK

The wireless industry is evolving from today's circuit-switched Signaling System No.7 (SS7) architecture to an IP based core networks. As seen from chapter 2 and chapter 3, the wireless telephony is currently lack of a global standard. Therefore, different approaches are needed for addressing different evolving paths. Two partnership projects are created to handle this issue: 3rd Generation Partnership Project (3GPP) and 3rd Generation Partnership Project 2 (3GPP2).

4.5.1 3GPP IP Network Architecture

3GPP members include ETSI, TI (North America), Association of Radio Industries and Businesses (ARIB)/ TTC (Japan), Telecommunications Technology Association (TTA) (Korea), and CWTS (China). The main activity of 3GPP is to evolve the US TDMA standard toward 3G architecture based on EDGE and GPRS, and in evolving to an IP network, 3GPP has decided to base on GPRS. Figure 4-7 is an illustration of the proposed 3GPP IP reference architecture. In this architecture, service control is separated from connection control, it started with GPRS as the core packet network and overlaid it with call control and gateway functions that are required for supporting voice over IP (VoIP) and other multimedia services. As shown in the illustration, Call State Control Function (CSCF) is provided here to handle call control in an IP network, Roaming Gateway and PSTN Gateway are provided for communicating with 2G and PSTN networks, and the GPRS home location register (HLR) is enhanced for services that use IP protocol. Here, Mobile IP architecture can be incorporated into the GPRS GGSN (Gateway GPRS Support Node) for providing mobility. However, this is still a framework without a final detailed solution. (Patel and Dennett, 2000)

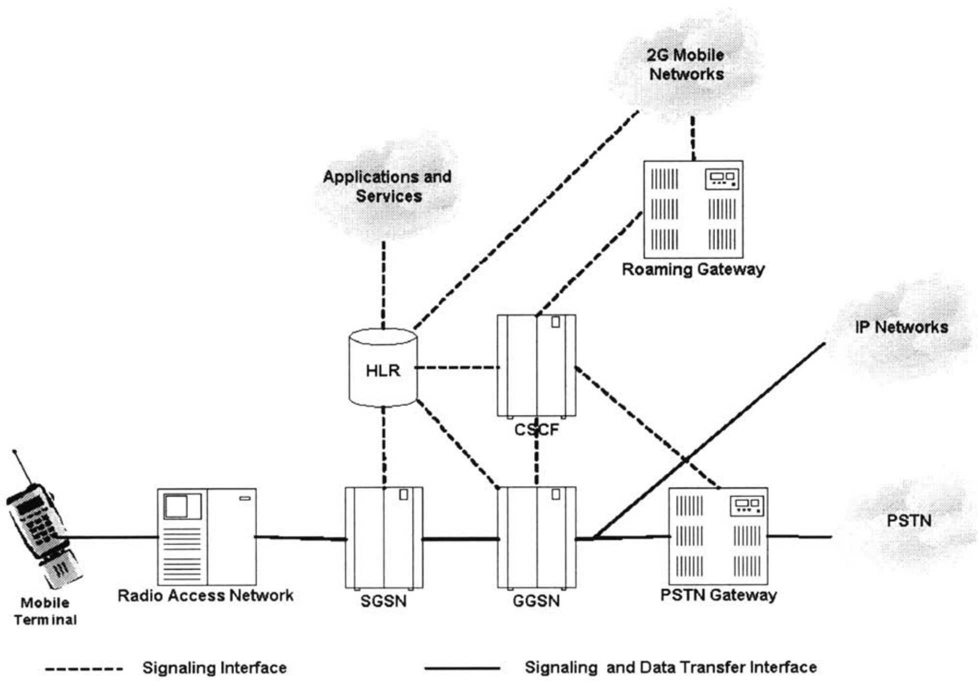

Figure 4-7 3PGG IP Reference Architecture

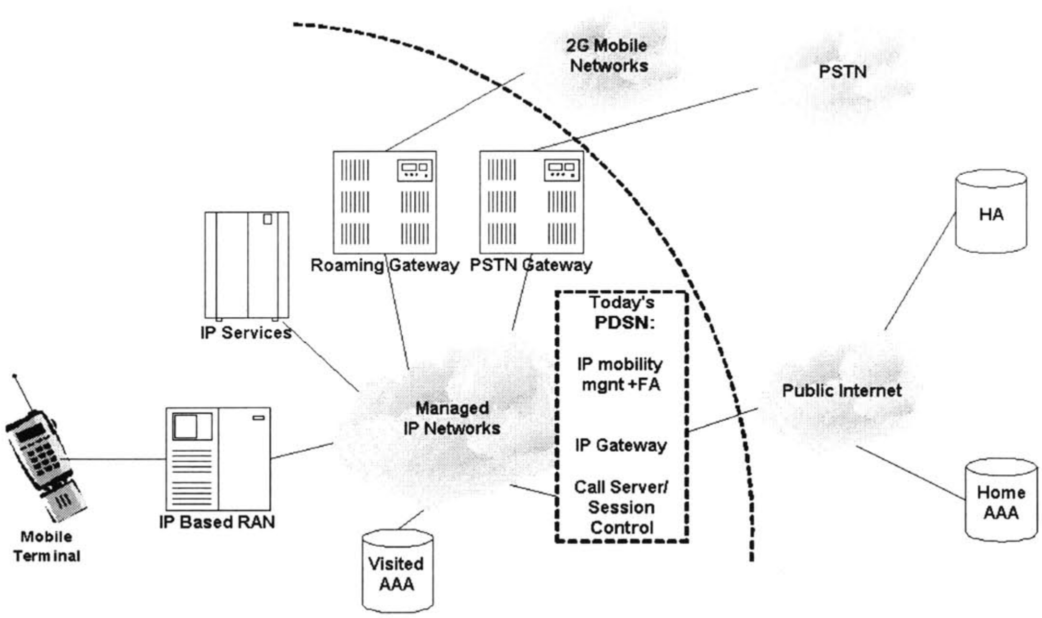

Figure 4-8 3PGG2 IP Architecture

4.5.2 3GPP2 IP Network Architecture

3GPP2 members include TIA, ARIB/TCC, TTA, and CWTS and are developing 3G standards for IS-95 based CDMA systems. It has taken advantage of the existing work in Mobile IP and combined it with the 3G high data rate feature. The concept of 3GPP2 IP network is to enhance IP architecture for multimedia applications and to use a single network for all services. Figure 4-8 shows the proposed future interworking network.

In this architecture, the mobile terminal uses Mobile IP based protocol to identify itself. The PDSN (Packet Data Serving Node) contains FA that can establish Mobile IP tunnel to the HA. HomeAAA is the authorization, authentication, and accounting server locates in home network to authenticate the mobile terminal. And there is also a visited AAA, which is the AAA in the visited network. In this mechanism, the data services connected to the mobile terminal can be handled over to any other access device that supports Mobile IP. Thus, this approach supports mobility across different access networks as shown in Figure 4-8. However, since address translation is used here to provide mobility, it is still not a fast enough solution for address updates. To address this problem, there has been a lot of research works established for building an All-IP-based future network. Studies on converting cellular phone numbers to IP addresses have also initiated. Theses schemes all have similar concepts but with different implementations, and could be used as an optimization of Mobile IP applications in 3GPP2. (Patel and Dennett, 2000)

4.6 CONCLUSIONS

In this chapter, basic mechanism of Mobile IP has been discussed; including Mobile IPv4, Mobile Ipv4 with routing optimization, and Mobile IPv6. Mobile IP protocols has been designed to be independent of the access interface, therefore, it is possible for existing or future wireless service providers to incorporate their data network with Mobile IP functions at appropriate network nodes. As a result, it is essential to design protocols, which enable interworking between Mobile IP protocol and wireless mobility management protocols. Studies has been initiated in 3GPP and 3GPP2 toward outlining requirements, necessary changes and interworking mechanisms for providing Mobile IP services in GPRS and CDMA networks. Also, security, quality of Service, and location privacy issues has been addressed in these studies. The third generation wireless network is envisioned to evolve into an IP based network, and in the fourth generation network, IP mobility capability becomes an essential part for future high-speed wireless multimedia services.

CHAPTER 5

SOFTWARE-DEFINED RADIO

Software-Defined Radio is one of the key technologies, which enables fourth generation integrated networks.

Converging regional standards into a single, global wireless system has long been a goal in wireless communication indusrty. Major telecommunication players are hoping to expand their market and reach economic scale by unifying system requirements, at the same time, they also want to secure their huge investments in previous technologies. The UMTS is leading a vision towards global cellular technologies convergence. At the same time, different second generation wireless standards such as GSM in Europe and Asia, cdma2000 in US and PDC in Japan are still seeking their migration path to third generation high data rate services, respectively. In reality, regional systems will still exist, and evolve. This means there will still be different handset designs and incompatible software/hardware systems.

Significant amount of research work has done to provide multi-mode handsets; for example, a single handset that could access GSM, DCS 1800, DECT, and TETRA[6] services in Europe, and many GSM handsets that are able to receive signals from dual, or triple frequencies, 900 MHz, 1,800

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[6] Trans-European Trunked Radio

MHz and 1,900 MHz. These could almost achieve the goal of global roaming, however, there are still other standards such as D-AMPS in US, PCD in Japan, and emerging third generation systems.

New standards and technologies are coming out continuously, but old technologies do not fade out immediately. The coexistence will still continue for a period of time, just like the coexistence of tape and CD players. Thus, IMT-2000 of third generation wireless communication has come up with the concept of " family of systems". Even in studies on fourth generation networks, the vision of "communication anytime, anywhere" is still not rely on a universal single standard for everything. Instead, emphasis is on the concept of *Software-Defined Radio (SDR), an emerging technology thought to build flexible radio systems, multiservice, multistandard, multiband, reconfigurable and reprogrammable by software.* (Buracchini, 2000)

5.1 CONCEPT OF SOFTWARE-DEFINED RADIO

The concept of "software-defined radio" was first described by Joseph Mitola III in 1992. It was first introduced as a military –related technology. The early implementation of software-defined radio was a US military software application called SPEAKeasy, which demonstrated the accommodation of different modulation methods using integrated modular radio elements, such as analog elements, A/D converter, and DSP on an open architecture bus. (Haruyama, 2000)

The Modular Multifuction Information Transfer System (MMITS) Forum was founded in March 1996 to address the development of this technology, which included participants from major telecommunication companies. The Forum was then renamed as Software-Defined Radio Forum, with the anticipation of transferring SDR from being a military to a commercial technology.

As various mobile communication standards will continue to exist, the term software defined radio (SDR) is used to enable the coexistence of several mobile communication services. The radio receivers and transmitters used today mostly consist of dedicated analog circuits for filtering, tuning and demodulating/modulating a specific type of waveform. Low cost, low power, and multistandard implementation of the digital signal processing is a key challenge. Previously, ASIC (Application-Specific Integrated Circuits) have been specially designed to achieve this capability. However, these kind of dedicate hardware resulted in long product development cycles and are inflexible to changes.

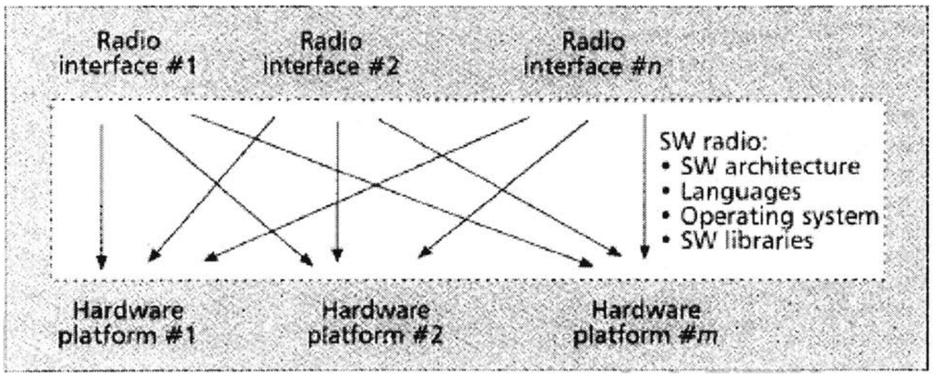

Figure 5-1 Concept of Software-Defined Radio

(Adoped from Buracchini, 2000)

The rapid improvement of silicon technology makes it possible to develop general purpose Digital Signal Processors (DSP) instead of dedicated hardware. By reprogramming software, the DSP could easily be adapted to the existing multiple radio standards and accommodate the rapid evolving new features and higher data rates. This provides a single hardware platform with software control of a variety of modulation techniques, wide-band or narrow-band operations, and waveform requirements over a broader frequency range. (See Figure 5-1) By migrating processing functions from dedicated ASIC implementations to software implementations, users can enjoy a scalable hardware that can be used globally without the need for different handsets when changing to another operator who uses different standard. From the operator's point of view, they would provide services without having to support a myriad number of handheld. For infrastructure suppliers, they could lower the cost and secure investment without frequent change hardware components. As for terminal manufacturers, add on capabilities could be done with software patches without needing to design new terminals. For application developers, programs could be developed without concern for hardware types. Figure 5-2 illustrates the conceptual terminal with SDR.

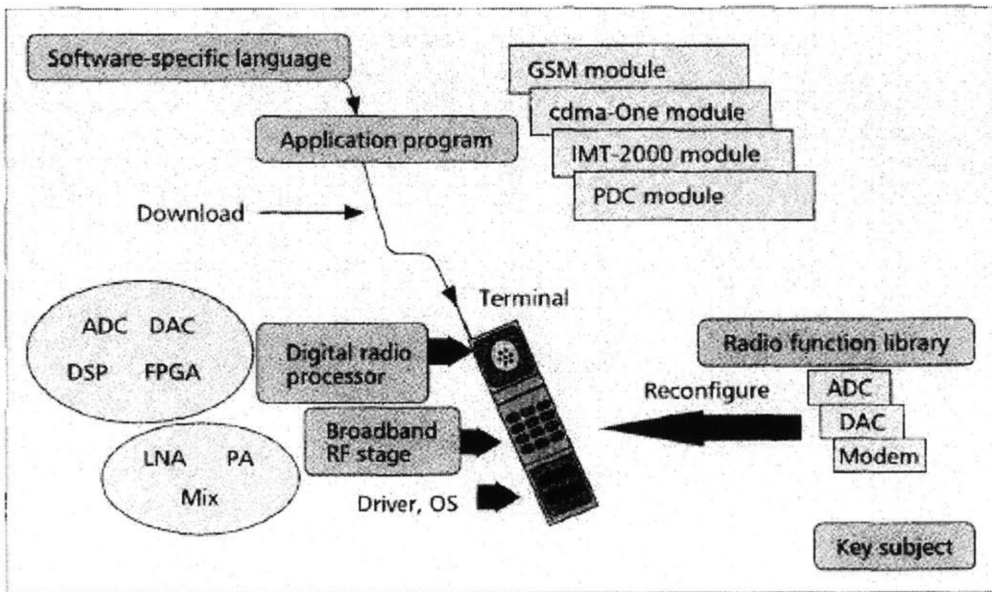

Figure 5-2 SDR Terminal Concept

(Adopt from Tsurumi and Suzuki, 1999)

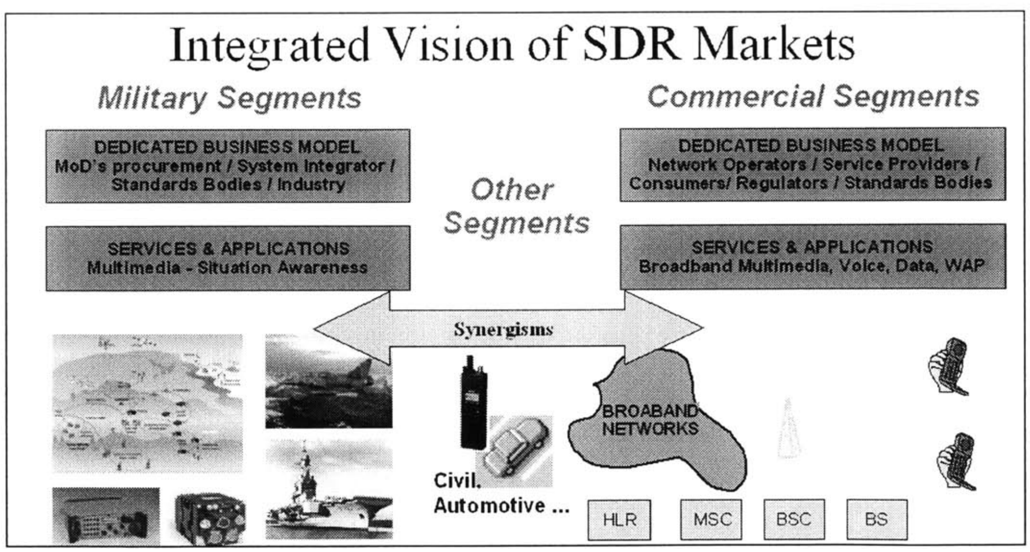

Figure 5-3 Integrated Vision of SD Markets

(Adopt from SDR Forum)

5.2 APPLICATIONS OF SOFTWARE-DEFINED RADIO

5.2.1 SDR Forum Vision

Software-Defined Radio technology can apply not only to cellular telephony but also all areas of radio communications and broadcasting. A variety of potential applications ranging from market sectors of commercial, military to civil are indicated at SDR Forum. (Table 5-1) Figure 5-3 illustrates the integrated vision of SDR market.

Commercial	**Civil**	**Military**
True international connectivity	Portable Command Station for crisis management	Secure, encrypted
Location awareness	Inter-agency communications when desired	Mission reconfigurability
"Freedom of Choice" - applications, band/protocols MP3, AM/FM Media distribution Interactive betting CD quality music	Instant routing of emergency information	Options to select communications channel by availability
Virtual private networks - Closed user groups		Real-time flexibility
Media Distribution		Portable Command Post
Combined delivery of e-mail, voice mail, messages & FAX		Integrated radio, router, computer
Browser malleability		International connectivity to prevailing networks

Table 5-1 SDR Applications

(Source: SDR Forum)

5.2.2 Cellular Telephony Market

Table 5-2 shows the divergent of existing and emerging cellular standards in terms of frequency band, access method, channel width and modulation mechanisms. The diversified major standards such as GSM, IS-95, PCD and migrating standards GPRS, EDGE towards W-CDMA add enormous complexity to business users as well as player in the wireless industry. Not to mention to the current protocols for wireless Internet access such as WAP, compat_html[7].

Standard	GSM/DCS-1800/PCS-1900	D-AMPS (IS-54/136)	CDMA (IS-95)	PDC	IMT-2000
Frequency band (MHz)	900/1800/1900	800/1900	800/1900	800/1500	2000
Mobile to base station (MHz)	890-915/1710-1785/1850-1890	824-849/1850-1890	824-849/1850-1890	940-956/1429-1441 and 1453-1465	1920-1980
Base station to mobile (MHz)	935-960/1805-1880/1930-1970	869-894/1930-1970	869-894/1930-1970	810-826/1477-1489 and 1501-1513	2110-2170
Access	TDMA, 8 time slots (later 16)	TDMA, 3 time slots	CDMA	TDMA, 3 time slots (later 6)	W-CDMA
Channel width	200 kHz	30 kHz	1.25 MHz	25 kHz	5 MHz
Modulation	GMSK	π/4 DQPSK	BPSK/QPSK	π/4 DQPSK	BPSK/QPSK

Table 5-2 Divergent Existing Cellular Standards

While standards for different generations coexist, it would be convenient if the reconfiguration can be achieved in software. The advantage by using software-defined radio is that is can make

[7] compact_html is the markup language used by NTT DoCoMo's I-mode service. It's a simplified version of HTML, the markup language currently used by World Wide Web

quick change in order to support multiple standards, and the software-defined radio handset can reconfigure itself while users moving between different cellular standard areas. SDR can also apply to cellular base stations. It could potentially offer benefits such as reducing the size, add complexity, lower power consumption to base stations. (Haruyama, 2000) By loading new proposals into the base station, it can support the above modulations summarized in Table 5-2 simultaneously and switch between each other if required.

5.2.3Wireless LAN Integration

A variety of approaches are emerging in the Wireless LAN field such as Bluetooth, HomeRF, IEEE 802.11, which will be discussed in chapter 7. Table 5-3 summarizes various proposed Wireless LAN standards:

Standard	Bluetooth	HomeRF	IEEE 802.11	BRAN	Wireless 1394/ IEEE 802.11a/ MMAC
Frequency (GHz)	2.4	2.4	2.4	5	5
Data Rate (Mbps)	1	2	2	54	54
Modulation	FH	FH	FH/DS	OFDM	DMT/OFDM

Table 5-3 Wireless LAN proposed standards

(Source: Haruyama, 2000)

The concept of fourth generation networks includes not only cellular telephony, but also a broad range of wireless access systems like Wireless LAN. Software-Defined Radio can realize the integration of different systems and the connection between wireless areas. In one vision of Bluetooth application, a handset could be a cellular terminal outside, a line phone indoors, and a cordless phone when needed. SDR here can reduce the problem of incompatibility between digital devices and services, and pave the road towards a truly global roaming scenario.

5.3 DIFFERENCE BETWEEN SOFTWARE-DEFINED RADIO AND CONVENTRIOANL RADIO

5.3.1 Channel Selection

In conventional cellular stations, each channel has a dedicated receiver tuned exclusively to one band. In order for base stations to be capable of receiving different frequency bands, many receivers are required, each consuming power and adding size and cost to the base station. SDR use a single, high performance wide-band radio receiver to capture the entire band, then digital mixing and filtering is used to select and receive individual channels. Instead of using radio per channel in conventional architecture, a high performance single radio is used in the front end and shared between all channels. (See Figure 5-4)

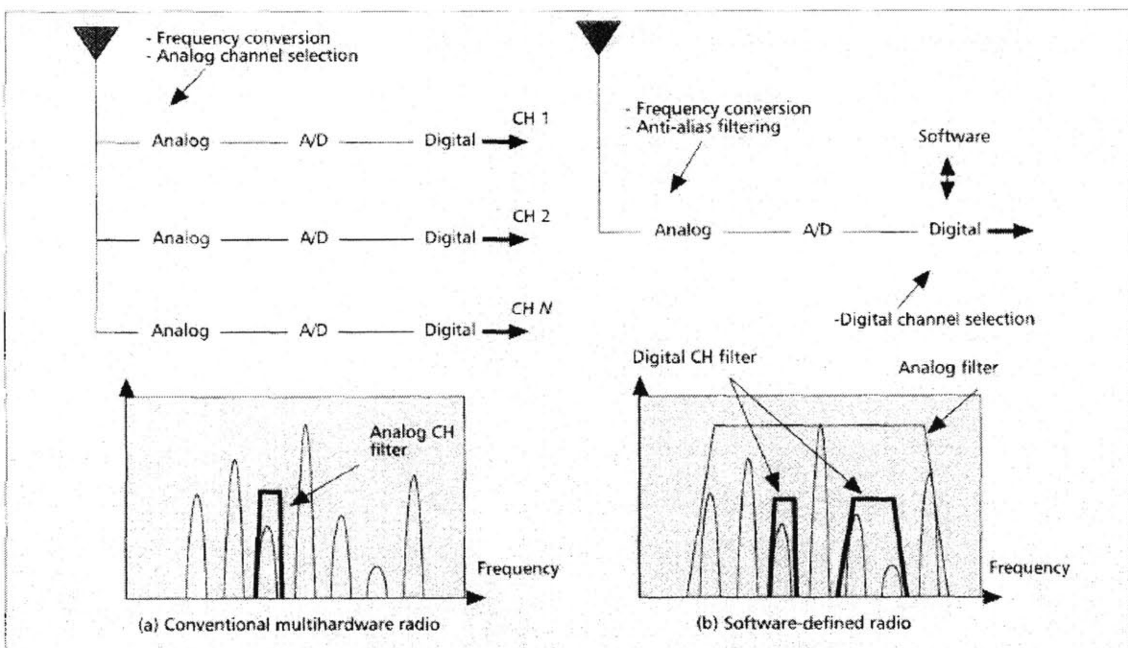

Figure 5-4 Channel Selection Mechanism bwteen Conventioal Radio and SDR

(Adopt from Tsurumi and Suzuki, 1999)

In Figure 5-4 (a), a receiver chain for each standard is equipped, it selects a different carrier frequency and channel bandwidth using fixed analog channel selection filters. In Figure 5-4 (b), a broadband RF stage feels the entire system bandwidth to a high-speed ADC (Analog Digital Converter), and software-defined channel selection filters of DSP select the specific channels. (Tsurumi and Suzuki, 1999)

5.3.2 Traditional Superheterodyne Receiver

Figure 5-5 illustrated a conventional narrow-band super heterodyne receiver. In a traditional superheterodyne radio receiver, RF signals are received from the antenna and goes through a band-pass filter (BPF). The signal is then multiplied by a sinusoidal Local Oscillator (LO) signal in a mixer and transmitted to an Intermediate Frequency (IF). An ADC is then samples the output from IF stage into digital signals and feed that to DSP. Because analog filter are usually fixes narrowband, it's difficult to adopt that for wideband SDR. Analog components are also have problems such as thermal variation and aging effect. Therefore, the approach of SDR is to reduce the analog components in a traditional radio receiver. (Haruyama, 2000)

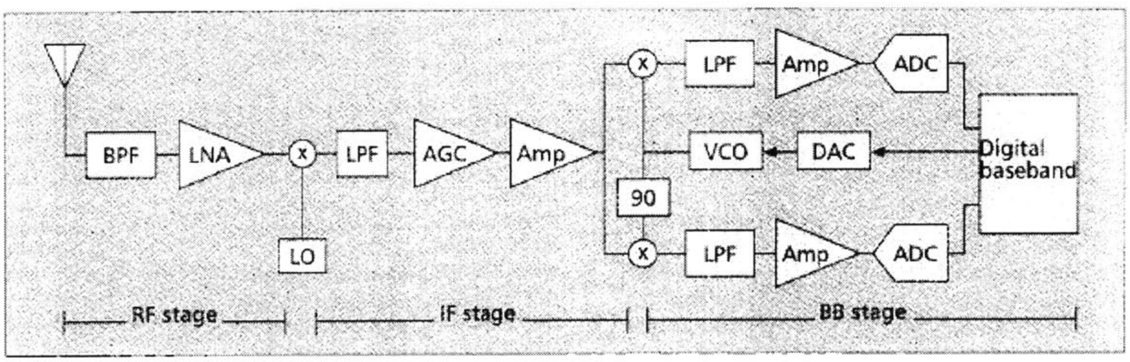

Figure 5-5 Conventional Superheterodyne Receiver

(Adoped from Buracchini, 2000)

5.3.3 Digital Radio Receiver

Figure 5-6 is a most promising solution known as *digital radio transceiver*, where it moves the ADC to the IF stage. The ideal of SDR receiver is to replace as much analog components into digital components as possible. However, since the frequency bands of current mobile communication standards range from several hundred MHz to several GHz, it is not possible to use today's semiconductor ADC technology, which has sampling rates up to 100 MHz. (Haruyama, 2000)

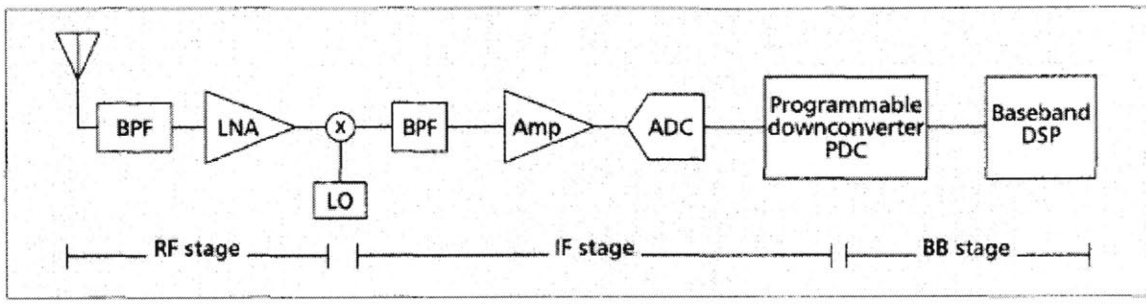

Figure 5-6 Digital Radio Receiver

(Adoped from Buracchini, 2000)

Therefore, analog components to convert RF signals into IF signals are still needed. Then SDC transfers the IF signals directly to digital signals.

5.4 DSP AND FPGA

5.4.1 Software Radio Solutions

Software Radio Technology describes all communication components in digital signal processing language. Software programs for specific standard are then downloaded to digital signal processing hardware such as Field Programmable Gate Arrays (FPGA) and Digital Signal Processor (DSP).

	Power Consumption	Size	Cost	Field Upgradeable	Silicon Evolution	Tools
High-Speed DSP	Very high	Modest	Moderate/high	High	Easy	Some
ASIC	Moderate	Large	High	None	Difficult	Available
Parameterized Hardware	Moderate	Moderate	Moderate	Some	Moderate	Some
Reconfigurable Logic	Low	Low	Moderate/low	High	Easy	Unavailable

Table 5-4 Software Radio Technologies

(Source: Cummings and Haruyama, 1999)

Conventional base band and controller functions are based on processors optimized for high-speed operations with single-stream instructions, such as ASIC and microcontrollers. The advance of silicon technology makes it possible to produce high-speed processors for multimode, multiband operations; include High-Speed DSP, ASIC, Parameterized Hardware and Reconfigurable Logic. Table 5-4 summarized those technical solutions and comparison in various aspects.

High-speed DSP chip does signal processing by fetching instructions and data from memory, does operation, and stores the results back to memory. DSP differs from CPU by having a special block called MAC (Multiply and Accumulate) that does the high-speed operations.

ASIC is an integrated circuit designed to perform a fixed specific task. An approach that uses DSP complemented by multiple ASICs, one for each service, has been widely employed. This is considered easy and direct in terms of solving performance problems, however, multiple ASICs requires large silicon area, high cost, and high power consumption. As ASIC is fixed, this approach needs a lot of support and resources when it comes to modification.

Parameterized hardware has several different forms such as ASIC designed for a certain subtask, or a processor with switchable microcode. It is normally implemented with specific combination of standards and are not able to handle addition upgrades in the field.

Reconfigurable logic such as FPGA (Field Programmable Gate Array consist of an array of gates with programmable interconnect and logic functions that can be redefined after manufacture. (See Figure 5-7) It was formally used for fast ASIC prototyping. Designing system with reconfigurable FPGAs, the silicon area does not grow with the number of air interfaces supported, instead, this technology enabled the possibility of having a single or small number of platforms which will support all the combination of standards. A new feature designed for FPGA are being developing, that is dynamic reconfiguration. The would enable reconfiguring part of FPGA while it is operation, such that a receiver can be reconfigured to adopt different reception algorithms for receiving signals from dynamic changing channels (Cummings and Haruyama, 1999; Haruyama, 2000)

5.4.2 FPGA V.S. DSP

DSP and FPGA are, among the above software radio technologies, chips that have general-purpose reconfiguration features. Table 5-5 summarizes differences between these two chips.

	FPGA chip	**DSP chip**
Programming Language	VHDL, Verilog	C, Assembly
Easy of Software Programming	Fairly easy. However, the programmed needs to understand the hardware architecture before programming	Easy
Performance	Can be very fast if an appropriate architecture is designed	Speed is limited by the clock speed of a SDP chip
Reconfigurability	SRAM-type FPGAs can be reconfigurable infinite times	Can be reconfigurable by changing program memory content.
Reconfiguration Method	Reconfiguration is done by downloading configuration data to a chip electronically	Reconfiguration is done by simply reading a program at a different memory address
Areas where FGPA can outperform DSPs or vice versa	FIR filter, IIR filter, correlateor, convolver, FFT, etc.	A signal processing program of sequential nature
Power Consumption	Can be minimized if the circuit is designed to save power, or the power is dynamically controlled	Even if program A is larger than program B, power consumption does not change as long as the number of memory chips is the same.
Implementation Method of MAC	Parallel multiplier/adder or distributed arithmetic	Repeated operation of MAC function.
Speed of MAC	Can be fast if a parallel algorithm is used. If a filter is implemented using distributed arithmetic, the seed does not depend on the number of tapes.	Limited by the speed MAC operation of a SDP chip. If a filter is implemented, the speed becomes slower if the number of tapes increases.
Parallelism	Can be parallelized to achieve high performance	DSP chip programming is usually sequential and cannot be parallelized.

Table 5-5 FPGA and DSP comparison

(Source: Cummings and Haruyama, 1999)

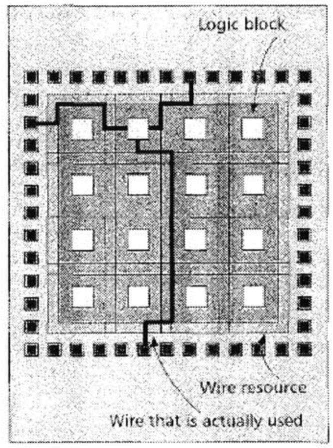

Figure 5-7 FPGA Architecture

(Adopted from Cummings and Haruyama, 1999)

The rapid growth in the use of general-purpose DSP and FPGA chips makes it commercially viable to manufacture general-purpose programmable devices at low costs. The speed of these software implementation is now reaching that of hardware implementations, thus adding to the advantage of software-defined radio implementations.

5.5 LAYERED ARCHITECTURE

Figure 5-8 compares SDR implementations in wireless handheld with generic PC model.

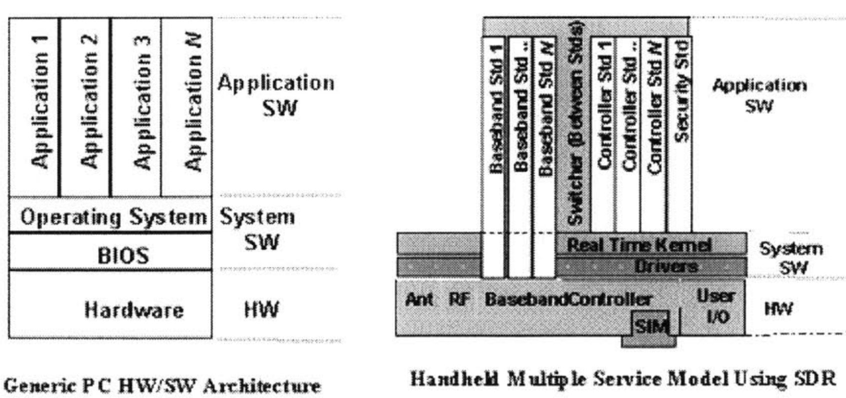

Figure 5-8 SDR Architecture Compares to Generic PC Architecture

(Adopted from SER Forum)

In the left side of Figure 5-8, it illustrated the generic PC HW/SW architecture. In the right hand side, SDR architecture is shown, the baseband implementations for different air interfaces or services interface directly with the hardware layer because of the performance constraints on execution speed and power consumption. In order to achieve processing speed and efficiency, the majority of baseband implementations are programmed very close to the underlying hardware or logic, using low-level language such as microcode or assembly code. In order to have effective switcher/downloader, there should be a set of interface standards for the components that are being switched or downloaded. SDR Forum has taken the approach to standardizing APIs to allow maximum opportunity for innovation in implementing the modules inside the APIs. The T-shaped component labeled as Switcher between standards resides in the application software layer and takes control when switching or downloading events is in process.

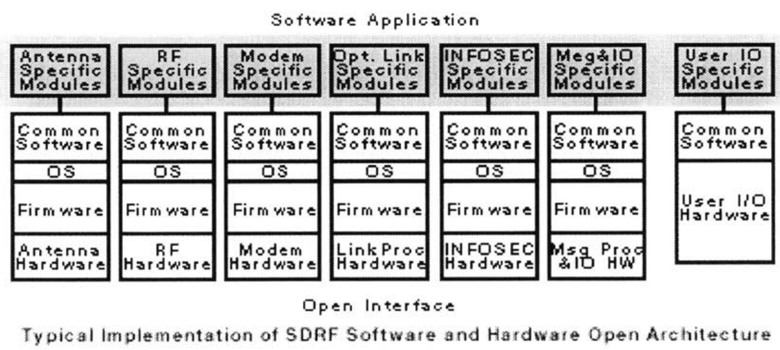

Figure 5-9 SDR Software and Hardware Open Architecture

(Adopted from SDR Forum)

SDR architecture is based on a high-level generic model with specific functional blocks connected via open interface standards recommendations. The software is implemented by controlling the specific device characteristics through hierarchical and peer level modules that support scalability and flexible extensions of applications. It is important to notice that modularity is the key for implementing software application within open systems. Interfaces are defined between modules such that the developer can be free to effectively implement new functionality. Figure 5-9 shows the open architecture of SDR SW/HW implementations published by SDR Forum.

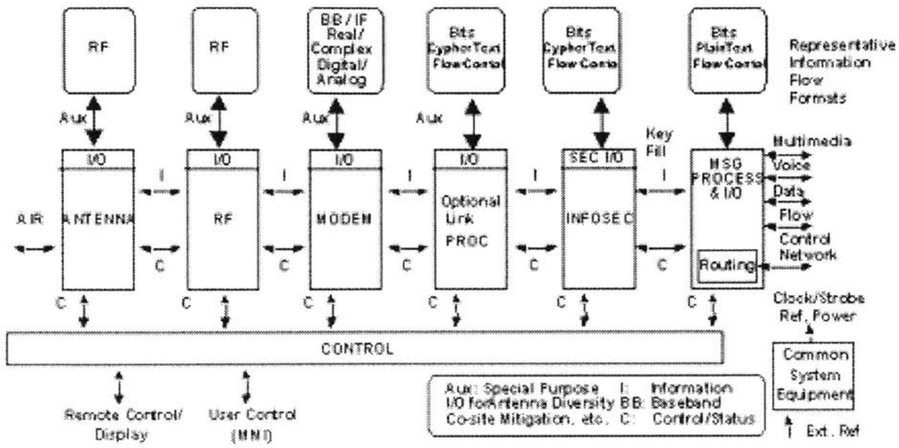

Figure 5-10 SDR Functional Interface Diagram

(Adopted from SDR Forum)

The SDR open architecture shown above consists of functions connected through open interfaces. In Figure 5-9, there are seven independent subsystems interconnected by open interfaces, each has hardware, firmware and an operating system. The common software modules may be the same for some applications, and the application layer is modular, flexible and software specific. The software API is standardized with common functions that have open and published interfaces. In this architecture, peer-to-peer interfaces are not required.

Figure 5-10 illustrates functional interface diagram published by SDR Forum to demonstrate how the SDR Forum architecture can extends to the definition of functional interfaces.

5.6 BENEFITS AND CHALLENGES

Besides the ability of supporting different standards, SDR also has many potential benefits:

- Allow the reuse of commercial digital architecture and software protocol stacks to reduce cost and time to market.
- Facilitate the introduction of new features and services with software upgrades.
- Enable customization for special niche market.

- Integrate devices and allow applications to be used on different platforms.

However, there are remain some challenges:

- Strong competition from system-specific implementations using ASICs. Although ASIC implementation leads to a longer time to market, it can potentially lower the cost at present because the equipment could be made for specific standards such that it's possible to minimize the hardware and software overhead.

- While DSP technology is growing rapidly, similar as PC market, the DSP chip may be obsolete when new software features become upgradeable. Therefore, the system hardware may still need to be redesigned or changed.

- Under the generic architecture, hardware specific implementations are still needed for each subsystem. This causes the difficulty for SDR development.

SDR Forum has been actively proposing standard interfaces for SDR. They are using CORBA (Common Object Request Broker Architecture) and IDL (Interface Definition Language) to define the standard SDR software architecture an planning to come up with a common SDR application of testing. The standardization is important for future wildly adopt of SDR platforms.

CHAPTER 6

INTELLIGENT COMMUNICATION TECHNOLOGIES

This chapter examines some technology trends for building the Next Generation Network (NGN). First, Intelligent Network (IN) concept used in the public switched telephone network (PSTN) is introduced, then a migration path towards future IN architecture is presented. Two most mentioned technologies to constitute future IN, CORBA (Common Object Request Broker Architecture) and MAT (Mobile Agent Technology), are briefly explained afterwards. Also, special sections will dedicate to two other promising intelligent technologies that are integrating into current and future networks and are believed to be important elements for the 4th generation network, which are Intelligent Transport System and smart antenna system.

6.1 INTELLIGENT NETWORK (IN)

IN (Intelligent Network) concept was developed as early as 1980s, it has been motivated by the need for reducing the time frame between new service ideas to actual implementations. Traditionally, telecommunications protocols were realized over switched networks. It led to monolithic, centralized and fixed implementations that are controlled by equipment vendors. The desire of IN was to free network operators from dependence on specific vendors and to enable services from third-party providers. IN aims to facilitate new services by decoupling the functions required to support call and connection control from those required to support service control, thereby allowing the two sets of functions to be placed on different physical platforms. In this manner, new services can be defined and implemented efficiently without the need to change the switch systems.

6.1.1 IN Architecture

IN architecture separates Service Control Function (SCF) from Service Switch Function (SSF) and Connection Control Function (CCF). The SSF and CCF are typically provided by switching system and implement the call process. SCF executes service logic and provides capabilities to influence call processing by request SSF/CCF or other functional entity to perform specified actions. The Service Data Function (SDF) separates the service data from service logic and can be accessed on a per-service or per-customer basis. SDF and SCF often integrated into a Service Control Point (SCP).

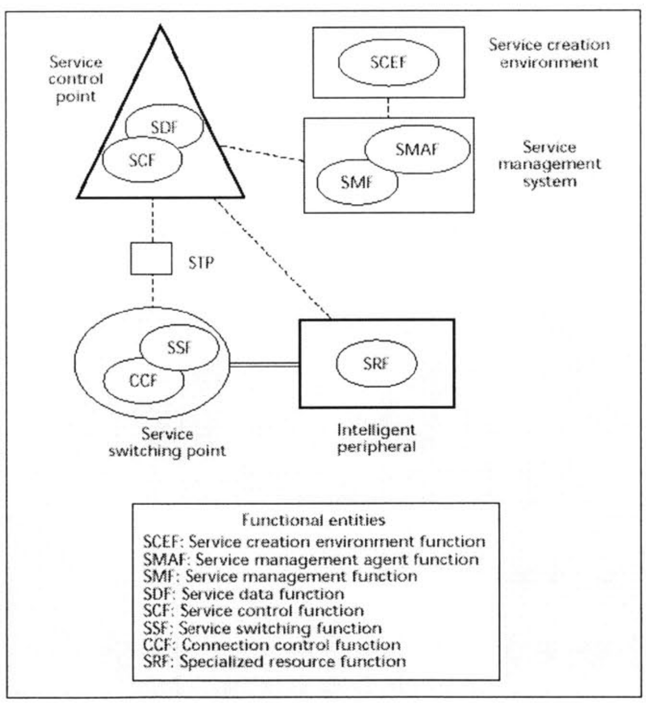

Figure 6-1 IN Entities

(Adopted from Finkelstein, M., Garrahan, J. et al., 2000)

Service Management System (SMS) contains Service Management Agent Function (SMAF) that coordinates and allows access to the various services and Service Management function (SMF) that manages services and operation of services in IN. The Service Creation Environment Function (SCEF) gives the control over services to the service providers and can be defined and customized by them. Figure 6-1 shows the functional entities described above. (Finkelstein, Garrahan et al., 2000)

6.1.2 Limitation of Traditional IN

Traditional IN implementations limits service logic to call setup control in response to triggers activated at network switches. However, there is an increasing need to extend the capabilities of IN to allow control of calls as well as possibly involvement of multimedia data exchange or new services. The traditional IN architecture aimed to reduce the time from service conception to full implementation, however, the current architecture is still not open enough, variations of versions of communications protocols and service logic hinder the task of getting equipment from different vendors to interoperate properly.

6.1.3 IN Evolution

The lack of standardized interfaces for service creation is one key barrier to the development of IN into a real open service environment. Many approaches have been initiated to resolve this problem. One of the first revolutionary stages is to have IN interworking with the Internet; for example, the service management could be done using a Web-based access manner. The interworking mechanism is illustrated in Figure 6-2. It is envisioned that the Next Generation Network will combine fixed IN services and Mobile IN services and present a fixed-mobile convergent IN service domain.

6.1.4 Vendor/Technology Independence

It is important to realize a interoperable IN platform in order to serve the market needs. However, in the IN market, the interoperation of service logic and proposals between different vendors and technologies is still limited. Among many imitations, CORBA and MAT have emerged as two possible solutions that offer the potential to overcome these difficulties by making service logic independent of underlying hard aware/software architectures and communication protocols. The discussions of CORBA and MAT are in the next two sections.

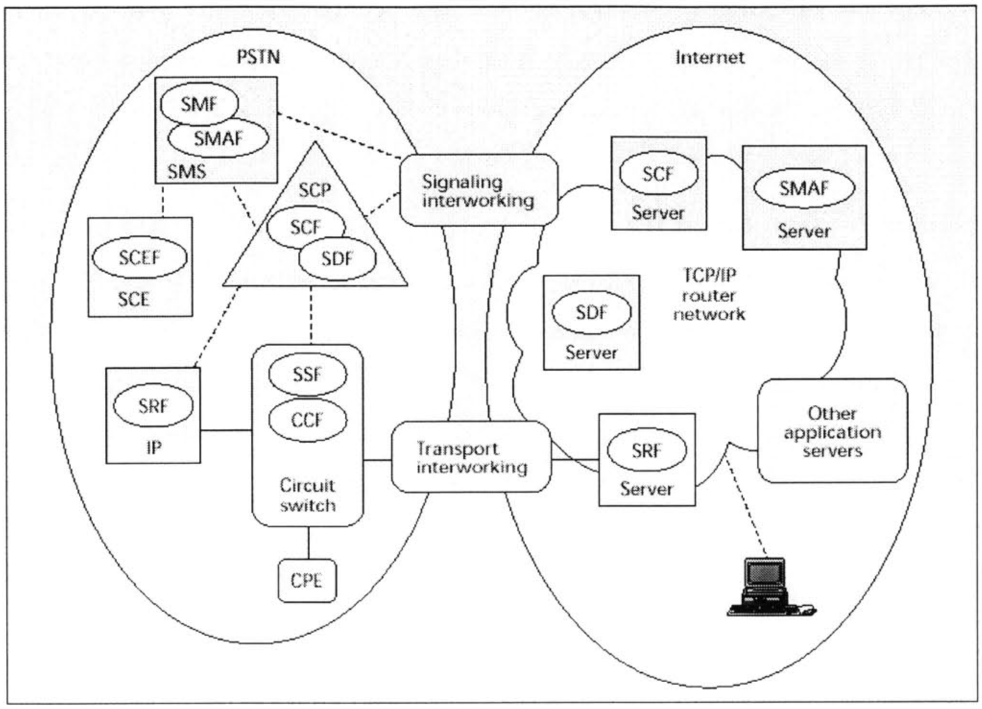

Figure 6-2 IN/Internet Interworking

(Adopted from Finkelstein, Garrahan, et al., 2000)

6.2 CORBA (COMMON OBJECT REQUEST BROKER ARCHITECTURE)

CORBA, Common Object Request Broker Architecture, is defined by OMG (Object Management Group). CORBA is an abstract object model based on networking software that a set of components can exchange messages over an open distributed computing environment despite their location, type of host computer, or programming language.

6.2.1 Monolithic Application Architecture

Traditional software was often monolithic. Monolithic software contains the user interface, business logic, and data access functionality in one large application. Figure 6-3 shows a typical monolithic application architecture.

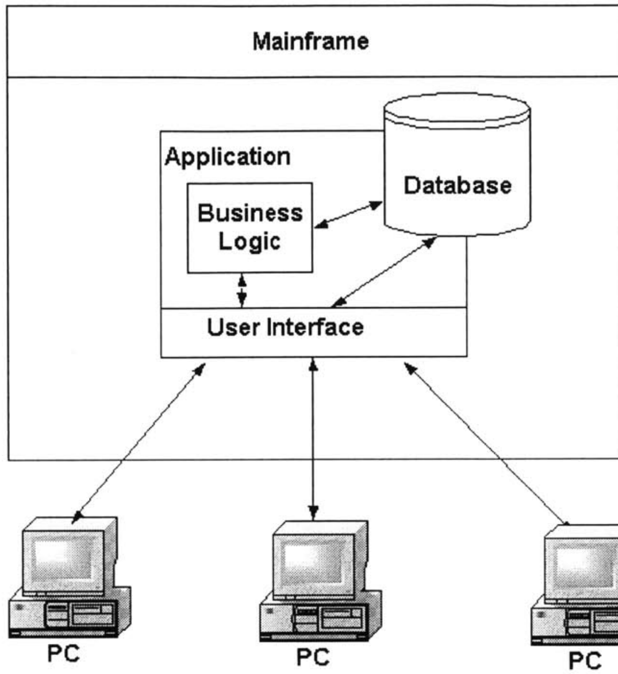

Figure 6-3 Monolithic Application Architecture

6.2.2 Client/Server Architecture

Client/Server applications normally distribute the components of applications to both server and client machines. Figure 6-4 is an illustration of client/server application architecture where business logic can reside in either or both components, and the user interfaces reside in the clients.

6.2.3 CORBA Architecture

The plug and play approach relies on something called *component technology*. The idea is to create applications from self-contained pieces that plug together and play the software in the way a specific user wants. The ultimate vision of this approach is to have *smart components* that could facilitate things like versioning, security, or compatibility. Figure 6-5 illustrates a general CORBA architecture based on components. In this illustration, ORB (Object Request Broker) handles the responsibility to resolve requests for object references and enabling application components to establish connectivity with each other. In this architecture, distributed ORBs can communicate with each other by GIOP

(General Inter-ORB Protocol) or IIOP (Internet Inter-ORB Protocol). This provides the illusion of a unified address space that spans machine, OS or different networks.

Typical CORBA objects can enable two processes to communicate even if they are implemented using different languages. A term called *implementation transparency* is used to describe this feature. Here, IDL (Interface Definition Language) is the language used to define interfaces between application components.

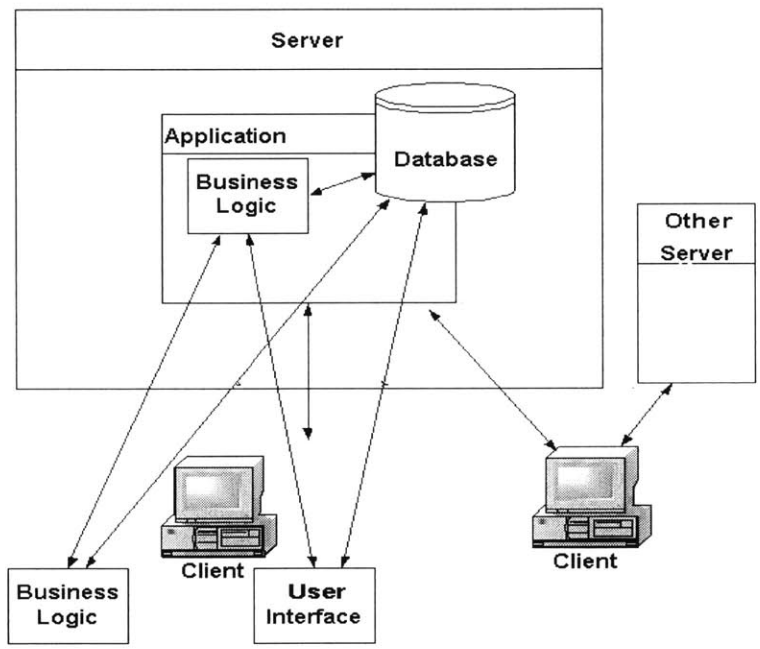

Figure 6-4 Client/Server Application Architecture

In Sep 1998, the Telecoms Domain Task Force of the OMG produced a specification focusing on the interworking of CORBA-based systems with telecommunications signaling systems, such as IN and mobile systems. The main technical approach is to provide interworking mechanisms for existing service infrastructure and to facilitate increased interconnection capabilities with external resources such as the Internet and private database.

Middleware technologies like CORBA are increasingly seen as a potential infrastructure for future service networks because of the advantage of distributed object-oriented processing environment. Some existing off-the-shelf CORBA services such as security, naming, messaging and notification can possibly be integrated into the CORBA-based IN systems and accelerate application development.

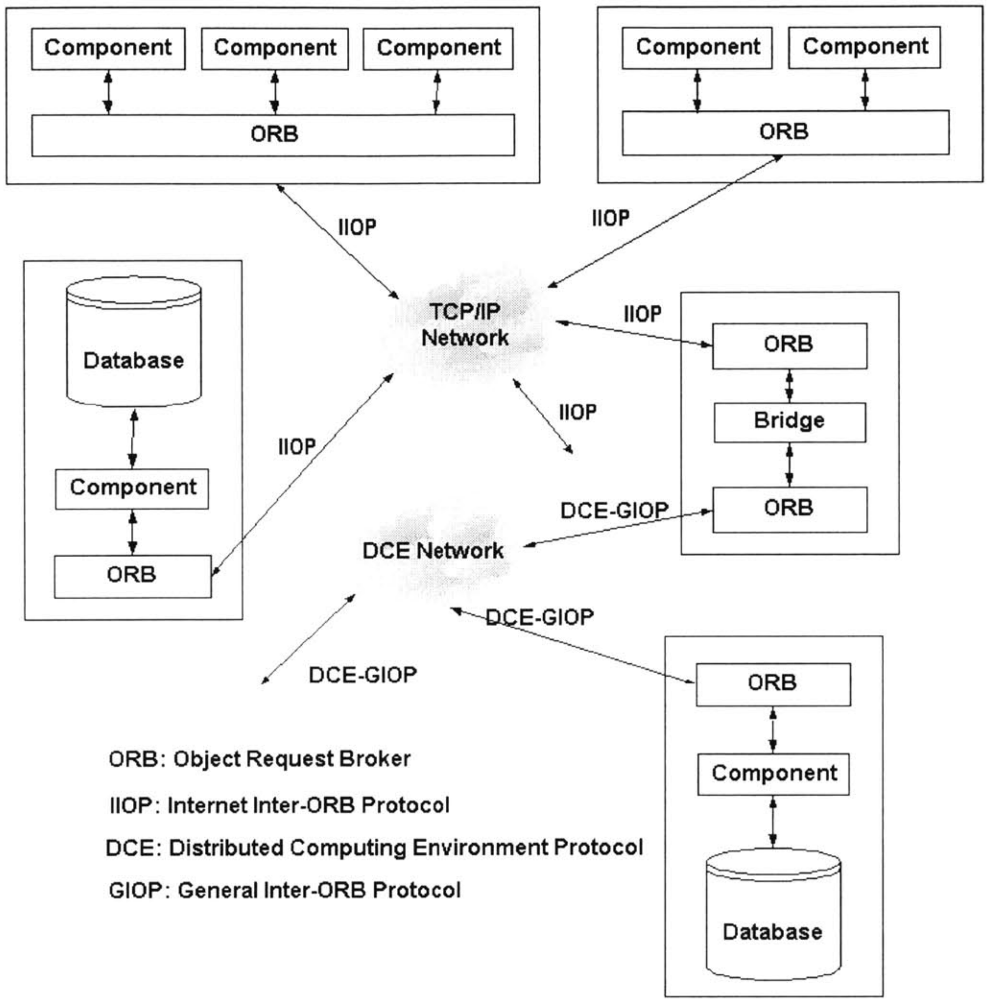

Figure 6-5 General CORBA Architecture

6.3 MAT (MOBILE AGENT TECHNOLOGY)

Another important technology in distributed systems architecture is the *Mobile Agent Technology (MAT)*, an object that can move from host to host. Mobile agents allow processing to be used dynamically; they can be used, for example, to balance the processing. In a general view, mobile agents are software objects that are able to stop their execution while being executed in a computer node, transfer themselves to a remote computer and resume execution there. An interesting consequence of technologies like the mobile agent is that they simplify the structure of information systems. A system built using these technologies is adaptable, or even adaptive, so its structure can be tuned when necessary. Most mobile agents are implemented using JAVA programming language since the abstraction of JAVA Virtual Machine allows agents to execute irrespective of the underlying operating system or hardware architecture.

In telecommunication field, mobile agent has drawn attention because of the ability of personalizing services. While services are implemented with MAT, it can follow the users to whichever network they are registering at instead of being invoked remotely. MAT can use the communication mechanism offered by CORBA; in the design of Distributed Intelligent Broadband Network Architecture (DIBA), both technologies are employed to overcome the limitations of traditional IN without altering its basic concepts. (Chatzipapadopoulos, Perdikeas and Venleris, 2000)

6.4 INTELLIGENT TRANSPORTATION SYSTEMS

Intelligent Transportation Systems (ITS) researches were started firstly by Japan and the United States, among other countries. ITS contains advanced information technologies and telecommunications networks such as Electronic toll collection (ETC), Vehicle Information and Communication Systems (VICS), Inter-Vehicle Communications (IVC), Road-Vehicle Communications (RVC) and Automated Highway Systems (AHS). In Japan, ETC, and VICS are already used practically. ITS is an integrated system that could provide drivers with comfortable and safe driving environment. Figure 6-6 illustrates the concept of ITS communications. In this figure, IVC allows communications among vehicles without the need of roadside infrastructure. RVC, on the other hand, are expected to base on Radio on Fiber (ROF) transmission technology that could transmit a broadband radio signal with low loss. RVC could assist safe driving systems or AHS and will play an important role in the future ITS. In Japan, for example, test facilities has been set up in CRL Yokosuka (Yokosuka Radio Communications Research Center, Communications Research Laboratory, MPT Japan), and a 60 GHz millimeter-wave radio signal can be successfully transmitted through the optical fiber for RVC. For IVC, millimeter-wave at around 60 GHz is also used in the experimental facility. (Fujise, Kato et al, 2000; Ohmori and Yamao, 2000) Besides providing traffic information to avoid accident and congestions, ITS is also expected to be a huge market place in the future where multimedia services can be provided for drivers and passengers.

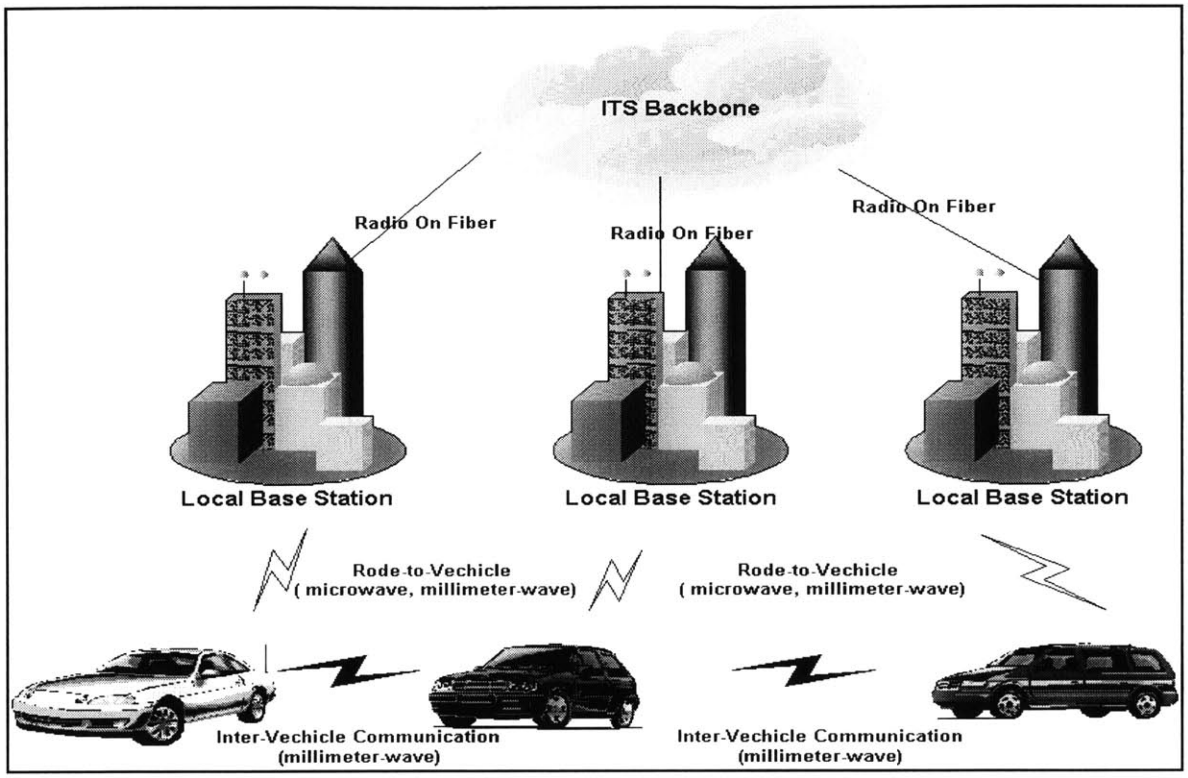

Figure 6-6 Concept of ITS communications

6.5 SMART ANTHENNA

Limited spectrum and increasing demand to accommodate more users in a mobile communication environment have led to the exploration of new radio transmission options in order to accomplish high-data rate requirement and avoid interference. This approach is also one key element while discussing 4th generation networks. One of the most promising techniques for increasing capacity in cellular systems is through the use of smart antennas. The air interface technology used for smart antenna is sometimes referred as Spatial Division Multiple Access (SDMA). SDMA is believed to use in combination of other air interface technologies such as

TDMA, CDMA for future cellular communication systems.

6.5.1 SDMA

Spatial Division Multiple Access (SDMA) is a technology, which increases the system capacity and quality of transmission by focusing the radio signal to narrow transmission beams. By using SDMA, narrow beams can focus radio energy of the RF signal so that it can travel further. Also, because of the narrow size of these beams, mobile radios outside the coverage area will not receive interference even if they are operating in the same frequency. As a result SDMA allows cell sites to have larger radio coverage areas with less radiated energy. Also, the narrow beams have their own receiving directions such that the quality of communication channels can be improved. Two types of SDMA systems to be introduced are as following.

6.5.2 Multibeam Antenna System

Multibeam Antenna System uses approximately 20 or more focused antenna on top of a cell cite to focus radio energy to a specific area. When the mobile terminal moves outside the coverage area of a narrow beam, the cell site will transfer the signal to the next adjacent antenna automatically as illustrated in Figure 6-7. (Harrte, L., Hoenig, M et al., 1999)

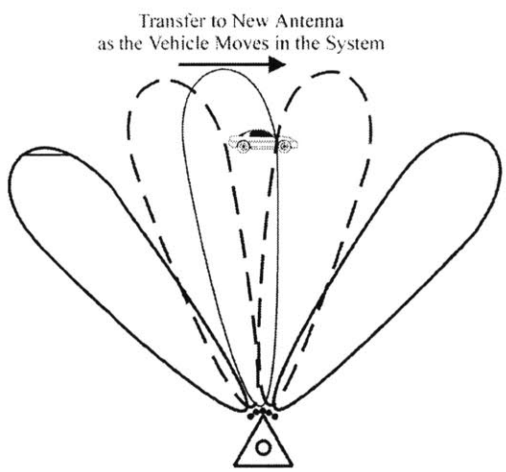

Figure 6-7 Multibeam Antenna System

(Adopted from Harrte, L., Hoenig, M et al., 1999)

6.5.3 Adaptive Antenna System

Smart Antenna System uses advanced algorithm and adaptive digital signal processing technology that allows antenna systems to focus their transmission beamwidth electrically. Therefore, the beams can focus on specific locations as shown at Figure 6-8. Adaptive antenna system can continuously distinguish between the desired signal and the interfering signals and calculate their angles of arrivals to dynamically minimize interference and maximize intended signal reception.

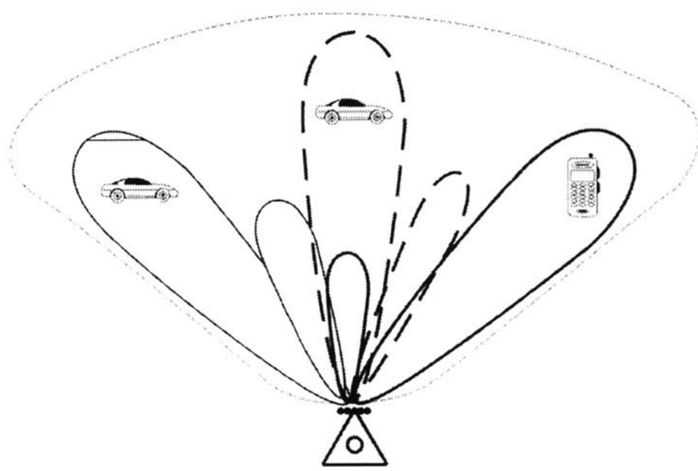

Figure 6-8 Adaptive Antenna System

(Adopted from Harrte, L., Hoenig, M et al., 1999)

6.6 SUMMARY

In this chapter, Intelligent Network (IN), Common Object Request Broker Architecture (CORBA), Mobile Agent Technology (MAT), Intelligent Transport Systems (ITS) and Smart Antenna systems have been overviewed. As mobile communication becomes more global, heterogeneous, and distributed, traditional IN used for PSTN to conduct communications between service logic and switch systems need to evolve into a hardware/software/technology/protocol independent mechanism in order to facilitate today's service implementation. CORBA and MAT are both based on distributed object –orient concept and are believed to be two important key technologies in the IN migration path. ITS contains a series of research activities that aim on adding intelligence into traditional transportation system and has a huge market potential in terms of providing multimedia localized services. While the above four technologies provide intelligent mechanism for future mobile multimedia services, adaptive smart antenna is considered to be a solution for accommodating the crowded air spectrum and increased radio interference from the increasing demand of those services.

CHAPTER 7

HIGH-SPEED WIRELESS LANS

7.1 INTRODUCTION OF HIGH SPEED WIRELESS LAN

7.7.1 Multimedia Services require more Bandwidth

Fourth generation wireless networks include not only cellular telephone systems but also a variety of different high-speed voice and data communication systems. In public wireless networks, IMT-2000 has already been developed in the ITU to provide a standard sets for the third generation wireless cellular telephone system. The intention is to achieve interoperability across different wireless services and mobility on a global scale.

Data rates of third generation services are still limited to 2 Mbps, far below the transmission speeds of 155 Mbps for current optical fiber networks. That means, there still exist a huge gap between wired and wireless services. Studies of Fourth Generation (4G) wireless networks have targeted on enabling high-performance streaming of multimedia content to mobile users and providing seamless global connectivity, where at least 2 Mbps data rate is required for users on a moving vehicle and around 20~30 Mbps data rates for normal users.

Multimedia applications consist of simultaneously voice, date, images and video information. Access to motion video using MPEG format, for example, requires at lease 1.5~6 Mbps. That means, the suggested data rates for a wireless multimedia system is approximately 10 Mbps. For a base station accessed by multiple users, the aggregate radio transmission speed will need to be several tens of Mbps. (Nix, Beach et al., 1999) Consequently, the 2 Mbps data rate supported by either IMT-2000 or the 2 Mbps ~ 30 Mbps data rate targeted by future fourth generation cellular system are still not sufficient for the whole scope of wireless broadband multimedia services.

7.1.2 The Increase of Broadband Households

In the private network market, the allocation of worldwide available unlicensed radio spectrum at 2.4 GHz ISM (Industrial, Scientific and Medial) band and 5 H U-NII (Unlicensed National Information Infrastructure) band has become very popular for wireless data communication systems. Significant changes are occurring in the way people communicate at home, office or some short-range indoor area. Figure 7-1 shows the growth statistics and prediction of households' broadband Internet usages.

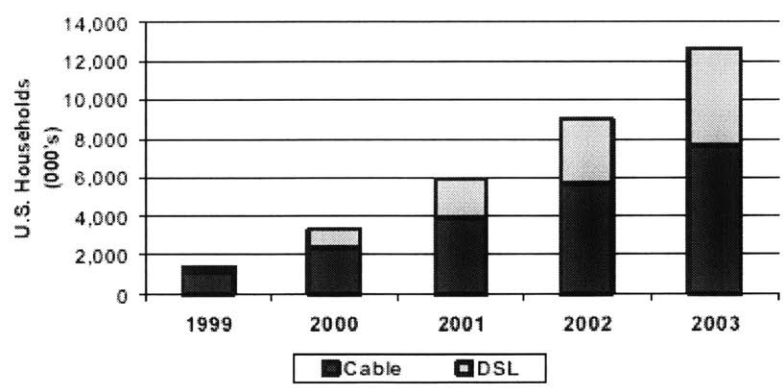

Figure 7-1 Broadband Subscribers in US Households

(Source: Yankee Group)

Industry shows increasing interests on indoor wireless connection solutions, more and more homes are equipped with more than one computer. This excites the wireless LAN (WLAN) industry.

The new series of IEEE 802.11 and HIPERLAN are competing standards developed in the US and Europe, and are both evolving into very high-speed wireless LAN solutions. Besides the above two standards, two other short-range radio technologies HomeRF and Bluetooth are emerging to the market. In this chapter, an overview of the above four wireless data communication standards: IEEE 802.11, HIPERLAN/2, Home RF SWAP, and Bluetooth will be presented. Also, their influence on the future trends towards building an integrated fourth generation wireless environment will be discussed.

7.2 WIRELESS NETWORKING STANDARDS

Wireless LAN, as its name suggests, provides users a local area network, which includes functions such and file sharing, peripheral sharing and Internet access, without wire. Wireless LAN adds mobility compares to the fixed LAN, for example, managers in an office environment do not need to unplug and plug again their network cable while doing presentations with their laptop from conference room one to conference room two. WLAN products for ISM bands have appeared in the market since the 90s. In 1997, IEEE 802.11 standardized for 2.4 GHz band to support 1 Mbps and optionally 2 Mbps. And a higher speed version of 802.11, 802.11b provides 11 Mbps throughput was approved in 1998, which is currently the main stream of WLAN in corporate environment. A newer version, 802.11a, which moves from the 2.4 GHz spectrum to the U-NII 5 GHz bands and provides physical layer data rate as high as 54 Mbps, is expected to substitute 802.11b as enterprise networking solution by 2002. Similarly, HIPERLAN/2, developed by ETSI, also aims on 54 Mbps of physical layer data rate at the 5 GHz frequency band. HomeRF is developed by an industry working group, the HomeRF consortium, which includes major players in PC industry, wireless telecommunications and consumer electronic industry. It focuses on the fast growing home networking market, and their mission is described as bringing together electronic devices anywhere in and around the home. Bluetooth technology supports ad hoc wireless networks for electronic devices and provides 1 Mbps communication data rate and around 10 to 100 meters short-range communication capacity. The main vision of Bluetooth is to replace cables between diversified devices at home and overcome the light-of-sight limitation of infrared links used nowadays. Brief introduction and technical overviews of these four standards are presented in the following sections.

7.2.1 IEEE 802.11

The IEEE 802.11, IEEE standard for Wireless LAN Medium Access (MAC) and Physical Layer (PHY) Specifications, is a wireless system suitable for indoor communication, which focuses on the MAC and PHY functionality for access point based infrastructure networks and ad hoc networks. (See Figure 7-2)

Infrastructure Network and Ad hoc Network

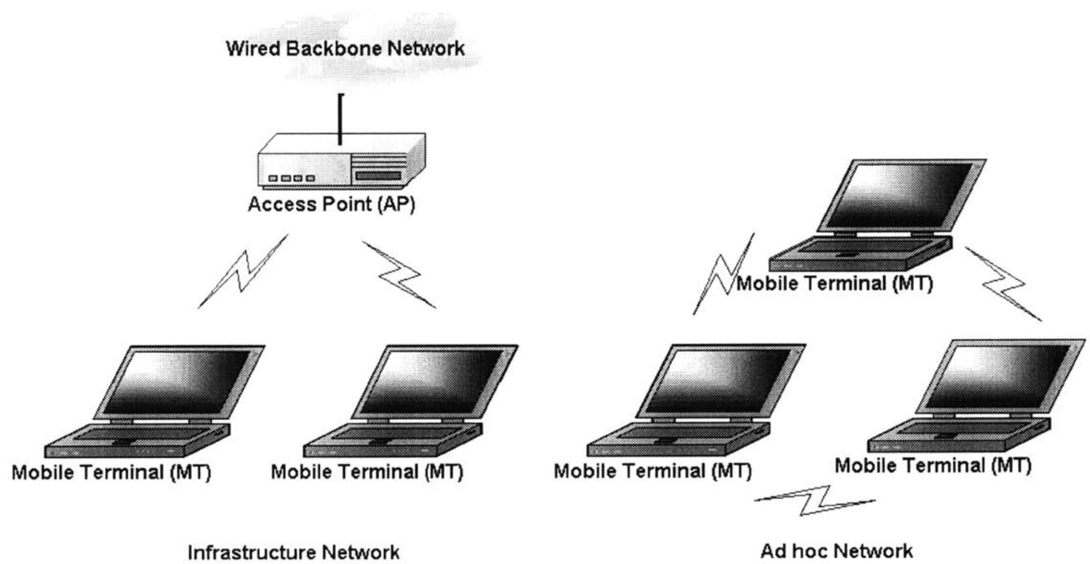

Figure 7-2 IEEE802.11 Network Types

The 802.11 standard supports wireless connectivity for fixed, portable, and moving stations at pedestrian and vehicular speeds with a local area. Two types of networks supported by 802.11 are infrastructure networks and ad hoc networks. The ad hoc network as shown in the right side of Figure 7-2 normally have stations communicate directly to each other and do not connect to the wired network. In an infrastructure network, as shown in the left side of Figure 7-2, an *Access Point (AP)*, which is connected to the wired network, covers a area called the *Basic Service Set (BSS)* where *Mobile Terminals (MT)* communicate directly to the AP; the interconnection among BSSs are realized through *Access Point (AP)* and form an *extended Service Set (ESS)*.

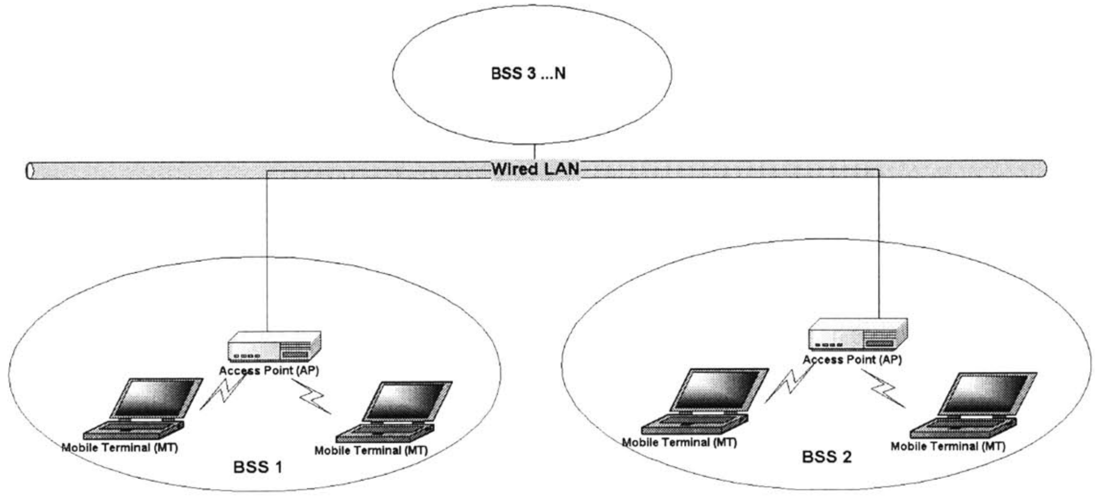

Figure 7-3 Extended Service Set (ESS)

802.11 Physical Layer (PHY)

At the Physical (PHY) layer, IEEE 802.11 defines three physical characteristics for wireless local area networks: infrared, Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS). The infrared PHY operates at the base band and the other two radio-based PHYs operate at the 2.4 GHz ISM band, a global ISM band which do not need end user license. Both radio based PHYs support data rate of 1 Mbps and 2 Mbps. After 802.11 standardized, the extension version 802.11b also operates at the 2.4 GHz ISM band and supports physical data rate up to 11 Mbps. 802.11b, which is currently the main stream used for corporate wireless environment, uses DSSS data transmission scheme. The DSSS works by first multiplying the narrowband message by a larger bandwidth signal, usually a pseudorandom noise, before sent it out by the transmitter. This broadens the spectrum. This broadening technique enables multi-access systems by applying different pseudorandom noises to different user's transmissions and send the signals within the same frequency band, when the broadened signal is received, it can then be de-spread back to the original transmitted data. However, IEEE 802.11b DSSS standard cannot use this feature because it can only tolerate relatively very low interference, which is much less than the interference will be caused by another use on the same channel. Thus, 802.11b separate simultaneous transmissions into three different frequencies, each has a 22 MHz bandwidth. The 2.4 GHz ISM bad, which is also used by HomeRF, Bluetooth, and microwave ovens, has become overpopulated in the past few years. This caused the main concern about interference in the home-networking environment.

In contrast, 802.11a uses the 5 GHz U-NII spectrums (5.15 to 5.35 GHz and 5.725 to 5.825 GHz), which in the United States were originally aimed for inexpensive computer networking in public schools. Since this is still an unoccupied spectrum, it is regarded as a network autobahn. This makes it possible for 802.11a standard to define a physical data rate up to 50 Mbps in a 20 MHz channels increments. IEEE 802.11a assigned eight such channels in the lower 200 MHz region and four channels in the upper 100 MHz region of this spectrum. IEEE 802.11a is based on OFDM (Orthogonal Frequency Division Multiplexing) modulation scheme, which has drawn increasing attention recently as a solution for high data rate access technology.

802.11 Medium Access Layer (MAC)

The 802.11 basic MAC uses a scheme called Carrier Sense Multiple Access with Collision Avoidance (CDMA/CA). This mechanism assigns random back-off time following a busy medium condition; after a busy condition, collision is most likely to happen because multiple stations are trying to send the messages and are waiting for the busy medium to become available again. By assigning random back-off time, it could result in the avoidance of the collision of packets from multiple stations, when the backed-off packet discovers that the medium is busy again, it backs-off again. A positive acknowledgment (ACK frame) will be received for all directed traffic, if no ACK is received, the sender will schedule retransmission.

7.2.2 HIPERLAN

HIPERLAN (High Performance Radio Local Area Networks) represents Europe's attempt to produce a next generation high-speed wireless LAN standard. The name collectively referred to a family of wireless network standards specified by ETSI Project Broadband Radio Access Networks (BRAN). Within this family of standards, HIPERLAN Type 1 for high speed wireless LAN, HIPERLAN Type 2 for short range wireless access to IP, ATM, and UMTS core networks are both operate in the 5GHz bands, HIPERACCESS for fixed wireless broadband point-to-multipoint radio access supports 25 Mbps data rate operates in various bands, and HIPERLINK for wireless broadband point-to-point interconnection supports 155 Mbps data rate over 150m distance operates in the 17 GHz band. (Pahlavan, Li, et al., 2000) Among these, HIPERLAN/2 has emerged as a stronger candidate towards future wireless data network. Below will introduce the main characteristics of HIPERLAN/2.

Topology

HIPERLAN/2 has a network topology very similar to IEEE 802.11, the MT communicate with the AP over an air interface defined by HIPERLAN/2 standard. The user of MT can move from one AP to another AP within the HIPERLAN/2 network, and the connected fix network will transfer related AP handover signals. (See Figure 7-4)

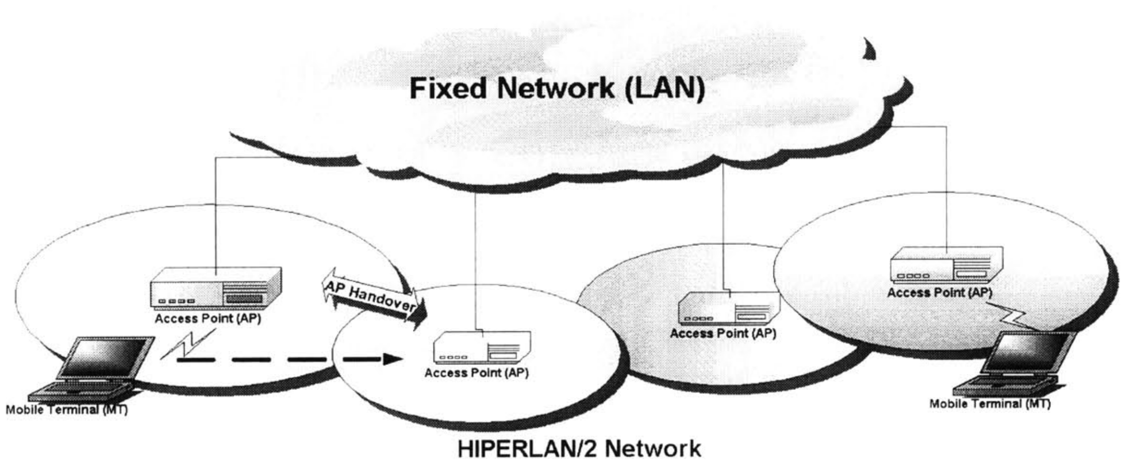

Figure 7-4 HIPERLAN/2 Network

HIPERLAN/2 is suitable for applications such as:

- **Corporate LAN:** HIPERLAN/2 is used for the last segment between MTs and the LAN. Moving MT can change connection to different APs while remaining its seamless connection.

- **Hot Spots:** HIPERLAN/2 can be used at hot spots such as airport, hotel, etc, to provide wireless connection for business people. A HIPERLAN/2 access server can route the PPP connection request to a VPN connection or ISP for network access.

- **Access to 3rd Generation Cellular Networks:** HIPERLAN/2 can be used in combination with W-CDMA networks, such that users will be automatically and seamlessly handed over between those two types of access network and the advantage of the most high-performance data transmission rate available.

- **Home Network:** HIPERLAN/2 can also provide a wireless infrastructure for home environment. The QoS feature of HIPERLAN/2 can support video streams transmission in conjunction with data applications.

Layer Architecture

Figure 7-5 shows the protocol reference layers of HIPERLAN/2 radio interface.

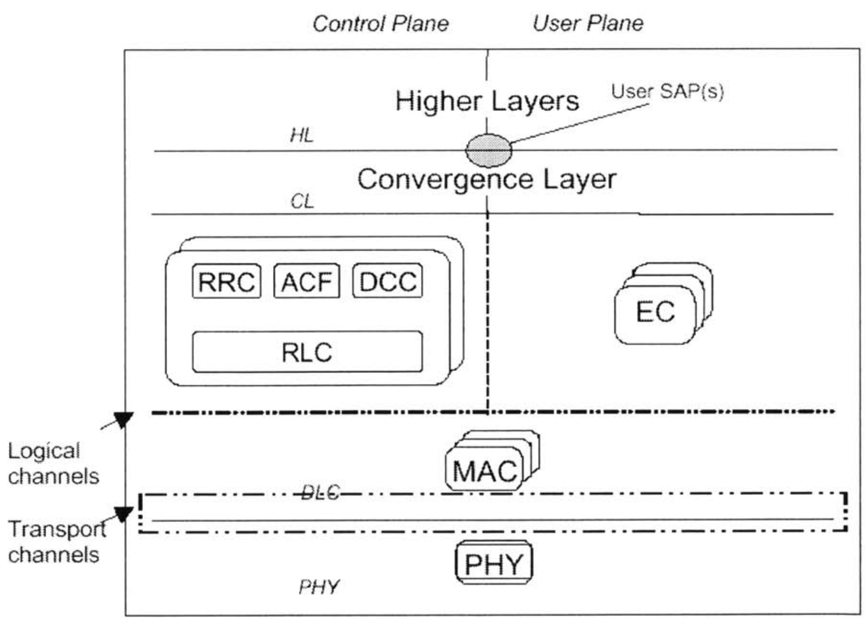

Figure 7-5 HIPERLAN/2 Layer Architecture

(Source: HiperLAN/2 Global Forum, 1999)

HIPERLAN/2 defines the two lowest layers of the open systems interconnections (OSI) model includes the physical and the data link control layer. The BRAN project took this approach to standardize the radio access network and convergence layer functionality to different core networks such as UMTS, ATM, or TCP/IP. It has three basic layers, Physical Layer (PHY), Data Link Control

Layer (DLC) and Convergence Layer (CL):

- **Physical Layer (PHY):** OFDM is used as the multicarrier modulation scheme here due to its excellent performance on highly dispersive channels. The channel spacing is 20 MHz, which allows high bit rates per channel but still has a reasonable number of channels in the allocated spectrum. One channel has 52 subcarriers, where 48 carry real data and 4 are used to facilitated phase tracking for coherent demodulation. The physical layer provided several modulation and coding alternatives to both adapt to current radio link quality and to meet the requirements for different physical later properties as defined for the transport channels within DLC.

- **Data Link Control Layer (DLC):** the DLC constitute logical link between an AP and MTs. It consists of set of sublayers:

  - **Medium Access Control Protocol (MAC)** is used for access to the medium with the resulting transmission of data onto that medium (radio link). The control is centralized to AP, which inform MTs when the MAC frame they are allowed to transmit their data according the resources requested from each MT. The MAC protocol is Time-Division Duplex (TDD) based dynamic TDMA, i.e., the time-slotted structure of the medium allows for simultaneous communication in both downlink and uplink communication within the same time frame called MAC frame in HIPERLAN/2. All data from both AP and MTs is transmitted in dedicated timeslots except fro the random access channel where contention for the time slot is allowed. The MAC frame and the transport channels form the interface between DLC and the physical layer.

  - **Error Control (EC) Protocol** is used to increase the reliability over the radio link. It initiate retransmission if detects bit errors.

  - **Radio Link Control (RLC) Protocol** gives a transport service for the signaling entities Association Control Function (ACF), Radio Resource Control Function (RRC) and the DLC user Connection Control Function (DCC). These four entities comprise the DLC control plane and handle the signaling message exchange between AP and MT.

- **Convergence Layer (CL):** CL has two main functions, one is to adapt services requested from higher later to the service provided by DLC, the other is to convert the higher later packets with variable or possibly fixed size into fixed size that is used within DLC. Two different types of CLs are defined: cell-based and packet-based. The former is intended for interconnection to ATM networks, and the later can be used in a variety of configurations depending on fixed network type and how the interworking is specified. (See Figure 7-6 for an illustrative explanation)

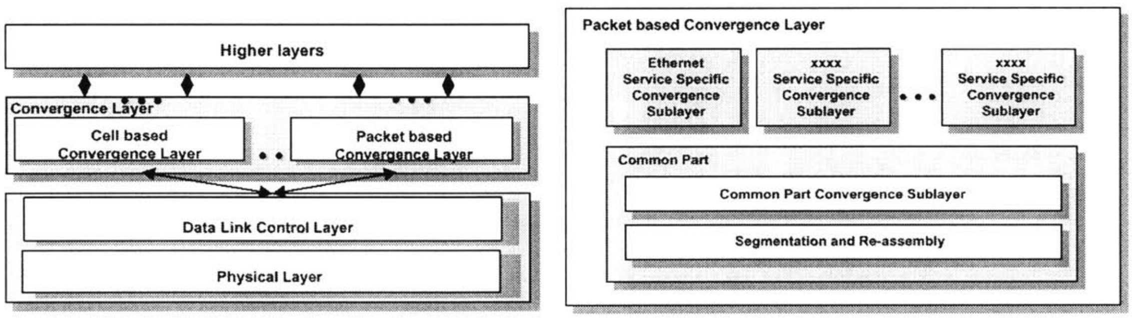

Figure 7-6 Convergence Layer and Packet-based CL Structure

(Source: HiperLAN/2 Global Forum, 1999)

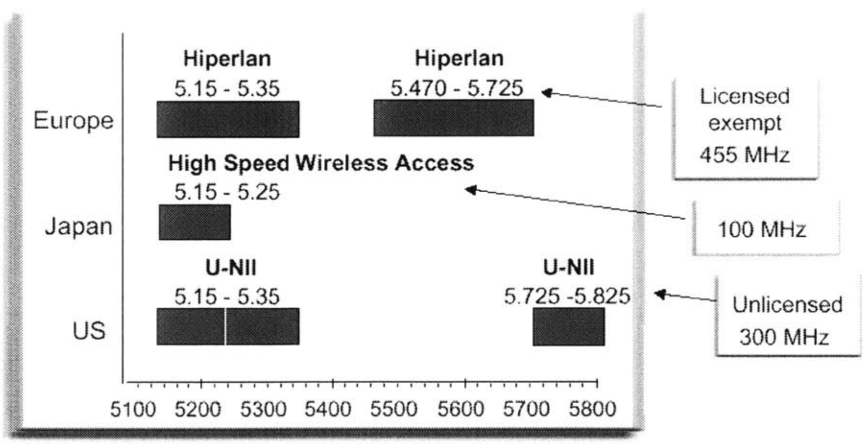

Figure 7-7 5GHz Spectrum Allocation

(Source: HiperLAN/2 Global Forum, 1999)

Spectrum Allocations and Coverage

The 5GHz spectrum bands have drawn increasingly attention for high-data rate wireless communication usages. Figure 7-7 shows the spectrum allocations around 5GHz in Europe, Japan, and US respectively. In Europe, a total of 455 MHz between 5.15-5.35 GHz and 5.470- 5.725 GHz is the license free bands that can be used for HIPEPRLAN systems. In Japan, 100 MHz between 5-15-5.25 GHz is allocated for Wireless LANs, and more spectrums is under investigation. In the US, a total of 300 MHz between 5.15-5.35 GHz and 5.725-5.825 GHz is the U-NII bands and will be used for IEEE 802.11a systems. A HIPERLAN/2 AP typically covers approximately 30 meters in doors to a maximum of 150 meters.

HIPERLAN/2 Features

HIPERLAN/2 provides very high transmission rate, 54 Mbps at the physical layer, same as IEEE 802.11a. The OFDM modularization method used is also the same as IEEE802.11a with different parameters. HIPERLAN/2 uses TDMA as its air interface; a connection between the MT and AP has to be established first before data gets transmitted. Point-to-Point and Point-to-Multipoint are two types of connections available for HIPERLAN/2; in addition, there is also a dedicated broadcast channel through which traffic reaches all MTs from one AP.

Characteristic	802.11	802.11b	802.11a	HiperLAN/2
Spectrum	2.4 GHz	2.4 GHz	5 GHz	5 GHz
~Max physical rate	2 Mb/s	11 Mbit/s	54 Mb/s	54 Mbit/s
~Max data rate, layer 3	1.2 Mb/s	5 Mb/s	32 Mb/s	32 Mb/s
Medium access control/Media sharing	Carrier sense – CSMA/CA			Central resource control/ TDMA/TDD
Connectivity	Conn.-less	Conn.-less	Conn.-less	Conn.-oriented
Multicast	Yes	Yes	Yes	Yes[1]
QoS support	(PCF)[2]	(PCF)[2]	(PCF)[2]	ATM/802.1p/RSVP/ DiffServ (full control)
Frequency selection	Frequency-hopping or DSSS	DSSS	Single carrier	Single carrier with Dynamic Frequency Selection
Authentication	No	No	No	NAI/IEEE address/X.509
Encryption	40-bit RC4	40-bit RC4	40-bit RC4	DES, 3DES
Handover support	(No)[3]	(No)[3]	(No)[3]	(No)[4]
Fixed network support	Ethernet	Ethernet	Ethernet	Ethernet, IP, ATM, UMTS, FireWire, PPP[5]
Management	802.11 MIB	802.11 MIB	802.11 MIB	HiperLAN/2 MIB
Radio link quality control	No	No	No	Link adaptation

Table 7-1 Comparison between IEEE802.11 and HIPERLAN/2

(Source: HiperLAN/2 Global Forum, 1999)

The connection-oriented nature of HIPERLAN/2 enables the specific assignment of QoS towards each connection. This facilitates the simultaneous transmission of many different types of data streams such as video, voice, image and data, which require different QoS respectively. HIPERLAN/2 also supports automatic frequency allocation; an AP selects an appropriate radio channel automatically in regard of the situation to minimize interference with the environment. The protocol stack illustrated above ensures a flexible architecture for easy adaptation and integration with a variety of network systems includes fixed network and public cellular infrastructure.

7.2.3 HomeRF

HomeRF, as its name suggests, is aimed at the growing home networking market. As the number of household electronic equipments increases, a home networking infrastructure can serve for the integration and a variety of peripherals such that multiple computers in a household can share the same printer, digital camera, scanner and so on. It is estimated that the revenue of home networking market will reach 1.4 billion for the US households. (See Figure 7-8, HomeRF Working Group, 2001)

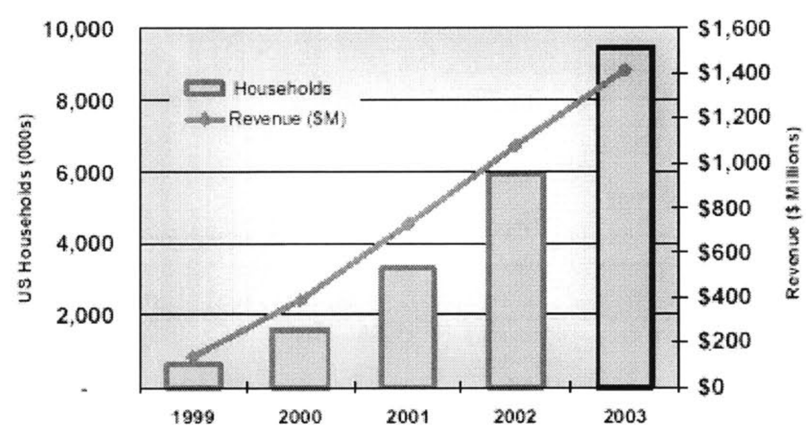

Figure 7-8 Home Networking Market Prediction

(Adopted from HomeRF Working Group)

HomeRF uses the Shared Wireless Access Protocol (SWAP), which defines a common air interface for both wireless data and voice services. SWAP was developed by HomeRF Working Group, a joint effort from major consumer electronics companies, which was formed to provide the foundation of a broad range of interoperable consumer devices by establishing an open industry specification for wireless digital communication between PCs and all other consumer electronics devices around the home. SWAP operates in the 2.4 GHz ISM band using Frequency Hopping Spread Spectrum (FHSS) technique.

Topology

HomeRF is designed for simultaneously broadband speed Internet access, resource sharing, multiple streaming media sessions, and multiple toll-quality voice connections. Figure 7-9 illustrates the network topology for HomeRF.

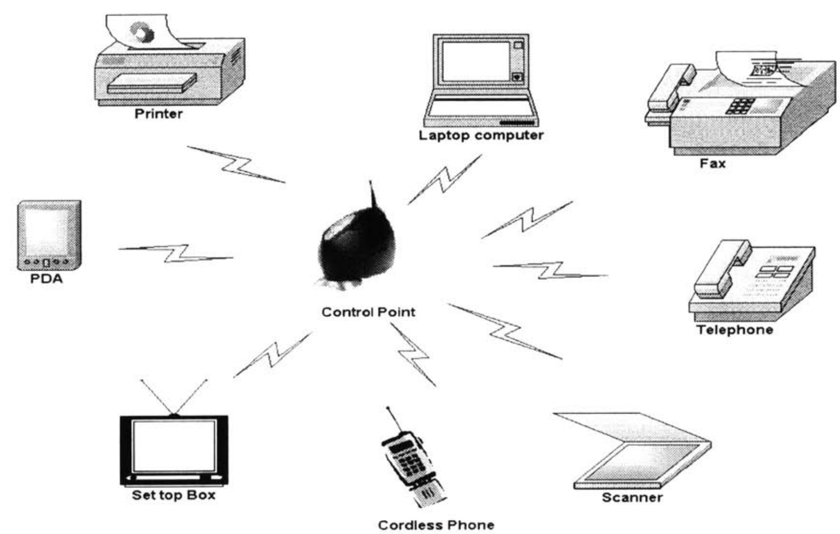

Figure 7-9 HomeRF Topology

Layer Architecture

HomeRF combines the benefits of both Digital Enhanced Cordless Telecommunications (DECT), which is good for voice communication, and IEEE 801.11, which has high performance in data communication. The protocol architecture is similar to the IEEE 802.11 in PHY, and in MAC, HomeRF defines two separate subsets for its two primary services, voice and data. The Voice packets are sent with a guaranteed access TDMA/TDD protocol using DECT standards to provide isochroous services. The data packets are sent using a wireless version of Ethernet built on the CSMA/CA protocol for delivery of higj-speed packet data, such as TCP/IP. (See Figure 7-10, 7-11)

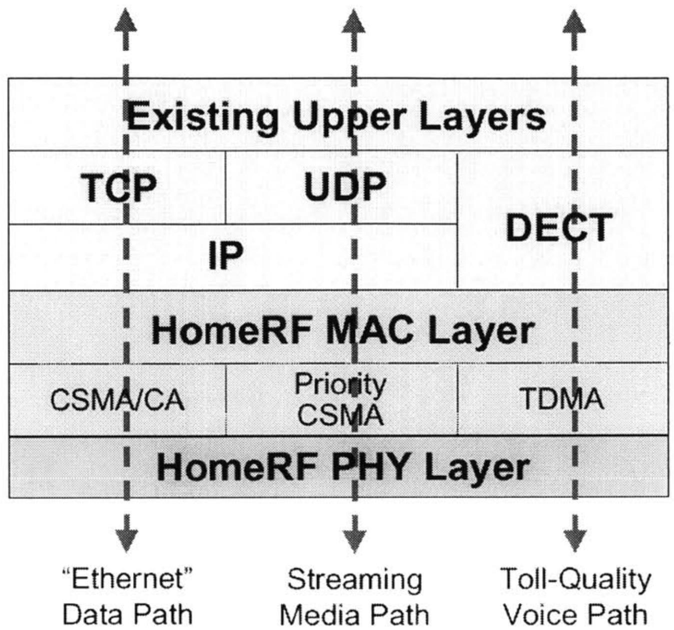

Figure 7-10 HomeRf Network Layer Stacks

(Adopted from HomeRF Working Group, 2001)

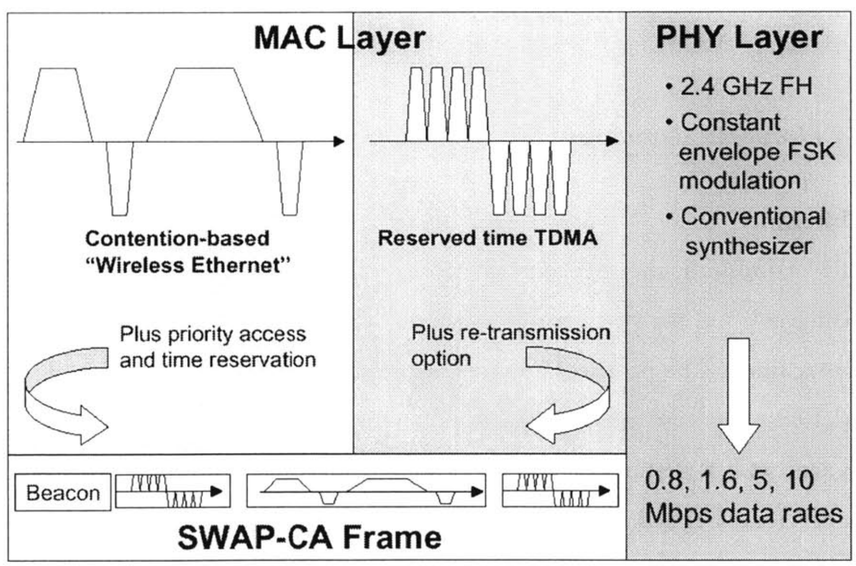

Figure 7-11 HomeRF MAC and PHY Layer

(Adopted from HomeRF Working Group, 2001)

Data Rate Roadmap

HomeRF PHY layer operate in the 2.4 GHz band using FHSS at 50-100 hops/s, the radios are simple and similar to Bluetooth. The first generation HomeRF currently covers most of the home wireless networking market share, it has peak data rate of 1.6 Mbps and covers around 50 meters. Second Generation HomeRF is due to ship in mid-2001 use 10 Mbps peak data rates, and third generation HomeRF devices are planned to ship in the second half of 2002, which will reach a 20 Mbps data rates capable for receiving HDTV services. HomeRF used to have the price advantage over enterprise targeted IEEE 802.11b. Also, because of the two MACs architecture, HomeRF handles voice communication data much better than IEEE 802.11b. However, as IEEE 802.11 series lower the price and step into the huge home market, and the new version, IEEE 802.11a jumps out from the crowded 2.4 GHz bands to avoid interference as well as enjoy the 5 GHz high-speed autobahn, HomeRF will probably face a strange competition.

7.2.4 Bluetooth

Bluetooth SIG

Bluetooth Special Interest Group was founded in 1998, original promote companies consist of five leading companies within the telecommunication and computer industries Ericsson, Intel, IBM, Nokia and Toshiba. In 1999, four more companies 3Com, Microsoft, Motorola, Lucent joined the SIG, and it currently have more than 2000 other manufacturers, from all parts of the world and various fields of business, joined the Bluetooth family. This makes it by far the fastest growing industry standard ever. In brief, Bluetooth is a global standard that eliminates wires and cables between both stationary and mobile devices, facilitates both data and voice communication and offers the possibility of ad hoc networks and delivers the ultimate synchronicity between all electronic personal devices.

The name "Bluetooth" refers to the Danish king Harald Bland (Bluetooth) who unified Denmark and Norway. In the beginning of the Bluetooth wireless technology era, it was aimed at unifying the telecom and computing industries. Since then, the Bluetooth wireless technology has grown to influence pretty much all areas where cable replacement is needed. It is estimated that by 2005 the Bluetooth wireless technology will be a built-in feature in more than 670 million products.

Topology

Bluetooth is a radio communications technology designed to enable wireless short-range communications between mobile devices, such as laptops, palmtops, headsets and so on. It's implemented as an inexpensive power-effective radio chip that is small enough to fit inside an electronic device or machine that provides local connectivity. Bluetooth operates in the 2.4GHz ISM band, same as HomeRF and IEEE802.11b, and has a range of around 10 meters (or 35 feet) to 100 meter; it transfers data at a rate of 720 kbps.

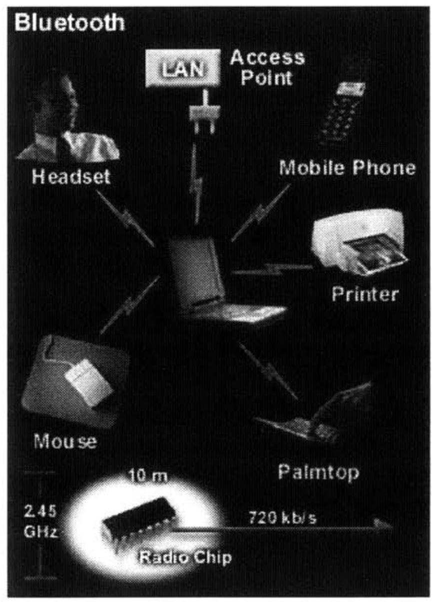

Figure 7-12 Bluetooth Network

(Source: Ericsson, 2000)

Bluetooth provides two kinds of connections: ad hoc point-to-point and point-to-multipoint connections. Figure 7-12 is an illustration of point-to-multipoint Bluetooth network. Two or more Bluetooth units that share a channel form a piconet, and several piconets can be established and linked together to allow communication and data exchange in flexible configurations, where each piconet is identified by a different frequency hopping sequence and all user participating the same piconet are synchronized to this hopping sequence. Unlike infrared devices, Bluetooth units are not limited to line-of-sight communication.

Within a piconet, one unit becomes a master and all other units become salves. And up to seven slaves can actively communicate with one master.

Technology

Bluetooth uses FHSS with a hop rate up to 1500 hops/s to give a high degree of interference immunity; the signal hops among 79 frequencies at 1 MHz intervals. The radio specification was designed specifically for enabling single-chip implementation in CMOS circuits, thereby reducing cost, power consumption and the chip size required for implementation in mobile devices. In handling voice data, up to three simultaneous synchronous voice channels are used, or a channel, which simultaneously supports asynchronous data and synchronous voice. Each voice channel supports a 64 kbps synchronous (voice) channel in each direction. For data signals, the asynchronous data channel can support maximal 723.2 kbps asymmetric and still up to 57.6 kbps in the return direction, or 433.9 kbps symmetric.

Usage Scenario

Several usage scenario have be defined for Bluetooth:

- **File Transfer:** transfer files between master and slave devices, such as between laptop and PCs.
- **Internet Bridge:** A mobile phone or laptop with embedded Bluetooth functionality can access to the net via a wire-bound connection point, the mobile device will connect directly to the Internet without the need of a cable.
- **LAN Access:** Bluetooth devices can be integrated into a LAN environment and form a wirelessLAN.
- **Synchronization:** Bluetooth can automatically synchronize the calendar, address book, etc. between laptop and PDA or mobile phones. While receiving new mails, it will synchronize to the email software in PDA or mobile phone even without bringing out the laptop from the suitcase.
- **Three-in-One Phone:** Bluetooth enables a phone terminal becomes a mobile phone while being outside, a cord phone while being inside and a cordless phone when

needed.

- **Ultimate Headset:** Bluetooth allows users to use mobile phone while keeping their hands free.

Hardware and Software Architecture

Figure 7-13, 7-14 illustrate Bluetooth hardware and software architecture respectively.

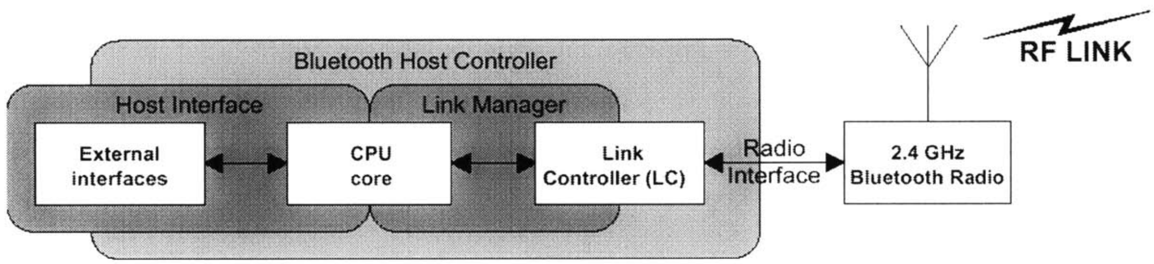

Figure 7-13 Bluetooth Hardware Architecture

(Adopted from Ericsson)

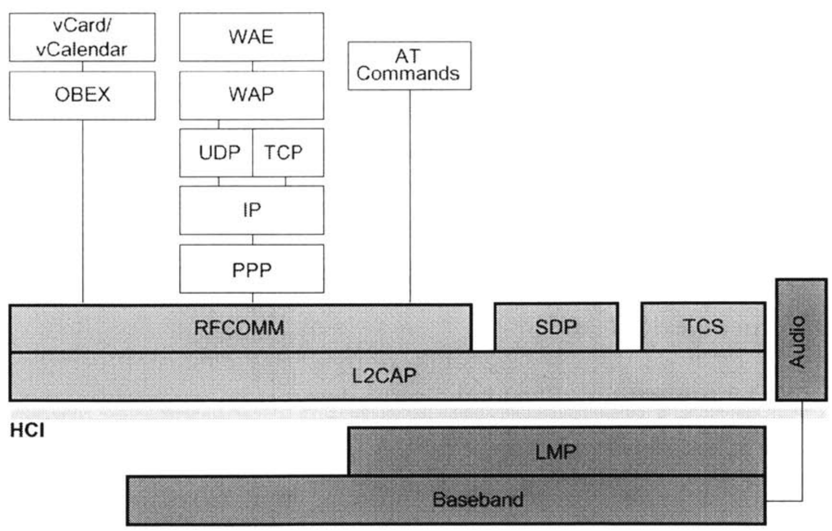

Figure 7-14 Bluetooth Software Architecture

(Adopted from Ericsson)

The Bluetooth hardware consists of both analog radio part and digital Host Controller part. The Host Controller has a hardware digital signal processing part called the Link Controller (LC), a CPU core and interfaces to the host environment. The Link Controller consists of hardware that performs baseband processing and physical layer protocols to perform asynchronous transfers, synchronous transfers, audio coding and encryption. On the CPU core, Link Manager (LM) software discovers other LMs and communicates with them via the Link Manager Protocol (LMP) to perform its service provider role and to use the services of the underlying Link Controller.

The Bluetooth software part consists of protocols like the Service Discovery Protocol (SDP), RFCOMM (emulating a serial port connection) and the Telephony Control protocol (TCS), they are interfaced to baseband services via the Logical Link Control and Adaptation Protocol (L2CAP). Between software and hardware, Host Controller Interface (HCI) is a common interface to ensure compatibility of different hardware implementations.

7.3 COMPIRISION OF WIRELESS NETWORKING CHOICES

The above four standards, Bluetooth, HomeRF, IEEE 802.11 and HIPERLAN/2, though target on different market segments and have some different features as well as architectures, are similar but competing standards. While Bluetooth, HomeRF, and IEEE 802.11b all operate on the 2.4 GHz ISM ban, the fast FHSS Bluetooth signal, which is designed to be always on in order to automatically configure itself into an ad hoc network as devices come into the range, is very possible to kill HomeRF or 802.11 packet when coexisted. Bluetooth is short-range and is often referred to as a Personal Area Network (PAN) selection. However, it has overlapping usage scenarios with the Home Area Network (HAN) oriented HomeRF. IEEE 802.11 and HIPERLAN/2 are two incompatible and competing standards, which represent the enterprise WLAN approaches in the US and Europe. The newer versions of these two standards both operate on the 5GHz band and have high-speed data rate. Consideration of integrating these two standards into one has been discussed, however, at this point, concrete result has not emerged yet. In the long term, Bluetooth will probably be integrated into other WirelessLAN technologies to avoid interference. An illustration of the related scopes of Bluetooth, HomeRF, 802.11, HIPERLAN/2 and cellular system is in Figure 7-15, and Table 7- 2 summaries the data rate, technology used, mobility, coverage, and frequency bands of these standards.

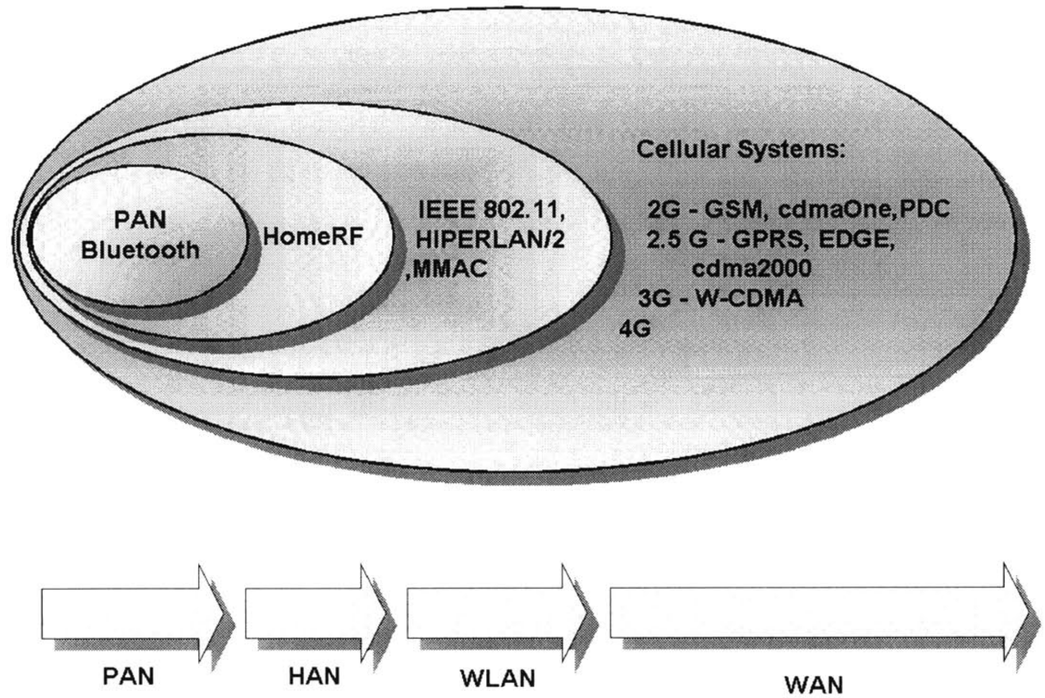

Figure 7-15 Wireless Data Communication Scope

	Bluetooth	HomeRF	IEEE 802.11a	HIPERLAN/2	UMTS
Data Rate	720 kbps	1.6 ~10 Mbps	54 Mbps (PHY)	54 Mbps (PHY)	2 Mbps
Technology	FHSS	FHSS	OFDM, TDD	OFDM, TDD	W-CDMA
Range	10-100 m	50 m	50-300 m	50-300 m	30 m-20 Km
Mobility	Very Low	Low	Low	Low	High
Frequency Range	2.4 GHz	2.4 GHz	5 GHz	5 GHz	2 GHz

Table 7-2 Summary of Wireless Data Communication Technologies

7.4 CHALLENGES AND FUTURE TRENDS

Although the above standards have their own advantage and specific feature, customers are unlikely to purchase four solutions for one similar wireless data network requirement. As a result, inter-technology mobility becomes very important issue in the future integration consideration. Inter-technology mobility could ensure the seamless roaming between cellular network and WLAN solutions, and users who choose one WLAN solution will not confine themselves from potential usage of all other solutions. Software-defined radio as discussed in chapter 5, or IN discussed in chapter 6 will probably achieve this inter-technology mobility in the future. This is believed to be one part of the 4^{th} generation wireless system.

PART III

THE IMPACTS

CHAPTER 8

CONCLUSION

The evolutionary generation changes in wireless communication industry have occurred every decade. From the 1980s First Generation analog cellular telephone system, the 1990s Second Generation digital cellular system, to the 2000s Third Generation wireless system.

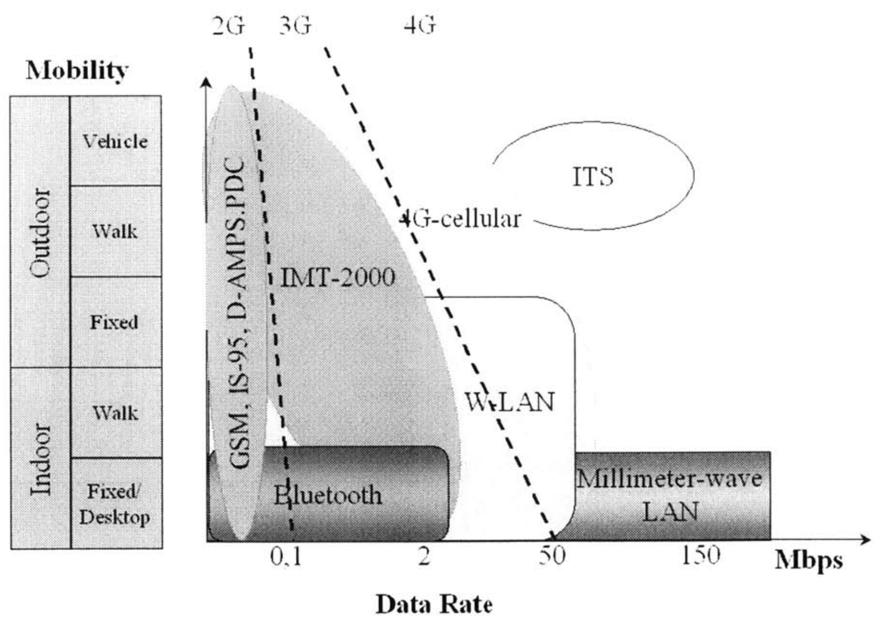

Figure 8-1 Wireless Communication Evolution

The data transmission rates have also grown from the 9.6 Kbps in AMPS analog system launched in 1979, early GSM and IS-136, the 14.4 Kbps in early IS-95 systems launched around 1995, to the 114 Kbps in GPRS launched in 2000 and the anticipated 384 kbps~2Mbps in Third Generation UMTS/IMT-2000 systems.

In the next decade, Fourth Generation Network is expected to emerge as a converged access platform for both broadband wireless and wired systems. In Figure 8-1, the wireless communication industry evolution path is shown. The upcoming Fourth Generation Network will combine Fourth Generation Cellular system that has a minimum data rate of 2 Mbps and up to 20~30 Mbps in lower mobility situation, Intelligent Transport System (ITS) that uses the millimeter wave frequency around 60 GHz and carry a data rate to around 150 Mbps, current Wireless LANs that use the 2.4 GHz and 5GHz frequencies and have transmission data rates up to 54 Mbps, and the future Ultra High Speed Wireless LAN that uses also 60 GHz millimeter wave frequency and carry a data rate more than 150 Mbps.

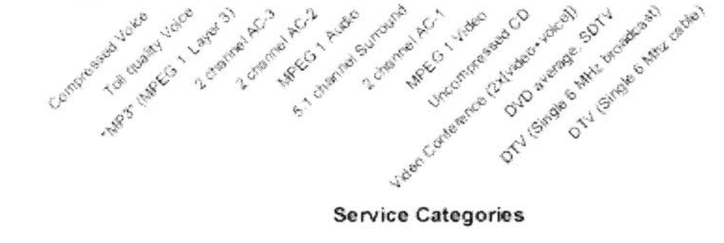

Figure 8-2 Multimedia Services Data Rate Requirement

(Adopted from HomeRF Working Group, 2000)

8.1 MOBILE MULTIMEDIA SYSTEMS

Fourth Generation network is designed to enable high-performance streaming multimedia content such as streaming video and audio to mobile users. The Quality of Service (QoS) requirements for the streaming of audio and video over a wireless network are dramatically different from the requirements for the transmission of standard data. Figure 8-2 summaries the data rate requirements for different multimedia services. As a result, higher level of QoS not originally included in these networking standards is particularly important to address in designing next generation networks.

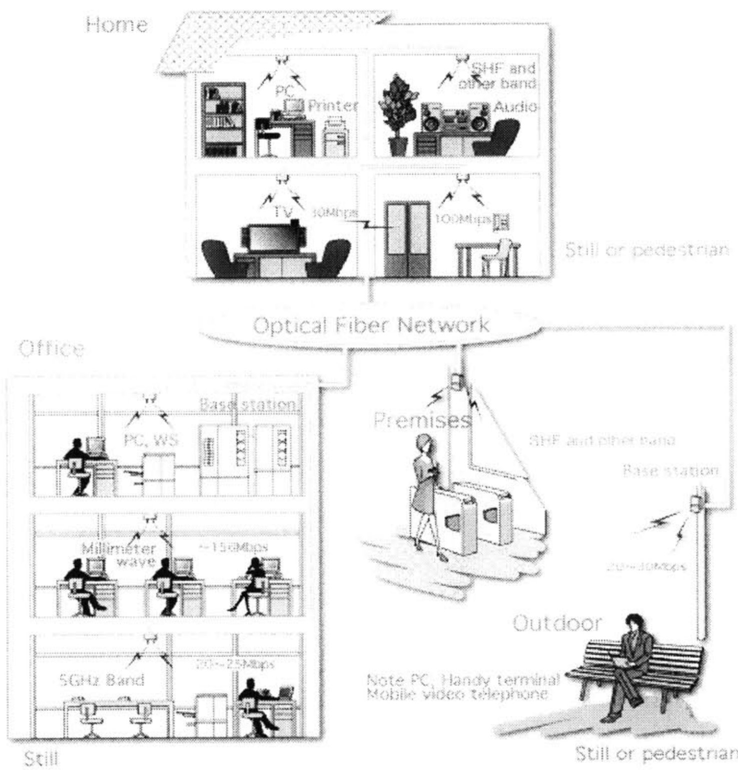

Figure 8-3 Multimedia Mobile Communication Access System in Japan

(Adopted from MMAC)

To accommodate the various multimedia services data rate requirements, the Fourth generation network will result in an integrated network that consists of different access technologies to serve different data rate requirements. Figure 8-3 is the Multimedia Mobile Communication Access

System planed to launch in Japan in 2002, which combines:

- High Speed Wireless Access (outdoor, indoor): Mobile Communication System, which can transmit at up to 30 Mbps using the 3-60 GHz SHF bands. It can be used for mobile video telephone conversations.

- Ultra High Speed Wireless LAN (indoor): Wireless LAN, which can transmit up to 156 Mbps using the millimeter wave radio band (30-300 GHz). It can be used for high quality TV conferences.

- 5GHz Band Mobile Access (outdoor, indoor): ATM type Wireless Assess and Ethernet type Wireless LAN using 5GHz band. Each system can transmit at up to 20-25Mbps for multimedia information.

- Wireless Home-Link (indoor): Wireless Home-Link which can transmit up to 100Mbps using the SHF and other band (3-60GHz). It can be used for between PCs and Audio Visual equipments transmit multimedia information. (Source: MMAC)

8.2 SEAMLESS NETWORKS

Fourth Generation Network is aiming to enable global seamless roaming capability. From the user's perspectives, there will be a variety of broadband access technologies that could be divided into five layer structures:

- **Distributed Layer:** Includes Digital Audio Broadcast (DAB) and Digital Video Broadcast (DVB) technologies that provide full coverage, global access and full mobility.

- **Cellular Layer:** Includes 2G GSM, PDC, IS-95 system, 3G UMTS'IMT-2000 systems, and future 4G cellular telephone systems. This layer provides also full coverage, full mobility and global roaming capability.

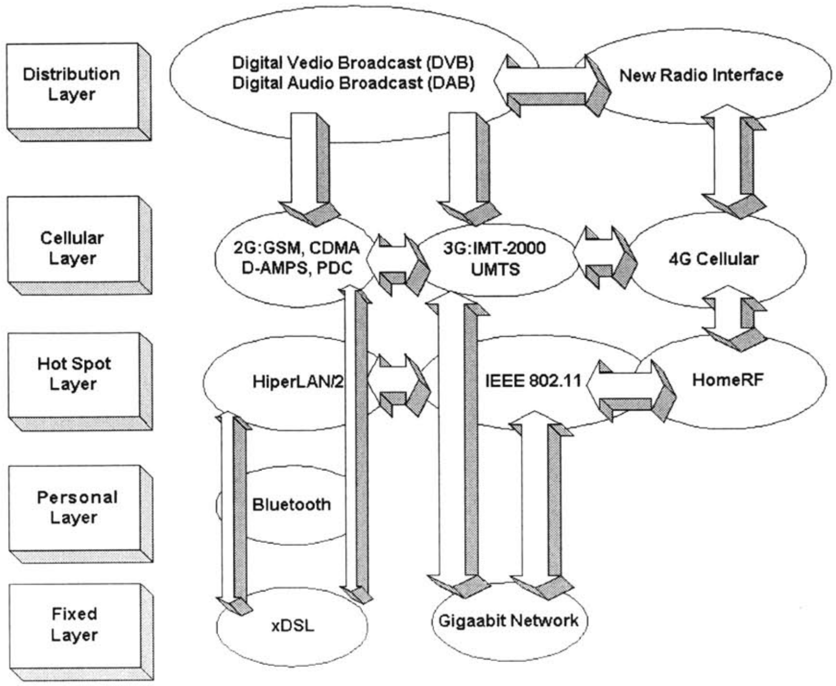

Figure 8-4 Layered Structure of Future Interworking Networks

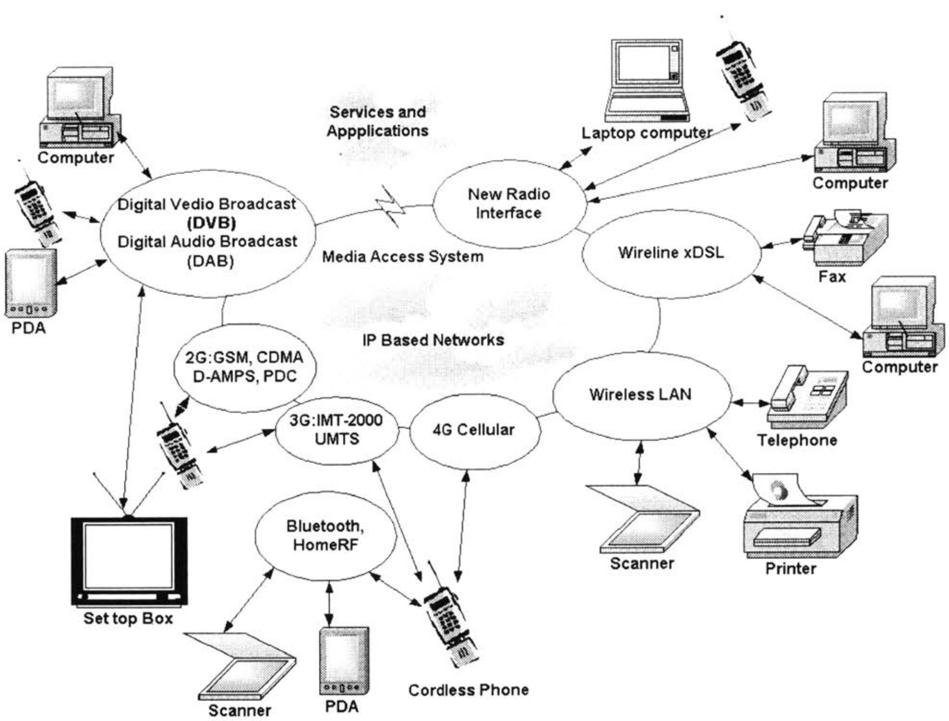

Figure 8-5 Seamless Future Network

- **Hot Spot Layer:** Includes Wireless LAN systems such as IEEE 802.11, HiperLAN/2, HomeRF. This layer provides local coverage, local mobility and global roaming capability.

- **Personal Layer**: Includes personal network technology such as Bluetooth that provides short-range communication and global roaming capability.

- **Fixed Layer:** Includes fixed network infrastructure such as fiber optics, Ethernet, ISDN, cable modem and xDSL. This layer provides no mobility but ensures high data rate and reliable transmission.

Figure 8-4 illustrates the horizontal handover between systems within the same layer and vertical handover between systems within different layers.

8.3 SUMMERY

The future Fourth Generation system will be based on IP core network that allows global IP mobility capability. It will combines a variety of different access technologies like cellular telephone systems, Intelligent Transport System, high-speed Wireless LAN systems and provide a common platform to complement the features and limitations of different service requirements. Software technologies such as software-defined radio, Mobile Agent Technology (MAT) and CORBA Technology will be used to ensure smooth handover between systems and divergent legacy networks. In addition to use newer frequency spectrum, smart antenna system can provide an intelligent way to accommodate more users. As shown in Figure 8-5, the future Fourth Generation Network will integrate mobile and fixed networks and offer seamless connectivity for high-performance multimedia services.

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APPENDIX

INDEX

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