Enhanced Radio Access Technologies for Next Generation Mobile Communication

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CHAPTER 1

OVERVIEW OF MOBILE COMMUNICATION

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Abstract: Following chapter introduces the mobile communication, gives a short history of wireless communication evolution, and highlights some application scenarios predestined for the use of mobile devices. Cellular and wireless based systems related to different generations of mobile communication, including GSM, IS-95, PHS, AMPS, D-AMPS, cdma2000 and WCDMA are also described by this Chapter. Much attention in this chapter is given to express the wireless based networks, such as Wi-Fi and WiBro/WiMax, and wireless broadcasting systems, including DMB, DVB-H, and ISDB-T. We conclude the chapter with the future vision of mobile communication evolution

Keywords: mobile communication; wireless communication; first generation (1G); second generation (2G); thirdgeneration (3G); IMT-2000; UMTS; WCDMA; cdma2000; TDSCDMA; IEEE 802.11; WiFi-; IEEE 802.15; Bluetooth; UWB; WiBro; WiMax; wireless broadcasting; DMB; DVB-H; ISDB-T; OFDMA; MC DS-CDMA

1. INTRODUCTION TO MOBILE COMMUNICATION SYSTEM

To this day, there have been three different generations of mobile communication networks. First-generation of (1G) wireless telephone technologies are the analog cell phone standards that were introduced in the 80s and continued until being replaced by **2G** digital cell phones in 1990s. Example of such standards are **NMT** (Nordic Mobile Telephone), used in Nordic countries, **NTT** system in Japan, and the **AMPS** (Advanced Mobile Phone System) operated in the United States. The second-generation **(2G)** technology is based on digital cellular technology. Examples of the 2G are the Global System for Mobile Communications **(GSM),** Personal Digital Cellular (**PDC**), and North American version of CDMA standard (**IS-95**). The third generation **(3G)** started in October 2001 when **WCDMA** network was launched in Japan. The services associated with 3G provide the ability to transfer both voice data (a telephone call) and non-voice data (such as downloading information, exchanging email, and instant messaging).

Y. Park and F. Adachi (eds.), Enhanced Radio Access Technologies for Next Generation Mobile Communication, 1–37.

Technology	1G	2G	2.5G	3G	3.5G	4G
Standard	AMPS, TACS, NMT, ETC.	TDMA, CDMA, GSM, PDC	GPRS, EDGE, 1×RTT	WCDMA, CDMA2000	HSDPA WiBro(Mobile WiMax)	Single standard
Implementation	1984	1991	1999	2002	2006	2010
Data Rate	1.9Kbps	14.4Kbps	384Kbps	2Mbps	10 ~ 50Mbps	100Mbps ~ 1Gbps
Multiplexing	FDMA	TDMA, CDMA	TDMA, CDMA	CDMA	CDMA, OFDMA	CDMA, OFDMA, ?
Service	Analog voice, synchronous data to 9.5 Kbps	Digital voice, Short messages	Higher capacity, packetized data	Higher capacity, broadband data up to 2Mbps	Portable Internet, High speed Wireless Internet, multimedia	Higher capacity, completely IP oriented, multimedia, data up to 1Gbps

Figure 1. Mobile communication generations

Figure 1 illustrates a brief overview on each generation. More detail information about mobile communication evolution steps is given in section 2.

The advances in cellular systems, wireless LANs, wireless MANs, personal area networks (PANs), and sensor networks are bound to play a significant role in the people communication manner in the future. It is expected that in the following years most of the access part of the Internet will be wireless. Increasing capacity and data rate of mobile communication systems enable to develop extended applications and services. **Figure 2** demonstrates some application environments and modern services focusing on South Korea and Japan's markets and technology trends. The current and awaited mobile services in these countries can be viewed as follows:

E-mail: This is a killer application regardless of the mobile network generation. The e-mail applications both send a message to other mobile phone or to anyone who has an Internet e-mail address. Mobile terminals also can receive e-mail. Low cost and fully compatibility with normal Internet e-mail makes this service popular among the mobile Internet users.

Web Browsing: Although mobile browsing is not popular everywhere today, it is very likely that within next ten years from now, mobile phone users will connect to Internet and use a mobile browser as an everyday tool. But this requires that the mobile browsing user experience improves: connection speed, number of services, and usability must increase, while cost per byte must decrease. While 2G networks allow predominantly text-based HTML browsing, 2.5G and 3G mobile terminals with TFT displays with 262,144 colors enables mobile users to browse Internet contents with high quality.

Two candidates aimed to enabling the Web browsing application to be built with wireless technology. One of them is Wireless Application Protocol (WAP) which was designed to provide services equivalent to a Web browser with some mobile-specific additions, being specifically designed to address the limitations of very small portable devices. The Japanese *i-mode* system is the other major competing wireless data protocol. WAP was hyped at the time of its introduction, leading users to expect WAP to have the performance of the Web. In terms of speed, ease of use, appearance, and interoperability, the reality fell far short of expectations. This led

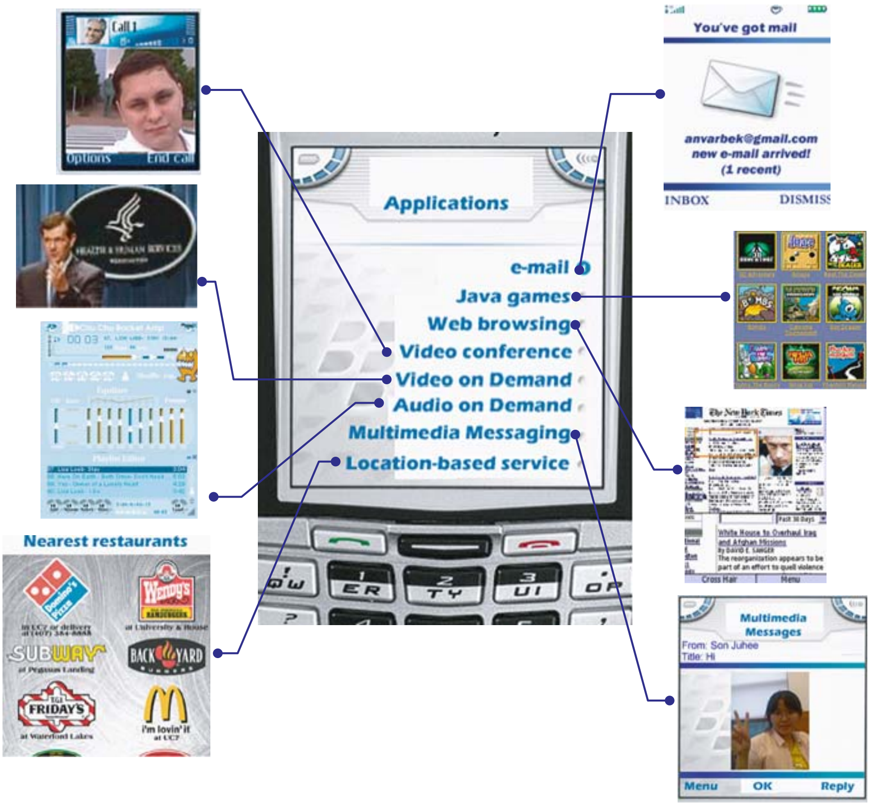

Figure 2. Mobile applications

to the wide usage of sardonic phrases such as "Worthless Application Protocol", "Wait And Pay", and so on. While WAP did not succeed, *i-mode* soon became a tremendous success. *i-mode* phones have a special *i-mode* button for the user to access the start menu. There are numerous official sites – and even more unofficial ones – that can be made available by anyone, using HTML and with access to a standard Web server. As of June 2005, *i-mode* has 45 million customers in Japan and over 5 million in the rest of the world.

Multimedia Messaging Service (MMS) is a technology for transmitting not only text messages, but also various kinds of multimedia content (e.g. images, audio, and/or video clips) over wireless telecommunications networks. MMS-enabled mobile phones enable mobile users to compose and send messages with one or more multimedia parts. Mobile phones with built-in or attached cameras, or with built-in MP3 players are very likely to also have an MMS messaging client – a software program that interacts with the mobile subscriber to compose, address, send, receive, and view MMS messages.

Java Application: Most recent mobile devices are able to run wide variety of Java-based applications. It was expected that Java capable phones will be used for financial services and other e-commerce businesses, but however main Java-based applications are the video games. NTT DoCoMo was the first carrier globally to introduce Java to mobile phones and for games on mobile phones. Since the start of *i-mode* in February 1999, the global development of mobile games has been pioneered and is driven by *i-mode* games. Java runs atop a Virtual Machine (called the KVM) which allows reasonable, but not complete, access to the functionality of the underlying phone. This extra layer of software provides a solid barrier of protection which seeks to limit damage from erroneous or malicious software. It also allows Java applications to move freely between different types of phone (and other mobile device) containing radically different electronic components, without modification.

Videoclip/Music Download: Current 3G networks allow mobile users to download video and audio content with enhanced speeds of up to 384 Kbps. Recent mobile devices with built in multimedia players and high resolution displays can access to rich content of video clips, movie trailers, music files, news highlights and so on.

Video phone: Visual phone service which is capable of both audio and video duplex transmission is a typically on the top of the 3G networks. This service utilizes a circuit switch connection with 64 Kbps.

Location-dependent services: Contemporary mobile networks offer the opportunity to employ recently developed position-determining devices and to offer many new and interesting location-dependent services. In many cases it is important for an application to know something about the location or the user might need location information for further activities. In 2001 Japanese company NTT DoCoMo launched the first location-dependent Web browsing service. The service delivers mobile users a broad range of location-specific Web content. The location estimation accuracy depends on cell size and the associated base station. The mobile user can gain access to cell-range information such as restaurants, hotels, shopping centers, and download relevant maps. On April 2004 Korean SK Telecom also launched the commercial Location-Based Service, called "Becktermap". Unlike existing Location-Based Services that show the location by downloading a complete map like a photo, the Becktermap service directly draws a map with a specific location on the cellular screen. It does this by downloading its configuration information from base stations or a Global Positioning System. This service includes weather conditions at the location, discount information at department stores, nearby restaurant information, and the changing location information of the pedestrian.

Future location based service systems will use both GPS and network information, and will support the interoperability between outdoor (GPS, Cellular, etc.) and indoor (based on WLAN, UWB, etc.) localization and tracking systems.

Figure 3 shows the mobile communication services and applications evolution towards 3G. Today's mobile users already comprise some, but future users will comprise many mobile communication systems and mobility aware applications.

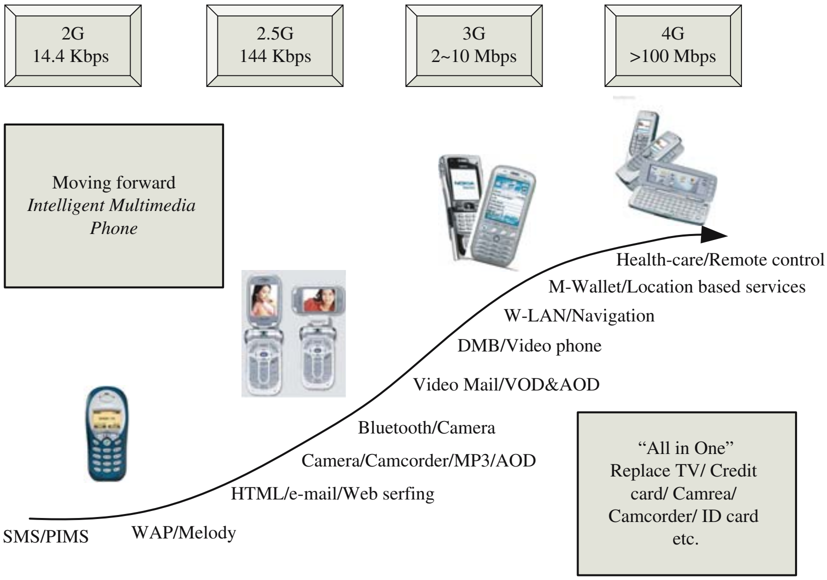

Figure 3. Mobile applications and services evolution

Music, news, road conditions, weather and financial reports, business information, infotainment and others are received via digital audio broadcasting (DAB) with 1.5 Mbps. DMB (Digital Multimedia Broadcasting) allows to transmit data, radio and TV to mobile devices. For personal communication a UMTS phone might be available offering voice and data connectivity with 384 Kbps. Satellite communications can be used for remote areas, while the current position of mobile user is determined using GPS.

In the next generation the cell phone will be an important mobile platform for daily life tools. The machine-to-machine services such as remote control of vendor machines, home-security, commuter pass, delivery tracking, and telemetry are now becoming commercially available, and it is reasonable to expect that this application area will grow into a significant component of next generation services.

The major standardization bodies that play an important role in defining the specifications for the mobile technology are:

- ITU (*International Telecommunication Union*): International organization within the United Nations, where governments and the private sector coordinate global telecom networks and services. One of the sectors of ITU, *ITU-T* produces the quality standards covering all the fields of telecommunications. More than 1500 specialists from telecommunication organizations and administrations around the world participate in the work of the Radiocommunication Sector of ITU (*namely ITU-R*). ITU's *IMT-2000* (*International Mobile Telecommunications-2000*) global standard for 3G wireless communications has opened the way to enabling innovative applications and services (e.g. multimedia entertainment, infotainment and location-based services, among others). The new concept from the ITU for mobile communication systems with capabilities which go further than that of IMT-2000 is *IMT-Advanced*, previously known as "*systems beyond IMT-2000*". For more detail information refer to ITU homepage by http://www.itu.int/home/index.html.

- IEEE (*Institute of Electrical and Electronics Engineers*) is one of the leading standards-making organizations in the world. IEEE performs its standards making and maintaining functions through the IEEE Standards Association (IEEE-SA). IEEE standards affect a wide range of industries including: power and energy, information technology (IT), telecommunications, nanotechnology, information assurance, and many more. One of the more notable IEEE standards is the *IEEE 802 LAN/MAN* group of standards which includes the:
  - 802.3 *Ethernet standard,*
  - 802.11 *Wireless Local Area Networks (Wi-Fi),*
  - 802.15 *Wireless Personal Area Networks (Bluetooth, ZigBee, Wireless USB),*
  - 802.16 *Broadband Wireless Access (WiMax, Mobile WiMax/WiBro)*,
  - 802.20 *Mobile Broadband Wireless Access (suspended until 1 October 2006)*, etc.

For more information about *IEEE* and *802 LAN/MAN* group refer to http://www.ieee.org/ and http://www.ieee802.org/ Web pages, respectively.

- ETSI (*European Telecommunication Standard Institute*) is an independent, non-profit, standardization organization of the telecommunications industry (equipment makers and network operators) in Europe, with worldwide projection. ETSI has been successful in standardizing the GSM cell phone system and the TETRA professional mobile radio system. Owing to the technical and commercial success of the GSM, this body plays an important role in the development of 3G mobile systems. See http://www.etsi.org/ for detailed information.
- *ARIB* (The Association of Radio Industries and Businesses) was chartered by the Minister of Posts and Telecommunications of Japan as a public service corporation on May 15, 1995. Established in response to several trends such as the growing internationalization of telecommunications, the convergence of telecommunications and broadcasting, and the need for promotion of radio-related industries, this body is playing an important role in the 3G development. ARIB Web page located at http://www.arib.or.jp/english/.
- TTA (*Telecommunications Technology Association*) is a Korean IT standards organization that develops new standards and provides one-stop services for the establishment of IT standards as well as testing and certification for IT products. One of the successful standards approved by TTA is the TTA PG302, the standard for 2.3 GHz Portable Internet (*WiBro*). For further information see TTA organization Web site at http://tta.or.kr/English/.
- 3GPP (*Third Generation Partnership Project*) was created to maintain overall control of the specification design and process for 3G networks. The scope of 3GPP is to make a globally applicable 3G mobile phone system specification within the scope of the ITU's IMT-2000 project. The 3GPP is an

international collaboration of a number of telecommunications standards bodies to standardize UMTS (*Universal Mobile Telecommunications System*). The original scope of 3GPP was to produce globally applicable Technical Specifications and Technical Reports for a 3rd Generation Mobile System based on evolved GSM core networks and the radio access technologies that they support. The current Organizational Partners are Japanese (*ARIB and TTC*), Chinese (*CCSA*), European (*ETSI*), American (*ATIS*) and Korean (*TTA*). 3GPP Web site located at http://www.3gpp.org/ .

- 3GPP2 is the other major 3G standardization organization, which promotes the cdma2000 system. In the world of IMT-2000, this proposal is known as IMT-MC. The major difference between 3GPP and 3GPP2 approaches into the air specification development is that 3GPP has specified a completely new air interface without any constraints from the past, whereas 3GPP2 has specified a system that is backward compatible with IS-95 systems. Official Web page of 3GPP2 organization is http://www.3gpp2.org/.

Next in this chapter we discuss the aforesaid mobile communication generations in detail and describe the services and applications suitable for mobile communication systems.

2. EVOLUTION OF MOBILE COMMUNICATION SYSTEMS

For a better understanding of today's wireless communication systems and developments, we will present a short history of wireless communications. The name, which is closely connected with the success of wireless communication, is that **Guglielmo Marconi**. In 1895, he gave the first demonstration of **wireless telegraphy**. Six years later in 1901 the first transatlantic transmission followed. The first radio broadcast took place in 1906 when **Reginald A. Fessenden** transmitted voice and music for Christmas. Within the next years huge work has been made, and in 1915 the first **wireless transmission** was set up between New York and San Francisco. Since, all this done using long wave transmission, sender and receiver still needed huge antennas and high transmission power (up to 200 kW).

The situation was resolutely changed with the **discovery of short waves** in 1920 by Marconi. Since then became possible to send short radio waves around the world bouncing at the ionosphere. After the Second World War governments started to invest in development of wireless communication projects. In 1958 Germany launches the first analogue wireless network named **A-Netz**, using 160 MHz carrier frequency. Connection setup was only possible from the mobile station, no handover, i.e., changing of the base station, was possible. System had coverage of 80 percent and 11,000 customers. In 1972 **B-Netz** followed in Germany, using the same 160 MHz. This network could initiate the connection setup from a station in the fixed telephone network, but, the current location of the mobile receiver had to be known. In 1979, B-Netz had 13,000 customers and needed a heavy sender and receiver, typically built into cars.

At the same time, the Northern European countries of Denmark, Finland, Norway and Sweden agreed upon the **Nordic Mobile Telephone (NMT)** system. NMT is based on analog technology (first generation or 1G) and two variants exist: **NMT-450** and **NMT-900**. The numbers indicate the frequency bands uses. NMT-900 was introduced in 1986 because it carries more channels than the previous NMT-450 network. The cell sizes in an NMT network range from 2 km to 30 km. With smaller ranges the network can serve more simultaneous callers; for example in a city the range can be kept short for better service. NMT used full duplex transmission, allowing for simultaneous receiving and transmission of voice. Car phone versions of NMT used transmission power of up to 15 watt (NMT-450) and 6 watt (NMT-900), handsets up to 1 watt. NMT had automatic switching (dialing) and handover of the call built into the standard from the beginning. Additionally, the NMT standard specified billing as well as national and international roaming.

In 1979 NTT introduced the analog mobile phone system using frequency division multiplexing (FDMA) and operating at 800MHz band. NTT system aimed to provide nationwide service by introducing the cellular architecture, location registration and handoff. In 1983 Bell Labs officially introduced the analog mobile phone system standard **Advanced Mobile Phone System (AMPS),** using FDMA and working at 850 MHz. Though analog is no longer considered advanced at all, AMPS introduced the relatively seamless cellular switching technology, that made the original mobile radiotelephone practical, and was considered quite advanced at the time. Using FDMA, each cell site would transmit on different frequencies, allowing many cell sites to be built near each other. However it had the disadvantage that each site did not have much capacity for carrying calls. It also had a poor security system which allowed people to force a phone’s serial code to use for making illegal calls.

The boundary line between 1G and 2G systems is obvious: it is the analog/digital split. The 2G systems have much higher capacity than the 1G systems. One frequency channel is simultaneously divided among several users, either by code or time division. There are four main standards for 2G: *Global System for Mobile* (GSM), *Digital AMPS* (D-AMPS), code-division multiple access (CDMA, IS-95), and *Personal Digital Cellular* (PDC).

PDC is the Japanese 2G standard. Originally it was known as *Japanese Digital Cellular (**JDC**)*, but the name was changed to PDC to make system more attractive outside Japan. However, this renaming did not bring about the desired result, and this standard is commercially used only in Japan. PDC operates in two frequency bands, 800 MHz and 1,500 MHz. It has both analog and digital modes. PDC has been very popular system in Japan.

Another, popular Japanese 2G system is **Personal Handy-phone System** (**PHS**), also marketed as the **Personal Access System (PAS)**, is a mobile network system operating in the 1880-1930 MHz frequency band. PHS is, essentially, a cordless telephone with the capability to handover from one cell to another. PHS cells are small, with transmission power a maximum of 500mW and range typically measures in tens or at most hundreds of meters, as opposed to the multi-kilometer ranges of

GSM. Originally developed by NTT Laboratory in Japan in 1989 and far simpler to implement and deploy than competing systems like PDC or GSM, the commercial services have been started by 3 PHS operators (NTT-Personal, DDI-Pocket and ASTEL) in Japan in 1995. However, the service has been pejoratively dubbed as the "poor man's cellular" due to its limited range and roaming capabilities in Japan. Recently, PHS has been reconsidered again in Japan as a cost-effective solution to providing broadband services of data rate up to 64Kbps, which is much faster than any other 2G systems. Also in other Asian countries, e.g., China, PHS has been deployed in addition to 2G cellular systems.

In accordance with the general idea of European Union, the European countries decided to develop a pan-European phone standard in 1982. The new system aimed to:

- use a new spectrum at 900 MHz;
- allow roaming throughput Europe;
- be fully digital;
- offer voice and data service.

The "**Groupe Speciale Mobile**" **(GSM)** was founded for this new development. From 1982 to 1985 discussions were held to decide between building an analog or digital system. After multiple field tests, a digital system was adopted for GSM. The next task was to decide between a narrow or broadband solution. In May 1987, the narrowband time division multiple access (TDMA) solution was chosen. In 1989, ETSI took over control and by 1990 the first GSM specification was completed, amounting to over 6,000 pages of text. Commercial operation began in 1991 with Radiolinja in Finland. GSM differs significantly from its predecessors in that both signaling and speech channels are digital, which means that it is considered a second generation (2G) mobile phone system. This first version GSM, now called global system for mobile communication, works at 900 MHz and uses 124 full-duplex channels. GSM offers full international roaming, automatic location services, authentication, encryption on the wireless link, and a relatively high audio quality. GSM is by far the most successful and widely used 2G system. Originally designed as a Pan-European standard, it was quickly adopted all over the world.

It was soon discovered that the analog AMPS in the US and digital GSM at 900 MHz in Europe are not sufficient for the high user densities in cities. These triggered off the search for more able systems. While the Europeans agreed to use the GSM in the new 1800 MHz band (**DCS 1800**), in the US, different companies developed three different new, more bandwidth-efficient technologies to operate side-by-side with AMPS in the same frequency band. This resulted in three incompatible systems, the analog narrowband AMPS (IS-88), and the two digital systems D-AMPS (IS-136) and CDMA (IS-95).

D-AMPS (also known as US-TDMA) is used in the Americas, Israel, and in some Asian countries. D-AMPS uses existing AMPS channels and allows for smooth transition between digital and analog systems in the same area. Capacity was increased over the preceding analog design by dividing each 30 kHz channel pair into three time slots (TDMA) and digitally compressing the voice data, yielding three times the call capacity in a single cell. A digital system also made calls more secure because analog scanners could not access digital signals.

The first **CDMA**-based digital cellular standard **IS-95** (Interim Standard 95) is pioneered by Qualcomm. The brand name for IS-95 is ***cdmaOne***. IS-95 is also known as TIA-EIA-95. CDMA or "code division multiple access" is a digital radio system that transmits streams of bits (PN Sequences). CDMA permits several users to share the same frequencies. Unlike TDMA, a competing system used in GSM, all transmitters can be active all the time, because network capacity does not directly limit the number of active users. Since larger numbers of users can be served by smaller numbers of cell-sites, CDMA-based standards have a significant economic advantage over TDMA-based standards, or the oldest cellular standards that used FDMA.

In 1993 South Korea adopts CDMA, although some experts worried Korea would lag behind with the launch of the then-untested CDMA network, while the world was commercializing the GSM standard. The decision to adopt CDMA technology turned a new page in Korea's telecommunications history. In January 1996, Korea successfully launched the world's first commercial operation of CDMA network in Seoul and its neighboring cities. Since then, CDMA has become the fastest-growing of all wireless technologies, with over 100 million subscribers worldwide. In addition to supporting more traffic, CDMA brings many other benefits to carriers and mobile users, including better voice quality, broader coverage and stronger security. IS-95 is the only CDMA standard so far to be operated commercially as a 2G system.

Note that quite often when the 2G is discussed, *digital cordless systems* are also mentioned. In 1991, ETSI adopted the standard **Digital European cordless telephone (DECT)** for digital cordless telephony. DECT works at a spectrum of 1880–1900 MHz with a range of 100–500m. 120 duplex channels can carry up to 1.2 Mbps for data transmission. Several new features, such as voice encryption and authentication, are built-in. Today, DECT has been renamed *digital enhanced cordless telecommunications*.

2.5 Generation (2.5G) is a designation that broadly includes all advanced upgrades for the 2G networks. 2.5G provides some of the benefits of 3G (e.g. it is packet-switched) and can use some of the existing 2G infrastructure in GSM and CDMA networks. **Figure 4** demonstrates the evolution of cellular based systems from 2G towards 4G. **General Packet Radio Service (GPRS)** is a 2.5G technology used by GSM operators. Some protocols, such as **EDGE (Enhanced Data Rates for Global Evolution)** for GSM and **CDMA2000 1x-RTT** for CDMA, can qualify as "3G" services (because they have a data rate of above 144 Kbps), but are considered by most to be 2.5G services because they are several times slower than "true" 3G services.

With **GPRS** technology, the data rates can be pushed up to 115 Kbps, or even higher. It provides moderate speed data transfer, by using unused TDMA channels in the GSM network. Originally there was some thought to extend GPRS to cover

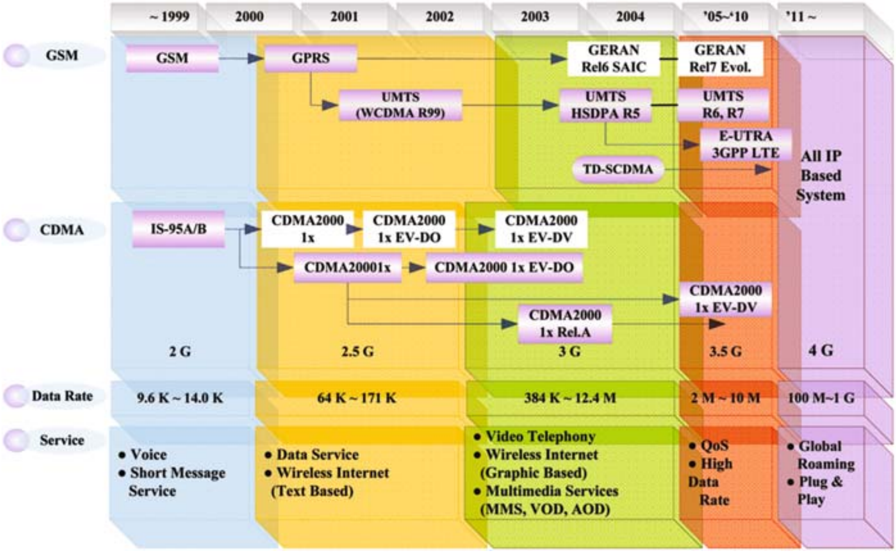

Figure 4. Mobile communication systems evolution towards 4G

other standards, but instead those networks are being converted to use the GSM standard, so that it is the only kind of network where GPRS is in use. First it was standardized by ETSI but now that effort has been handed onto the 3GPP. GPRS is packet switched, and thus it does not allocate the radio resources continuously but only when there is something to be sent. A consequence of this is that packet switched data has a poor bit rate in busy cells. The theoretical limit for packet switched data is approx. 160.0 Kbps (using 8 time slots). A realistic bit rate is 30–80 Kbps, because it is possible to use max 4 time slots for downlink. GPRS is especially suitable for non-real-time applications, such as e-mail and Web surfing. It is not well suited for real-time applications, as the resource allocations in GPRS is connection based and thus it cannot guarantee an absolute maximum delay.

A change to the radio part of GPRS called **EDGE** (sometimes called EGPRS or Enhanced GPRS) allows higher bit rates of between 160 and 236.8 Kbps (theoretical maximum is 473.6 Kbps for 8 timeslots). Although EDGE requires no hardware changes to be made in GSM core networks, base stations must be modified. EDGE compatible transceiver units must be installed and the base station subsystem (BSS) needs to be upgraded to support EDGE. New mobile terminal hardware and software is also required to decode/encode the new modulation and coding schemes and carry the higher user data rates to implement new services.

CDMA2000 1xRTT, the core CDMA2000 wireless air interface standard, is known by many terms: 1x, 1xRTT, IS-2000, CDMA2000 1X, and cdma2000 (lowercase). The designation “1xRTT” (1 times Radio Transmission Technology) is used to identify the version of CDMA2000 radio technology that operates in a pair of 1.25-MHz radio channels (one times 1.25 MHz, as opposed to three times 1.25 MHz in 3xRTT as shown in **Figure 5**). 1xRTT almost doubles voice capacity over IS-95 networks. Although capable of higher data rates, most deployments have limited the peak data rate to 144 Kbps. While 1xRTT officially qualifies as 3G technology, 1xRTT is considered by some to be a 2.5G (or sometimes 2.75G) technology. This has allowed it to be deployed in 2G spectrum in some countries which limit 3G systems to certain bands.

Year 1998 marked the beginning of mobile communication using satellites with the **Iridium** system. The Iridium satellite constellation is a system of 66 active communication satellites in low earth orbit and uses 1.6 GHz band for communication with the mobile phone. The system was originally to have 77 active satellites, and was named for the element iridium, which has atomic number 77. Iridium allows worldwide voice and data communications using handheld devices. Iridium communications service was launched on November 1, 1998 and went into bankruptcy on August 13, 1999. Its financial failure was largely due to insufficient demand for the service. The increased coverage of terrestrial cellular networks (e.g. GSM) and the rise of roaming agreements between cellular providers proved to be fierce competition. Nowadays the system is being used extensively by the U.S. Department of Defense for its communication purposes through the DoD Gateway in Hawaii. The commercial Gateway in Tempe, Arizona provides voice, data and paging services for commercial customers on a global basis. Typical customers include maritime, aviation, government, the petroleum industry, scientists, and frequent world travelers. Iridium Satellite LLC claims to have approximately 142,000 subscribers as of December 31, 2005.

In 1999 IEEE published several powerful WLAN standards. One of them is **802.11b Wi-Fi** standard offering 11 Mbps at 2.4 GHz. 802.11b products appeared on the market very quickly, since 802.11b is a direct extension of the DSSS (Direct-sequence spread spectrum) modulation technique defined in the original

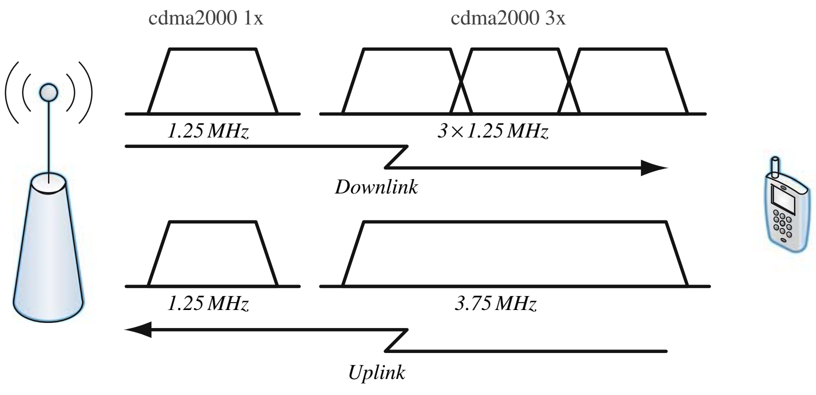

Figure 5. Relationship between 1x and 3x modes in spectrum usage

standard. Hence, chipsets and products were easily upgraded to support the 802.11b enhancements. The dramatic increase in throughput of 802.11b (compared to the original standard) along with substantial price reductions led to the rapid acceptance of 802.11b as the definitive wireless LAN technology. The same spectrum is used by **Bluetooth**, a short-range technology to set-up wireless personal area networks (PANs) with gross data rates less than 1 Mbps. Bluetooth is an industrial specification for PANs, also known as **IEEE 802.15.1**. Bluetooth provides a way to connect and exchange information between devices like personal digital assistants (PDAs), mobile phones, laptops, PCs, printers and digital cameras via a secure, low-cost, globally available short range radio frequency.

The rapid development of mobile communication systems was one of the most notable success stories of the 1990s. The 2G systems began their operation at the beginning of the decade, and since then they have been expanding and evolving continuously. In 2000 there were 361.7 million GSM and more than 100 million CDMA subscribers worldwide. Main disadvantage of 2G systems was that the standards for developing the networks were different for different parts of the world. Hence, it was decided to have a network that provides services independent of the technology platform and whose network design standards are same globally. Thus, **3G** was born. To understand the background to the differences between 2G and 3G systems, we need to look at the new requirements of the 3G systems which are listed below:

- Bit rates up to 2 Mbps;
- Variable bit rate to offer bandwidth on demand;
- Multiplexing of services with different quality requirements on a single connection, e.g. speech, video and packet data;
- Delay requirements from delay-sensitive real time traffic to flexible best-effort packet data;
- Quality requirements from 10% frame error rate to 10^{-6} bit error rate;
- Co-existence of 2G and 3G systems and inter-system handovers for coverage enhancements and load balancing;
- Support asymmetric uplink and downlink traffic, e.g. Web browsing causes more loading to downlink than to uplink;
- High spectrum efficiency;
- Co-existence of FDD and TDD modes.

ITU started the process of defining the standard for 3G systems, referred to as **IMT-2000**. In 1998 Europeans agreed on the **Universal Mobile Telecommunications System (UMTS)** as the European proposal for the 3G systems. UMTS uses Wideband-CDMA (**WCDMA**) as the underlying standard, is standardized by the 3GPP, and represents the European/Japanese answer to the ITU IMT-2000 requirements for 3G systems.

IMT-2000 offers the capability of providing value-added services and applications on the basis of a single standard. The system envisages a platform for distributing converged fixed, mobile, voice, data, Internet, and multimedia services. One of its key visions is to provide seamless global roaming, enabling users to move across borders while using the same number and handset. IMT-2000 also aims to provide seamless delivery of services, over a number of media (satellite, fixed, etc…). It is expected that IMT-2000 will provide higher transmission rates: a minimum speed of 2Mbps for stationary or walking users, and 348 Kbps in a moving vehicle.

3. MODERN CELLULAR COMMUNICATION SYSTEMS

In 2001 the 3G systems started with the **FOMA** service in Japan, with several field trials in Europe and with **cdma2000** in South Korea. The first country which introduced 3G on a large commercial scale was Japan. In 2005 about 40% of subscribers use 3G networks only, and 2G is on the way out in Japan. It is expected that during 2006 the transition from 2G to 3G will be largely completed in Japan, and upgrades to the next 3.5G stage with maximum around 14 Mbps data rate is underway.

3G technologies are an answer to the ITU's IMT-2000 specification. Originally, 3G was supposed to be a single, unified, worldwide standard, but in practice, there are two main competing technologies, WCDMA and cdma2000. Also there is another 3G standard called TD-SCDMA, developing by the Chinese Academy of Telecommunications Technology (CATT).

This section describes the stated above 3G systems, lists their main parameters and gives information about their evolutions, like HSDPA/HSUPA for WCDMA and 1x EV-DO/EV-DV for cdma2000 systems.

3.1 WCDMA/HSDPA/HSUPA

WCDMA (Wideband Code Division Multiple Access) is a type of 3G cellular network. WCDMA is the technology behind the 3G UMTS standard and is allied with the 2G GSM standard. WCDMA was developed by NTT DoCoMo as the air interface for their 3G network. Later NTT DoCoMo submitted the specification to the ITU as a candidate for the international 3G standard known as IMT-2000. The ITU eventually accepted WCDMA as part of the IMT-2000 family of 3G standards. Later WCDMA was selected as the air interface for UMTS, the 3G successor to GSM.

WCDMA is a wideband Direct-sequence Code Division Multi Access (DS-CDMA) system. Compared to the first DS-CDMA based standard, IS-95, WCDMA uses a three times larger bandwidth equal to 5 MHz, as a result using 3.84 Mcps chip rate. Higher chip rate of 3.84 Mcps enables higher bit rate and provides more multipath diversity than the chip rate of 1.2288 Mcps (IS-95), especially in urban cells. In order to support high bit rates up to 2 Mbps, WCDMA supports the use of variable spreading factor and multicode connections.

WCDMA supports highly variable user data rates and the Bandwidth on Demand (BoD) is well supported. Although, the user data rate is constant during each 10 ms frame, the data capacity among the users can change from frame to frame. WCDMA utilizes fast closed loop power control in both uplink and downlink. Fast power control in the downlink improves link performance and enhances downlink capacity. However, this requires new functionalities in the mobile, such as SIR (signal-to-interference ratio) estimation and outer-loop power control. Also, WCDMA supports both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) operation modes. In the FDD mode, separate 5 MHz carrier frequencies are used for uplink and downlink respectively, whereas in TDD only 5 MHz is time-shared between the uplink and downlink. WCDMA supports the operation of asynchronous base stations, so that there is no need for a global time reference such as GPS. Deployment of indoor and micro base stations is easier when no GPS signal needs to be received.

In standardization forums, WCDMA technology has emerged as the most widely adopted 3G air interface. Its specification has been created in 3GPP. Within 3GPP, WCDMA is called Universal Terrestrial Radio Access (UTRA) FDD and TDD, the name WCDMA being used to cover both FDD and TDD operation. Further, experience from 2G systems like GSM and cdmaOne has enabled improvements to be incorporated in WCDMA. Focus has also been put on ensuring that as much as possible of WCDMA operators' investments in GSM equipment can be reused. Examples are the re-use and evolution of the core network, the focus on co-siting and the support of GSM handover. In order to use GSM handover the subscribers need dual mode handsets.

Inter-frequency handovers are considered important in WCDMA, to maximize the use of several carriers per base station. In cdmaOne inter-frequency measurements are not specified, making inter-frequency handovers more difficult. Also, WCDMA includes transmit diversity mechanism to improve the downlink capacity to support asymmetric capacity requirements between downlink and uplink.

WCDMA supports up to 1920 Kbps data transfer rates (and not 2 Mbps as previously expected), although at the moment users in the real networks can expect performance up to 384 Kbps – in Japan, its evolved version High Speed Down Link Packet Access (HSDPA) will be deployed in 2006 to provide mobile users with higher rate packet services than WCDMA. HSDPA and High Speed Up Link Packet Access (HSUPA) will enable high-speed wireless connectivity comparable to wired broadband. HSDPA/HSUPA enables individuals to send and receive email with large file attachments, play real-time interactive games, receive and send high-resolution pictures and video, download video and music content or stay wirelessly connected to their office PCs – all from the same mobile device.

HSDPA refers to the speed at which individuals can receive large data files, the "downlink." In this respect it extends WCDMA in the same way that EV-DO extends CDMA2000. HSDPA provides a smooth evolutionary path for UMTS networks allowing for higher data capacity (up to 14.4 Mbps in the downlink). It is an evolution of the WCDMA standard, designed to increase the available data rate by a factor of 5 or more. HSDPA defines a new WCDMA channel, the high-speed downlink shared channel (HS-DSCH) that operates in a different way from existing WCDMA channels, but is only used for downlink communication to the mobile.

HSUPA (high-speed uplink packet access) refers to the speed at which individuals can send large data files, the "uplink." HSUPA extremely increases upload speeds up to 5.76 Mbps. HSUPA is expected to use an uplink enhanced dedicated channel (E-DCH) on which it will employ link adaptation methods similar to those employed by HSDPA. Similarly to HSDPA there will be a packet scheduler, but it will operate on a request-grant principle where the MSs request a permission to send data and the scheduler decides when and how many MSs will be allowed to do so. In HSUPA, unlike in HSDPA, soft and softer handovers will be allowed for packet transmissions. Similar to HSDPA, HSUPA is considered **3.75G.**

HSDPA considerably improves the 3G end-user data experience by enhancing downlink performance. HSDPA significantly reduces the time it takes a mobile user to retrieve broadband content from the network. A reduced delay is important for many applications such as interactive games. In general, HSDPA allows a more efficient implementation of "interactive" and "background" Quality of Service (QoS) classes as standardized by 3GPP. HSDPA high data rates also improve the use of streaming applications, while lower roundtrip delays will benefit Web browsing applications. In addition, HSDPA's improved capacity opens the door for new and data-intensive applications that cannot be fully supported with Release 99 because of bandwidth limitations.

3.2 cdma2000/1xEV-DO/1xEV-DV

The other significant 3G standard is **cdma2000**, which is an outgrowth of the earlier 2G CDMA standard IS-95. cdma2000's primary proponents are outside the GSM zone in the Americas, Japan and Korea. cdma2000 is managed by 3GPP2, which is separate and independent from UMTS's 3GPP. The various types of transmission technology used in cdma2000 include 1xRTT, cdma2000-1xEV-DO and 1xEV-DV. cdma2000 offers data rates of 144 Kbps to over 3 Mbps. It has been adopted by the International Telecommunication Union - ITU. Arguably the most successful introduction of cdma2000 3G systems is South Korean SK Telecom, which has more than 20 million 3G subscribers. In October 2000, they debuted the world's first commercial CDMA 1x service; and in February 2002, they released the first commercial CDMA 1xEV-DO service, which achieves data rates up to 2.4 Mbps.

Same as IS-95 cdma2000 1x uses one times the chip rate of 1.2288 Mcps. However, in addition, the cdma2000 also supports Spreading Rate 3 (or 3x), which is used when higher data rate transmissions are required. Spreading Rate 3 has two implementation options: DSSS (Direct-sequence spread spectrum) or MCSS (multicarrier spread-spectrum).

On the downlink of the MC system three narrowband 1x carriers, each with 1.25 MHz, are bundled to form a multicarrier transmission with approximately 3.75 MHz (3x) bandwidth. On the uplink, cdma2000 3x system uses the DSSS option, which allows the mobile to directly spread its data over a wider bandwidth