CHAPTER 1

An Overview of Wireless Systems

1.1 Introduction

The cellular system employs a different design approach than most commercial radio and television systems use [1,2]. Radio and television systems typically operate at maximum power and with the tallest antennas allowed by the regulatory agency of the country. In the cellular system, the service area is divided into cells. A transmitter is designed to serve an individual cell. The system seeks to make efficient use of available channels by using low-power transmitters to allow frequency reuse at much smaller distances. Maximizing the number of times each channel can be reused in a given geographic area is the key to an efficient cellular system design.

During the past three decades, the world has seen significant changes in the telecommunications industry. There have been some remarkable aspects to the rapid growth in wireless communications, as seen by the large expansion in mobile systems. Wireless systems consist of wireless wide-area networks (WWAN) [i.e., cellular systems], wireless local area networks (WLAN) [4], and wireless personal area networks (WPAN) (see Figure 1.1) [17]. The handsets used in all of these systems possess complex functionality, yet they have become small, low-power consuming devices that are mass produced at a low cost, which has in turn accelerated their widespread use. The recent advancements in Internet technology have increased network traffic considerably, resulting in a rapid growth of data rates. This phenomenon has also had an impact on mobile systems, resulting in the extraordinary growth of the mobile Internet.

Wireless data offerings are now evolving to suit consumers due to the simple reason that the Internet has become an everyday tool and users demand data mobility. Currently, wireless data represents about 15 to 20% of all air time. While success has been concentrated in vertical markets such as public safety, health care, and transportation, the horizontal market (i.e., consumers) for wireless data is growing. In 2005, more than 20 million people were using wireless e-mail. The Internet has changed user expectations of what data access means. The ability to retrieve information via the Internet has been "an amplifier of demand" for wireless data applications.

More than three-fourths of Internet users are also wireless users and a mobile subscriber is four times more likely to use the Internet than a nonsubscriber to

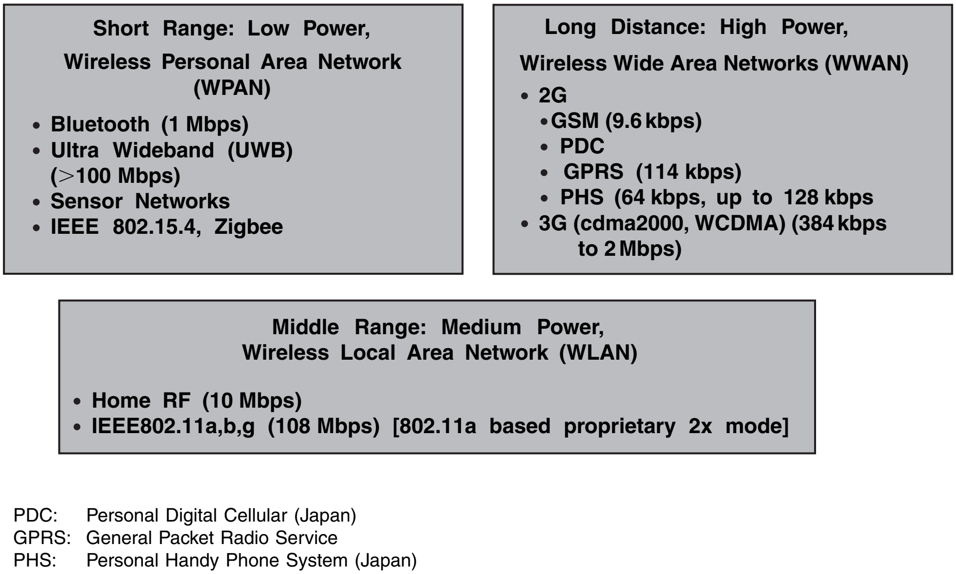

Figure 1.1 Wireless networks.

mobile services. Such keen interest in both industries is prompting user demand for converged services. With more than a billion Internet users expected by 2008, the potential market for Internet-related wireless data services is quite large.

In this chapter, we discuss briefly 1G, 2G, 2.5G, and 3G cellular systems and outline the ongoing standard activities in Europe, North America, and Japan. We also introduce broadband (4G) systems (see Figure 1.2) aimed on integrating WWAN, WLAN, and WPAN. Details of WWAN, WLAN, and WPAN are given in Chapters 15 to 20.

1.2 First- and Second-Generation Cellular Systems

The first- and second-generation cellular systems are the WWAN. The first public cellular telephone system (first-generation, 1G), called Advanced Mobile Phone System (AMPS) [8,21], was introduced in 1979 in the United States. During the early 1980s, several incompatible cellular systems (TACS, NMT, C450, etc.) were introduced in Western Europe. The deployment of these incompatible systems resulted in mobile phones being designed for one system that could not be used with another system, and roaming between the many countries of Europe was not possible. The first-generation systems were designed for voice applications. Analog frequency modulation (FM) technology was used for radio transmission.

In 1982, the main governing body of the European post telegraph and telephone (PTT), la Conférence européenne des Administrations des postes et des

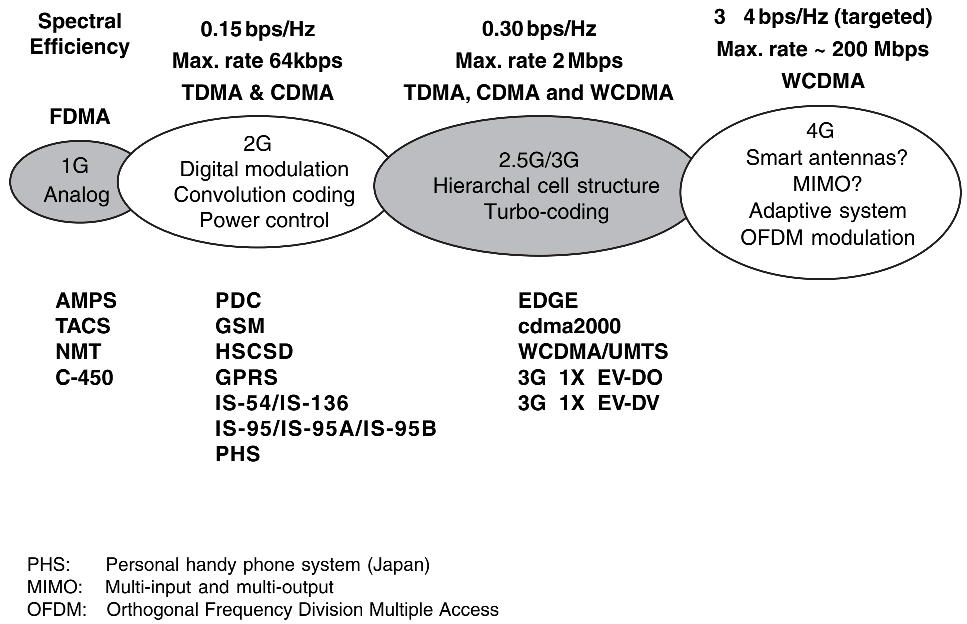

Figure 1.2 Wireless network from 1G to 4G.

télécommunications (CEPT), set up a committee known as Groupe Special Mobile (GSM) [9], under the auspices of its Committee on Harmonization, to define a mobile system that could be introduced across western Europe in the 1990s. The CEPT allocated the necessary duplex radio frequency bands in the 900 MHz region.

The GSM (renamed Global System for Mobile communications) initiative gave the European mobile communications industry a home market of about 300 million subscribers, but at the same time provided it with a significant technical challenge. The early years of the GSM were devoted mainly to the selection of radio technologies for the air interface. In 1986, field trials of different candidate systems proposed for the GSM air interface were conducted in Paris. A set of criteria ranked in the order of importance was established to assess these candidates.

The interfaces, protocols, and protocol stacks in GSM are aligned with the Open System Interconnection (OSI) principles. The GSM architecture is an open architecture which provides maximum independence between network elements (see Chapter 7) such as the Base Station Controller (BSC), the Mobile Switching Center (MSC), the Home Location Register (HLR), etc. This approach simplifies the design, testing, and implementation of the system. It also favors an evolutionary growth path, since network element independence implies that modification to one network element can be made with minimum or no impact on the others. Also, a system operator has the choice of using network elements from different manufacturers.

GSM 900 (i.e., GSM system at 900 MHz) was adopted in many countries, including the major parts of Europe, North Africa, the Middle East, many east Asian countries, and Australia. In most of these cases, roaming agreements exist to make it possible for subscribers to travel within different parts of the world and enjoy continuity of their telecommunications services with a single number and a single bill. The adaptation of GSM at 1800 MHz (GSM 1800) also spreads coverage to some additional east Asian countries and some South American countries. GSM at 1900 MHz (i.e., GSM 1900), a derivative of GSM for North America, covers a substantial area of the United States. All of these systems enjoy a form of roaming, referred to as Subscriber Identity Module (SIM) roaming, between them and with all other GSM-based systems. A subscriber from any of these systems could access telecommunication services by using the personal SIM card in a handset suitable to the network from which coverage is provided. If the subscriber has a multiband phone, then one phone could be used worldwide. This globalization has positioned GSM and its derivatives as one of the leading contenders for offering digital cellular and Personal Communications Services (PCS) worldwide. A PCS system offers multimedia services (i.e., voice, data, video, etc.) at any time and any where. With a three band handset (900, 1800, and 1900 MHz), true worldwide seamless roaming is possible. GSM 900, GSM 1800, and GSM 1900 are second-generation (2G) systems and belong to the GSM family. Cordless Telephony 2 (CT2) is also a 2G system used in Europe for low mobility.

Two digital technologies, Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) (see Chapter 6 for details) [10] emerged as clear choices for the newer PCS systems. TDMA is a narrowband technology in which communication channels on a carrier frequency are apportioned by time slots. For TDMA technology, there are three prevalent 2G systems: North America TIA/EIA/IS-136, Japanese Personal Digital Cellular (PDC), and European Telecommunications Standards Institute (ETSI) Digital Cellular System 1800 (GSM 1800), a derivative of GSM. Another 2G system based on CDMA (TIA/EIA/IS-95) is a direct sequence (DS) spread spectrum (SS) system in which the entire bandwidth of the carrier channel is made available to each user simultaneously (see Chapter 11 for details). The bandwidth is many times larger than the bandwidth required to transmit the basic information. CDMA systems are limited by interference produced by the signals of other users transmitting within the same bandwidth.

The global mobile communications market has grown at a tremendous pace. There are nearly one billion users worldwide with two-thirds being GSM users. CDMA is the fastest growing digital wireless technology, increasing its worldwide subscriber base significantly. Today, there are already more than 200 million CDMA subscribers. The major markets for CDMA technology are North America, Latin America, and Asia, in particular Japan and Korea. In total, CDMA has been adopted by almost 50 countries around the world.

The reasons behind the success of CDMA are obvious. CDMA is an advanced digital cellular technology, which can offer six to eight times the capacity of analog technologies (AMP) and up to four times the capacity of digital technologies such as TDMA. The speech quality provided by CDMA systems is far superior to any other digital cellular system, particularly in difficult RF environments such as dense urban areas and mountainous regions. In both initial deployment and long-term operation, CDMA provides the most cost effective solution for cellular operators. CDMA technology is constantly evolving to offer customers new and advanced services. The mobile data rates offered through CDMA phones have increased and new voice codecs provide speech quality close to the fixed wireline. Internet access is now available through CDMA handsets. Most important, the CDMA network offers operators a smooth migration path to third-generation (3G) mobile systems, [3,5,7,11].

1.3 Cellular Communications from 1G to 3G

Mobile systems have seen a change of generation, from first to second to third, every ten years or so (see Figure 1.3). At the introduction of 1G services, the mobile device was large in size, and would only fit in the trunk of a car. All analog components such as the power amplifier, synthesizer, and shared antenna equipment were bulky. 1G systems were intended to provide voice service and low rate (about 9.6 kbps) circuit-switched data services. Miniaturization of mobile devices progressed before the introduction of 2G services (1990) to the point where the size of mobile phones fell below 200 cubic centimeters (cc). The first-generation handsets provided poor voice quality, low talk-time, and low

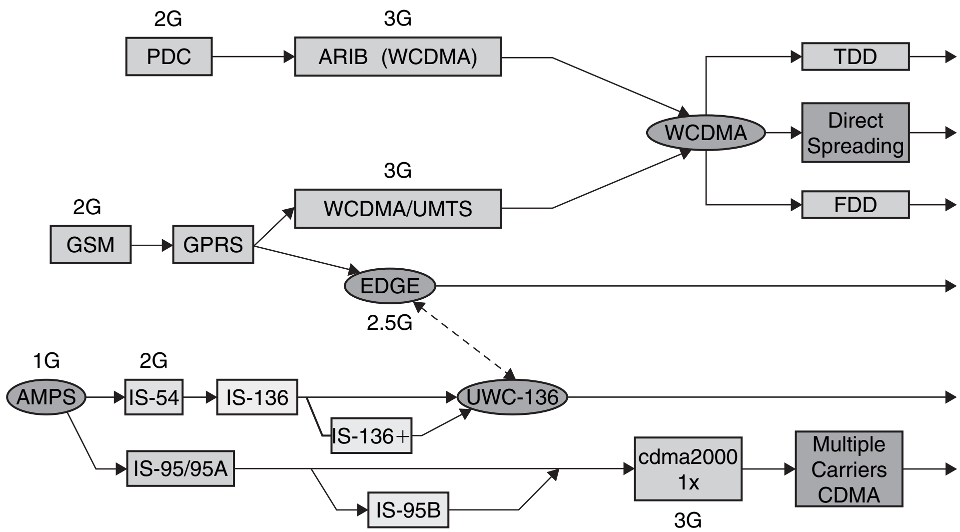

Figure 1.3 Cellular networks (WWAN) evolution from 1G to 3G.

standby time. The 1G systems used Frequency Division Multiple Access (FDMA) technology (see Chapter 6) and analog frequency modulation [8,20].

The 2G systems based on TDMA and CDMA technologies [6] were primarily designed to improve voice quality and provide a set of rich voice features. These systems supported low rate data services (16–32 kbps).

For second-generation systems three major problems impacting system cost and quality of service remained unsolved. These include what method to use for band compression of voice, whether to use a linear or nonlinear modulation scheme, and how to deal with the issue of multipath delay spread caused by multipath propagation of radio waves in which there may not only be phase cancellation but also a significant time difference between the direct and reflected waves.

The swift progress in Digital Signal Processors (DSPs) was probably fueled by the rapid development of voice codecs for mobile environments that dealt with errors. Large increases in the numbers of cellular subscribers and the worries of exhausting spectrum resources led to the choice of linear modulation systems.

To deal with multipath delay spread, Europe, the United States, and Japan took very different approaches. Europe adopted a high transmission rate of 280 kbps per 200 kHz RF channel in GSM [13,14] using a multiplexed TDMA system with 8 to 16 voice channels, and a mandatory equalizer with a high number of taps to overcome inter-symbol interference (ISI) (see Chapter 3). The United States used the carrier transmission rate of 48 kbps in 30 kHz channel, and selected digital advanced mobile phone (DAMP) systems (IS-54/IS-136) to reduce the computational requirements for equalization, and the CDMA system (IS-95) to avoid the need for equalization. In Japan the rate of 42 kbps in 25 kHz channel was used, and equalizers were made optional.

Taking into account the limitations imposed by the finite amount of radio spectrum available, the focus of the third-generation (3G) mobile systems has been on the economy of network and radio transmission design to provide seamless service from the customers' perspective. The third-generation systems provide their users with seamless access to the fixed data network [18,19]. They are perceived as the wireless extension of future fixed networks, as well as an integrated part of the fixed network infrastructure. 3G systems are intended to provide multimedia services including voice, data, and video.

One major distinction of 3G systems relative to 2G systems is the hierarchical cell structure designed to support a wide range of multimedia broadband services within the various cell types by using advanced transmission and protocol technologies. The 2G systems mainly use one-type cell and employ frequency reuse within adjacent cells in such a way that each single cell manages its own radio zone and radio circuit control within the mobile network, including traffic management and handoff procedures. The traffic supported in each cell is fixed because of frequency limitations and little flexibility of radio transmission which is mainly optimized for voice and low data rate transmissions. Increasing traffic leads to costly cellular reconfiguration such as cell splitting and cell sectorization.

The multilayer cell structure in 3G systems aims to overcome these problems by overlaying, discontinuously, pico- and microcells over the macrocell structure with wide area coverage. Global/satellite cells can be used in the same sense by providing area coverage where macrocell constellations are not economical to deploy and/or support long distance traffic.

With low mobility and small delay spread profiles in picocells, high bit rates and high traffic densities can be supported with low complexity as opposed to low bit rates and low traffic load in macrocells that support high mobility. The user expectation will be for service selected in a uniform manner with consistent procedures, irrespective of whether the means of access to these services is fixed or mobile. Freedom of location and means of access will be facilitated by smart cards to allow customers to register on different terminals with varying capabilities (speech, multimedia, data, short messaging).

The choice of a radio interface parameter set corresponding to a multiple access scheme is a critical issue in terms of spectral efficiency, taking into account the ever-increasing market demand for mobile communications and the fact that radio spectrum is a very expensive and scarce resource. A comparative assessment of several different schemes was carried out in the framework of the Research in Advanced Communications Equipment (RACE) program. One possible solution is to use a hybrid CDMA/TDMA/FDMA technique by integrating advantages of each and meeting the varying requirements on channel capacity, traffic load, and transmission quality in different cellular/PCS layouts. Disadvantages of such hybrid access schemes are the high-complexity difficulties in achieving simplified low-power, low-cost transceiver design as well as efficient flexibility management in the several cell layers.

CDMA is the selected approach for 3G systems by the ETSI, ARIB (Association of Radio Industries and Business—Japan) and Telecommunications Industry Association (TIA). In Europe and Japan, Wideband CDMA (WCDMA/UMTS [Universal Mobile Telecommunication Services]) was selected to avoid IS-95 intellectual property rights. In North America, cdma2000 uses a CDMA air-interface based on the existing IS-95 standard to provide wireline quality voice service and high speed data services at 144 kbps for mobile users, 384 kbps for pedestrians, and 2 Mbps for stationary users. The 64 kbps data capability of CDMA IS-95B provides high speed Internet access in a mobile environment, a capability that cannot be matched by other narrowband digital technologies.

Mobile data rates up to 2 Mbps are possible using wide band CDMA technologies. These services are provided without degrading the systems' voice transmission capabilities or requiring additional spectrum. This has tremendous implications for the majority of operators that are spectrum constrained. In the meantime, DSPs have improved in speed by an order of magnitude in each generation, from 4 MIPs (million instructions per second) through 40 MIPs to 400 MIPs.

Since the introduction of 2G systems, the base station has seen the introduction of features such as dynamic channel assignment. In addition, most base stations began making shared use of power amplifiers and linear amplifiers whether or not modulation was linear. As such there has been an increasing demand for high-efficiency, large linear power amplifiers instead of nonlinear amplifiers.

At the beginning of 2G, users were fortunate if they were able to obtain a mobile device below 150 cc. Today, about 10 years later, mobile phone size has reached as low as 70 cc. Furthermore, the enormous increase in very large system integration (VLSI) and improved CPU performance has led to increased functionality in the handset, setting the path toward becoming a small-scale computer.

1.4 Road Map for Higher Data Rate Capability in 3G

The first- and second-generation cellular systems were primarily designed for voice services and their data capabilities were limited. Wireless systems have since been evolving to provide broadband data rate capability as well.

GSM is moving forward to develop cutting-edge, customer-focused solutions to meet the challenges of the 21st century and 3G mobile services. When GSM was first designed, no one could have predicted the dramatic growth of the Internet and the rising demand for multimedia services. These developments have brought about new challenges to the world of GSM. For GSM operators, the emphasis is now rapidly changing from that of instigating and driving the development of technology to fundamentally enable mobile data transmission to that of improving speed, quality, simplicity, coverage, and reliability in terms of tools and services that will boost mass market take-up.

People are increasingly looking to gain access to information and services whenever they want from wherever they are. GSM will provide that connectivity. The combination of Internet access, web browsing, and the whole range of mobile multimedia capability is the major driver for development of higher data speed technologies.

GSM operators have two nonexclusive options for evolving their networks to 3G wide band multimedia operation: (1) they can use General Packet Radio Service (GPRS) and Enhanced Data rates for GSM Evolution (EDGE) [also known as 2.5G] in the existing radio spectrum, and in small amounts of new spectrum; or (2) they can use WCDMA/UMTS in the new 2 GHz bands [12,15,16]. Both approaches offer a high degree of investment flexibility because roll-out can proceed in line with market demand and there is extensive reuse of existing network equipment and radio sites.

The first step to introduce high-speed circuit-switched data service in GSM is by using High Speed Circuit Switched Data (HSCSD). HSCSD is a feature that enables the co-allocation of multiple full rate traffic channels (TCH/F) of GSM into an HSCSD configuration. The aim of HSCSD is to provide a mixture of services with different user data rates using a single physical layer structure. The available capacity of an HSCSD configuration is several times the capacity of a TCH/F, leading to a significant enhancement in data transfer capability.

Ushering faster data rates into the mainstream is the new speed of 14.4 kbps per time slot and HSCSD protocols that approach wire-line access rates of up to 57.6 kbps by using multiple 14.4 kbps time slots. The increase from the current baseline 9.6 kbps to 14.4 kbps is due to a nominal reduction in the error-correction overhead of the GSM radio link protocol, allowing the use of a higher data rate.

The next phase in the high speed road map is the evolution of current short message service (SMS), such as smart messaging and unstructured supplementary service data, toward the new GPRS, a packet data service using TCP/IP and X.25 to offer speeds up to 115.2 kbps. GPRS has been standardized to optimally support a wide range of applications ranging from very frequent transmissions of medium to large data volume. Services of GPRS have been developed to reduce connection set-up time and allow an optimum usage of radio resources. GPRS provides a packet data service for GSM where time slots on the air interface can be assigned to GPRS over which packet data from several mobile stations can be multiplexed.

A similar evolution strategy, also adopting GPRS, has been developed for DAMPS (IS-136). For operators planning to offer wide band multimedia services, the move to GPRS packet-based data bearer service is significant; it is a relatively small step compared to building a totally new 3G network. Use of the GPRS network architecture for IS-136 packet data service enables data subscription roaming with GSM networks around the globe that support GPRS and its evolution. The IS-136 packet data service standard is known as GPRS-136. GPRS-136 provides the same capabilities as GSM GPRS. The user can access either X.25 or IP-based data networks.

GPRS provides a core network platform for current GSM operators not only to expand the wireless data market in preparation for the introduction of 3G services, but also a platform on which to build UMTS frequencies should they acquire them.

GPRS enhances GSM data services significantly by providing end-to-end packet switched data connections. This is particularly efficient in Internet/intranet traffic, where short bursts of intense data communications actively are interspersed with relatively long periods of inactivity. Since there is no real end-to-end connection to be established, setting up a GPRS call is almost instantaneous and users can be continuously on-line. Users have the additional benefits of paying for the actual data transmitted, rather than for connection time.

Because GPRS does not require any dedicated end-to-end connection, it only uses network resources and bandwidth when data is actually being transmitted. This means that a given amount of radio bandwidth can be shared efficiently between many users simultaneously.

The significance of EDGE (also referred to as 2.5G system) for today's GSM operators is that it increases data rates up to 384 kbps and potentially even higher in good quality radio environments that are using current GSM spectrum and carrier structures more efficiently. EDGE will both complement and be an alternative to new WCDMA coverage. EDGE will also have the effect of unifying the GSM, DAMPS, and WCDMA services through the use of dual-mode terminals.

GSM operators who win licenses in new 2 GHz bands will be able to introduce UMTS wideband coverage in areas where early demand is likely to be greatest. Dual-mode EDGE/ UMTS mobile terminals will allow full roaming and handoff from one system to the other, with mapping of services between the two systems. EDGE will contribute to the commercial success of the 3G system in the vital early phases by ensuring that UMTS subscribers will be able to enjoy roaming and interworking globally.

While GPRS and EDGE require new functionality in the GSM network with new types of connections to external packet data networks, they are essentially extensions of GSM. Moving to a GSM/UMTS core network will likewise be a further extension of this network.

EDGE provides GSM operators—whether or not they get a new 3G license—with a commercially attractive solution for developing the market for wide band multimedia services. Using familiar interfaces such as the Internet, volume-based charging and a progressive increase in available user data rates will remove some of the barriers to large-scale take-up of wireless data services. The move to 3G services will be a staged evolution from today's GSM data services using GPRS and EDGE. Table 1.1 provides a comparison of GSM data services.

Table 1.1 Comparison of GSM data services.

Service type	Data unit	Max. sustained user data rate	Technology	Resources used
Short Message Service (SMS)	Single 140 octet packet	9 bps	simplex circuit	SDCCH or SACCH
Circuit-Switched Data	30 octet frames	9.6 kbps	duplex circuits	TCH
HSCSD	192 octet frames	115 kbps	duplex circuits	1-8 TCH
GPRS	1600 octet frames	115 kbps	virtual circuit packet switching	PDCH (1-8 TCH)
EDGE (2.5G)	variable	384 kbps	virtual circuit/ packet switching	1-8 TCH

Note: SDCCH: Stand-alone Dedicated Control Channel; SACCH: Slow Associated Control Channel; TCH: Traffic Channel; PDCH: Packet Data Channel (all refer to GSM logical channels)

The use of CDMA technology began in the United States with the development of the IS-95 standard in 1990. The IS-95 standard has evolved since to provide better voice services and applications to other frequency bands (IS-95A), and to provide higher data rates (up to 115.2 kbps) for data services (IS-95B). To further improve the voice service capability and provide even higher data rates for packet and circuit switched data services, the industry developed the cdma2000 standard in 2000. As the concept of wireless Internet gradually turns into reality, the need for an efficient high-speed data system arises. A CDMA high data rate (HDR) system was developed by Qualcomm. The CDMA-HDR (now called 3G 1X EV-DO, [3G 1X Enhanced Version Data Only]) system design improves the system throughput by using fast channel estimation feedback, dual receiver antenna diversity, and scheduling algorithms that take advantage of multi-user diversity. 3G 1X EV-DO has significant improvements in the downlink structure of cdma2000 including adaptive modulation of up to 8-PSK and 16-quadrature amplitude modulation (QAM), automatic repeat request (ARQ) algorithms and turbo coding. With these enhancements, 3G 1X EV-DO can transmit data in burst rates as high as 2.4 Mbps with 0.5 to 1 Mbps realistic downlink rates for individual users. The uplink design is similar to that in cdma2000. Recently, the 3G 1X EV-Data and Voice (DV) standard was finalized by the TIA and commercial equipment is currently being developed for its deployment. 3G 1X EV-DV can transmit both voice and data traffic on the same carrier with peak data throughput for the downlink being confirmed at 3.09 Mbps.

As an alternative, Time Division-Synchronous CDMA (TD-SCDMA) has been developed by Siemens and the Chinese government. TD-SCDMA uses adaptive modulation of up to quadrature phase shift keying (QPSK) and 8-PSK, as well as turbo coding to obtain downlink data throughput of up to 2 Mbps. TD-SCDMA uses a 1.6 MHz time-division duplex (TDD) carrier whereas cdma2000 uses a 2×1.25 MHz frequency-division duplex (FDD) carrier (2.5 MHz total). TDD allows TD-SCDMA to use the least amount of spectrum of any 3G technologies.

Table 1.2 lists the maximum data rates per user that can be achieved by various systems under ideal conditions. When the number of users increases, and if all the users share the same carrier, the data rate per user will decrease.

One of the objectives of 3G systems is to provide access "anywhere, any time." However, cellular networks can only cover a limited area due to high infrastructure costs. For this reason, *satellite* systems will form an integral part of the 3G networks. Satellite will provide extended wireless coverage to remote areas and to aeronautical and maritime mobiles. The level of integration of the satellite system with the terrestrial cellular networks is under investigation. A fully integrated solution will require mobiles to be dual mode terminals to allow communications with orbiting satellite and terrestrial cellular networks. Low Earth orbit (LEO) satellites are the most likely candidates for providing worldwide coverage. Currently several LEO satellite systems are being deployed to provide global telecommunications.

Table 1.2 Network technology migration paths and their associated data rates.

Technology	Carrier width (MHz)	Duplexing	Multiplexing	Modulation	Max. data rates	End-user data rates
Analog					9.6 kbps	4.8–9.6 kbps
CDPD (1G)					19.2 kbps	about 16 kbps
GSM Circuit Switched Data (2G)	0.20	FDD	TDMA	GMSK	9.6–14.4 kbps	about 12 kbps
GPRS	0.20	FDD	TDMA	GMSK	up to 115.2 kbps (8 channels)	10–56 kbps
EDGE (2.5G)	0.20	FDD	TDMA	GMSK, 8-PSK	384 kbps	about 144 kbps
WCDMA (3G)	5.00	FDD	CDMA	QPSK	2 Mbps (stationary); 384 kbps (mobile)	50 kbps uplink; 150–200 kbps downlink
IS-54/IS-136 TDMA Circuit Switched Data (2G)	0.03	FDD	TDMA	QPSK	14.4 kbps	about 10 kbps
EDGE (2.5G) for North American TDMA system	0.20	FDD	TDMA	GMSK, 8-PSK	64 kbps uplink (initial roll out)	Initial roll out in 2001/2002: 45–50 kbps uplink; 80–90 kbps downlink
					384 kbps	2003: 45–50 kbps uplink; 150–200 kbps downlink

cdma2000 (3G) 1X	1.25	FDD	CDMA	QPSK	153 kbps	90–130 kbps (depending on the number of users and distance from BS)
3G 1X EV-DO (data only)	1.25	FDD	TD-CDMA	QPSK, 8-PSK, 16-QAM	2.4 Mbps	700 kbps
3G 1X EV-DV (data and voice)	1.25	FDD	TD-CDMA	QPSK, 8-PSK, 16-QAM	3–5 Mbps	>1 Mbps
TD-SCDMA	1.60	TDD	TD-CDMA	QPSK, 8-PSK	2 Mbps	1.333 Mbps

Note: FDD = Frequency Division Duplex; TDD = Time Division Duplex; PSK = Phase Shift Keying; QPSK = Quadrature Phase Shift Keying; GMSK = Gaussian Minimum Shift Keying; QAM = Quadrature Amplitude Modulation

1.5 Wireless 4G Systems

4G networks (see Chapter 23) can be defined as wireless ad hoc peer-to-peer networking with high usability and global roaming, distributed computing, personalization, and multimedia support. 4G networks will use distributed architecture and end-to-end Internet Protocol (IP). Every device will be both a transceiver and a router for other devices in the network eliminating the spoke-and-hub architecture weakness of 3G cellular systems. Network coverage/capacity will dynamically change to accommodate changing user patterns. Users will automatically move away from congested routes to allow the network to dynamically and automatically self-balance.

Recently, several wireless broadband technologies [20] have emerged to achieve high data rates and quality of service. Navini Networks developed a wireless broadband system based on TD-SCDMA. The system, named Ripwave, uses beamforming to allow multiple subscribers in different parts of a sector to simultaneously use the majority of the spectrum bandwidth. Beamforming allows the spectrum to be effectively reused in dense environments without having to use excessive sectors. The Ripwave system varies between QPSK, 16 and 64-QAM, which allows the system to burst up to 9.6 Mbps using a single 1.6 MHz TDD carrier. Due to TDD and 64-QAM modulation the Ripwave system is extremely spectrally efficient. Currently Ripwave is being tried by several telecom operators in the United States. The Ripwave Customer Premise Equipment is about the size of a cable modem and has a self-contained antenna. Recently, PC cards for laptops have become available allowing greater portability for the user.

Flarion Technologies is promoting their proprietary Flash-orthogonal frequency-division multiple (OFDM) as a high-speed wireless broadband solution. Flash-OFDM uses frequency hopping spread spectrum (FHSS) to limit interference and allows a reuse pattern of one in an OFDM access environment. Flarion's Flash-OFDM system uses 1.25 MHz FDD carriers with QPSK and 16-QAM modulation. Peak speeds can burst up to 3.2 Mbps with sustained rates leveling off at 1.6 Mbps on the downlink. Flarion has not implemented an antenna enhancement technology that may further improve data rates.

BeamReach is a wireless broadband technology based on OFDM and beamforming. It uses TDD duplexed 1.25 MHz paired carriers. Spread spectrum is used to reduce interference over the 2.5 MHz carriers allowing a frequency reuse of one. Individual users can expect downlink rates of 1.5, 1.2, and 0.8 Mbps using 32-QAM, 16-QAM, and 8-PSK modulation respectively. The aggregate network bandwidth is claimed to be 88 Mbps in 10 MHz of spectrum or 220 Mbps in 24 MHz of spectrum, which equates to a high spectral efficiency of 9 bps/Hz. It should be noted that the system uses either 4 or 6 sectors and these claims are based on those sectoring schemes. For any technology with a reuse number of 1 to achieve 9 bps/Hz per cell with 4 or 6 sectors, the efficiency in each sector would need to be a reasonable 2.3 or 1.5 bps/Hz, respectively.

IPWireless is the broadband technology based upon UMTS. It uses either 5 or 10 MHz TDD carriers and QPSK modulation. The theoretical peak transmission speeds for a 10 MHz deployment is 6 Mbps downlink and 3 Mbps uplink. The IPWireless system only uses QPSK modulation and no advanced antenna technologies. With the inclusion of advanced antenna technologies and the development of High Speed Downlink Packet Access (HSDPA), IPWireless has significant potential.

SOMA networks has also developed a wireless broadband technology based on UMTS. Like UMTS, SOMA's technology uses 5 MHz FHSS carriers. Peak throughput is claimed to be as high as 12 Mbps, making SOMA one of the faster wireless broadband technologies. Table 1.3 compares the wireless broadband technologies and their lowest order modulation data throughput.

1.6 Future Wireless Networks

As mobile networks evolve to offer both circuit and packet-switched services, users will be connected permanently (always on) via their personal terminal of choice to the network. With the development of intelligence in core network (CN), both voice and broadband multimedia traffic will be directed to their intended destination with reduced latency and delays. Transmission speeds will be increased and there will be far more efficient use of network bandwidth and resources. As the number of IP-based mobile applications grows, 3G systems will offer the most flexible access technology because it allows for mobile, office, and residential use in a wide range of public and nonpublic networks. The 3G systems will support both IP and non-IP traffic in a variety of modes, including packet, circuit-switched, and virtual circuit, and will thus benefit directly from the development and extension of IP standards for mobile communications. New developments will allow parameters like quality of service (QoS), data rate, and bit error rate (BER)—vital for mobile operation—to be set by the operator and/or service provider.

Wireless systems beyond 3G (e.g., 4G) will consist of a layered combination of different access technologies:

- Cellular systems (e.g., existing 2G and 3G systems for wide area mobility)
- WLANs for dedicated indoor applications (such as IEEE 802.11a, 802.11b, 802.11g)
- Worldwide interoperability for microwave access (WiMAX) (IEEE 802.16) for metropolitan areas
- WPANs for short-range and low mobility applications around a room in the office or at home (such as Bluetooth)

These access systems will be connected via a common IP-based core network that will also handle interworking between the different systems. The core network will enable inter- and intra-access handoff.

Table 1.3 Non-line of sight (LOS) wireless broadband technologies.

Developer	Technology	Multiplexing	Duplexing	Carrier (MHz)	Modulation	System DL Peak (Mbps)	System DL LOM (Mbps)	Avg. DL efficiency (bps/Hz)
Navini	TD-SCDMA	TD-CDMA	TDD	1.6	QPSK to 64-QAM	8.0	2.0	2.5
IPwireless	TD-WCDMA	TD-CDMA	TDD	5.0	QPSK	3.0	3.0	1.2
Flarion	Flash-OFDM	FHSS OFDM	FDD	1.25	QPSK, 16-QAM	3.2	1.6	1.28
SOMA	UMTS	CDMA	FDD	5.0	QPSK, 16-QAM	12.0	6.0	1.2
Beam Reach	AB-OFDM	DSSS-OFDM	TDD	2.5	8-PSK, 16-, 32-QAM	3.33	2.0	1.6

TDD carriers need one carrier for Tx and Rx, thus efficiency is doubled; BeamReach system throughput includes 6 sectors, thus it was divided by six; LOM—sustained system throughput estimated using lowest order modulation

The peak data rates of 3G systems are around 10 times more than 2G/2.5G systems. The fourth-generation systems may be expected to provide a data rate 10 times higher than 3G systems. User data rates of 2 Mbps for vehicular and 20 Mbps for indoor applications are expected. The fourth-generation systems will also meet the requirements of next generation Internet through compliance with IPv6, Mobile IP, QoS control, and so on.

1.7 Standardization Activities for Cellular Systems

The standardization activities for PCS in North America were carried out by the joint technical committee (JTC) on wireless access, consisting of appropriate groups from within the T1 committee, a unit of the Alliance for Telecommunications Industry Solutions (ATIS), and the engineering committee TR46, a unit of the Telecommunications Industry Association (TIA). The JTC was formed in November of 1992, and its first assignment was to develop a set of criteria for PCS air interfaces. The JTC established seven technical ad hoc groups (TAGs) in March of 1994, one for each of the selected air interface proposals. The TAGs drafted the specifications document for the respective air interface technologies and conducted validation and verification to ensure consistency with the criteria established by the JTC. This was followed by balloting on each of the standards. After the balloting process, four of the proposed standards were adopted as ANSI standards: IS-136-based PCS, IS-95-based PCS, GSM 1900 (a derivative of GSM) and Personal Access Communication System (PACS). Two of the proposed standards—composite CDMA/TDMA and Oki's wide band CDMA—were adopted as trial use standards by ATIS and interim standards by TIA. The Personal Wireless Telecommunications-Enhanced (PWT-E) standard was moved from JTC to TR 46.1 which, after a ballot process, was adopted in March of 1996. Table 1.4 provides a comparison of seven technologies using a set of parameters which include access methods, duplex methods, bandwidth per channel, throughput per channel, maximum power output per subscriber unit, vocoder, and minimum and maximum cell ranges.

The 3G systems were standardized under the umbrella of the International Telecommunications Union (ITU). The main proposals to the ITU International Mobile Telecommunications-2000 (IMT-2000) are: ETSI UMTS Terrestrial Radio Access (UTRA), ARIB WCDMA, TIA cdma2000, and TD-SCDMA. These third-generation systems will provide the necessary quality for multimedia communications. The IMT-2000 requirements are: 384 kbps for full area coverage (144 kbps for fast-moving vehicles between 120 km per hour and 500 km per hour), and 2 Mbps for local coverage. It is, therefore, important to use packet-switched data service to dynamically allocate and release resources based on the current needs of each user.

The ETSI agreed on a WCDMA solution using FDD mode. In Japan, a WCDMA solution was adopted for both TDD and FDD modes. In Korea, two

Table 1.4 Technical characteristics of North American PCS standards.

	TAG-1	TAG-2	TAG-3	TAG-4	TAG-5	TAG-6	TAG-7
Standard	Composite CDMA/ TDMA	IS-95 based PCS	PACS	IS-136 based PCS	GSM 1900	PWT-E	Oki's Wide band CDMA
Access	CDMA/ TDMA/ FDMA	CDMA	TDMA	TDMA	TDMA	TDMA	CDMA
Duplex Method	TDD	FDD	FDD	FDD	FDD	TDD	FDD
Frequency Reuse	3	1	16×1	7×3	7×1, 3×3	Portable selected	1
Bandwidth/channel	2.5/5 MHz	1.25 MHz	300 kHz	30 kHz	200 kHz	1 kHz	5, 10, 15 MHz
Throughput/ channel (kb/s)	8	8.55/13.3	32	8	13	32	32
Max. Power/subscriber unit	600 mW	200 mW	200 mW	600 mW	0.5–2.0 W	500 mW	500 mW
Vocoder	PHS HCA	CELP	ADPCM	VCELP/ ACELP	RPE-LTE ACELP	ADPCM	ADPCM
Max. Cell Range (km)	10.0	50.0	1.6	20.0	35.0	0.15	5.0
Min. Cell Range (km)	0.1	0.05	0–1	0.5	0.5	0.01	0.05

different types of CDMA solutions were proposed—one based on WCDMA similar to that of Europe and Japan and the other similar to the cdma2000 proposed in North America.

A number of groups working on similar technologies pooled their resources. This led to the creation of two standards groups—the third-generation partnership project (3GPP) and 3GPP2. 3GPP works on UMTS, which is based on WCDMA and 3GPP2 works on cdma2000.

The IEEE standard committee 802.11 is responsible for the WLAN standard. There are two IEEE standards committees that are involved in certification of wireless broadband technologies. The 802.16x committee focuses on the wireless metropolitan area network (WMAN) using CDMA and OFDM technologies. 802.16x allows for portability and data rates above 1 Mbps. The newly formed IEEE 802.20 committee, evolved from the 802.16e committee, focuses on mobile wide area network (MWAN). Several key performance requirements include megabit data rates and mobile handoff at speeds of up to 250 km per hour.

The Worldwide Interoperability for Microwave Access (WiMAX) Forum is a nonprofit organization formed by equipment and component suppliers to promote the adoption of IEEE 802.16-compliant equipment by operators of broadband wireless access systems. The organization is working to facilitate the deployment of broadband wireless networks based on IEEE 802.16 standards by helping to ensure the compatibility and interoperability of broadband wireless access equipment.

1.8 Summary

In this chapter, we presented the scope of wireless networks and gave an overview. We briefly discussed 1G, 2G/2.5G, and 3G cellular systems. The advantage of wireless data networking is apparent. Wireless data network users are not confined to the locations of "wired" data jacks, and enjoy connectivity that is less restrictive and therefore well suited to meet the needs of today's mobile users. Wireless network deployment in three service classifications—wireless personal access network (WPAN), wireless local area network (WLAN), and wireless wide area network (WWAN)—was discussed. Today, the core technology behind the wireless service in each of these service classifications is unique and, more important, not an inherently integrated seamless networking strategy. As an example, a user of a personal digital assistant (PDA), such as a PALM (XXX) connecting to the Internet via a WWAN service provider will not be able to directly connect to a WLAN service. Simply stated, they are different services, with different hardware requirements, and have fundamentally different service limitations. In the future, wireless networks have to evolve to provide interoperability of WPAN, WLAN, and WWAN systems.

Problems

1.1 Name the wireless access techniques used in 1G, 2G, and 3G wireless systems.

1.2 What are the three classes of wireless data networking?

1.3 Define the roles of WPAN technology in wireless data networking.

1.4 List the main features of 3G systems.

1.5 What is the role of GPRS in enhancing 2G GSM systems?

1.6 Show how CDMA IS-95 systems are moving to provide 3G services.

1.7 Show how 2G GSM systems are moving to achieve 3G services.

1.8 What are the data rate requirements for 3G systems?

1.9 Define IPWireless technology.

1.10 What are the goals of 4G systems?

References

1. Balston, D. M., and Macario, R. C. V. *Cellular Radio Systems*. Norwood, MA: Artech House, 1993.
2. Balston, D. M. *The Pan-European Cellular Technology*. IEE Conference Publication, 1988.
3. Cai, J., and Goodman, D. J. General packet radio service in GSM. *IEEE Communications Magazine*, vol. 35, no. 10, October 1997, pp. 121–131.
4. Crow, B. P., Widjaja, I., Kim, L. G., and Sakai, P. T. IEEE 802.11 Wireless Local Area Networks. *IEEE Communications Magazine*, September 1998, pp. 116–126.
5. Dasilva, J. S., Ikonomou, D., and Erben, H. European R&D programs on third-generation mobile communications systems. *IEEE Personal Communications*, vol. 4, no. 1, February 1997, pp. 46–52.
6. Dinan, E. H., and Jabbari, B. Spreading codes for direct sequence CDMA and wide band CDMA cellular networks. *IEEE Communications Magazine*, September 1998.
7. The European path towards UMTS. *IEEE Personal Communications*, Special Issue. February 1995.
8. Garg, V. K., and Wilkes, J. E. *Wireless and Personal Communications Systems*. Upper Saddle River, NJ: Prentice Hall, 1996.
9. Garg, V. K., and Wilkes, J. E. *Principles and Applications of GSM*. Upper Saddle River, NJ: Prentice Hall, 1998.
10. Garg, V. K. *CDMA IS-95 and cdma2000*. Upper Saddle River, NJ: Prentice Hall, 2000.
11. 3GPPweb Third generation partnership project website: *http://www.3gpp.org*.
12. 3GPP2web Third generation partnership project-2 website: *http://www.3gpp2.org*.

13. Marley, N. *GSM and PCN Systems and Equipment*. JRC Conference, Harrogate, 1991.
14. Mouly, M., and Pautet, M.-B. *The GSM System for Mobile Communications*. Palaiseau, France, 1992.
15. Nakajma, N. Future mobile communications systems in Japan. *Wireless Personal Communications*, vol. 17, no. 2–3, June 2001, pp. 209–223.
16. Nikula, E., Toshala, A., Dahlman, E., Girard, L., and Klein, A. FRAMES multiple access for UMTS and IMT-2000. *IEEE Personal Communications Magazine*, April 1998, pp. 16–24.
17. Negus, K., Stephens, A., and Lansford, J. Home RF: Wireless networking for the connected home. *IEEE Personal Communications*, February 2000, pp. 20–27.
18. Pirhonen, R., Rautava, T., and Pentinen, J. TDMA convergence for packet data services. *IEEE Personal Communications Magazine*, vol. 6, no. 3, June 1999, pp. 68–73.
19. Rapeli, J. UMTS: Targets, system concepts, and standardization in a global framework. *IEEE Personal Communications*, February 1995.
20. Shafi, M., Ogose, S., and Hattori T. (editors). *Wireless Communication in the 21st Century*. Wiley-Interscience, 2002.
21. Young, W. R. Advanced mobile phone services—Introduction, background and objectives. *Bell Systems Technical Journal*, vol. 58, 1979, pp. 1–14.