CELLULAR RADIO

The cellular radio system is sometimes called a mobile phone system or a car phone system. Due to the daily needs of subscribers, cellular systems have expanded considerably all over the world. This article discusses the history of cellular systems and the difficulty of deploying them in the mobile radio environment, elaborating on employing digital cellular systems, Personal Communication Services (PCS) mobile satellite systems, and the future IMT-2000 system.

HISTORY OF THE CELLULAR RADIO SYSTEMS

Analog System

Start-Up Period (From 1964 to 1987). In 1964, AT&T Bell Labs actively developed a high-capacity mobile radio phone system called Advanced Mobile Phone Service (AMPS) (1), which is an analog frequency modulation (FM) system. The system consists of many so-called cells. Each cell has one or multiple transceivers. Because of the cell formation, the system is referred to as a cellular system. In the analog AMPS system, mobile units are compatible with all the cellular systems operating in the United States, Canada, and Mexico. A spectrum of 50 MHz (limited to 825 MHz to 849 MHz for mobile transmissions and 869 MHz to 896 MHz for base station transmissions) is shared by two cellular system providers in each market (city). Each one provider operates over a bandwidth of 25 MHz in a duplex fashion (using 12.5 MHz in each direction between cell sites and mobile units). There are 416 channels, comprising 21 setup channels and 395 voice channels. The channel bandwidth is 30 kHz. Mobile cellular telecommunications systems (2) leave two unique features:

1. First, they invoke the concept of frequency reuse for increasing spectrum efficiency. The same set of frequency channels can be assigned to many cells. These cells are called co-channel cells. The separation between two co-channel cells is engineered by the D/R ratio (see Fig. 1), where D is the co-channel cell separation and R is the cell radius. A 4-mile cell implies $R = 4$ miles. The D/R ratio is characteristic of a cellular system. If the D/R ratio is high, the voice quality is improved by reducing the system's user capacity.
2. A second feature, handing off communications from one frequency to another occurs when a mobile unit enters a new cell. The scheme is called a handoff in North America and a handover in Europe. The system handles this operation automatically, and the users do not need to intervene. A good handoff algorithm can reduce both the call drop rates and interference. In general, there are two kinds of handoffs: (1) Soft handoffs, which implies making a new connection before breaking the old one; and (2) Hard handoffs, which is breaking the old connection before making the new one.

The first installation of a cellular system occurred in Tokyo in 1979, using a minor modification of AMPS. The first AMPS cellular system installed in the United States took place in Chicago in 1983. Analog cellular systems are in use over most of the world, employing different versions of AMPS: In Japan the Nippon Telephone and Telegraph (NTT) AMPS system, in the UK, the Total Access Communications System (TACS); and in northern Europe, the Nordic Mobile Telephone (NMT).

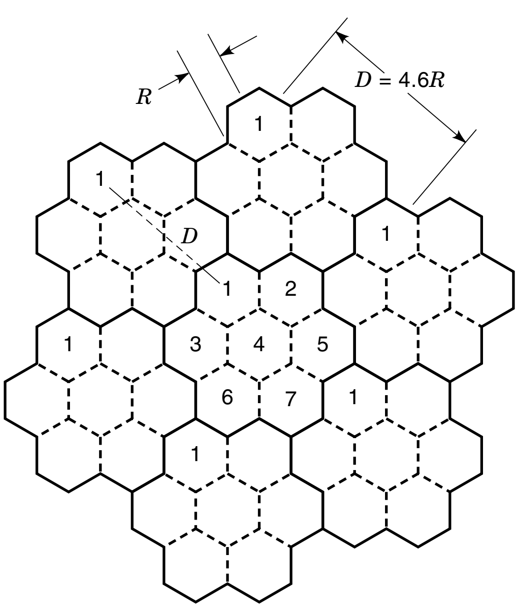

Figure 1. Hexagonal coils in an AMPS system. R = radius of cells, D = minimum separation of co-channel cells, $q = D/R = 4.6$, K = number of cells in a cluster = 7. Clusters are indicated, and the six cells that effectively interfere with cell 1 are numbered 2 through 7. The shaded cells are co-channel cells.

The major difference is their reduced channel bandwidths of 25 kHz instead of 30 kHz as in AMPS.

Mature Period (From 1987 to 1992). From 1987 to 1992, the 90 MSA (metropolitan statistical area) markets, as well as most of the 417 RSA (rural service area) markets, had cellular operations in the United States. The number of subscribers reached 1 million. The cell-split (reducing the size of cells) technique and dynamic frequency assignment were applied to increase the user capacity.

When the cell radius R is less than half a kilometer, the cell is called a microcell. In such small cells it is harder to reduce the so-called co-channel interference in order to increase capacity, requiring special technological approaches called microcell technology. The world was also becoming more aware of the potential future markets. Suddenly, finding the means to increase capacity became urgent.

Digital System

Introduction Period. In 1987, the capacity of the AMPS cellular system started to show its limitations. The growth rate of cellular subscribers far exceeded expectations. In 1987, the Cellular Telecommunication Industry Association (CTIA) formed a subcommittee for Advanced Radio Technology to study the use of a digital cellular system (3) to increase capacity. At that time, the Federal Communications Commission (FCC) had clearly stated that no additional spectrum would be allocated to cellular telecommunications in the foreseeable future. Therefore, the existing analog and forthcoming digital systems would have to share the same frequency band. In December 1989, a group formed by the Telecommunication Industry Association (TIA) completed a draft of a digital cellular standard.

The digital AMPS, which must share the existing spectrum with the analog AMPS, is a duplex time-division multiple-access (TDMA) system. The channel bandwidth is 30 kHz. There are 50 TDMA frames per second in each channel. Three or six time slots per frame can serve three calls or six calls at the same time in one channel. The speech coding rate is 8 kb per second. An equalizer is needed in the receiver to reduce the intersymbol interference that is due to the spread in time delay caused by the dispersed time arrival of multipath waves. The North American TDMA system was first called IS-54 by the TIA. Later, the system was modified and renamed as IS-136.

During this period, not all mobile telephone systems in Europe were compatible. A mobile phone unit working in one country could not operate in another country. In 1983, in response to the need for compatibility, a special task force called the Special Mobile Group (4) was formed among European countries to develop a digital cellular system called GSM (group of special mobile systems) in 1994, then changed to stand for global system for mobile communications. The operating principles of the GSM system resemble those of the AMPS in radio operation, but the system parameters are different; this will be described later.

In the United States, in addition to the TDMA being considered above, another particularly promising technology is code-division multiple access (CDMA) (3). It is a spread spectrum technique with a bandwidth of 1.25 MHz. The maximum number of traffic channels is 55. This CDMA system is called IS-95 or cdmaOne.

There are three mobile data systems in the United States: namely Ardis, operated by IBM/Motorola; Ram, operated by Ericsson; and CDPD (Cellular Digital Packet Data) system. The transmission rates for all data systems are around 8 kbps. Only CDPD operates in the cellular spectrum band.

The Future. Starting in 1996, the so-called PCS systems were deployed. They were cellular-like systems, but operated in the 1.8 GHz band in Europe and the 1.9 GHz range in North America. In Europe, the so-called DCS-1800 PCS systems were endorsed, which are based on the GSM system. In the United States, the PCS had three versions: DCS-1800 (a GSM version), TDMA-1900 (IS-136 version), and CDMA-1900 (IS-95 version). The PCS could have six operational licenses (A, B, C, D, E, F) in each city. Therefore, more competitors would be in the mobile phone services business.

In addition, the mobile satellite systems that use the LEO concept (low earth orbit) were deployed. Iridium (66 satellites) and Globalstar (48 satellites) were launched at 900 km and 400 km altitudes, respectively. These systems can integrate with cellular systems and enhance cellular coverage domestically and roam internationally as a global system. Other LEO systems are also in the development stage. There is a special LEO system called Teledesic that will be operating at 26 GHz with 840 satellites in orbit. This system is used for wideband data and video channels to serve subscribers in a high capacity network.

A future cellular system, called the International Mobile Telephone (IMT-2000) system, is now in the planning stage. A universal cellular standard (or PCS) system with high capacity and high transmission rate may be realized by the year 2002.

MOBILE RADIO ENVIRONMENT: A DIFFICULT ENVIRONMENT FOR CELLULAR RADIO SYSTEMS

Understanding the Mobile Radio Environment

The Limitations of Nature. In the mobile radio environment, there are many attributes that limit the system performance for wireless communication. In the past, there were attempts to adapt digital equipment such as data modems and FAX machines used for wireline to celluar systems. The data engineers at that time only realized the blanking and burst interruption in the voice channel as a unique feature of handoffs and power control. They modified data signaling by overcoming the impairments caused by blanking and burst signaling interruption. This modified data modem did not work as expected in the cellular system. Actually, the blanking and burst interruption scheme was not the sole cause of the inadequate data transmission and would have been relatively easy to handle. But without entirely understanding the impairments, the unexpected poor performance could not be offset by merely overcoming the blanking and burst signaling impairment.

Choosing the Right Technologies. In designing radio communication systems, there are many different technologies, and among them no single technology is superior to the others. Choosing a technology depends on real conditions in the environment of a particular communication. In satellite communication or microwave link transmission, the radio environments are different from that of the mobile radio environment. There are many good technologies that work in satellite communication and microwave link transmission, but they may not be suitable for the terrestrial mobile radio environment. Therefore, choosing the right technology must depend on the transmission environment.

Description of the Mobile Radio Environment

The mobile radio environment is one of the most complex ones among the various communication environments.

Nature Terrain Configuration. Because the antenna height of a mobile unit or a portable unit is very close to the ground, the ground-reflected wave affects the reception of the signal from the transmitting site via the direct path. The free space loss is 20 dB/dec (dec stands for decade, a period of ten) or, in other words, it is inversely proportional to the distance d^{-2}. However, in the mobile radio environment, due to the existing ground-reflected wave and the small incident angle θ, as shown in Fig. 2, the total energy of the ground-reflected wave is reflected back to space. Due to the nature of electromagnetic waves, when the wave hits the ground, the phase of the wave changes by 180°. Therefore, at the mobile, the direct wave and reflected wave cancel each other instead of adding constructively. As a result, the signal that is received becomes very weak. A simple explanation is as follows: If the path length of the direct wave is d, and the path length of the reflected wave is $d + \Delta d$. Then the received power of the two combined waves is proportional to d^{-4} as demonstrated below

$$P_r \propto \left(\frac{1}{d} - \frac{1}{d+\Delta d}\right)^2 = \left(\frac{\Delta d}{d(d+\Delta d)}\right)^2 = \frac{(\Delta d)^2}{d^4} \qquad (1)$$

where Δd is assumed to be much less than d and Δd is a function of the antenna height h_1 at the base station. From Eq. (1), the mobile radio path loss follows the inverse fourth power rule or 40 dB/dec, and the antenna height gain follows the second power rule or 6 dB/oct. In the mobile radio environment, the average signal strength at the mobile unit varies due to the effective antenna height h_e at the base station measured from the mobile unit location. Since the mobile unit is traveling, the effective antenna height is always changing as a function of terrain undulations and so is the average signal strength. This phenomenon is shown in Fig. 3.

This two-wave (direct wave and ground-reflected wave) model is only used to explain the propagation loss of 40 dB/dec in the mobile radio environment, not the multipath fading.

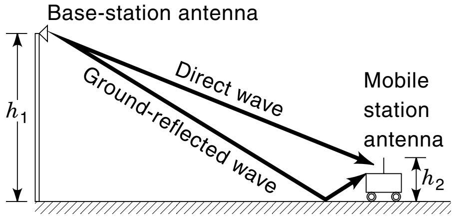

Figure 2. Two-wave propagation model.

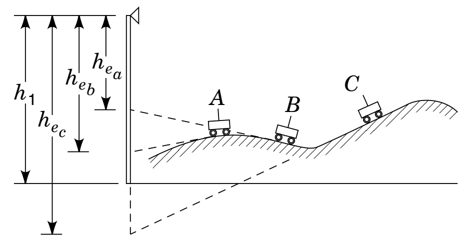

Figure 3. Effective antenna heights at base station based on different locations of mobile stations.

Man-Made Effect

Man-Made Communities. These can be classified as metropolitan areas, urban areas, suburban areas, and open areas, and so on. The distribution of buildings and homes depends on the population size. The reception of the signal is affected by the differences in man-made communities and results in different propagation path loss.

Man-Made Structures. Different geographical areas use different construction materials, different types of construction frames, and different sizes of buildings.

Cities such as Los Angeles, San Francisco, and Tokyo are in earthquake zones and follow earthquake construction codes. The signal reception in those cities is different from that in others. Man-made structures will affect the propagation path loss and multipath fading due to reflection and the signal penetration through the buildings.

Man-Made Noise. This can be classified into two categories: Industrial noise or the automotive ignition noise. The high spikes in automotive ignition or in machines are like impulses in the time domain; their power spectrum density will cover a wide spectrum in the industrial frequency domain. At 800 MHz, automotive ignition noise is determined by the number of vehicles. For a traffic volume from 100 cars/h to 1000 cars/h, the noise figure increases 7 dB. As the application of Ultra High Frequency (UHF) devices and microwave systems increase, so does the noise pollution for cellular systems. As we will mention later, a communication system is designed to maintain the minimum required carrier-to-interference ratio (C/I_s). The interference I may, under certain circumstances, be included in noise the N. If the interference level is higher, the level of the carrier, C should be also higher in order to meet the $(C/I)_s$ requirement. This means that when the man-made noise level is high, either the transmission power at the base station should be increased or the cell size must be reduced.

Moving Medium. If the mobile unit is in motion, the resulting signal from multipath waves at one location is not the same at another, thus the mobile receiver observes an instantaneous fluctuation in amplitude and phase. The amplitude change is called Rayleigh phase, and the phase change is a uniformly distributed process, or random FM in FM systems. The signal fading can be fast or slow depending on the speed of the vehicle. When the vehicle speed is slow, the average duration of fading is long. This average fading duration can be, for example, 7 ms at −10 dB below the average level when the vehicle speed is 24 km/h at a propagation frequency of 850 MHz. In an analog system, a fade duration of 7 ms does not affect the analog voice; the ear cannot detect these short fades. However, the fade duration of 7 ms is long enough to corrupt the digital (voice and data) transmissions. At a transmission rate of 20 kbps, 140 bits will sink in the fade. Furthermore, the vehicle speed of all the users is not constant, and the use of interleaving and channel coding to protect the information bits is very difficult. Furthermore, voice communication is operating in real time unlike data transmission which can be in any time-delay fashion. Many schemes used by data communication cannot be used for digital voice communication.

Dispersive Medium. Because of human-made structures, the medium becomes dispersive. In a dispersive medium, two phenomena occur. One is time delay spread and the other is selective fading. The time delay spread is caused by a signal transmission from the base station reflected from different scatterers and arriving at the mobile unit at different times. In urban areas, the mean time delay spread, Δ, is typically 3 μs; in suburban areas, Δ is typically 0.5 μs. In an open area, Δ is typically 0.2 μs, and in an in-building floor, Δ is around 0.1 μs or less. These time delay spreads do not affect the analog signal because the ear cannot detect the short delay spread. However, in a digital system when a symbol (bit) is sent, many echoes arrive at the receiver at different times. If the next symbol is sent out before the first one dies down, intersymbol interference occurs. The dispersive medium also causes frequency selective fading (Fig. 4).

The selective fading will not hurt the moving receiver because when the mobile unit is moving, only the average power is considered. Then, in order to make a mobile phone call when the mobile unit is at a standstill, it usually requires that all the signal strengths from four frequencies have two strong setup channels and two strong voice channels. A pair of frequencies is formed by a channel carrying a call on both a forward link and a reverse link. When the mobile unit is moving, the average power of the four frequencies is the same. Then we base our quality estimates on one $(C/I)_s$ value. But when the mobile unit is still, the signals of four frequencies at one location are different due to frequency selective fading. Unless all four frequencies are above the acceptable threshold level, the call cannot be connected.

Concept of *C/I*

In designing high-capacity wireless systems, the most important parameter is the carrier-to-interference ratio (*C/I*). The *C/I* ratio and the *D/R* ratio are directly halted. The *D/R* ratio

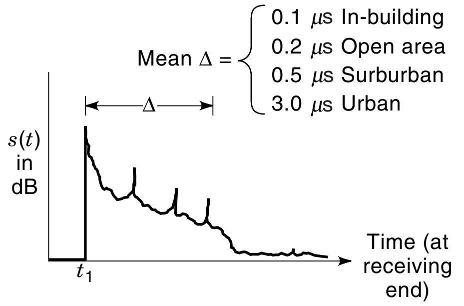

Figure 4. Time delay spread Δ at the receiving end when transmitting one bit in a dispersive medium.

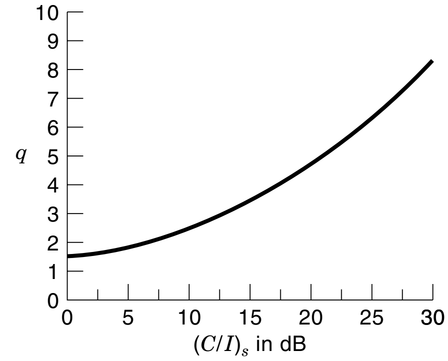

Figure 5. Relationship between q and $(C/I)_s$ [Eq. (3)].

is determined by the *C/I* ratio. Usually, with a given received signal level *C*, the lower the interference level, the higher the *C/I* ratio and hence the quality improves. There is a specific *C/I* level, namely $(C/I)_s$, that the system design criterion is based on. We may derive the relationship between *C/I* and *D/R* as follows: Assume that the first tier of six co-channel interference cells is the major cause for the interference *I*. Based on the 40 dB/dec propagation rule, we obtain

$$\frac{C}{I} = \frac{C}{\sum_{i=1}^{6} I_i} \approx \frac{C}{6 \cdot I_i} = \frac{R^{-4}}{6 \cdot D^{-4}} = \frac{(D/R)^4}{6} \tag{2}$$

A general equation of the co-channel interference reduction factor q can be expressed, from Eq. (2), as

$$q = (D/R)_s = (6(C/I)_s)^{1/4} \tag{3}$$

where $(C/I)_s$ is obtained from a subjective test corresponding to the required voice (or data) quality level, as mentioned previously. Equation (3) is plotted in Fig. 5. The $(C/I)_s$ ratio is chosen according to either the required voice or data channel quality.

The Predicted Signal-Strength Models

Since the $(C/I)_s$ is a system design parameter, system planning engineers would like to use an effective model to predict both *C* and *I* in a given area. There are two different prediction models. One predicts the average signal strength along the radio path based on the path loss slope. The Okumura and Hata's model (5,6) represents these types of models. The other predicts the local-mean signal strength along a particular mobile path (street or road) based on the particular terrain contour. Lee's model (7) represents these types of models.

REASONS FOR DIGITAL CELLULAR

Compatibility in Europe

Again, due to the lack of a standard mobile radio system in Europe during the early 1980s, the mobile phone unit used in each country could not be used in other countries. Starting in 1982, ETSI (European Telecomms Standard Institute) formed a group called the Group of Special Mobile to construct an international mobile radio system called GSM for Europe.

The system chosen was to be a digital system using TDMA for the access scheme. The GSM advanced intelligent network (AIN) was adopted from the wireline telephone network. GSM was the first digital mobile phone system in the world.

Capacity in North America

Frequency spectrum is a very limited resource commonly shared by all wireless communications. Among the wireless communications systems, cellular is the most spectral efficient system where the so-called spectral efficiency is related to the number of traffic channels per cell. From this number, we can derive the Erlang/cell ratio, which translates to Erlang/km^2, or the number of traffic channels/km^2 based on the traffic model and the size of the cells.

However, a spectrum of only 50 MHz has been allocated to cellular operators in the United States. Furthermore, since two operators are licensed in each market, the spectrum of 50 MHz must be split in two. Therefore, system trunking efficiency is reduced and interference caused by an operator in one market often contaminates the other operator's allocated spectrum. Furthermore, manufacturing companies were always considering lowering the cost of cellular units and increasing sales volume. As a result, the specification of cellular units could not be kept tight, and thus more interference prevailed. Once interference increased and could not be controlled by cellular operators, both voice quality and system capacity decreased.

In 1987, the top 10 US markets were already feeling the constraints of channel capacity; they would not be able to meet the market demand in the future. The solution for this increasing need for high capacity was to go digital (1–3). Going digital was the best solution because of the nature of the digital waveform. If system compatibility is not an issue, the top 10 US markets might and could go digital by themselves. However, for the sake of compatability the United States needed one standard for the entire North American cellular industry.

The Advantages of a Digital System

Digital systems offer the following advantages:

1. The digital waveform is discrete in nature. Therefore, the digital waveform can be regrouped easily for transmission needs.
2. Digital transmission is less susceptible to noise and interference.
3. Digital modulation can confine the transmitted energy within the channel bandwidth.
4. Digital equipment may consume less battery power, and hence may reduce equipment weight.
5. Digital systems can provide reliable authentication and privacy (encryption).

REQUIREMENT FOR CELLULAR AND PCS

In 1996, the Telecommunications Act Bill was passed by the U.S. Congress and stated, in simple terms, that everyone could get into everyone's business. Cellular service is moving toward digital and is trying to compete with PCS. The PCS spectrum was auctioned in early 1996. There are wideband PCSs and narrowband PCSs (see Fig. 6). The spectrum of wideband PCS is allocated at 1900 MHz in order to operate the same technology as the cellular system. The spectrum of narrowband PCS is allocated at 900 MHz and is used for two-way paging. The joint requirements of both cellular and PCS are as follows:

From the end users perspective: The PCS and cellular units should be light in weight, small in size, and have

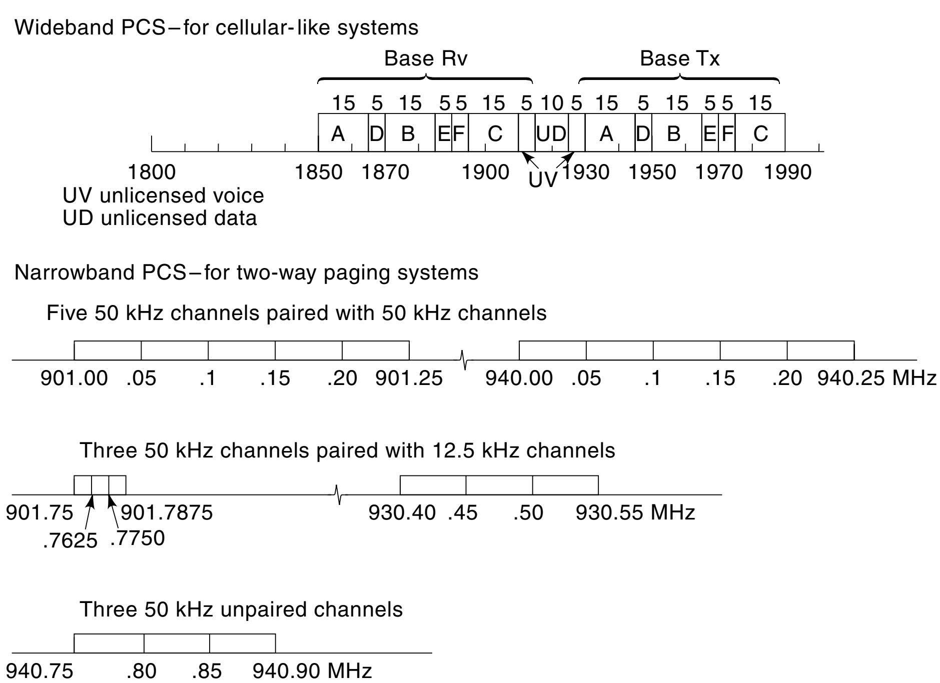

Figure 6. Spectrum allocated for wideband PCS and narrowband PCS.

long talk-time capabilities without battery recharging and good quality in voice and data. The unit should be employable for initiating and receiving calls anywhere using any telephone feature. The important requirement of PCS and cellular is to please the vast majority of subscribers who always prefer to carry a single unit, not many units. This unit can be classified according to the different grades of service.

From the system providers perspective: The PCS should provide full coverage and large system capacity to serve end users. An end user unit ideally should be serviced by one system with different grades of service and unless there are natural limitations by the various personal communication environments (such as mobile vehicle, pedestrian, and indoor public communication). Then one end user unit should be capable of accessing more than one system.

DIGITAL MODULATIONS AND MULTIPLE ACCESS

Digital Modulation Schemes

Digital modulation schemes can be selected to confine the transmitted energy of a digital voice signal in a given frequency bandwidth while transmitting in a mobile radio environment. The information may have to be modulated by signal phases or frequencies, rather than amplitudes, because the multipath fading impairs the signal amplitude.

Multiple Access

Digital transmission can use time-division multiple access (TDMA), frequency-division multiple access (FDMA), or code-division multiple access (CDMA), but in analog transmission only FDMA can be used. FDMA provides many different frequency channels, where each is assigned to support a call. TDMA means chopping a relatively broadband channel over time into many time slots. Each time slot is assigned to support a call. CDMA means generating many different code signatures over a long code-bit stream channel, where each code signature is assigned to convey a call. FDMA is a narrowband system. It is a low-risk system to develop but was voted down by the industry in 1987. FDMA is not suitable for high-speed data transmission. TDMA was first developed in Europe and is called GSM. TDMA has been developed in North America. For the ADC (American Digital Cellular system), CDMA needs more advanced technology and is relatively harder to implement than the other two multiple access schemes, especially in the mobile radio environment. However, the improved user capacity of CDMA has given the cellular industry the incentive to develop this system. Therefore, digital transmission in the mobile radio environment has only two competing multiple accesses. The North America selected TDMA based on the influence from the European GSM.

THE SPECIFICATIONS OF DIFFERENT CELLULAR/PCS SYSTEMS

Analog Systems

Each traffic channel in an analog system uses two frequencies, one receiving and one transmitting frequency. In general, we often refer to “a 30 kHz channel” when we really mean a bandwidth of 30 kHz on one of two frequencies. Therefore, the total occupied spectrum for each traffic channel is 60 kHz. There are three analog systems: The AMPS from North America, the NTT system from Japan, and the TACS system from the UK. Their specifications are listed in Table 1.

TDMA Systems

The following TDMA systems can be grouped into two different duplexing techniques, FDD and TDD:

FDD (frequency division duplexing). Each traffic channel consists of two operational frequencies. The analog system can only use a FDD system, whereas the digital system has a choice.

GSM. The term GSM often implies DCS-1800 and DCS-1900 services. They are in the same family, only the

Table 1. Large-Capacity Analog Cellular Telephones Used in the World

	Japan	North America	England
System transmission frequency (MHz):			
Base station	870–885	869–894	917–950
Mobile station	925–940	824–849	872–905
Spacing between transmission and receiving frequencies (MHz)	55	45	45
Spacing between channels (kHz)	25, 12.5	30	25
Number of channels	600	832 (control channel 21 × 2)	1320 (control channel 21 × 2)
Coverage radius (km)	5 (urban area) 10 (suburbs)	2–20	2–20
Audio signal:			
Type of modulation	FM	FM	FM
Frequency deviation (kHz)	±5	±12	±9.5
Data transmission rate (kb/s)	0.3	10	8
Message protection	Transmitted signal is checked when it is sent back to the sender by the receiver.	Principle of majority decision is employed.	Principle of majority decision is employed.

Source: Report from International radio Consultative Committee (CCIR) 1987.

Table 2. Physical Layer Parameters of GSM

Parameter	Specifications
Radio carrier bandwidth	200 kHz
TDMA structure	8 time slots per radio carrier
Time slot	0.577 ms
Frame interval	8 time slots = 4.615 ms
Radio carrier number	124 radio carriers (935–960 MHz downlink, 890–915 MHz uplink)
Modulation scheme	Gaussian minimum shift keying with BT[a] = 0.3
Frequency hopping	Slow frequency hopping (217 hops/s)
Equalizer	Equalization up to 16 μs time dispersion
Frequency hop rate	217 hops/s
Handover	Hard handover

[a] BT = Bandwidth × Time.

carrier frequencies are different. We list the physical layer parameters in Table 2.

NA-TDMA (North American-TDMA). NA-TDMA, sometimes called ADC, is North America's standard system. It incorporates both 800 MHz and 1900 MHz system versions. The network follows philosophy of the GSM intelligent network. The physical layer is shown in Table 3.

The PDC (personal digital cellular) system. This system was developed in Japan and is very similar to the NA-TDMA system, but its radio carrier bandwidth is 25 kHz.

IDEN (Integrated Digital Enhanced Network). This system was developed by Motorola. It was called MIRS (Mobile Integrated Radio System); then Motorola modified the system and renamed it IDEN. This system uses the SMR (Special Mobile Radio) band, which is specified by Part 90 of FCC CFR code of Federal regulations in the private sector. The system now can be used for cellular-like commercial services. The physical parameter system is as follows:

1. Full-duplex communication system
2. Frequency—806 to 824 MHz (mobile transmitter), 851 MHz
3. Channel bandwidth—25 kHz
4. Multiple access—TDMA
5. Number of time slots—6
6. Rate of speech coder—VSELP (Vector sum excitation linear predicted)
7. No equalizer implemented
8. Handoff
9. Transmission rate—6.5 kbps/slot
10. Forward error correction—3 kbps
11. Dispatch capability

Table 3. Physical Layer of NA-TDMA

Parameter	Specifications
Radio carrier bandwidth	30 kHz
TDMA structure	3 time slots per radio carrier
Time slot	6.66 ms
Frame interval	20 ms
Radio carrier number	2 × 416 (824–849 MHz reverse link, 869–894 MHz forward link)
Modulation scheme	$\frac{\pi}{4}$ − DQPSK
Equalizer	Equalization up to 60 μs time dispersion

TDD (time division duplexing). Transmission and reception are shared by one frequency. Certain time slots are for transmission and certain time slots are for reception.

CT-2 (Cordless Phone Two). CT-2 was developed by GPT Ltd. in the UK for so-called Telepoint Applications. Phone calls can be dialed out but cannot be received. The transmission parameters for CT-2 are as follows:

1. Full duplex system
2. Voice coder—32 kbps adaptive differential pulse-code modulation (ADPCM).
3. Duplexing—TDD. The portable and base units transmit and receive on the same frequency but different time slots.
4. Multiple access—TDMA-TDD, up to four multiplexed circuits
5. Modulation—$\pi/4$ DQPSK differential QPSK, roll-off rate = 0.5
6. Data rate—192 ksps (192 kilo symbols per second or 384 kbps)
7. Spectrum allocation—1895 MHz to 1918.1 MHz. This spectrum has been allocated for private and public use.
8. Carrier frequency spacing—300 kHz

PHS (Personal Handy-Phone System). It was developed in Japan. Now there are three operators: NTT, STEL, and DDI. The system serves for the low tier subscribers, like teenagers. There are around seven million customers. The specifications for transmission parameters are as follows:

1. Full duplex system
2. Voice coder—32 kpbs adaptive differential pulse-code modulation (ADPCM).
3. Duplexing—TDD. The portable and base units transmit and receive on the same frequency but different time slots.
4. Multiple access—TDMA-TDD, up to four multiplexed circuits.
5. Modulation—$\pi/4$ DQPSK, roll-off rate = 0.5
6. Data rate—192 ksps (or 384 kbps).
7. Spectrum allocation—1895 MHz to 1918.1 MHz. This spectrum has been allocated for private and public use.
8. Carrier frequency spacing—300 kHz.

Another system called PACS (Personal Access Communication Systems) (3) is in the same system family as PHS.

DECT (Digital European Cordless Telephone) (3). DECT is a European standard system for slow motion or in-

Table 4. Comparative Low-Earth-Orbiting Mobile Satellite Service Applications

System Characteristics	Loral/QUALCOMM	Motorola IRIDIUM	TRW ODYSSEY	Constellation ARIES (b)	Ellipsat ELLIPSO
Number of satellites	48	66	12	48	24
Constellation altitude (NM)	750	421	5600	550	1767 × 230
Unique feature	Transponder	Onboard processing	Transponder	Transponder	Transponder
Circuit capacity (US)	6500	3835	4600	100	1210
Signal modulation	CDMA	TDMA	CDMA	FDMA/CDMA	CDMA
Gateways in US	6	2	2	5	6
Gateway spectrum band	C-band existing	New Ka band	New Ka band	Unknown	Unknown
Coverage	Global	Global	Global	Global	Northern hemisphere

building communications. Its system structure is as follows:

1. Duplex method—TDD
2. Access method—TDMA
3. RF (radio frequency) power of handset—10 mW
4. Channel bandwidth—1.728 MHz/channel
5. Number of carriers—five (a multiple-carrier system)
6. Frequency—1800 to 1900 MHz

DECT's characteristics are as follows:

1. Frame—10 ms
2. Time slots—12
3. Bit rate—38.8 kb/slot
4. Modulation—GFSK (Gaussian Filtered FSK)
5. Handoff—Yes

CDMA Systems

CDMA is another multiple-access scheme using different orthogonal code sequences to provide different call connections. It is a broadband system and can be classified by two approaches: (1) Frequency Hopping System approach (3), and (2) direct sequence system approach (3). The commercial CDMA system applies the direct sequence approach. Developed in the United States, it is called the IS-95 Standard System. The first CDMA system was deployed in Hong Kong and then in Los Angeles in 1995. CDMA is a high-capacity system. It has been proven, theoretically, that CDMA system capacity can be 20 times higher than analog capacity. In a CDMA system, all the cells share the same radio carrier in an operating system. The handoff from cell to cell is soft (i.e., not only is the frequency kept unchanged, but the cell is connected in both the old cell and the new cell in the handoff region). The IS-95 CDMA is now called cdmaOne. The CDMA radio specifications are as follows:

1. CDMA shares the spectrum band with AMPS
2. Total number of CDMA radio carriers is 18.
3. Radio carrier bandwidth is 1.2288 MHz.
4. Pseudo noise (PN) chip rate is 1.2288 Mcps.
5. Pilot channel is one per radio carrier.
6. Power control step is 1 dB in 1 ms.
7. Soft handoffs are used.
8. Traffic channels are 55 per each radio carrier.
9. Vocoder is Qualcomm Code Excited Linear Prediction (QCELP) at a variable rate.
10. Modulation is Quaternary Phase Shift Keying (QPSK).
11. Data frame size is 20 ms.
12. Orthogonal spreading is 64 Walsh functions.
13. Long PN code length is $2^{42} - 1$ chips
14. Short PN code length is $2^{15} - 1$ chips.

Mobile Satellite Systems

Mobile satellite systems (MSS) are used to enhance terrestrial radio communication, either in rural areas or in terms of global coverage. Therefore, MSS becomes, in a broad sense, a PCS system. By taking advantage of reduced transmitting power and short time delays, the low earth orbit (LEO) systems are being developed. However, there is a drawback. Each LEO system needs many satellites to cover the earth. There are many LEO systems, as shown in Table 4. There is also another LEO referred to as the Teledesic system, which will operate at 24 GHz with a spectrum band of 500 MHz. This LEO system is not just for enhancing cellular or PCS coverage, but also can replace the terrestrial long-distance telephone network in the future.

IMT-2000

Since the CDMA One system has been successfully deployed in Korea and the United States, in mid-1997 the European countries under the auspices of the so-called (ETSI) European Telecom. Standard Institute, Japan (ARIB) Association of Radio Industrial and Business, and the United States (TIA) Telecom Industrial Asso. began planning a universal single-standard system for the so-called IMT-2000 (International Mobile Telephone—Year 2000). There are three general proposals. The proposals disagree on many issues, but they do agree on the following general guideline principles:

1. Use wideband CDMA (WCDMA).
2. Use direct sequence as spread spectrum modulation.
3. There should be a multiband, single mobile unit.
4. The standard band should be 5 MHz.
5. There is a need for international roaming.
6. There should be given up IPR (intellectual property right) issues in developing the new global system among all the international vendors.

The IMT-2000 system will require a great deal of compromise in selecting technologies due to the political differences in the international standards bodies. The formal IMT-2000 system will be adapted by the ITU (International Telecommunication Union). It remains uncertain if there will be a single universal IMT-2000 by the year 2000.

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AirTouch Communication

CELLULAR STANDARDS.

See MOBILE TELECOMMUNICATIONS STANDARDS.