CHAPTER 8

Wireless Modulation Techniques and Hardware

Upon completion of this chapter, the student should be able to:

- Discuss the general characteristics of wireline and fiber-optic transmission lines.
- Discuss the propagation conditions peculiar to the air interface for wireless mobile systems and wireless LANs.
- Discuss the coding techniques used by wireless mobile systems to combat transmission errors.
- Explain the basic fundamental concepts of digital modulation techniques and their advantages.
- Explain the basic operation and characteristics of spread spectrum modulation systems.
- Discuss the basic principles behind the operation of ultra-wideband radio technology.
- Explain the theory behind the use of diversity techniques for the improvement of wireless communications.
- Discuss the typical BSC and RBS hardware found at a modern cell site.
- Discuss the technical attributes of a subscriber device.

8.1 TRANSMISSION CHARACTERISTICS OF WIRELINE AND FIBER SYSTEMS

Fixed telecommunication infrastructure takes on many forms and uses many different techniques to transmit information from point to point. Depending upon the distance, form of the information (analog or digital), required data transmission rate, and the environment that needs to be traversed, one might choose from any one of many different technologies to deliver the desired signal or signals from one point to another. For either relatively short or extremely long fixed terrestrial point-to-point networks, one typically finds some form of guided-wave transmission media used. The physical implementations of these media are commonly known as transmission lines. Although today one can point to numerous examples of short-haul, fixed point-to-point radio links that have recently come into their own in terms of popularity, this section will limit its coverage to conductor-based (wireline) and fiber-optic transmission lines. A brief overview of the common types of transmission lines and their characteristics follows. In all cases, these types of transmission media provide a more reliable channel than the typical wireless radio channel.

Conductor-Based Transmission Lines

$X_C = \frac{1}{2\pi f C}$ $f_c = \frac{1}{2\pi RC}$ $f_c = \frac{1}{2\pi f C}$

The purpose of a **transmission line** (TL) is to guide a signal from point to point as efficiently as possible. At low frequencies (with extremely long wavelengths), current flows within the conductors and is not prone to radiate away from the TL. At higher frequencies, the current flow takes place near the conductor surface (due to the so-called skin effect). At radio frequencies (RF) and higher (microwaves and millimeter waves), the transmission line acts as a structure that guides an electromagnetic wave (EM). Many specialized TLs exist for use at these extremely high frequencies but will not be discussed here.

There are numerous types of TLs available for use in today's telecommunication links. Some of the more commonly encountered **wireline** TLs are unshielded and shielded twisted pair (UTP and STP), LAN Category-n cable, and coaxial cable. These cables are used to provide the local-loop connection to the telephone central office, LAN connectivity, and broadband cable TV service to name just a few applications. In all cases, wireline transmission lines act like low-pass filters, their signal attenuation increases with frequency. The individual characteristics of these wireline cables provide differing levels of bandwidth, maximum transmission rate, and reliability. Therefore, when designing a new telecommunication link or choosing what type of TL to use, one should choose a TL designed for that particular application.

In general, the most important TL characteristics to consider are bandwidth, susceptibility to noise, and frequency response. For the cases of bandwidth and frequency response these characteristics are fairly stable with time and can be designed around or adapted to by intelligent systems (ADSL, HDSL, etc.). These types of systems test the link to determine its initial characteristics and adaptively adjust their operation before attempting to use it. They continue to test the link periodically thereafter and adapt to any changes as necessary. TL susceptibility to noise is another issue. Different twisted pairs within a binder of multiple pairs can have varying amounts of ingress of near- and far-end cross talk (NEXT and FEXT noise) associated with the pair depending upon the various types of traffic being carried on the other pairs within the binder. Also, the existence of other nearby or not-so-nearby electrical noise sources (atmospheric, man-made EMI, etc.) can also impair signal transmission. Coaxial cables offer the advantage of shielding as do various types of shielded twisted pairs. Shielding allows the coaxial cable to be placed in environments that are unfavorable to simple unshielded transmission lines. However, for both coaxial cable and STP, noise ingress can occur at termination points, splices, or connectors. To compensate for these facts, various coding schemes and transmission protocols have been developed to respond to the ultimate result of too much noise, bit errors, or frame errors in transmitted data. Use of these error detection and correction schemes tends to provide reliable data transport over wireline TLs.

Fiber-Optic Cables

The ultimate telecommunications transmission media is the fiber-optic cable. Besides having a potential for almost unlimited bandwidth, it is not susceptible to electromagnetic interference (EMI) and its physical construction typically blocks any ingress (or egress for that matter) of stray photons that could cause problems. It is not that fiber-optic cables do not have any noise problems, it is just that the noise is quantum in nature. Therefore, if the optical detector used at the far end of the optical link has a sufficient number of photons reaching it, the bit error rate (BER) will be extremely low and for all practical purposes is nonexistent. In fact, other components in the fiber-optic link (sources, detectors, amplifiers, optical switches, etc.) may contribute more to the generation of noise and bit errors than the cable itself. This fact has led to the popularity of using fiber-optic cables for long-haul, high-capacity (gbps and tbps) backbone telecommunications links and the development of optical transport technologies like SONET that take advantage of these low BERs. In the case of both wireline cables and fiber-optic cables, extremely reliable communications links may be established. Unfortunately, this cannot be said for the radio channel. The next section will examine the characteristics of the air interface.

Radio Wave Propagation and Propagation Models

Before looking at any particular EM propagation models, a general overview of terrestrial EM propagation is warranted. EM waves below approximately 2 MHz tend to travel as ground waves. Launched by vertical antennas, these waves tend to follow the curvature of the earth and lose strength fairly rapidly as they travel away from the antenna. They do not penetrate the ionospheric layers that exist in the upper portions of the earth's atmosphere. Frequencies between approximately 2 and 30 MHz propagate as sky waves. Bouncing off of ionospheric layers, these EM waves may propagate completely around the earth through multiple reflections or "hops" between the ground and the ionosphere. Frequencies above approximately 30 MHz tend to travel in straight lines or "rays" and are therefore limited in their propagation by the curvature of the earth. These frequencies pass right through the earth's ionospheric layers. The daily and seasonal variations that occur in the characteristics of the ionospheric layers give rise to the repeated use of the word *approximately* in the previous explanations.

Other propagation considerations include antenna size and the penetration of structures by EM waves. Antenna size is inversely proportional to frequency. The higher the frequency of operation the smaller the antenna structure can be, which is an important consideration for a mobile device. Also, as frequency increases and wavelength decreases, EM waves have a more difficult time penetrating the walls of physical structures in their path. At frequencies above 20 GHz for example, signals generated within a room will usually be confined within the walls of a room. At even higher frequencies, atmospheric water vapor or oxygen will attenuate the signal as it propagates through the atmosphere. These effects, although appearing detrimental at first, can be used to one's advantage for certain applications. More will be said about this topic later on.

When first-generation AMPS cellular radio was first deployed in the United States, it used frequency bands (in the 800-MHz range) refarmed from the upper channels of the UHF television band. These frequencies provided appropriate propagation conditions, antenna size, and building penetration properties. The PCS bands in the 1900-MHz range and the new AWS bands in the 1710- and 2100-MHz range are also suitable for mobile wireless. These services all use licensed spectrum in the ultrahigh-frequency (UHF) band that has been auctioned off (or will be) by the FCC in various-size pieces to different operators and service providers in different basic and major trading areas. New standards for wireless LANs call for operation in either the unlicensed instrumentation, scientific, and medical (ISM) frequency bands or the new unlicensed national information infrastructure (U-NII) bands. The use of either expensive licensed frequencies or free unlicensed frequencies puts a new spin on how the wireless industry will evolve.

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Wave Propagation Effects at UHF and Above

Since all of the world's mobile wireless systems use the UHF (300–3000 MHz) band, some additional details about propagation above 300 MHz will be given at this time. Note also that the presently used ISM and U-NII bands are located in both the UHF and superhigh-frequency (SHF) bands (3–30 GHz). For signal propagation both indoors and outdoors, three major effects tend to determine the final signal level that is received at the mobile station from the base station and, the reverse case, the signal level received by the base station from the mobile. In theory, by what is known as the reciprocity theorem, the path loss for these two cases should be almost identical.

These three primary propagation effects are reflection, scattering, and diffraction. Reflection occurs for EM waves incident upon some type of large (compared to a wavelength) surface. For a smooth surface the EM wave undergoes a specular reflection, which means that the angle of incidence equals the angle of reflection. How much of the signal power is reflected from a smooth surface or transmitted into it is a complex function of the type of material, the surface roughness, frequency of the incident EM wave, and other variables. In general, the more electrically conductive the surface or the higher the material's relative dielectric constant, , the greater the amount of signal reflection. And, conversely, the lower the value of , the greater the amount of signal transmission into the medium. Scattering occurs when the signal is incident upon a rough surface or obstacles smaller than a wavelength. This case produces what is known as a diffuse reflection (i.e., the signal is scattered in many different random directions simultaneously). Finally, diffraction is a subtle effect that causes EM waves to appear to bend around corners. An EM wave incident upon a sharp corner (e.g., the edge of a building rooftop) causes the generation of a weak point source that can illuminate a shadow or non-LOS (NLOS) area behind the object.

See Figure 8–1 for an example of an outdoor propagation case and Figure 8–2 for an example of an indoor propagation case. As shown by Figure 8–1 several signal paths may (and usually do) exist between the base station antenna and the mobile station. The primary signal tends to follow the line-of-sight (LOS) path while several to many other secondary, tertiary, or higher-order reflections also arrive at the mobile. In addition, diffraction of the base station signal can occur from almost any type of object and therefore any number of diffracted signals might also arrive at the mobile. For this case, all the signals arriving at the number of diffracted signals

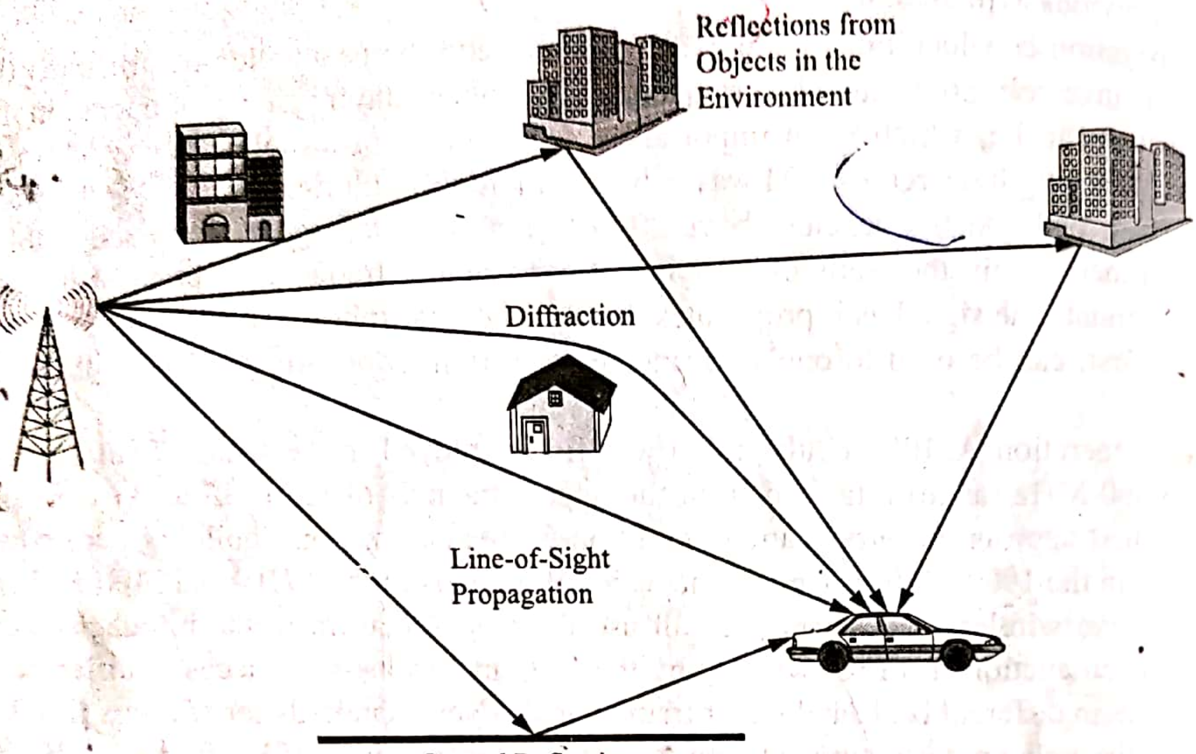

Figure 8–1 Typical outdoor propagation case.

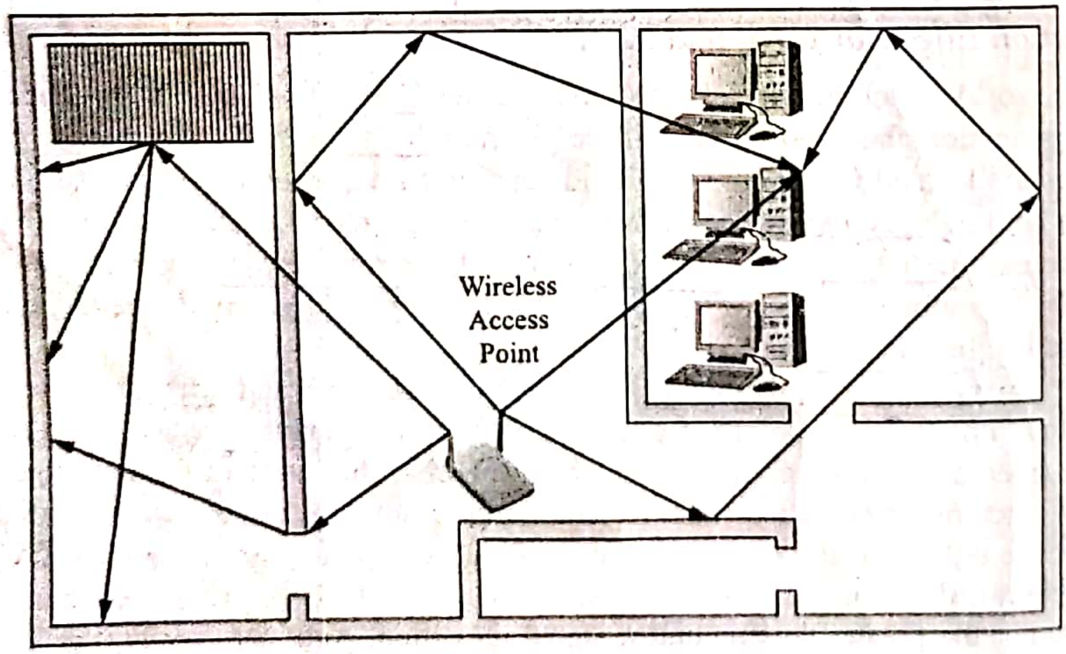

Figure 8–2 Typical indoor propagation case.

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mobile add together vectorially (i.e., both amplitude and phase), with the strongest signals tending to create the composite received signal. **Multipath** is the common term used to describe this type of propagation scenario. Also, note that due to the distances involved, there can be a fairly large spread of delays relative to the LOS signal due to the variety of possible paths that the other secondary signals might travel.

Figure 8–2 shows an example of an indoor propagation situation similar to what might be encountered with a wireless LAN access point and a wirelessly enabled laptop. In this case, the signal from the transmitter propagates through the walls between the rooms, experiences numerous reflections off of walls in a corridor and other interior walls, and undergoes diffraction and scattering due to various other obstacles and sharp corners. Again, all the signals arriving at the receiver will add together vectorially to create the composite received signal. For this case, due to the short propagation distances involved, there will be only a small spread of delays between the arriving signals. This important point will be expanded upon shortly. For the case of a cellular call being received within a structure or a particular wireless LAN situation there may be no direct or unobstructed LOS signal. This being the case, the composite received signal is primarily composed of many weaker secondary signals. As the reader may have already concluded, there are a myriad of possible situations and conditions that might arise for both outdoor and indoor propagation cases. Additionally, the effect on received signals for the case of a mobile moving about within a system's coverage area has not been addressed as of yet.

Path Loss Models for Various Coverage Areas

The first **path loss** model to consider is that for free space propagation. It may be shown fairly easily that without any outside influences the propagating signal power of an EM wave decreases by the square of the distance traveled as it spreads out. Therefore, the EM wave undergoes an attenuation of −6 dB every time the distance it travels doubles. The power received from an antenna radiating P_T watts in free space is given by the following equation (known as the Friis equation):

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 \qquad \textbf{8-1}$$

where G_T and G_R are the transmitting and receiving antenna link gains, respectively, λ is the signal wavelength, and d is the distance from the transmitting antenna. A typical technique to simplify the usage of this equation is to rewrite it as:

$$P_R = P_0/d^2 \qquad \textbf{8-2}$$

where P_0 is the received signal strength at a distance of one meter. Once P_0 has been calculated, it is a simple task to determine the received signal strength at other distances. Also important to note here is that in the free space environment the velocity of propagation for an EM wave translates into an approximately 3.3-ns-per-meter time delay. This means that it takes 3300 ns for a signal to travel a distance of 1000 meters in free space. This fact will be called upon later in our further discussions about multipath propagation. At this point, a free space path loss example is appropriate.

Example 8–1

What is the received power in dBm for a signal in free space with a transmitting power of 1 W, frequency of 1900 MHz, and distance from the receiver of 1000 meters if the transmitting antenna and receiving antennas both use dipole antennas with gains of approximately 1.6? What is the path loss in dB?

Solution: First calculate P_0 from Equation 8-1

$P_0 = (1)(1.6)(1.6)(0.1579)/4\pi(1))^2 = .0004042$ W or −3.934 dBm

P_R in dBm: $10 \log \left(\frac{P_R}{1\,\text{m}\ldots}\right.$

$P_t = 10 \, Log \left(\frac{60 \times 10^{-3}}{10^{-3}} \right)$

$P_{R \, in \, dBm} = 10 \, Log \left(\frac{P_{R \, in \, W}}{10^{-3}} \right)$

$P_R = P_0/d^2 = (\quad) \, dBm$

$(\quad) \, W$

Then from Equation 8-2,

$$P_R = (P_0/d^2) = (.4042 \text{ mW}/1000^2) = .4042 \text{ nW or } -63.934 \text{ dBm}$$

The path loss in dB is the difference between the transmitted power, P_T, and the received power, P_R. Or, in equation form:

$$Path\ Loss = P_T - P_R \tag{8-3}$$

For this particular example, the path loss is equal to +30 dBm (–63.934 dBm) or 93.934 dB. Note, 1W = +30 dBm.

Unfortunately, the free space model, though instructive, does not give accurate results when applied to mobile radio environments. As already discussed, typically the transmitted signal reaches the receiver over several different paths. At this time several other models will be discussed in the context of relative cell size and environment (i.e., indoor and outdoor).

12.2 LINE-OF-SIGHT PROPAGATION

In Section 2 of Chapter 8, the Friis equation for line-of-sight radio wave propagation was discussed. This equation may be used to predict radio wave propagation in free space and also for fixed terrestrial line-of-sight systems if the transmitting and receiving antennas are high enough above the ground and there are no obstructions between them. The Friis equation, repeated here for convenience, predicts the power that will be received from a transmitter at a distance, *d*.

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 \qquad \text{12-1}$$

In general, if the link is stationary or fixed, there is even more predictability to the relative received signal strength and the reliability of the link. As pointed out previously in Chapter 8, there are many other propagation effects that can come into play and affect the transmission link. For terrestrial systems, some of these factors include atmospheric attenuation, precipitation, shadowing, and reflected and scattered signal propagation paths. For satellite systems, one adds the effects of transionospheric propagation (i.e., the Faraday effect), signal frequency shift due to the Doppler effect, and signal blocking to the list. The net result in both cases is the possibility of reduced RSS and severe signal-strength fades.

Design of these types of transmission links is usually performed by using software design tools that are optimized for the particular application. For terrestrial links, propagation models based on the line-of-sight Friis equation are combined with terrain data available from geographic information systems (GIS) to provide detailed analysis of point-to-point and point-to-multipoint systems. These sophisticated software programs incorporate transmission component and antenna characteristics, frequency of operation, rainfall rate predictions, the curvature of the earth, clutter height and type, and Fresnel zone and path obstruction diffraction effects. These and other factors are used to design and predict link reliability with a fairly high degree of accuracy. Other design software features usually include signal interference analysis, colorized signal-strength contour maps, diversity schemes, and the ability to generate sophisticated reports of the transmission network, its characteristics, and an inventory of the digital microwave network equipment.

The mathematical prediction of the received signal level from a geosynchronous satellite system is fairly straightforward since the signal propagation path approximates a fixed line-of-sight, obstruction-free link. To deal with the various propagation effects that tend to degrade the received power, a link margin is typically assumed. The link margin is usually specified in dBs and increases with increasing frequency of operation. For these types of calculations one may rearrange and evaluate the Friis equation using dB as shown here:

$$P_R(\text{dBm}) = P_T(\text{dBm}) + G_T(\text{dB}) + G_R(\text{dB}) - 20\log\left(\frac{4\pi d}{\lambda}\right) \qquad \text{12-2}$$

Example 12–1

If the nominal transmitter output power is 120 watts for a DIRECTV DBS and the transmitting antenna gain is 34 dB, determine the received signal power if the eighteen-inch receiving dish has a nominal gain of 33 dB. Assume that the operating frequency is 12.45 GHz and the receiving antenna is directly below the satellite.

Solution: First calculate the wavelength, λ, in meters. Since,

$$\lambda = \frac{300}{f\ (\text{MHz})}, \qquad \lambda = \frac{300}{12,450} = 0.0241\ \text{m}$$

Next, convert 120 watts to dBm; this can be done by using the formula,

$$P_T\,(\text{dBm}) = 10\log\left(\frac{120\text{W}}{1\text{mW}}\right) = 50.8\ \text{dBm}$$

Now, using Equation 12-2 one calculates:

$$P_R = 50.8\text{dBm} + 34\text{dB} + 33\text{dB} - 20\log\left(\frac{4\pi \times 35,786,000}{0.0241}\right) = 117.8$$

50.8 +826.

$$P_R = 117.8\text{dBm} - 205.4\text{dB} =$$
$$P_R = -87.6\text{dBm}$$

Thus the received signal level is approximately –87.6 dBm. With a receiver noise temperature of about 75°K, combined with the forward error correction coding scheme used by the transmitter, this is a sufficient signal level to provide fairly good-quality video reception.

Digital M... ...nsed bands or the new unlicensed

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user often has the ability to mix or partition the type of transmitted data signals. Today's equipment commonly uses QPSK, 8-PSK, 16-QAM, 32-QAM, or higher-order QAM modulation techniques and allows transmission of a mix of nxDSn (i.e., various combinations of multiple DS1s or DS3s or a mix of both) and Ethernet at various bit rates. Typical transmitter output powers are in the +16 to +25 dBm range with receiver sensitivities in the –70 to –90 dBm range depending upon the frequency of operation, the type of modulation, transmitted signal bandwidth, and the final mix of data transmission streams.

Example 12–2

A digital microwave link is set up to transmit 24 DS1s using 16-QAM with a 20-MHz bandwidth at 38 GHz. Both the transmitting and receiving antennas have diameters of 30 cm and a nominal gain of 38.5 dB. If the transmitter output power is +16 dBm and the receiver sensitivity is –74 dBm for a bit error rate of 10^{-7}, determine the maximum system range assuming unobstructed LOS propagation and a 15-dB link margin.

Solution: Using Equation 12-2, one may calculate:

$$P_R(\text{dBm}) = +16\text{dBm} + 38.5\text{dB} + 38.5\text{dBm} - 20\log\left(\frac{4\pi d}{\lambda}\right)$$

With a link margin of 15 dB, the received signal power must be at least –74 dBm +15 dB = –59 dBm for perfect conditions. Therefore,

$$-59\text{dBm} = 93\text{dBm} - 20\log\left(\frac{4\pi d}{\lambda}\right)$$

The wavelength of a 38-GHz signal is given by,

$$\lambda = \frac{300}{38000} = 0.00789 \text{ m}$$

And substitution into the prior expression yields $d = 25.0$ km

Therefore, the maximum predicted useful range possible for this digital microwave link is approximately 25 km using this overly simplified mathematical model.

7.1 INTRODUCTION TO MOBILE WIRELESS DATA NETWORKS

The growth of the Internet and its daily use by the average person coupled with the public's desire for anytime, anywhere voice and data communications has been the driving force behind the growth and development of mobile wireless data networks. If one plots the number of Internet Web sites or Internet users versus time, the resulting upward curve is closely matched only by the growth in the number of worldwide wireless cellular subscribers. If desired, the reader may view any number of the previously listed Web sites (i.e., GSM, UMTS, CDMA forums or industry collaborations) that provide impressive, near real-time running totals of existing subscribers to a particular air interface technology and maps of worldwide deployment and coverage areas with detailed information about the service providers, frequency bands used, technology used, and so on. Most cellular industry predictions of future system expansion and total numbers of wireless subscribers are heavily optimistic, with double-digit growth predicted for at least this decade.

Overview of the Packet Data Network

A short review of the packet data network is appropriate at this time. Essentially, the packet data network consists of an interconnection of numerous data networks, both public and private, that use packet switching to deliver data to a final destination. The network is set up to deliver data packets through the use of header information appended to the beginning of the data. The packet header typically includes such information as the destination address, the sender's address, and other overhead information necessary for the successful and perhaps necessary timely delivery of the data contained in the packet. Some of this overhead information might also be appended to the end of the packet (thus encapsulating the data). Within the packet data network there are nodes (routers) that connect to other routers and eventually to other packet networks and so on and so forth. The function of these routers is to inspect the packet header destination information and forward or switch individual packets on to the correct router output interconnection as they make their way toward their final destinations (hence the term *connectionless switching*). Numerous types of packet data networks exist, both public and private. As technology has evolved, various protocols (review Chapter 1 and its coverage of the OSI model) have been developed to facilitate the transmission of data over networks utilizing different types of physical media, providing different and ever increasing data rates, dealing with various quality of service (QoS) issues, using different error handling techniques, and interconnecting with other possibly different networks. Furthermore, depending upon the physical scope of the data network (i.e., LAN, MAN, or WAN) many sophisticated transport technologies (Ethernet, ATM, SONET, frame relay, X.25, T-carrier, xDSL, etc.) exist today.

Interestingly, the almost universal use of transport control protocol/ internet protocol (TCP/IP) makes the packet data network transparent to the user and basically hides the network hardware from view. At this point, most consider the packet data network and the Internet one in the same. The wireless packet data network is an extension of the Internet that provides the end user mobility with Internet connectivity in a WAN environment somewhat similar to the untethered environment offered by a wireless LAN.

CDPD

As mentioned before, CDPD was created to provide bursty packet data delivery over the AMPS system. It is able to perform this data service by defining a specific network architecture, a set of protocols, and having a radio interface that is compatible with the AMPS technology. CDPD works by sharing AMPS spectrum (and later on, NA-TDMA spectrum) for both data and voice services. It uses idle time on the AMPS channels to transmit data packets and dedicated spectrum from an NA-TDMA system. It should be pointed out that CDPD can also be overlaid on a CDMA network. The CDPD network architecture is depicted by Figure 7–1.

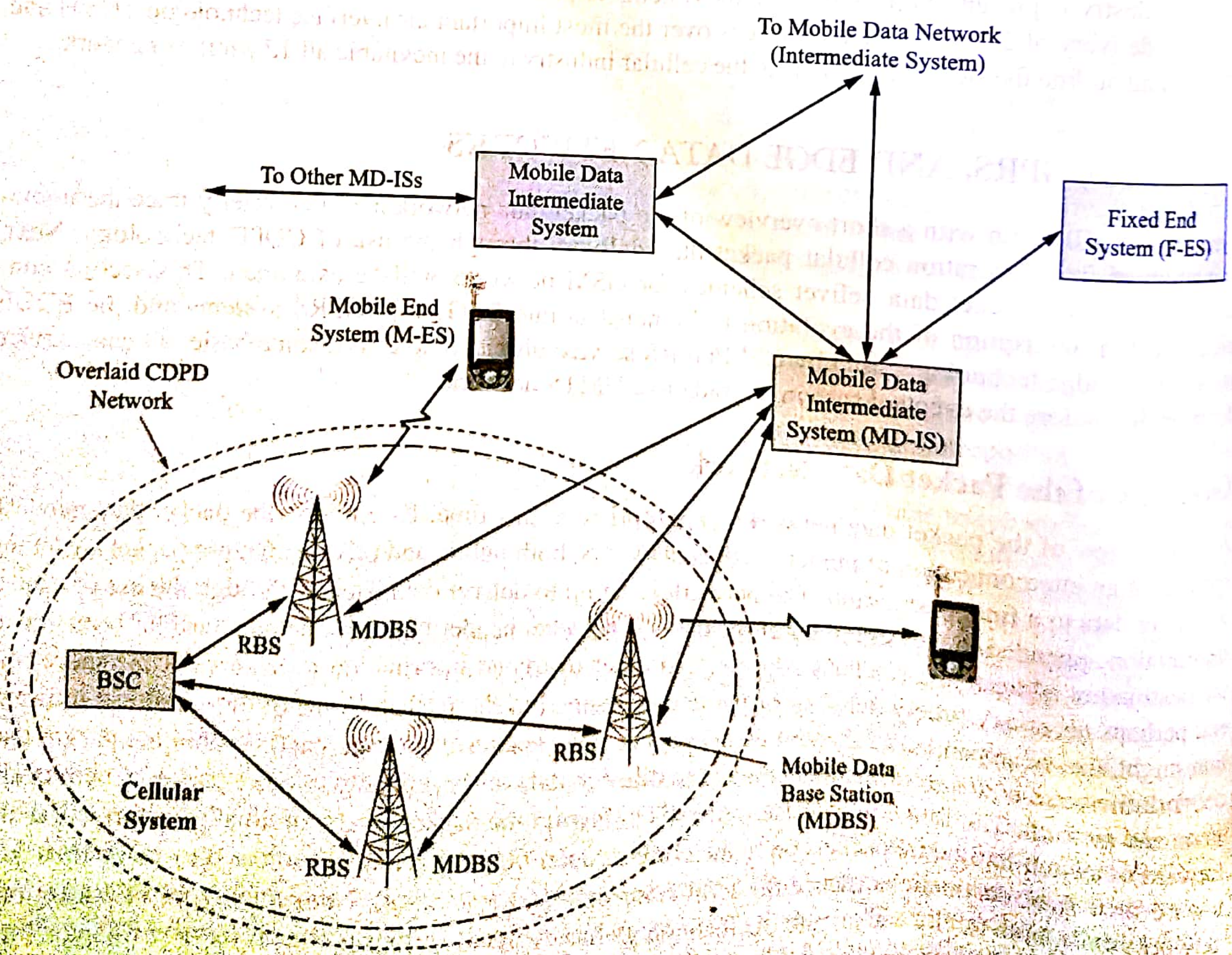


Figure 7–1 Typical CDPD network architecture.

...network elements that...

As shown by Figure 7–1, the CDPD network consists of several network elements that provide the functionality necessary for system operation. The basic CDPD network elements are the intermediate systems, the mobile data intermediate system, and the mobile data base stations. The intermediate systems act as gateways between the CDPD network and other packet data networks. Essentially, they are routers that form the CDPD network backbone and provide the necessary connections to other external networks. The mobile data intermediate system provides the interface between the fixed CDPD network and the mobile user of the network. This network element provides the end user with mobility within the system and performs similar functions as the HLR and the VLR in a cellular network. The mobile data base stations provide the radio interface to the end users of the network. Every cell that supports CDPD delivery contains a base station supporting CDPD operation. Lastly, the CDPD standard specifies two types of end terminal devices, the user mobile end system (M-ES) and a fixed end system (F-ES). The M-ES might be a credit card verification unit installed in a taxi cab, a wirelessly enabled PDA, or some other form of handheld. Since the CDPD system is able to be colocated with the host AMPS system (and other later cellular systems) and share both the antenna and the site, CDPD was viewed as a cost-effective solution to packet data service early on in the evolution of cellular technology.

For proper CDPD operation, the CDPD wireless network must overlay the host AMPS network. This is accomplished through one of several possible scenarios involving the two networks. The AMPS system can dedicate one or more of its available traffic channels for CDPD service. This will certainly provide superior-quality CDPD service; however, if there is not a great deal of CDPD traffic it might compromise the AMPS service. Another possible arrangement is to have shared channels for CDPD and voice traffic with voice calls having the highest priority. In this case, the CDPD network detects unused or idle voice channels and allocates them to packet data calls as needed. If the AMPS system needs the channel for a voice call, it will be relinquished by the CDPD network. The CDPD network will continue the data call if it can detect another idle voice channel within the system and transfer the call to it before the expiration of a system timer. In this case, the performance of the CDPD network depends upon the amount of voice traffic on the AMPS network. A third option is to dedicate a number of the AMPS channels as voice only and then share a number of channels for both voice and data traffic. This option guarantees a certain level of AMPS performance at the expense of the CDPD network. For colocated operation with host NA-TDMA or CDMA networks, the CDPD network usually requires a dedicated allocation of spectrum.

The operation of a CDPD wireless network is very similar to typical wireless cellular system operation. For an M-ES-originated packet data call, the mobile device must acquire a CDPD channel. Depending upon the system setup, either a dedicated CDPD channel will be specified and programmed into the M-ES's memory or the mobile device will need to perform what is known as channel sniffing to find a CDPD-enabled channel. Once a CDPD channel has been acquired by the M-ES it will perform a registration and authentication process with the CDPD network. The CDPD network's versions of the HLR and VLR (located in the mobile data intermediate system) will be updated with the mobile device's present location and required routing information. Once these operations are complete, the M-ES may commence sending and receiving packets over the radio link that has been setup. For an M-ES-terminated packet data call the process is somewhat different. Each MD-IS broadcasts identification information about itself over the forward CDPD radio link. If the M-ES moves from its home MD-IS serving area into a new MD-IS serving area, it will register with the system and hence provide its present location within the system to the network. Packet data destined for the M-ES will be routed to the new serving area and be broadcast over the forward link. All M-ESs within the radio coverage area will receive the data packets, but only M-ESs with valid network identifiers are able to decode them.

GPRS

When the second-generation GSM standards were developed, the digital-based GSM system was designed to be an integrated wireless voice-data service network that offered defined data services. Phase 1 of GSM deployment defined both teleservices and bearer services that included short message service, teletex, FAX, both asynchronous and synchronous data, and synchronous packet data delivery albeit at low data rates by today's standards (9600 bps maximum). Phase 2 of the GSM specifications added enhanced circuit data throughput rates, and Phase 2+ of the standards have addressed the evolution to higher packet data transfer rates. Phase 2+ calls for GSM support for high-speed circuit-switched data (HSCSD), the ability to transfer small data packets over radio interface signaling channels, general packet radio service (GPRS), and enhanced data rate for global evolution (EDGE). This section will discuss GPRS in more detail and the next section will discuss EDGE technology.

GPRS Networks

Although GSM wireless networks have the vast majority of cellular subscribers worldwide, extensive GSM networks have only recently been introduced into the United States. Nationwide GSM/GPRS networks are being rapidly built out by several service providers in the PCS bands (1900 MHz) while other service providers have systems operating at 850 MHz. In a related development, NA-TDMA service providers have deployed GSM/GPRS systems to provide high-speed packet data services to complement their legacy voice service systems (requires a dual-mode handset). The overlay of these new GSM/GPRS systems will gradually reduce the spectrum available for NA-TDMA systems and eventually these service providers will migrate totally to GSM/GPRS/EDGE wireless networks. As always, economics will dictate the speed at which these events happen. However, the process has been set into motion and there appears to be a worldwide commitment by the wireless industry to deploy true 3G service-capable networks during the middle of this decade. The conversion to GSM by the NA-TDMA operators affords them a clearer migration path to 3G than they previously had.

Figure 7–2 shows a typical GSM/GPRS network. The GPRS network runs in concert with a GSM wireless network. A typical GPRS public land mobile network (PLMN) allows a mobile user to roam within the geographical coverage area of the GSM/GPRS system and provides continuous, moderate-speed, wireless packet data service. In the case of a mobile subscriber moving about the system, the GSM PLMN keeps track of the subscriber's location and aids the GPRS PLMN in routing the incoming data packets to the correct serving cell.

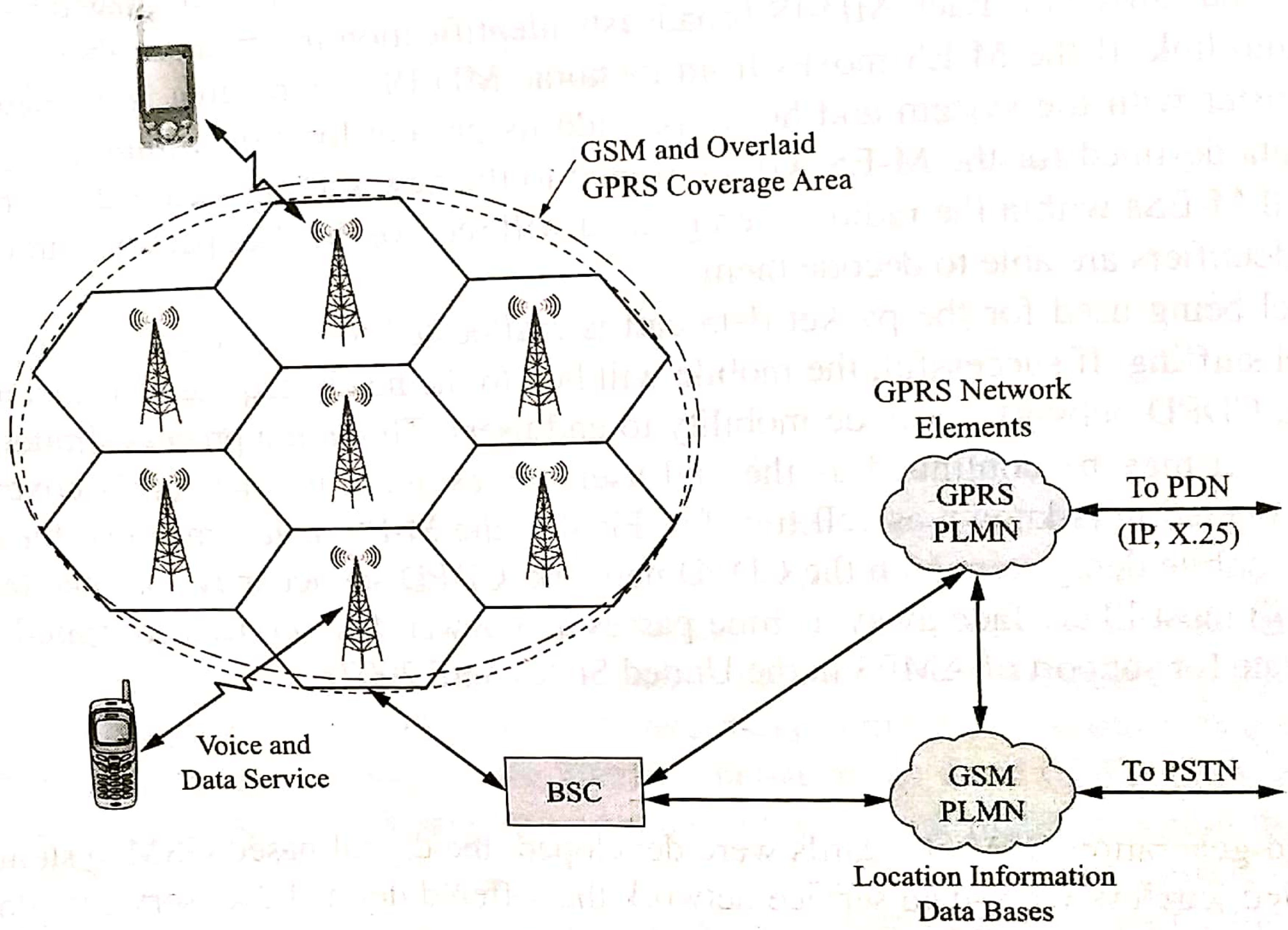


Figure 7–2 Typical GSM/GPRS network.

The GPRS PLMN uses the GSM air interface to provide packet data service to the subscriber and the fixed portion of the network interfaces with the public data network using standard packet data protocols. Network layer protocols like X.25 and IP (Internet protocol) are supported and therefore the end user is able to access Internet Web sites and private enterprise servers via the GPRS PLMN. The GPRS user can also receive voice services via the GSM PLMN. Depending upon the mobile's capabilities, these services may be accessed either one at a time or simultaneously.

The GPRS standard supports many different and useful features: roaming between different GPRS networks, several different connection topologies (point-to-point, point-to-multipoint, etc.), SMS service over packet data channels, different quality of service (QoS) levels, different modes of addressing (e.g., static, dynamic, multiple simultaneous), and security and confidentiality through a GSM-based system of authentication, sophisticated encryption, and a packet temporary mobile subscriber identity (P-TMSI).

GPRS Network Details

A GPRS PLMN is made up of several network elements and various communications links that interface these elements to one another. The GSM standards specify a GPRS network reference model with these network elements and signaling interfaces and their interconnection to the standard GSM network elements. Figure 7–3 depicts the components of a GPRS network and the GPRS logic architecture with some of the signaling interfaces labeled. The key new network elements in the GPRS PLMN are the **GPRS support nodes** (GSNs) of which there are two types. There is a gateway GPRS support node (GGSN) that serves as the gateway between the GPRS network and other packet data networks, and the serving GPRS support node (SGSN) that controls GPRS service in a coverage area. The GGSN is also responsible for routing data to the correct SGSN. All of the GSNs within a GPRS PLMN are interconnected by an IP backbone and perform routing functions specific to the GPRS PLMN.

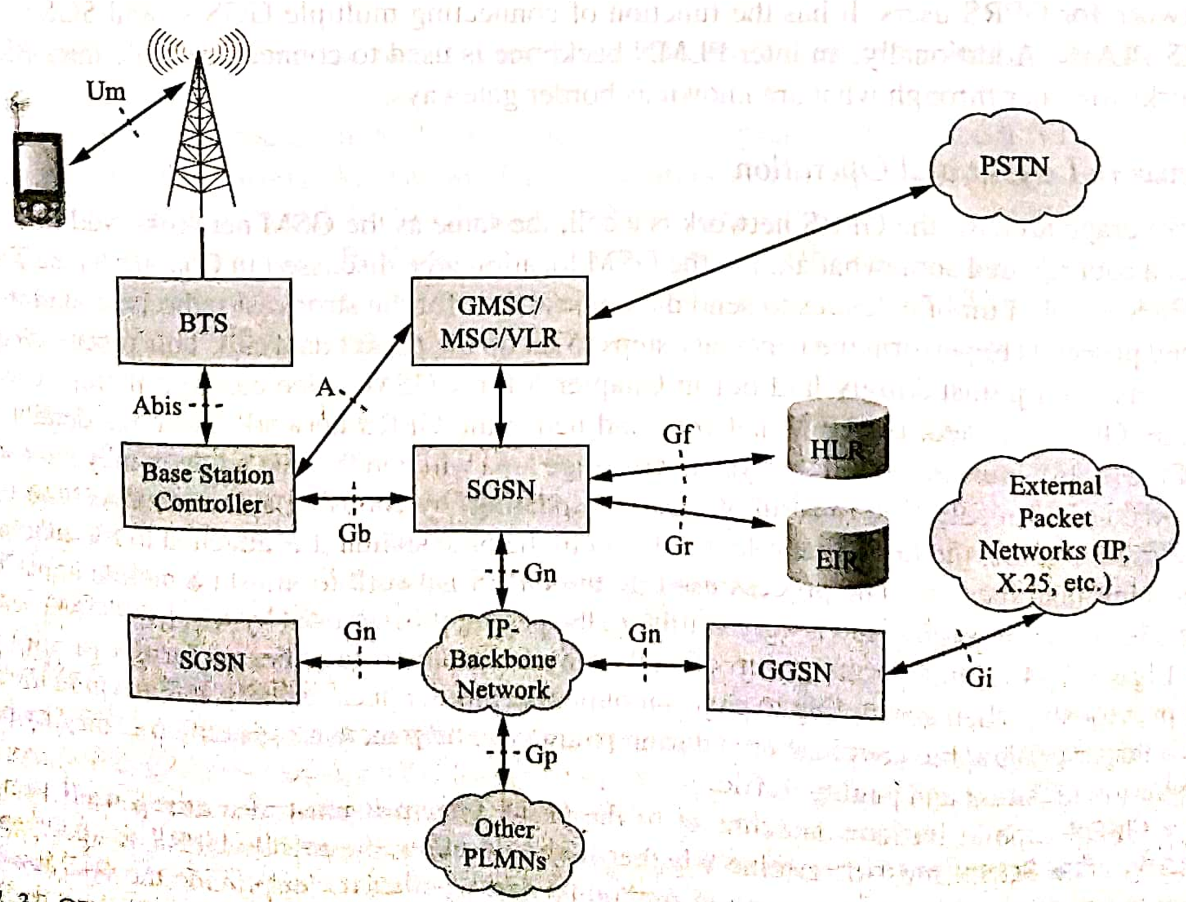


Figure 7–3 GPRS network components.

GPRS Network Elements The gateway GSN serves as the access point to the packet data networks supported by the GPRS PLMN. The primary function of the GGSN is to route packets from the packet data networks to the GSM mobile station. When a mobile station attaches to the GSM network and activates its packet data address, the mobile becomes registered with the GGSN. The GGSN's routing table is updated with the correct serving GSN (SGSN), indicating the mobile's point of attachment. The GGSN also is tasked with performing mobile station address management and activation functions. That is, if the mobile needs a packet data address, the GGSN will provide it and also activate the mobile's address in its routing table. The serving GSN node basically provides a point of attachment to the GPRS mobiles. The SGSN is responsible for the delivery of packets to and from the mobile. To perform this function correctly, the SGSN must be aware of the location of the mobiles attached to it (akin to the function of a VLR). Furthermore, the SGSN is tasked with performing GPRS system security functions (authentication, encryption, etc.), which are performed in conjunction with the HLR of the host GSM system. Both the GGSN and the SGSN are linked to the GSM PLMN and therefore have access to the network elements of the GSM system (MSC/VLR, SMS-GMSC, HLR, etc.), which facilities the performance of their operations. The SGSN is normally connected to the base station system by Frame Relay or some other high speed data transport technology. The SGSN may provide service to multiple base stations thus providing coverage to a group of cells. Lastly, the functionality of the SGSN and the GGSN may be physically combined into a single SGSN/GGSN unit by a wireless equipment vendor.

Within a GPRS PLMN, both the GSM base station subsystem and the mobile stations must be able to cope with GPRS data. The GSM HLR already has the responsibility of keeping track of the mobile subscriber's location within the GSM network and hence within the GPRS network. Therefore, in support of GPRS service, the HLR manages GPRS subscription data that includes mobile roaming privileges, details of QoS-level privileges, and the mobile's static IP or other packet data address information. Other network elements within the GPRS network include an intra-PLMN backbone (high-speed data network). This is a private network for GPRS users. It has the function of connecting multiple GGSNs and SGSNs within the same GPRS PLMN. Additionally, an inter-PLMN backbone is used to connect multiple intra-PLMN backbone networks together through what are known as border gateways.

GPRS Network Layout and Operation

GPRS Packet Data Transfers

Assuming that a GPRS-enabled mobile has attached to the GPRS network and activated an IP address, it is now ready to begin transferring packet data. Packet data transfers between the GGSN and the GPRS mobile take place using a technique known as "tunneling." In this context, tunneling is the process of encapsulating a data packet so that it may be routed through the GPRS PLMN IP backbone network eliminating the problem of protocol interworking. An example of this process should help the reader understand this technique. Data packets for a certain IP address arrive from the public data network at the GGSN that anchors the IP address. At the GGSN, the data packets are given new headers. Inside the GPRS PLMN IP network,

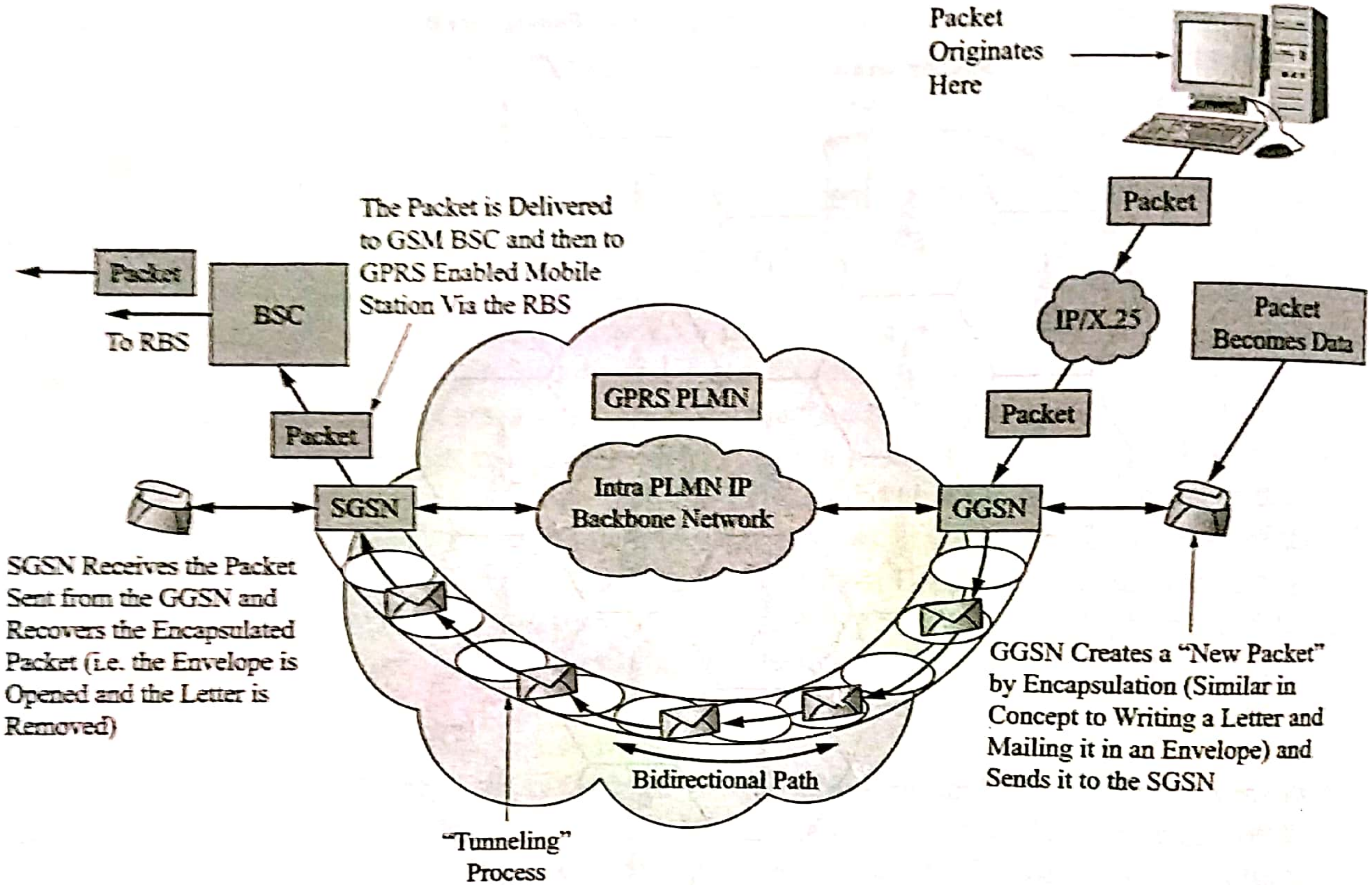
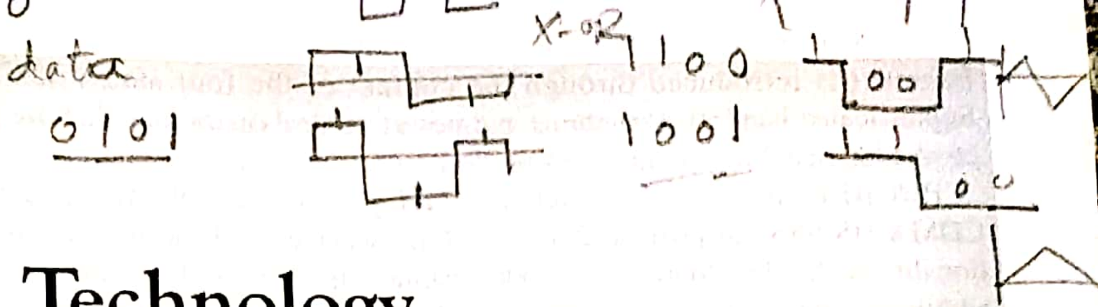


Figure 7–5 GPRS data transfer via tunneling.

these packets are routed based on the new header while the original packet is transported as the data. Once through the network, the new header is stripped of the packet and the data packet is now routed based on the original header. Likewise, packets sent from the GPRS mobile to the public data network must be sent from the SGSN to the GGSN in the same fashion. See Figure 7–5 for a depiction of this process. This use of tunneling within the GPRS network solves the mobility problem and hides the fact that the GPRS mobile is in fact a mobile station.

GPRS Protocol Reference Model



CHAPTER 6

CDMA Technology

Upon completion of this chapter, the student should be able to:

- Discuss the basic concepts and evolution of CDMA technology.
- Discuss the difference between the various access technologies; namely FDMA, TDMA, and CDMA.
- List the United States frequency bands used for CDMA technology.
- Discuss CDMA network and system architecture.
- Discuss network management.
- Discuss CDMA channel and frame concepts.
- Discuss the functions of the forward and reverse logical channels.
- Discuss CDMA system operations: initialization, call establishment, call handoff, and power control.
- Discuss the implementations of 3G cellular using CDMA technology.

This chapter introduces another cellular wireless air interface technology known as code division multiple access or CDMA. Because of the importance of CDMA as the air interface technology of the future and the amount of detail included in this chapter, it has been organized into three parts: CDMA system overview, CDMA basics, and 3G CDMA. First deployed commercially in 1995, CDMA is a relatively new technology. However, CDMA-based systems are overwhelmingly being counted on to provide the needed infrastructure to implement future 3G systems and beyond (4G). Part I of this chapter begins with an introduction to the first deployment of 2G CDMA systems and the subsequent evolution to 3G CDMA systems. Included in this introduction is an explanation of basic CDMA operation, the frequency allocations allowed for CDMA use in the United States, and CDMA frequency reuse issues. An overview of the present cdma2000 (the initial phase of 3G cellular) network and system architecture is presented next with short descriptions of the operation and functions of the network elements included in the overview. Since many of the common network elements have been previously discussed, the emphasis in this chapter is on new network elements and differences in the wireless network due to the use of CDMA technology. A detailed introduction to cellular network management techniques is included also.

In an effort to not overwhelm the reader, the second part of this chapter provides a detailed explanatior of the IS-95B CDMA channel concept and the actual implementation details of the air interface signals fo this 2G technology. Forward and reverse logical channels are described and their functionality within th system is explained. The CDMA frame format is also introduced and its significance within the systei explained for both forward and reverse logical channels. With the basic technical details fairly well coverec

Evolution of 3G CDMA

Cdma2000 is the term used for 3G CDMA systems. Cdma2000 was one of five proposals the ITU approved for IMT-2000 third-generation (3G) standards. As previously mentioned in Chapter 2, cdma2000 is the wideband enhanced version of CDMA. It is backward compatible with TIA/EIA-95-B and provides support for data services up to 2 mbps, multimedia services, and advanced radio technologies. The implementation of cdma2000 technology is to occur in planned phases with the first phase known as 1xRTT (1X radio transmission technology) happening over a standard 1.25-MHz CDMA channel. The next phase of implementation is known as cdma2000 1xEV (where EV stands for evolutionary). There are two versions of 1xEV: 1xEV-DO (data only) and 1xEV-DV (data and voice). 1xEV-DO can support asymmetrical peak data rates of 2.4 mbps in the downlink direction and 153 kbps in the uplink direction. 1xEV-DV can support integrated voice and data at speeds up to 3 mbps over an all-IP network architecture. The changeover from cdmaOne to cdma2000 1xRTT has been ongoing in the United States and the rest of North America since late in the year 2000. Currently, there are several cdma2000 1xEV-DO systems in operation worldwide with more in the planning stage. Again, see the CDMA Development Group's Web site for information about the worldwide deployment of 3G cdma2000 systems. Further information about cdma2000 and other 3G CDMA technologies will be presented later in this chapter.

CDMA Basics

CDMA is a multiple-access technology that is based on the use of wideband spread spectrum digital techniques that enable the separation of signals that are concurrent in both time and frequency. All signals in this system share the same frequency spectrum simultaneously. The signals transmitted by the mobile stations and the base stations within a cell are spread over the entire bandwidth of a radio channel and encoded in such a way as to appear as broadband noise signals to every other mobile or base station receiver. The identification and subsequent demodulation of individual signals occur at a receiver through the use of a copy of the code used to originally spread the signal at the transmitter. This process has the net effect of demodulating the signal intended for the receiver while rejecting all other signals as broadband noise. Since a specific minimum level of signal-to-noise ratio is necessary to provide for a certain level of received signal quality, the level of background noise or interference from all system transmissions ultimately limits the number of users of the system and hence system capacity. Therefore, CDMA systems are carefully designed to limit the output power of each transmission to the least amount of power necessary for proper operation.

At this time, it will be helpful to compare the CDMA air interface scheme with the frequency division multiple access (FDMA) and time division multiple access (TDMA) air interfaces (see-Figure 6–2). For FDMA, the available radio spectrum is divided into narrowband channels and each user is given a particular channel for his or her use. The user confines transmitted signal power within this channel, and selective filters are used at both ends of the radio link to distinguish transmissions that are occurring simultaneously on many different channels. The frequency allocations can only be reused at a distance far enough away that the resulting interference is negligible. The TDMA scheme goes one step further by dividing up the spectral allocation into timeslots. Now, each user must confine its transmitted spectral energy within the particular timeslot assigned to it. For this case, the mobile and the base station must employ some type of time synchronization. This technique increases spectral efficiency at the expense of each user's total data rate. In CDMA, each mobile has continuous use of the entire spectral allocation and spreads its transmitted energy out over the entire bandwidth of the allocation. Using a unique code for each transmitted signal, the mobiles and the base station are able to distinguish between signals transmitted simultaneously over the same frequency allocation. CDMA can also be combined with FDMA and TDMA technologies to increase system capacity.

capacity.

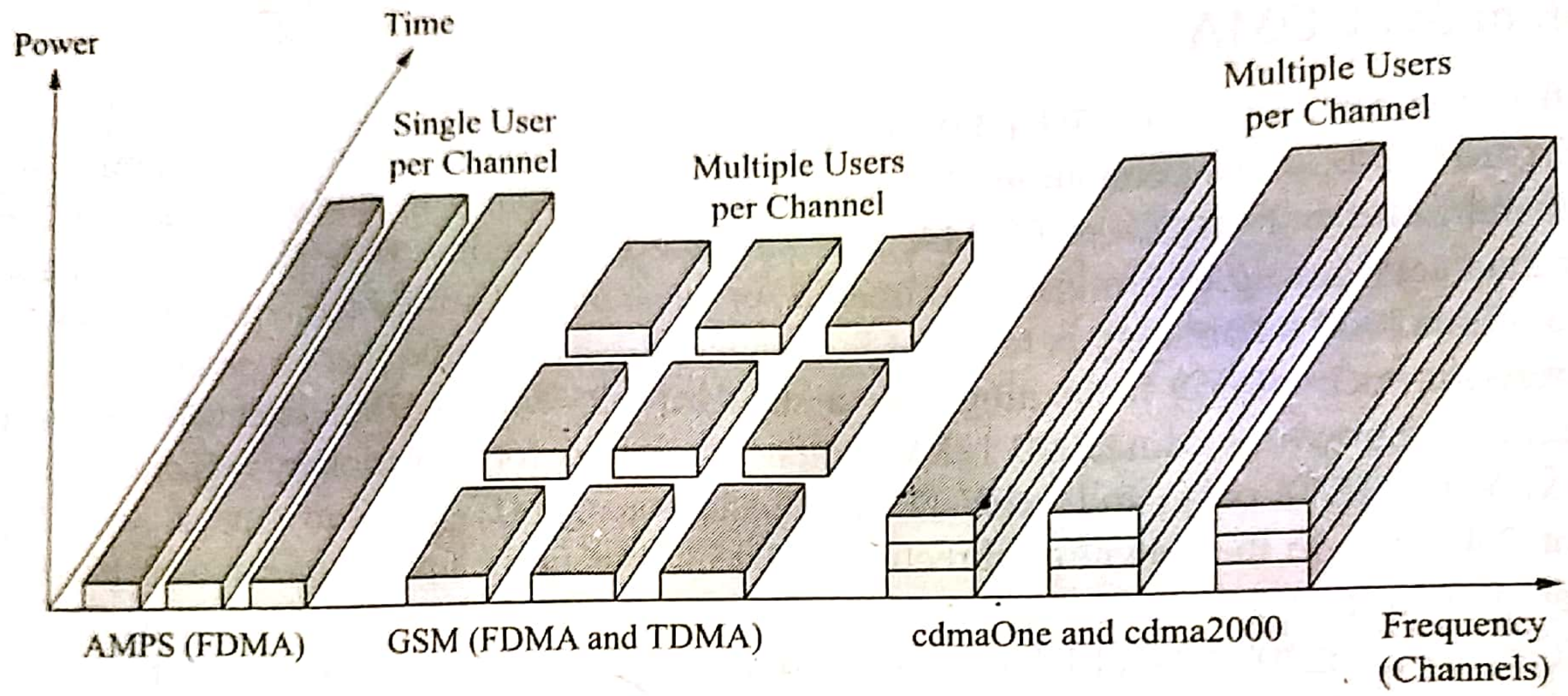


Figure 6–2 Comparison of FDMA, TDMA, and CDMA air interfaces.

For 2G CDMA systems, one might be inclined to state that the frequency separation between adjacent carriers or channels is 1.25 MHz. In CDMA standards, the terms *carrier* and *channel* are carefully distinguished from one another. A carrier frequency may be divided by means of codes into sixty-four different channels. Each of these channels may carry information related to a separate and distinct conversation or data connection in digital form. This distinction is also true of TDMA systems where each carrier is divided into timeslots and each timeslot serves as a channel. In older FDMA systems, the two terms are synonymous and hence a source of confusion when discussing these new technologies.

CDMA Frequency Bands

Presently, in the United States, CDMA systems can be deployed for use in the existing cellular frequency bands (Band Class 0) and the personal communications service (PCS) bands (Band Class 1). In the future, 3G CDMA systems will also be allowed in the newly released 1710–1755 MHz and 2110–2155 MHz advanced wireless services (AWS) bands (see the FCC Web site at www.fcc.gov for further details about the use of these bands). In other parts of the world there are various additional frequency bands (with band class designations given by the CDMA standards) available for CDMA use including a lower frequency band at 450 MHz. When used in the cellular bands, a frequency separation of 45 MHz between the forward and reverse channels is employed. The MS transmit frequency band is 824–849 MHz and the BS transmit frequency band is 869–894 MHz. In this band, not all of the frequencies are designated for use by CDMA cellular wireless networks. Recall that the FCC requires AMPS service to be supported until 2007, so some of the channels are reserved for this purpose. This dual use of the cellular frequency band gives rise to dual-mode CDMA phones.

The 1900-MHz PCS band may be used for either GSM, NA-TDMA, or CDMA technologies. Refer back to Figure 5–2 for details of the PCS bands and Table 5–3 for GSM carrier frequencies. Table 6–1 shows the corresponding CDMA and NA-TDMA PCS channel numbers and carrier frequencies. For CDMA, with a 50-kHz channel spacing, the chart indicates a total of 1200 CDMA channel numbers (carrier frequencies) over the 60 MHz of allocated frequency. The chart also indicates the NA-TDMA channel numbers. One can see that there is not a one-to-one correspondence between the CDMA and NA-TDMA channel numbering systems or between either of these systems and the GSM channel numbers shown in Table 5–3. Additionally, the CDMA spacing between transmit and receive frequencies is 80 MHz whereas for NA-TDMA it is 80.04 MHz and for GSM it is 90 MHz. All this means is that there are possible interference concerns between all of these systems on both the uplink and downlink frequencies where coexisting systems are located.

Table 6–1 CDMA and NA-TDMA channel numbers and frequency assignments for the PCS band (Band Class 1) (Courtesy of 3GPP2)

Transmitter	*CDMA PCS Channel Number (N)*	*Center Frequency for CDMA Channel (MHz)*	*TDMA PCS Channel Number (N)*	*TDMA PCS Channel Frequency (MHz)*
Mobile Station	$0 \leq N \leq 1199$	$1850.000 + 0.050\ N$	$1 \leq N \leq 1999$	$1849.980 + 0.030 \times N$
Base Station	$0 \leq N \leq 1199$	$1930 + 0.050\ N$	$1 \leq N \leq 1999$	$1930.020 + 0.030 \times N$

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... produces or can tolerate.

6.2 CDMA NETWORK AND SYSTEM ARCHITECTURE

The reference architecture for wireless mobile systems deployed in North America is based upon standards developed by the TIA. The TIA Committee TR-45 develops system performance, compatibility, interoperability, and service standards for the cellular band, and committee TR-46 coordinates the same activities for the PCS band. The TR-45.3 subcommittee deals with NA-TDMA and the TR-45.5 subcommittee with CDMA. Furthermore, the TR-45 committee works closely with the 3GPP2 organization to specify the standards for cdma2000. For more information about these activities visit the TIA Web site at www.tiaonline.org.

The initial reference architecture for IS-95 CDMA is very similar to the GSM reference architecture presented in Chapter 5. The adoption of TIA/EIA-95 provided for additional network interfaces that exist between the various system elements. This reference model developed by TR-45/46 is depicted by Figure 6–3.

The new cdma2000 reference architecture (see Figure 6–4) has been enhanced to include even more additional network access interfaces. These interfaces are mainly concerned with the evolving structure of cdma2000 toward an all-IP core network.

As was discussed with GSM cellular, messaging between CDMA system network elements is carried out through the use of protocols very similar to SS7. TIA/EIA-634-B is an open interface standard that deals with signaling between the MSC and the BSC (over the A interface), and TIA/EIA-41-D describes

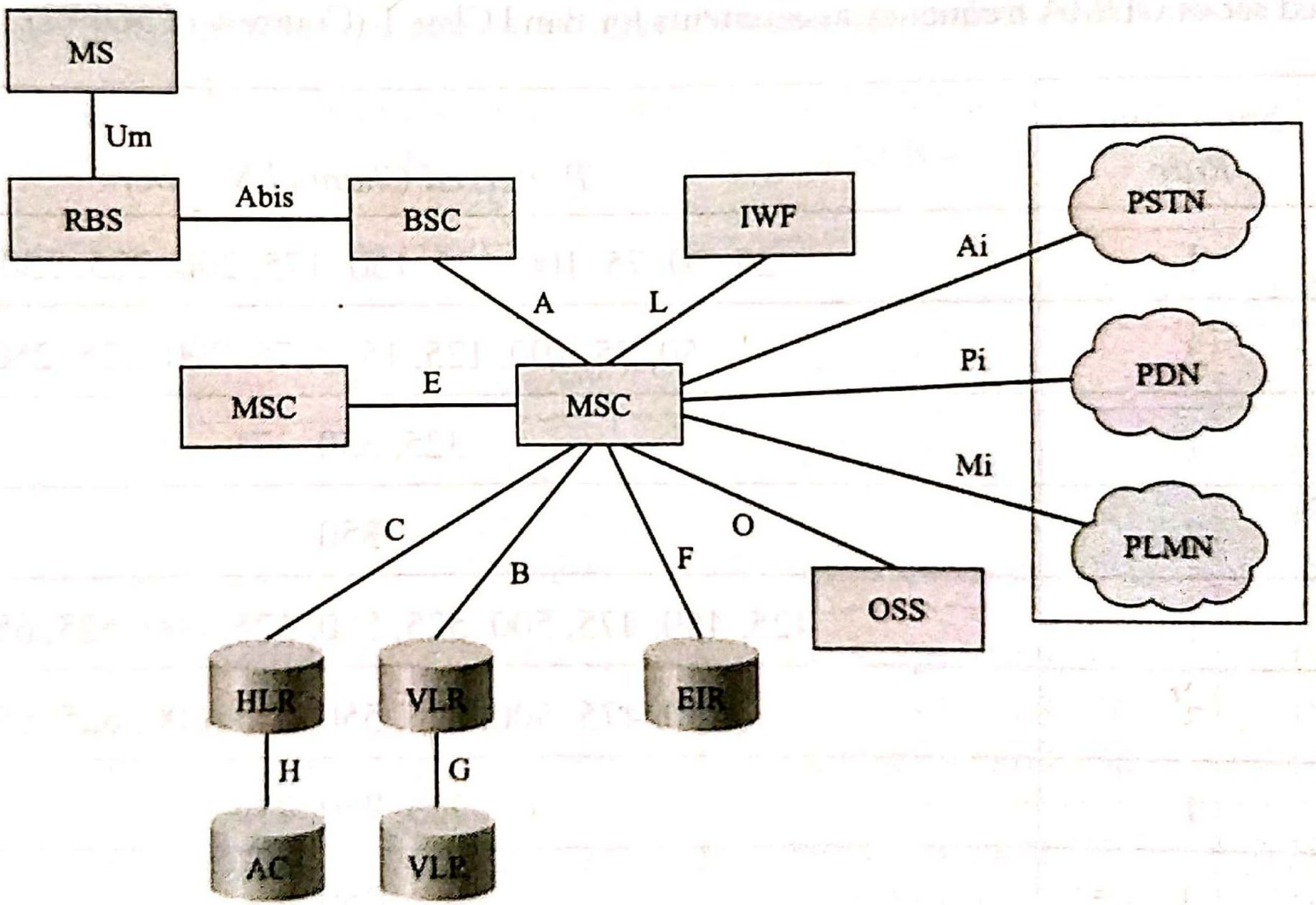


Figure 6–3 Initial CDMA (IS-95) reference architecture.

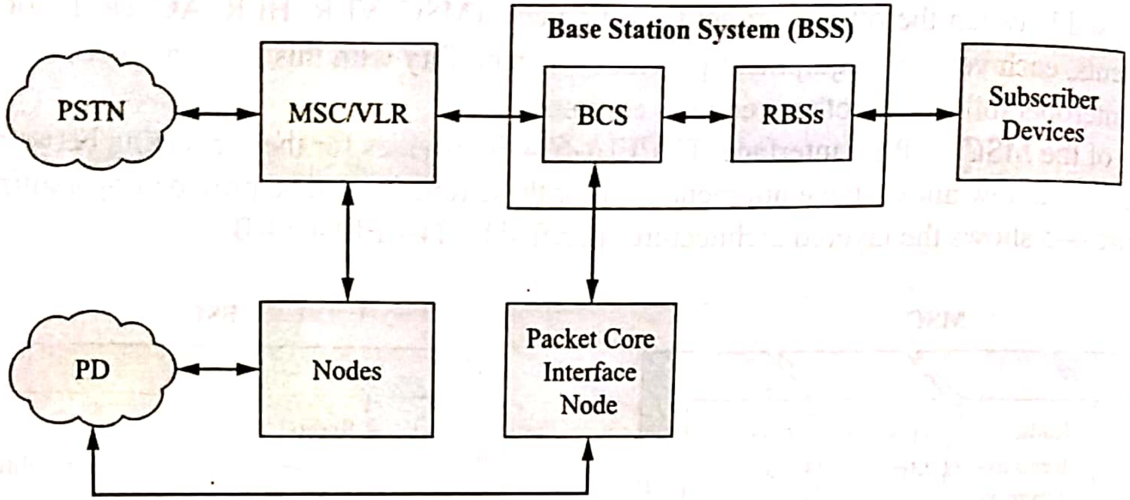
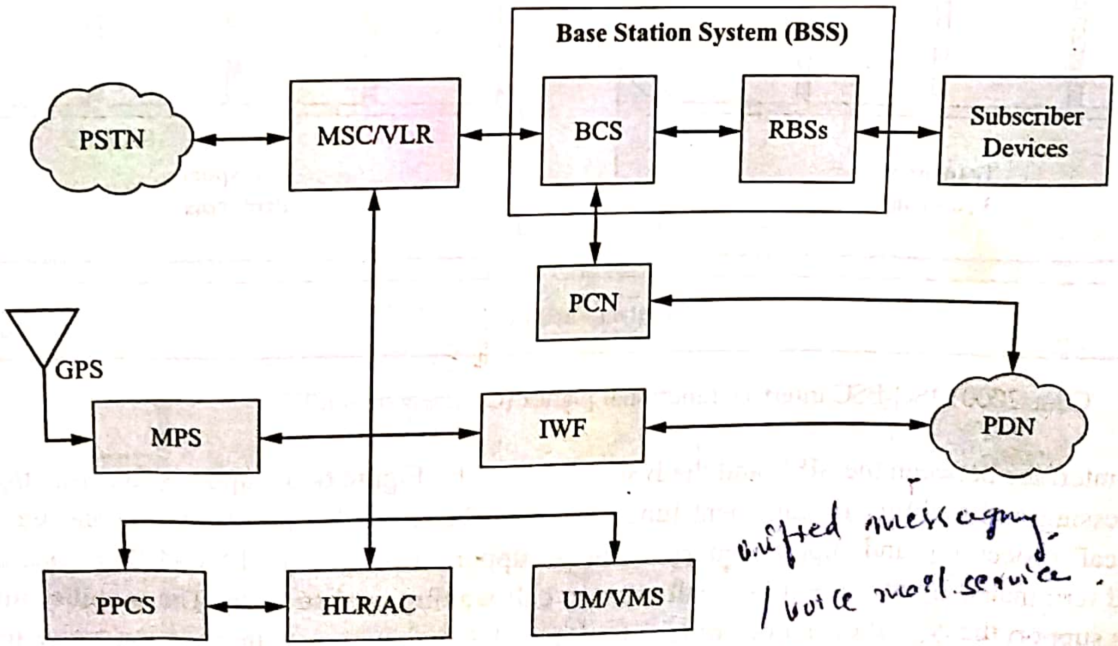


Figure 6–6 Major network components of a cdma2000 wireless system (Courtesy of Ericsson).



unified messaging
/ voice mail service.

Figure 6–7 Details of the network nodes found in a cdma2000 wireless system (Courtesy of Ericsson).

Mobile Services Switching Center and Visitor Location Register

wireless system (Courtesy of Ericsson).

Mobile-Services Switching Center and Visitor Location Register

The CDMA mobile-services switching center (MSC) serves as the interface between the public switched telephone network (PSTN) and the base station subsystem (BSS). The MSC performs the functions necessary for the establishment of calls to and from the system's mobile subscribers. Additionally, the MSC, in conjunction with other network system elements, provides the functionality needed to permit subscriber mobility and roaming. Some of these operations include subscriber registration and authentication, location updating functions, call handoffs, and call routing for roaming subscribers.

Typically the visitor location register (VLR) function is colocated with the MSC. Its function is to provide a database containing temporary information about registered subscribers that may be needed by the MSC in the performance of call control operations and the provisioning of subscriber services for the mobiles currently registered in the MSVC/VLR service area.

Interworking Function

In the early (IS-95) CDMA systems, the interworking function (IWF) node is the only gateway between the wireless network and the packet data network (PDN). As such, it provides a direct connection to the PDN for packet data calls. Additionally, the IWF node supports circuit-switched data calls by providing internal modems for connections to dial-up Internet service providers (ISPs). These circuit-switched data calls are routed to the PSTN through the MSC. Today, the IWF typically uses Ethernet for the signaling between itself and the MSC and for the exchange of packet data between itself and the PDN. In cdma2000, the IWF's packet data transfer function is augmented by the packet core network (PCN) element.

Mobile Positioning System

In an ongoing program mandated by the FCC and designed to upgrade the United States' cellular systems, a location system is incorporated by the CDMA system that can determine the geographic position of a mobile subscriber. This **mobile positioning system** (MPS) is based on the Global Positioning System (GPS) and is to be used for emergency services. The ability to locate the caller is known as Enhanced 911 or E911. Other proposed uses of this system capability relate to what are known as "location-based services" or location-specific marketing tools.

For Phase 1 of the wireless E911 program, the cellular system must be able to tell a local public safety answering point (PSAP) the location of the cellular antenna that is handling the emergency call. In Phase 2 of the first implementations of this location determining system, the MPS uses a form of mobile-assisted GPS and triangulation to determine the latitude and longitude of the mobile within 50 to 100 meters. It is believed that later phases of this system will be able to lower the system uncertainty even further. The FCC has set a timetable for the rollout of this service with an expected implementation by cellular service providers by the end of 2005.

There has already been much discussion about the idea of "big brother" knowing one's location via one's cell phone and it remains to be seen where this technology will lead to over the coming years vis-à-vis the privacy issue. Additionally, unwanted spam over the Internet and unsolicited calls from telemarketers have recently become hot political topics and it remains to be seen whether location-based services will be accepted by the cellular subscriber or just become another form of telemarketing or wireless spam.

Unified Messaging/Voice Mail Service

Ericsson Corporation's new cdma2000 systems contain a unified messaging/voice mail service (UM/VMS) node that integrates e-mail and voice mail access. This node provides messaging waiting indication using short message service (SMS) and multiple message retrieval modes including the use of DTMF or either a Web or WAP browser. As shown in Figure 6–7, the UM/VMS node connects to the PDN and the MSC in Ericsson's system.

HLR/AC

The home location register (HLR) and authentication center (AC) are typically colocated in cdma2000 systems. The HLR holds subscriber information in a database format that is used by the system to manage the subscriber device (SD) activity. The type of information contained in the HLR includes the SD electronic serial number (ESN), details of the subscriber's service plan, any service restrictions (no overseas access, etc.), and the identification of the MSC where the mobile was last registered.

The AC provides a secure database for the authentication of mobile subscribers when they first register with the system and during call origination and call termination. The AC uses shared secret data (SSD) for authentication calculations. Both the AC and SD calculate SSD based on the authentication key or A-key, the ESN, and a random number provided by the AC and broadcast to the SD. The A-key is stored in the SD and also at the AC and never transmitted over the air. The AC or MSC/VLR compares the values calculated by the AC and the SD to determine the mobile's status with the system.

PPCS and Other Nodes

The prepaid calling service (PPCS) node provides a prepaid calling service using the subscriber's home location area MSC. This node provides the MSC with information about the subscriber's allocated minutes and provides the subscriber with account balance information. The PPCS node is usually associated with a prepaid administration computer system that provides the necessary database to store subscriber information and update it as needed. The prepaid administration system (PPAS) provides the subscriber account balance information to the PPCS system. The MSC sends information about subscriber time used to the PPAS for account updating. In the future, other additional nodes may be added to the system to provide increased system functionality like intersystem roaming.

Base Station Subsystem

A base station subsystem (BSS) consists of one base station controller (BSC) and all the radio base stations (RBSs) controlled by the BSC (refer back to Figure 6–6). The BSS provides the mobile subscriber with an interface to the circuit switched core network (PSTN) through the MSC and an interface to the public data network (PDN) through the packet core network (PCN). There can be more than one BSS in a cdma2000 system. Today, the combination of all the CDMA BSSs and the radio network management system that oversees their operation is known as the CDMA radio access network or C-RAN.

Base Station Controller

In a cdma2000 system, the base station controller (BSC) provides the following functionality. It is the interface between the MSC, the packet core network (PCN), other BSSs in the same system, and all of the radio base stations that it controls. As such, it provides routing of data packets between the PCN and the RBSs, radio resource allocation (the setting up and tearing down of both BSC and RBS call resources), system timing and synchronization, system power control, all handoff procedures, and the processing of both voice and data as needed.

Radio Base Station

The cdma2000 radio base station (RBS) provides the interface between the BSC and the subscriber devices via the common air interface. The functions provided by the RBS include CDMA encoding and decoding of the subscriber traffic and system overhead channels and the CDMA radio links to and from the subscribers. The typical RBS contains an integrated GPS antenna and receiver that is used to provide system timing and frequency references, a computer-based control system that monitors and manages the operations of the RBS and provides alarm indications as needed, communications links for the transmission of both system signals and subscriber traffic between itself and the BSC, and power supplies and environmental control units as needed.

PLMN Subnetwork

A cdma2000 public land mobile network (PLMN) (refer back to Figure 3–5) provides mobile wireless communication services to subscribers and typically consists of several functional subnetworks. These subnetworks are known as the circuit core network (CCN), the packet core network (PCN), the service node network (SNN), and the CDMA radio access network (C-RAN). The cdma2000 PLMN subscriber has access to the PSTN and the PDN through these subnetworks. The organization of the PLMN into subnetworks facilitates the management of the system.

Circuit Core Network

The circuit core network (CCN) provides the switching functions necessary to complete calls to and from the mobile subscriber to the PSTN. The major network element in the CCN is the MSC. This portion of the system is primarily concerned with the completion of voice calls between the subscriber and the PSTN. The MSC is basically an extension of the PSTN that services the various cells and the associated radio base stations within the cells. The MSC provides circuit switching and provides features such as call charging, subscriber roaming support, and maintenance of subscriber databases.

CDMA Radio Access Network

In cdma2000, the CDMA radio access network or **C-RAN** provides the interface between the wireless cellular subscriber and what is known as the circuit core network (CCN). The CCN consists of the MSC and other system components involved with connections to the PSTN for all circuit-switched voice and data calls. The C-RAN can consist of multiple base station subsystems (BSSs) and some form of radio network manager (RNM) system. The RNM system provides operation and management (O&M) support for multiple BSSs.

Packet Core Network

In cdma2000, the **packet core network** (PCN) provides a standard interface for wireless packet-switched data service between the C-RAN and the public data network (PDN). The PCN provides the necessary links to various IP networks to and from the C-RAN. The PCN typically consists of three main hardware nodes: the authentication, authorization, and accounting (AAA) server, the home agent (HA), and the packet data serving node (PDSN). Figure 6–8 depicts the elements of the PCN and their interconnection to each other and the relationship of the PCN to the PDN and the C-RAN.

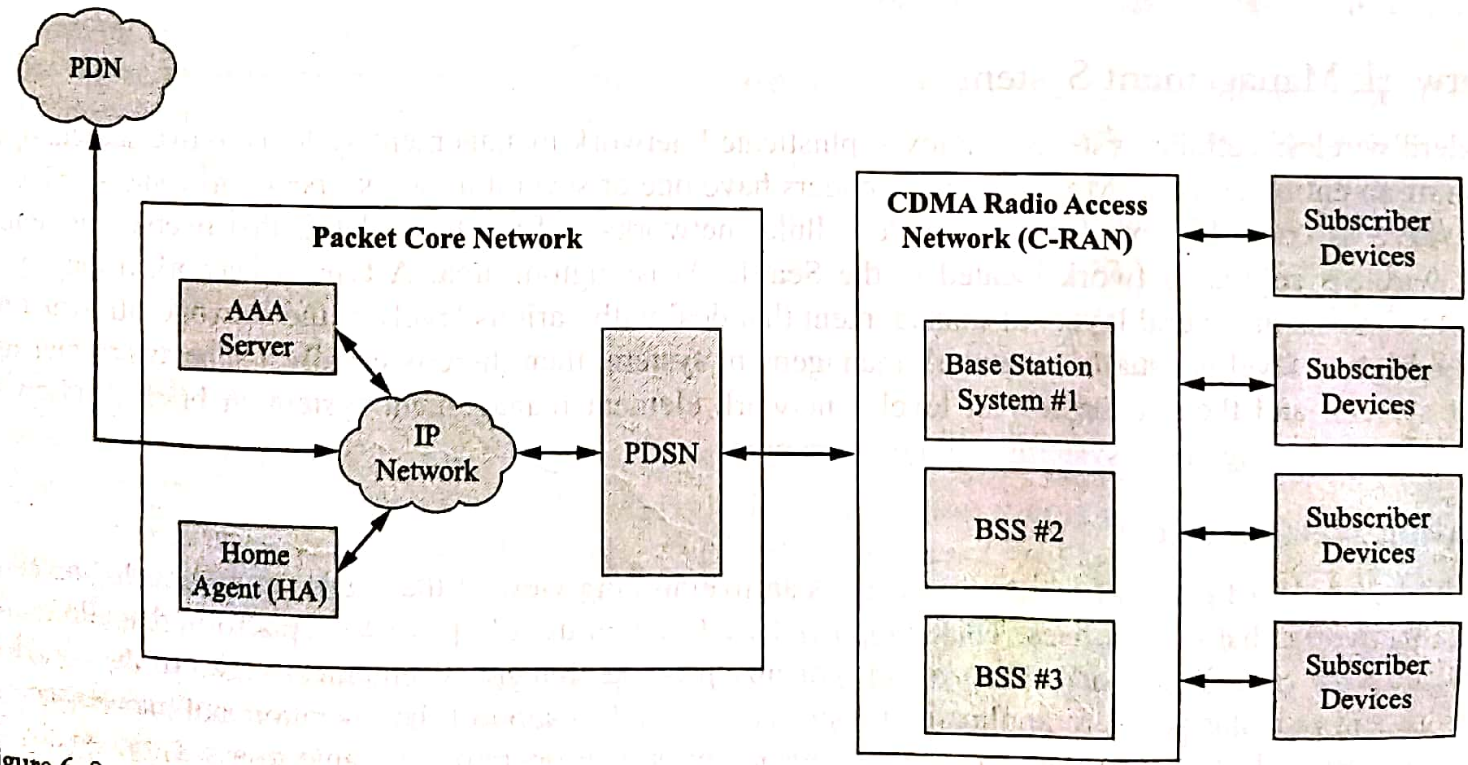


Figure 6–8 Elements of the cdma2000 packet core network (Courtesy of Ericsson).

In a cdma2000 cellular system, the packet data serving node (PDSN) provides the needed IP transport capability to connect the C-RAN and hence the subscriber to the public data network. The PDSN connects to the C-RAN through the A_{quater} interface (also known as the radio-packet (R-P) interface). The PDSN also interfaces the C-RAN with the home agent and the authentication, authorization, and accounting nodes. In such a capacity, it sets up, maintains, and terminates secure communications with the home agent and the authentication, authorization, and accounting nodes. It further serves as a point of connection to the radio network and the IP network and provides IP service management to offered IP traffic. Finally, to facilitate wireless mobile IP functionality, it also serves as a foreign agent to register network visitors (this topic will be discussed in more detail shortly).

The authentication, authorization, and accounting **(AAA) server** both authenticates and authorizes the subscriber device to employ the available network services and applications. To facilitate this operation, the AAA server manages a database that contains user profiles. The user profile information will also include information about quality of service (QoS) for the PDSN. The AAA server receives accounting information from the PDSN node that together with session information can be used for billing of the subscriber. An AAA server may be configured primarily for billing purposes. If that is the case, the PDSN may send accounting information to the billing AAA server and use a different AAA server for authentication and authorization.

In the cdma2000 system, the **home agent** (HA) has the task of forwarding all packets that are destined for the subscriber device (SD) to the PDSN over an IP network. The PDSN then sends the packets to the SD via the C-RAN and the common air interface. To be able to perform this operation the HA in conjunction with the PDSN authenticates mobile IP registrations from the mobile subscriber, performs SD registration, maintains current location information for the SD, and performs the necessary packet tunneling. Packet tunneling refers to the following operation: IP packets destined for a particular SD's permanent address are rerouted to the SD's temporary address. If the SD is registered in a foreign network (i.e., not its home network), then the SD has been assigned a temporary dynamic IP address by the **foreign agent** (this functionality is provided by the foreign network PDSN) and this temporary address is sent to the HA.

A relatively recent addition to the elements of the PCN is a wireless LAN serving node (WSN). This node provides IP transport capability and connectivity between the wireless network and wireless LAN-enabled subscriber devices through wireless LAN access points (APs). More will be said about this topic in a later chapter.

Network Management System

Modern wireless cellular systems employ sophisticated network management systems to oversee the operation of an entire network. Most service providers have one or several network operations centers or NOCs that serve as control points for nationwide cellular networks. AT&T has a NOC that oversees its entire U.S. wireless cellular network located in the Seattle, Washington, area. A typical network management system consists of several layers of management that deal with various levels of the network infrastructure. At the highest level is usually a network management system, then there is usually a subnetwork management system, and then at the lowest level a network element management system. A brief overview of each of these management systems will be given next.

Network Management

The highest level of network management gives an overarching view of the entire network including all of the subnetworks that it comprises. This computer-based system usually provides a platform that allows one to monitor the overall network. The system typically provides integrated graphical views of the complete network and modular software applications that may be used to support the operation and maintenance of the entire network, and it further provides the means by which operators are able to assess the quality of network service and to provide corrective action when network problems occur.

There are basically five functions that a wireless network management system will perform: network surveillance or fault management, performance management, trouble management, configuration management, and security management. Fault management is concerned with the detection, isolation, and repair of network problems to prevent network faults from causing unacceptable network degradation or downtime. Using the tools provided by the system, a human operator can attempt to repair the problem from the NOC. Performance management functions are concerned with the gathering and reporting of relevant network performance statistics that can be used to continuously analyze network operation. Trouble management functions allow for the display and subsequent description of occurrences that have affected the network and also provide the operator with the ability to communicate this information to other persons involved with the maintenance of the network. If the operator at the NOC is unable to clear a trouble or a fault and depending upon the type of problem, it must be escalated and communicated to someone in the field who will now have the responsibility of dealing with it. Configuration management functions are used to support the administration and configuration of the network. These functions support the installation of new network elements as well as the interconnection of network nodes. Finally, security management functions manage user accounts and provide the ability to control and set user-based access levels.

Subnetwork Management and Element Management

Subnetwork management platforms provide management of the circuit, packet, and radio networks that compose the typical CDMA system. The circuit core network management system is mainly concerned with the CDMA mobile-services switching center. It provides fault, performance, configuration, software, and hardware management functions that support the operation of this particular network element at the subnetwork level. The computer system used for this function provides an operator with access to one or more MSCs for the performance of the various functions listed earlier. The packet core network management system is concerned with the PCN node of the CDMA system. Besides the standard functions of fault and performance management, the PCN management platform can perform statistics administration, online documentation, backup and restore functions, and maintain dynamic network topology maps and databases for the PCN nodes. The CDMA radio access network (C-RAN) management system is concerned with CDMA base station subsystems. It provides the ability to configure the radio and network parameters of the system BSSs, monitor C-RAN alarms and performance, and install or upgrade software to any network element in the C-RAN. Additionally, it provides the capability to manage user security and the ability to back up and restore the configuration of any C-RAN element.

Element management refers to the ability to interface directly with a network element through a "craft" data port. Using element specific software, a technician on-site with a laptop computer or off-site through a remote connection is able to interface directly with the specific network element. This type of software-driven element management is usually performed at a cell site during the initial deployment, installation, and testing of a radio base station and during any necessary diagnostic testing and troubleshooting if an escalated alarm or hardware trouble develops with the system.

System Communication Links

Today, equipment vendors are still using legacy channelized T1/E1/J1 copper pairs for connectivity from the MSC to the PSTN. Recently, however, CDMA equipment vendors have started to add fiber-optic interfaces to deliver SONET signals at data rates of 155.52 mbps as shown by Figure 6–9. Channelized T1/E1/J1 with control information is used over the A interface between the MSC and the BSC. Between the BSC and the RBSs unchannelized T1/E1/J1 is used. Between the MSC and the various network elements such as HLR, AC, and so on, signaling protocol TIA/EIA-41-D is used over T1/E1/J1 timeslots. T1/E1/J1 is used to transport data between the nodes and the MSC. Data between the service nodes and the PDN is typically carried by Ethernet at 10/100 mbps. Between the BSC to the PCN, fiber-optic signals at 155.52 mbps are converted to Ethernet at 10/100 mbps. Lastly, from PCN to PDN, data is carried by Ethernet at 10/100 mbps rates.

Recently, most wireless equipment vendors are offering integrated network solutions to service providers by providing microwave links capable of T1/E1/J1 transport or higher data rates for backhaul of aggregated signals to the PSTN. Several vendors offer high-capacity microwave radio systems that offer OC3/STM-1 data rates with the ability to transport asynchronous transfer mode (ATM) traffic. As service providers upgrade their systems to offer 3G CDMA services with high-data-rate access, the C-RAN will need to be interconnected and serviced by data transport technologies that offer higher data rates than T-carrier transport technology. At this point, it appears that ATM has been selected to be the data transport technology around which the next generation of radio access networks for 3G CDMA systems will be designed.

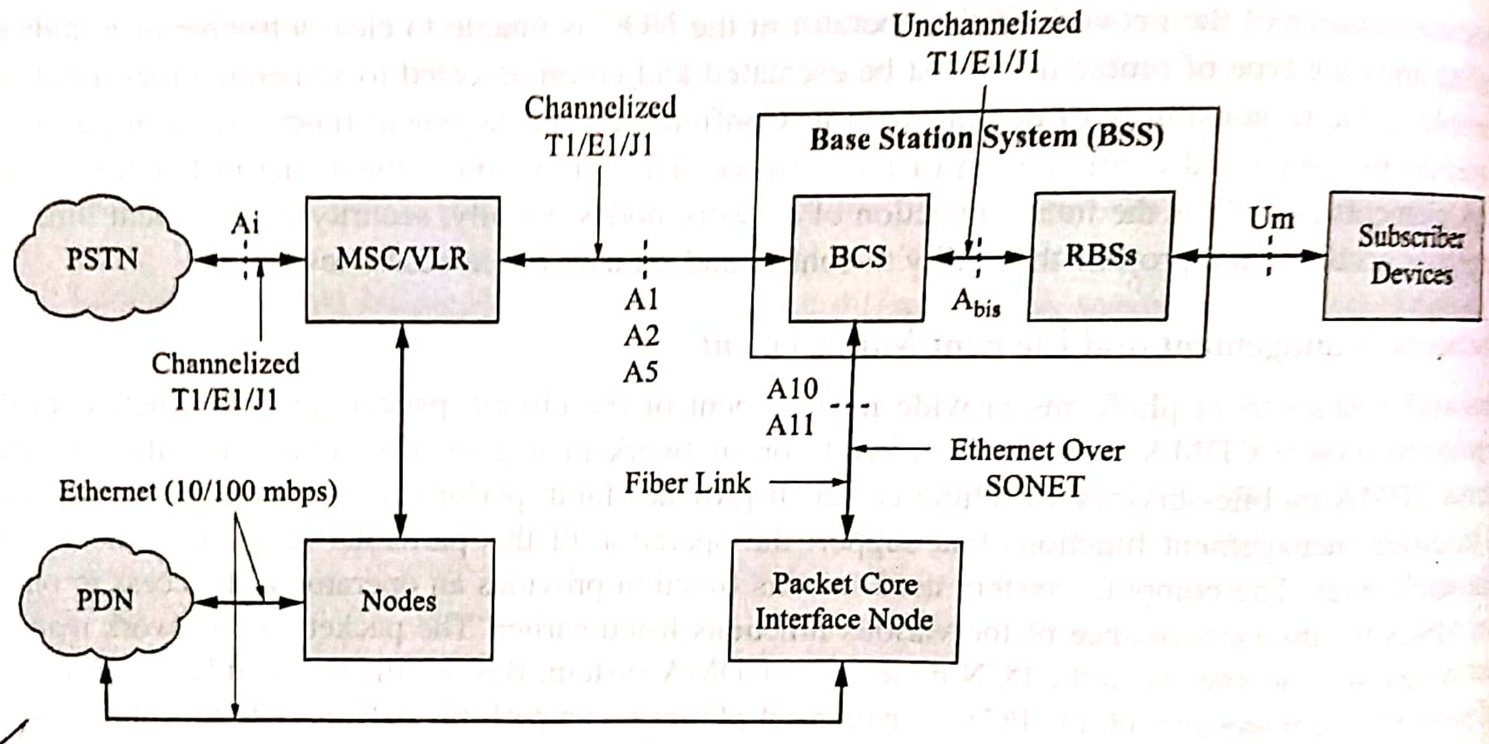


Figure 6–9 Network interfaces for CDMA systems (Courtesy of Ericsson).

Subscriber Devices

Subscriber device (SD) is a generic term used to describe several types of wireless phones and data devices that perform CDMA encoding/ decoding and vocoding operations for the transmission of voice or data in a wireless mobile environment. Each subscriber device has a band or set of radio bands over which it can operate and various modes of possible operation. Subscriber devices can be divided into two broad groups or categories depending upon their applications. Portable devices can operate in the cellular, PCS, or in both bands and can handle the transmission of voice, data, and other nonvoice applications. Typically, these types of SDs are used by people for mobile voice connectivity first, with the other data capabilities being of secondary importance. Wireless local loop (WLL) devices can handle the transmission of data over the CDMA system and typically are used with a laptop or personal digital assistant (PDA) type of device for high-speed Internet access. In the near future, the latter type of SD will probably be used to provide Voice over IP (VoIP) capabilities that will allow wireless video conferencing over either a laptop or tablet PC. In the coming years, the typical SD will include additional functionality for multimedia applications and the ability to use any additional frequency bands that might support CDMA services.

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phones.

7.1 INTRODUCTION TO MOBILE WIRELESS DATA NETWORKS

The growth of the Internet and its daily use by the average person coupled with the public's desire for anytime, anywhere voice and data communications has been the driving force behind the growth and development of mobile wireless data networks. If one plots the number of Internet Web sites or Internet users versus time, the resulting upward curve is closely matched only by the growth in the number of worldwide wireless cellular subscribers. If desired, the reader may view any number of the previously listed Web sites (i.e., GSM, UMTS, CDMA forums or industry collaborations) that provide impressive, near real-time running totals of existing subscribers to a particular air interface technology and maps of worldwide deployment and coverage areas with detailed information about the service providers, frequency bands used, technology used, and so on. Most cellular industry predictions of future system expansion and total numbers of wireless subscribers are heavily optimistic, with double-digit growth predicted for at least this decade.

What is not so certain, however, are the predictions concerning the user take-up rate for mobile digital data services. Although the initial response for these services has been extremely encouraging in several applications areas (SMS, MMS, etc.), disruptive technologies like wireless local area networks (WLANs) and even newer initiatives like radio LANs (RLANs) and mobile wireless metropolitan area networks (WMANs) have started to cast some doubt as to the eventual shakeout that will occur in this industry. Another critical issue involves the subscriber's end device. The classic cellular telephone itself just does not provide the same experience when browsing the World Wide Web as does the traditional desktop PC or a notebook PC despite efforts to improve this situation through specialized software and mobile operating systems. It has been very difficult to get around the small display screen employed by most low-cost mobile phones. What this problem has spawned is the evolution of the end device. Personnel digital assistants (PDAs) have been around for a number of years and continue to evolve into what are now known as handhelds. Devices in this category are able to provide wireless connectivity either through WLAN hot spots or over nationwide wireless data networks and also provide acceptable-size, high-resolution color screens to improve the delivered data services experience to a more acceptable level. In some cases, PDA devices have incorporated cell phone functionality. At the same time, high-end cellular telephones have been morphing into multimedia infotainment/connectivity devices with the addition of larger, color, high-