PART II CDMA BASICS

6.3 CDMA CHANNEL CONCEPT

As mentioned in previous chapters, cellular telephone networks use various control and traffic channels to carry out the operations necessary to allow for the setup of a subscriber radio link for the transmission of either data or a voice conversation and the subsequent system support for the subscriber's mobility. The cdmaOne and cdma2000 cellular systems are based on the use of code division multiple access (CDMA) technology to provide additional user capacity over a limited amount of radio frequency spectrum. This feat is accomplished by using a spread spectrum encoding technique that provides for numerous radio channels that all occupy the same frequency spectrum. To enable these distinct but same frequency channels, orthogonal Walsh spreading codes are used for channel encoding. Several of these encoded channels are used specifically within the CDMA system to provide precise system timing, control, and overhead information while other channels are used to carry user traffic.

This text will not attempt to derive the values or properties of these **Walsh codes** but only describe the basic structure of the 64-bit codes and their usage in IS-95 CDMA systems. To that end, each Walsh code consists of a binary combination of sixty-four 0s and 1s, and all the codes except one (the all-0s Walsh code—W_0^{64}) have an equal number of 0s and 1s. Suffice to say that the sixty-four Walsh codes used in the IS-95 CDMA systems have the unique quality of being orthogonal to one another. As stated earlier, this principle is exploited to create sixty-four distinct communications channels that can all exist in the same frequency spectrum. Also, as mentioned before, all other Walsh encoded signals will appear as broadband noise to the CDMA receiver except for the unique signal that was created with the same Walsh code as the one the receiver uses for demodulation. Figure 6–10 shows the basic principle behind the use of an 8-bit Walsh orthogonal spreading code to create a distinct signal. Note how the use of the spreading code increases the number of bits sent in the same time interval as the original digital signal and hence increases the overall signal bandwidth.

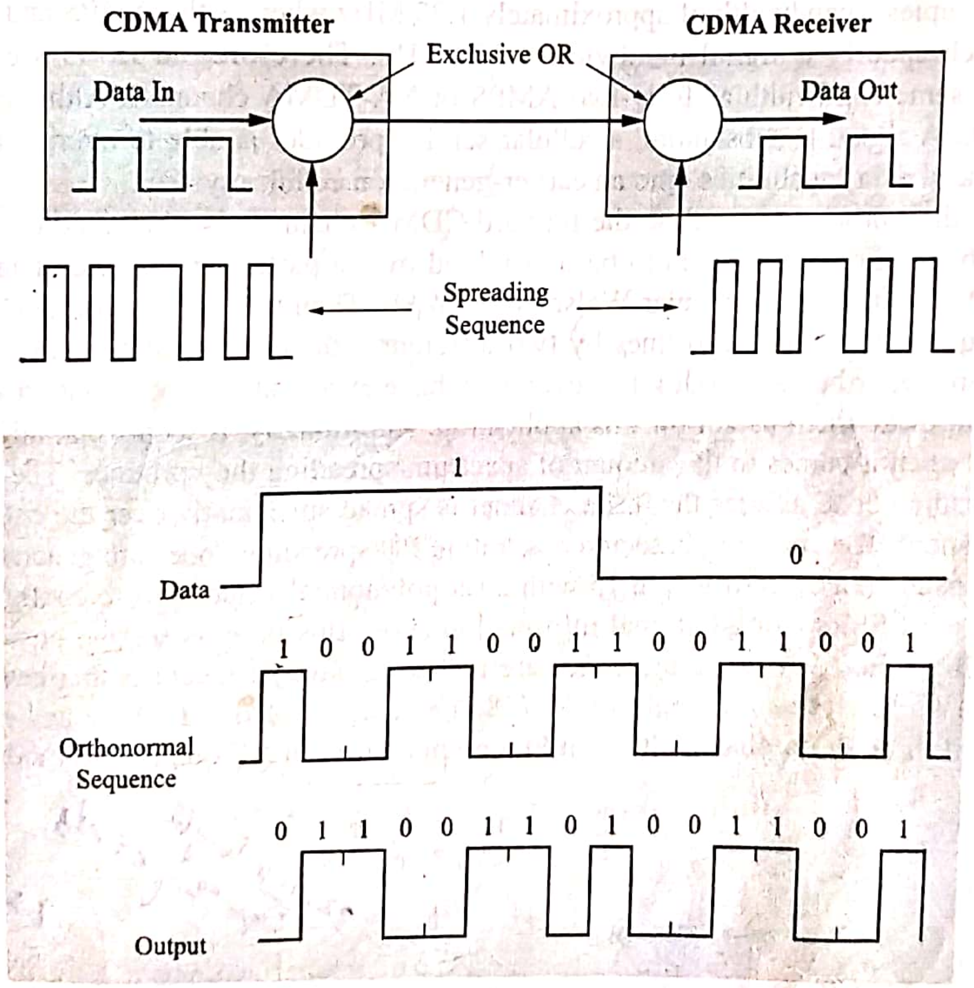


Figure 6–10 The basic spectrum spreading operation.

It should be pointed out right away that the forward channels in a CDMA system are encoded differently than the reverse channels. The different encoding schemes will be explained in more detail in the following sections about the forward and reverse CDMA logical channels.

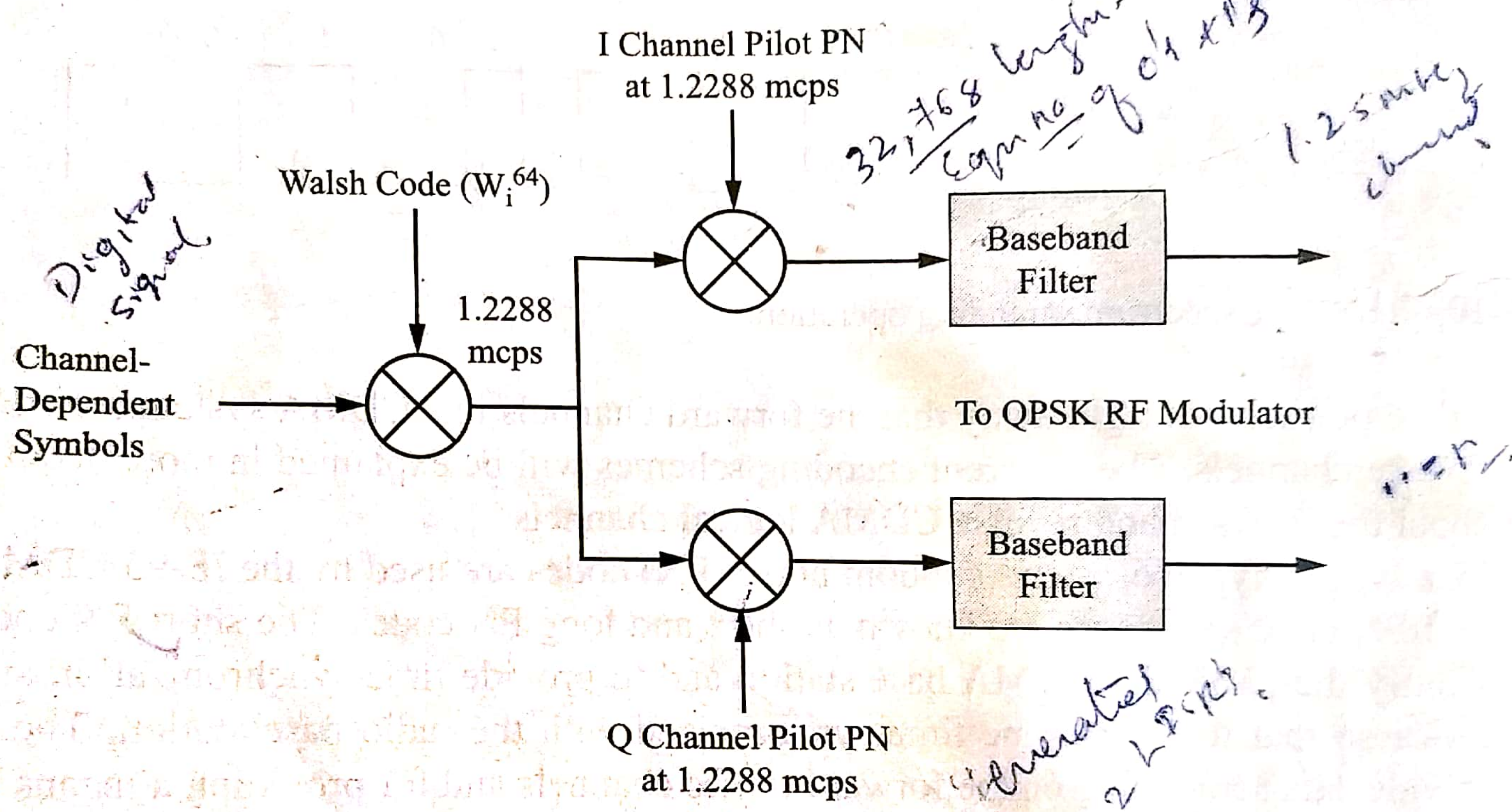
Additionally, two types of pseudorandom noise (PN) codes are used by the IS-95 CDMA system. These two types of PN code sequences are known as short and long PN codes. The short PN code is time shifted both to identify the particular CDMA base station and to provide time synchronization signals to the subscriber device so that it can become time synchronized with the radio base station. The long PN code is used to provide data scrambling on the forward traffic channels and for providing a means by which reverse link channels may be distinguished. These concepts will be explored further in the next few sections.

In summary, for an IS-95 CDMA cellular system, a single radio base station may consist of up to sixty-four separate channel elements (CEs) that all use the same carrier frequency or portion of the radio frequency spectrum. Each of the base station's modulated signals effectively becomes a separate channel when the digital signal to be transmitted is encoded with a distinct Walsh code. Several of the Walsh codes are reserved for use with particular forward channels that serve various logical system functions as will be presented next. At this time, only the basic IS-95 CDMA system will be discussed. Later, the modifications and improvements incorporated into IS-95B and then into cdma2000 will be discussed. Chapter 8 will present more detail about the actual hardware used to implement a CDMA system.

Forward Logical Channels

The IS-95 CDMA forward channels exist between the CDMA base station and the subscriber devices. The first CDMA systems used the same frequency spectrum as the AMPS and NA-TDMA systems. However, the IS-95 signal occupies a bandwidth of approximately 1.25 MHz whereas the AMPS and NA-TDMA system standards each specify a signal bandwidth of 30 kHz. Therefore, an IS-95 signal will occupy approximately the same bandwidth as forty-two AMPS or NA-TDMA channels. Although the bandwidth required for a CDMA signal is substantial, a cellular service provider is able to overlay an IS-95 CDMA system with enhanced data capabilities onto an earlier-generation cellular system.

The basic spreading procedure used on the forward CDMA channels is illustrated by Figure 6–11. As shown in Figure 6–11, the digital signal to be transmitted over a particular forward channel is spread by first Exclusive-OR'ing it with a particular Walsh code (W_i^{64}). Then the signal is further scrambled in the in-phase (I) and quadrature phase (Q) lines by two different short PN spreading codes. These short PN spreading codes are not orthogonal codes; however, they have excellent cross-correlation and auto-correlation properties that make them useful for this application. Additionally, it seems that all Walsh codes are not created equal when it comes to the amount of spectrum spreading they produce. Therefore, the use of the short PN spreading code assures that each channel is spread sufficiently over the entire bandwidth of the 1.25-MHz channel. The short in-phase and quadrature PN spreading codes are generated by two linear feedback shift registers (LFSRs) of length 15 with a set polynomial value used to configure the feedback paths of each of the LFSRs (for additional information about this process see the present CDMA standards). The resulting short PN spreading codes are repeating binary sequences that have approximately equal numbers of 0s and 1s and a length of 32,768. The outputs of the in-phase and quadrature phase signals are passed through baseband filters and then applied to an RF quadrature modulator integrated



ure 6–11 Basic spreading procedure used on CDMA forward channels.

circuit (IC) that upconverts the final output signal to the UHF frequency bands. This channel element signal is linearly combined with other forward channel element signals, amplified, and the composite passband signal is transmitted over the air interface.

The short PN spreading codes provide the CDMA system with the ability to differentiate between different base stations (or cells) transmitting on the same frequency. The same short PN code sequence is used by all CDMA base stations; however, for each base station the PN sequence is offset from the sequences used by other area base stations. The offset is in 64-bit increments, hence there are 512 possible offsets. In a scheme analogous to the frequency reuse plans described for other access techniques in Chapter 4, the same offset may be reused at a great enough distance away from its first use. Figure 6–12 shows but one example of this reuse method. The use of this offset scheme requires that the base stations used in a CDMA system must all be time synchronized on the downlink radio channels. This precise timing synchronization is achieved through the use of the Global Positioning System (GPS) to achieve a system time that has the required accuracy.

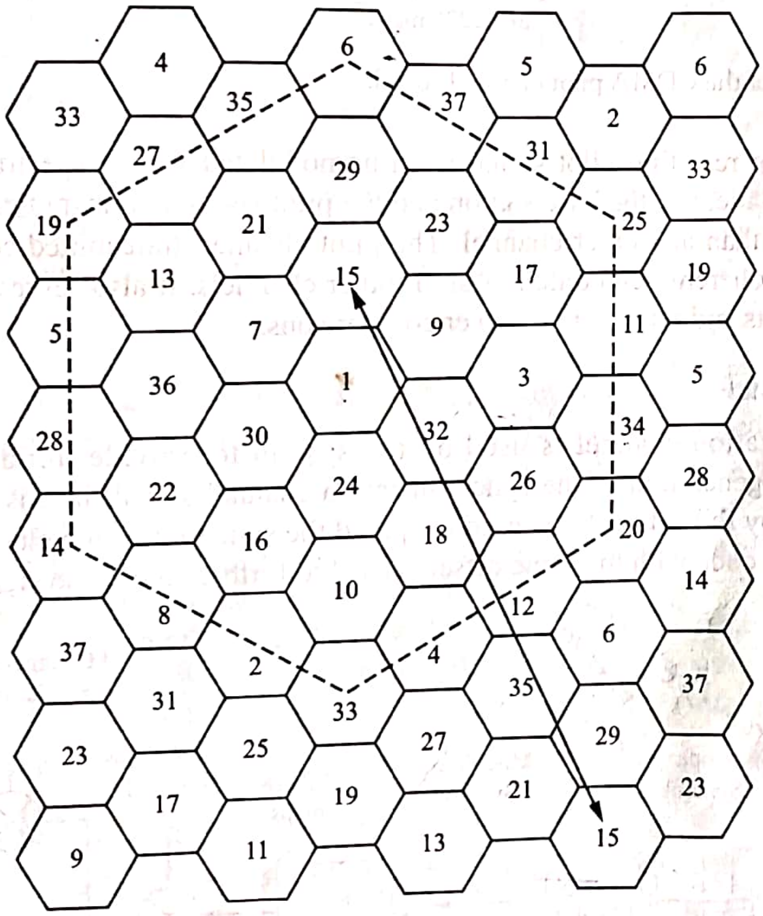


Figure 6–12 CDMA base station timing offset reuse pattern.

Figure 6–12 CDMA base station timing offset reuse pattern.

The initial IS-95 CDMA system implementation uses four different types of logical channels in the forward direction: the pilot channel, synchronization channel, paging channels, and traffic/power control channels. Each one of these types of forward channels will be discussed in more detail in the following sections.

Pilot Channel

The CDMA pilot channel is used to provide a reference signal for all the SDs within a cell. Figure 6–13 depicts the generation of the pilot channel signal. The all-0s Walsh code (W_0^{64}) is used for the initial signal spreading on a sequence of all 0s. This results in a sequence of all zeros that are further spread using the short PN spreading sequences resulting in a sequence of 0s and 1s. The I and Q signals drive a quadrature

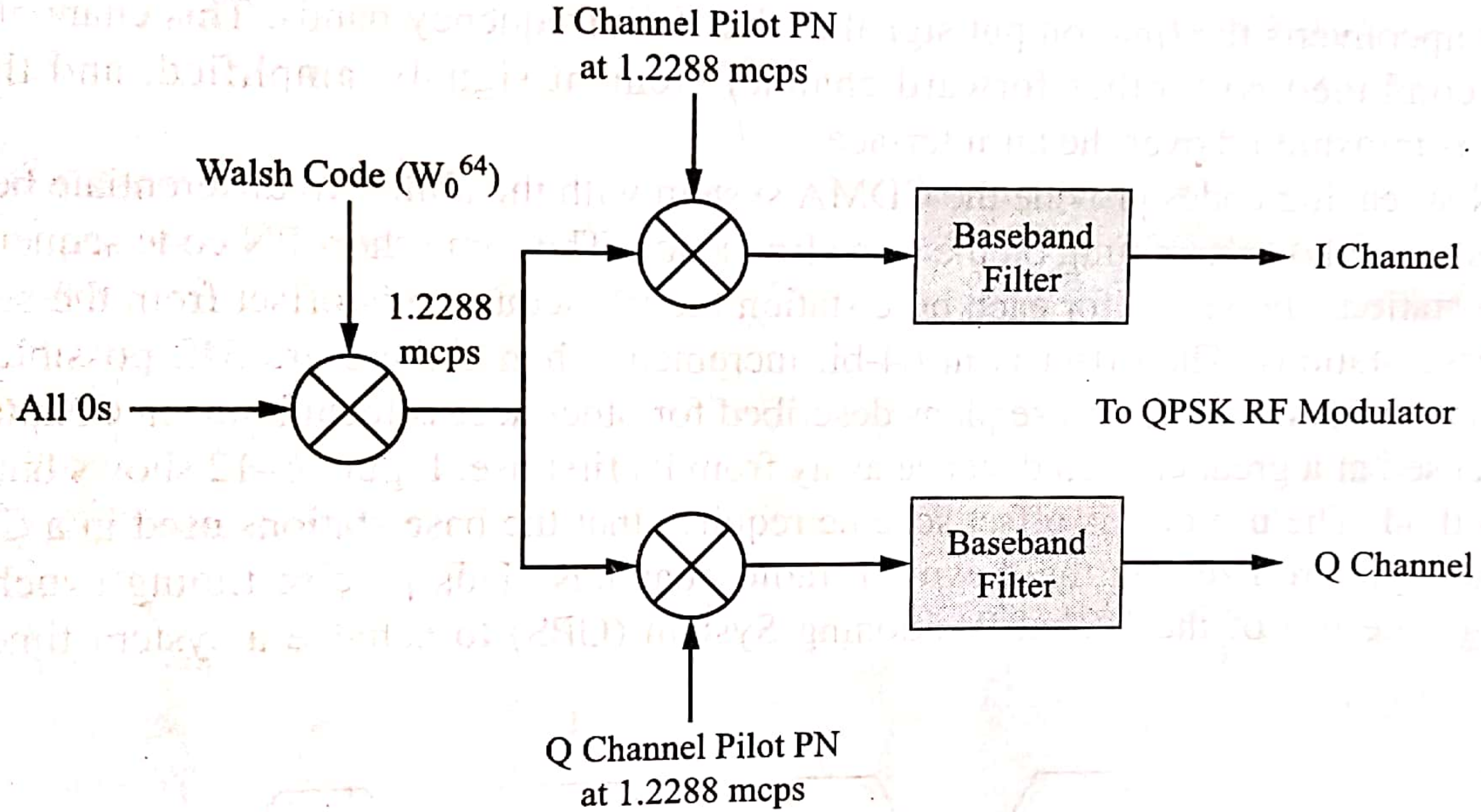


Figure 6–13 Generation of the CDMA pilot channel signal.

modulator. Therefore, the resulting pilot signal is an unmodulated spread spectrum signal. The short PN spreading code is used to identify the base station and the pilot signal is transmitted at a fixed output power usually 4–6 dB stronger than any other channel. The pilot channel, transmitted continuously, is used as a phase reference for the coherent demodulation of all other channels. It also serves as the reference for signal strength measurements and other signal power comparisons.

...ization Channel

...rovide initial time synchronization

strength measurements and other signal power comparisons.

Synchronization Channel

The CDMA synchronization channel is used by the system to provide initial time synchronization. Figure 6–14 depicts the generation of the synchronization channel signal. In this case, Walsh code W_{32}^{64} (thirty-two 0s followed by thirty-two 1s) is used to spread the synchronization channel message. Again, the same short PN spreading code with the same offset is used to further spread the signal.

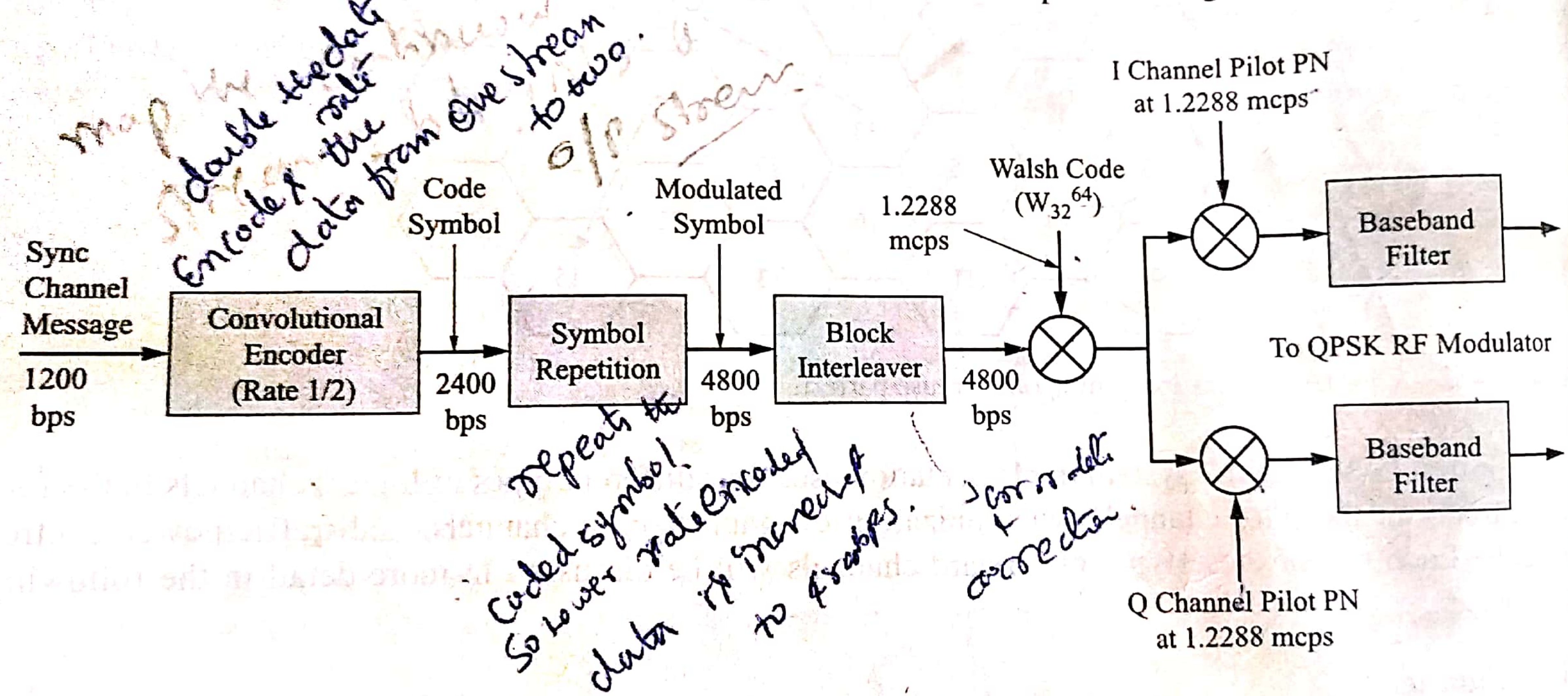
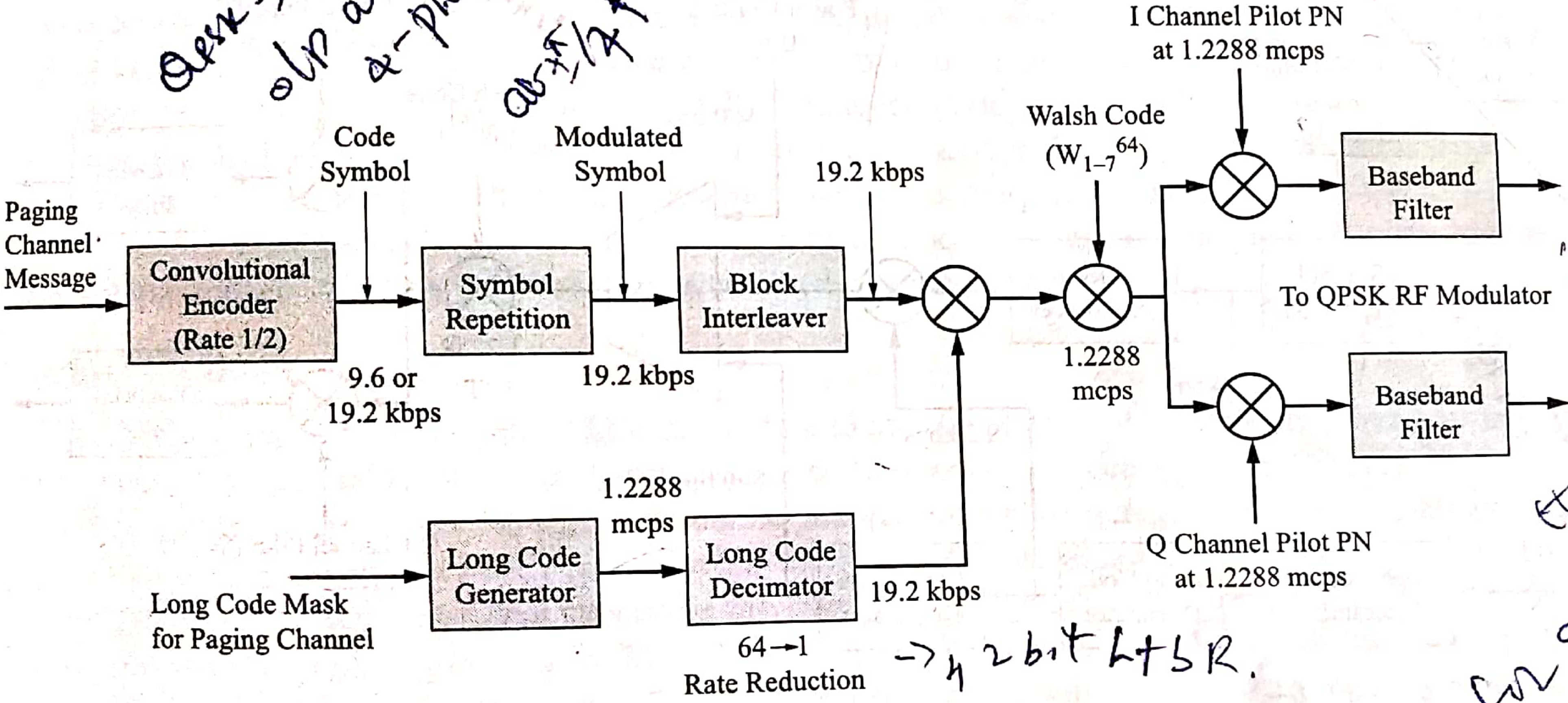


Figure 6–14 Generation of the CDMA synchronization channel signal.

As shown in Figure 6–15, the initial synchronization channel message has a data rate of 1200 bps. The sync messages undergo convolutional encoding, symbol repetition, and finally block interleaving (to be explained in Chapter 8). This process raises the final sync message data rate to 4.8 kbps. The information

QPSK → the binary I & Q o/p are mapped onto α-phase & quadr... π/4, 3π/4

F-C → 869 to 894
RV → 824 − 849 MHz



→ 42 bit LFSR.

RF mod r. data are raised to the cellular radio band for 935 to 960 MHz, 890 to 915

Figure 6–15 Generation of the CDMA paging channel signal.

contained in the sync message includes the system and network identification codes, identification of paging channel data rates, the offset value of the short PN spreading code, and the state of the long PN spreading code. Like the pilot channel, the synchronization channel has a fixed output power.

Paging Channels

Paging Channels

The CDMA paging channels serve the same purpose as the paging channels in a GSM cellular system. These channels are used to page the SDs when there is a mobile-terminated call and to send control messages to the SDs when call setup is taking place. Figure 6–15 depicts the generation of a paging channel message.

For IS-95 CDMA there can be as many as seven paging channels in operation at any one time. Walsh codes W_1^{64} through W_7^{64} are used for this purpose. As seen in Figure 6–15, the paging channel undergoes an additional scrambling operation using the long PN spreading code sequence. The long PN code is generated by using a 42-bit linear feedback shift register that yields a repeating sequence of length 2^{42}. The paging channel message also goes through a convolutional encoding process, symbol repetition, and block interleaving before being scrambled by a slower version of the long PN code.

Traffic/Power Control Channels

The CDMA forward traffic channels carry the actual user information. This digitally encoded voice or data can be transmitted at several different data rates for IS-95 CDMA systems. Rate Set 1 (RS1) supports 9.6 kbps maximum and slower rates of 4.8, 2.4, and 1.2 kbps. Rate Set 2 (RS2) supports 14.4, 7.2, 3.6, and 1.8 kbps. Figure 6–16 and Figure 6–17 depict the generation of a forward traffic channel. As shown in Figure 6–17, for generation of Rate Set 2 traffic an additional operation is performed after the symbol repetition block. For a data rate of 14.4 kbps the output from the symbol repetition block will be 28.8 kbps. The "puncture" function block selects 4 bits out of every 6 offered and thus reduces the data rate to 19.2 kbps, which is what the block interleaver needs to see. More details about this operation will be presented in Chapter 8.

All of the CDMA system's unused Walsh codes may be used to generate forward traffic channels. The traffic channels are further scrambled with both the short PN sequence codes and the long PN sequence codes before transmission. As also shown in Figures 6–16 and 6–17, power control information is transmitted to the mobile stations within the cell over the traffic channels. This power control information is used to

Unused code to the case.

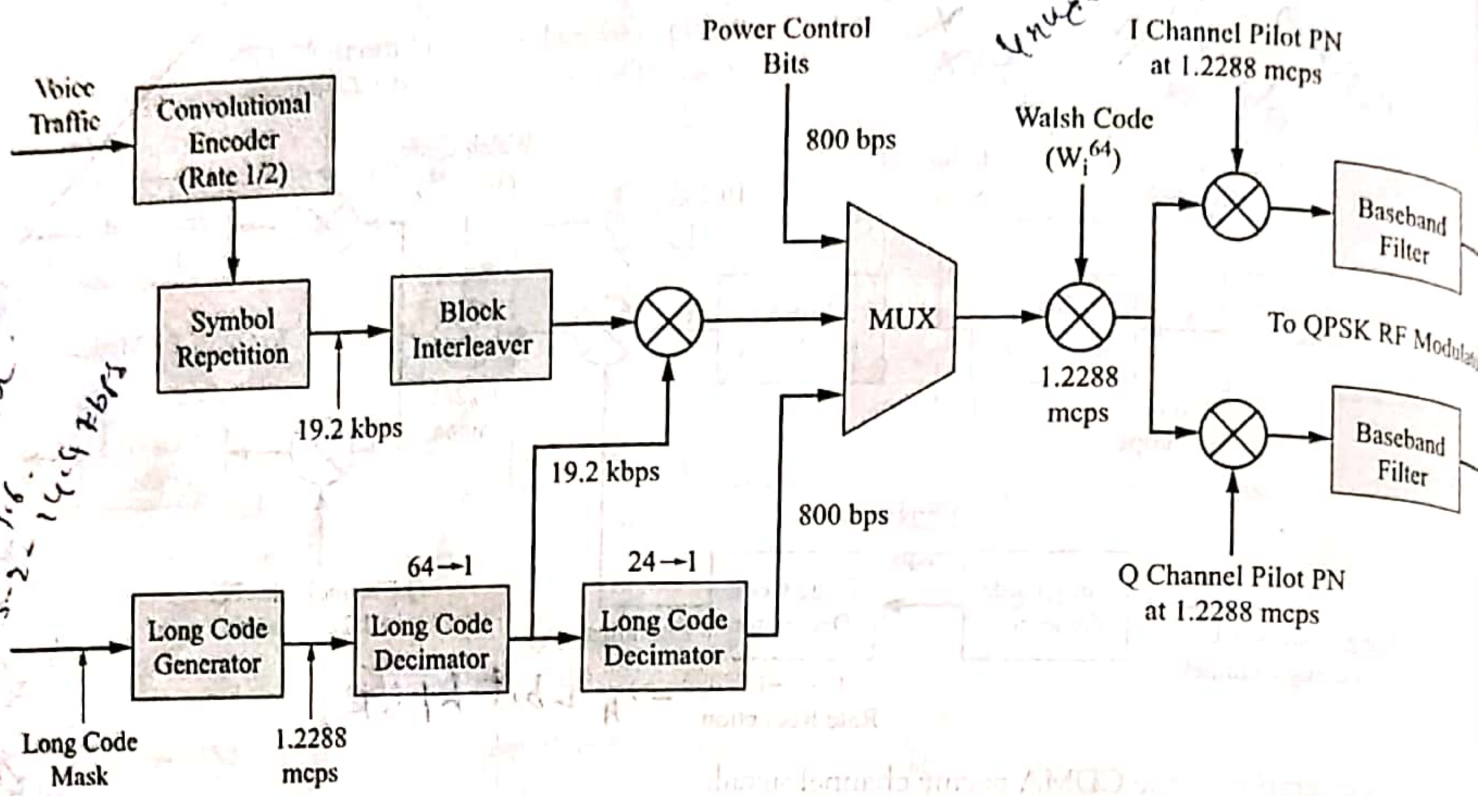


Figure 6–16 Generation of the CDMA forward traffic/power control channel for 9.6-kbps traffic.

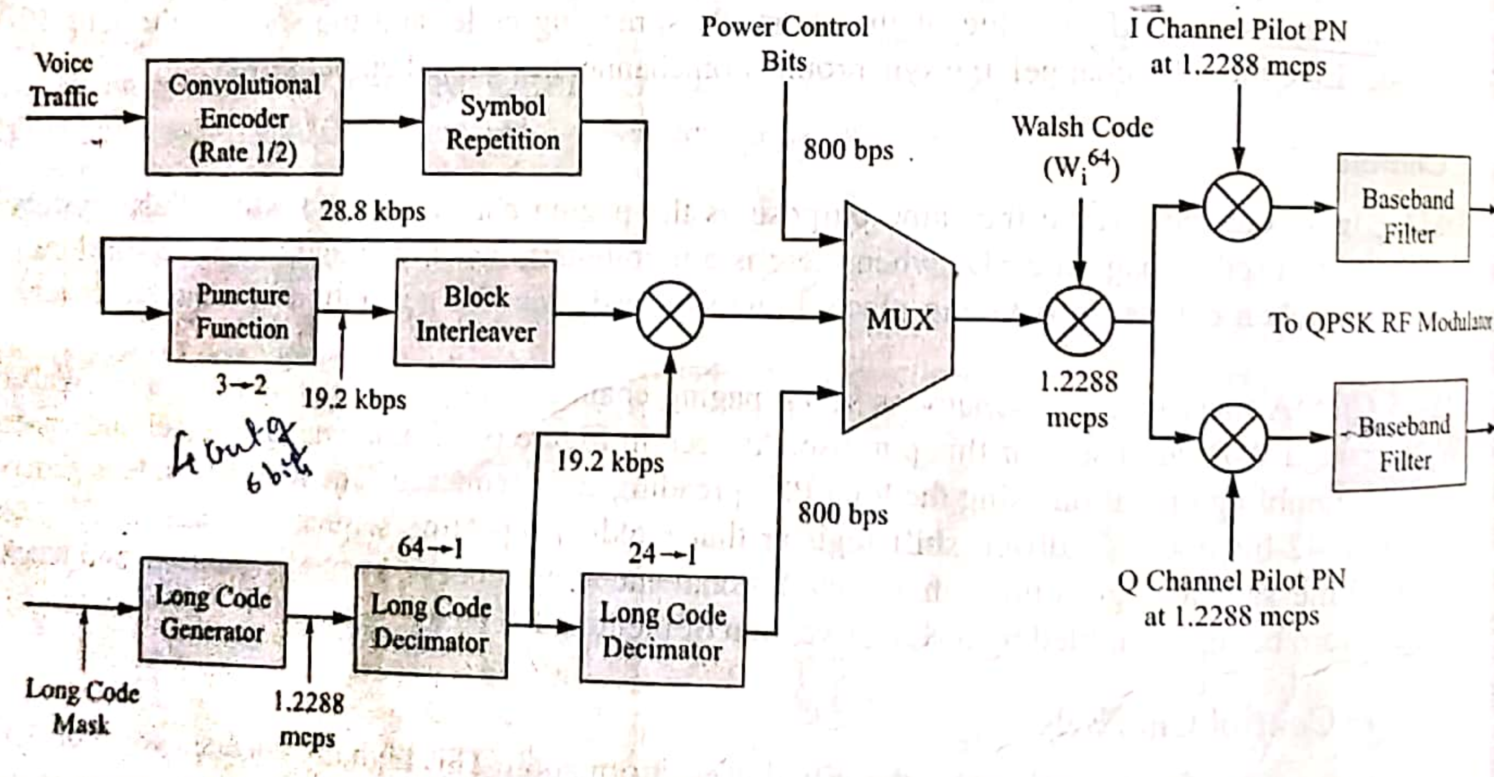


Figure 6–17 Generation of the CDMA forward traffic/power control channel for 14.4-kbps traffic.

set the output power of the mobile on the reverse link and is multiplexed with the scrambled voice bits at a rate of 800 bps or 1 bit every 1.25 msec.

HAPTER

8

Wireless Modulation Techniques and Hardware

pon 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.

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

Conductor-Based Transmission Lines

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.

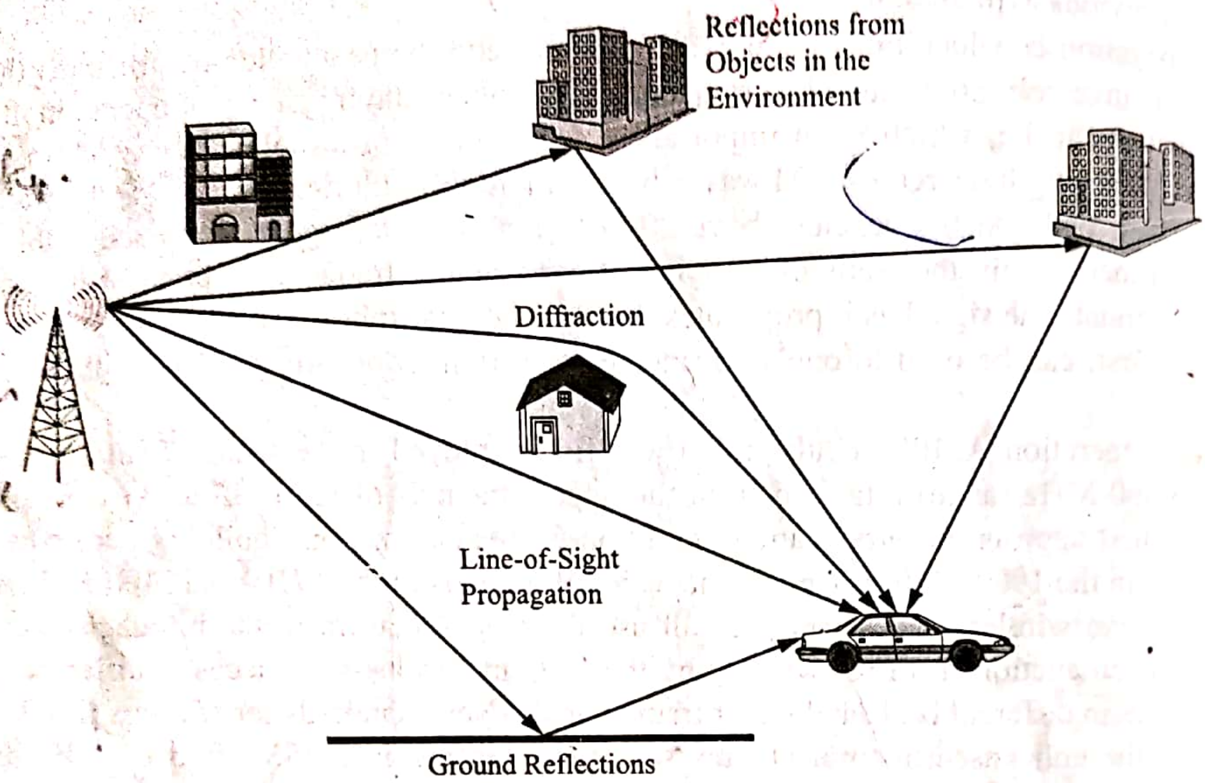
puts a new spin on how the wireless industry will evolve.

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 ...



250 Km
Stratosphere
Troposphere
Earth

Figure 8–1 Typical outdoor propagation case.

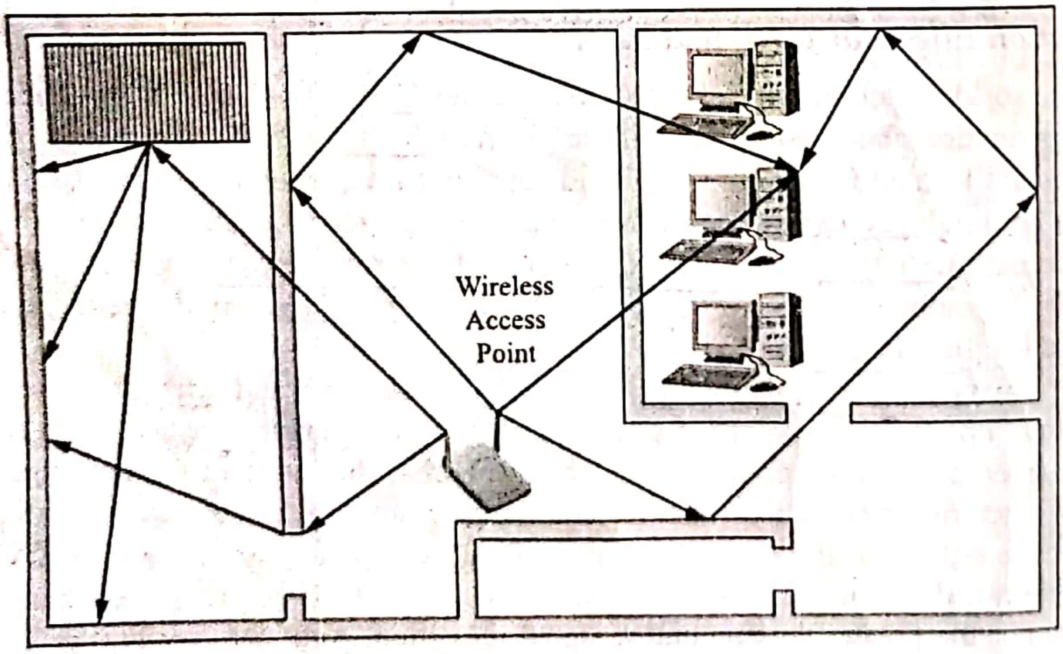


Figure 8–2 Typical indoor propagation case.

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.

Scanned with CamScanner

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

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

P_R in dBm = $10 \log \left(\frac{P_R}{1 \text{ mW}}\right.$

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

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

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

$(\ \ )\,W$

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:

$$\textit{Path Loss} = P_T - P_R \qquad \text{8-3}$$

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).

Scanned with CamScanner

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.

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

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:

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

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 + 82.6.

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

$$P_R = -87.6\text{dBm}$$

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... ...licensed bands or the new unlicensed 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.

8.7 DIVERSITY TECHNIQUES

As has been explained earlier, the biggest problem encountered in the use of the urban mobile radio channel is the large and rapid fluctuations that can occur in RSS due to multipath fading. It is impractical to try and counteract the diminished RSS by raising the system transmitting power since typical fades can cover several orders of magnitude with deep fades covering over three or four orders of magnitude, well beyond the limits of transmitter power control systems. The most effective technique that can be used to mitigate the effects of fading is to employ some form of time, space, or frequency diversity for either or both the transmission and reception of the desired signal. The basic idea behind these solutions is that fading will not remain the same as time passes nor will it be the same over different signal paths or for different frequencies over the same paths. There are several methods that can be used to provide diversity to a wireless mobile system. In each case, several different received signals are usually combined to improve the system's performance. Some of the more popular ways to obtain two or more signals for this purpose are to make use of specialized receivers, physically provide additional antennas, operate over more than one frequency, and use smart antenna technology. The operation of a system over more than one frequency has been previously addressed during the discussions of FHSS, GSM frequency hopping, and multicarrier systems. Therefore, this topic will not be pursued any further here. The next several sections will address the other techniques that have been mentioned and some newly emerging technologies.

Specialized Receiver Technology

In an effort to combat multipath effects, several innovative receiver implementations have been created. Recognizing that multiple signals will arrive at a receiver over the mobile radio channel, these receivers exploit that fact by isolating the signal paths at the receiver. Furthermore, if one recognizes that the fading of each multipath signal is different, then it can be seen that this isolation process will in fact yield the diverse signals needed to improve receiver performance. An early embodiment of this concept is the **RAKE receiver** originally designed in the 1950s for the equalization of multipath. See Figure 8–16 for a block diagram of the structure of a typical RAKE receiver used for CDMA.

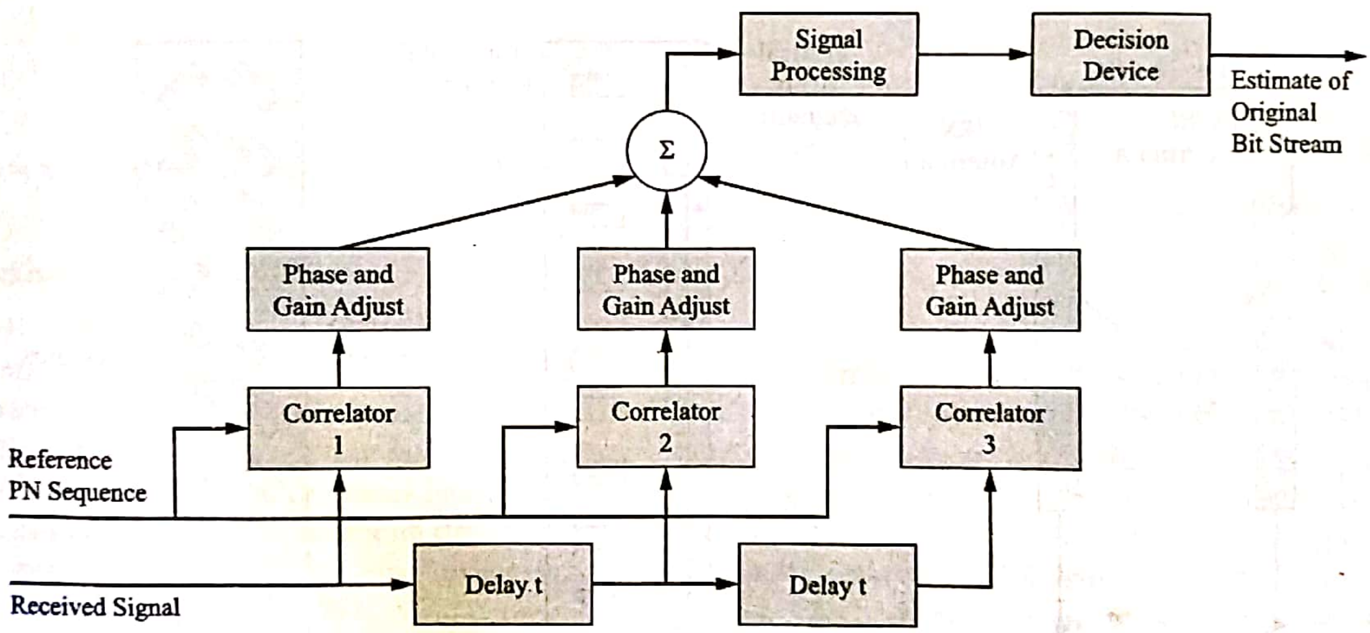


Figure 8–16 RAKE receiver block diagram.

Modern, digitally implemented RAKE receivers used in today's CDMA wireless mobile systems may only have a few RAKE taps but possess the ability to dynamically adjust the taps (move the rake fingers) in response to a search algorithm used to locate multipath components. These smart receivers can generate several signals that can be further combined by several standard diversity combining techniques to provide a more reliable receiver output and therefore improve system performance.

There are potential problems with this type of receiver that are tied to the multipath delay and spread introduced to the radio link. The multipath components that can be resolved have a time dependence that is proportional to the inverse of the system chip rate and the system-tolerated multipath spread is proportional to the inverse of the symbol time. For the IS-95 CDMA system, using a chip rate of 1.2288 mcps allows the resolution of multipath components of the order of approximately 1/1.2288 mcps or 800 ns by the RAKE receiver. For a symbol rate of 14.4 kbps (encoded with QPSK) a multipath spread of up to approximately

1/7200 or 140 s may be tolerated without ISI. Since the typical multipath spread for an outdoor environment is in the order of tens of microseconds and for indoor environments nanoseconds, CDMA systems do not suffer from ISI and these types of receiver can be implemented. However, in an indoor environment the CDMA RAKE receiver would not be able to resolve multipath components.

The GSM system employs an equalization technique at the receiver to improve system performance. As outlined in Chapter 5, a training sequence of 0s and 1s is transmitted during the middle of a normal burst of user data (refer back to Figure 5–15). The receiver uses this training sequence to train the complex adaptive equalizer incorporated into the GSM mobile receiver to improve system performance. Due to the complexity of these systems no further details will be presented here.

Space Diversity

A typical technique used to improve mobile wireless system performance is to employ **space diversity** in the form of additional receiving antennas located at the base station. At this time it is still problematic to achieve antenna diversity for a mobile station due to its typically small size in relation to a wavelength of the radio frequency employed. This fact may change in the near future with the adoption of advanced antenna technology schemes (MINO, smart antennas, etc.). In theory, the paths taken by the reverse signal to arrive at each antenna will not be affected equally by multipath fading or spread. There are many ways to achieve the needed space diversity at the base station site. Figures 8–17 shows several practical implementations.

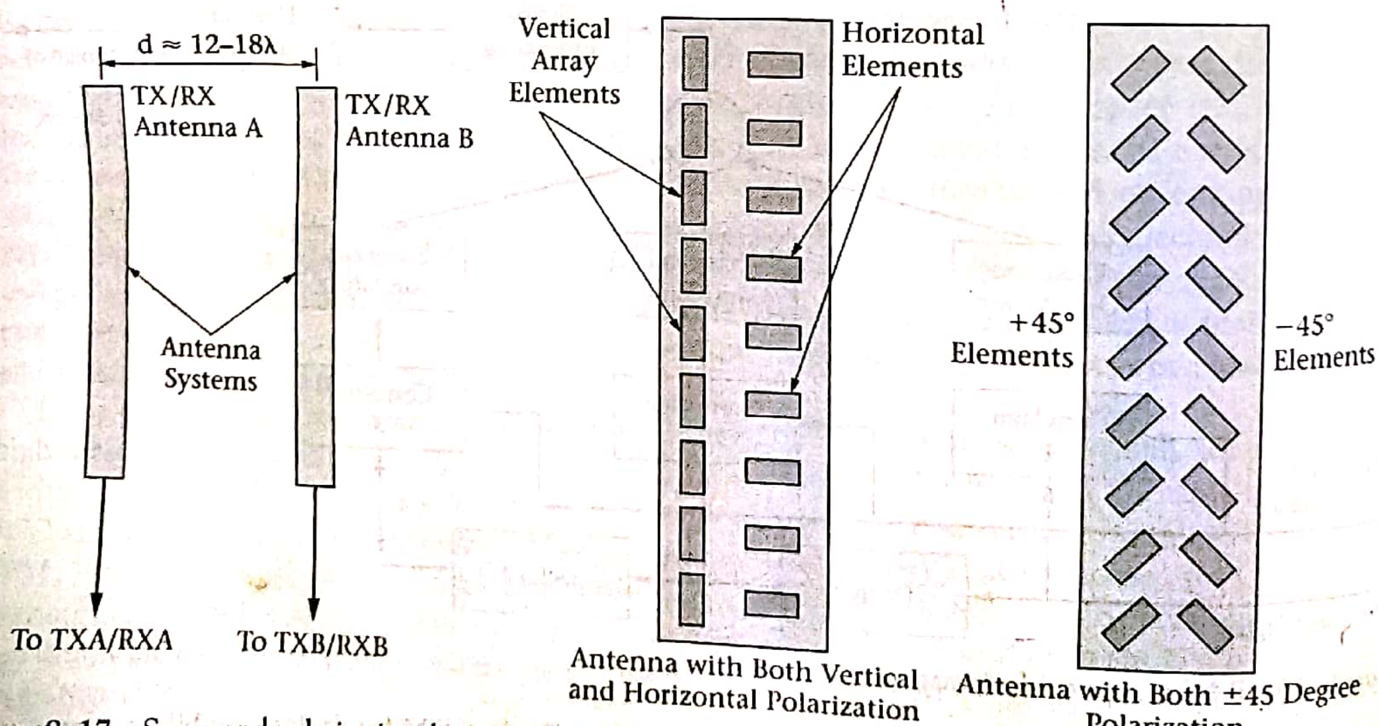


Figure 8–17 Space and polarization diversity antenna schemes.

As can be seen in the figures, both space and polarization diversity can be used by the appropriate positioning of the antenna units. The antennas feed multiple receivers, with the strongest received signal being used by the system. This technique is universally implemented by wireless mobile service providers in the design of their systems. Polarization diversity is used to counter the change in EM signal polarization that can be induced by the environment during reflection, scattering, and so on.

Smart Antennas

In the 3G specifications, the support of smart antenna technology is included. This technique to improve system performance makes use of phased array or "beam steering" antenna systems. These types of antennas can use narrow pencil-beam patterns to communicate with a subset of the active users within a cell. Once a mobile subscriber has been located by the system, a narrow radio beam may be pointed in the user's direction through the use of sophisticated antenna technology. The use of a radio link that approaches point-to-point type link characteristics is extremely useful in a mobile environment. Besides the elimination of most multipath signals, a fact that will certainly improve system performance, the amount of interference received will be reduced and system capacity can be increased. As the mobile user moves about the coverage area, the smart antenna will track the mobile's motion. See Figure 8–18 for a depiction of a smart antenna system.

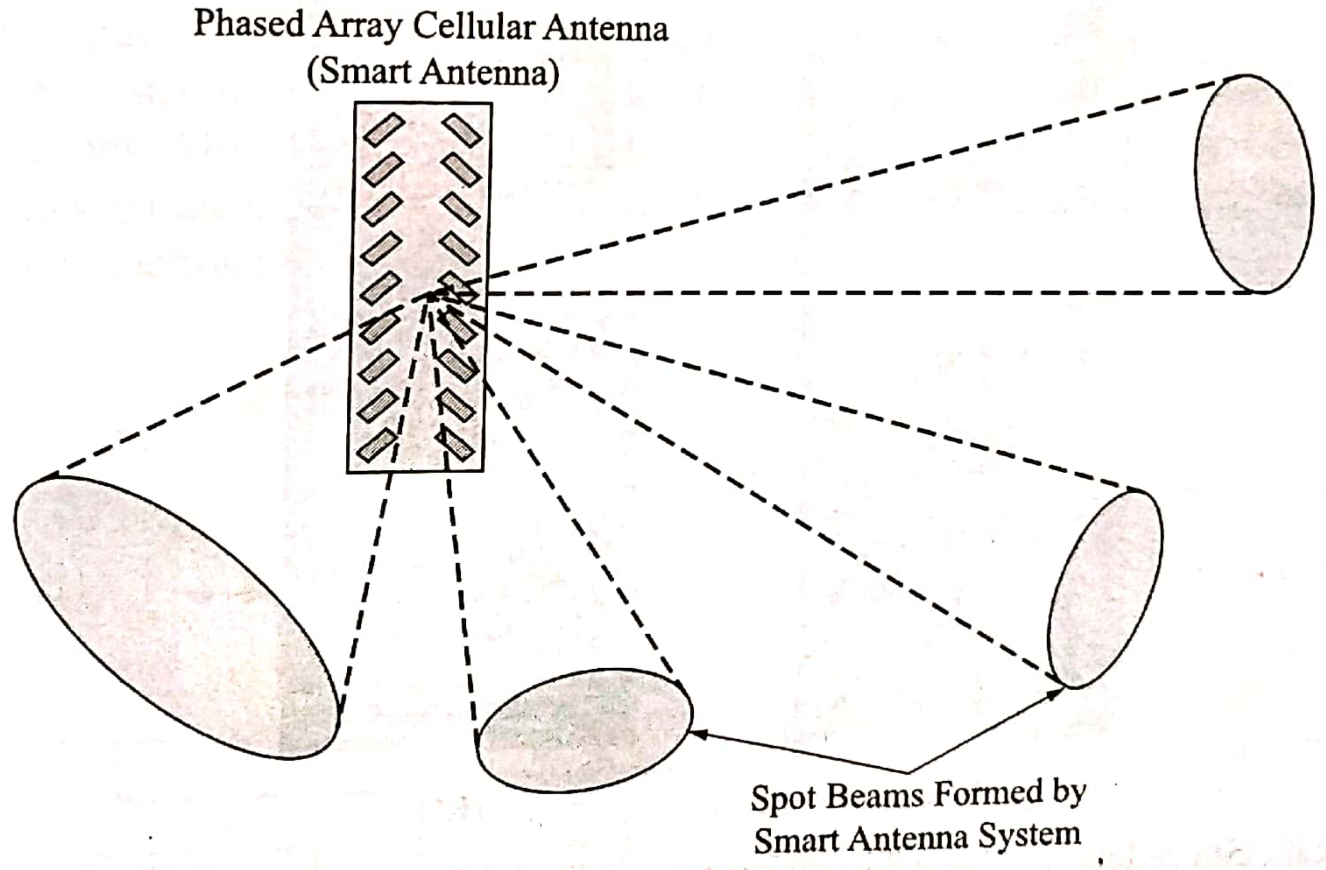


Figure 8–18 Depiction of a 3G smart antenna system.