CHAPTER 8

CDMA TECHNOLOGY, IS-95, AND IMT-2000

8.1 INTRODUCTION

In the cellular telephone industry, CDMA is primarily an air-interface or radio transmission technology and access technique that is based on direct sequence spread spectrum techniques described in Chapter 3.[1] Error control coding, spreading of the spectrum, soft handoffs, and strict power control play a very important role in the design and operation of CDMA-based systems. Although the air interface is significantly different in the case of CDMA compared with TDMA techniques, the core fixed network infrastructure that supports the wireless interface is very similar to the structure of the GSM core network. In fact, the core network for North American CDMA and TDMA systems are more or less identical.

In the previous chapter, we discussed the GSM in some detail. The GSM standard came about in Europe as a result of initiatives by ETSI toward a unified digital cellular system. Although the original goals of GSM could be met only by defining a new air-interface, the group went beyond just the air-interface and defined a system that complied with emerging ISDN-like services and other emerging fixed network features. To this end, the committee also defined a number of other interfaces between the hardware and software elements of the network, making GSM a complete digital cellular standard.

Unlike GSM in the EU, in the United States, standards activities are based on developed technologies and have considerable input from the industry. The Telecommunications Industry Association (TIA), or the T1P1 Committee of the Alliance for Telecommunications Industry Solutions (ATIS), develops North American wireless standards. The so-called *Interim Standards* (IS) developed by the TIA form the basis for deploying cellular systems until they are formally specified as TIA or ITU standards. The AMPS was the predominant analog cellular service in the 1980s in the United States. Although AMPS specified the air-interface, very little standardization was available in the backbone infrastructure leading to proprietary implementations and lack of interoperability. Roaming across system boundaries was very complicated, requiring subscriber intervention. To solve these problems, the TIA worked on the IS-41 standard that specifies an open communications interface between two AMPS systems. Digital cellular services evolved in two different directions for the air-interface—TDMA and the IS-136 standard and CDMA and the IS-95 standard. Interoperability between these standards was impossible over the air-interface except via dual mode telephones that are actually implementing two separate radio systems and coordinating the mobile terminal with the available wireless service in an area. The backbone infrastructure specified by the IS-41 standard, however, has now evolved to support both the IS-136 and IS-95 standards.

IS-95 is the North American digital cellular standard that employs CDMA as the access method as well as the air-interface. This technology was developed by Qualcomm around 1990 and is also called cdmaOne today. In 1989, Qualcomm

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[1] Bluetooth technology uses CDMA with frequency hopping spread spectrum, and UWB technology uses CDMA with pulse position modulation.

first demonstrated its technology and developed the common air-interface specifications in 1991. In 1993, the TIA published Qualcomm's common air-interface specifications as the interim standard IS-95. Since then, this standard has undergone several revisions, such as IS-95a and IS-95b.

Third-generation (3G) systems are being standardized all over the world currently by the ITU under the banner of *International Mobile Telecommunications beyond 2000* (IMT-2000), and there are once again two major paths that are emerging—the first being an evolution of GSM to IMT-2000 and the second an evolution of the North American IS-136 and IS-95 standards to IMT-2000. In both cases, CDMA is the air-interface. The former is being specified by the Third Generation Partnership Project (3GPP) and the latter by a second association called 3GPP2. The 3GPP specified standard is commonly referred to as WCDMA, and the 3GPP2 specification is called CDMA2000. CDMA2000 is meant to be backward compatible with IS-95 or cdmaOne standards.

In this chapter, we look at the North American reference architecture for cellular telephony and consider the air-interface aspects of CDMA through both the 2G IS-95 standard and the emerging 3G standards. The treatment of the reference model and the networking aspects is very brief because of its close similarity to that of the GSM described in the previous chapter. The main emphasis is on the description of the CDMA air-interface specifications used in cdmaOne and IMT-2000. There are several similarities between all these systems in terms of the CDMA air-interface. We present a unified treatment by pointing out the differences. Once again, the reader is referred to several references [e.g., GAR00] for additional details.

8.2 REFERENCE ARCHITECTURE FOR NORTH AMERICAN SYSTEMS

The reference architecture for North American Systems is based on interim standards developed by TIA. The reference architecture is very similar to the GSM reference architecture with a few differences. The Committee TR-45 develops performance, compatibility, interoperability, and service standards for mobile and PCSs in the 800 MHz and 1,800 MHz spectrum bands. These standards consider, among other things, service information, wireless terminal equipment, wireless base station equipment, wireless switching office equipment, and intersystem operations and interfaces. TR-45.3 deals with TDMA technology and TR 45.5 with CDMA technology. The TR45 committee is also closely working with the 3GPP2 group to specify the CDMA2000 standard. TR-46 is the adaptation of TR-45 for the PCS bands, which includes some minor changes and interchanging the names of some elements. Figure 8.1 shows the TR-45/46 reference model.

Example 8.1: The TR-45/46 Reference Model versus the GSM Reference Model

In Chapter 7, we discussed the GSM reference architecture. Figures 7.1 and 7.2 shows the GSM reference architecture; Figure 8.1 shows the TR-45/46 reference architecture. The two are very similar with the exception of a few interfaces and

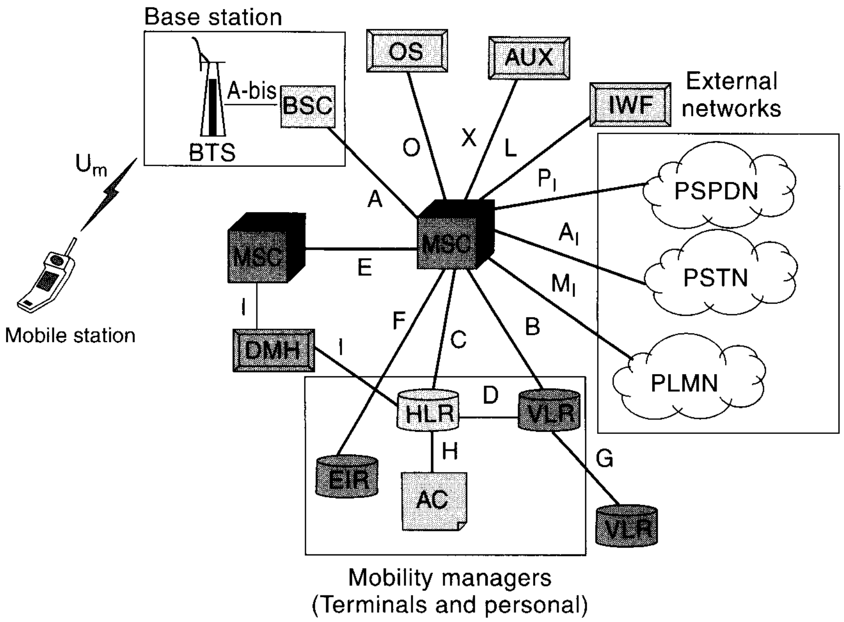


Figure 8.1 TR-45/46 reference model.

elements. In particular, the data message handler (DMH) that collects billing information, the interworking function (IWF) that allows an MSC to connect to other networks, and the auxiliary (AUX) equipment that can connect to an MS are new. The authentication center (AuC) in GSM is shown as the AC in Figure 8.1 and the operation and maintenance center (OMC) is shown as the operation system (OS).

As in the case of GSM, messaging in the infrastructure is carried out by protocols very similar to SS-7 or modifications thereof. In particular, two interim standards are important in the backbone handling of messages. The IS-634 is an open interface standard between the mobile switching center and the radio base station subsystem in a cellular network. The IS-41 protocol permits intersystem roaming and specifies basic and supplementary services.

8.2.1 The IS-634 Standard For MSC-BS Interface

The IS-634 is now formalized as TIA/EIA-634 MSC-BS interface for public wireless communications systems standard. It defines the functional capabilities, including services and features of the messages communicated along the MSC-BS interface, their sequencing and timers at the BS and MSC. In Figure 8.1, this interface is labeled the *A-interface*. The idea behind the standard is that a standard interface allows the BS and MSC equipment to evolve independently and to be provided by multiple vendors. It partitions the tasks between the BS and the MSC without dictating implementation, and it supports all services provided by North American standards. Previously this interface was not standardized, and, hence, both the BS and MSC elements had to be provided by a single vendor. Figure 8.2 shows the layered architecture specified by IS-634.

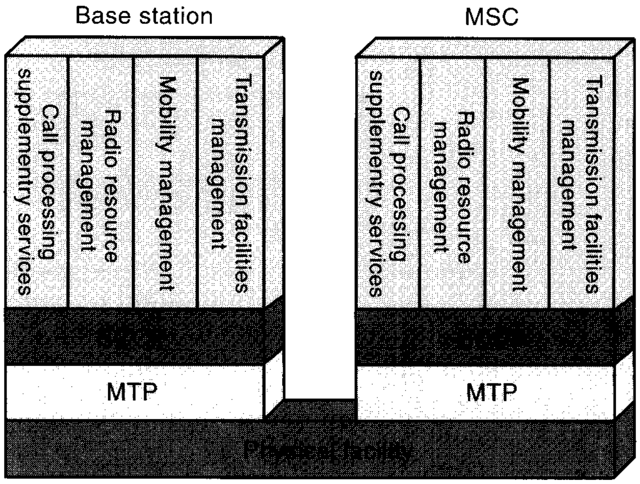


Figure 8.2 IS-634 layered architecture.

In IS-634, the underlying physical layer is based on ISDN over one or multiple T1 carriers at 1.544 Mbps, and in that sense it is similar to GSM. The physical link can be used to transport either signaling or user traffic. The message transport part (MTP) and the signaling connection control part (SCCP) are similar to those in SS-7 and are used only for error-free transport of signaling messages. The IS-634 applications include call processing, radio resources management, mobility management, and transmission facilities management.

Example 8.2: Services Supported over IS-634

Call processing and mobility management procedures occur between the MS and the MSC. Call processing and supplementary services supported over IS-634 include mobile originated and terminated calls, call release, call waiting, and so on. Several messages are defined in IS-634 to support these services. Mobility management supports the usual registration, deregistration, authentication, and voice privacy.

Radio resource management and transmission facilities management procedures occur between the BS and the MSC. RRM, as defined in Chapter 6, is responsible for maintaining a good radio link by supervision, management, and handoff initiation. In the case of CDMA, it has to additionally support soft handoff. The transmission facilities management handles the terrestrial circuits that carry voice, data, or signaling information (e.g., call blocking, overload, etc.).

In Figure 8.3, the functional architecture of IS-634 is shown. Here we see that several BTSs will connect to a BSC. As discussed later on, this is also a result of soft handoff when an MS connects to several BTSs simultaneously. However, from an IS-634 perspective, the BSC is the BS. The transcoder converts the speech from the air-interface QCELP format to the wireline PCM format. This has a bearing on the size of data because QCELP has voice encoded at 13 kbps and PCM at 64 kbps. Depending on where the transcoder is located, the quantity of data to be

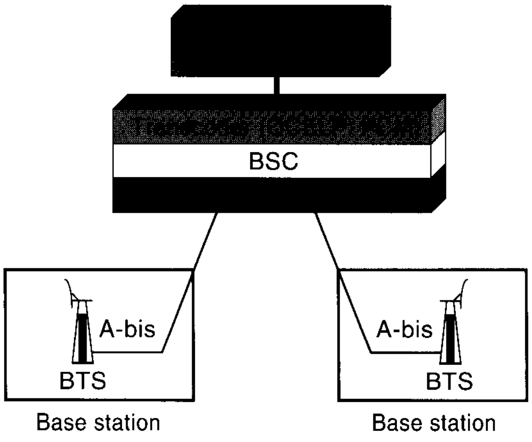


Figure 8.3 IS-634 functional architecture.

transported from the BS to the MSC may be different. IS-634 allows the transcoder to be placed either at the BSC or at the MSC or somewhere in between.

8.2.2 The IS-41 Standard for the MSC-MSC Interface

The TIA/EIA-41 specification, formalized from IS-41, is primarily used in the core network to provide services such as automatic roaming, authentication, intersystem handoff, short message service, and so on. All wireless network elements such as the MSC, HLR, VLR, EIR, and AUC, use this messaging protocol to communicate among themselves. The IS-41 standard provides an open architecture similar to GSM to allow two different North American systems to accommodate roaming.

In its preliminary form, IS-41 simply specified general handoff procedures when it was first introduced in 1988. Since then, Revision A in January 1991 specifies roaming; Revision B in December 1991 specifies dual mode AMPS/TDMA handoff operations; Revision C in 1997 the authentication, CDMA handoff, and short messaging services; Revision D, aspects of international roaming; and Revision E, QoS handling and multimedia services.

With reference to Figure 8.1, the IS-41 standard specifies communications between the core network elements such as the MSC, VLR, HLR, AC, and so on. The signaling protocol stack of IS-41 is very similar to SS7, an out-of-band common channel signaling scheme used in wired telephony, as well as to communicate between different entities in the network through multiple nodes. Only certain application services are different. In addition to SS7's transaction capabilities application part (TCAP), IS-41 also supports the *mobile applications part* or MAP. The MAP defines various messages transported between the core network elements.

If handoff involves two base station subsystems connected to the same MSC, the wireline network is not involved to the extent when the two BSSs are controlled by different MSCs. In the former case, IS-41 has very little role to play because the messaging is restricted to one MSC that also controls the HLR and VLR. In the latter case, IS-41 is involved in so-called *intersystem handoffs*. In this case, the current MSC will request a RSS measurement from the candidate MSC. Once RSS measurements indicate the candidate BSS as suitable for handoff, the two MSCs will complete the intersystem handoff. There are three types of handoffs—handoff forward (transfer from one MSC to another MSC of a new system), handoff backward (transfer from the new MSC back to the old MSC), and handoff third (transfer from a MSC in a second system to a MSC of a third system). In the last case, procedures may also be carried out to reduce the total number of trunks utilized because of the handoff (essentially re-creating the call circuit if necessary).

During handoff, IS-41 signaling messages will carry terminal information (the IMSI, the electronic serial number [ESN], system identifier, the MS capabilities, etc.), the call information (billing ID, trunks carrying the call between the two MSCs), and the air-interface information (serving and destination cells and channels). It also performs authentication procedures between two systems.

8.3 WHAT IS CDMA?

CDMA is both an access method and an air-interface. The rest of the network and system is very similar to any other TDMA system such as GSM that was described in Chapter 7. Radio resource management, mobility management, and security of the CDMA systems are all implemented in the same way as in TDMA systems. There are differences in terms of handling the power control and employing soft handoffs. In this chapter we only address these differences and concentrate on the implementation of the air-interface. For more details of the fixed infrastructure for CDMA and other North American systems, the reader is referred to [GAR00], [GOO97].

With CDMA, all user data, and in most implementations the control channel and signaling information, are transmitted at the same frequency at the same time. All the CDMA systems employ direct sequence spread spectrum and powerful error control codes. The primary significance of CDMA is that by employing a variety of physical layer schemes, it is possible to reuse frequencies in all cells unlike the traditional cellular telephony described in Chapter 5. These include spread spectrum with processing gain, RAKE diversity gain, powerful error correcting codes, variable rate voice coders that provide a gain from pauses in natural conversation, a fast power control mechanism to minimize interference, and soft handoff. This is made possible by reducing the required signal to noise ratio (E_b/N_t) for proper operation. In Chapter 3, we discussed the basics of spread spectrum and error control coding techniques. In this chapter we discuss the details of implementation in CDMA systems. Depending on the system, the actual implementation of CDMA may be different. There are three CDMA systems that need consideration—the IS-95 2G digital cellular standard that specifies the U_m interface in the 800–900 MHz bands for cellular radio in the United States, the JTC-Std-008 for the 1,900 MHz PCS bands, and the emerging WCDMA and CDMA2000 standards for IMT-2000.

CDMA, as it has been implemented in the IS-95 standard, has demonstrated an increase in system capacity compared with the analog and TDMA systems. CDMA improves quality of voice by using a better voice coder, has resistance to multipath and fading, implements soft handoffs, has less power consumption (6–7 mW on average), that is, about 10 percent of analog or TDMA phones because of implementation of power control, and does not require frequency planning because all cells employ the same frequency at the same time. This has resulted in CDMA becoming the popular choice for 3G systems. Although CDMA does provide an inherent flexibility for multimedia traffic, its disadvantage lies in the necessity for power control and implementation complexity. Analysis of the capacity of CDMA systems is presented in Chapter 4 with a comparison among CDMA, FDMA, and TDMA systems.

The air-interface in CDMA systems is by far the most complex of all systems, and it is not symmetrical on the forward and reverse channels unlike TDMA systems. The way spreading the spectrum and error control coding are employed on the forward and reverse channels are different. In the forward channel, transmissions originate at a single transmitter (the BS) and transmissions for all users are synchronized. It is thus possible to employ *orthogonal* spreading codes to minimize the interference between users. On the reverse channel, mobile terminals transmit whenever they have to. As the transmissions are not synchronized, the way spreading is employed is to use the same orthogonal codes for orthogonal modulation to reduce the error rate. In the following sections, we look at the specifics of the forward and reverse channels. We discuss the IS-95 as an example first and discuss the variations in the 3G standards such as WCDMA and CDMA2000 later.

8.3.1 The IS-95 CDMA Forward Channel

The CDMA forward channel is between the base station and the mobile station. The forward link in IS-95 occupies the same frequency spectrum as AMPS and IS-136 North American TDMA standards. Each carrier of the IS-95 occupies a 1.25 MHz of band, whereas carriers of AMPS and IS-136 each occupy 30 kHz of bandwidth. The IS-95 forward channel consists of four types of logical channels—pilot channel, synchronization channel, paging channel, and traffic channels. As shown in Figure 8.4, each carrier contains a pilot, a synchronization, up to seven paging, and a number of traffic channels. These channels are separated from one another using different spreading codes. The modulation scheme employed for transmission of spread signal in the forward channel is QPSK.

The fundamental format of the spreading procedure for all channels is shown in Figure 8.5. Any information contained in the form of *symbols* (after coding, interleaving, etc.) is modulated by *Walsh Codes* which are obtained from *Hadamard Matrices* discussed in Chapter 3. Each Walsh code identifies one of the 64 forward channels. After the channel symbols are spread using the orthogonal codes, they are further *scrambled* in the in-phase and quadrature phase lines by what are called the *short PN-spreading codes*. The PN spreading codes are not orthogonal, but possess excellent autocorrelation and cross-correlation properties to minimize interference among different channels. The PN-spreading codes are M-sequences generated by LFSRs of length 15 with a period of 32,768 chips. The orthogonal codes are used to isolate the transmissions between different channels *within* a cell, and the PN spreading codes are used to separate the transmissions between different cells. In effect the PN sequences are used to differentiate between several BSs

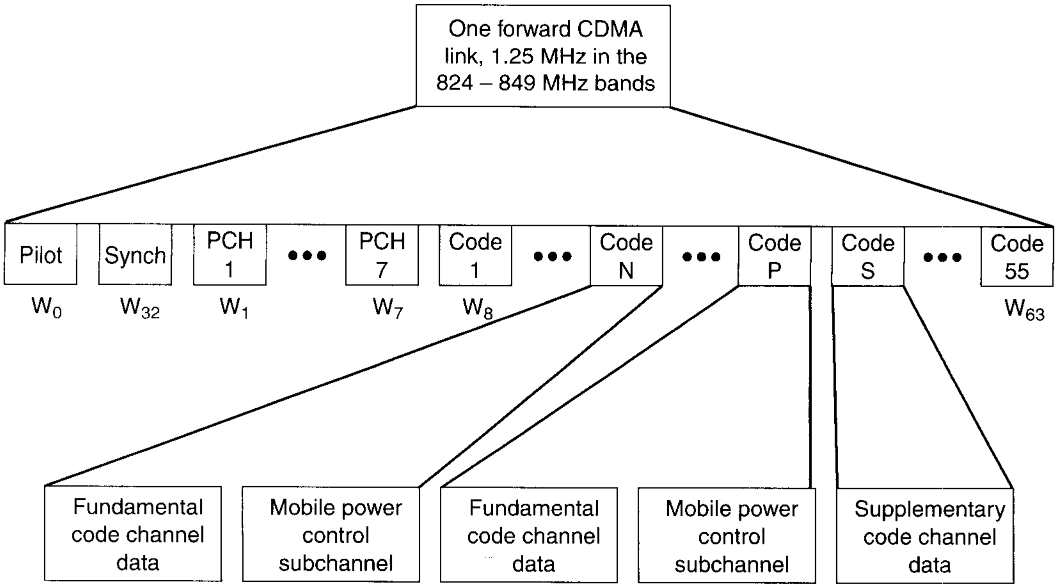


Figure 8.4 IS-95 forward channels.

in the areas that are all employing the same frequency. The same PN sequence is used in all BSs, but the PN sequence of each BS is *offset* from those of other BSs by some value. For this reason, BSs in IS-95 have to be synchronized on the downlink. Such synchronization is achieved using GPS.

The rows of the Hadamard matrix form Walsh codes such that each row in the matrix is orthogonal to every other row. It is possible to generate a Hadamard matrix recursively.

Example 8.3: Recursive Generation of Hadamard Matrices and Walsh Codes

The Hadamard matrix of order 2 is defined as $H_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$. All other higher order Hadamard matrices can be obtained via the recursion $H_{2N} = \begin{bmatrix} H_N & H_N \\ H_N & \overline{H_N} \end{bmatrix}$. Here the matrix $\overline{H_N}$ is the matrix H_N with all zeros and ones interchanged.

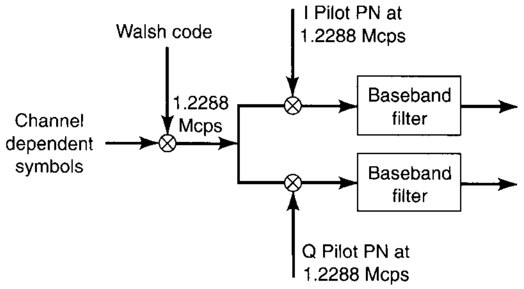


Figure 8.5 Basic spreading procedure on the forward channel in IS-95.

Proceeding in this fashion, it is easy to generate H_{64} that is employed in IS-95. Each row of the Hadamard matrix corresponds to a Walsh code. Consider

$$H_8 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 \end{bmatrix}$$

The first Walsh code from this matrix is W_0 = [0 0 0 0 0 0 0 0], that is, the all zero code. The last Walsh code is W_7 = [0 1 1 0 1 0 0 1]. Note that all pairs of Walsh codes are orthogonal.

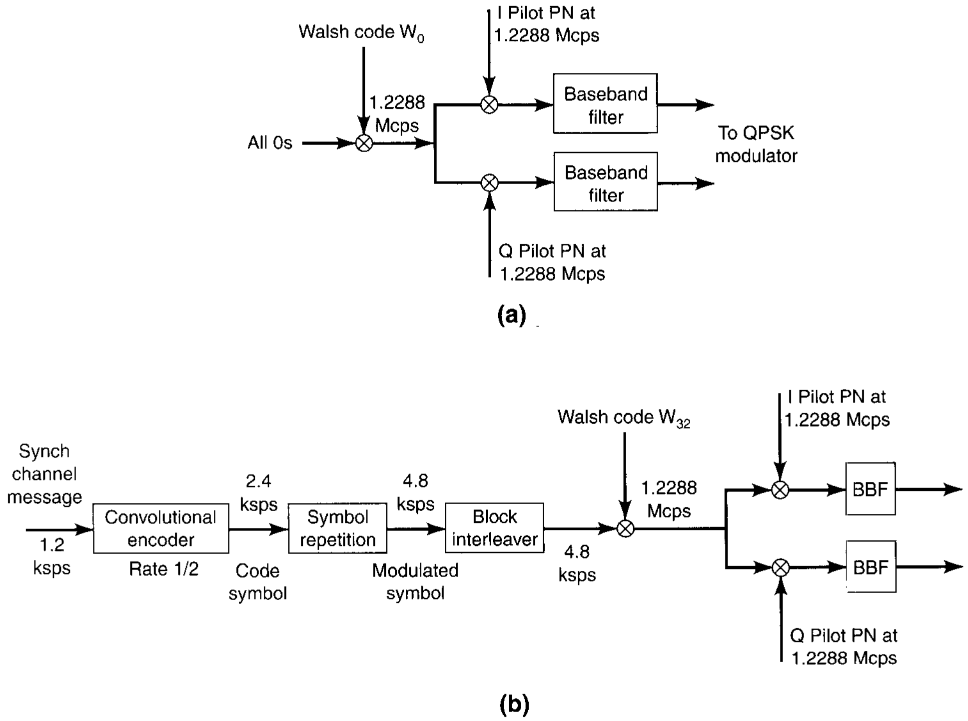
Various Walsh codes are used for spreading various logical channels in IS-95. The pilot channel employs the all zero Walsh code W_0. The synchronization channel is assigned the Walsh code W_{32} and so on. The assignment of Walsh codes is shown in Figure 8.4.

Example 8.4: The Pilot and Sync Channels

The way the pilot channel is created is shown in Figure 8.6(a). The pilot channel is intended to provide a reference signal for all MSs within a cell that provides the phase reference for coherent demodulation. It is about 4-6 dB stronger than all other channels. The pilot channel is used to lock onto all the other logical channels. It is also used for signal strength comparison. It uses the all zero Walsh code and contains no information except the RF carrier. It is also spread using the PN-spreading code to identify the BS. The way to identify the BS is to *offset* the PN sequence by some number of chips. In IS-95, the PN sequences are used with offsets of 64 chips that provide 512 possible spreading code offsets, providing for unique BS identification in dense microcellular areas as well.

The sync channel is used to acquire initial time synchronization and the way in which it is formed is shown in Figure 8.6(b). It uses the Walsh code W_{32} for spreading. Note that it uses the same PN spreading codes for scrambling as the pilot channel. The sync channel data operates at 1,200 bps. After a rate ½ convolutional encoding, the data rate is increased to 2,400 bps, repeated to 4,800 bps, and then block interleaving is employed. The synch message includes the system and network identification, the offset of the PN short code, the state of the PN-long code (see next section), and the paging channel data rate (4.8 or 9.6 kbps).

The paging channel, as in the case of GSM, is used to page the MS when there is an incoming call, and to carry the control messages for call setup. Figure 8.7 shows how a paging channel message is created. It employs Walsh codes 1 to 7 so that there may be up to seven paging channels. There is no power control for the pilot, synch, and paging channels. The paging channel is additionally scrambled by the PN long code as shown in Figure 8.7. The long code is generated using a paging



(a)

(b)

Figure 8.6 (a) Pilot and (b) sync channel processing in IS-95.

channel long code mask of length 42. This means that the PN long code is generated by an LFSR of length 42 and has a period of 2^{42} chips.

The traffic channels carry the actual user information (i.e., digitally encoded voice or data). The forward traffic channel has two possible *rate sets* called RS1 and RS2. RS1 supports data rates of 9.6, 4.8, 2.4, and 1.2 kbps. RS2 supports 14.4, 7.2, 3.6, and 1.8 kbps. RS1 has mandatory support for IS-95, and RS2 can be optionally supported. The way in which the symbols are processed for the two rate sets is shown in Figure 8.8 and 8.9, respectively. Walsh codes W_2 through W_{31} and W_{33}

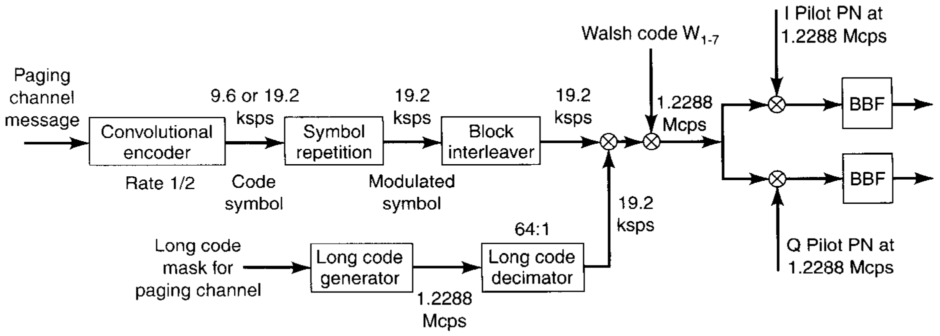


Figure 8.7 Paging channel processing in IS-95.

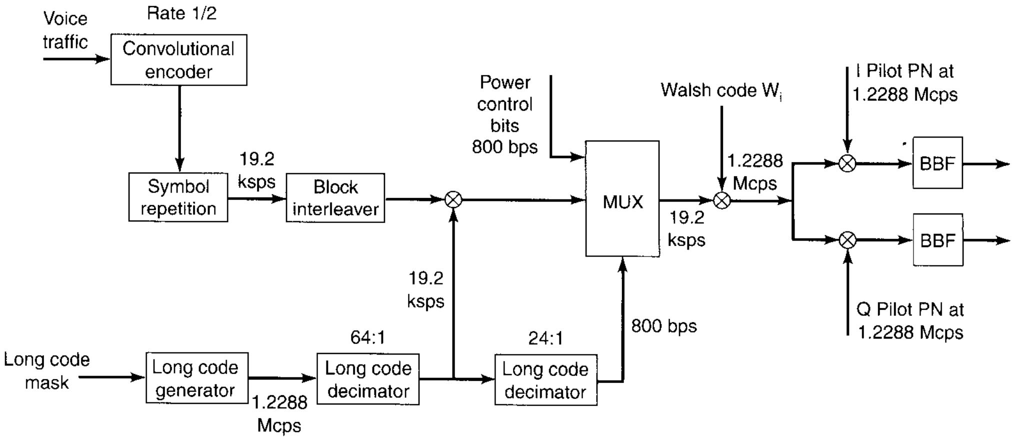


Figure 8.8 Forward traffic channel processing in IS-95 (rate set 1).

through W_{63} can be used to spread the traffic channels depending on how many paging channels are supported in the cell.

Example 8.5: Forward Traffic Channels

On the forward traffic channels, a rate ½ convolutional encoder is used that effectively doubles the data rate. In the case of RS1, symbol repetition is used to increase the data rate to 19.2 kbps. There is no repetition for 9.6 kbps-encoded voice and a repetition of four times for voice at 2.4 kbps. In the case of RS2, the rate at the output of the symbol repeater is 28.8 kbps that is *punctured* by selecting only four out of every six bits. This reduces the data rate to 19.2 kbps at the input of the block interleaver. The forward traffic channels are multiplexed with power control information for the reverse link as shown in Figures 8.8 and 8.9. Power control bits are multiplexed with the scrambled voice bits at 800 bps. Note

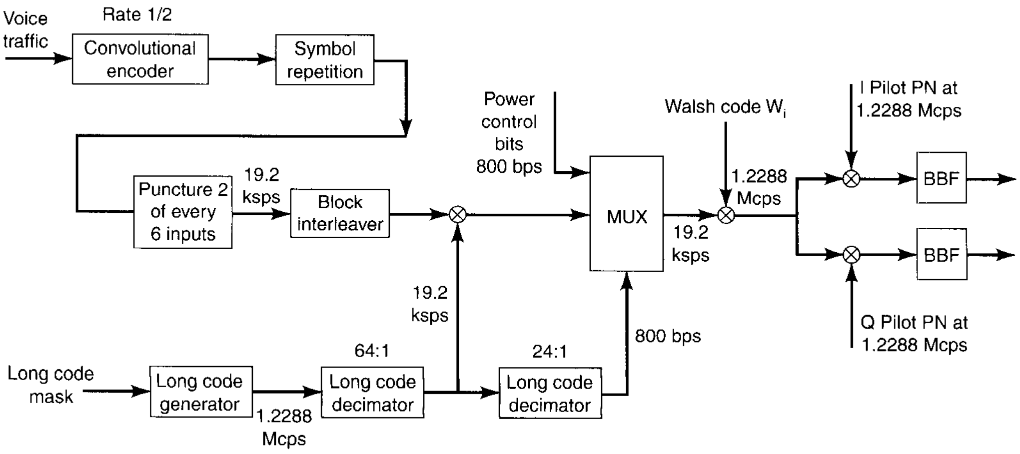


Figure 8.9 Forward traffic channel processing in IS-95 (rate set 2).

that the traffic channels are scrambled with both the PN long code and the PN short codes to further reduce interference among channels.

8.3.2 The IS-95 CDMA Reverse Channel

The CDMA reverse channel is fundamentally different from the forward channel. It employs OQPSK rather than QPSK used in the forward channel. The OQPSK is closer to a constant envelop modulation. As described in Chapter 5, constant envelop modulation techniques provide for a more power efficient implementation of the transmitter at the MS. The QPSK modulation is easier for demodulation again at the MS. The overall structure of the reverse channels in IS-95 is shown in Figure 8.10.

Compared with the forward channel, there is no spreading of the data symbols using orthogonal codes. Instead, the orthogonal codes are used for *waveform encoding*. This means that the reverse link employs an orthogonal modulation scheme that consumes bandwidth but reduces the error rate performance of the system.

Example 8.6: Waveform Encoding in IS-95

As a simple example of waveform encoding, consider the example of the Hadamard matrix H_8. There are eight orthogonal Walsh codes. We can perform a mapping between inputs of three bits to one of eight waveforms as shown in Figure 8.11. A different mapping scheme is employed in IS-95. Consider the Walsh codes of length 64. There are 64 such codes, and they are orthogonal to one another. If these codes are used as waveforms to represent a group of information bits, we can *encode* $\log_2 64 = 6$ bits using a Walsh code. For example, an input

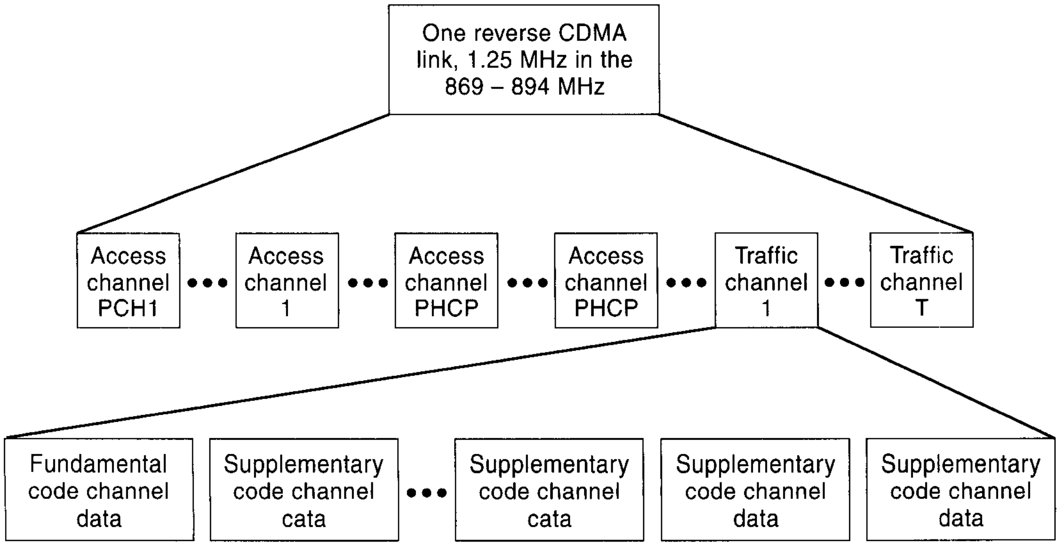


Figure 8.10 IS-95 reverse channels.

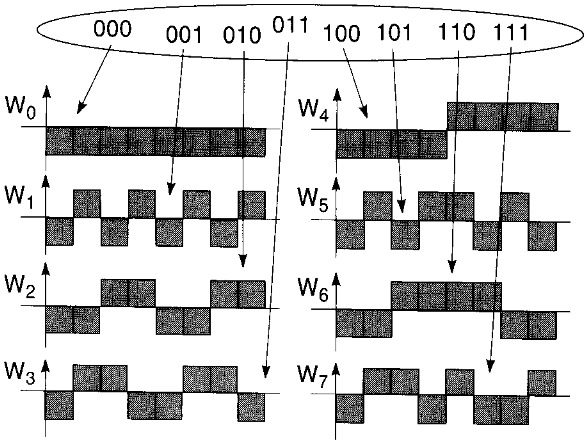


Figure 8.11 Mapping data bits to Walsh encoded symbols.

data stream 0 0 0 0 0 0 can be transmitted using the all zero Walsh code W_0. This is something like a 64-ary modulation scheme where there are 64 symbols or alphabets for transmission. Cross correlation at the receiver is employed to detect the alphabets. In IS-95, the Walsh code that is used for encoding is determined by the equation

$$i = c_0 + 2c_1 + 4c_2 + 8c_3 + 16c_4 + 32c_5$$

where c_5 is the most recent bit. For instance, if the input six bits are (1 1 1 0 1 0), the Walsh code selected is $i = 1 + 2 \times 1 + 4 \times 1 + 8 \times 0 + 16 \times 1 + 32 \times 0 = 23$, i.e., W_{23} is transmitted.

There are basically two types of reverse channels in IS-95—the access channels and the reverse traffic channels.

Example 8.7: The Access Channel in IS-95

The MS transmits control information such as call origination, response to a page, and so on to the BS via the access channels. The data rate over the access channels is fixed at 4,800 bps. It is sent through a rate 1/3 convolutional encoder that increases the data rate to 14.4 kbps. Symbol repetition is employed to increase the data rate to 28.8 kbps. Every six bits is now mapped into 64 bits using the 64-ary orthogonal modulator. The long PN code is used to distinguish between different access channels. It spreads each of the bits at the output of the 64-ary orthogonal modulator by a factor of four that yields a chip rate of 1.288 Mcps. Details are shown in Figure 8.12.

The reverse traffic channel, like the forward traffic channel, supports voice data at two rate sets—RS1 and RS2. In either case, as Figures 8.13 and 8.14 show the data burst after coding and interleaving, but just before the 64-ary orthogonal modulation is at a rate of 28.8 kbps. The output of the 64-ary orthogonal modulator is $28.8 \times 64 / 6 = 307.2$ kcps. After spreading by the long PN code by a factor of

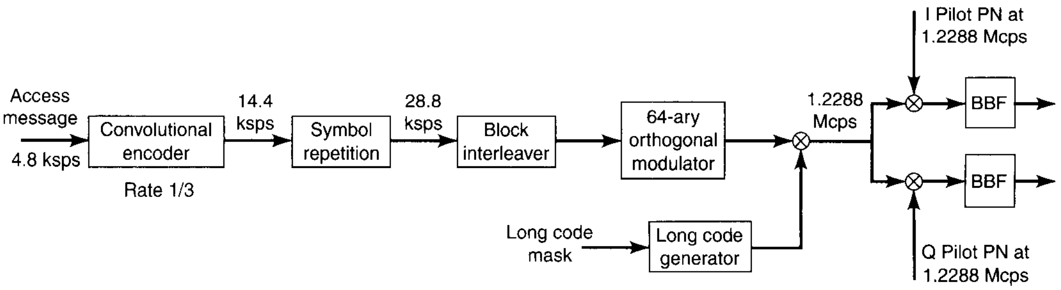


Figure 8.12 Access channel processing in IS-95.

four, the final chip rate is 307.2 × 4 = 1.2288 Mcps. A data randomizer is used in the fundamental code channel to mask out redundant data in case of symbol repetition. More about this is discussed in the section on power control. The reverse traffic channel sends information related to the signal strength of the pilot and frame error rate statistics to the BS. It is also used to transmit control information to the BS such as a handoff completion message and a parameter response message.

8.3.3 Packet and Frame Formats in IS-95

As discussed in the previous sections, the forward logical channels are of four types—the pilot, the synch, the paging and the traffic channels. The reverse channels are either access channels or traffic channels. The forward traffic channel carries user data (either data bits or encoded voice) at 9,600, 4,800, 2,400 or 1,200 bps in RS1 and 14,400, 7,200, 3,600, or 1,800 bps in RS2. The forward traffic channel frame is 20 ms long. Table 8.1 shows the number of information bits, frame error control check bits, and tail bits in each case.

The synch channel provides the MS information about the system identification (SID), the network ID (NID), PN short sequence offset, the PN long code state, and

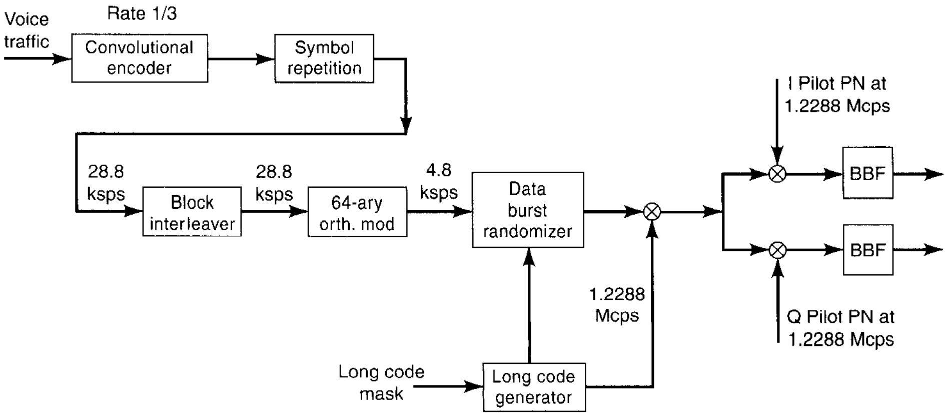


Figure 8.13 Reverse traffic channel processing for fundamental code channel in IS-95.

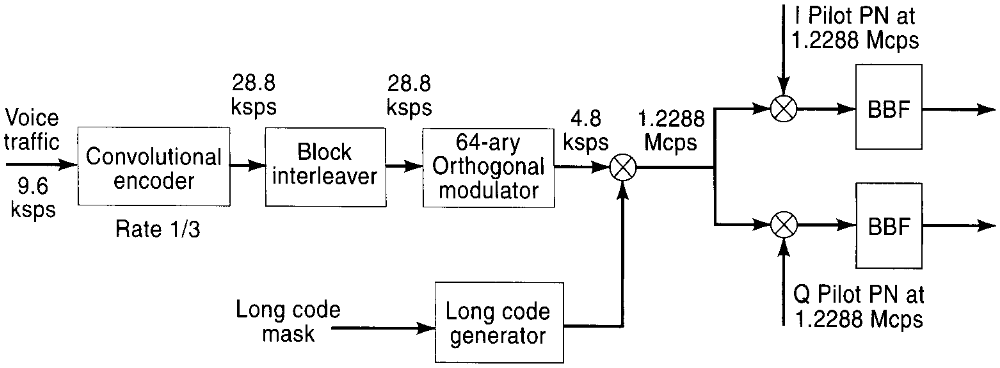


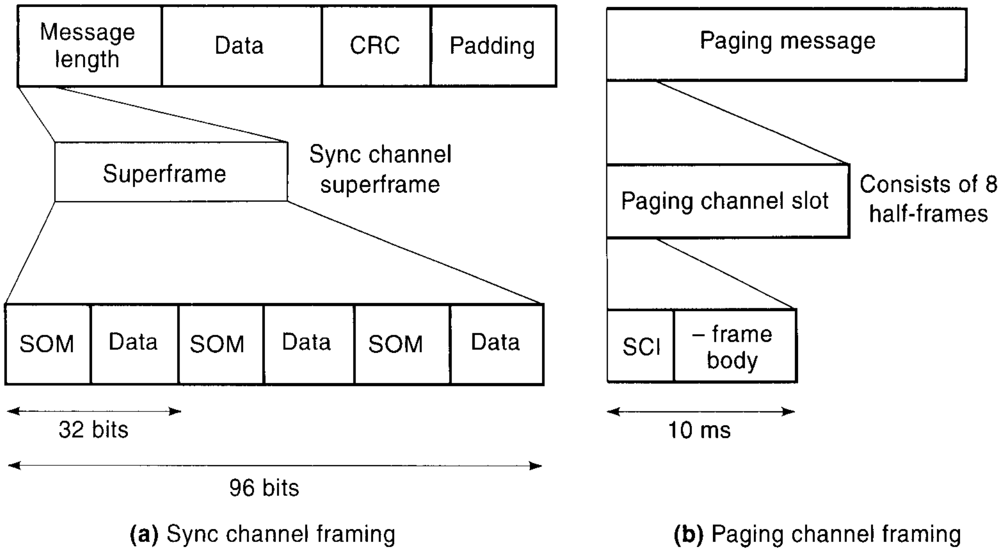
Figure 8.14 Reverse traffic channel processing for supplementary code channel in IS-95.

the system time among other things. Such *messages* can be long and are fragmented into *synch channel frames* of 32 bits shown in Figure 8.15(a). Three of the synch channel frames are combined into a synch channel superframe of 96 bits. The start of message (SOM) bit is 1 for the first synch channel frame and zero for subsequent ones that belong to the same message. The message itself (shown in the top part) consists of the message length, the data, an error checking code, and some padding. Padding with zeros is used to ensure that every new message starts in a new superframe.

The paging channel, shown in Figure 8.15(b) announces a number of parameters to the MS that includes the traffic channel information, the temporary mobile subscriber identity, response to access requests, and list of neighboring base stations and their parameters. Paging can be slotted or unslotted. In the former case, which enables the MS to save on battery power, the channel is divided into 80 ms slots. The paging channel message is similar in structure to the synch channel message (it has a message length, data, CRC, etc.). Because it is too long for transmission in one slot, it is fragmented into 47 or 95 bits (data rate of 4,800 or 9,600 bps) and transmitted over a paging channel *half-frame* (10 ms long). The half-frame has one bit called the synchronization capsule indicator (SCI) that has functionality similar to the SOM bit. In this case however, a message can start anywhere (not necessarily in a half-frame) and a zero value for the SCI could indicate that one paging message ends and another starts within the same half-frame. Eight paging half-frames are combined into one paging slot of 80 ms.

Table 8.1 Frame Contents for Forward Traffic Channels

Rate Set 1				Rate Set 2			
Data Rate	**Information Bits**	**CRC Bits**	**Tail Bits**	**Data Rate**	**Information Bits**	**CRC Bits**	**Tail & Reserved**
9,600 bps	172	12	8	14,400	267	12	9
4,800 bps	80	8	8	7,200	125	10	9
2,400 bps	40	0	8	3,600	55	8	9
1,200 bps	16	0	8	1,800	21	6	9



(a) Sync channel framing (b) Paging channel framing

Figure 8.15 Framing in IS-95 forward channels.

Example 8.8: Number of Bits in the Paging Channel Half-Frame and Slot

The number of bits depends upon the data rate. If the data rate is 9,600 bps, a 10 ms half-frame will carry 96 bits (one bit is the SCI) and 48 bits if the data rate is 4,800 bps. Consequently, a paging slot, that has 8 half-frames together, will contain $96 \times 8 = 768$ bits at 9,600 bps and $48 \times 8 = 784$ bits at 4,800 bps.

The access channel data rate is 4,800 bps and each access channel message (very similar in structure to a synch message) is composed of several access channel frames lasting 20 ms. Thus an access channel frame is 96 bits long. An *access channel preamble* always precedes an access channel message, and it consists of several 96-bit frames with all bits in the frame equal to zero. The actual message itself is fragmented into 96-bit frames that have 88 bits of data and 8 tail bits set to zero.

The reverse traffic channel is once again broken into 20 ms traffic channel frames. The frame is further divided into 1.25 ms *power control groups* (PCGs). There are thus 16 PCGs in one frame. A data burst randomizer randomly masks out individual PCGs depending on the data rate that results in less interference on the reverse channel. For instance, at 4.8 kbps (half the data rate), eight PCGs are masked. In addition to voice traffic, the traffic channel can also be used to transfer signaling or secondary data. In the *blank and burst* case, the entire frame carries data. In the *dim and burst* case, part of the frame carries voice and part of it data. The frame structures for the reverse traffic channel are very similar to that of the forward traffic channel.

8.3.4 Mobility and Radio Resource Management in IS-95

Of all the 2G cellular systems, the IS-95 standard is the most complex because of the use of spread spectrum that brings with it a set of advantages not available to TDMA-based systems. These include a frequency reuse factor of one, robust performance in the presence of interference and multipath, and the ability to increase capacity. Operation with a RAKE receiver is an important characteristic of CDMA. It provides inherent diversity in the presence of multipath fading to improve voice quality. The fingers of a RAKE receiver can select either a multipath signal or a signal from another base station if it is within the range of the MS. This ability is employed in IS-95 to perform what are known as *soft handoffs,* which improve voice quality during handoff. Mobility management outside of soft-handoff is based on the general mobility management procedures discussed in Chapter 6. In the case of CDMA specific messages are additionally included.

Using spread spectrum has a disadvantage in that the near-far effect becomes predominant and in order to prevent the signal from one user overwhelming that of another user, strict power control has to be implemented. The advantage of implementing strict power control is that the MS can operate at the minimum *required* E_b/N_t for adequate performance. This increases battery life and reduces the size and weight of the mobile terminal.

8.3.4.1 Soft Handoff

Soft handoff refers to the process by which an MS is in communication with multiple candidate BSs before finally deciding to communicate its traffic through one of them. The reason for implementing soft handoff has its basis in the near-far problem and the associated power control mechanism. If an MS moves far away from a BS and continues to increase its transmit power to compensate for the near-far problem, it will very likely end up in an unstable situation. It will also cause a lot of interference to MSs in neighboring cells. To avoid this situation and ensure that an MS is connected to the BS with the largest RSS, a soft handoff strategy is implemented. An MS will continuously track all BSs nearby and communicate with multiple BSs for a short while if necessary before deciding which BS to select as its point of attachment.

In the IS-95 standard, three types of soft handoffs are defined that are depicted in Figure 8.16. In the *softer* handoff case shown in Figure 8.16(a), the handoff is between two sectors of the same cell. In the *soft* handoff case of Figure 8.16(b), the handoff is between two sectors of different cells. In the *soft-softer* handoff case, illustrated in Figure 8.16(c), the candidates for handoff include two sectors from the same cell and a third sector from a different cell. In all cases, the handoff decision mechanism is more or less the same. Whether the connection in the infrastructure needs to be torn down and set up again depends on the sectors involved in the final handoff.

The soft handoff procedure involves several base stations. A controlling primary BS coordinates the addition or deletion of other base stations to the call during soft handoff. The primary BS uses a handoff direction message (HDM) to indicate the pilot channels to be used or removed as part of the soft handoff process. At some point of time, the primary BS is also changed after handoff. The signals from multiple BSs are combined in the BSC or MSC and processed as a single call. This process is achieved using a *frame selector join* message. Figure 8.17 shows the setup and ending of handoff in a two-way soft handoff. The MS detects a pilot signal from a new BS and informs the primary BS. After a traffic channel is

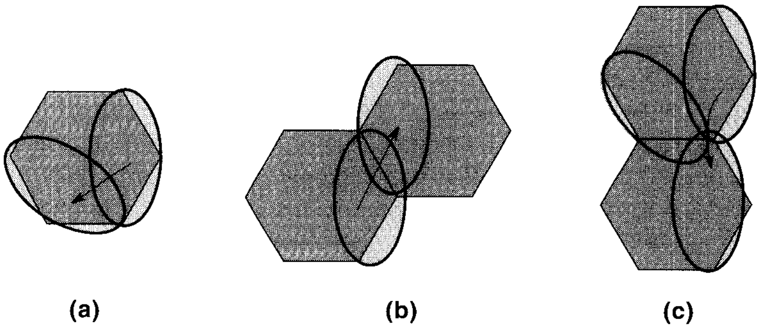


Figure 8.16 (a) Softer, (b) soft, and (c) soft-softer handoff.

set up with the new BS, the frame selector join message is used to select signal from both BSs at the BSC/MSC. After a while, the pilot signal from the old BS starts falling, and the MS will request its removal, which is achieved via a *frame selector remove* message.

The pilot channels of each cell are involved in the handoff mechanism. The reason behind this is that this is the only channel not subject to power control and provides a measure of the RSS. The MS maintains a list of pilot channels that it can hear and classifies them into the following four categories. The *active set* consists of pilots that are being continuously monitored or used by the MS. The MS has three RAKE fingers in IS-95 that allows it to monitor or use up to three pilots. The active set pilot

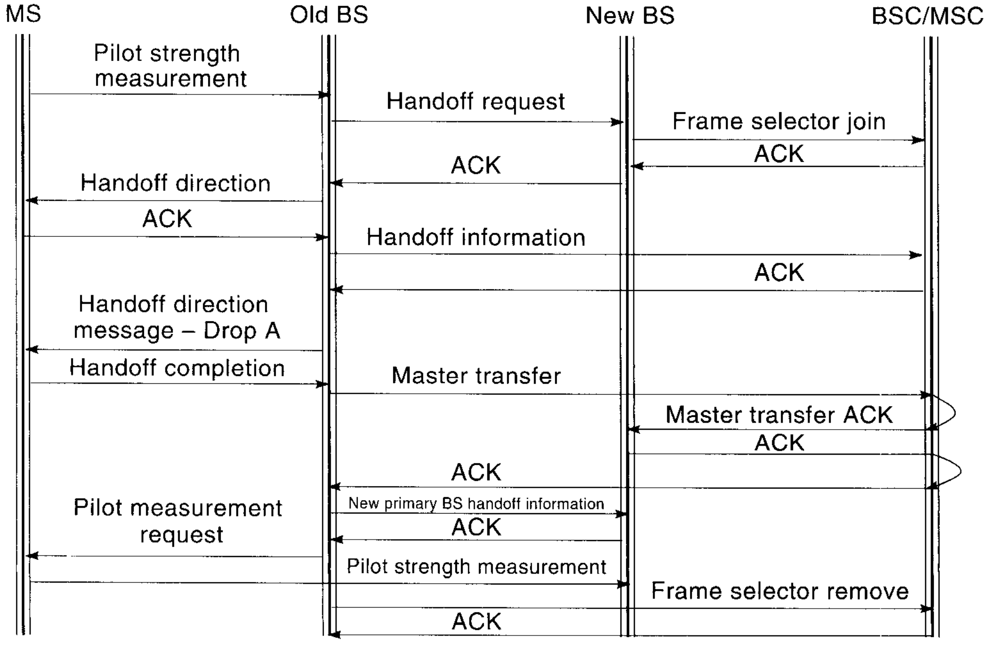


Figure 8.17 Setup and ending of soft handoff.

channels are indicated in the HDM on the downlink by the BS. The *candidate set* can have at most six pilots, and these refer to pilots that are not in the active set but that have sufficient RSS to be demodulated and used in demodulating the associated traffic channels. The *neighbor set* contains pilots that belong to neighboring cells and are intimated to the MS by a system parameters message on the paging channel. The *remaining set* contains all other possible pilots in the system. Because the receiver uses a RAKE to capture multipath components, it employs *search windows* to track each of the sets of pilot channels. The search windows are large enough to capture all the multipath components of the pilot from a BS but small enough to minimize searching time. The multipath delays are a function of the distance between the MS and the BS, and, consequently, the search windows are also affected.

Several thresholds are used in the soft handoff procedure. These are similar to the RSS thresholds discussed in Chapter 6. Details are available in [GAR00]. Whenever the strength in a pilot falls below a threshold, the MS starts a dwell timer. Unless the pilot strength goes back above the threshold before the timer expires, the MS will drop it from a given set. There is a trade-off in setting high or low values for these thresholds and timers.

Example 8.9: Pilot Detection Threshold in IS-95

The MS maintains a list of pilots that are being used in the active set. Initially the MS is connected to one BS and only its pilot and the multipath components of the pilot are in the active set (and indicated by the HDM). As the MS moves away, the pilot of the adjacent cell becomes stronger. If its strength is above the *pilot detection threshold* (T_ADD), this pilot must be added to the active set and the MS enters a soft handoff region. If the pilot detection threshold is too small, there may be false alarms caused by noise or interfering signals. If the pilot detection threshold is too large, useful pilots are not detected, and the call may be dropped. Thus a trade-off is required in the value of this threshold.

Example 8.10: Using Various Thresholds in Soft Handoffs

Figure 8.18 shows an example (from [GAR00]) of how the handoff thresholds work. As soon as the strength of the pilot exceeds T_ADD, it is transferred to the candidate set (1), and the MS sends the pilot strength measurement to the BS that is transmitting the pilot. The BS sends a handoff direction message to the MS (2) at which time the pilot is transferred to the active set. The MS acquires a traffic channel and sends a handoff completion message (3). After the pilot strength drops below T_DROP, the handoff drop timer is started. If the strength is still below T_DROP after the timer expires, the MS sends another pilot strength measurement to the BS associated with the pilot (5). When it receives the corresponding HDM without the pilot in it, the MS moves the pilot to the neighbor set (6) and sends a handoff completion message (7). At some point, the BS may send it a neighbor update list message that no longer contains the pilot and it is moved into the remaining set (8).

All signal strength measurements are based on the pilot channel. The handoff is also a mobile assisted handoff because the MS reports the signal strength mea-

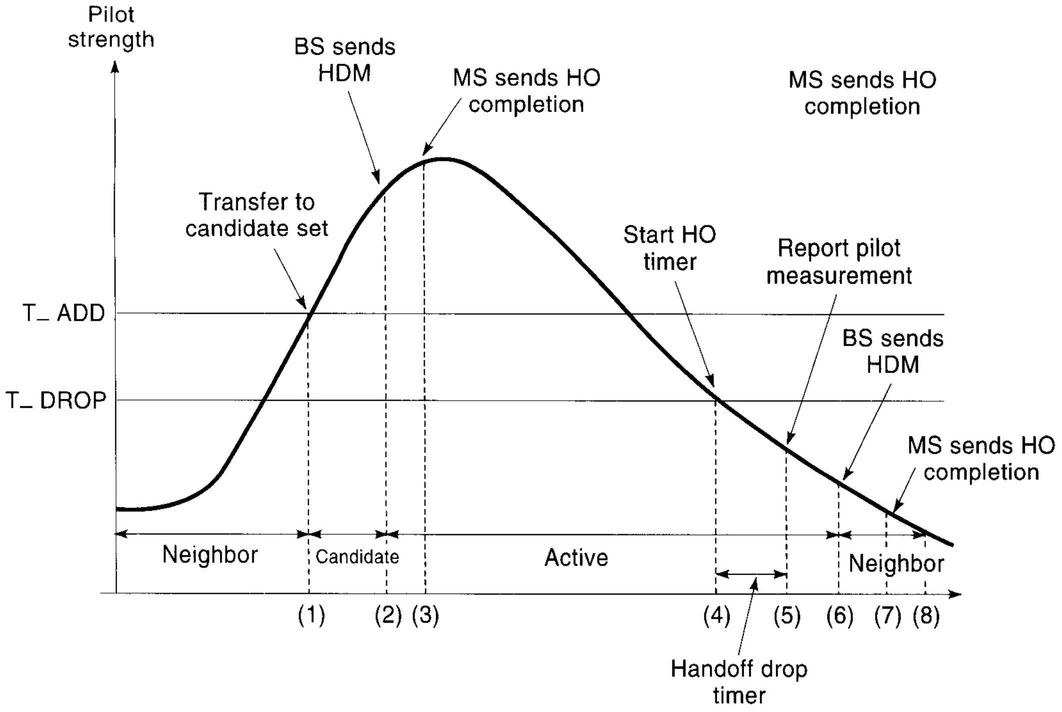


Figure 8.18 Handoff thresholds in IS-95.

surements to the network. The handoff thresholds may be adjusted dynamically to provide improvement in system performance.

8.3.4.2 Power Control

Like all cellular telephony systems, CDMA is also interference limited. However, co-channel and adjacent channel interference are not the major problems here. Instead the interference is from other users transmitting in the same frequency band at the same time. In order to avoid the near-far effect, it is important to implement good power control. Also, in order to maintain a good link quality, effects such as fading and shadowing need to be countered by increasing the transmit power. In the case of CDMA, an important factor is that the signal strength may be good, but frames are still received in error because of interference. Consequently, using the frame error rate (FER) for power control decisions is preferred over using the signal strength used in other systems. It is usually assumed that a FER of 1 percent with maximum error bursts of two frames is optimum and a range of 0.2 percent to 3 percent is allowed, with error bursts of up to four frames.

In IS-95, power control is very important especially on the reverse link where non-coherent detection is employed. Two types of power control are implemented—an open loop and a closed loop as discussed in Chapter 6. A slow mobile assisted power control is employed on the forward link.

Example 8.11: Open Loop Reverse Link Power Control in IS-95

Before a traffic channel is assigned, there is no closed loop power control in CDMA because the closed loop power control involves feedback from the BS that is delivered on the traffic channel 800 times per second. For this reason and in order to prevent the sudden fall of signal strength, an open loop power control scheme is implemented. The rule here is to use a transmit power that is inversely proportional to the received signal strength of pilots from all BSs. On the access channel, the MS sends a request using a weak signal if the pilot is strong. An acknowledgment may not be received because of collisions or because the transmit power was low. If no acknowledgement is received, a stronger access probe is transmitted. This is continued a few times, and then the attempt is stopped after a maximum power level is reached. Then the process is repeated after a back-off delay. Up to 15 attempts can be made to obtain a traffic channel. The disadvantages of the open loop power control are the assumption that the forward and reverse link characteristics are identical, slow response times (30 ms), and using the total power received from all BSs in calculating the required transmit power.

Example 8.12: Closed Loop Reverse Link Power Control in IS-95

On the downlink traffic channel, a power control bit is transmitted every 1.25 ms (800 times per second) as shown in Figure 8.19. A zero bit indicates that the MS should increase its transmit power and a 1 that the MS should decrease its transmit power. Every 1.25 ms, in the BS, the receiver determines the received E_b/I_t (the signal to interference ratio) by sampling it 16 times, and if it is above a preset target, the MS is instructed to reduce its power by 1 dB. If it is not above the target, the MS is instructed to increase its power by 1 dB. This is called the *inner-loop power control*

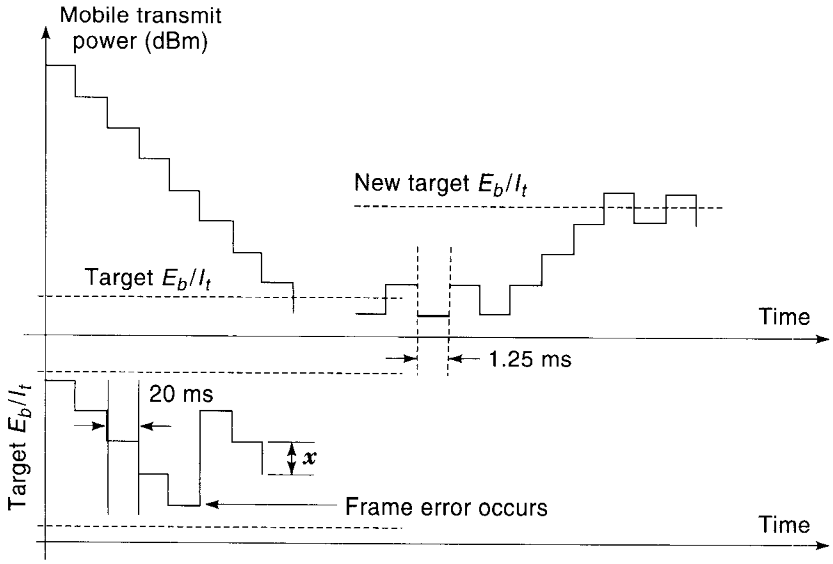


Figure 8.19 Inner- and outer-loop closed loop power control on the reverse link in IS-95.

as it enables changing the transmit power value in the MS. The target value in the base station controls the long-term frame error rate. The FER is not linearly dependent on the E_b/I_t, but is also a function of the velocity, fading, environment, and so on. The target E_b/I_t is also varied over time to reflect accurate values. It is reduced by a value of x dB every 20 ms if the FER is small enough. Typically, the value of $100x$ is 3 dB. The target value may be rapidly increased if the FER starts to increase. This mechanism to change the target E_b/I_t is called *the outer-loop power control.*

Example 8.13: Forward Link Power Control

Power control on the forward link is employed to reduce intercell interference. Within a cell, multiple users employ orthogonal sequences, and the primary source of interference is from users of other cells or from multipath. A *mobile assisted* power control is used. The MS periodically reports the FER on the forward link to the BS station, which will then adjust its transmit power accordingly. Maximum and minimum transmit power values are preset to prevent excessive interference and to avoid allowing voice quality to drop respectively.

8.4 IMT-2000

The ITU is on an accelerated pace to specify the 3G mobile communications standards. The primary standard for 3G systems is referred to as the International Mobile Telecommunications beyond the year 2000 (IMT-2000)—the goal of which is to support higher data rates that can support multimedia applications, provide a high spectral efficiency, make as many of the interfaces standard as possible, and provide compatibility to services within the IMT-2000 [ZEN00]. Although voice traffic will continue to be the main source of revenue, packet data for Internet access, advanced messaging services such as multimedia email, and real-time multimedia for applications such as telemedicine and remote security are envisaged in IMT-2000. The requirements for IMT-2000 include improved voice quality (wireline quality), data rates up to 384 kbps everywhere and 2 Mbps indoor, support for packet and circuit switched data services, seamless incorporation of existing 2G and satellite systems, seamless international roaming, and support for several simultaneous multimedia connections.

In the late 1980s, ITU formed a group to study wireless standards for very high-speed data and multimedia services. In 1992, the world administrative radio conference (WARC) assigned 230 MHz of spectrum globally for IMT-2000. In June 1998, 15 proposals were received by ITU-R (the radio communications sector of ITU) for candidate radio transmission technologies (RTTs). Most of the proposals were based on CDMA as CDMA provides a better voice quality and is more flexible for customized multimedia applications. In order to avoid multiple standards, efforts were made to harmonize a single converged global standard. Backward compatibility with legacy systems is also a major issue with support for the GSM-MAP and ANSI-41 (the core GSM and IS-41 backbone infrastructures) essential. Both of these core networks are supposed to evolve towards a common 3G-core network that will be very likely all IP.

As far as the RTTs are concerned, there were two major competing proposals—the W-CDMA based on the UMTS Terrestrial Radio Access (UTRA) FDD and TDD proposals and the CDMA2000 proposal that is backward compatible with IS-95. The main differences can be summarized as follows [ZEN00].

1. Although CDMA2000 proposes multiples of 1.2288 Mcps chip rates to allow greater compatibility with IS-95 (in particular, 3.6864 Mcps is suggested), W-CDMA employs 3.84 Mcps.
2. In IS-95 and CDMA2000, the BSs operate synchronously by obtaining timing from GPS. W-CDMA advocates asynchronous operation to enable deploying picocells within buildings where GPS is not available.
3. The frame length of W-CDMA is 10 ms to ensure small end-to-end delays, though it is 20 ms in CDMA2000.

The harmonization activities were initiated via a 3GPP that consisted of members from industry and standards bodies to work on the core network, the radio access network, service and system aspects, and the mobile terminal. To include non-GSM technologies, a 3GPP2 was initiated in parallel by ANSI to prepare technical specifications for a 3G mobile system based on CDMA2000 and the IS-41 based core network. Both 3GPP and 3GPP2 are expected to cooperate in harmonization and consolidation. Meanwhile, an operators harmonization group (OHG) set up at the end of 1998 agreed on a further harmonized Global 3G (G3G) standard (Figure 8.20) that has the following components:

1. Three air-interface standards—two frequency division duplex modes: a direct sequence (DS) mode based on W-CDMA at 3.84 Mcps chip rate, a multicarrier (MC) mode based on CDMA2000 with a chip rate of 3.6864 Mcps, and one time division duplex mode operating at 3.84 Mcps

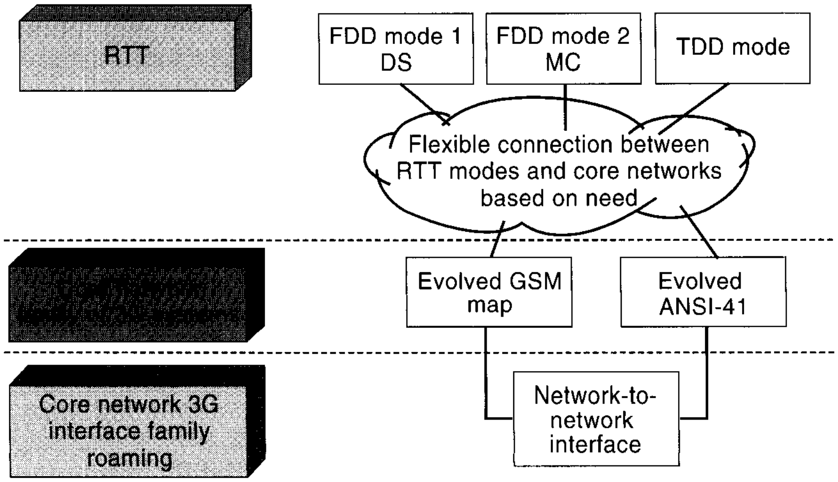


Figure 8.20 The G3G proposal.

2. Support for both GSM-MAP and ANSI-41 with all air-interface modes
3. Support for functionality based synchronous operation
4. Seamless handoff between DS and MC modes, as well as interoperability of sorts between the UMTS core network and ANSI-41

The idea is also to minimize the complexity of multimode terminals that include all of the standards. Table 8.2 describes the characteristics of the two air-interfaces [ZEN00], [HOL00].

8.4.1 Forward Channels in WCDMA and CDMA2000

The primary requirements of 3G systems are that they should be able to support a variety of application data rates (from 384 kbps circuit switched connections to 2 Mbps in indoor areas) and operation environments. This means that there must be support for quality of service and operation from megacells to picocells. The

Table 8.2 The Major 3G RTT Proposals

	3GPP	**3GPP2**
Parameters	**UTRA DS-FDD/TDD**	**CDMA2000**
Multiple access	DS-CDMA	Uplink: DS-CDMA Downlink: MC-CDMA/DS-CDMA
Chip rate	3.84 Mcps	N × 1.2288 Mcps N = 1,3,6,9,12
Pilot structure	Dedicated pilots on the uplink and common or dedicated pilots on the downlink	Uplink: Code-divided continuous dedicated pilot Downlink: Code-divided continuous common pilot and dedicated or common auxiliary pilots
Frame length	10 ms with 15 slots	5, 10, 20, 40, 80 ms
Modulation	Uplink: Dual channel QPSK Downlink: QPSK	Uplink: BPSK; Downlink: QPSK
Spreading modulation	QPSK both directions	Uplink: HPSK Downlink: QPSK
Detection	Coherent pilot aided	Coherent pilot aided
Channelization codes	OVSF codes	Uplink: Walsh codes Downlink: Walsh or quasi-orthogonal codes
Scrambling codes	Uplink: Short code (256 chips from S[2]) or long code (38,400 chips Gold code) Downlink: Gold code	Long code ($2^{42}-1$ chips) Short code ($2^{15}-1$ chips)
Access schemes	Random access with power ramping with acquisition indication	RsMa—Flexible • Basic access • Power controlled access • Reserved access • Designated access (initiated by BS)
Inter-base station operation	Asynchronous Synchronous (optional)	Synchronous

forward channels are referred to as *transport channels* in the UTRA W-CDMA standard proposed by 3GPP. The forward channel modifications are as follows.

In W-CDMA, the BSs can operate in a asynchronous fashion that obviates the need of GPS availability to synchronize base stations. W-CDMA employs what is known as the orthogonal variable spreading factor (OVSF) codes. OVSF codes allow a variable spreading factor technique that maintains orthogonality between spreading codes of different lengths. The logical channels are called *transport channels* in W-CDMA.

cdma2000 employs multiple carriers to provide a higher data rate compared with W-CDMA. It employs N carriers ($N = 1, 3, 6, 9$) for an overall chip rate of $N \times 1.2288$ which is 3.6864 Mcps for $N = 3$. Alternatively, a single carrier can be employed to chip at the larger chipping rate. The former mode of operation is suitable for overlaying cdma2000 over existing IS-95 systems. Walsh codes from 128 chips to 4 chips are employed to provide variable spreading and processing gains. All N carriers use the same single code for scrambling. The BSs still need to be synchronized and use the PN-code offsets for differentiation as before. Pilot channels are used for fast acquisition and handoff as before. QPSK modulation is employed before spreading with the Walsh codes to increase the number of usable Walsh codes. In addition to the pilot, synch, and paging channels, auxiliary pilot channels can be used to supply beam-forming information if smart antennas are employed. A dedicated MAC channel (DMCH) may be available for sending MAC layer messages to specific mobiles. To support QoS at different rates, a fundamental channel (FCH) for signaling and a supplemental channel (SCH) for traffic can be made available. Turbo codes are employed on the forward supplemental channels for high data rates.

8.4.2 Reverse Channels in W-CDMA and cdma2000

Support for variable data rates and operation in a variety of environments once again governs the implementation of the reverse link for 3G systems. In W-CDMA, Gold codes and S(2) codes are used for scrambling on the uplink. The periodicity of the Gold code is 38,400 chips for using a RAKE receiver in the BS and that of the S(2) codes is 256 chips for employing multiuser detection.

In cdma2000, the reverse link is made more symmetrical with the forward link in many aspects. For instance, a *reverse pilot channel* is employed between each mobile and the BS for initial acquisition, time tracking, and power control measurement. More powerful codes are used such as a rate ¼ convolutional code with a constraint length of 9. Turbocodes are employed on the reverse supplementary channels. Variable rate spreading is supported to enable better error correction capability and a variety of data rates.

8.4.3 Handoff and Power Control in 3G Systems

cdma2000 is very similar to IS-95 in terms of power control and handoff procedures. In W-CDMA, a fast power control scheme is used at 1,500 bps as compared with 800 bps with IS-95 and cdma2000. In W-CDMA, the handoff procedure is somewhat different. Once again, different sets of pilots are maintained, and the active set corresponds to the pilot channels being used for completing the call. Relative threshold values are employed instead of absolute values as in IS-95 (i.e., the pilot strengths are compared with each other instead of T_ADD and T_DROP values that need tuning depending on the environment in IS-95). The working of the algorithm is illustrated by the following example from [HOL00].

Example 8.13: Soft Handoff in W-CDMA

Figure 8.21 shows an example of soft handoff in W-CDMA. The events indicated along the abscissa correspond to adding a pilot to the active set if the active set is not full or removing a pilot from the active set. At event 1A, a pilot is added to the active set because its strength is greater than the strength of the best pilot minus a reporting range plus a hysteresis margin for more than a time ΔT. A pilot is removed from the active set (event 1B) if its strength is below that of the best pilot by the sum of a reporting range and a hysteresis margin for a time greater than ΔT. Event 1C corresponds to a combined addition and deletion of pilots. This happens when the active set is full and the worst pilot in the set is smaller than the best pilot minus a hysteresis margin for a time ΔT. In this case, the worst pilot is deleted, and the best candidate pilot is added to the active set. The reporting range is a threshold for soft handoff.

It should be noted that when the signal strength comparisons are made, averaged values are used and not instantaneous samples.

In WCDMA, closed loop power control is implemented in a manner similar to IS-95 with the power control bits transmitted 1,500 times a second. This allows a very fast control of power and provides significant capacity gains in W-CDMA, especially at pedestrian speeds. Both inner and outer loop power control mechanisms

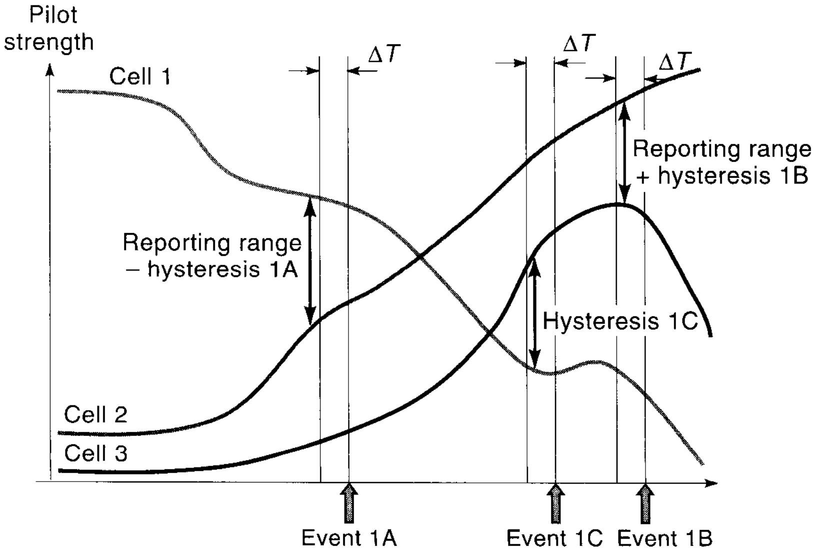


Figure 8.21 Handoff thresholds in W-CDMA.

are employed. The interested reader is referred to [HUB00], [DAHL98], [SWE00], [3GPPweb], [3GPP2web] and [GAR02] for details of 3G systems.

QUESTIONS

8.1 What is IS-634? What are its functionalities?

8.2 What is IS-41? Why is it important in North American cellular systems?

8.3 What is IS-95?

8.4 What is TR-45?

8.5 What are the bandwidths and chip rates used in WCDMA and how they compare with cdmaOne?

8.6 How many physical channels are available in each IS-95 carrier? What type of coding separates these channels from one another?

8.7 Name the forward and reverse channels used in IS-95.

8.8 How are Walsh codes employed in the cdmaOne forward and reverse channels? Explain the difference.

8.9 Why does WCDMA use Walsh codes in forward and reverse channels for separating users, while cdmaOne uses them only in the forward channel?

8.10 What are the bit rates of the data services supported by IS-95?

8.11 What is soft handoff and how does it compare with hard and seamless handoffs? Give one example system for each of these three handoff methods.

8.12 Why is power control important in CDMA?

8.13 What forward channels are involved in IS-95 for power control?

8.14 Handoff decisions in wireless networks are performed using received signal strength measurements. Name the forward channel in IS-95 that is used for this purpose.

8.15 Why are several pilot channels monitored in IS-95? When does a pilot channel from a base station move from an active set to a candidate set?

PROBLEMS

8.1 **a.** Sketch all four of the 4-bit Walsh codes.

b. Sketch the autocorrelation function of all four codes.

c. Sketch the cross-correlation function of the first and the second code.

8.2 Repeat Problem 8.1 for 16-bit Walsh codes.

8.3 The M-sequence is a class of spread spectrum sequences used in IS-95 CDMA systems. Compute the autocorrelation of an M-sequence, which is given by the following vector. Assume that the chip duration is T_c and the duration of the M-sequence "pulse" is T. The M-sequence is: $[1\ -1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ 1]$. You can use the `xcorr` function in Matlab to verify your results.

8.4 **a.** Using Table 3A.1, calculate required γ_b for the BER of 10^{-3} for the QPSK modulation used in IS-95. (*Hint:* you can use the Matlab function `erfc` for calculation of the complementary error function.)

b. Use Eq. (4.4) with γ_b (the same as S_r) determined in part (a) to calculate the number of simultaneous users, M, in a cell operating in one sector of a 3-sector antenna with one IS-95 carrier. Assume a data transmission rate of $R = 9{,}600$ bps and a performance improvement factor of $K = 4$ (6 dB).

c. Repeat parts (a) and (b) for different values of BER between 10^{-2} and 10^{-12} to produce a computer plot of BER in logarithmic scale vs. number of users, M, in linear scale. Using this curve, explain the effects of error rate requirement on the capacity of a CDMA system.

d. Repeat the plot in part (c) for a normalized number of users per MHz of band. If we change the system to an IMT-2000 system, does this plot or the plot in part (c) change? Explain why.

8.5 **a.** Assume we want to support a 19.2 kbps data service with minimum required error rate of 10^{-3} over a W-CDMA system. What is the minimum chip rate and bandwidth needed to support 100 simultaneous users with one carrier of this W-CDMA system? Assume a performance improvement factor of $K = 4$ (6 dB) using Table 3A.1 and Eq. (4.4).

b. What would be the bandwidth requirement in (a) if number of users was increased to 200?

c. What would be the bandwidth requirement in (a) if the data rate requirement were increased to 192 kbps?

d. What would be the bandwidth requirement in (a) if the error rate requirement were increased to 10^{-4}?