5

Link Structure

5.1 Asymmetric Links

The IS-95 CDMA system is unique in that its forward and reverse links have different link structures. This is necessary to accommodate the requirements of a land-mobile communication system. The forward link consists of four types of logical channels: pilot, sync, paging, and traffic channels. There is one pilot channel, one sync channel, up to seven paging channels, and several traffic channels. Each of these forward-link channels is first spread orthogonally by its Walsh function, then it is spread by a quadrature pair of short PN sequences. All channels are added together to form the composite SS signal to be transmitted on the forward link.

The reverse link consists of two types of logical channels: access and traffic channels. Each of these reverse-link channels is spread orthogonally by a unique long PN sequence; hence, each channel is identified using the distinct long PN code. The reason that a pilot channel is not used on the reverse link is that it is impractical for each mobile to broadcast its own pilot sequence.

5.2 Forward Link

In Section 3.5.1, we defined the structure of a Hadamard matrix and described how Walsh codes are generated using such a matrix. The IS-95 CDMA system uses a 64 by 64 Hadamard matrix to generate 64 Walsh functions that are orthogonal to each other, and each of the logic channels on the forward link is identified by its assigned Walsh function.

5.2.1 Pilot Channel

The pilot channel is identified by the Walsh function 0 (w_0). The channel itself contains no baseband information. The baseband sequence is a stream of 0s that are spread by Walsh function 0, which is also a sequence of all 0s. The resulting sequence (still all 0s) is then spread, or multiplied, by a pair of quadrature PN sequences. Therefore, the pilot channel is effectively the PN sequence itself (see Figure 5.1). The PN sequence with a specified offset uniquely identifies the particular sector that is transmitting the pilot signal. Note that both Walsh function 0 and the PN sequence are running at a rate of 1.2288 Mcps. After PN spreading, baseband filters are used to shape the digital pulses. These filters effectively lowpass filter the digital pulse stream and control the baseband spectrum of the signal. This way, the signal bandwidth may have a sharper roll-off near the band edge.

The pilot channel is transmitted continuously by the base station sector. The pilot channel provides the mobile with timing and phase reference. The mobile's measurement of the signal-to-noise ratio (i.e., E_c/I_0) of the pilot channel also gives an indication of which is the strongest serving sector of that mobile.

5.2.2 Sync Channel

Unlike the pilot channel, the sync channel carries baseband information. The information is contained in the *sync channel message* that notifies the mobile

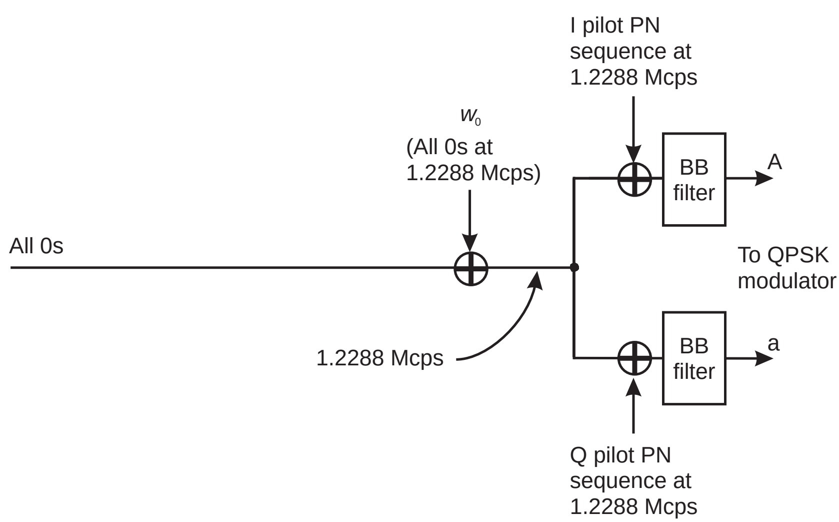

Figure 5.1 Pilot channel. After [1].

of important information about system synchronization and parameters. Figure 5.2 shows that the baseband information is error protected and interleaved. It is then spread by Walsh function 32 and further spread by the PN sequence that is identified with the serving sector. The baseband information is at a rate of 1.2 Kbps.

At the bit level, the sync channel is transmitted in groups of *sync channel superframes*; each superframe contains 96 bits and lasts 90 ms, yielding a data rate of (96 bits/90 ms) = 1,200 bps. Each superframe contains three s*ync channel frames* of equal length and duration (see Figure 5.3). Each sync channel frame is aligned with the short PN sequence associated with the transmitting sector. Note that the short PN sequence repeats every 26.67 ms, and *each period of the short PN sequence is synchronized with each sync channel frame.* Therefore, once the mobile acquires synchronization with the pilot channel, the alignment for the sync channel is immediately known. This is because the sync channel is spread with the same pilot PN sequence, and because the frame timing of the sync channel is aligned with that of the pilot PN sequence [1]. Once the mobile achieves alignment with the sync channel, the mobile can start reading the *sync channel message.*

The *sync channel message* itself is long and may occupy more than one sync channel frame. Therefore, the *sync channel message* is organized in a structure called the *sync channel message capsule.* A sync channel message capsule consists of the *sync channel message* and *padding.* The sync channel message resides in more than one sync channel frame, and padding (of bits) is used to fill up the bit positions all the way up to the beginning of the next sync channel superframe, where the next *sync channel message* starts.

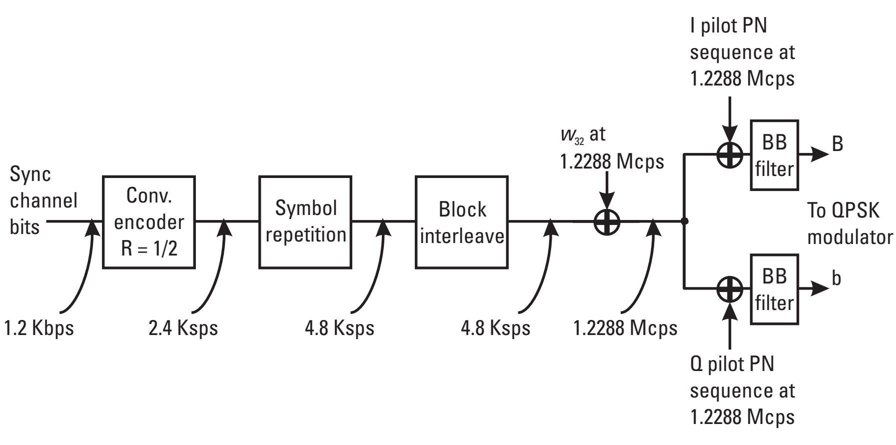

Figure 5.2 Sync channel. After [1].

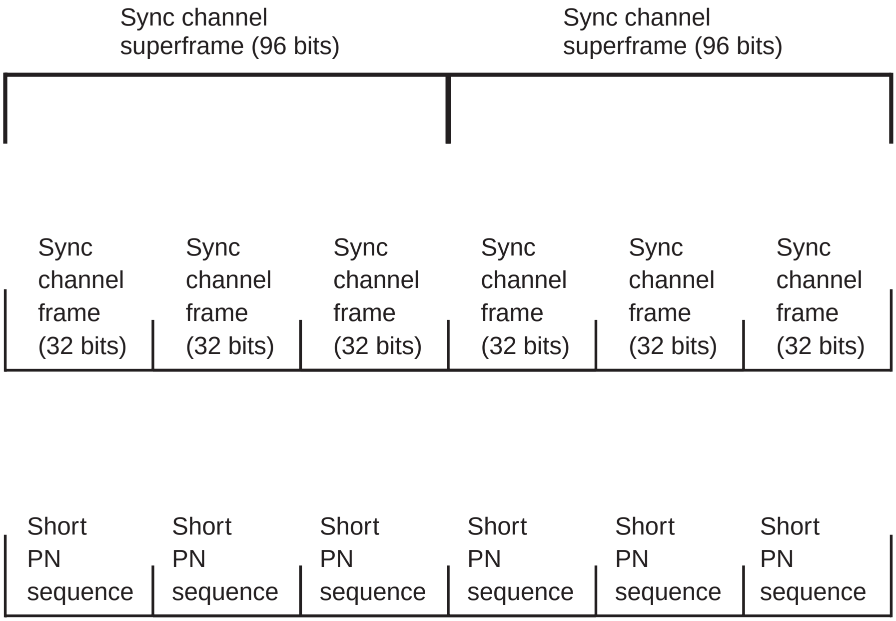

Figure 5.3 Sync channel frame structure.

Each sync channel frame begins with the *start-of-message* (SOM) bit. The SOM bit is the first bit of the sync channel frame; an SOM of 1 indicates the start of the *sync channel message*, and an SOM of 0 indicates that the current sync channel frame has the contents of a running *sync channel message* that started in some previous frame. This way, the base station can transmit the sync channel message in consecutive sync channel frames. Note that an SOM of 1 also coincides with the start of a sync channel superframe. In other words, a sync channel message always starts at the beginning of a sync channel superframe. Note that each sync channel frame starts with the SOM bit, and the rest of the frame is referred to as the *sync channel frame body*. Figure 5.4 shows the structure of a hypothetical *sync channel message* that occupies two consecutive superframes.

The *sync channel message* itself contains different fields; the message contains information such as the offset of the pilot PN sequence used by the transmitting sector (i.e., the PILOT_PN field). The message also contains information to enable the mobile to synchronize with the long PN sequence. This is done by reading the LC_STATE and SYS_TIME fields of the *sync channel message*. The base station sets the LC_STATE field to the long-code state at some future time given by the SYS_TIME field. And at the precise time given

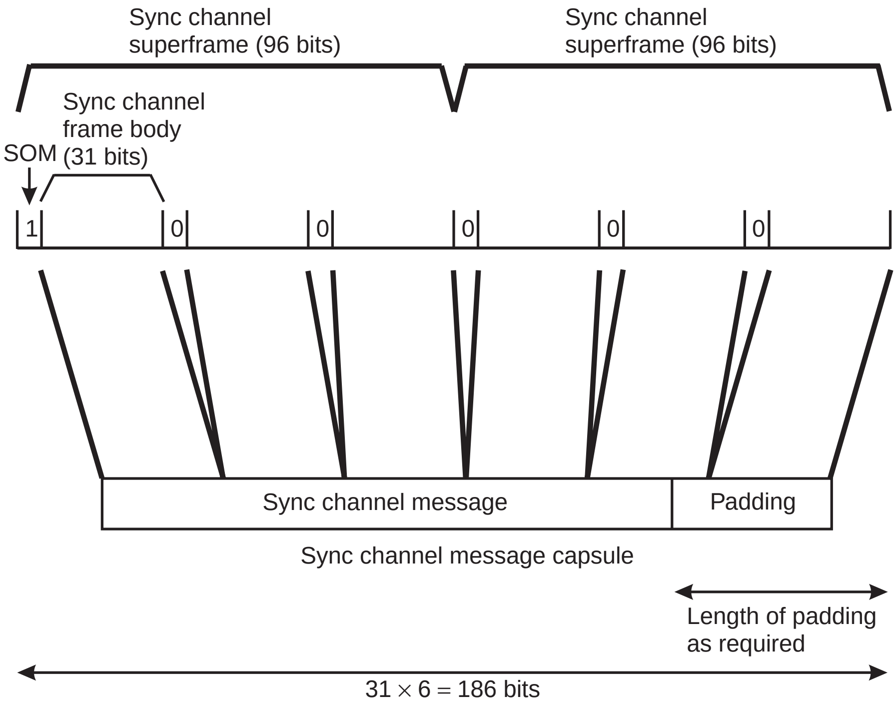

Figure 5.4 Sync channel message structure for a hypothetical message that occupies two consecutive superframes. After [1].

by the SYS_TIME field, the mobile starts running the long PN sequence (at the state given by the LC_STATE field). Thus, after the successful reception of the *sync channel message*, the mobile is synchronized with the short PN sequence transmitted by the base station, the mobile knows the exact PN offset of that short PN sequence, and the mobile is synchronized with the long PN sequence.

5.2.3 Paging Channel

Similar to the sync channel, the paging channel also carries baseband information. But unlike the sync channel, the paging channel transmits at higher rates; it can transmit at either 4.8 or 9.6 Kbps. The PRAT field in the sync channel message informs the mobile of the data rate of the paging channel. Once the mobile acquires timing and synchronization using the sync channel, the mobile begins to monitor the paging channel. Although there can be up to seven paging channels per sector, each mobile only monitors one paging channel.

As shown in Figure 5.5, the baseband information is first error protected, then if the data rate is at 4.8 Kbps, the bits are repeated once. Otherwise, they are not repeated. Following interleaving, the data is first scrambled by a decimated long PN sequence, then it is spread by a specific Walsh function assigned to that paging channel and further spread by the short PN sequence assigned to the serving sector. Also note from Figure 5.5 that the long PN code undergoes a decimation ratio of 64:1 (i.e., from 1.2288 Mcps to 19.2 Ksps). The long-code generator itself is masked with a mask specific to each unique paging channel number (i.e., 1 through 7). Therefore, the long-code mask used for paging channel 1 (spread by Walsh function 1) is different from that used for paging channel 3 (spread by Walsh function 3).

The paging channel is divided into 80-ms slots. A group of 2,048 slots is called a *maximum slot cycle*. An 80-ms slot is divided into four paging channel *frames*, and each paging channel frame is further divided into two paging channel *half-frames*. The first bit of each half-frame is called the *synchronized capsule indicator* (SCI) bit. Figure 5.6 depicts the frame structure of paging channel.

A message on the paging channel may occupy more than one paging channel half-frames, and a message may end in the middle of a paging channel half-frame. The message on the paging channel may be transported by either

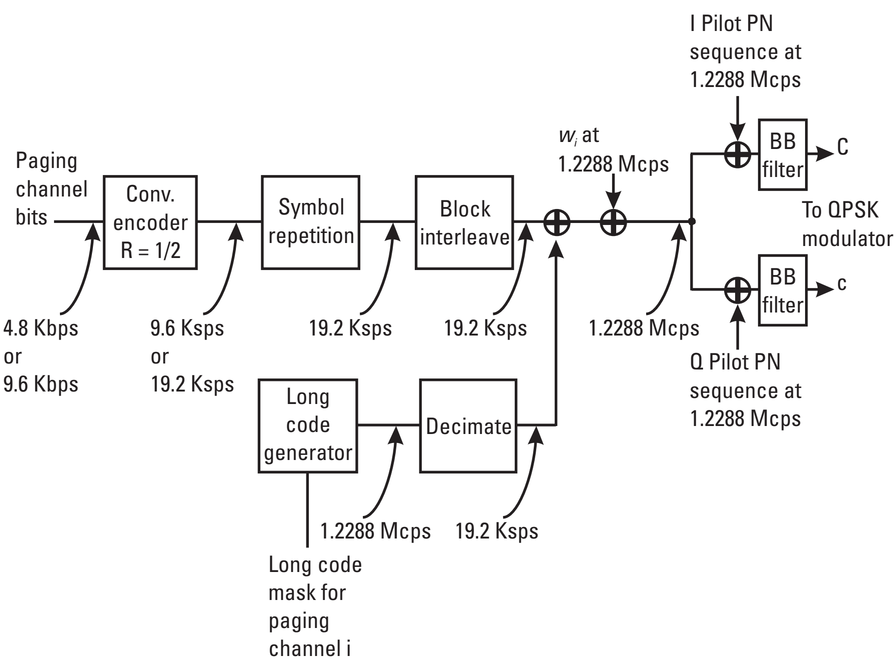

Figure 5.5 Paging channel. After [1].

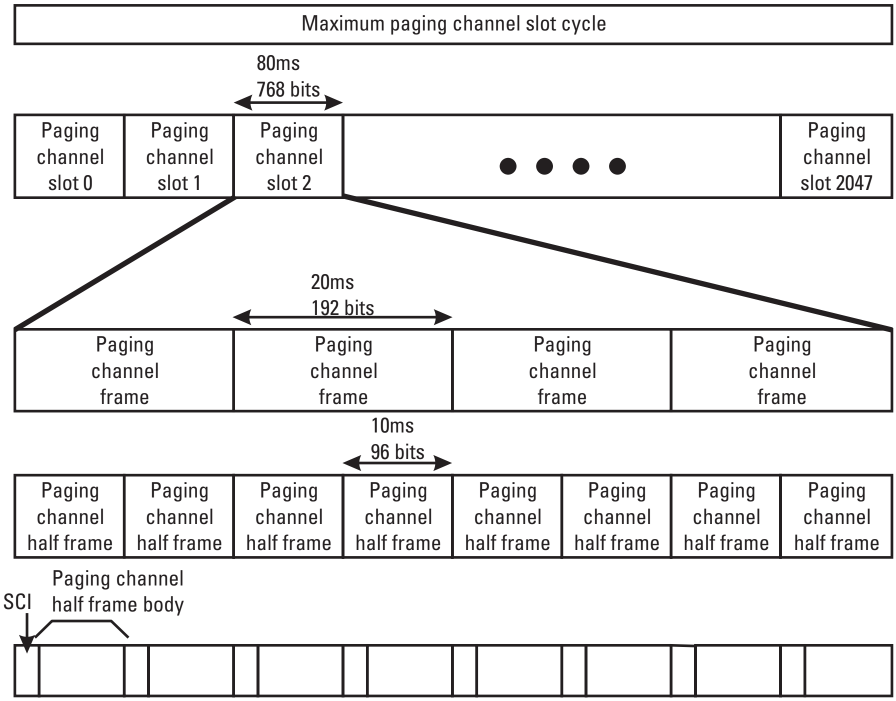

Figure 5.6 Paging channel frame structure for a paging channel rate of 9.6 Kbps. After [1].

synchronized paging channel message capsules or *unsynchronized paging channel message capsules.* If a message ends in the middle of a paging channel half-frame, and if there are less than eight bits between the end of that message and the SCI bit of the next half-frame, then the base station would include enough padding bits at the end of the current message capsule to extend the capsule up to the beginning of the next half-frame. If the next message capsule to be transmitted is a synchronized message capsule, then the base station would also include enough padding bits at the end of the current message capsule to extend the capsule up to the beginning of the next half-frame.

However, if a message ends in the middle of a paging channel half-frame, and if there are more than eight bits between the end of that message and the SCI bit of the next half-frame, then the base station may transmit an unsynchronized message capsule immediately after that message. In this case, no padding bits are added.

Therefore, the SCI bit flags the start of a brand new message capsule in the current half-frame (i.e., if the SCI bit is 1). Then a new message capsule starts immediately follows that SCI bit. The SCI bit is set to 0 in all other cases.

Figure 5.7 shows three hypothetical paging channel messages that are transmitted consecutively.

Messages such as *overhead* and *paging* are sent over the paging channel. Overhead information is used to notify the mobile of important system configuration parameters. Examples of overhead messages are the *system parameters message*, the *access parameters message*, and the *neighbor list message*. The *system parameters message* contains important system configuration parameters; these include the following:

- Handoff parameters for the mobile to use [1]:
  T_ADD—pilot detection threshold;
  T_DROP—pilot drop threshold;
  T_COMP—active set versus candidate set comparison threshold;
  T_TDROP—drop timer value;
  SRCH_WIN_A—search-window size for the active and candidate sets;
  SRCH_WIN_N—search-window size for the neighbor set;
  SRCH_WIN_R—search-window size for the remaining set;
  NGHBR_MAX_AGE—neighbor set maximum age.

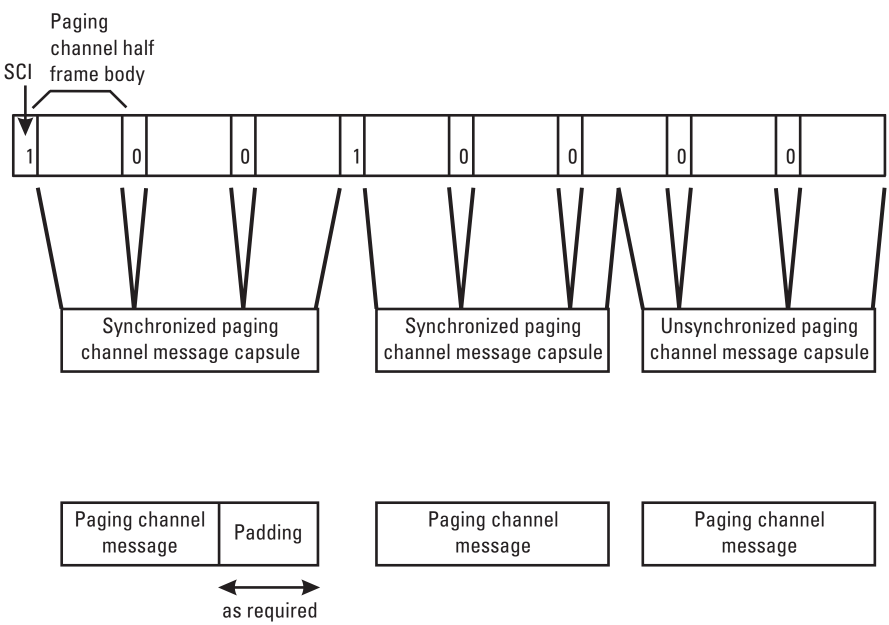

Figure 5.7 Paging channel message structure for three different hypothetical messages, each of which occupies more than two paging channel half-frames. After [1].

- Forward power-control parameters for the mobile to use [1]:
  PWR_REP_THRESH—power-control reporting threshold;
  PWR_REP_FRAMES—power-control reporting frame count;
  PWR_THRESH_ENABLE—threshold report mode indicator;
  PWR_PERIOD_ENABLE—periodic report mode indicator;
  PWR_REP_DELAY—power report delay.

The *access parameters message* contains important access configuration parameters; these include the following:

- Reverse power-control parameters for the mobile to use [1]:
  NOM_PWR—nominal transmit power offset;
  INIT_PWR—initial power offset for access;
  PWR_STEP—power increment.

- Access parameters for the mobile to use [1]:
  NUM_STEP—number of access probes;
  PROBE_PN_RAN—time randomization for access channel probes;
  ACC_TMO—acknowledgment timeout;
  PROBE_BKOFF—access channel probe backoff range;
  BKOFF —access channel probe sequence backoff range;
  MAX_REQ_SEQ—maximum number of access probe sequences for an access channel request;
  MAX_RSP_SEQ—maximum number of access probe sequences for an access channel response.

- Access channel parameters for the mobile to use [1]:
  MAX_CAP_SZ—maximum access channel message capsule size;
  PAM_SZ—access channel preamble length.

The *neighbor list message* contains a list of neighboring sectors for the mobile to use; these include PN offsets of neighbors (i.e., NGHBR_PN) [1].

In addition, paging messages are sent over the paging channel. A *page message* may contain a page to one particular mobile, or it may contain a page to a group of mobiles.

5.2.4 Traffic Channel

The forward traffic channel is used to transmit user data and voice; signaling messages are also sent over the traffic channel. The structure of the forward traffic channel is similar to that of the paging channel. The only difference is that the forward traffic channel contains multiplexed PCBs, which are discussed in Chapter 4.

Figure 5.8 shows the forward traffic channel for Rate Set 1. For this rate set, the vocoder is capable of varying its output data rate in response to speech activities. Four different data rates are supported: 9.6, 4.8, 2.4, and 1.2 Kbps. For example, during quiet periods of speech, the vocoder may elect to code the speech at the lowest rate of 1.2 Kbps.

The baseband data from the vocoder is convolutionally encoded for error protection. For Rate Set 1, a rate 1/2 convolutional encoder is used. The encoding effectively doubles the data rate. After convolutional encoding, the data undergoes symbol repetition, which repeats the symbols when lower rate data are produced by the vocoder. The following is the repetition scheme:

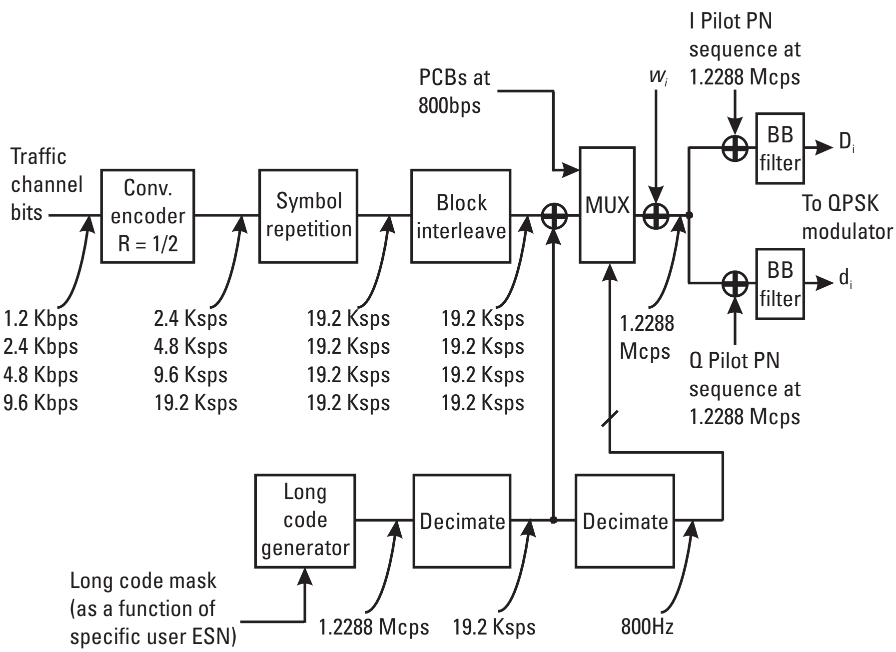

Figure 5.8 Forward traffic channel for Rate Set 1. After [1].

- When the data rate is 9.6 Kbps, the code symbol rate (at the output of the convolutional encoder) is 19.2 Ksps. In this case, no repetition is performed.
- When the data rate is 4.8 Kbps, the code symbol rate is 9.6 Ksps; each symbol is repeated once, yielding a final modulation symbol rate of 19.2 Ksps.
- When the data rate is 2.4 Kbps, the code symbol rate is 4.8 Ksps; each symbol is repeated three times, yielding a final modulation symbol rate of 19.2 Ksps.
- When the data rate is 1.2 Kbps, the code symbol rate is 2.4 Ksps; each symbol is repeated seven times, yielding a final modulation symbol rate of 19.2 Ksps.

The reason for repeating symbols is to reduce overall interference power at a given time when lower rate data are transmitted. Figures 5.9(a) and 5.9(b) illustrate the concept. Two cases are presented in Figures 5.9(a) and 5.9(b). In the first case, the system wants to transmit at a rate of 2 symbols per second, and in the second case, the system wants to transmit at a lower rate of 1 symbol per second. We further assume that the integrator needs to accumulate 1W of signal power in order to successfully demodulate a symbol.

In the first case, the original symbols are not repeated. If each symbol is sent at an energy level of 2, then the integrator (in the receiver) is able to accumulate 1W during each original symbol period. The symbols in this case are successfully demodulated. Note that in this case, the original symbol period is 0.5 second.

In the second case, the original symbols are repeated once, yielding a symbol rate of 2 symbols per second. However, since the original symbol rate is only 1 symbol per second, we can lower the energy of each *repeated* symbol by one-half. This way, when the integrator accumulates energy over the *original* symbol period (i.e., 1 sec), the integrator would still accumulate the necessary 1W per each original symbol period. Note that in this case, the original symbol period is 1 sec. The motivation for the symbol repetition scheme is to *decrease the power per repeated (transmitted) symbol* when the vocoder is running at a lower rate. The scheme is effectively a way of taking advantage of the voice activity factor in hardware implementation (i.e., when the vocoder is transmitting at lower rates, the forward transmit power is reduced).

In a real CDMA system, when the vocoder is transmitting at 4.8 Kbps, the energy per symbol transmitted is one-half that of 9.6 Kbps. When the

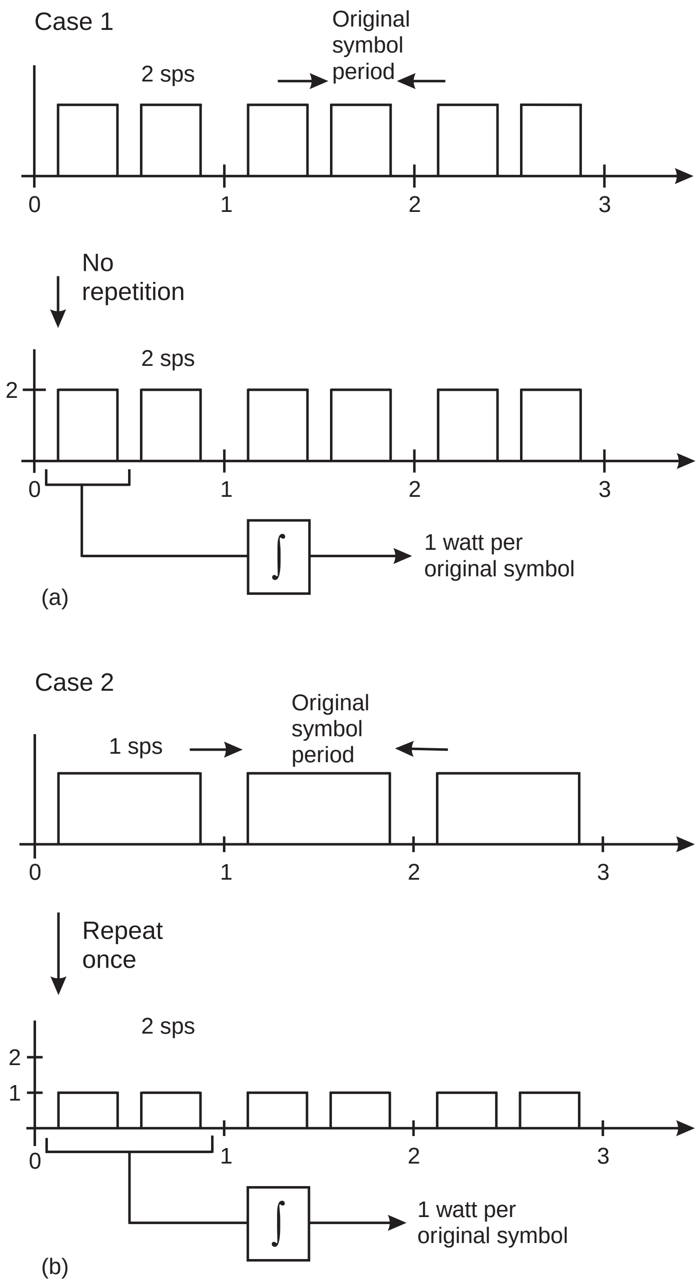

Figure 5.9 (a) Reduction of power as a result of symbol repetition—Case 1; (b) reduction of power as a result of symbol repetition—Case 2.

vocoder is transmitting at 2.4 Kbps, the energy per symbol transmitted is one-forth that of 9.6 Kbps, and when the vocoder is transmitting at 1.2 Kbps, the energy per symbol transmitted is one-eighth that of 9.6 Kbps.

After symbol repetition, the data is interleaved to combat fading (see Figure 5.8), then the interleaved data is scrambled by a decimated long PN sequence. The long PN sequence is generated by a long PN code generator. The generator outputs a long PN sequence at 1.2288 Mcps. Because the data rate at the interleaver output is 19.2 Ksps, the PN sequence is *decimated* by a ratio of 64:1 to also achieve a rate of 19.2 Kcps; the decimated long PN sequence at 19.2 Kcps is then multiplied with the 19.2-Ksps data stream. Note that the long-code generator produces the long PN sequence using a mask that is specific to the mobile. In reality, the mask is a function of the mobile's *electronic serial number* (ESN).

The PCBs at 800 bps are then multiplexed with the scrambled data stream at 19.2 Ksps. A PCB can be punctured into any one of the first 16 bit positions of a PCG (which contains 24 bits). The exact location of the PCB in the PCG is determined in a pseudorandom fashion. More specifically, given that the input of the decimator is the long PN sequence, the PCB bit position is determined by the decimal value of the four most significant bits of the decimator output. It is important to recognize that the exact location of the PCB in the PCG is not fixed, but is determined in a pseudorandom manner. For more details on the power control subchannel and PCB puncturing, consult Section 7.1.3.1.7 of [1].

At this point, the multiplexed data stream (still at 19.2 Ksps) is orthogonally spread by the assigned Walsh function. Each forward traffic channel is identified by its assigned Walsh function. The spreading Walsh function is at a rate of 1.2288 Mcps; each symbol is spread by a factor of 64, and the result is a spread data stream at a rate of 1.2288 Mcps.

The data stream is further spread by the assigned short PN sequence of the transmitting sector. The short PN sequence provides a second layer of isolation that distinguishes among the different transmitting sectors. This way, all 64 available Walsh functions can be reused in every sector. Remember that each unique short PN sequence is characterized by its PN offsets.

The forward traffic channel structure is similar for Rate Set 2. The Rate Set 2 vocoder codes speech at higher rates, and it delivers a better voice quality than that of Rate Set 1. The Rate Set 2 vocoder supports four variable rates: 14.4, 7.2, 3.6, and 1.8 Kbps. Figure 5.10 shows the forward traffic channel for Rate Set 2. Note that in order to maintain the output of the block interleaver at 19.2 Ksps, the rate of the convolutional encoder is increased to $R = 3/4$.

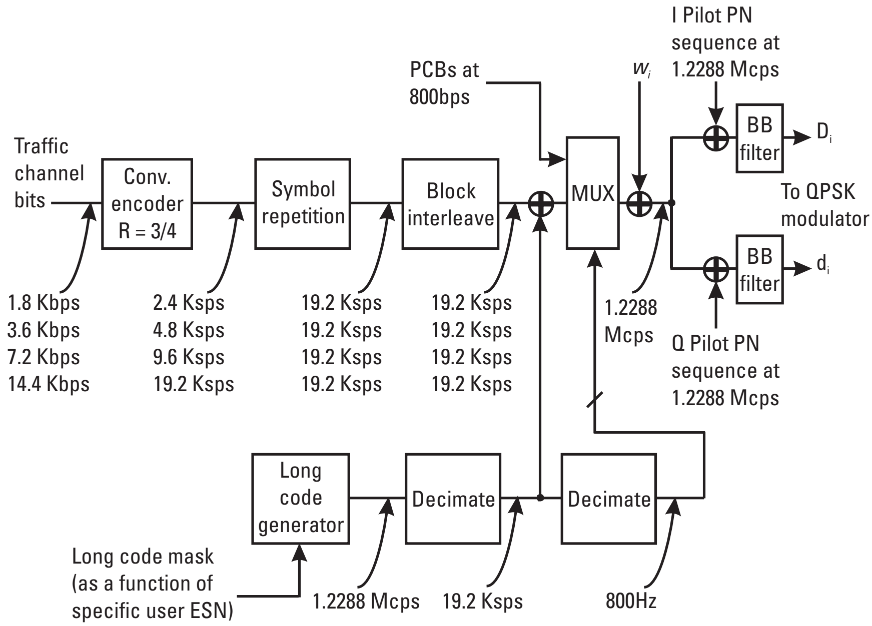

Figure 5.10 Forward traffic channel for Rate Set 2.

5.2.5 Modulator

The output of the logical channels is fed into the modulator. Figure 5.11 shows the structure of the forward channel modulator [2]. The gain of each logical channel, including pilot, sync, paging, and all traffic channels, is first adjusted by the gain control function. The gain of each channel dictates how much power is to be transmitted for that channel. The gains for the individual traffic channels are dynamically changing (i.e., they are controlled by the forward power-control process described in Chapter 4).

After the channel gains are adjusted, the signals are coherently added together to form the composite spread-spectrum signal. After the summation, both the *I* and the *Q* paths are up-converted by their respective carriers. The up-converted signals then are added together to form the final passband QPSK signal.

5.3 Reverse Link

The reverse link supports two types of logical channels: access channels and traffic channels. Because of the noncoherent nature of the reverse link, Walsh

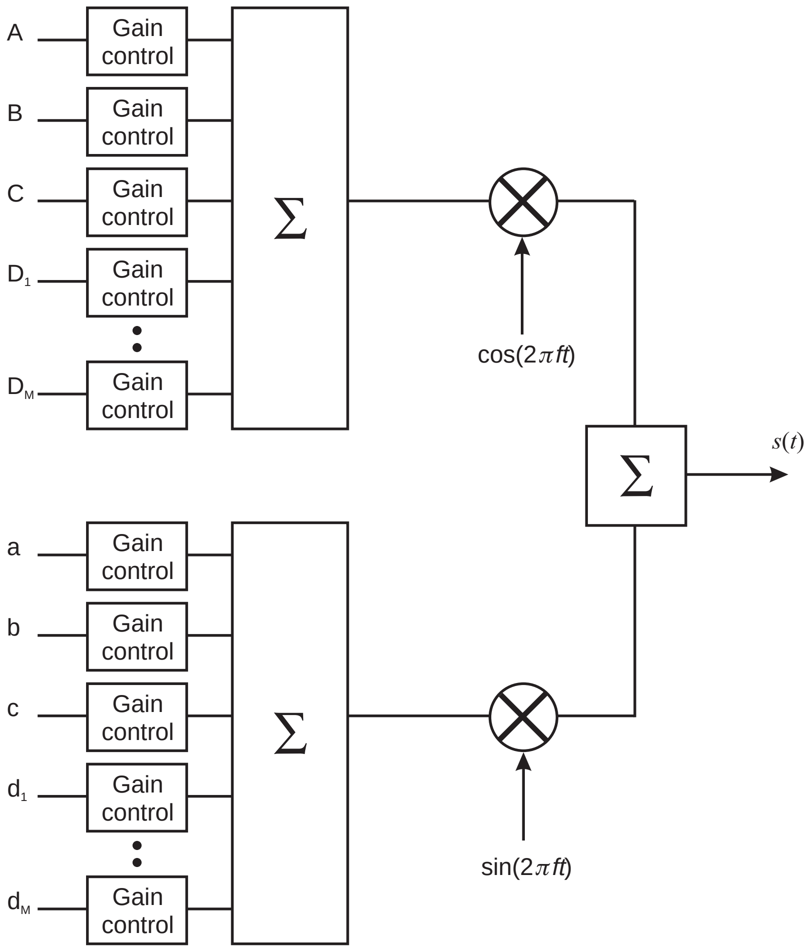

Figure 5.11 Modulator for the CDMA forward link. After [2]. Note that the inputs A, B, C, D, and a, b, c, and d are drawn from Figures 5.1, 5.2, 5.5, and 5.8.

functions are not used for channelization. Instead, long PN sequences are used to distinguish the users from one another.

5.3.1 Access Channel

The access channel is used by the mobile to communicate with the base station when the mobile doesn't have a traffic channel assigned. The mobile uses this channel to make call originations and respond to pages and orders. The baseband data rate of the access channel is fixed at 4.8 Kbps.

As shown in Figure 5.12, the baseband information is first error protected by an $R = 1/3$ convolutional encoder. The lower encoding rate makes error protection more robust on the reverse link, which is often the weaker of the two links. The symbol repetition function repeats the symbol once, yielding a code symbol rate of 28.8 Ksps. The data is then interleaved to combat fading.

Following interleaving, the data is coded by a 64-ary orthogonal modulator. The set of 64 Walsh functions is used, but here the Walsh functions are used to modulate, or represent, groups of six symbols. The reason for orthogonal modulation of the symbols is again due to the noncoherent nature of reverse link. When a user's transmission is not coherent, the receiver (at the base station) still has to detect each symbol correctly. Making a decision of whether or not a symbol is +1 or −1 may be difficult during one symbol period.

However, if a group of six symbols is represented by a unique Walsh function, then the base station can easily detect six symbols at a time by deciding which Walsh function is sent during that period. The receiver can easily decide which Walsh function is sent by correlating the received sequence with the set of 64 known Walsh functions. Note that on the forward link, Walsh functions are used to distinguish among the different channels. On the reverse link, Walsh functions are used to distinguish among the different symbols (or among groups of six symbols).

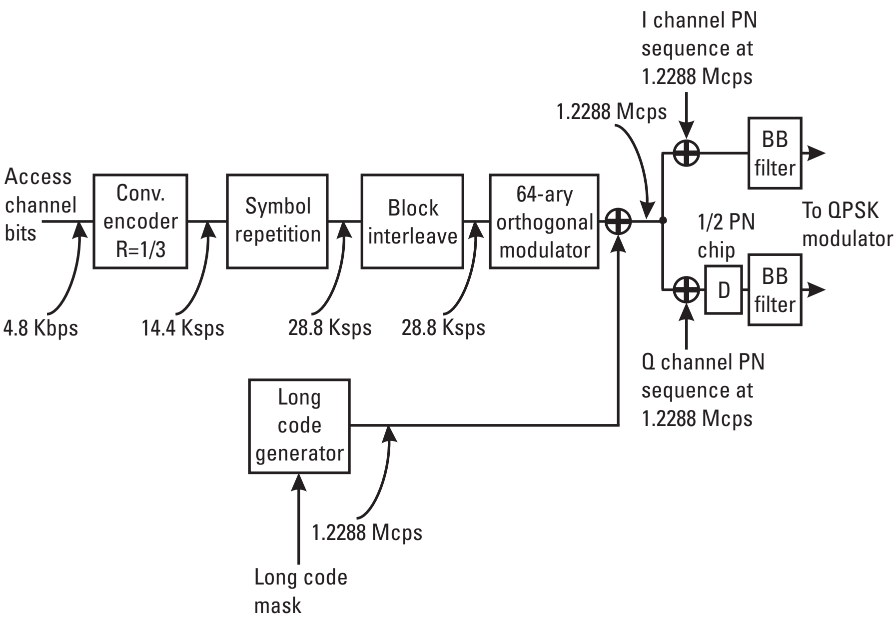

Figure 5.12 Access channel. After [1].

In reality, a group of six binary symbols corresponds to a decimal value between 0 and 63. The pattern of the six-symbol group (and the corresponding decimal value) dictates which Walsh function (0 to 63) is used to represent that group of six symbols. For example, a group of six symbols (−1, +1, −1, +1, +1, −1) corresponds to a binary value of 010110, or a decimal value of 22. Thus Walsh function 22 is the output of the orthogonal modulator.

The orthogonally modulated data at 4.8 Ksps (modulation symbols) or at 307.2 Ksps (code symbols) are then spread by the long PN sequence. The long PN sequence is running at 1.2288 Mcps, and the bandwidth of the data after spreading is 1.2288 Mcps. Remember that the long PN sequence is used to distinguish the access channel from all other channels that occupy the reverse link.

The data is further scrambled in the *I* and the *Q* paths by the short PN sequences (also running at 1.2288 Mcps) defined in the IS-95 standard. Because the reverse link uses OQPSK modulation, the data in the *Q* path is delayed by one-half a PN chip. See Chapter 3 for a description of OQPSK. The primary purpose of this chip delay is to make sure that the QPSK signal envelope will not collapse to zero. This property is important because the power amplifier of the mobile is typically small and limited in performance. If we can ensure that the signal envelope never reaches zero and always stays above a certain level, then the amplifier would only have to remain linear over a smaller dynamic range.

Information is transmitted on the access channel in *access channel slots* and *access channel frames*. Each slot contains (3 + MAX_CAP_SZ) + (1 + PAM_SZ) frames [1], and each frame contains 96 bits and lasts 20 ms, which corresponds to a baseband data rate of 4.8 Kbps. Recall that MAX_CAP_SZ is the maximum access channel message capsule size and PAM_SZ is the access channel preamble length. Figure 5.13 depicts the frame structure of the access channel.

As shown in Figure 5.13, although the base station allows each slot to contain (3 + MAX_CAP_SZ) + (1 + PAM_SZ) frames, the mobile may not need that many frames in the slot to transmit its message. The mobile would set a variable CAP_SZ according to the length of the actual message. The constraint is that the CAP_SZ has to be less than (3 + MAX_CAP_SZ). Figure 5.14 shows the message structure of the access channel. We have the access channel preamble consisting of (1 + PAM_SZ) frames. Each access channel frame consists of 88 information bits and 8 encoder tail bits. For those frames that are not in the preamble, the information bits in the frame bodies are combined to form the *access channel message capsule,* which contains (CAP_SZ × 88) bits. The access channel message capsule contains the *access channel message* and *padding*. Again, the *access channel message* may occupy more

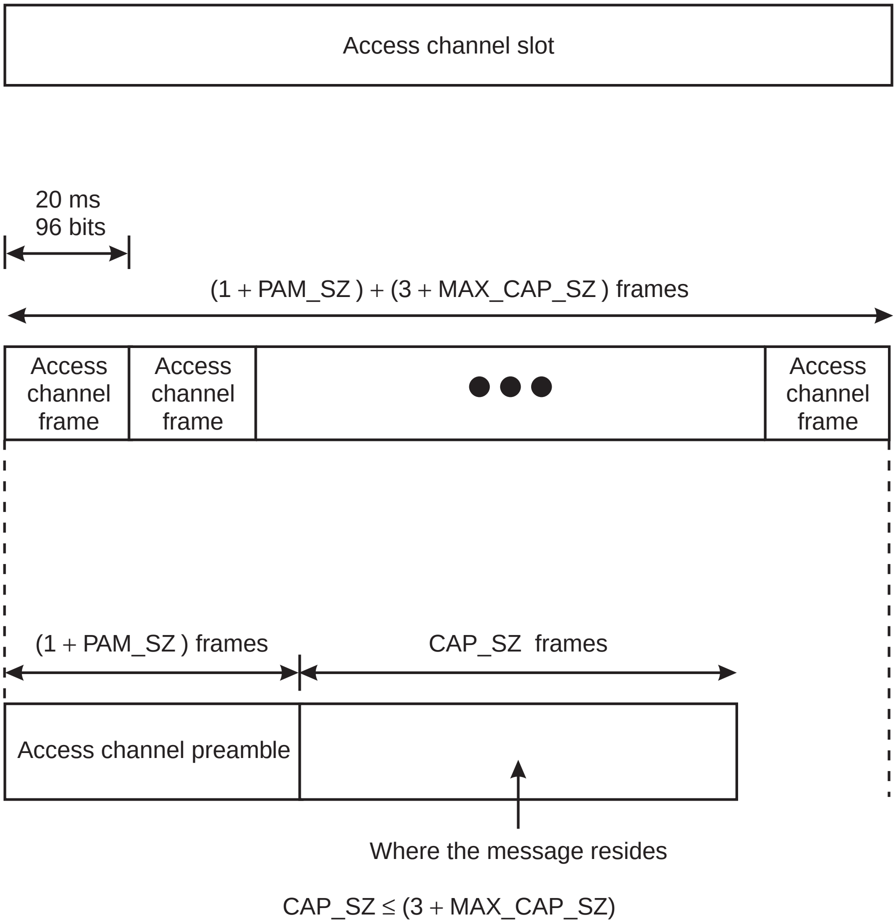

Figure 5.13 Access channel frame structure.

than one frame, and padding bits are added so that the total length of the *access channel message* and padding is equal to (CAP_SZ × 88) bits.

There are two types of messages sent on the access channel: a *response* message (in response to a base station message) or a *request* message (sent by the mobile station). Different procedures are used to send these two types of messages. Chapter 6 describes these procedures in more detail.

5.3.2 Traffic Channel

The reverse traffic channel is used to transmit user data and voice; signaling messages are also sent over the traffic channel. The structure of the reverse

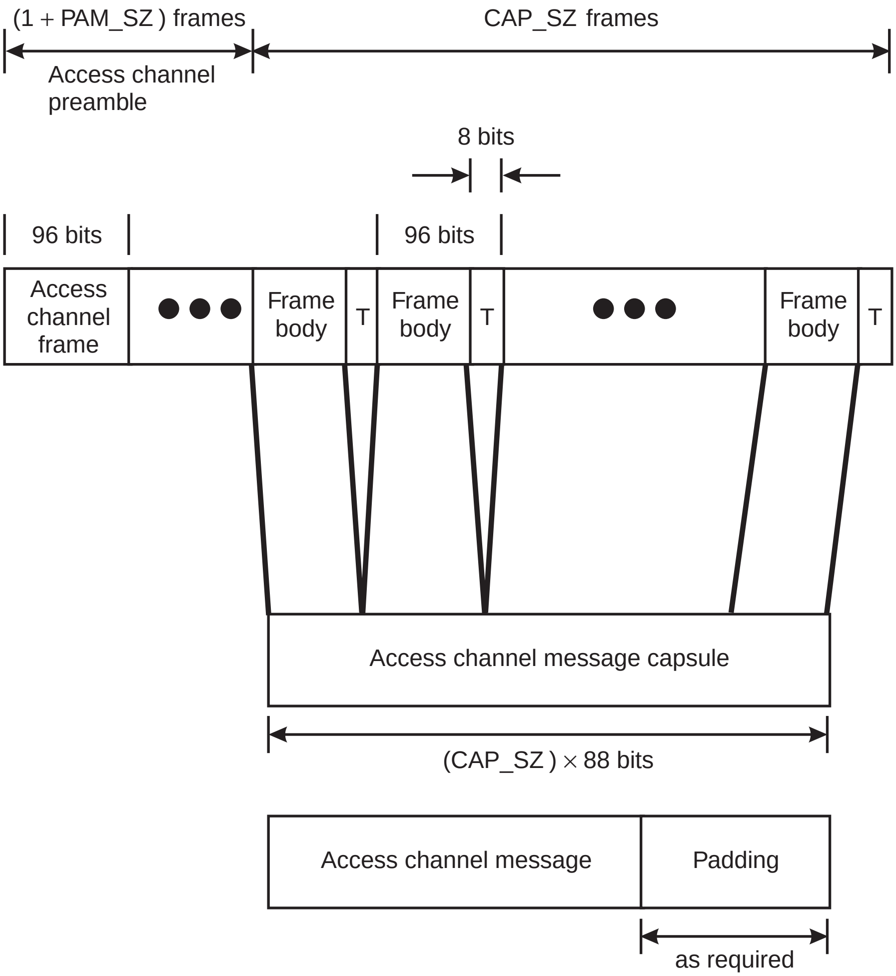

Figure 5.14 Access channel message structure.

traffic channel is similar to that of the access channel. The major difference is that the reverse traffic channel contains a data burst randomizer, as shown in Figure 5.15.

The orthogonally modulated data is fed into the data burst randomizer. The function of the data burst randomizer is to take advantage of the voice activity factor on the reverse link. Recall that the forward link uses a different scheme to take advantage of the voice activity factor—when the vocoder is operating at a lower rate, the forward link transmits the repeated symbols at a reduced energy per symbol and thereby reduces the forward-link power during

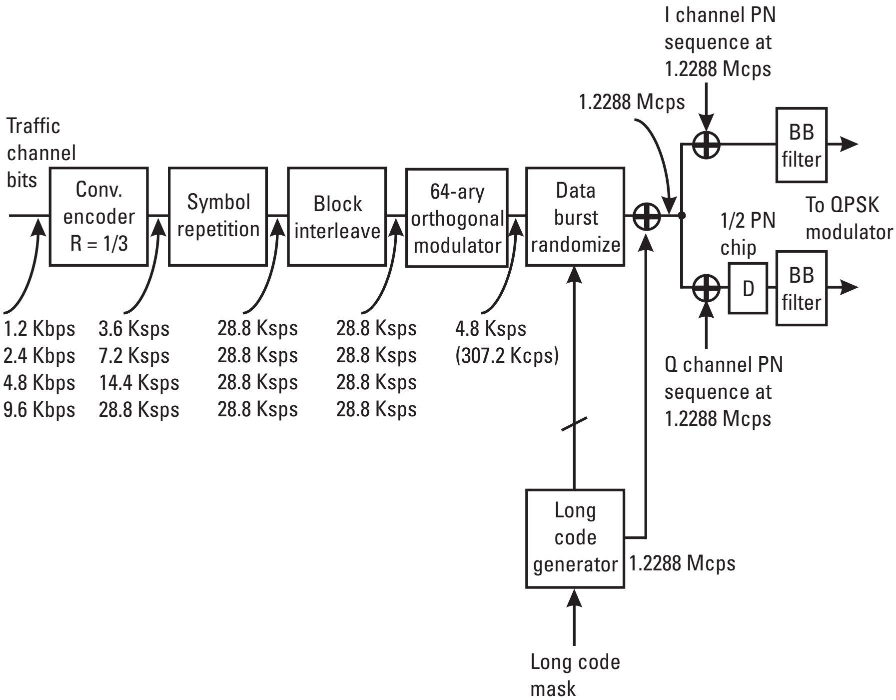

Figure 5.15 Reverse traffic channel for Rate Set 1. After[1].

any given period. As shown by Figure 5.9, at a reduced rate (i.e., 1 sps) and thus at a reduced energy, the integrator needs to integrate over a longer period of time (i.e., 1 sec) in order to accumulate enough power for proper symbol detection. In other words, at a reduced rate, the receiver takes longer to detect each symbol. This scheme is fine for a forward link where the speed requirement of forward-link power control is not stringent. After all, the mobile measures FER over a relatively longer period of time and reports this FER back to the base station. Then, the base station would act upon the information and adjust its forward power.

The scheme described for the forward link is inadequate for the reverse link. The reason is that the requirement of power-control speed is much more stringent on the reverse link. The base station measures the E_b/N_0 (a quantity that is quickly measured) on the reverse link, then the base station immediately makes a power-control decision and sends a PCB back to the mobile. The base station needs to quickly detect each symbol, even when the vocoder is operating at a lower rate, and the base station cannot afford to wait for the integrator to accumulate energy over a long period of time.

The approach taken to reduce reverse-link power during quieter periods of speech is to pseudorandomly mask out redundant symbols produced by symbol repetition. This is accomplished by the data burst randomizer. The data burst randomizer generates a masking pattern of 0s and 1s that randomly masks out redundant data. The masking pattern is partially determined by the vocoder rate. If the vocoder is operating at 9.6 Kbps, then no data is masked. If the vocoder is operating at 1.2 Kbps, then the symbols are repeated seven times, and the data burst randomizer masks out, on average, seven out of eight groups of symbols.

In actuality, each 20-ms traffic channel frame is divided into 16 power control groups, each 1.25 ms in length. The data burst randomizer pseudorandomly masks out individual power-control groups. When the vocoder operates at 9.6 Kbps, no PCG is masked out; when the vocoder operates at 4.8 Kbps, an average of 8 PCGs are masked out in a frame; when the vocoder operates at 2.4 Kbps, an average of 12 PCGs are masked out in a frame; and when the vocoder operates at 1.2 Kbps, an average of 14 PCGs are masked out in a frame. Figure 5.16 shows an example of this operation when the vocoder operates at 2.4 Kbps. In addition to depending on the vocoder rate, the masking pattern also depends on the long PN sequence used to spread the previous frame. For details of the masking algorithm, consult [1].

The reverse traffic channel structure is similar for Rate Set 2. The Rate Set 2 vocoder codes speech to data at a higher rate, and it delivers a better voice quality than that of Rate Set 1. The Rate Set 2 vocoder supports four variable rates: 14.4, 7.2, 3.6, and 1.8 Kbps. Figure 5.17 shows the reverse traffic channel for Rate Set 2. Note that in order to maintain the output of the block interleaver at 28.8 Ksps, the rate of the convolutional encoder is increased to $R = 1/2$.

5.4 Traffic Channel Formats

For both forward and reverse links, the traffic channel frames are 20 ms in duration. The frame at full rate contains 192 bits, yielding a rate of 9.6 Kbps; the frame at half rate contains 96 bits, yielding a rate of 4.8 Kbps; the frame at one-quarter rate contains 48 bits, yielding a rate of 2.4 Kbps; and the frame at one-eighth rate contains 24 bits, yielding a rate of 1.2 Kbps. The full-rate and half-rate frames contain frame quality indicator (CRC) bits, and all frames contain encoder tail bits (eight encoder tail bits per frame). Figure 5.18 shows the traffic channel frame structure [1].

We mentioned previously that voice, data, and messaging information may be transmitted over the traffic channel. This is true for both forward and

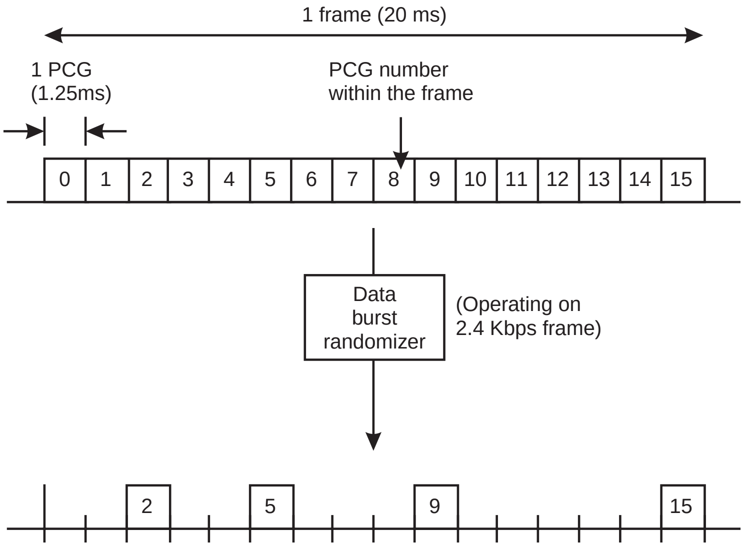

Figure 5.16 An example of data burst randomizer operation. After [1].

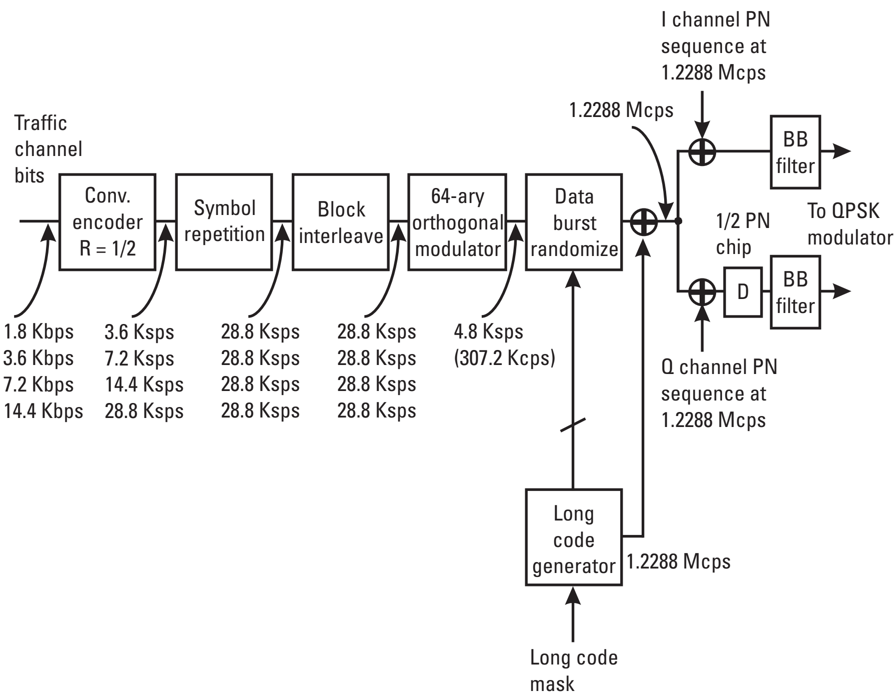

Figure 5.17 Reverse traffic channel for Rate Set 2.

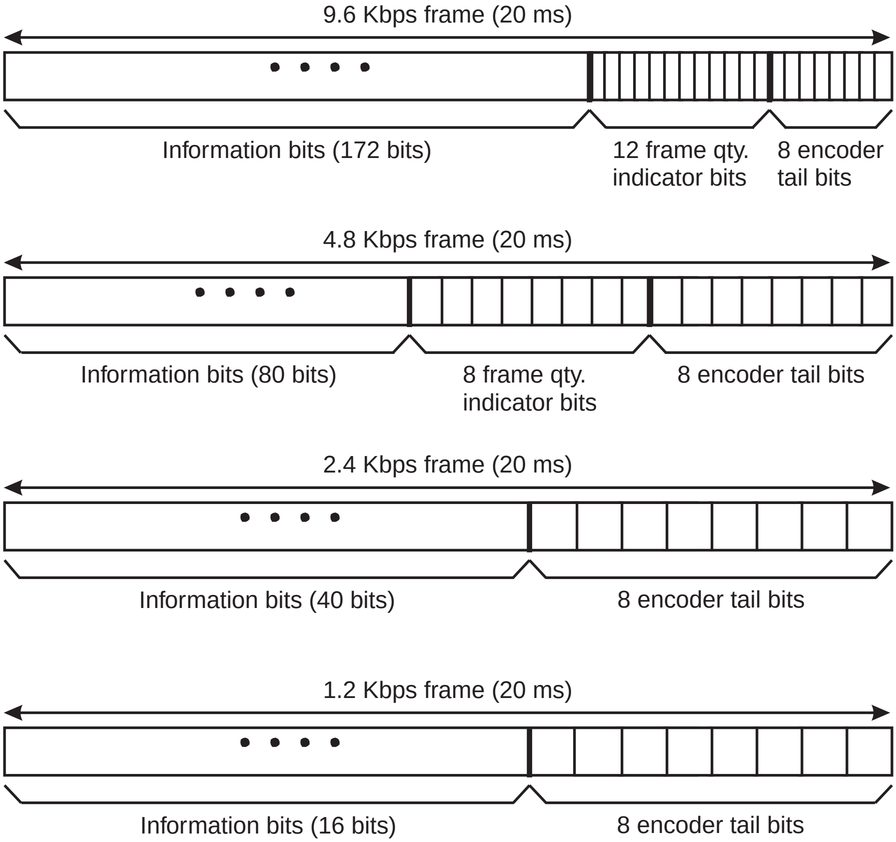

Figure 5.18 Traffic channel frame structure for both forward and reverse links. After [1].

reverse traffic channels. In fact, the system has the ability to multiplex *primary* and *signaling* or *secondary* data on the same traffic channel. The IS-95 CDMA system uses Multiplex Option 1 to transmit primary (i.e., voice) and secondary (i.e., data) traffic. This option is also used to transmit primary (i.e., voice) and signaling (i.e., messaging) traffic. Multiplex Option 1 uses the following techniques to simultaneously transmit primary and secondary or signaling traffic:

- *Blank and burst*: The entire traffic channel frame is used to send only secondary data. The entire traffic channel frame is also used to send only signaling data. The secondary or signaling data effectively blanks out the primary data.

- *Dim and burst*: The traffic channel frame is used to send both primary and secondary data. The traffic channel frame is also used to send both primary and signaling data.

It is important to note that these techniques are only used on those traffic channel frames that are full rate. In other words, secondary or signaling data is never multiplexed onto traffic channel frames that are half rate, one-quarter rate, or one-eighth rate. These lower rate frames contain primary traffic only.

Format bits in the beginning of a full-rate frame indicate what kind of traffic is contained in the frame. For example, if the first format bit of the frame is 0, then the frame is to be used for primary traffic only. If the first format bit of the frame is 1 and the following three format bits are 000, then 80 bits in the frame are to be used for primary traffic and 88 bits in the frame are to be used for signaling traffic. This is an example of dim and burst; note that in this case, the primary traffic is effectively sent at half rate (i.e., 80 bits per frame).

For a complete specification of Multiplex Option 1, consult Section 6.1.3.3.11 and Section 7.1.3.5.11 of [1].

5.4.1 Forward Link

When the mobile is communicating with the base station on a traffic channel, the base station may elect to send messages to the mobile while the traffic channel is still active. During traffic channel operation, the base station sends signaling messages to the mobile using the forward traffic channel [1]. The signaling information is sent over the traffic channel using Multiplex Option 1, described in the previous section. The base station may use one or more forward traffic channel frames to send a particular message.

The following are some important messages that the base station sends to the mobile on the forward traffic channel:

The *in-traffic system parameters message* contains important system configuration parameters such as the current handoff parameters for the mobile to use [1]:

- T_ADD—pilot detection threshold;
- T_DROP—pilot drop threshold;
- T_COMP—active set versus candidate set comparison threshold;
- T_TDROP—drop timer value;
- SRCH_WIN_A—search-window size for the active and candidate sets;

- SRCH_WIN_N—search-window size for the neighbor set;
- SRCH_WIN_R—search-window size for the remaining set;
- NGHBR_MAX_AGE—neighbor set maximum age.

The *handoff direction message* contains information that the mobile needs in order to commence communication with a new base station (or new base stations). In effect, the current base station transmits the following three fields for each member of the mobile's new active set [1]:

- PILOT_PN—pilot PN sequence offset index;
- PWR_COMB_IND—power-control symbol combining indicator;
- CODE_CHAN—code channel index indicating which Walsh function to use for the new traffic channel.

In addition, the base station updates the following handoff parameters in the *handoff direction message*:

- HDM_SEQ—handoff direction message sequence number;
- T_ADD—pilot detection threshold;
- T_DROP—pilot drop threshold;
- T_COMP—active set versus candidate set comparison threshold;
- T_TDROP—drop timer value;
- SRCH_WIN_A—search window size for the active and candidate sets

The *neighbor list update message* updates the mobile with a new list of neighbors. The message contains the NGHBR_PN parameter (neighbor pilot PN sequence offset index) for each pilot in the neighbor list. The *power control parameters message* updates the mobile parameters to use for forward power control:

- PWR_REP_THRESH—power-control reporting threshold;
- PWR_REP_FRAMES—power-control reporting frame count;
- PWR_THRESH_ENABLE—threshold report mode indicator;
- PWR_PERIOD_ENABLE—periodic report mode indicator;
- PWR_REP_DELAY—power report delay.

5.4.2 Reverse Link

When the mobile is communicating with the base station on a traffic channel, the mobile may send messages back to the base station while the traffic channel is still active. During traffic channel operation, the mobile sends signaling messages to the base station using the reverse traffic channel [1]. The signaling information is sent over the traffic channel using Multiplex Option 1, described in Section 5.4. The mobile may use one or more reverse traffic channel frames to send a particular message.

The following are some important messages that the mobile sends to the base station on the traffic channel.

The mobile sends the *pilot strength measurement message* informing the base station of the measured pilot strength for each member of its active and candidate sets [1]. The following parameters are reported for each member of the mobile's active and candidate sets:

- PILOT_PN_PHASE—pilot measured phase;
- PILOT_STRENGTH—pilot strength.

The *power measurement report message* is sent back to the base station to report error statistics measured on the forward link. This message is used by the base station for power control on the forward link. The following parameters are reported by the mobile [1]:

- ERRORS_DETECTED—number of frame errors detected;
- PWR_MEAS_FRAMES—number of forward traffic channel frames in the measurement period;
- PILOT_STRENGTH—pilot strength measured for each member of the active set.

The *handoff completion message* is sent back to the base station to report that the mobile has completed the handoff specified in a previous *handoff direction message*. The mobile reports the following parameters [1]:

- LAST_HDM_SEQ—*handoff direction message* sequence number that corresponds to the HDM_SEQ field from the *handoff direction message* that determined the current active set;
- PILOT_PN—pilot PN sequence offset for each member of the active set.

References

[1] TIA/EIA IS-95A, "Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System," Telecommunications Industry Association.

[2] Garg, V. K., K. Smolik, and J. E. Wilkes, *Applications of CDMA in Wireless/Personal Communications*, Upper Saddle River, NJ: Prentice Hall, 1997.

Select Bibliography

Harte, L., *CDMA IS-95 for Cellular and PCS: Technology, Applications, and Resource Guide*, New York, NY: McGraw-Hill, 1997.

Labedz, G., et al., "Predicting Real-World Performance for Key Parameters in a CDMA Cellular System," *Proc. 46th Annual Vehicular Technology Conf.*, IEEE, 1996, pp. 1472–1476.

Lin, S., and D. J. Costello, Jr., *Error Control Coding: Fundamentals and Applications*, Englewood Cliffs, NJ: Prentice Hall, 1983.

Qualcomm, *The CDMA Network Engineering Handbook, Vol. 1: Concepts in CDMA*, 1993.

TIA PN-3570 (TSB-74), "Support for 14.4 Kbps Data Rate and PCS Interaction for Wideband Spread Spectrum Cellular Systems," Telecommunications Industry Association.

TIA IS-665, "W-CDMA Air Interface Compatibility Standard for 1.85-1.99 GHz PCS Applications."

TIA/EIA IS-96A, "Speech Service Option Standard for Wideband Spread Spectrum Digital Cellular System," Telecommunications Industry Association.