PART II CDMA BASICS

6.3 CDMA CHANNEL CONCEPT

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

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

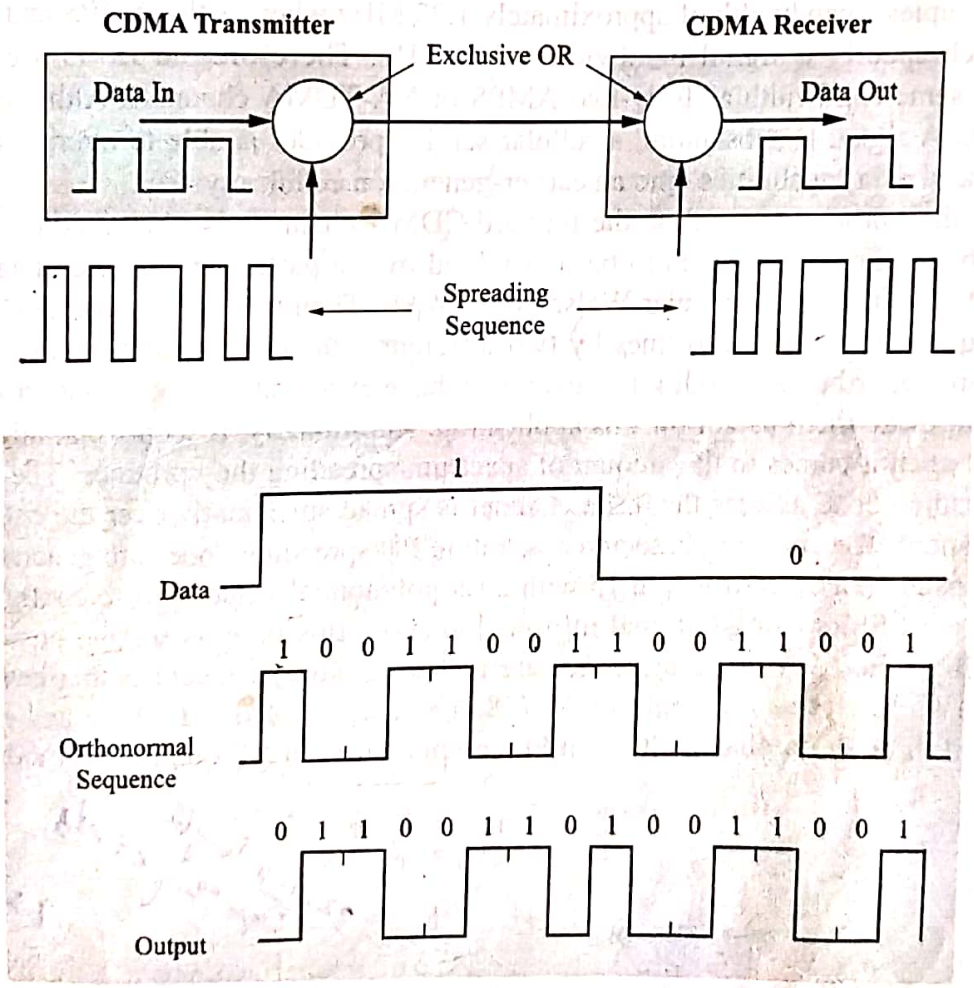


Figure 6–10 The basic spectrum spreading operation.

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

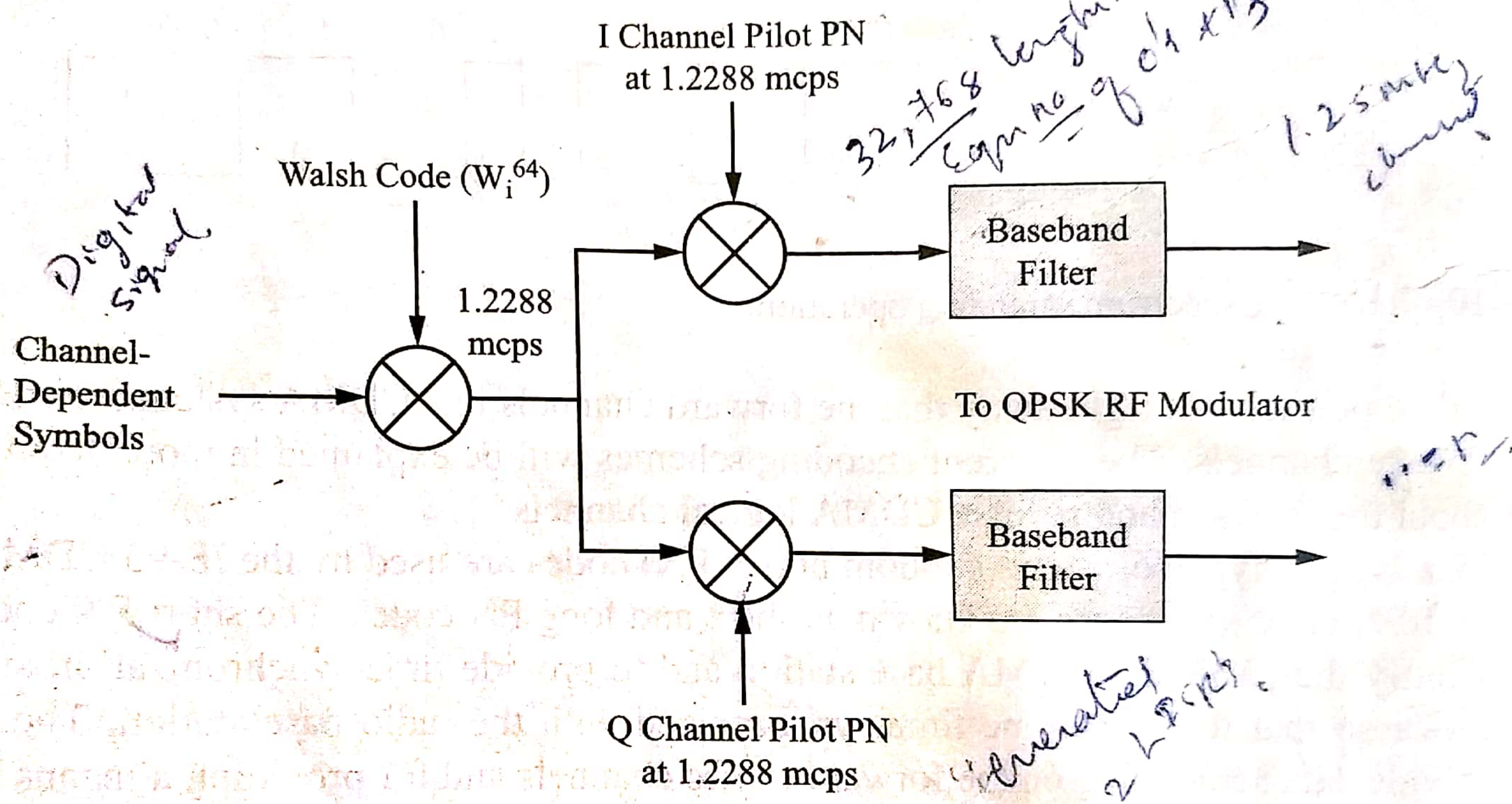
Additionally, two types of pseudorandom noise (PN) codes are used by the IS-95 CDMA system. These two types of PN code sequences are known as short and long PN codes. The short PN code is time shifted both to identify the particular CDMA base station and to provide time synchronization signals to the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

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

Forward Logical Channels

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

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



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

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

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

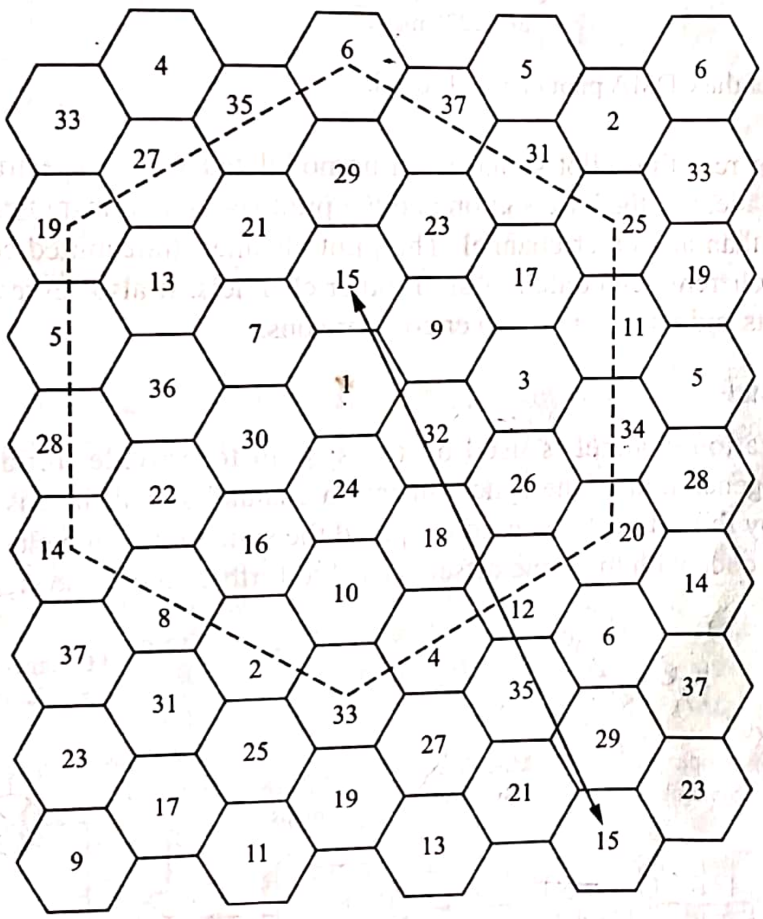


Figure 6–12 CDMA base station timing offset reuse pattern.

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

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

Pilot Channel

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

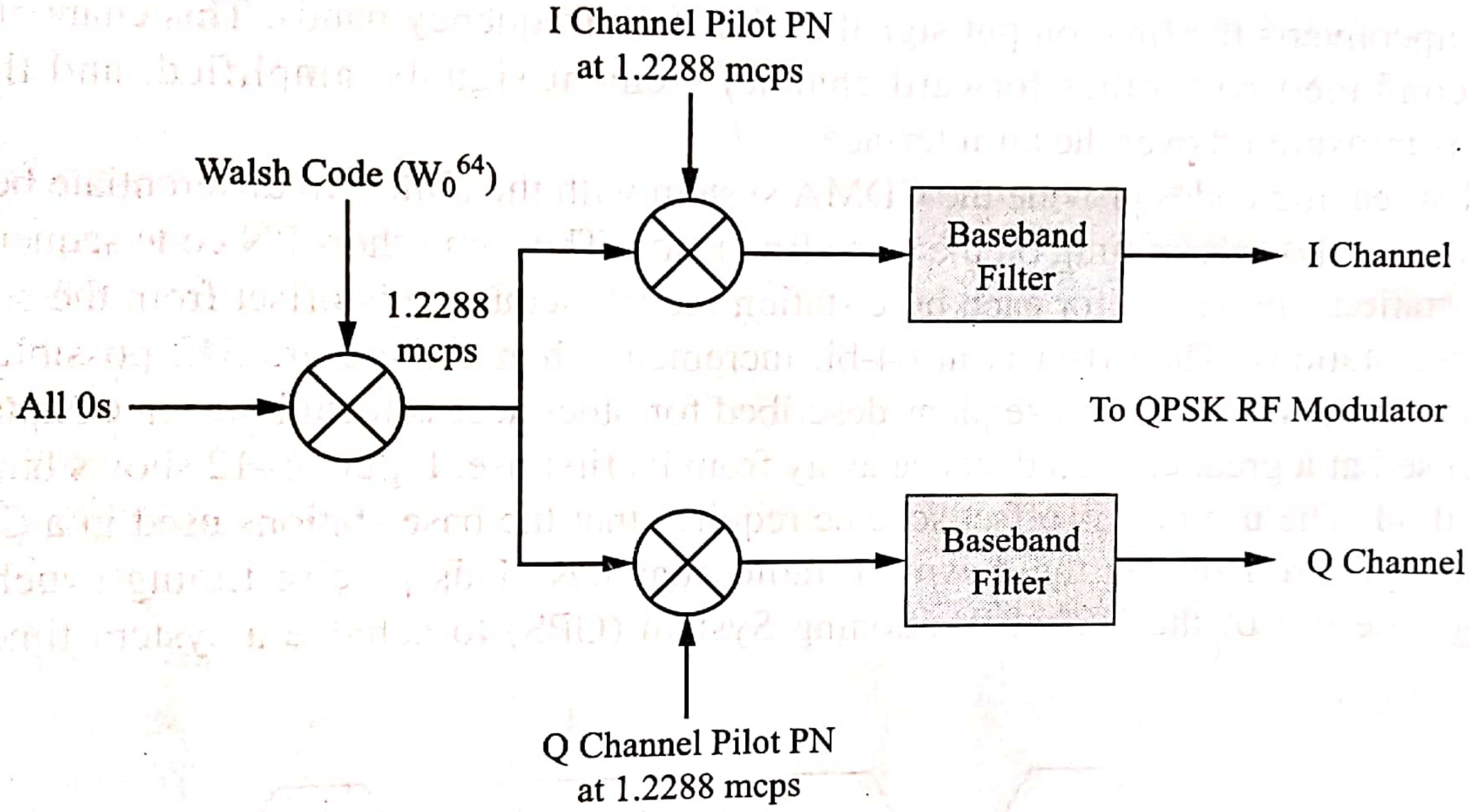


Figure 6–13 Generation of the CDMA pilot channel signal.

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

...ization Channel

...provide initial time synchronization

measurements and other signal power comparisons.

Synchronization Channel

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

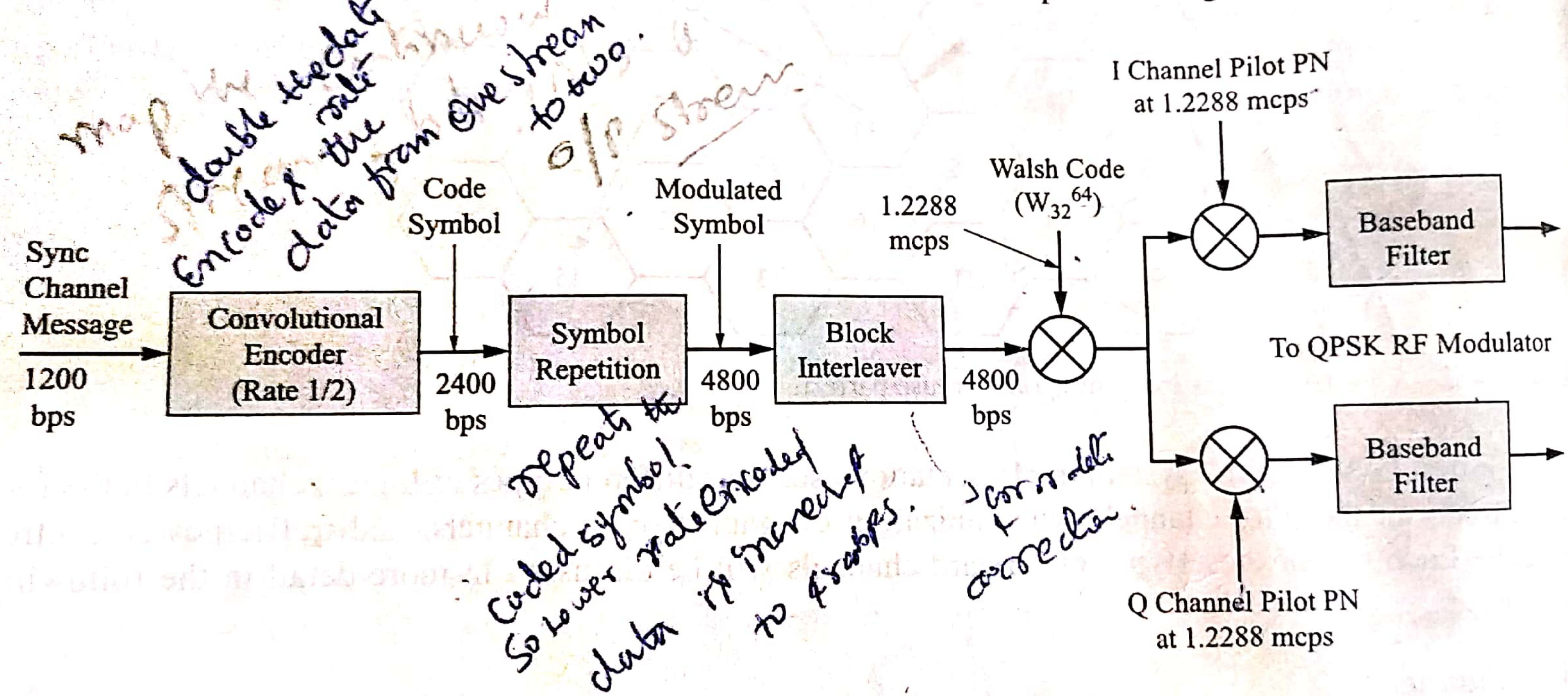
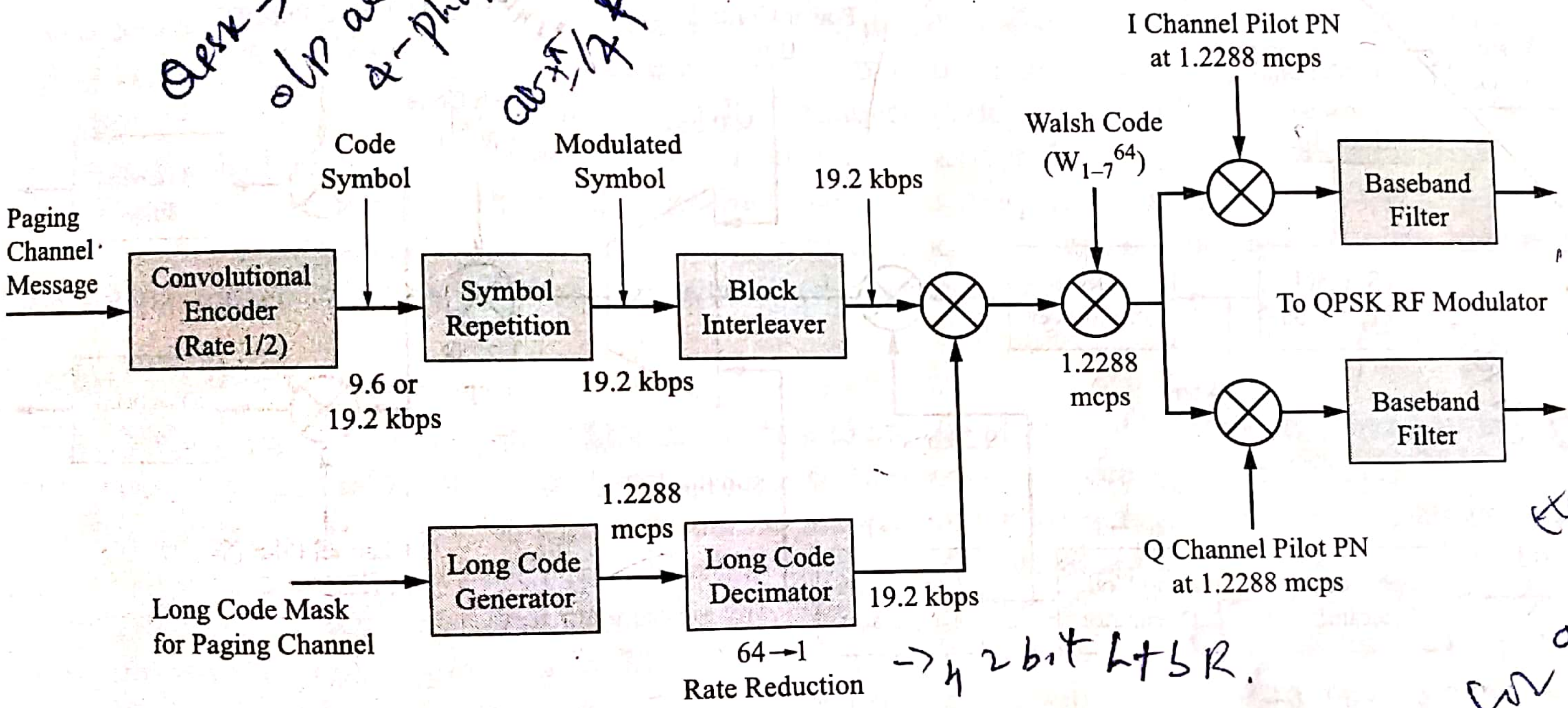


Figure 6–14 Generation of the CDMA synchronization channel signal.

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

QPSK → the binary I & Q o/p are mapped onto 4-phase 8 quadr at π/4, 3π/4

F-C → 869 to 894
Rv → 824 - 849 MHz



→ 42 bit LFSR.

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

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

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

Paging Channels

Paging Channels

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

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

Traffic/Power Control Channels

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

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

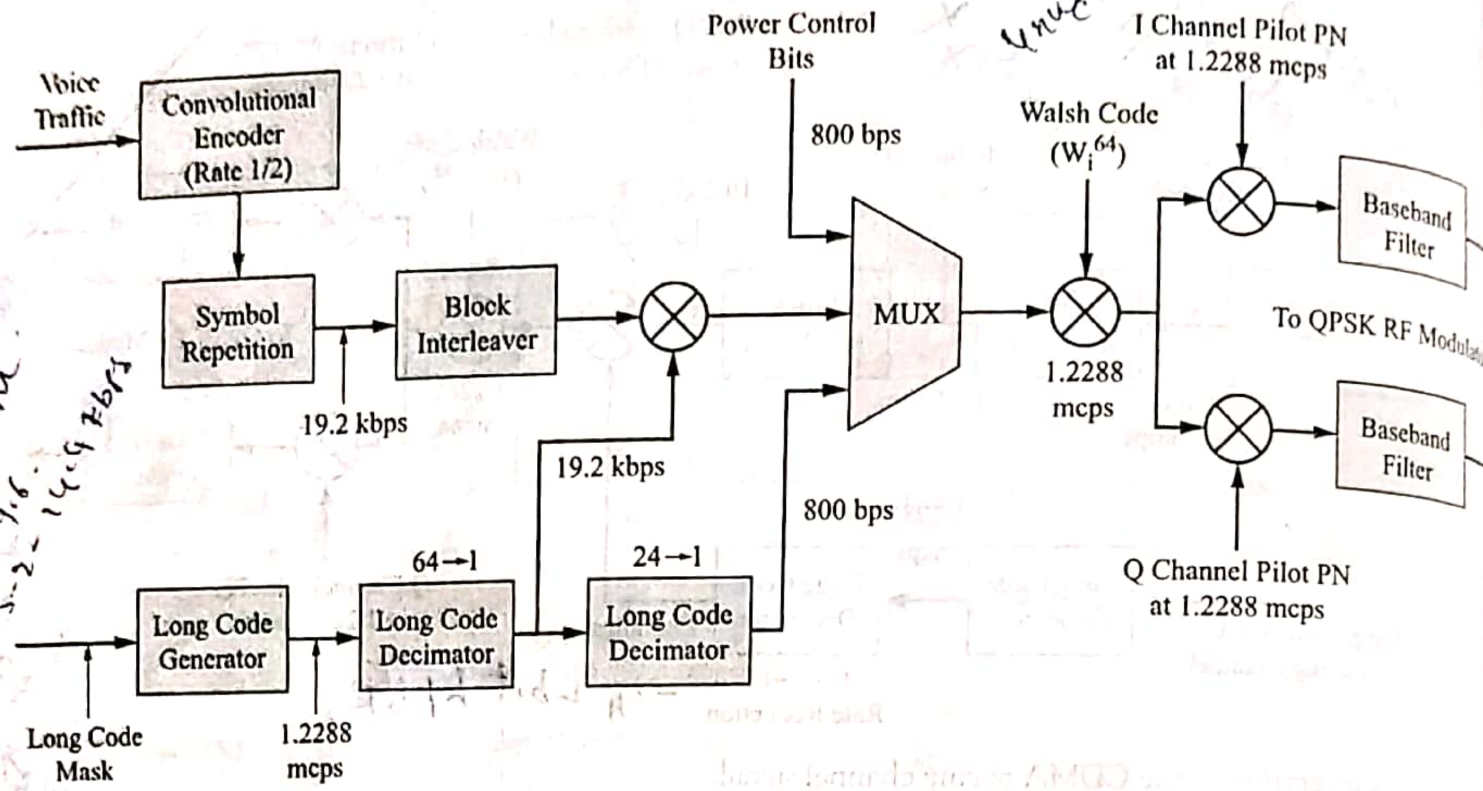


Figure 6–16 Generation of the CDMA forward traffic/power control channel for 9.6-kbps traffic.

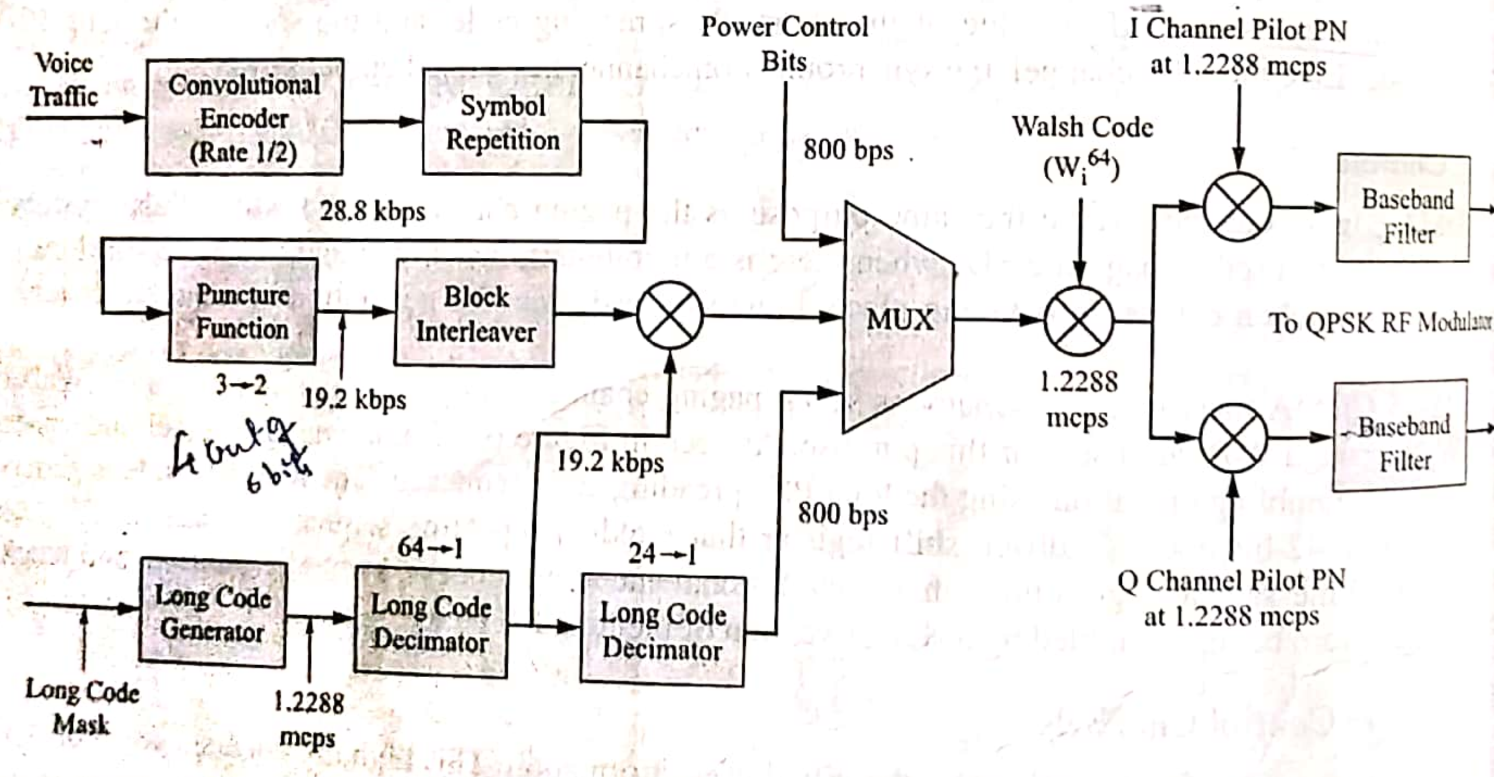


Figure 6–17 Generation of the CDMA forward traffic/power control channel for 14.4-kbps traffic.

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

Reverse Logical Channels

The IS-95 CDMA reverse logical channels exist between the subscriber devices and the CDMA base station. As mentioned previously, the encoding of digital information on the reverse channels is performed differently than on the forward channels. The data to be transmitted is not initially spread by a Walsh codes; instead, the data is mapped into Walsh codes that are then transmitted. Since there are sixty-four, 64-bit Walsh codes, every 6 bits of data to be transmitted may be mapped to a particular Walsh code. This technique yields an over tenfold increase in bandwidth since 64 bits are now transmitted for every 6 bits of data; however, the system error rate is reduced in the process. The mapping of groups of 6 data bits to a Walsh code is very straightforward since there exists a one-to-one relationship between the two.

Each reverse channel is spread by a long PN sequence code and scrambled by the short PN sequence code. The long PN sequence code is derived from the subscriber device's 32-bit electronic serial number (ESN) and therefore provides the means by which the user is uniquely identified within the CDMA system. There are basically two types of reverse CDMA channels: access channels and reverse traffic/control channels. These logical channels will be further described in the next sections.

Access Channels

The CDMA access channels are used by the mobile to answer pages and to transmit control information for the purpose of call setup and tear down. Figure 6–18 shows the access channel processing for a IS-95 CDMA system. As shown in the figure, an access message at 4.8 kbps undergoes the familiar convolutional encoding, symbol repetition, and block interleaving that raises the data rate to 28.8 kbps. At this point, the orthogonal modulation subsystem processes the signal by encoding every 6 bits into a 64-bit Walsh code. This process raises the signal rate to 307.2 kcps. The reader should note the use at this time of chips per second (cps) instead of bits per second. This is standard notation within the CDMA industry when referring to the signal spreading process. Next, the long PN code spreads the signal by a factor of 4 that yields a chip rate of 1.2288 mcps. The signal is further scrambled by the short PN sequence codes. The long PN code is used by the system to differentiate the thirty-two possible access channels.

6 bits data walsh code

I Channel Pilot PN
at 1.2288 mcps

Access Channels

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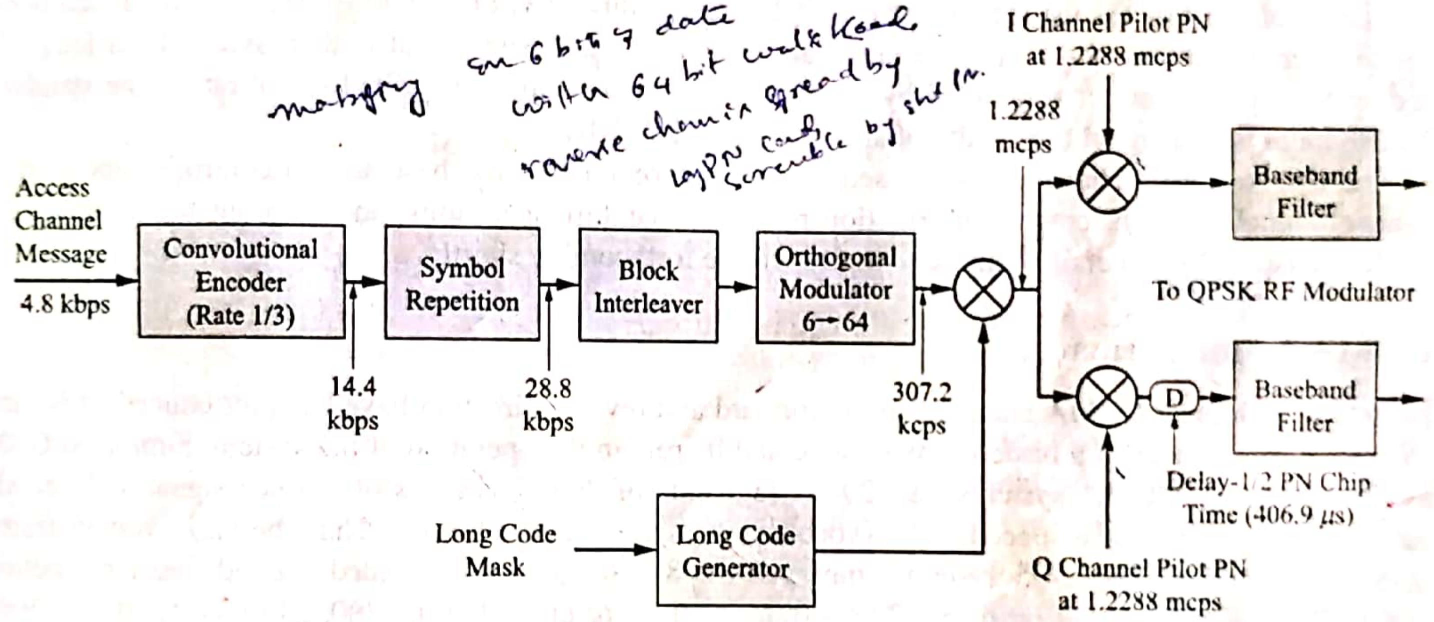

Figure 6–18 Generation of the CDMA reverse access channel.

At this point, the CDMA signal is applied to an RF quadrature modulator subsystem or IC. However, for the reverse channels, the form of modulation used to produce the final UHF passband signal is slightly different than for the forward channels. In this case, offset QPSK (OQPSK) is used instead of straight QPSK as in the case of the forward channels. Note the delay block of one-half of a PN chip (406.9 ns) used in the Q path to implement the OQPSK modulation. This form of modulation allows for a more power efficient and linear implementation by the subscriber device's RF electronics. As noted previously, any type of power savings technique that can lengthen battery life is usually employed when designing a mobile subscriber device.

Traffic/Power Control Channels

The IS-95 CDMA reverse traffic/power control channels support both voice and data at the two rate sets (RS1 and RS2) previously introduced. Figure 6–19 depicts the generation of a reverse traffic channel. In

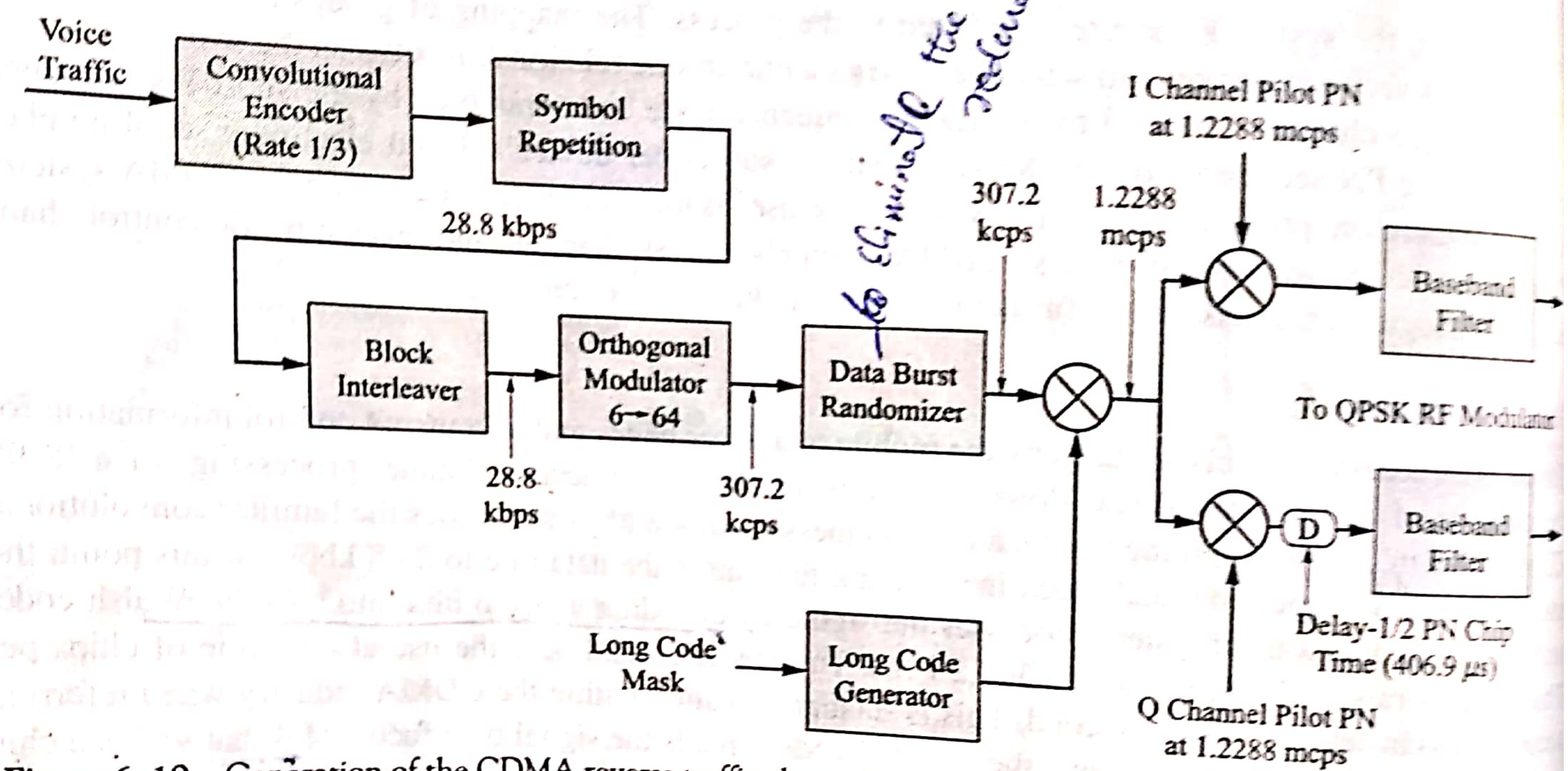

Figure 6–19 Generation of the CDMA reverse traffic channel.

either rate set case, the data rate at the input to the orthogonal modulator subsystem will be 28.8 kbps. At the output of this process the signal rate is 307.2 kcps. At this point the signal is processed by a data burst randomizer that in essence is used to eliminate redundant data. The signal is then spread by a long PN sequence code and further scrambled by the short PN sequence code. The final signal rate is the standard 1.2288 mcps with a signal bandwidth of approximately 1.25 MHz.

The reverse traffic channel is also used to send information to the base station controller about pilot channel signal strength, control information regarding handoff operations, and ongoing frame error rate (FER) statistics. More detail about these topics will be forthcoming shortly.

channel signal strength, control information regarding handoff operations, and ongoing frame error rate (FER) statistics. More detail about these topics will be forthcoming shortly.

CDMA Frame Format

Now that the logical CDMA channels in the forward and reverse direction have been introduced, it is time to examine the format of a basic CDMA frame and its role in the operation of the system. Similar to GSM system operation, CDMA systems take 20-ms segments of digital samples of a voice signal and encode them through the use of a speech coder (vocoder) into variable rate frames. Thus the basic system frame size is 20 ms. The first IS-95 systems employed the 8-kbps Qualcomm-coded excited linear prediction (QCELP) speech coder that produced 20-ms frame outputs of either 9600, 4800, 2400, or 1200 bps (Rate Set 1), with the addition of overhead (error detection) bits. The actual net bit rates are 8.6, 4.0, 2.0, or 0.8 kbps. A second encoder, the 13-kbps QCELP13 encoder, was introduced in 1995 and produced outputs of 14.4, 7.2, 3.6, and 1.8 kbps (Rate Set 2), with a net maximum bit rate of 13.35 kbps. In each case, the speech encoder makes use of pauses and gaps in the user's speech to reduce its output from a nominal 9.6 or 14.4 kbps to lower bit rates and 1.2 or 1.8 kbps during periods of silence.

The basic 20-ms speech encoder frame size is used in various configurations by several of the logical channels to facilitate CDMA system operation, increase system capacity, and improve mobile battery life. The next several sections will detail these operations.

Forward Channel Frame Formats

Of the four forward logical channels, only the pilot channel does not employ a frame format. It consists of a continuous transmission of the system RF signal (refer back to Figure 6–14). The forward traffic channel frames are 20 ms in duration and contain a varying number of information bits, frame error control check

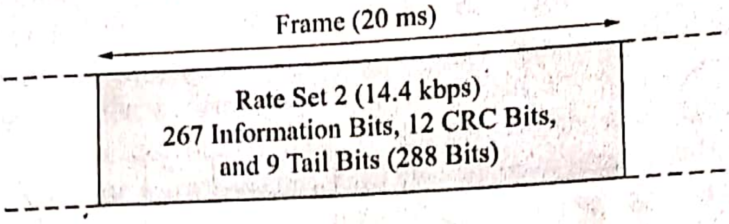

Figure 6–20 Rate Set 2 traffic channel structure.

bits, and tail bits depending upon the rate set and the data rate. Figure 6–20 depicts a forward traffic frame for Rate Set 2 at 14.4 kbps. The forward traffic channel frames are further logically subdivided into sixteen 1.25-ms power control groups. Power control bits transmitted over the forward traffic channels are randomly inserted into the data stream of each 1.25-ms power control group yielding a power control signal rate of 800 bps. More detail about the power control operation will be forthcoming later in this chapter.

The CDMA forward synchronization (sync) channel provides the mobile or subscriber device with system configuration and timing information. A sync channel message can be long and therefore the message is typically broken up into sync channel frames of 32 bits each. The sync channel frame consists of a start of message (SOM) bit and 31 data bits. The start of a sync message is indicated by a SOM bit set to 1 in the first frame and 0 in subsequent frames of the same message. At a data rate of 1200 bps, a sync channel frame is 26.666 ms in duration (the same repetition period employed by the short PN codes). Three sync channel frames of 96 bits form a sync channel superframe of 80-ms duration (equal to four basic 20-ms frames). The sync message itself consists of a field that indicates the message length in bits, the message data bits, error checking code bits, and additional padding bits (zeros) as needed.

The forward paging channels are used by the CDMA base station to transmit system overhead information and mobile station-specific messages. In IS-95A, the paging channel data rate can be either 4800 or 9600 bps. The paging channel is formatted into 80-ms paging slots of eight half frames of 10-ms duration. Each half frame starts with a synchronized capsule indicator (SCI) bit that is functionally similar to the SOM bit. A synchronized paging channel message capsule begins immediately after an SCI bit set to 1. To accommodate varying-length paging messages and to prevent inefficient operation of the paging channel, additional message capsules may be appended to the end of the first message capsule if space is available within the half frame or subsequent half frames. A paging message must be contained in at most two successive slots.

Furthermore, the paging channel structure is formatted into paging slot cycles to provide for increased mobile station battery life. A CDMA mobile may operate in either a slotted or unslotted mode. In the unslotted mode the mobile reads all the page slots while in the *mobile station idle state*. In the slotted mode, the mobile wakes up periodically to check for paging messages directed to it in specific preassigned slots (again, in the *mobile station idle state*). Therefore, slotted mode operation permits the mobile station to power down energy-consumptive RF electronic circuitry until its specific paging slot arrives. The mobile station will wake up for one or two paging slots (if required) of the paging slot cycle. The length of the paging cycle can vary from a minimum of sixteen slots (1.28 s) to a maximum of 2048 slots (163.84 s) (see Figure 6–21 for a diagram of the paging channel structure) as established by the system. Typically, minimal length cycles are employed; otherwise, significant delays in call termination could result. The CDMA system uses the mobile station's ESN to determine the correct slot to use for paging of the mobile. Further power savings are realized while in slotted mode by the transmission of a _DONE message by the base station after the end of the paging message scheduled for the particular mobile. In the case of a short message that uses only several half frames of a slot, the mobile can power down before the end of the slot to save even more battery power.

Reverse Channel Frame Formats

station will ...

The mobile station ... length of the paging cycle can vary from a minimum of sixteen slots (1.28 s) to a maximum of 2048 slots (163.84 s) (see Figure 6–21 for a diagram of the paging channel structure) as established by the system. Typically, minimal length cycles are employed; otherwise, significant delays in call termination could result. The CDMA system uses the mobile station's ESN to determine the correct slot to use for paging of the mobile. Further power savings are realized while in slotted mode by the transmission of a _DONE message by the base station after the end of the paging message scheduled for the particular mobile. In the case of a short message that uses only several half frames of a slot, the mobile can power down before the end of the slot to save even more battery power.

Reverse Channel Frame Formats

The reverse traffic channel, like the forward traffic channel, is also divided into 20-ms traffic channel frames. The reverse traffic channel frame is also further logically subdivided into sixteen 1.25-ms power control groups. As was the case for the forward traffic channel, variable rate ... reverse traffic channel. The coded bits from the convolutional encoder used in the reverse traffic channel are repeated before interleaving when the speech characteristics are such that the encoded data rate is less than the maximum. When the mobile transmit data rate is maximum, all sixteen power control groups are transmitted. If the transmitted data rate is one half of the maximum rate, then only eight power control groups are transmitted. Similarly, for a transmitted data rate of one-quarter or one-eighth, only four or two power control groups are transmitted per frame, respectively. As mentioned, this process, termed *burst transmission*, is made possible by the fact that reduced data rates have built-in redundancy that has been generated by the code repetition process. A data burst randomizer ensures that every repeated code symbol is only transmitted one time and that the transmitter is turned off at other times. This process reduces interference to other mobile stations operating on the same reverse CDMA channel by lowering the average transmitting power of the mobile and hence the overall background noise floor. The data burst randomizer generates a random masking pattern for the gating pattern that is tied to the mobile station's ESN. Figure 6–22 shows this process in more detail.

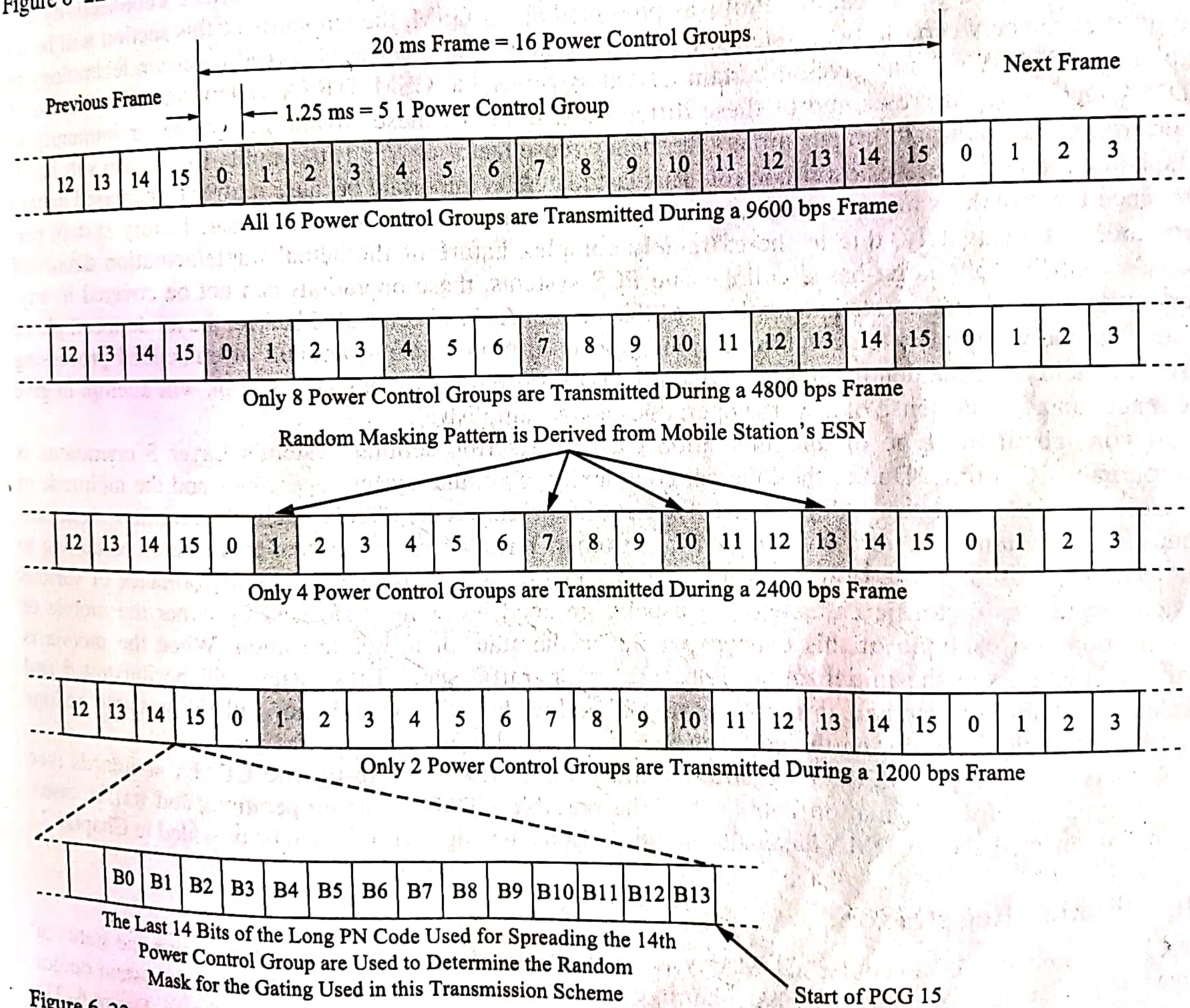

Figure 6–22 CDMA reverse channel variable data rate transmission.

The reverse access channel is used by the mobile station to communicate with the base station. The access channel is used for short message exchanges, such as responses to commands from the base station, for system registrations, and for call origination requests. The access channel data rate is 4.8 kbps using a

20-ms frame that contains 96 information bits. Each access channel message is typically composed of several access channel frames.

Since multiple mobile stations associated with the same paging channel may try to simultaneously access the same access channel, a random access protocol has been developed to avoid signal/data collisions. This topic will be discussed further in the next section about CDMA System Operations.

6.4 CDMA SYSTEM (LAYER 3) OPERATIONS

Initialization/Registration

As is the case with GSM cellular, CDMA system registration procedures are dependent upon the status of the mobile station. The mobile may be either in a detached condition (powered off or out of system range) or in an attached condition. When first turned on, the mobile goes through a power-up state (see Figure 6–23) during which it selects a CDMA system and then acquires the pilot and sync channels, which allows it to synchronize its timing to the CDMA system. When attached, the mobile may be in one of three states: the mobile station idle state, the system access state, or the mobile station control on the traffic channel state (see Figure 6–24).

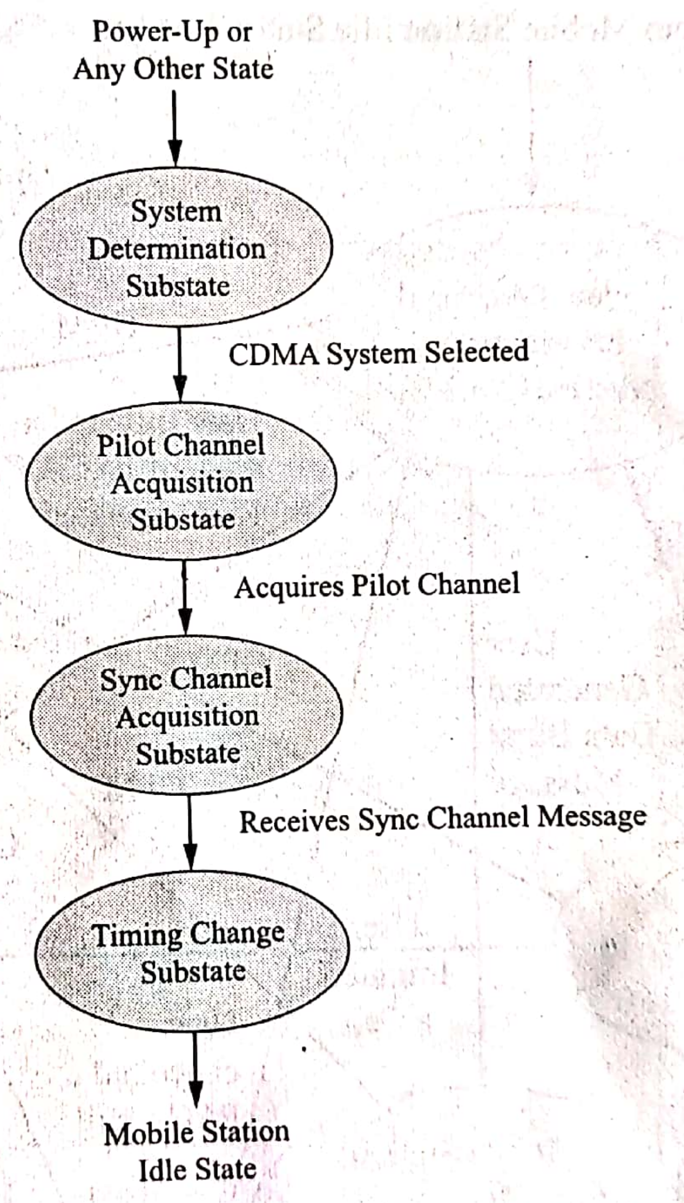

Figure 6–23 CDMA mobile station initialization state (Courtesy of 3GPP2).