

Chapter #4

An Overview of IS-95 and cdma2000

Key words: IS-95, cdma2000

Abstract: The cdma2000 system is the third-generation extension of the existing IS-95 CDMA system currently deployed worldwide. This chapter presents an overview of the cdma2000 air interface, starting from the original derivation of IS-95 and leading into the enhancements that make up cdma2000.

1. INTRODUCTION

Qualcomm Incorporated beginning in the mid-1980's developed the first CDMA system deployed for commercial use in the cellular band. This system was considered an attractive alternative to the existing FDMA technologies (AMPS, primarily) and TDMA systems (IS-54, IS-136, GSM) that were in use during this era. One of most interesting potential benefits of CDMA was the potentially enhanced voice capacity when compared to other competing wireless cellular systems.

However, previous work had already been performed in the area of spread spectrum communications as applied to cellular systems. For instance, Prof. George Cooper's work at Purdue University in the late 1970's also covered many of the same issues Qualcomm had to overcome in making CDMA viable for mass commercial deployment (for instance, [1]). In particular, Cooper recognized the need for some type of power control system for mobile users so as to overcome the near-far effect prevalent in CDMA systems.

While Qualcomm had the benefit of Cooper's previous work when laying the foundation for a commercially viable CDMA system, the need for a practical power control system and a means for mobility were still critical. In AMPS and TDMA systems, mobiles could roam from one base station to another based on the fact that each neighboring base station occupied

different frequencies on both the transmit and receive bands. As a result, such systems are hampered by the *frequency reuse factor*, which places a practical limit on the minimum number of neighboring base stations in a hexagonal grid that may use different frequencies. CDMA on the other hand was supposed to avoid these types of problems due to the fact that all base stations within a network could use the same frequency and any interference which one CDMA base station imposes on another could be suppressed in despreading the signal. However, this posed a problem: how does a mobile move from one base station to another without breaking the connection? Recall that mobiles in a CDMA system in general are in continuous communication with the base station. However, in a TDMA system, mobiles may monitor or initiate contact with other base stations prior to a handover during the periods of time where the mobile is not directly communicating with the base station, i.e. "break before make." CDMA systems solve this problem with the concept of soft handoff, which entails the mobile being in simultaneous communication with several base stations at once. Once the mobile roams from one base station to another, there is no need to suspend communication with either base station in the process. This feature also leads to some diversity benefits and potentially lowers the probability of dropped calls as a result of mobility.

1.1 Standardization History

Qualcomm's innovations in the area of CDMA for cellular systems resulted in the Telecommunications Industry Association (TIA) developing the IS-95 standard [2]. This standard formed the basis for the first CDMA systems deployed in the cellular band (from 800 to 900 MHz) in North America. This development eventually led to the TIA working with the T1P1 to develop the J-STD-008 [3] standard for the PCS band (from 1800 to 1900 MHz). Since then, there has been some effort to enhance symmetric data rates for IS-95, resulting in the formation of a new standard in 1998, IS-95-B.

Since then, the focus has been on developing the third-generation version of IS-95, which was entitled cdma2000. This effort was initiated in response to the International Telecommunications Union's IMT-2000 effort, which was designed to arrive at a global third-generation radio system. The initial development resulted in the submission of the candidate "radio technology text" (RTT) for cdma2000 by the TIA to the ITU in the middle of 1998.

In response to the growing need to address the interests of cdma2000 operators worldwide, the *Third-Generation Partnership Project 2* (3GPP2) was created at the end of 1998. The standardization bodies involved in the formation of the 3GPP2 were the TTA, the Association of Radio Industries and Businesses (Japan), the Telecommunication Technology Committee (Japan), the Telecommunication Technology Association (Korea), and the China Wireless Telecommunications Standards Group (People's Republic of China). The 3GPP2 was placed in charge of developing a global cdma2000-based standard.

In spring, 1999, a group of cellular operators and vendors worldwide known as the Operators Harmonization Group (OHG) agreed upon a global CDMA standard that encompassed cdma2000 and the standard being developed by the Third-Generation Partnership Project (3GPP) for Wideband CDMA (WCDMA). This agreement called for two types of systems: a direct-spread (DS) system and a multicarrier (MC) system. The DS system was based on WCDMA, while the MC system was based on cdma2000.

The 3GPP2 has continued in developing the multicarrier version of cdma2000, not only defining the air interface but also defining the core network and network interfaces as well. In 1999, work was initiated on the first packet-switched core network for an IS-95 based system in the 3GPP2. In addition, a global A-interface was developed for cdma2000 (Interoperability Specification, or IoS) that allowed for multi-vendor radio access networks.

The spectral deployment for IS-95 and cdma2000 systems is primarily in the cellular and PCS bands in North America. Both parts of the spectrum are deployed in *paired bands*, meaning that reverse link (uplink) and forward link (downlink) transmission is performed over separate parts of the spectrum that are associated with one another. The cellular band reverse link spectrum allocation is between 824 and 849 MHz, while the associated forward link allocation is between 869 and 894 MHz. These frequencies are also applicable to South Korea, the other major area of IS-95 deployment. Similarly, the PCS band deployment is between 1850 and 1910 MHz for the reverse link, and 1930 and 1990 MHz for the forward link. The PCS frequencies in South Korea and Japan are nearly the same.

2. OVERVIEW OF IS-95 AIR INTERFACE

The IS-95 system was originally designed to work in the cellular band in North America, leading to a necessity for a 1.25 MHz system. This was a result of the 30 kHz center frequency spacing in the cellular band. As a result, certain modulation and spreading parameters were chosen with this limitation in mind.

The IS-95 system achieved channelization in the forward link and reverse link using different means. Channelization in the forward link was accomplished through the use of orthogonal Walsh codes, while channelization in the reverse link was achieved using temporal offsets of the spreading sequence.

Different base stations are identified on the downlink based on unique time offsets utilized in the spreading process. Therefore, all base stations must be tightly coupled to a common time reference. In practice, this is accomplished through the use of the *Global Positioning System* (GPS), a satellite broadcast system that provides information on Greenwich Mean Time and can be used to extract location information about the receiver. This common time reference is known as *system time*.

There are two types of PN spreading sequences used in IS-95: the *long* code and the *short* codes. Both the PN sequences are clocked at 1.2288 MHz, which is the chipping rate. Two short code PN sequences are used since IS-95 employs quadrature spreading. These two codes are the in-phase sequence $P_I(x) = x^{15} + x^{13} + x^9 + x^8 + x^7 + x^5 + 1$ and the quadrature sequence $P_Q(x) = x^{15} + x^{12} + x^{11} + x^{10} + x^6 + x^5 + x^4 + x^3 + 1$. These two sequences are generated length-15 shift register sequences; although they are nominally $2^{15}-1=32767$ chips, a binary '0' is inserted in each sequence after a string of fourteen consecutive 0's appears in either sequence to make the final length of the spreading sequence an even 32768 chips.

The long code is given by the polynomial $p(x) = x^{42} + x^{35} + x^{33} + x^{31} + x^{27} + x^{26} + x^{25} + x^{22} + x^{21} + x^{19} + x^{18} + x^{17} + x^{16} + x^{10} + x^7 + x^6 + x^5 + x^3 + x^2 + x^1 + 1$. It is of length $2^{42}-1$ chips as it is generated by a 42-length shift register. It is primarily used for privacy, as each user of the mobile network may be assigned a unique temporal offset for the long code with reference to system time. Since the long code has a period of 41 1/2 days, it is nearly impossible to blindly detect a user's temporal offset. The offset is accomplished with the use of a long code mask, which is a 42-bit value that is combined with the shift

register state using a logical AND operation. The modulo-2 sum of the 42 bits which result from this AND operation provide a time-shifter version of the long code sequence.

The particulars of the IS-95 air interface will be presented in the ensuing sections. In order to facilitate description of the air interface, the forward link and reverse link descriptions will be presented separately.

2.1 IS-95 Forward Link

The IS-95 forward link is designed in such a way to take advantage of the inherent ability of CDMA systems to use a frequency reuse factor of 1. Moreover, the IS-95 forward link is also designed in a way to achieve coherent reception at mobile receivers by means of a pilot signal.

Channelization by means of code multiplexing is a fundamental feature of IS-95 systems. In particular, channelization is accomplished using length-64 Walsh codes, which are assigned to different channels. Recall from Chapter 2 that Walsh codes can be generated recursively; using this approach, all 64 length-64 Walsh codes can easily be generated and indexed according to their row number in the 64 by 64 Walsh matrix.

The types of channels used can be grouped into *common* channels and *dedicated* channels. Common channels are *broadcast* to all the users in the cell served by the base station. Dedicated channels are meant to be heard by only one user.

2.1.1 Common Channels

The three types of common channels used in IS-95 are the Pilot, Sync and Paging channels. Each has a unique Walsh code associated with it, and serves a particular purpose in the IS-95 forward link.

2.1.1.1 Pilot Channel

The mobile uses the pilot channel for the following purposes:

- a. Multipath channel amplitude estimation for coherent detection
- b. Timing recovery for synchronization to network time reference (GPS-based)

- c. Frequency offset correction for the mobile receiver
- d. Pilot strength measurements for soft and hard handoff decisions

There are also several other possible uses for the pilot at the mobile receiver, such as interference correction and interfrequency handoff measurements.

The pilot channel must be a known sequence to be useful at the mobile station. In this case, the pilot channel is simply all-binary 0's (see Figure 1).

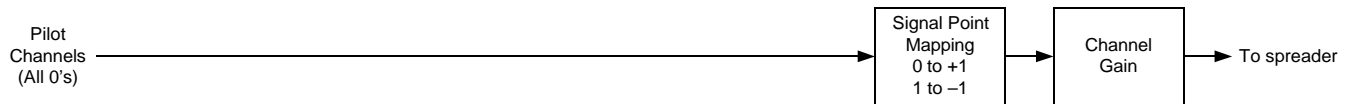


Figure 1: IS-95 Pilot Channel

The pilot channel undergoes orthogonal modulation with Walsh code 0, which is the first row of the Walsh-64 matrix and is the all binary-0's code. Since the orthogonal modulation of a binary 0 with a binary 0 is a binary 0, this actual operation does not have to be carried out in the spreading process. Instead, a stream of binary 0's is transmitted at the chipping rate for the pilot channel

The pilot channel must be transmit at a sufficiently high power such that mobiles at the cell boundaries can still receive it. As a result, the pilot must occupy a significant amount of base station transmitter power (typically 20% of the total power).

2.1.1.2 Sync Channel

The sync channel is primarily used by the mobile to acquire a timing reference. The mobile station, when it acquires the pilot channel, knows the PN timing of that particular base station. However, the mobile does not know how the timing of this base station relates to other base stations in the network.

Recall that an IS-95 system requires base stations to transmit at fixed time offsets from GPS-based time. This synchronization to system time ensures that one base station's signal does not interfere with another, as the partial correlation properties of the PN sequences used will allow the mobile to despread the desired base station and suppress other base station signals.

The Sync Channel Message appears on the sync channel to let the mobile know timing parameters such as the PN timing offset of the base station relative to system time. The bit rate of this message is 1.2 kbps. This

message is then convolutionally-encoded, repeated and block interleaved. The block interleaver depth is a function of the sync channel frame duration, which is $26 \frac{2}{3}$ ms.

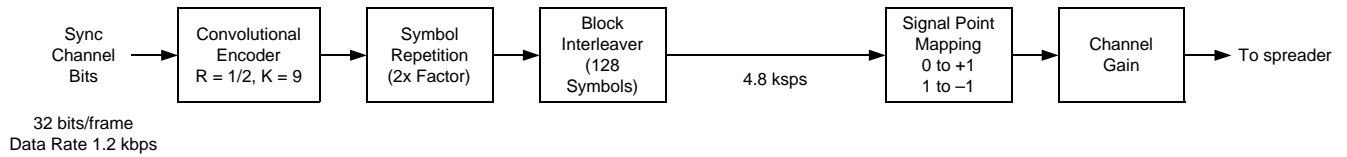


Figure 2: IS-95 Sync Channel

The sync channel undergoes orthogonal modulation via the length-64 Walsh code with row index 32.

2.1.1.3 Paging Channel

Up to 7 paging channels, each with their own unique Walsh code, may be used by the IS-95 base station. This channel provides system parameters, voice pages, short message services, and any other broadcast messaging to users in the cell. The paging channel can take two bit rates, 4800 bps or 9600 bps. The rate is given in the Sync Channel Message. This paging channel bits are then convolutionally-encoded, repeated and block interleaved. The block interleaver depth is a function of the paging channel frame duration, which is 20 ms.

The paging channel interleaver output bits are then scrambled. "Scrambling" entails an modulo-2 addition of the input bit and a bit from a predetermined sequence. In this case, the predetermined sequence is the long code generator sequence with a mask unique to the particular paging channel being used. This sequence is decimated from the nominal 1.2288 MHz rate to the necessary 19.2 kHz rate for scrambling by simply taking every 64'th bit from the masked long code generator output.

The basic modulation is shown in Figure 3.

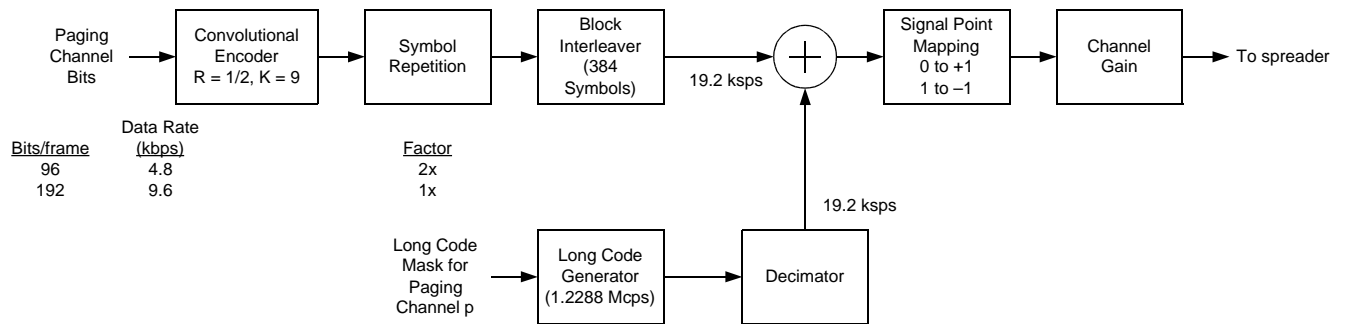


Figure 3: IS-95 Paging Channel

2.1.2 Dedicated Channels

Dedicated channels deliver user traffic and user-specific signalling. There are two types of dedicated channels that are used in IS-95: the forward fundamental channel and the forward supplemental code channel. The forward fundamental channel was simply called the forward traffic channel in IS-95-A, as it was the only channel capable of delivering dedicated traffic. In IS-95-B [4], the forward supplemental code channel was introduced as a means of improving data rates to individual users.

Voice always goes over a fundamental channel and can never go over a supplemental code channel. However, data may travel over both types of channels.

The fundamental channel is variable rate. This is to take advantage of periods of time where the voice activity is low and therefore the voice codec (i.e. *coder/decoder*) rate may be reduced. In IS-95 systems, voice codecs generally take four rates, sometimes denoted as full rate, half-rate, quarter-rate, and eight-rate. The first IS-95 systems used source rates of 9.6 kbps, 4.8 kbps, 2.4 kbps and 1.2 kbps; this set of data rates is known as *Rate Set 1*. These data rates were necessary for the first 8-kbps IS-95 vocoder (i.e. *voice encoder*), known as QCELP8. *Rate Set 2* (14.4 kbps, 7.2 kbps, 3.6 kbps, 1.8 kbps) was introduced to accommodate a 13-kbps vocoder known as QCELP13.

The supplemental code channel is not variable-rate, yet can take either 9.6 or 14.4 kbps forms. This channel is primarily used for providing higher data rates to individual users through the use of *code channel aggregation*,

where an individual user is assigned several supplemental code channels (up to 7) to increase data throughput.

The modulation streams for the two rates sets are shown in Figure 4 and Figure 5.

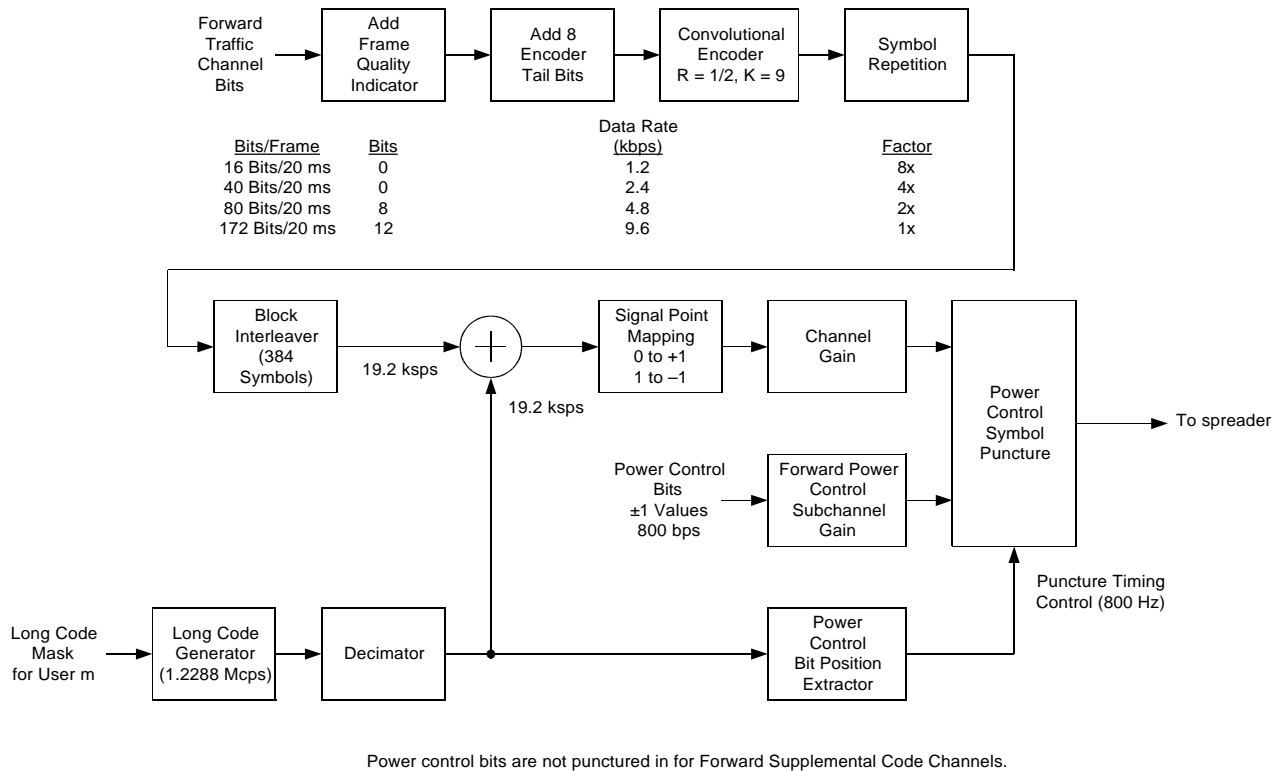
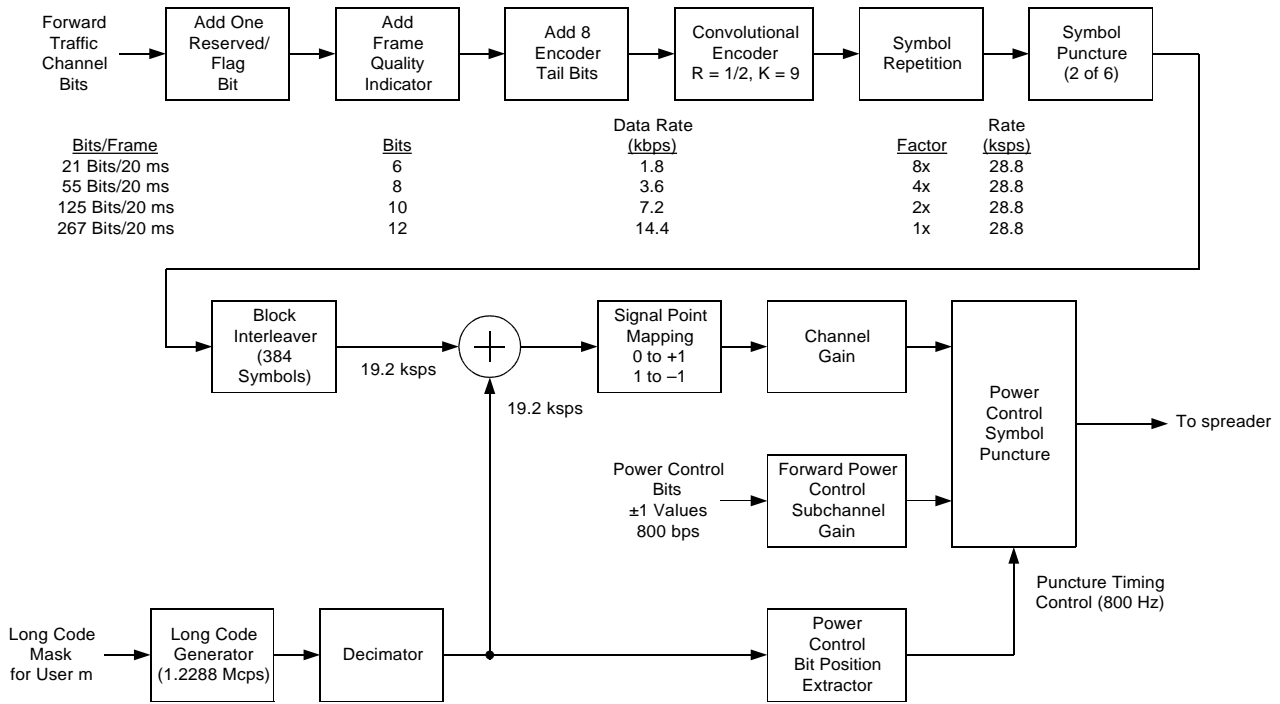


Figure 4: Rate Set 1 Traffic Channel



Power control bits are not punctured in for Forward Supplemental Code Channels.

Figure 5: Rate Set 2 Traffic Channel

Note that each frame is appended with a frame quality indicator, which is a cyclic redundancy check (CRC) that can be used by the receiver for error detection. In addition, each frame is appended with 8 "tail bits", which are binary 0's. The purpose of these bits is to flush the convolutional encoder and return it to the all-0 state at the end of each frame. This is helpful in the decoding process, as each frame can be decoded individually at the receiver.

Note also that a combination of symbol repetition and puncturing is used to keep the input to the block interleaver always at 384 symbols at a time. However, for lower data rates, the corresponding channel gain reduces as the data rate reduces. For instance, if the block interleaver output for full-rate symbols is transmitted with power E_s , the transmit power for a half-rate frame is $E_s/2$, quarter-rate is $E_s/4$, and eighth-rate is $E_s/8$.

The power control subchannel is punctured into the transmitted frame on the fundamental channel only. These are one-bit power control commands punctured at an 800 Hz rate. The puncturing location is randomized based

on the long code state. For the previous power control interval (known as a *power control group*, its duration is 1.25 ms).

2.2 IS-95 Reverse Link

The IS-95 reverse link channels may also be grouped into common and dedicated channels. The common channels in the IS-95 reverse link are meant primarily for tasks such as call origination, registration and authentication, page responses, and delivery of SMS.

Channelization of users in the reverse link is accomplished by the use of long code masks. Recall that each mobile must acquire a system time reference based on the pilot signal it receives from the base station and the associated sync channel information. Therefore, each mobile can utilize a unique long code mask assuming that the mobile's long code generator is synchronized with the long code generator being used by the base station. As a result, the mobile may transmit with a unique long code mask known only to the base station. In reality, due to propagation delays and imperfect timing references at the mobile stations, the base station must also examine other timing offsets near what the mask value indicates when acquiring an individual user. However, this process is still far less complex than if the base station had to blindly acquire the mobile's timing offset.

2.2.1 Common Channels - Reverse Access Channel

The reverse access channel (R-ACH) is the reverse link common channel in IS-95. The basic transmission operations are depicted in Figure 6.

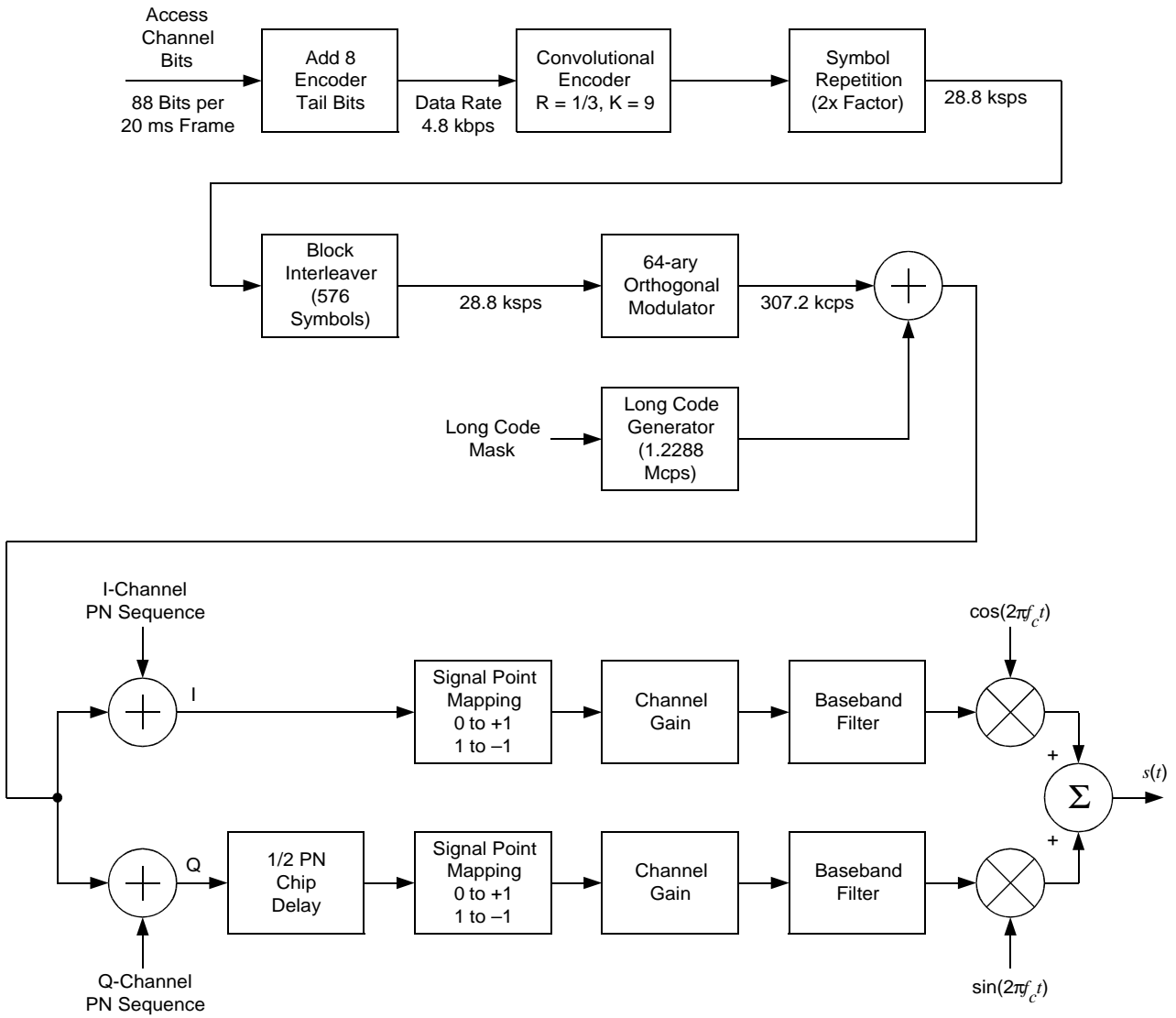


Figure 6: IS-95 Reverse Access Channel

The R-ACH messaging is at 4.8 kbps. It is convolutionally encoded, repeated, and interleaved over 576 symbols. Note that the next step is *64-ary orthogonal modulation*. This step entails grouping each set of 6 consecutive bits output from the interleaver into a row address to a memory that contains the 64 by 64 Walsh matrix. Once a row is selected, all 64 bits that make up the row entry are output at a rate of 307.2 kHz. Since the mobile is not transmitting a pilot signal on the reverse link (unlike the

forward link), coherent detection is not possible. As a result, the base station receiver may correlate the received signal with all of the 64 possible Walsh codes and determine a peak correlation to determine which row was sent. This operation does not require an estimate of the channel amplitude, but receiver performance is worse than if a pilot signal was used.

After orthogonal modulation, the sequence is spread to 1.2288 MHz by the long code; the long code generator state should be synchronized with the base station long code generator based on the information the mobile has received from the sync channel. The signal may now be quadrature spread; however, note the 1/2-chip delay in the Q-branch of the quadrature spreader. This results in *offset-QPSK* modulation. Offset QPSK modulation reduces the *peak-to-average ratio* (PAR) in the signal the mobile must transmit. Reducing PAR reduces the dynamic range one must design a mobile transmitter over, which generally results in simpler design.

2.2.1.1 R-ACH Timing

R-ACH timing is critical, as several mobiles may try to send R-ACH messages simultaneously. As a result, R-ACH messaging is sent in the form of *access probes*. The mobile sends an access probe aligned with system time and waits for a response from the base station on the forward paging channel. If it does not get a response before a timer expires, it sends another probe at a power greater than the previous probe. The power difference between the probes is a fixed step size measured in decibel units.

In order to reduce the probability that mobiles send probes simultaneously (i.e. a "collision" occurs), the access probe timing is aligned with system time and a *random backoff*. Based on a set sequence, the mobile transmits an access probe aligned with 20 ms increments of system time but backed off by a time offset based on the results of the algorithm. Since each mobile's algorithm is based on input parameters unique to the mobile, the chances of collision are reduced. The access probe power over time is shown in Figure 7.

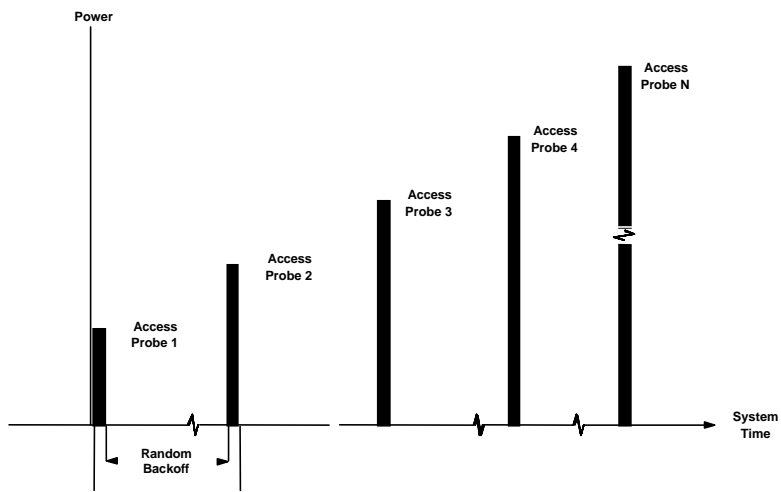


Figure 7: Access Probe Timing

16 probes are allowed in a sequence before the mobile must "give up" and start the process again at the original power levels.

2.2.2 Dedicated Channels

As in the forward link, reverse fundamental and supplemental channels are still applicable. The reverse fundamental channel must be able to deliver variable rate data at Rate Sets 1 and 2 for voice services, while the supplemental channels deliver data at full rate. The basic transmission sequences are depicted in Figure 8 and Figure 9.

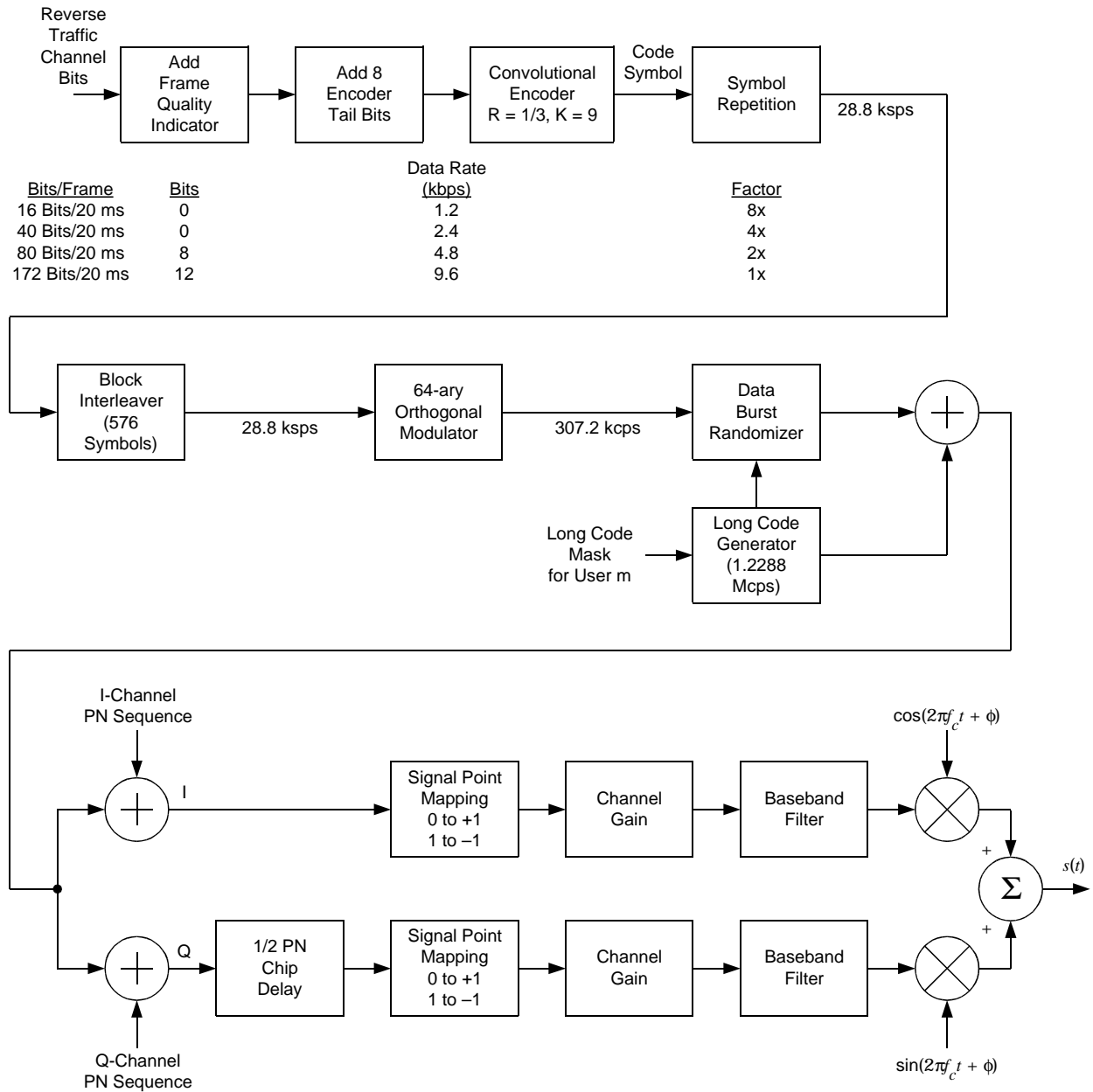


Figure 8: Rate Set 1 Reverse Traffic Channels

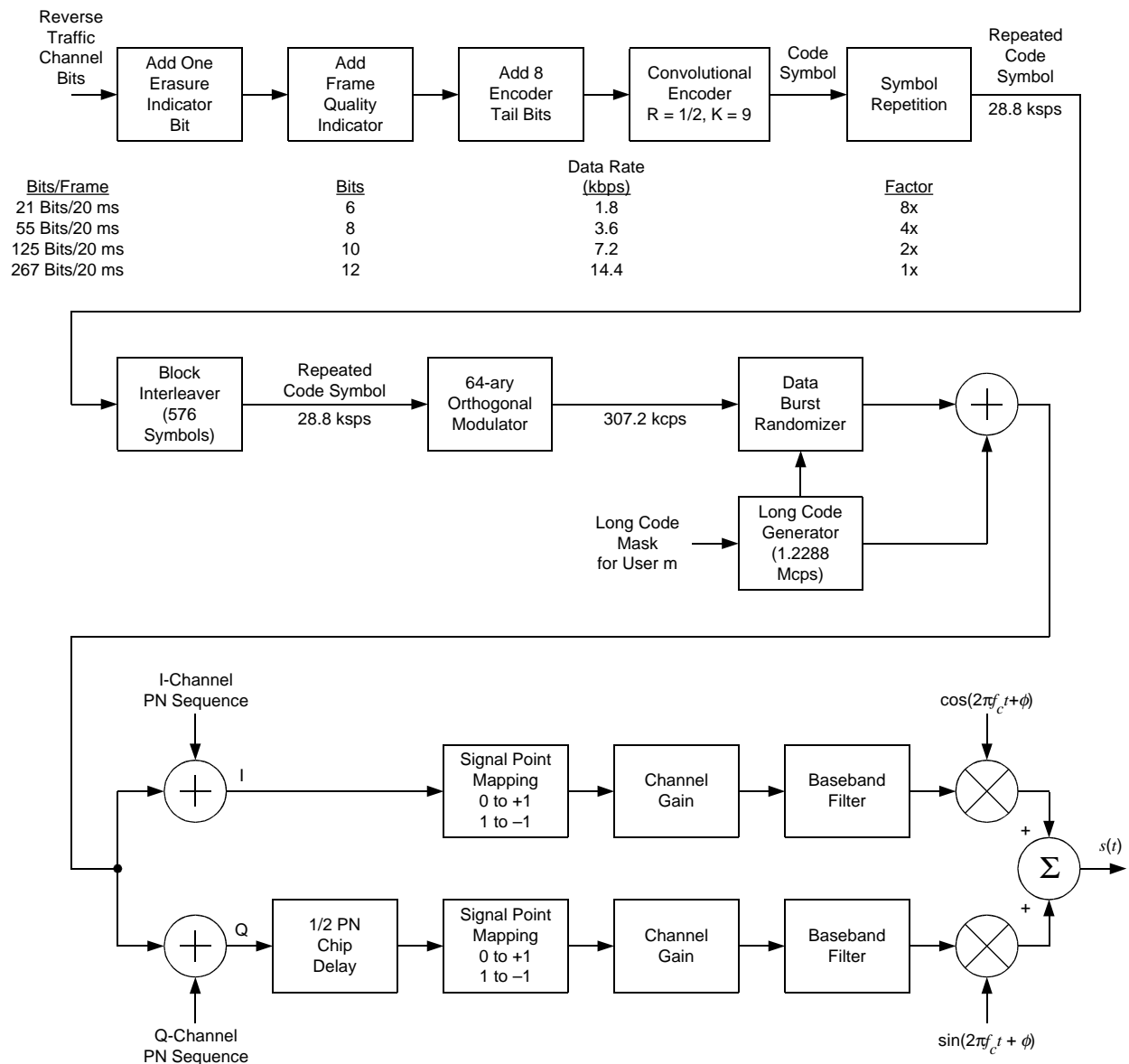


Figure 9: Rate Set 2 Reverse Traffic Channels

The FEC used in the reverse link is rate 1/3 for Rate Set 1, which is different from the forward link that uses rate 1/2. Note also the presence of the *data burst randomizer* for both Rate Sets. Recall that in the forward link for half-rate, quarter-rate and eighth-rate frames, symbol repetition was used with power reduction for each transmitted symbol. Although symbol

repetition is depicted for the reverse link at the input to the interleaver, in fact only one symbol repetition is actually transmitted. The data burst randomizer actually turns off ("gating off" the transmitter) the transmitter during periods where repetitions are transmitted so as to ensure that only one symbol repetition is ever actually sent. The pattern with which symbols are eliminated from the transmission sequence is pseudorandom, determined by the state of the long code generator at each power control group. As a result, the base station receiver must be able to detect these on-off transitions, and the mobile must ignore power control commands sent by the base station in response to a gated-off period.

Note also that the sinusoids used to modulate the spread signal to the carrier frequency have an associated phase offset ϕ . This phase offset is unique to each supplemental channel transmitted by the mobile, and can be determined by an index based on the additional number of supplemental channels used (see Table 1).

Additional Channel	Phase Offset from Fundamental Channel
1	$\pi/2$
2	$\pi/4$
3	$3\pi/4$
4	0
5	$\pi/2$
6	$\pi/4$
7	$3\pi/4$

Table 1: Reverse Supplemental Channel Phase Offsets

2.3 Baseband Pulse Shaping

The pulse-shaping filter specified in IS-95 is depicted in Figure 10. It is nominally a 48-tap finite impulse response (FIR) filter that *does not* satisfy the Nyquist criterion for zero-ISI pulse shaping. However, it does have a spectral characteristic (see Figure 11) that provides isolation for the 1.25 MHz transmitted signal. Given that the processing gain in an IS-95 system is 128, the interchip interference introduced by the filter is considered to be negligible.

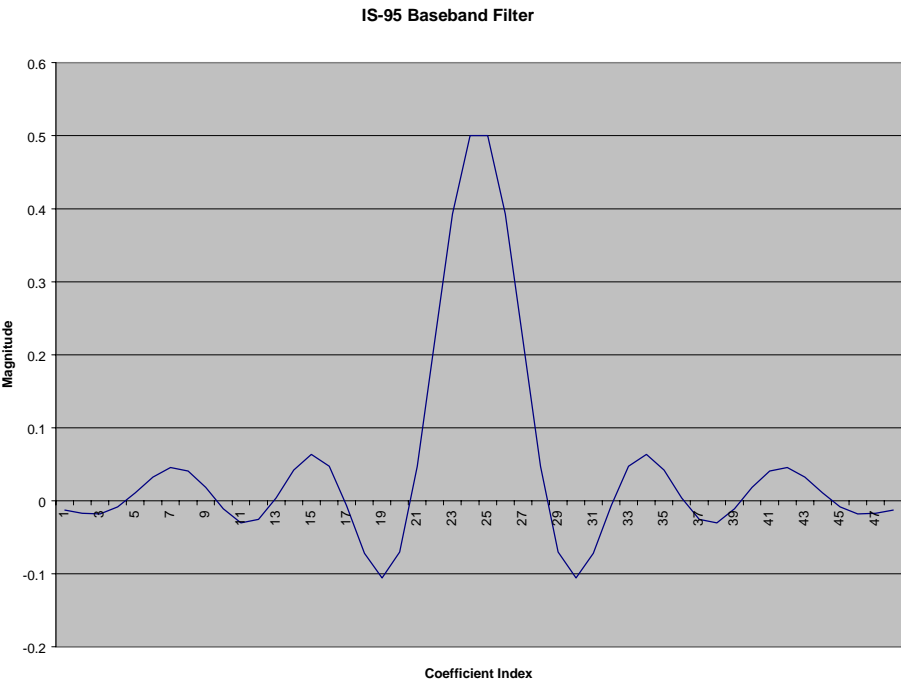


Figure 10: IS-95 Baseband Filter

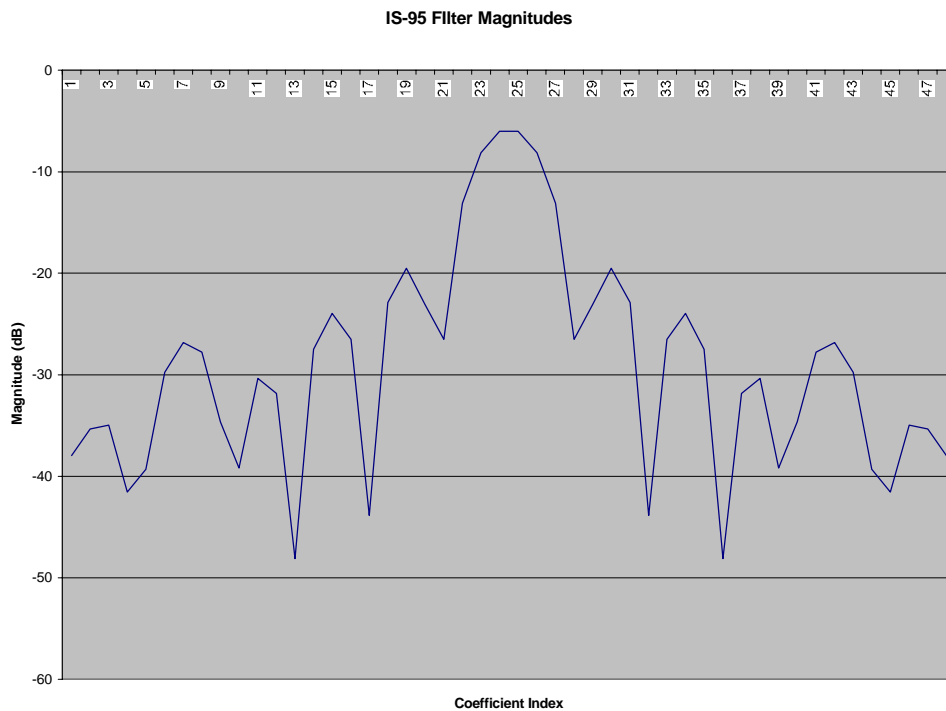


Figure 11: Baseband Filter Magnitude Response

2.4 Power Control

In IS-95, power control exists for the reverse link and forward link. Forward link power control generally operates at a slower rate than reverse link power control.

2.4.1 Reverse Link Power Control

Recall from Chapter 3 that power control in CDMA systems normally requires open loop, closed loop, and outer loop control.

Open loop power control is based on measuring the total in-band received power at the transmitter over a sufficiently long duration of time to attain an accurate mean received power estimate. This power estimate is added to a "turnaround constant" to form a base power level at the transmitter. In fact, due to the need for access probes to establish initial

contact with the base station, the final open loop estimate also includes the power increments for each consecutive access probe.

Closed loop power control in IS-95 works through the use of power control commands inserted at an 800 Hz rate into the forward fundamental channel (see Figure 4 and Figure 5). These one-bit commands instruct the mobile to increase or decrease power in 1 dB increments. It should be noted that there are three consequences of this type of power control mechanism:

- a. The puncturing of traffic symbols with power control bits actually weakens the error-correcting performance of the convolutional code.
- b. The 800 Hz rate at which commands are sent and the 1 dB step size place a restriction as to how small the coherence time (and therefore how large the coherence bandwidth) of the wireless transmission channel can be for power control to be effective.
- c. The power control commands themselves are not protected by an error-correcting code. This allows for quick demodulation of power control commands at the handset, but certain channel conditions could lead to very high error rates in the power control commands themselves.

Finally, outer loop power control works in the same fashion as described in Chapter 3. Outer loop algorithms are not specified in wireless standards normally, as they are considered implementation-dependent.

2.4.2 Forward Link Power Control

Forward link power control works at a much slower rate than reverse link power control in IS-95. For Rate Set 1 applications, the only means of implementing forward link power control is through the *Power Measurement Report Message* (PMRM). This is a message that the mobile may be triggered to send if the frame erasure rate it measures on the forward link traffic it receives exceeds a threshold. A mobile classifies a received frame as an erasure when it cannot detect the frame rate or fails to correctly decode the frame quality indicator. Upon receipt of a PMRM, the base station may choose to increase transmitted power to the mobile in question.

The PMRM-based power control mechanism normally works slowly in typical networks (about 3-4 Hz typically). Therefore, if Rate Set 2 is used, in the outgoing fundamental channel frame, the mobile may set an *Erasure*

Indicator Bit (EIB). This tells the base station whether the most recently received forward link frame was in error. Since the frame rate is 50 Hz, the forward link power control mechanism under Rate Set 2 is also 50 Hz.

2.5 Soft Handoff

Soft handoff in IS-95 requires the mobile to constantly search for multipaths from different base stations even while actively receiving and sending traffic. Soft handoff can be costly for network capacity if not implemented properly, as each base station that the mobile is in simultaneous contact with must allocate resources for the communications link.

In IS-95, the *active set* is the set of base stations (normally identified by their pilot channels, or simply pilots) that the mobile may be in simultaneous contact. This set is controlled by the base station based on measurement information relayed by the mobile (in the form of the *pilot strength measurement message* PSMM). The *candidate set* entails pilots that are not in the active set but can be successfully demodulated by the mobile. The maximum number of pilots in either the active or candidate sets is 6. The *neighbor set* is based on predetermined pilots that are in the vicinity of the base station or base stations the mobile is currently in contact with. This may have as many as 20 pilots in it. The *remaining set* covers all other pilots.

A base station is added to the active set not simply because a mobile determines it is of sufficient strength. The mobile alerts the base station with a PSMM when it detects a pilot has a sufficient strength to be added to the active set. The mobile determines sufficient strength by comparing the pilot E_c/I_{or} (chip energy to total in-band received power ratio) to a network-determined threshold T_{ADD} . This may cause the pilot to be promoted to the candidate set. In addition, the mobile may compare a candidate pilot with members of the active set to see if it exceeds any of the active set pilots by a threshold (T_{COMP}); this can result in a promotion of the pilot from the candidate set to the active set.

Similarly, the base station must also drop pilots from the active set whose strength has dropped below a certain threshold, T_{DROP} . This is also another event that can trigger the mobile to send a PSMM. Threshold comparisons to drop a pilot are timer based, meaning that the pilot must be

below T-DROP for a certain amount of time (given by T_TDROP) before the pilot is demoted.

In addition, the mobile may search for multipaths at certain PN offsets given the network deployment. For instance, if the base station knows the PN offsets of neighboring base stations, it may provide the mobile with search windows. The search windows define a range of time offsets with respect to PN offsets for pilots in the four handoff sets used in IS-95.

2.6 Coding

The type of coding used in IS-95 is convolutional coding (see Section 8.1, Chapter 2). In the forward link, the rate $\frac{1}{2}$ convolutional code discussed in Section 8.1 of Chapter 2 is used (see Figure 15, Chapter 2). In the reverse link, a rate $\frac{1}{3}$ convolutional code is used (see Figure 12).

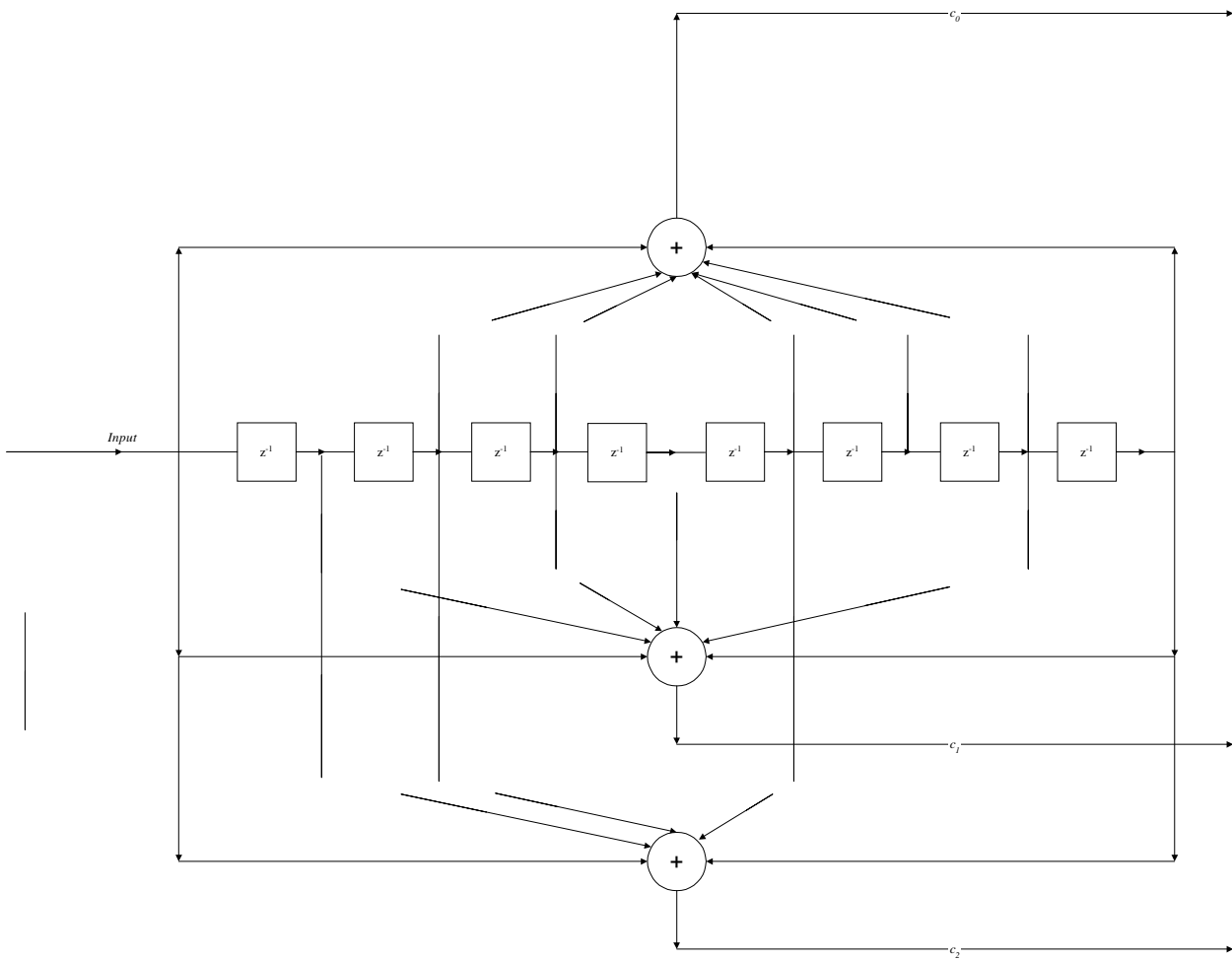


Figure 12: Rate 1/3 Convolutional Code

3. CDMA2000

cdma2000 came about as a response to the ITU's IMT-2000 effort for developing global third-generation wireless services (see Chapter 1). The cdma2000 system developed as a result of the TIA's efforts to evolve TIA/EIA-95B. Although the underlying motivation for evolution of TIA/EIA-95-B was to provide the types of services mandated by the ITU for 3rd Generation systems, cdma2000 was developed with the 2nd Generation system in mind. Therefore, an explicit requirement for cdma2000 was

backwards compatibility. This requirement ensures that 2nd Generation products could be easily evolved to meet 3rd Generation requirements.

3.1 System Design Issues

3.1.1 Bandwidth

An important design goal for all third generation proposals is to limit spectral emissions to a 5 MHz dual-sided passband. There are several reasons for choosing this bandwidth. First, data rates of 144 and 384 kbps, the main targets of third generation systems, are achievable within 5 MHz bandwidth with reasonable coverage. Second, lack of spectrum calls for limited spectrum allocation, especially if the system has to be deployed within the existing frequency bands already occupied by the second-generation systems. Third, the 5 MHz bandwidth improves the receiver's ability to resolve multipath when compared to narrower bandwidths, increasing diversity and improving performance.

3.1.2 Chip Rate

Given the bandwidth, the choice of chip rate depends on spectrum deployment scenarios, pulse shaping, desired maximum data rate and dual-mode terminal implementation. Figure 13 shows the relation between chip rate (CR), pulse shaping filter roll-off factor (α) and channel separation (Δf). If raised cosine filtering is used, spectrum is zero (in theory) after $CR/2 \cdot (1 + \alpha)$. In Figure 13, channel separation is selected such that two adjacent channel spectra do not overlap. Channel separation should be selected this way, if there can be high power level differences between the adjacent carrier. If channel separation is selected in such a way that the spectrum of two adjacent channel signals overlap, some power leaks from one carrier to another. Partly overlapping carrier spacing can be used, for example in micro cells, where the same antenna masts are used for both carriers.

cdma2000 continues to employ the linear-phase pulse-shaping filter, introduced in TIA/EIA-95. This filter complies with electromagnetic compatibility requirements of the United States Federal Communications Commission (FCC).

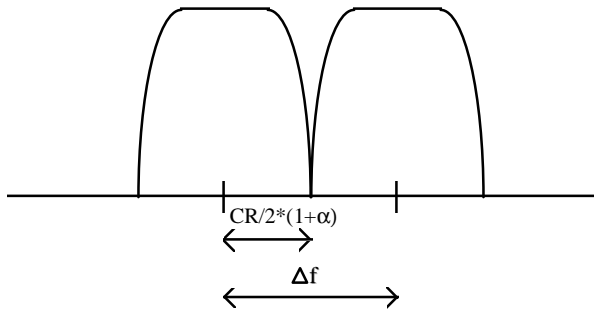


Figure 13: Relationship between chip rate (CR), roll-off factor (α) and channel separation (Δf)

3.1.3 Multirate

Multirate design means multiplexing different connections with different quality of service requirements in a flexible and spectrum efficient way. The provision for flexible data rates with different quality of service requirements can be divided into three sub-topics: how to map different bit rates into the allocated bandwidth, how to provide the desired quality of service, and how to inform the receiver about the characteristics of the received signal. The first problem concerns issues like multicode transmission and variable spreading. The second problem concerns coding schemes. The third problem concerns control channel multiplexing and coding.

Multiple services belonging to the same session can be either time or code multiplexed as depicted in Figure 14. The time multiplexing avoids multicode transmissions thus reducing peak-to-average power of the transmission. A second alternative for service multiplexing is to treat parallel services completely separate with separate channel coding/interleaving and map them to separate physical data channels in a multicode fashion as illustrated in the lower part of Figure 14. With this alternative scheme, the power and consequently the quality of each service can be controlled independently.

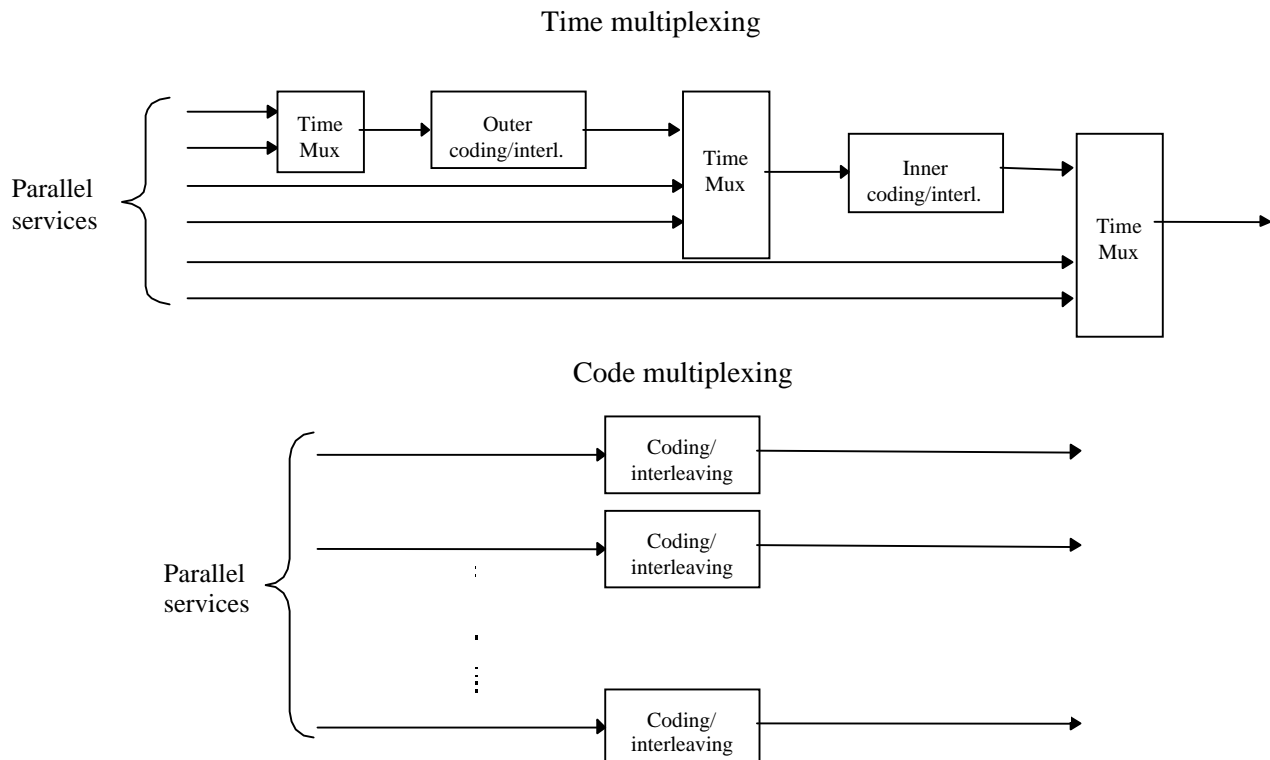


Figure 14: Time and code multiplexing principles

cdma2000 continues to support time multiplexing of services, as introduced in TIA/EIA-95-B in the form of primary and secondary traffic. In addition, multicode transmission is also supported. Although its time-multiplexing capability may be expanded, at present time multiplexing of service instances upon a single physical channel is not possible.

3.1.4 Spreading and Modulation Solutions

A complex spreading as shown in Figure 15, helps to reduce the peak-to-average power and thus improves power efficiency. It is essentially the HQPSK modulation method described in Chapter 2.

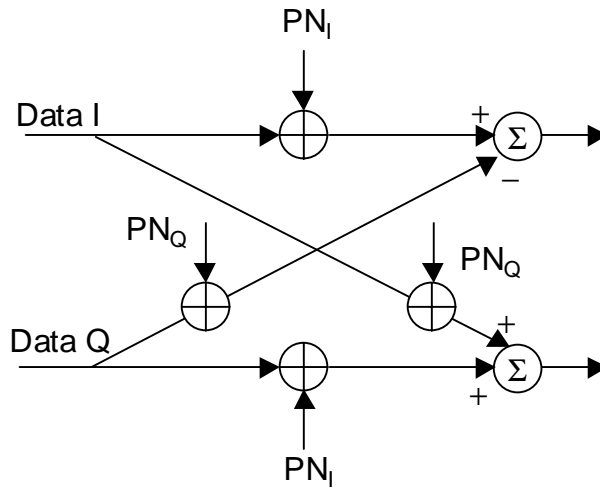


Figure 15: Complex Spreading

The spreading modulation can be either balanced or dual channel QPSK. In the balanced QPSK spreading the same data signal is split into I and Q channels. In dual channel QPSK spreading the symbol streams on the I and Q channels are independent of each other. In the forward link, QPSK data modulation is used in order to save code channels and allow the use of the same orthogonal sequence for I and Q channels. In the reverse link, each mobile station uses the same orthogonal codes; this allows for efficient use of BPSK data modulation and balanced QPSK spreading.

3.1.5 Coherent Detection in the Reverse Link

Coherent detection can improve the performance of the reverse link up to 3 dB compared to non-coherent reception used by the second generation CDMA system. To facilitate coherent detection a pilot signal is required. The actual performance improvement depends on the proportion of the pilot signal power to the data signal power and the fading environment.

3.1.6 Fast Power Control in Forward Link

To improve the forward link performance fast power control is used. The impact of the fast power control in the forward link is twofold. First, it improves the performance in a fading multipath channel. Second, it increases

the multiuser interference variance within the cell since orthogonality between users is not perfect due to multipath channel. The net effect, however, is improved performance at low speeds.

3.1.7 Soft Handoff

Soft handoff was to remain essentially the same in operation as in IS-95. This was possible due to the fact that cdma2000 is backwards compatible, and therefore existing cells did not need to be redeployed. As a result, handoff mechanisms did not need to change either.

3.1.8 Additional Pilot Channel in the Forward Link for Beamforming

An additional pilot channel on the forward link that can be assigned to a single mobile or to a group of mobiles enables deployment of adaptive antennas for beamforming since the pilot signal used for channel estimation needs to go through the same path as the data signal. Therefore, a pilot signal transmitted through an omniscell antenna cannot be used for the channel estimation of a data signal transmitted through an adaptive antenna.

3.1.9 Transmit Diversity

The forward link performance can be improved in many cases by using transmit diversity. For direct spread CDMA schemes, this can be performed by splitting the data stream and spreading the two streams using orthogonal sequences or switching the entire data stream between two antennas. For multicarrier CDMA, the different carriers can be mapped into different antennas.

3.1.10 Layering

In an effort to create a more layered approach to the protocol stack in cdma2000, functionality was aligned according to the OSI modelling put forth by the International Standards Organization (ISO) [5]. The OSI layers may be described as:

- Application: user access to OSI environment

- Presentation: translates application information to syntax for data communications
- Session: provides control for application-level peer-to-peer communications; responsible for establishing, maintaining, and terminating connections between peer entities
- Transport: provides sufficiently reliable transportation of data between peer entities
- Network: corresponds to underlying network (e.g. wireless network) over which packets from transport layer are transmitted; has own connection establishment and maintenance procedures
- Data link: provides sufficiently reliable transportation of network-level packets over physical layer
- Physical: actual transmission pipe over which raw data flows (e.g. microwave link in wireless network)

This type of layering model is difficult to implement in wireless networks due to functions requiring several layers to coordinate with each other. For instance, in a wireless system, the network layer may be in charge of radio resource control; however, that functionality cannot be totally independent from the physical layer due to functions such as soft handoff. Nevertheless, cdma2000 was structured to include layering for the network layer and below. The basic cdma2000 layers and their corresponding OSI layers are:

- Layer 3 signalling, packet data services, voice data - OSI Network layer and up)
- Link Access Control (LAC) - OSI Data link layer
- Medium Access Control (MAC) - OSI Data link layer
- Physical layer - OSI Physical layer

This has also led to the development of four standards related to these layers:

1. IS-2000.2: cdma2000 Physical Layer
2. IS-2000.3: cdma2000 Medium Access Control Layer
3. IS-2000.4: cdma2000 Link Access Control Layer (Layer 2)
4. IS-2000.5: cdma2000 Upper Layer Signalling (Layer 3)

4. CDMA2000 PHYSICAL LAYER

The cdma2000 physical layer retains backwards compatibility not only to leverage IS-95 equipment development but to also provide a smooth upgrade path for cellular operators. In this way, cdma2000 systems could be

gradually phased into existing IS-95 networks without disrupting service. As a result, many mechanisms such as reverse link power control and soft handoff remain essentially the same from the physical layer standpoint.

The cdma2000 physical layer classifies different modes of operation into *radio configurations* (RC's) for both the forward and reverse links. For instance, Radio Configurations 1 and 2 (RC1 and RC2) are the Rate Set 1 and Rate Set 2 modes of operation respectively in IS-95. However, radio configurations greater than 2 define new modes of operation in cdma2000.

In addition, the cdma2000 radio configurations encompass two modes of operation: 1X and 3X. 1X refers to the mode that is bandwidth-compatible with IS-95, i.e. its bandwidth is 1.25 MHz. 3X refers to the *multicarrier* option, which involves the use of 3 1X carriers to increase the data rate to the mobile user on the forward link. The data rates on the reverse link in the multicarrier version increase data rates via direct-spreading up to three times the 1X chip rate of 1.2288 MHz. More recently, modes that involve 3X forward link and 1X reverse link have been adopted to allow for asymmetric high-speed data services.

In this chapter, the 1X option for cdma2000 will be examined. This option is what is supported in the first cdma2000 products, deployed in South Korea in the spring of 2001.

4.1 Forward Link

In the cdma2000, several new code channels are introduced to improve data services. However, backwards compatibility is an issue. In particular, the cdma2000 forward link includes pilot, paging and sync channels which are identical in operation to their IS-95 counterparts. However, the dedicated channels for RC3 and higher have a different structure.

The basic spreading structure now involves hybrid quadrature spreading (see Chapter 2) with the same baseband filter as in IS-95. This is depicted in Figure 16.

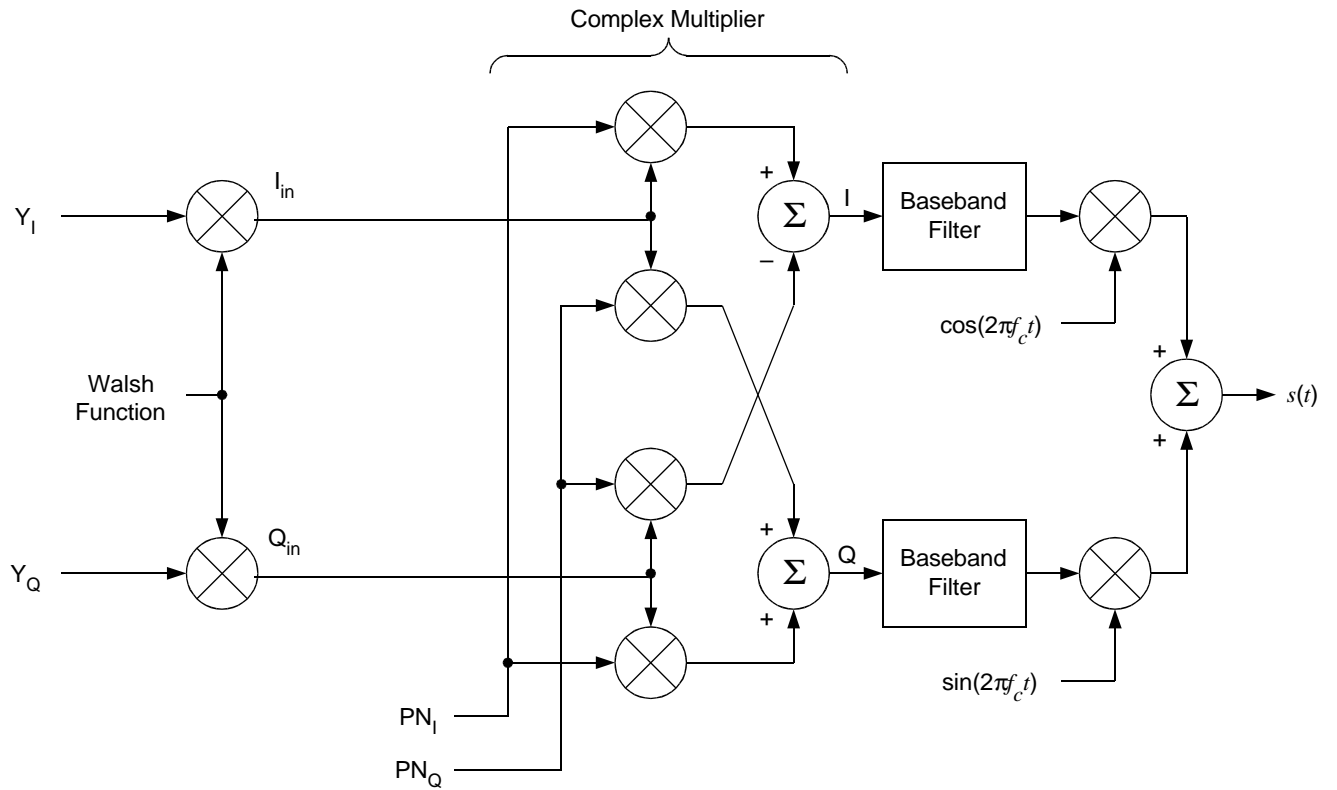


Figure 16: cdma2000 Spreading

The spreading function takes as inputs the appropriate Walsh function, and in-phase and quadrature inputs Y_I and Y_Q respectively. These inputs are derived from a demultiplexing operation (see Figure 17). With reference to Figure 17, when the input is X , then the output is split into the two streams Y_I and Y_Q by mapping each bit in the input stream to one of the two output streams alternately (starting from Y_I , i.e. a “top-to-bottom” approach). This is a pure QPSK system, as two bits of information are transmitted for each (I,Q) pair of inputs. However, two inputs X_I and X_Q may be mapped directly to Y_I and Y_Q as well. This feature is useful for backwards-compatible channels, as will be seen in the next section.

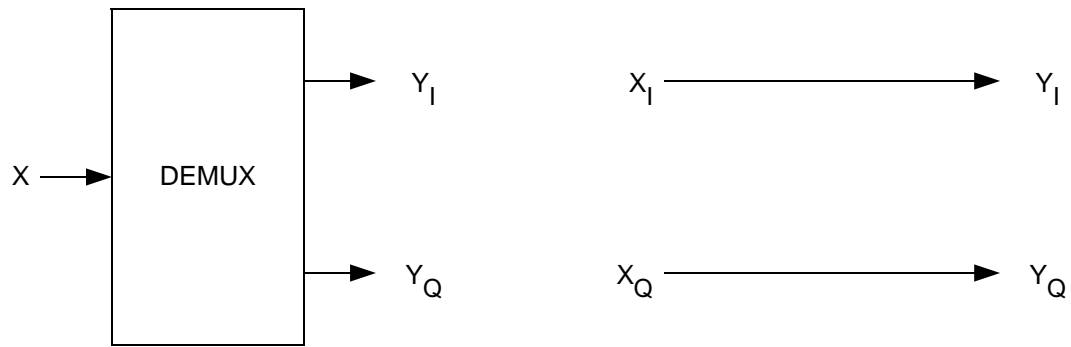


Figure 17: Demultiplexing Operation for 1X

4.1.1 Backwards-compatible Common Channels

The IS-95 pilot, paging and sync channels are still applicable to cdma2000 1X. As seen in Figure 18, the basic transmission sequence is the same.

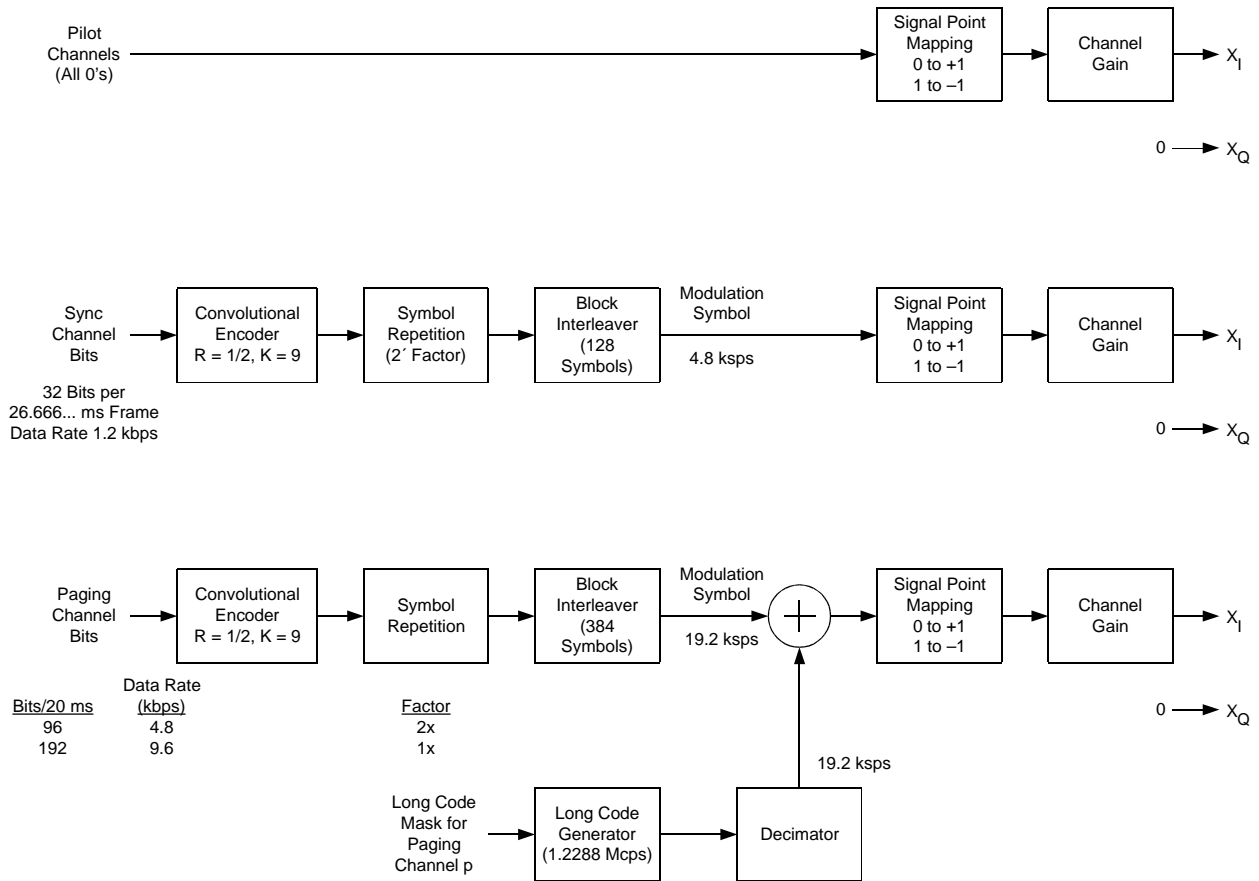


Figure 18: cdma2000 Backwards-Compatible Common Channels

However, note that the output after the signal point mapping for each of the channels is mapped only to X_I and zero is mapped to X_Q . When taken as input to the demultiplexer in Figure 17, X_I and X_Q are mapped directly to Y_I and Y_Q , meaning 0 is mapped to Y_Q . Therefore, when Y_I and Y_Q are provided as inputs to the spreader in Figure 16, then the hybrid quadrature spreading simplifies to basic quadrature spreading. As a result, both IS-95 and cdma2000 mobile stations can read these channels. Similar mappings occur for RC1 and RC2 so as to provide a means for cdma2000 base stations to support IS-95 mobiles.

Note that in cdma2000 nomenclature, abbreviations are given to designate channels. Thus the forward pilot, sync and paging channels can also be referred to as FPICH, FSYN and FPCH respectively.

4.1.2 New cdma2000 1X Common Channels

Several new common channels exist for cdma2000. The forward common control channel (FCCCCH) and forward broadcast control channel (FBCCH) may be used for carrying common signalling much like the paging channel. These channels may be used specifically for cdma2000 mobiles, thus relieving some of the overhead on the paging channel.

The forward common auxiliary pilot channel (F-CAPICH) is used to assist in sport coverage and transmit diversity applications. The Walsh code assignment for an auxiliary pilot can be of length 128, 256, or 512.

The forward quick paging channel (FQPCH) is an on-off keyed (OOK) indicator to the mobile to wake up for a message on the paging channel. This is useful for conserving battery life in the mobile when it is idling.

In addition, for new access modes on the reverse link, a forward common power control channel (FCPCH) exists in which users power control bits may be slotted in time.

4.1.3 New cdma2000 1X Dedicated Channels

cdma2000 1X introduces the forward dedicated common control channel (FDCCH) and forward supplemental channel (FSCH). The FDCCH may be used primarily for signalling and can be used for other high priority (non-voice) traffic such as retransmissions for data protocols. The FSCH is strictly for data traffic, and can take much higher rates than an IS-95 compatible forward supplemental code channel. The forward fundamental channel (FFCH) is still primarily for voice, although the lowest data rates for Rate Set 1-compatible data rates changed slightly from 1.2 and 2.4 kbps to 1.5 and 2.7 kbps respectively.

RC3 and RC4 in general are Rate Set 1 - compatible, while RC5 is Rate Set 2 - compatible. Note two notable exceptions regarding framing; now the dedicated channels can carry 5 ms frames for short messages, and the FFCH and FSCH can have longer framing (40 and 80 ms) in addition to 20 ms. The transmission sequences for the FDCCH are shown in Figure 19 through Figure 21. The transmission sequences for the FFCH and FSCH are shown in Figure 22 through Figure 24.

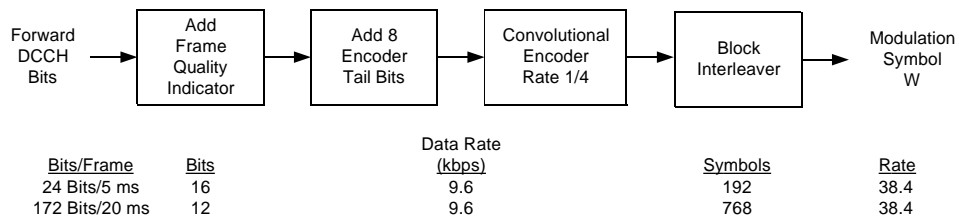


Figure 19: FDCCH for RC3

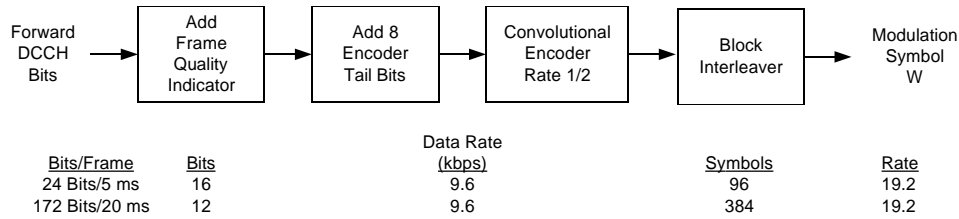


Figure 20: FDCCH for RC4

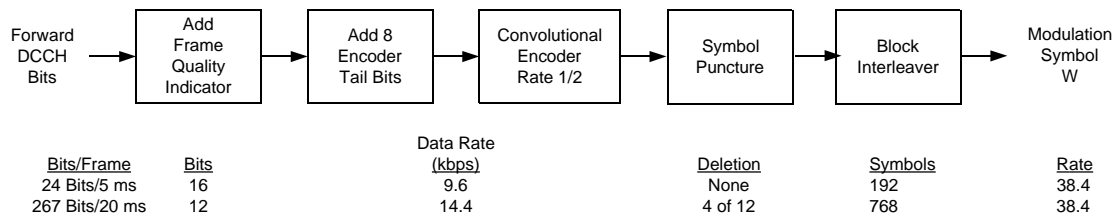
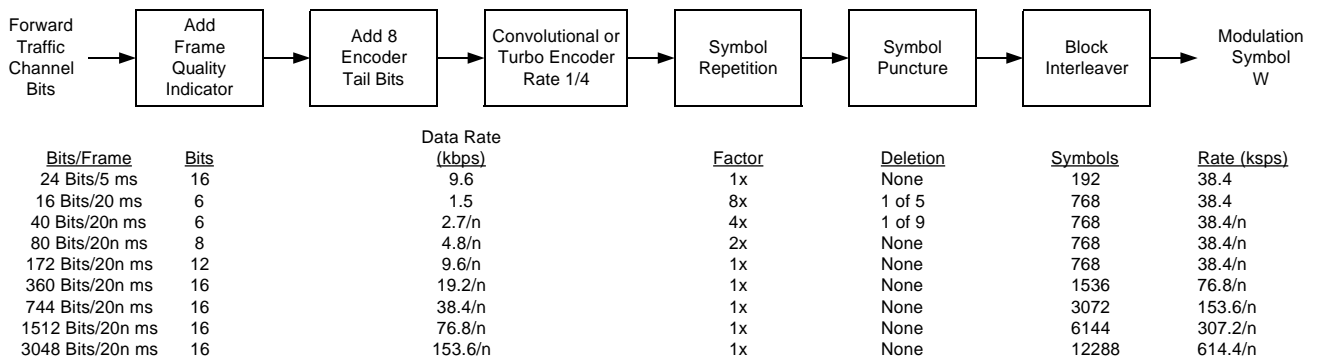
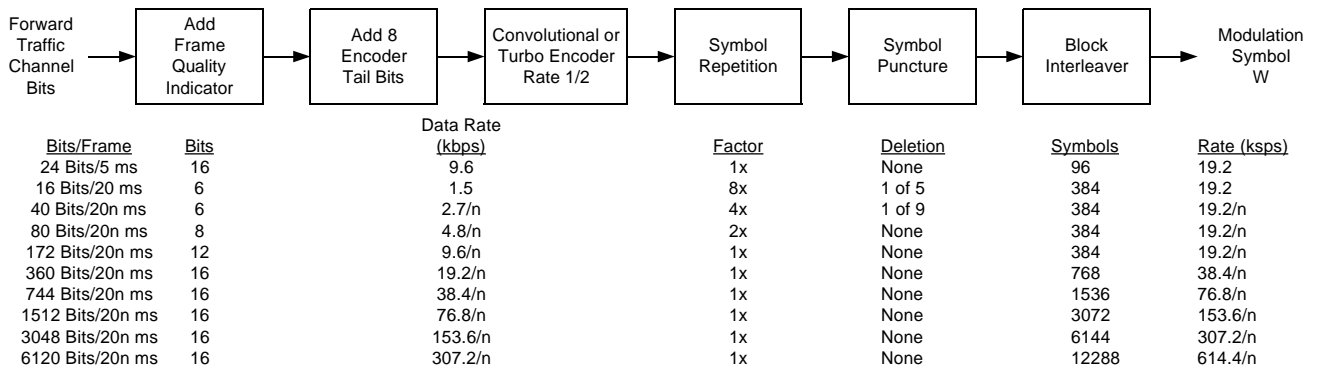


Figure 21: FDCCH for RC5



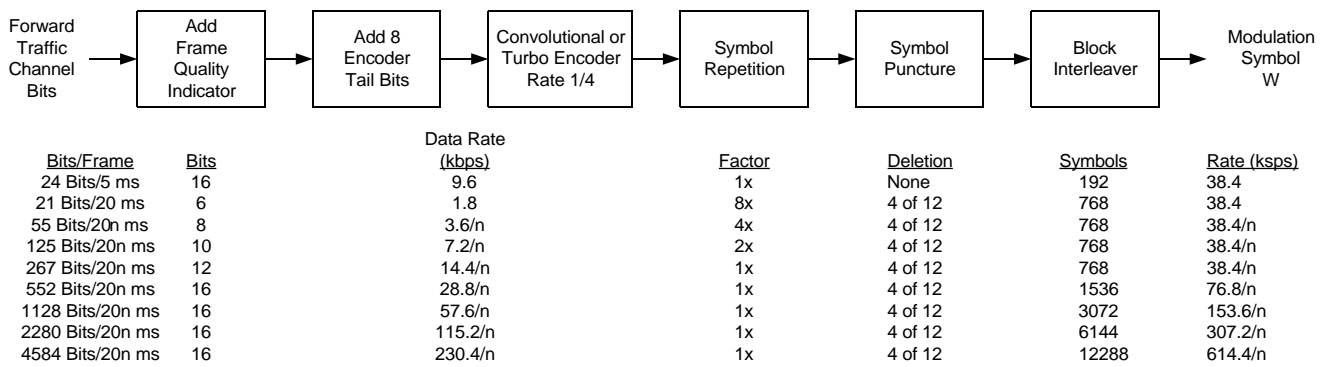
n=length of frame in multiples of 20 ms; n can equal 1, 2 or 4

Figure 22: FFCH and FSCH for RC3



n=length of frame in multiples of 20 ms; n can equal 1, 2 or 4

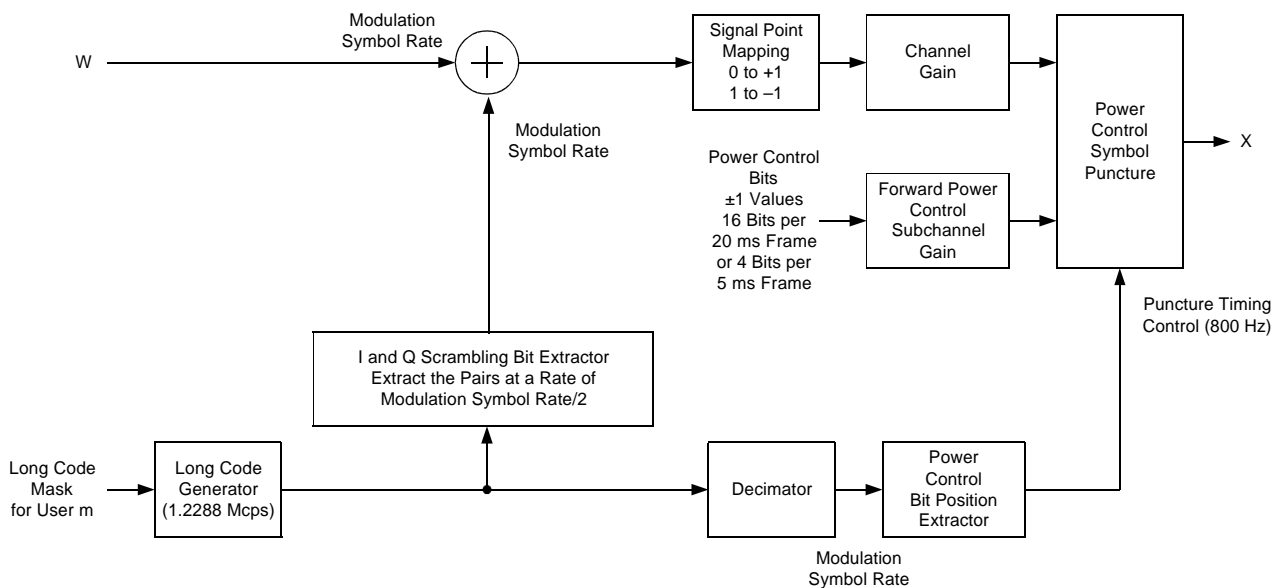
Figure 23: FFCH and FSCH for RC4



n=length of frame in multiples of 20 ms; n can equal 1, 2 or 4

Figure 24: FFCH and FSCH for RC5

The transmission sequences may now be scrambled and inserted with power control commands. Referring to Figure 19 through Figure 24, the transmission sequences all result in a stream of modulation symbols W . These symbols are then input into the multiplexing structure in Figure 25.



Power control symbol puncturing is on the Forward Fundamental Channels and Forward Dedicated Control Channels only.

Figure 25: Scrambling and Power Control Multiplexing

Note that the mobile may receive power control commands either on an FFCH or FDCCH (however never on both). With reference to Figure 25, the output symbol X may now be used as input to the demultiplexer structure of Figure 17.

4.1.4 Transmit Diversity

A new feature in cdma2000 that was not present in IS-95 was the capability to transmit over 2 antennas in the forward link, also known as *transmit diversity*. All channels except for pilot channels, FPCH, and FSYN may be transmitted in this fashion. Channels which are transmitted using the transmit diversity techniques of cdma2000 are demultiplexed differently from the demultiplexing shown in Figure 17; the transmit diversity demultiplexing procedure is shown in Figure 26. The demultiplexing operation is still top-to-bottom (see Section 4.1).

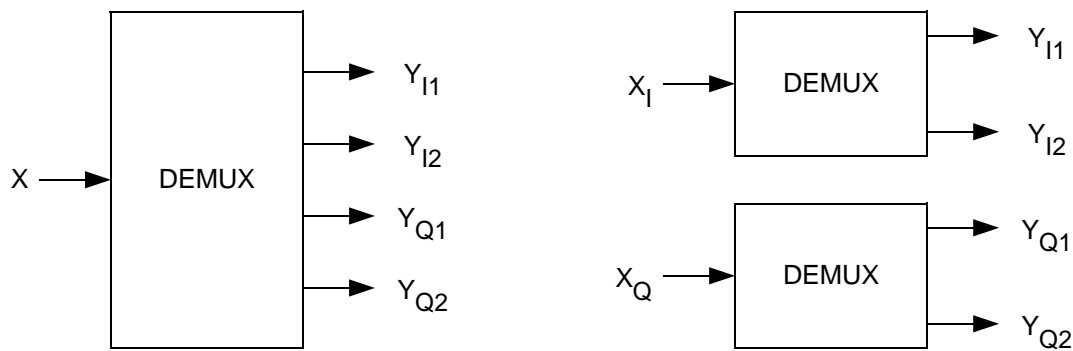


Figure 26: Transmit Diversity Demultiplexing

There are two methods of transmit diversity in cdma2000: *space-time spreading* (STS) and *orthogonal transmit diversity* (OTD). The STS spreading operation is shown in Figure 27.

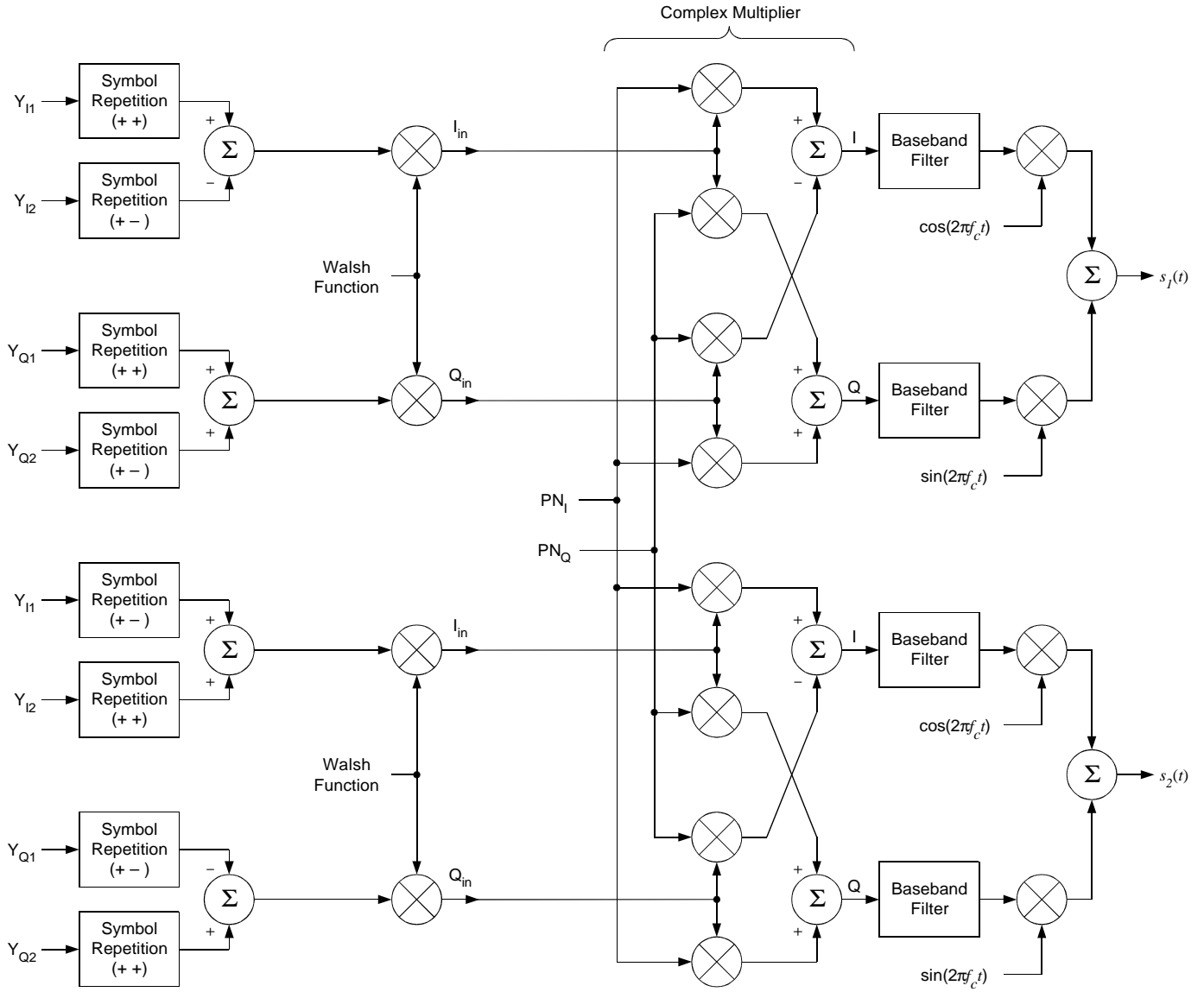


Figure 27: Space-Time Spreading

Assuming that the receiver is perfectly synchronized to the transmitted signal and as a despreading done properly, then the received symbols will have been subject to a complex channel gain associated with each of the two antenna; these two values will be denoted as $h_1(t)$ and $h_2(t)$. The receiver can find an estimate of these two values based on the pilot channel transmitted only over the primary antenna and an auxiliary pilot transmitted

only over the second antenna. Using these values and the receiver structure in Figure 28, the symbols input to the space-time spreader may be recovered with additional diversity gain from the transmission paths from both antennas.

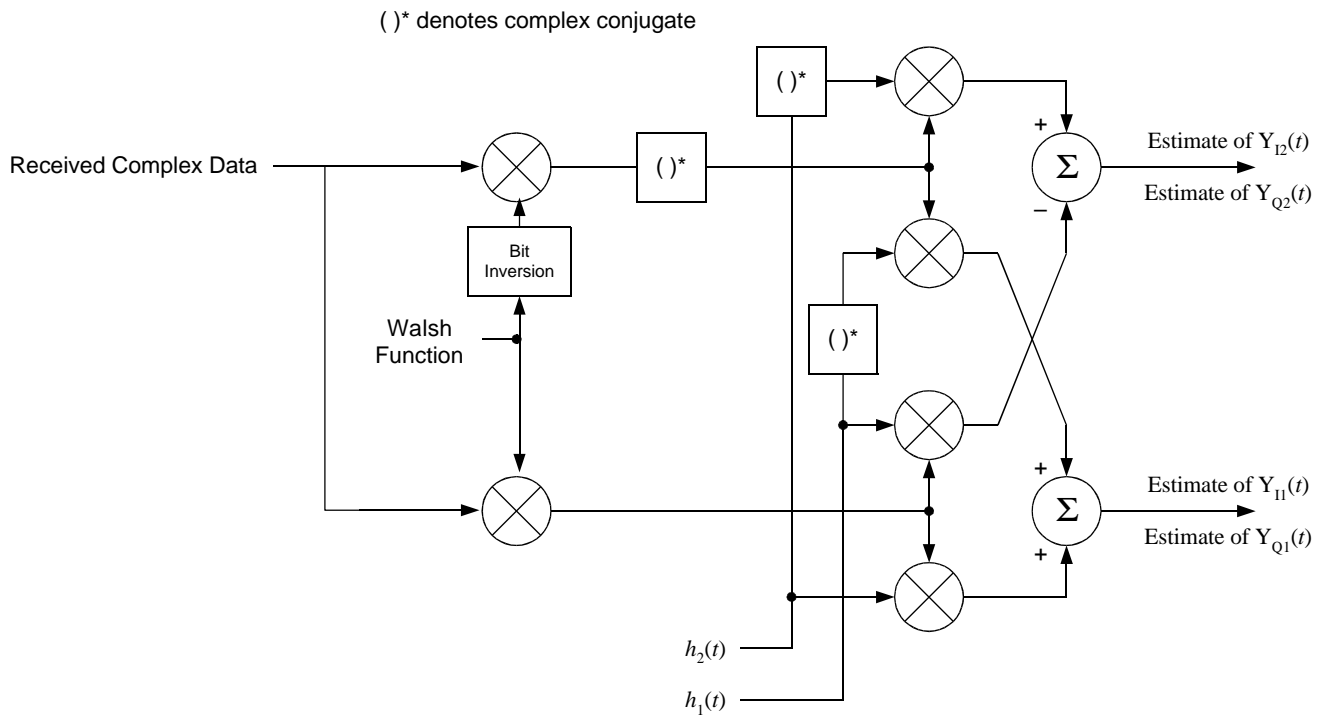


Figure 28: STS Receiver

The OTD spreader is given in Figure 29 and the receiver is given in Figure 30.

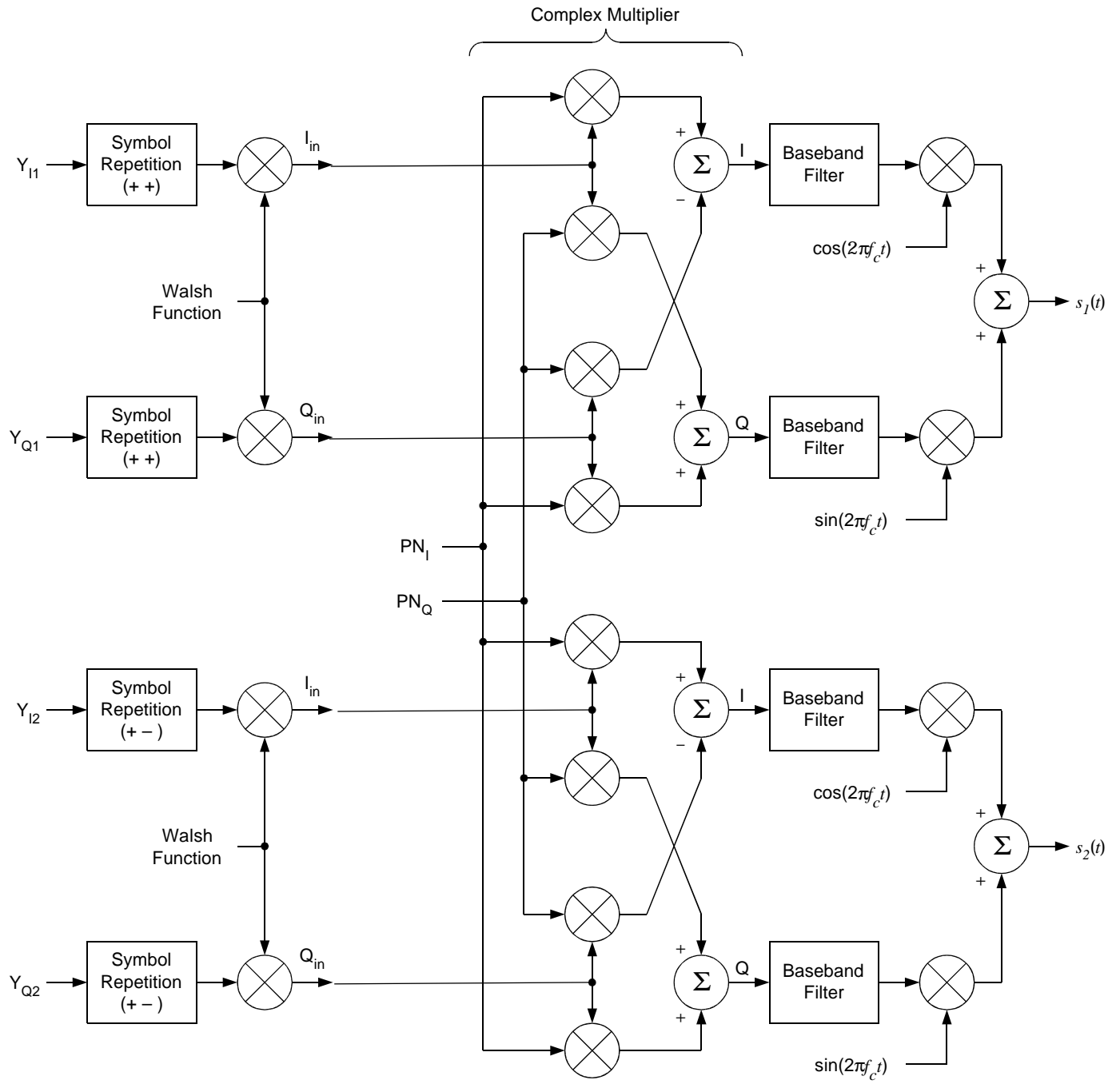


Figure 29: Orthogonal Transmit Diversity

$()^*$ denotes complex conjugate

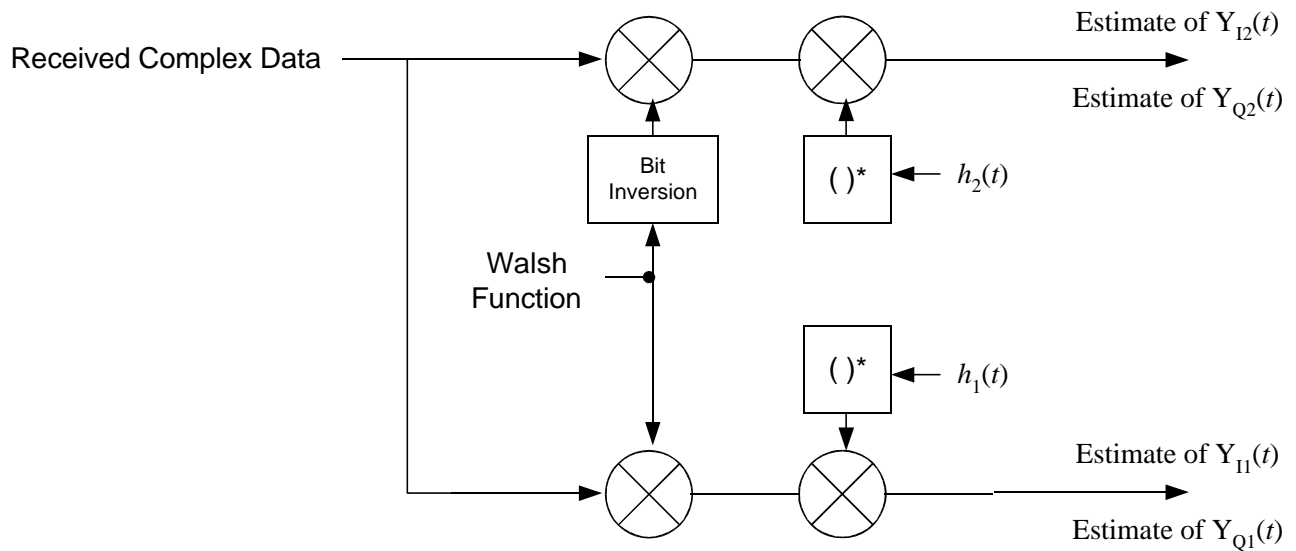


Figure 30: OTD Receiver

4.2 Reverse Link

The reverse link in cdma2000 was designed to introduce two important concepts that were not available in IS-95, namely coherent reverse link detection and fast forward link power control. As a result, a new physical layer was necessary for cdma2000.

The basic spreading structure is depicted in Figure 31. Note certain aspects of this spreading method which differ from the IS-95 reverse link:

- Inclusion of a pilot channel for coherent demodulation
- Use of Walsh code multiplexing for transmission of multiple data channels
- Long code spreading is slightly different so as to reduce peak-to-average ratio
- Use of hybrid quadrature spreading rather than offset-QPSK spreading

Several new code channels exist and will be discussed in the ensuing subsections. Each code channel will result in a modulation symbol indexed by A, B or C. These indices are with respect to the complex spreading inputs in Figure 31.

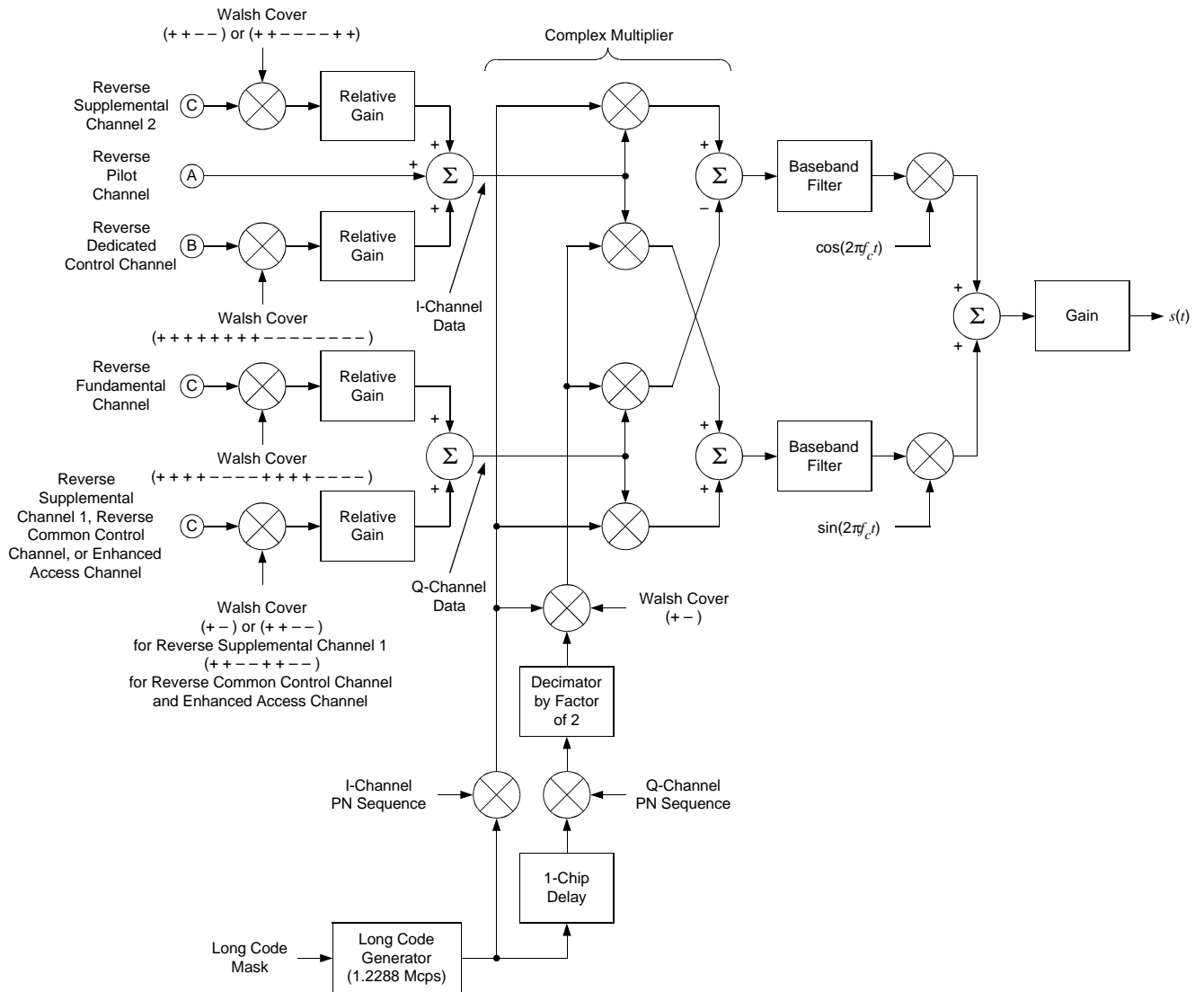


Figure 31: Reverse Link Spreading

4.2.1 Backwards-compatible Common Channels

The main backwards-compatible feature that exists in the cdma2000 reverse link for common channels is the presence of an reverse access channel (R-ACH) identical to that, which is used in IS-95.

4.2.2 New cdma2000 1X Common Channels

The reverse common control channel (RCCCH) and reverse enhanced access channel (REACH) were introduced to provide more reliable access by means of slotting different users before they transmit bursts on the reverse link and to provide a coherence form of reception for the base station access probe receiver. In addition, some burst data service that was not possible over the IS-95 access channel could be accommodated using these features.

For REACH operation, it is possible to transmit a burst in the form of an EACH header (see Figure 32). Otherwise, the transmission sequences for both the REACH and RCCCH are given in Figure 33. Note that both these channels are transmitted over the same Walsh code; their usage is different depending on the type of information being transmitted. The REACH is strictly for access. However, transmission on an RCCCH is possible after successful REACH transmission. In this case, the mobile is scheduled onto time slots (with respect to system time) for transmission of burst data. This type of operation is known as *reservation* mode. Moreover, operation on either the REACH or RCCCH can be *power controlled* by means of an assignment of the mobile to a power control slot on the *forward common power control channel* (FCPCH).

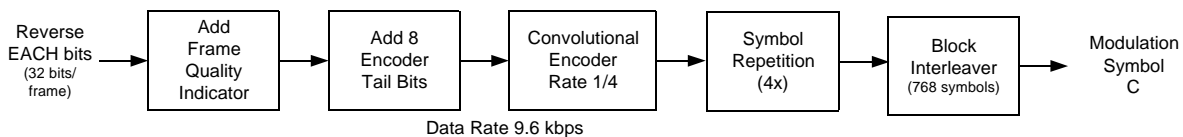


Figure 32: REACH Header

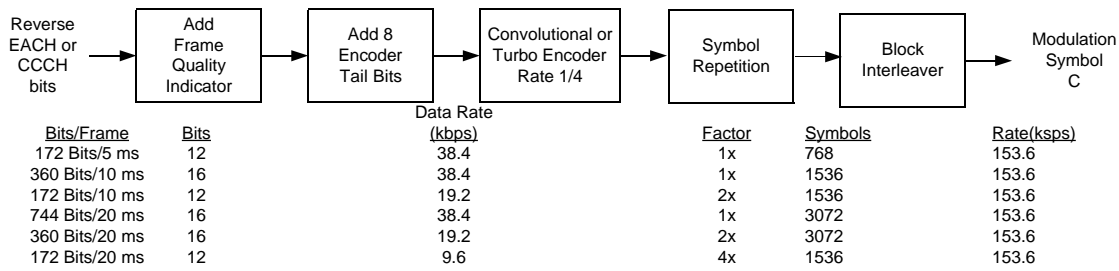


Figure 33: REACH and RCCCH

4.2.3 New cdma2000 1X Dedicated Channels

Several new dedicated control channels exist for the cdma2000 reverse link. Among them are the reverse pilot channel (RPICH), the reverse fundamental channel (RFCH), the reverse supplemental channel (RSCH), and the reverse dedicated common control channel (RDCCCH). Except for the RPICH, the types of data associated with each channel are identical to their forward link counterparts.

The RPICH actually has power control commands for fast forward power control multiplexed into the constant stream of all 0's at an 800 Hz rate (see Figure 34).

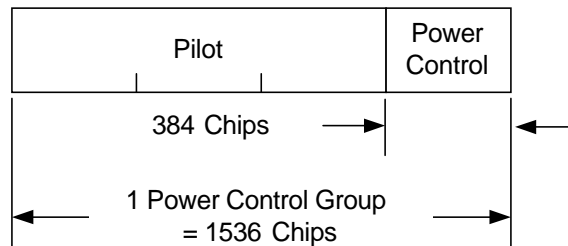
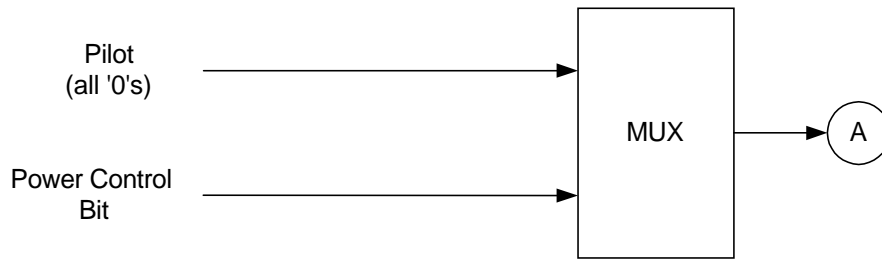


Figure 34: RPICH and Power Control Multiplexing

Just as with the forward link dedicated channels, the other three reverse link dedicated channels are associated with radio configurations. In general RC3 corresponds to Rate Set 1-compatible data rates, while RC4 corresponds to Rate Set 2-compatible data rates. Higher RC's correspond to 3X spreading factors. The transmission sequences for the RDCCH, RFCH and RSCH are given in

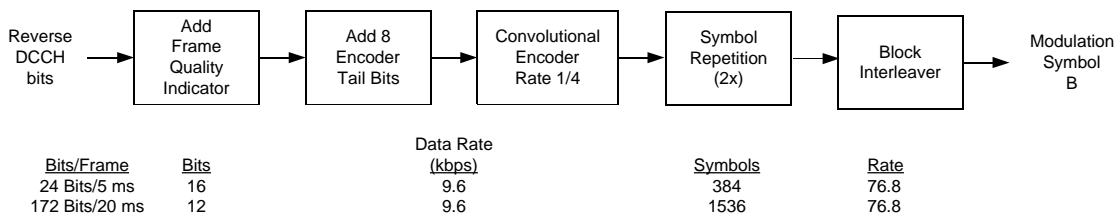


Figure 35: RDCCH for RC3

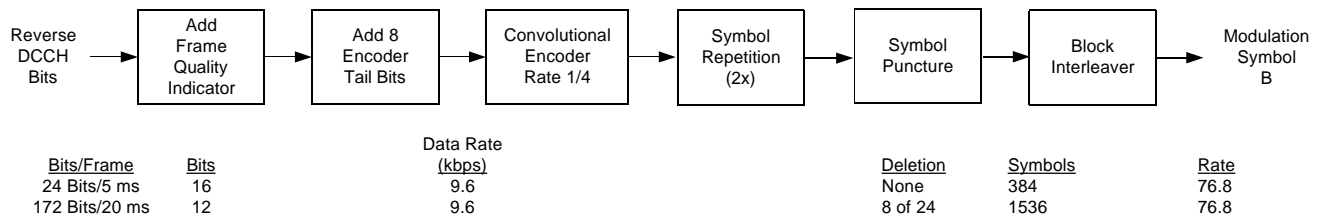
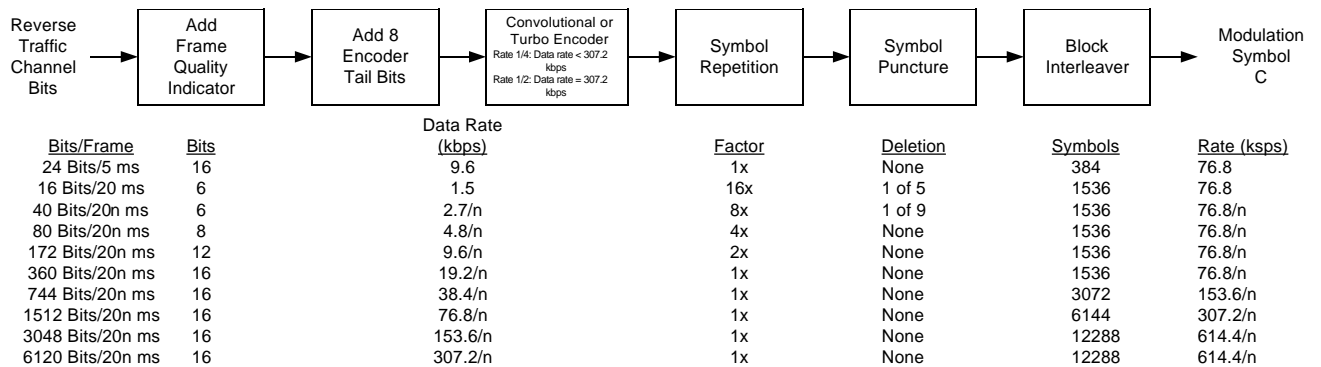
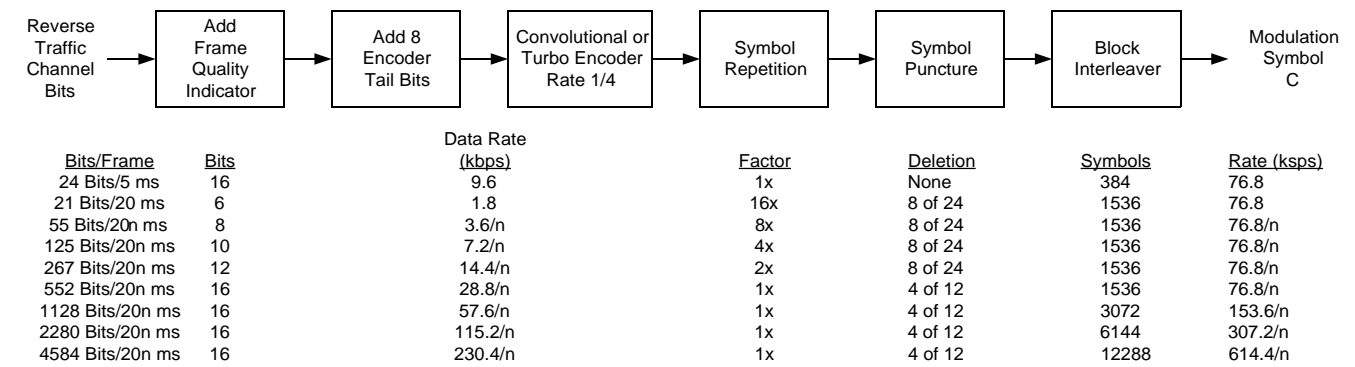


Figure 36: RDCCH for RC4



n=length of frame in multiples of 20 ms; n can equal 1, 2 or 4

Figure 37: RFCH and RSCH for RC3



n=length of frame in multiples of 20 ms; n can equal 1, 2 or 4

Figure 38: RFCH and RSCH for RC4

4.3 Coding

The convolutional coding described in Section 2.6 is still applicable to cdma2000 (with a rate $\frac{1}{4}$ code added to the existing convolutional codes of IS-95). However, optional turbo coding (see Section 8.2, Chapter 2) is also included in cdma2000 for high-rate data services. The turbo code defined for cdma2000 is shown in Figure 39. With respect to the figure, by simply puncturing the output bits $\{X, Y_0, Y_1, X', Y'_0, Y'_1\}$, the rate of the turbo code can be modified to fit a variety of different information bit rates.

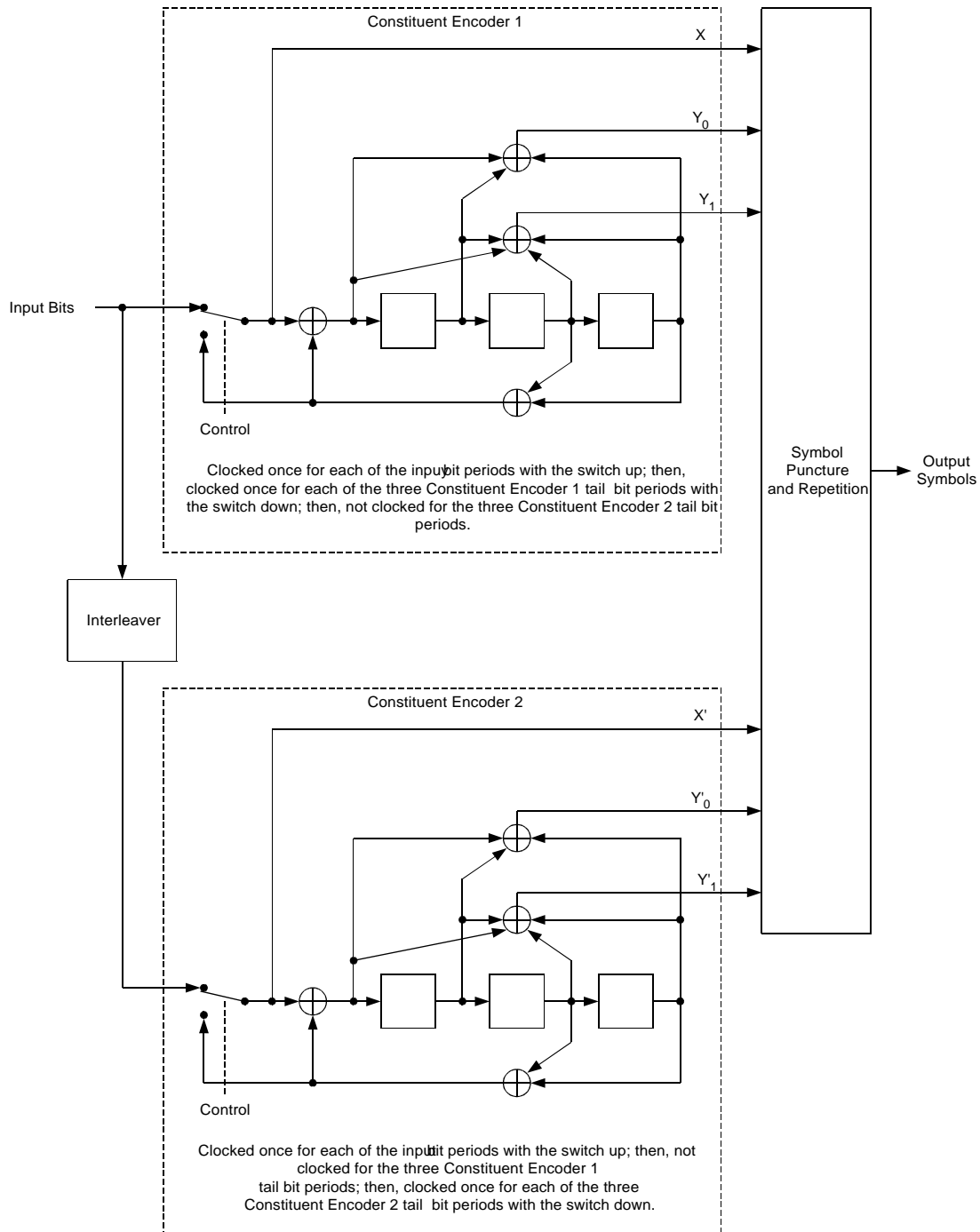


Figure 39: cdma2000 Turbo Code

4.4 Medium Access Control

cdma2000 introduced a MAC specification in an effort to ensure a correspondence between itself and the OSI layering model for data services. It receives its payload either from the link access control (LAC) layer or directly from one or more data services, provides the necessary functionality for multiplexing these different types of payload onto the physical layer, and also describes to an extent some aspects of the operation of the access modes for the cdma2000 reverse link. However, the new multiplex sublayer functionality introduced in the cdma2000 MAC will be focused upon in this section, due to its criticality for cdma2000 operation.

4.4.1 Multiplex Sublayer

The two basic multiplex options introduced in IS-95-B were multiplex options 1 and 2, for fundamental channel (FCH) rate set 1 and 2 configurations, respectively. These two options are also referred to by their hexadecimal representations 0x1 and 0x2. When supplemental code channels (SCCH's) are used, the new multiplex option (in decimal form) can be formed using the following equation:

$$m = n + 2r \quad (1)$$

where m is the multiplex option, n is the rate set (1 or 2), and r is the number of additional supplemental code channels (1 to 7). This formulation leads to a maximum multiplex option of 0x10. Each of these physical layer channels (FCH's or SCCH's) encompasses a single multiplex protocol data unit (i.e. MuxPDU), which is a basic information transmission unit for any type of payload.

These backwards-compatible multiplex options are still applicable to cdma2000 for radio configurations 1 and 2. However, for cdma2000's new radio configurations (radio configuration 3 and higher), these options are not directly applicable due to the following reasons:

- a. The physical layer code channels in cdma2000's new radio configurations can carry a much larger payload than IS-95-B FCH's or SCCH's.
- b. For multimedia services, it is desirable to have multiple MuxPDU's in a single physical layer code channel

frame. This provides for transmission of different types of data simultaneously.

As a result, new multiplex options with relaxed restrictions on the number of MuxPDU's per frame were introduced in cdma2000. The types of MuxPDU's were further specified:

- a. MuxPDU Type 1 – backwards-compatible Rate Set 1 MuxPDU's, i.e. FCH's and SCCH's. These MuxPDU's may also be used on supplemental channels (SCH's) and 20-ms-framed dedicated control channels (DCCH's) which are of the lowest rate (9600 or 14400 bps).
- b. MuxPDU Type 2 – similar to MuxPDU Type 1, except applicable to Rate Set 2.
- c. MuxPDU Type 3 – this type of MuxPDU may only be transmitted over high-rate SCH's. There are two allowable block sizes – single and double. The single block size is 170 bits for rate set 1 and 266 bits for rate set 2. Similarly, the double block size is 346 and 538 bits for rate sets 1 and 2 respectively.
- d. MuxPDU Type 4 – carries 5-ms block of data (24 bits total of payload). It can be used on an FCH or DCCH.
- e. MuxPDU Type 5 – this is a variable length PDU that can only be used on an SCH. Its size is specified in the PDU header, and provides flexibility to the higher layers in forming the PDU's to be placed into the physical layer.
- f. MuxPDU Type 6 – this is a variable length PDU that can only be used on the FCH or DCCH, and is intended to provide total flexibility in forming the effective data rate on these channels.

Making use of these MuxPDU types, all multiplex options higher than 0x10 can be formed simply by a 16-bit binary number using the guidelines of Table 2.

Bit indices (0=most significant, 15=least significant)	Description	Options
0-3	Format	'0000'
4-5	MuxPDU Type	'00' – MuxPDU Types 1, 2, or 4 '10' – MuxPDU Type 3 '01' – MuxPDU Type 6

5-6	Block Size	'11' – MuxPDU Type 5 '00' – Single size '01' – Double size '11' – Variable size
7-13	Maximum No. Data Block per Frame	'000000' – No restriction '000001' – '001000'
14-15	Rate Set	'00' – Not Applicable '01' – Rate Set 1 '10' – Rate Set 2

Table 2: Multiplex Option Numbering

It is possible to encapsulate MuxPDU's on the SCH into *logical transmission units* (LTU's), and to send multiple LTU's in a single 20-ms frame. An LTU can contain one or more MuxPDU's; however, a 16-bit cyclic redundancy check (CRC) must be appended at the end of each LTU to assure error detection within the LTU. The use of LTU's allows the receiver to recover parts of a frame when a frame in error has been detected.

4.4.2 Interface to LAC

The LAC sublayer encapsulates Layer 3 signalling into LAC service data units (LAC SDU's) with their own CRC's. Each LAC SDU is then segmented MAC SDU's to be transmitted over the physical layer. The MAC SDU's are mapped to the physical layer through MuxPDU's to be routed on specific code channels.

The receiving function of the LAC sublayer entails reassembling the LAC SDU based on the SDU's received from the MAC. If a LAC SDU is not reassembled without detecting errors, the LAC may recover the SDU through an automatic repeat request (ARQ) protocol that requests a retransmission of part of all of the LAC SDU.

4.5 Data Services and Radio Link Protocol

The conventional internet protocol (IP) stack, which is used for wireline data communications, tends to suffer from lack of robustness when used over a wireless cellular environment. This is due to the fact that IP-protocols generally rely on one layer of reliability, the *transmission control protocol* (TCP), which serves to recover lost octets based on ARQ methods. TCP is optimised for wireline networks; cellular networks, which generally suffer higher error rates and are subject to tighter bandwidth restrictions, cannot provide the basic performance needed for even TCP to be sufficient for error recovery. Moreover, some real-time applications that may be run at higher error rates but cannot sustain the delay of TCP octet recovery may

instead use the *universal datagram protocol* (UDP). UDP has no means of recovering packets lost over the wireless network.

As a result, wireless systems use *radio link protocols* (RLP's) to provide an additional layer of reliability on top of TCP. The basic IS-95/cdma2000 RLP-based protocol stack is depicted in Figure 40. Recall that the cdma2000 MAC layer can directly accept PDU's from either the LAC or a data service. The lowest layer of an IS-95-based data service is the RLP layer.

RLP does not accept IP packets directly in IS-95/cdma2000. Instead, IP packets are passed through a *point-to-point protocol* (PPP) instance. PPP serves primarily to provide some security to the IP datagrams. RLP therefore must be able to segment PPP packets for transmission, and reassemble received RLP PDU's into whole packets for delivery to the PPP layer.

RLP provides reliability by means of ARQ, more specifically *selective repeat* ARQ. This means that RLP PDU's are retransmitted only when the receiver specifically requests them. This type of ARQ is also sometimes referred to as a *NAK-based* protocol. NAK's (i.e. Negative Acknowledgments) are sent by the receiver to the transmitter to request retransmissions of specific PDU's. Thus, the RLP receiver must keep track of correctly received PDU's through the use of embedded sequence numbers. It maintains two counters $V(N)$ and $V(R)$; the former keeps track of the next PDU to be received, and the latter keeps track of the next PDU expected to be received. When these two counters point to the same sequence number, then this signifies that there are no outstanding RLP PDU's to be delivered. However, when these two are not equal, then this means that an RLP PDU was not received correctly and should be NAK'ed. If the receiver sends a NAK for a missing RLP PDU, it must initiate a timer for that RLP PDU (the *retransmission timer*). This timer, which is only incremented upon the receipt of valid RLP PDU's, cannot exceed a certain pre-established number (based on the expected *round trip time* RTT for a retransmission). This timer is terminated once the retransmission is received correctly. Otherwise, once this timer has expired, the receiver may send another NAK and start another timer known as the *abort timer* (also based on the RTT). If the abort timer expires, then the RLP receiver "gives up" and passes whatever correct octets it has received in the PPP packet up to the PPP layer. In this manner, RLP can provide some limited error recovery for data packets in the wireless channel, but it does not provide excessive

reliability so that upper layers may erroneously determine that the underlying connection has been lost.

When the receiver has detected a missing RLP PDU, or a timer has expired so that a NAK must be re-sent, RLP may send more than one NAK as a result. The maximum number of timer events for the recovery of an RLP PDU is also sometimes referred to as the number of NAK rounds allowed. There are a maximum number of NAK's per round as well.

For instance, in IS-95-B, upon detection of a missing RLP PDU, *two* NAK's are sent for the missing PDU and the retransmission timer is initialised for the PDU. Upon expiration of the retransmission timer, *three* NAK's are sent for the missing PDU and the abort timer is initialised. This is sometimes referred to as a (1,2,3) method of retransmission. Although 5 retransmissions might seem excessive, this feature is useful to provide resiliency in the presence of lost NAK's or lost retransmissions, and thus minimize overall packet delay.

cdma2000 has provided a means of negotiating the levels of reliability at the RLP layer during the initialisation of the data service. More precisely, the NAK's per round and maximum number of rounds may be negotiated at the beginning of the call [12].

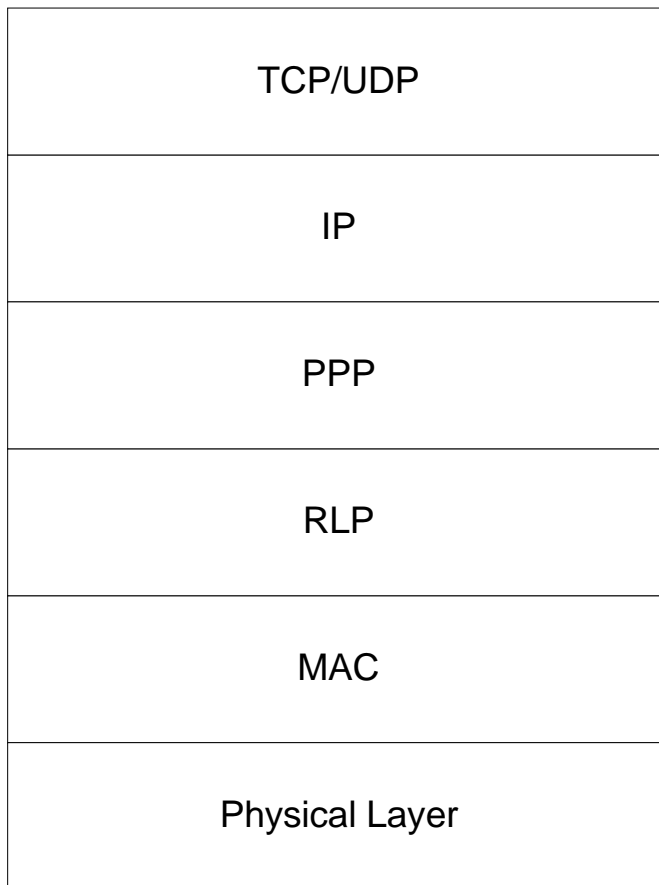


Figure 40: RLP-Based Protocol Stack

5. CONCLUSIONS

The IS-95 and cdma2000 systems were developed with the primary intention of increasing the voice capacity offered in cellular systems. As a result, these systems are also primarily optimised for circuit-switched data services. However, these systems have been extended (in the form of 1X-EV, as described in the next chapter) to make them more suitable for multiple-access packet-switched services.

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