2nd Generation Cellular Networks: CDMAOne

- CDMA System Architecture(IS95)
- CDMA System Characteristics
- CDMA Handoff
- IS-95 Logical Channels
- Forward and Reverse Channel Processing

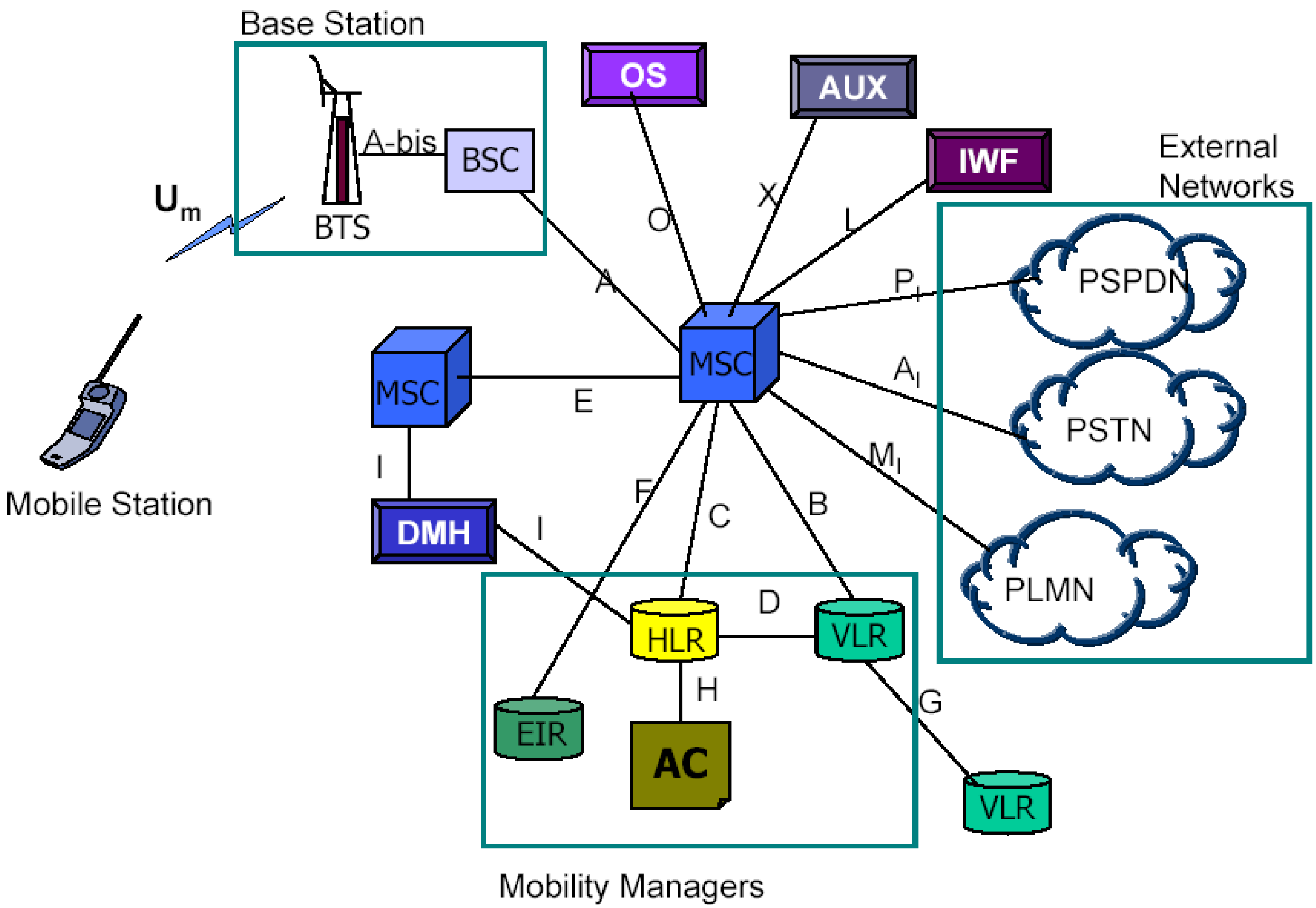
Review

- GPRS Services
- Reference Architecture
- Mobility and Location Management
- Channels
- Protocols
- Data Transfer, Coding

CDMA Systems

- IS-95 **(cdmaone)** is the North American digital cellular standard that employs CDMA as access method as well as the air interface developed by Qualcomm in the 90's
- The core fixed network infrastructure that supports the wireless interface is very similar to the GSM core network
  - Major difference is in the air interface
- The North American reference architecture for cellular telephony is based on interim standards (IS) developed by TIA (Telecommunications Industry Association)
  - TR-45 Committee develops performance , compatibility, interoperability and services for mobile and PCS (Personal Communications Services) in the 800MHz and 1,800MHz
    - TR-45.3 deals with TDMA technology
    - TR-45.5 deals with CDMA technology
    - TR-46 is an adaptation of TR-45 for PCS bands

TR-45/46 Reference Model [PK 02]



TR-45/46 Reference Model [PK 02]

- Differences from the GSM architecture
  - Data message Handler (DMH)
    - Collects billing information
  - Interworking Function (IWF)
    - Allows an MSC to connect to other networks
  - Auxiliary Equipment (AUX)
    - Can connect to an MS
- A- interface is given by the standard IS-634
  - Open standard between MSC and BSS
- IS-41
  - Standard for MSC-MSC interface

Some IS-634 characteristics [PK 02]

- several BTSs can be connected to a BSC
  - soft handoff when an MS connects to several BTSs simultaneously
- However, from an IS-634 perspective, the BSC is the BS
- The transcoder converts the speech from the air-interface QCELP format to the wireline PCM format
  - QCELP has voice encoded at 13 kbps and PCM at 64 kbps
    - Depending on where the transcoder is located, the quantity of data to be transported from the BS to the MSC may be different
    - IS-634 allows the transcoder to be placed either at the BSC or at the MSC or somewhere in between

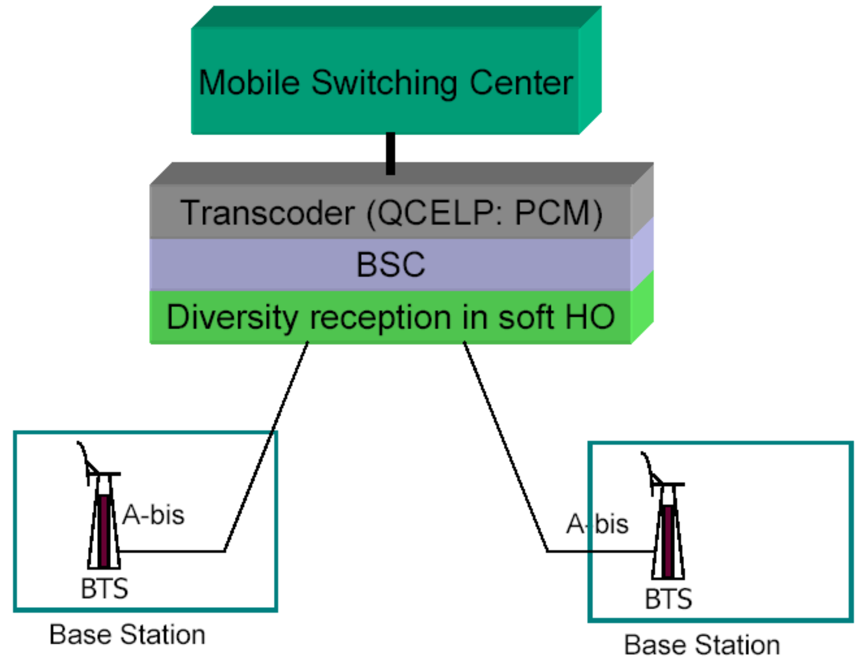
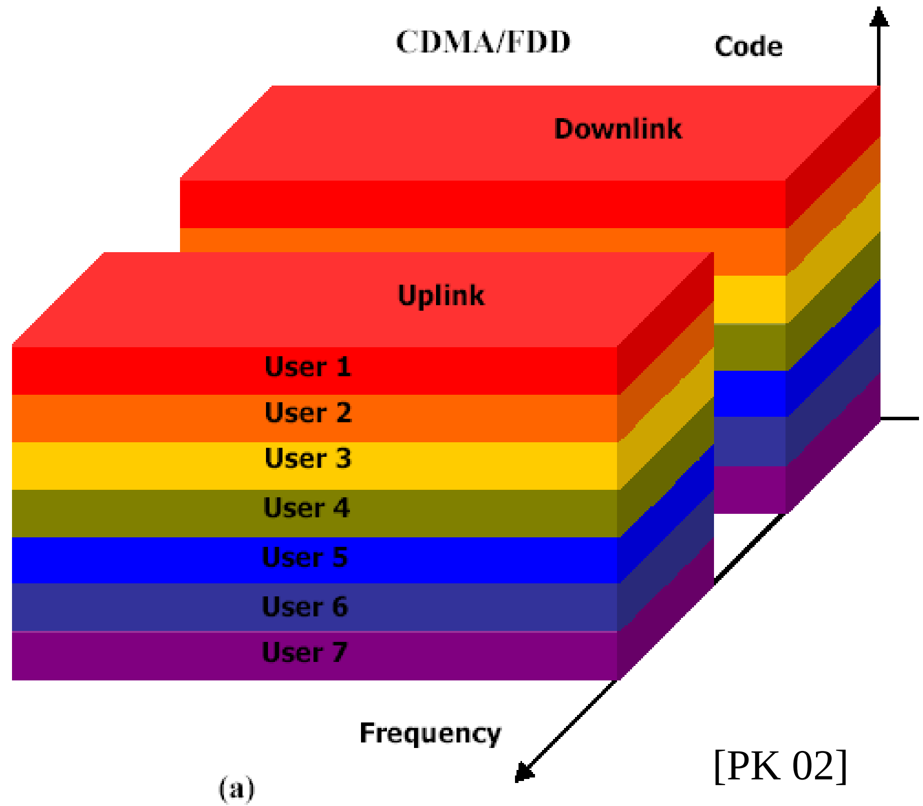


Figure 8.3: IS-634 Functional Architecture

CDMA System Characteristics

- Spectrum
  - Same as AMPS
  - 10 carriers of 1.25 MHz per Band
- Use of CDMA/FDD (IS-95 and IMT-2000)
- Capacity of CDMA
  - CDMA transmitter spreads the signal power over a spectrum N times wider (chip rate) than the spectrum of the message signal
  - If the user information bandwidth is R, the transmission bandwidth will be:

$$W = NR \quad (3.1)$$



[PK 02]

Capacity of a single CDMA cell [PK chapter 4]

- The receiver processes the received signal with a *processing gain* of N
  - The received signal having the code will be increased N times
- Capacity of a single CDMA cell
  - Assume
    - M simultaneous users on the reverse channel
    - Ideal power control
    - The system is interference limited
    - The background noise is dominated by the interference noise from other users
    - Received power from all terminals has the same value **P**
  - Then, the received power from the target user after processing at the receiver is **NP**
  - The received interference from M-1 terminals is **(M-1)P**
  - The received signal-to-noise ratio (S_r) will be:

$$S_r = \frac{NP}{(M-1)P} = \frac{N}{M-1} \quad (3.2)$$

Capacity of a single CDMA cell

- For a given modulation and coding specification of the system, the acceptable error rate will be supported by a minimum S_r. Then, solving equations 3.1 and 3.2, we have:

$$M = \frac{W}{RS_r} + 1 \cong \frac{W}{RS_r} \quad (3.3)$$

Capacity of a single CDMA cell

- Exercise: Using QPSK modulation and convolutional coding, the IS-95 digital cellular systems require 3dB < S_r < 9dB. The Bandwidth of the channel is 1.25MHz, and the transmission rate is R=9600bps. Find the capacity of a single CDMA cell.

$$10\log x = 3 \therefore \log x = \frac{3}{10} \therefore x = 10^{0.3} \approx 2$$

and

$$10\log y = 9 \therefore \log y = \frac{9}{10} \therefore y = 10^{0.9} \approx 8$$

$$M = \frac{1.25\times10^6}{9600}\times\frac{1}{8} \approx 16 \mathit{users}$$

to

$$M = \frac{1.25\times10^6}{9600}\times\frac{1}{2} \approx 65 \mathit{users}$$

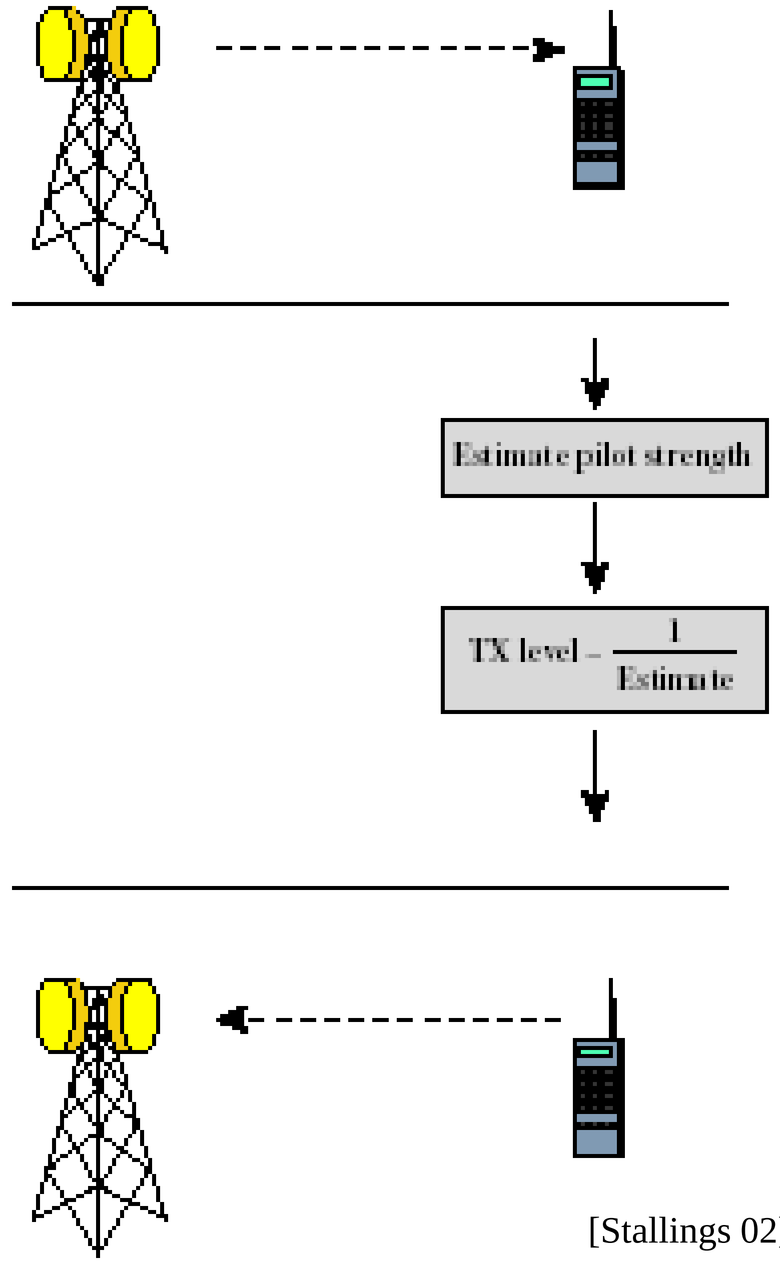
Capacity of a single CDMA cell

- In practical design, three other factors affect M
  - Sectorization Gain Factor (G_A)
    - The use of sectored antennas reduces the overall interference, increasing the allowable number of simultaneous users
    - A typical value of G_A for a three sector cell is 2.5 (4dB)
  - Voice activity interference reduction (G_V)
    - It is the ratio of the total connection time to the active talkspurt time
    - Each user talks roughly 50% of the time, with short pauses in the natural flow of conversation, the activity reduces to 40%
    - A typical value used for G_V is 2.5 (4dB)
  - The interference increase factor (H_0)
    - Users in other cells (all neighbouring cells operate at the same frequency)
    - They cause additional interference, but this interference in relatively small due to processing gain and the distance
    - A typical value of H_0 is 1.6 (2dB)
  - Incorporating these tree factors in equation 3.3 lead us to a **K** factor ($G_A G_V/H_0$)
  - How much would be M, taking in consideration typical values for ***performance improvement factor (K)?***

$$M = \frac{W G_A G_V}{R S_r H_0} = \frac{WK}{R S_r} \quad (3.4)$$

Open-loop power control

- Used in IS-95 (CDMA)
- The power control is made on the reverse link
  - No feedback from BS
- The MS measures the quality of a reference channel from the base station
  - Based on what?
  - How?
- Disadvantages:
  - The decision is based on the quality of the forward channel
    - the reverse and forward channel are not usually correlated
  - It may exist a significant delay
- Not as accurate as closed-loop, but it can react quicker to fluctuations in signal strength



(a) Open-loop power control

Open Loop Power Control in IS-95 CDMA

- Received signals from multiples users must all have the same RSS
  - for correct detection
  - all voice channels occupy the same time and frequency slots
  - a large power will jam the signals of the others
- MS uses the pilot channel to make the measurement
- The MS adjusts its transmit power based on the total received power from all BSs pilot channels
  - If the received signal is strong, the MS transmits a weak signal to the BS
  - Otherwise, it transmits a stronger signal to the BS

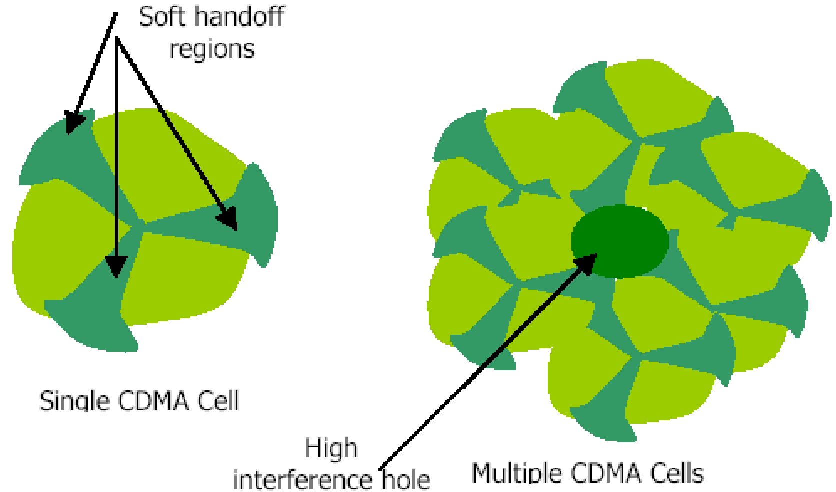
Frequency Planning for CDMA Systems

- Different from FDMA and TDMA systems
- A single CDMA carrier requires removing 41 contiguous AMPS channels
- All users operate on the same frequency carrier at the same time, resulting in everyone causing co-channel interference
- This problem is reduced by applying
  - synchronized orthogonal codes on the downlink
  - Combination of convolutional coding, spreading and orthogonal modulation on uplink
- CDMA completely eliminates the concept of conventional frequency reuse
- The quality of the signal is expressed by the acceptable energy per bit to total noise ratio E_b/N_t
  - Which roughly results in 1% frame error rate
- The value of E_b/N_t is usually around 6dB and depends on mobile's speed, propagation conditions, number of multi path signals
- N_t depends on the number of interfering signals and the transmit power of those signals
  - Power control is very important
  - The path loss is very similar, the signal strength drops roughly as the fourth power of the distance

[PK chapter 5]

Unique Issues in CDMA cells

- Managing the Noise Floor
  - The interference from many cells can raise the noise floor to such a level that holes may be created in the region where coding/spreading gain is not enough to overcome the interference level (figure)
  - It is not good to cover an area with more than three cells or sectors
- Cell Breathing
  - The boundary of a CDMA cell varies depending on where the E_b/N_t value is reached
  - As the number of users in the reverse link grows the handoff boundary shifts closer to the BS



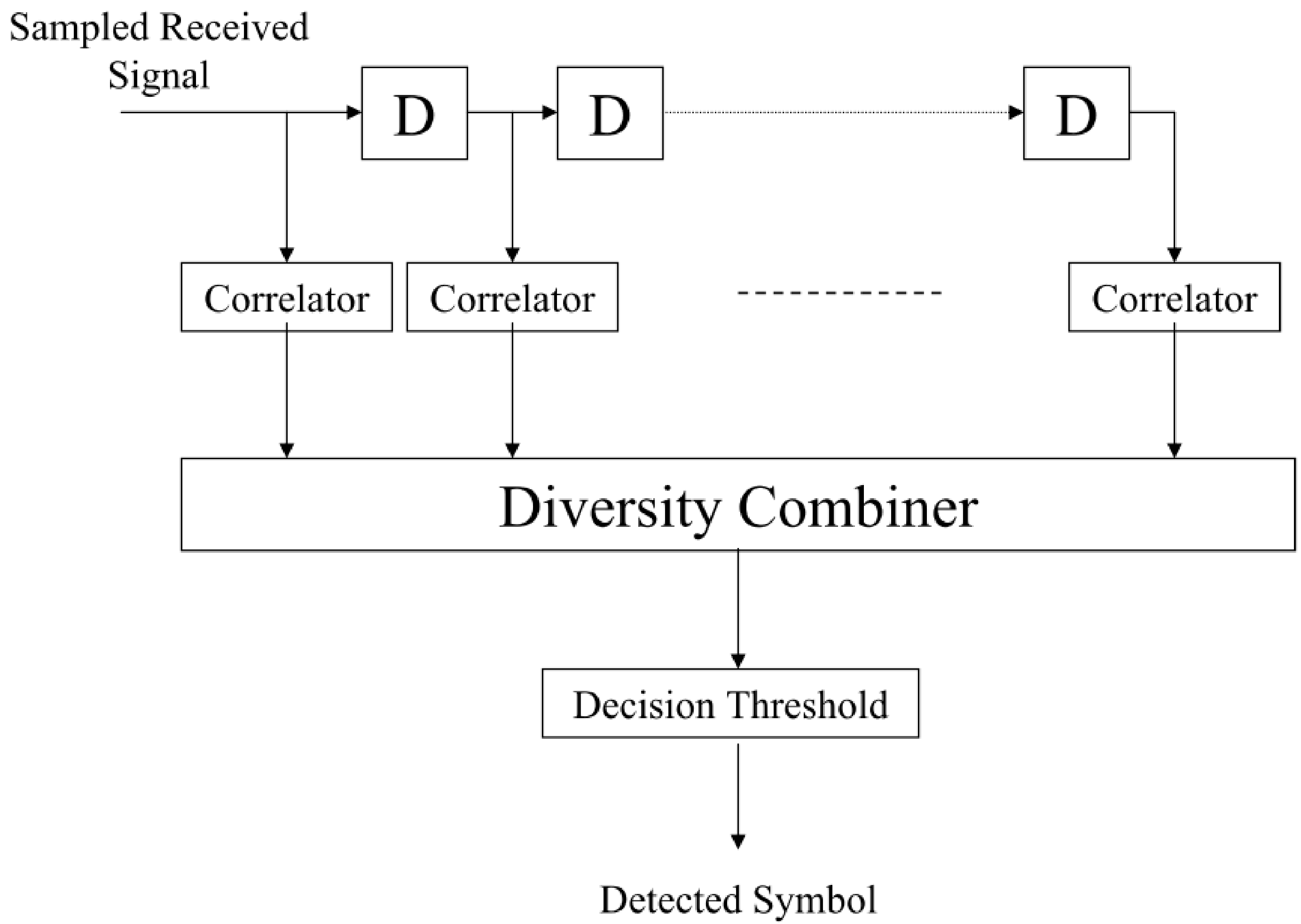
[PK chapter 5]

Mobile Wireless CDMA Design Considerations

- RAKE receiver
  - The RAKE receiver was invented in the 1950's in MIT's Lincoln Laboratory, today they are commonly used in DSSS receivers in CDMA phones
  - when multiple versions of a signal arrive more than one chip interval apart, a RAKE receiver attempts to recover signals from multiple paths and combine them
  - In a multipath environment (common in cellular systems), multiples versions of the signal arrive in the receiver
  - If the receiver recovers the signals from the multiple paths and then combine them, considering the suitable delays, it will be much better than taking in account only the dominant incoming signal and treating the remaining signals as noise
    - This principle is used in the RAKE receiver
  - It provides inherent diversity in the presence of the multi path fading to improve voice quality

[PK chapter 3]
[Stallings chapter 10]

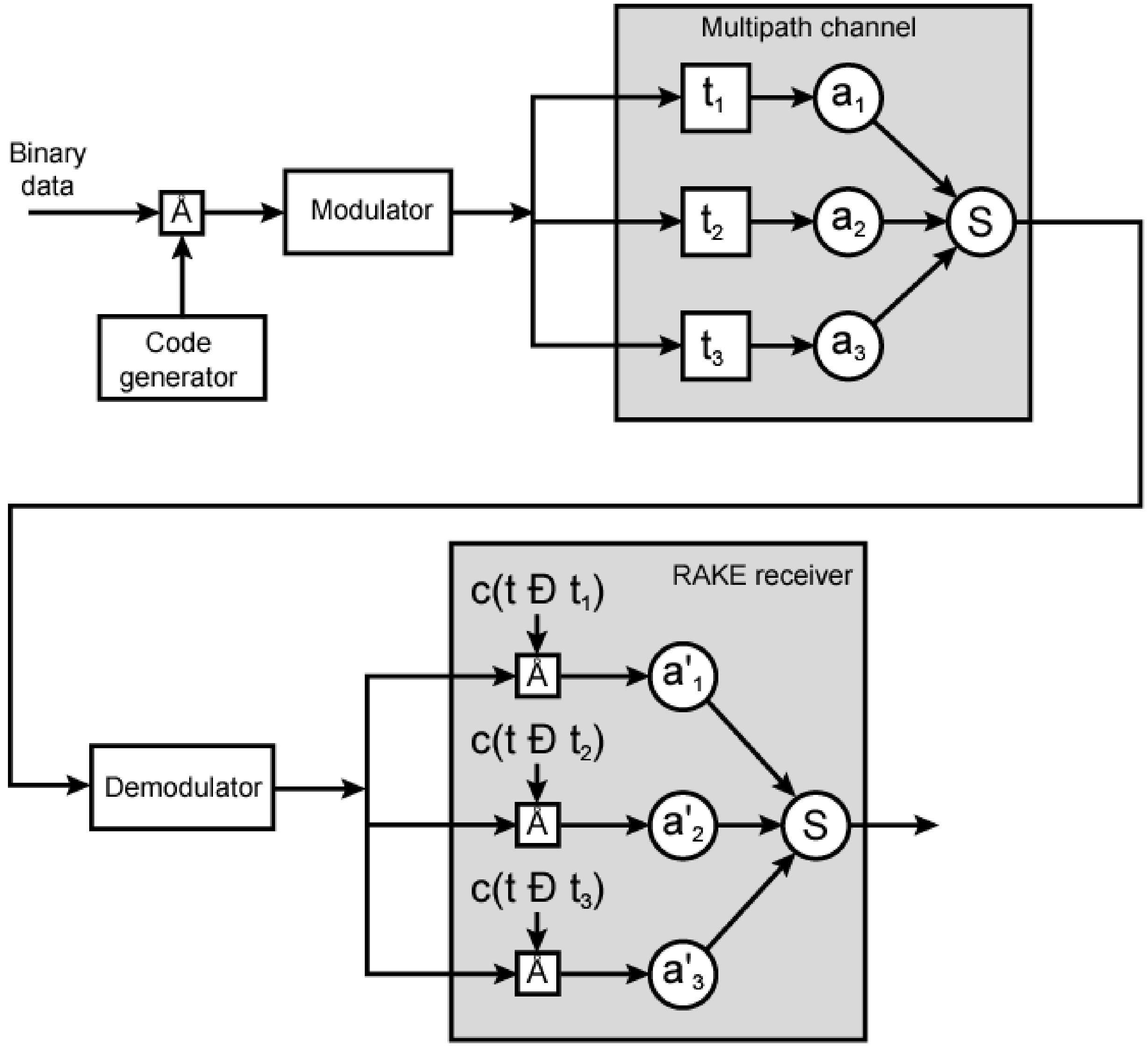
Rake Receiver Principle [PK 02]



RAKE receiver [Stallings 02 – 10.4] [PK 02 – 3.10]

- The multiple copies of the modulated signal arrive with a different time delay and with different attenuation factors
- At the receiver the demodulated chip stream is then fed into multiple correlators (“fingers”) , each delayed by a different amount of time
- The signals are them combined using weighting factors estimated from the channel
- IS-95 uses a RAKE receiver with 4 fingers
  - 1 finger is used for searching, while the other 3 are used for combining

Principle of the RAKE Receiver [PRAS98] [Stallings 02]



CDMA - Handoff Considerations

- CDMA Soft Handoff
  – mobile station temporarily connected to more than one base station simultaneously
- In IS-95, the fingers of a RAKE receiver can select either a multi path signal or a signal from another base station if it is within the range of the MS
  – This ability is known as soft handoff and improves voice quality during handoff
- The reason for implementing soft handoffs is the near-far problem and the associated power control mechanism
- An MS will continuously track all BSs nearby and communicate with multiple BSs for a short while if necessary before deciding which BS to select
- In IS-95
  – softer handoff - Figure 8.16(a)
  – soft handoff - Figure 8.16(b)
  – soft-softer handoff - Figure 8.16(c)

Types of Handoff in IS-95 [PK 02]

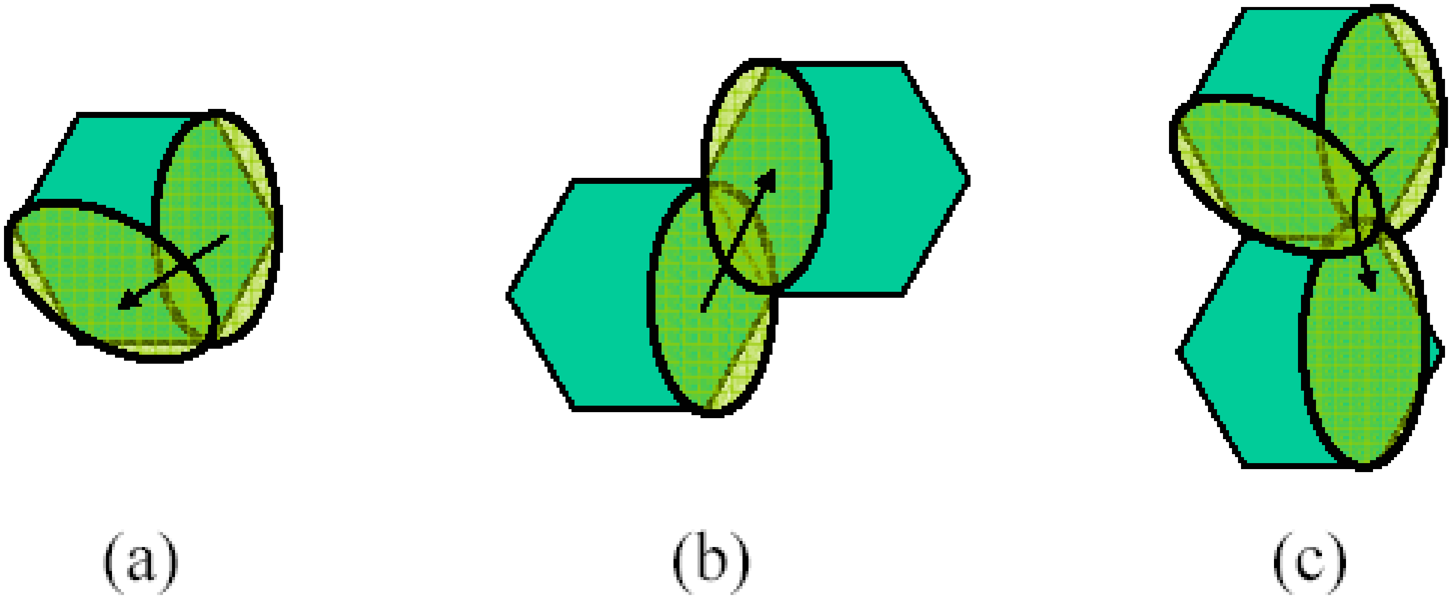


Figure 8.16: (a) Softer (b) soft and (c) soft-softer handoff

Pilot Channels and the Soft Handoff

- The pilot channels of each cell are involved in the handoff mechanism
  - The channel is not subject to power control and provides a measure of the RSS
- The MS maintains a list of pilot channels that it can hear and classifies them into four categories
- **Active set**
  - consists of pilots that are being continuously monitored or used by the MS
  - The MS monitors or uses up to three pilots (RAKE receiver)
- **Candidate set**
  - can have at most six pilots, and these refer to pilots that are not in the active set but that have sufficient RSS to be demodulated
- **Neighbour set**
  - contains pilots that belong to neighbouring cells and are informed to the MS by the paging channel
- **Remaining set**
  - contains all other possible pilot channels in the system

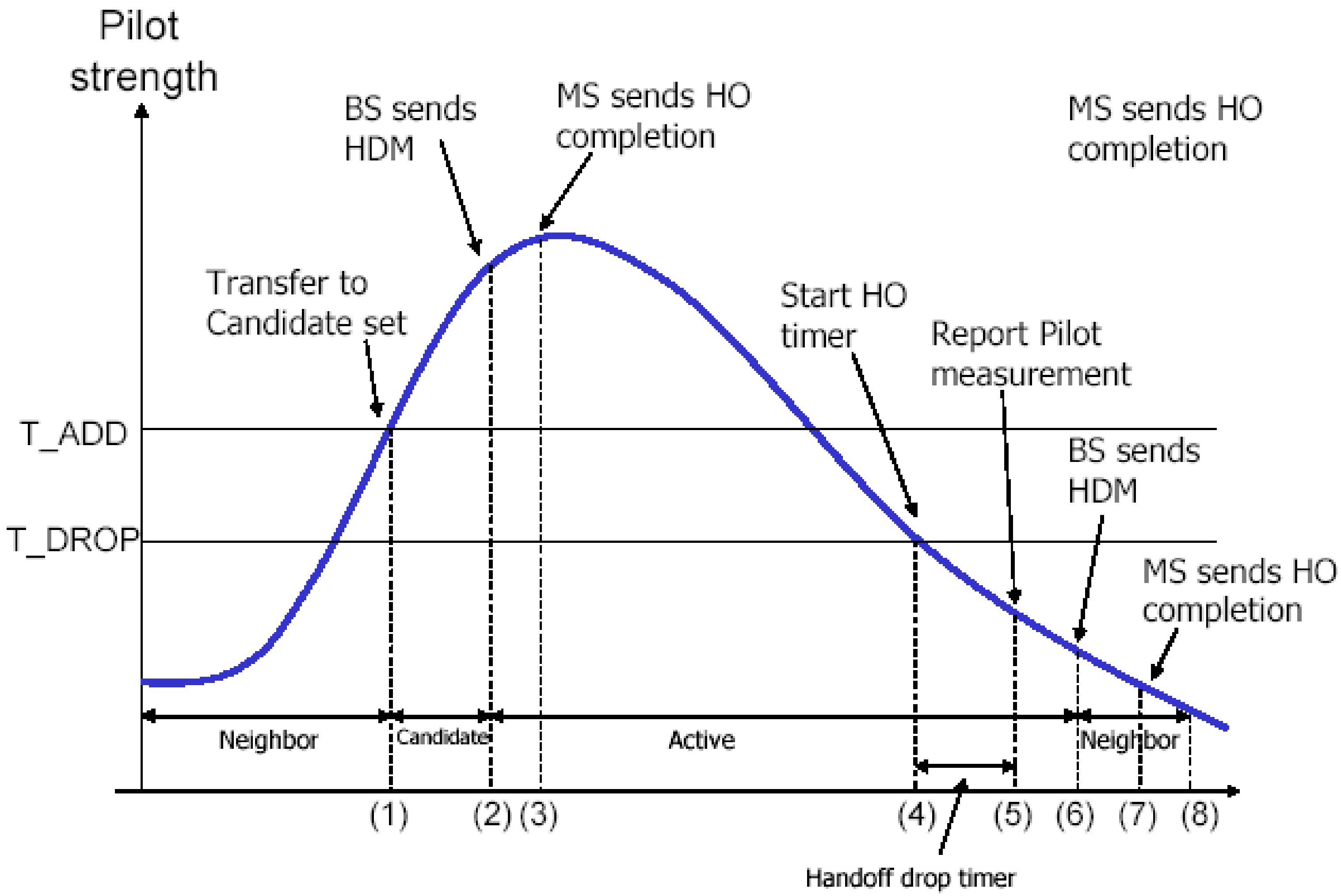
Pilot Detection Threshold in IS-95

- Initially the MS is connected to one BS and only its pilot and the multipath components of the pilot are in the active set
- As the MS moves away, the pilot of the adjacent cell becomes stronger
- If its strength is above the pilot detection threshold (T_ADD)
  - this pilot must be added to the active set and the MS enters in a soft handoff region
- Trade off for pilot detection threshold
  - threshold too small - false alarms caused by noise or interfering signals
  - threshold too large - useful pilots are not detected and the call may be dropped
- The thresholds for soft handoff procedure are similar to the RSS thresholds discussed in the Cellular Fundamentals section
- The soft handoff is a mobile assisted handoff
  - the MS reports the signal strength measurements to the network
- Handoff thresholds adjusted dynamically - improve system performance

Steps of a Soft Handoff in IS-95 [PK 02]

- (1) As soon as the strength of the pilot exceeds T_ADD, it is transferred to the **candidate set** and the MS sends the pilot strength measurement to the BS that is transmitting the pilot
- (2) The BS sends a ***handoff direction message (HDM)*** to the MS and the MS transfers the pilot to the **active set**
  - The active set pilot channels are indicated in the **HDM** message
- The MS acquires a traffic channel and sends a ***handoff completion message*** (3)
- After the pilot strength drops below T_DROP, the handoff drop timer is started
- If the strength is still below T_DROP after the timer expires, the MS sends another pilot strength measurement to the BS associated with the pilot (5)
- When it receives the corresponding **HDM** without the pilot in it, the MS moves the pilot to the **neighbour set** (6) and sends a ***handoff completion message*** (7)
- At some point, the BS may send a ***neighbour update list message*** to the MS that no longer contains the pilot and the pilot channel is moved into the **remaining set** (8)

Handoff Thresholds in IS-95 [PK 02]



Handoff Procedure in IS-95 [PK 02] [Gar 00]

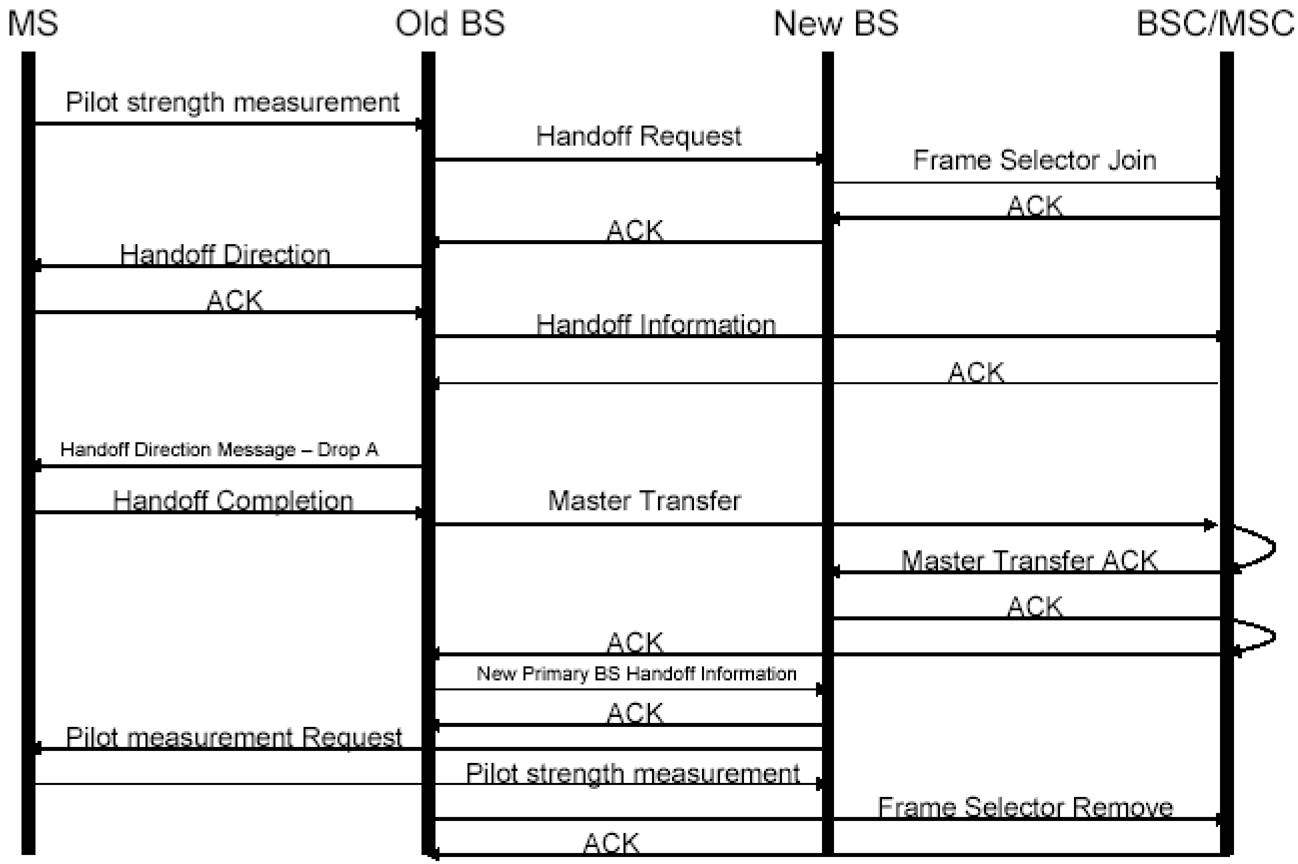
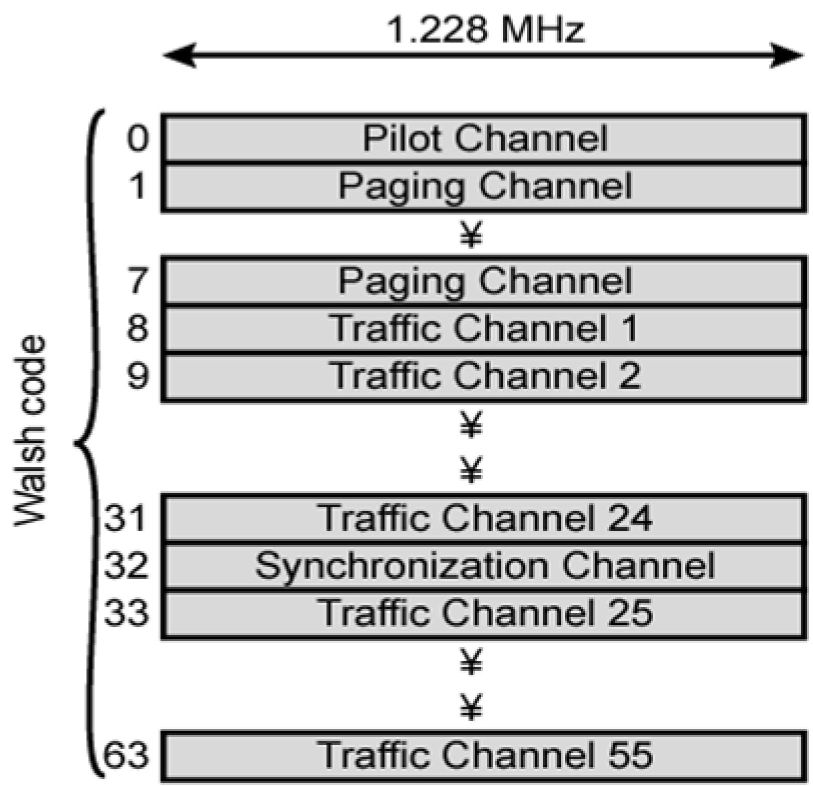


Figure 8.17: Setup and ending of soft handoff

IS-95 CDMA Logical Channels (Forward Link)

- Pilot (channel 0)
  - Allows the mobile unit to acquire timing information, provides phase reference and provides means for signal strength comparison
  - It is about 4-6 dB stronger than all other channels
  - It is used for signal strength comparison
  - Contains no information except the RF carrier
  - It is spread using the PN-spreading code to identify the BS
- Synchronization (channel 32)
  - Used by mobile stations to obtain identification information about cellular system
  - Same PN-spreading as pilot channel
  - Sync message includes network information, the offset of the PN short code, the state of the PN-long code and paging channel data rate (4.8 or 9.6 kbps)
- There is no power control for the pilot, synch, and paging channels

IS-95 CDMA Logical Channels (Forward Link) [Stallings 02]



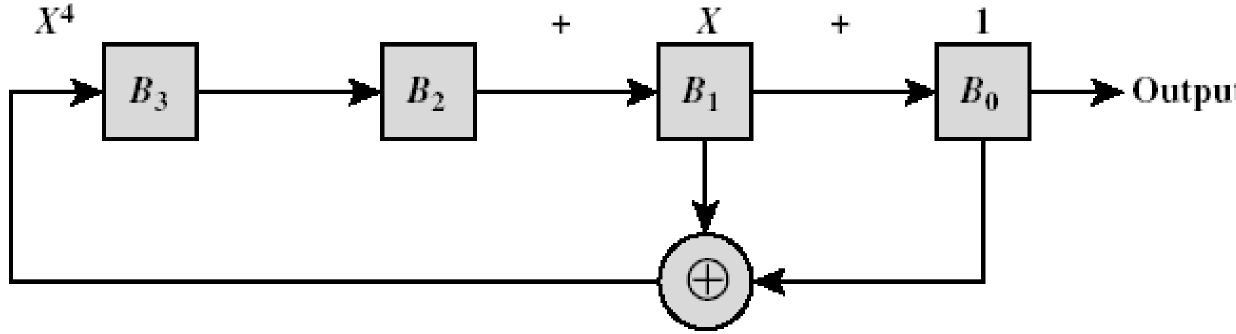
(a) Forward channels

IS-95 CDMA Logical Channels (Forward Link)

- Channel symbols are spread using the orthogonal codes, they are further scrambled by short PN-spreading codes
  - The orthogonal codes are used to isolate the transmissions between different channels within a cell
  - the PN spreading codes are used to separate the transmissions between different cells using the same carrier
- The PN (***Pseudo Noise***) spreading codes are not orthogonal, but possess excellent autocorrelation and cross-correlation properties
  - minimize interference among different channels
- The same PN sequence is used in all BSs, but the PN sequence of each BS is offset from those of other BSs
  - BSs have to be synchronized on the downlink (achieved using GPS)

PN Sequence Example

- Linear feedback shift register (4-bit LFSR)



(a) Shift-register implementation

State	B_3	B_2	B_1	B_0	$B_0 \oplus B_1$	output
Initial = 0	1	0	0	0	0	0
1	0	1	0	0	0	0
2	0	0	1	0	1	0
3	1	0	0	1	1	1
4	1	1	0	0	0	0
5	0	1	1	0	1	0
6	1	0	1	1	0	1
7	0	1	0	1	1	1
8	1	0	1	0	1	0
9	1	1	0	1	1	1
10	1	1	1	0	1	0
11	1	1	1	1	0	1
12	0	1	1	1	0	1
13	0	0	1	1	0	1
14	0	0	0	1	1	1
15 = 0	1	0	0	0	0	0

(b) Example with initial state of 1000

Walsh Codes Examples

$$\mathbf{W}_{2n} = \begin{pmatrix} \mathbf{W}_n & \mathbf{W}_n \\ \mathbf{W}_n & \overline{\mathbf{W}_n} \end{pmatrix}$$

$$\mathrm{W}_1 = (0)$$

$$W_2 = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$$

(a) 2×2

$$W_4 = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{pmatrix}$$

(b) 4×4

$$W_8 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 \end{pmatrix}$$

(c) 8×8

IS-95 CDMA Logical Channels (Forward Link) [PK 02]

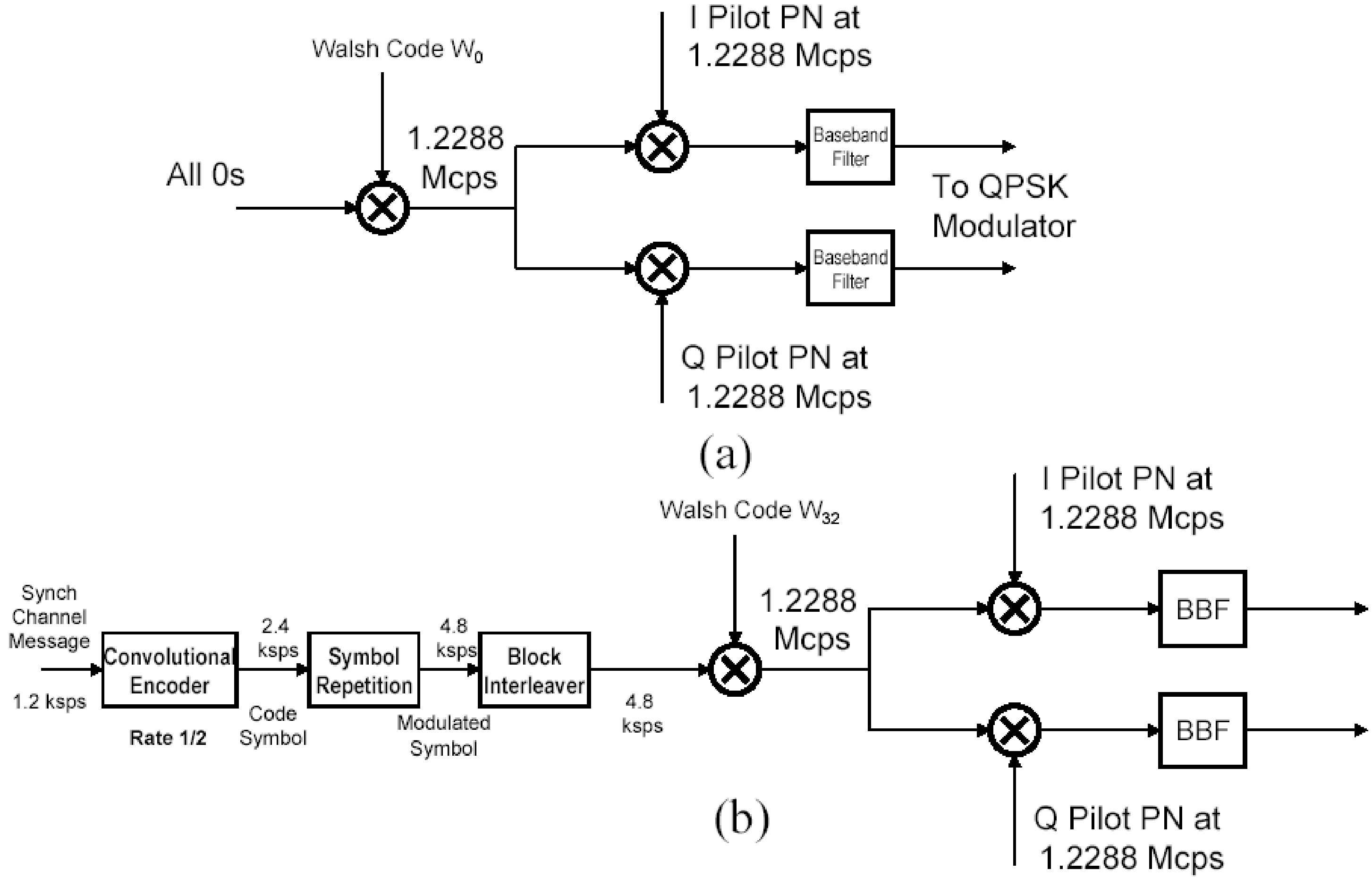


Figure 8.6: (a) Pilot and (b) Sync Channel Processing in IS -95

IS-95 CDMA Logical Channels (Forward Link)

- Paging (channels 1 to 7)
  - Contain paging messages for one or more mobile stations
  - Also carry control messages for call set up
  - It is scrambled by the PN long code
    - generated using a paging channel long code mask of length 42
  - Figure 8.7 shows how a paging channel message is created
- Traffic (channels 8 to 31 and 33 to 63)
  - The forward channel supports 55 traffic channels
  - Carry digitally encoded voice and data
  - Two possible rate sets
    - RS1 (Rate Set 1) supports 9.6, 4.8, 2.4 and 1.2 kbps (mandatory)
    - RS2 (Rate Set 2) supports 14.4, 7.2, 3.6 and 1.8 kbps (optional)

IS-95 CDMA Logical Channels (Forward Link) [PK 02]

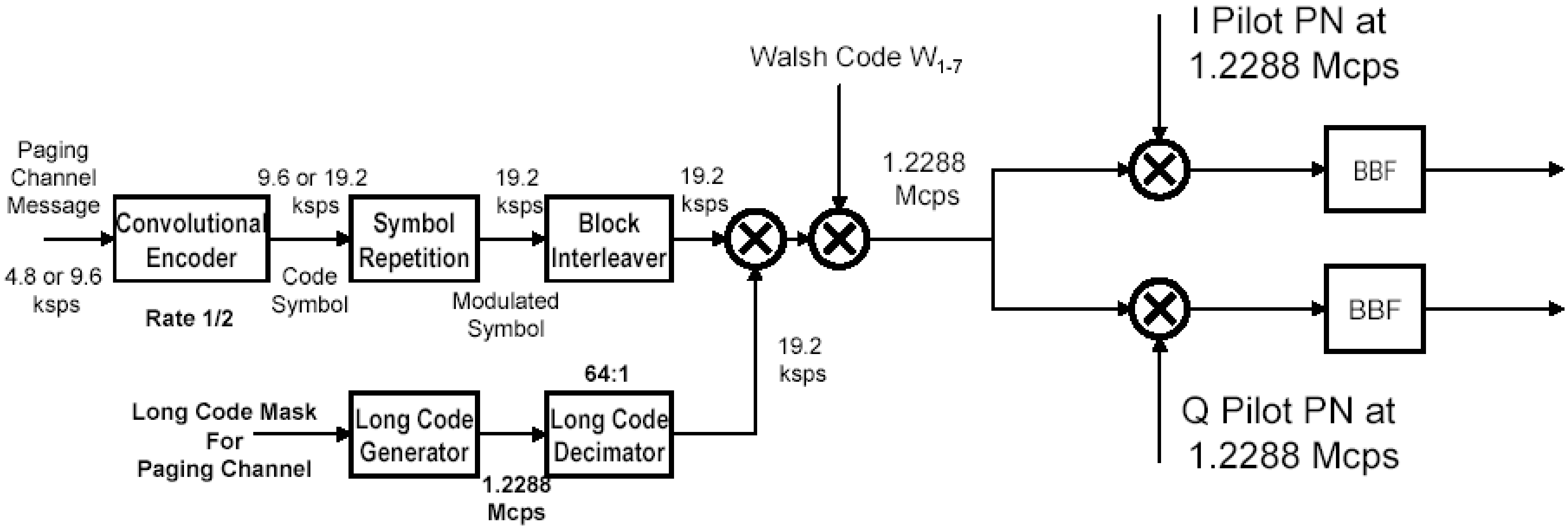
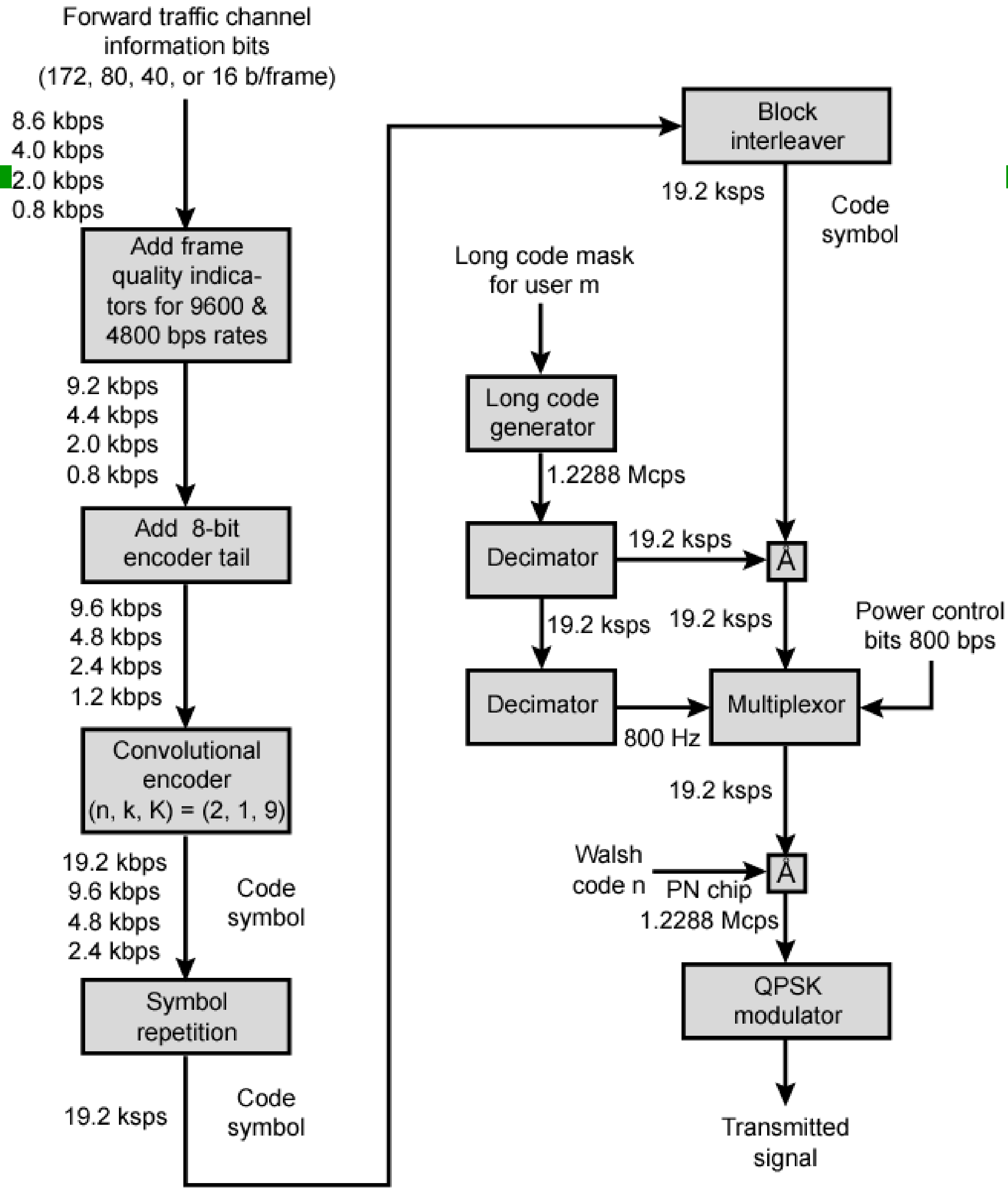


Figure 8.7: Paging Channel Processing in IS -95

FTC Processing [Stallings 02]



Forward Traffic Channel Processing Steps

- Time frame 20ms
- Speech is encoded at a rate of 8550 bps
- Additional bits added for error detection (9.6kbps)
- Data transmitted in 20ms blocks with forward error correction provided by a convolutional encoder (1/2) (19.2Kbps)
- Data interleaved in blocks to reduce effects of errors
- Data bits are scrambled, serving as a privacy mask
  - The scrambling is accomplished by means of a long code that is generated as a pseudorandom number from a shift register
  - The shift register is initialized with the user's electronic serial number
  - The output of the long code generator is at a rate of 1.2288 Mbps
  - only one bit in 64 is selected (by the decimator function)
- The resulting stream is XORed with the output of the block interleaver

Forward Traffic Channel Processing Steps

- Power control information inserted into traffic channel
  - The power control function of the base station robs the traffic channel of bits at a rate of 800 bps
  - The 800 bps channel carries info directing the mobile unit to increment, decrement, or keep its current output level
  - multiplexed into the 19.2 kbps by replacing some of the code bits, using the long code generator to encode the bits.
- DS-SS function spreads the 19.2 kbps to a rate of 1.2288 Mbps using one row of 64 x 64 Walsh matrix
- Digital bit stream modulated onto the carrier using QPSK modulation scheme

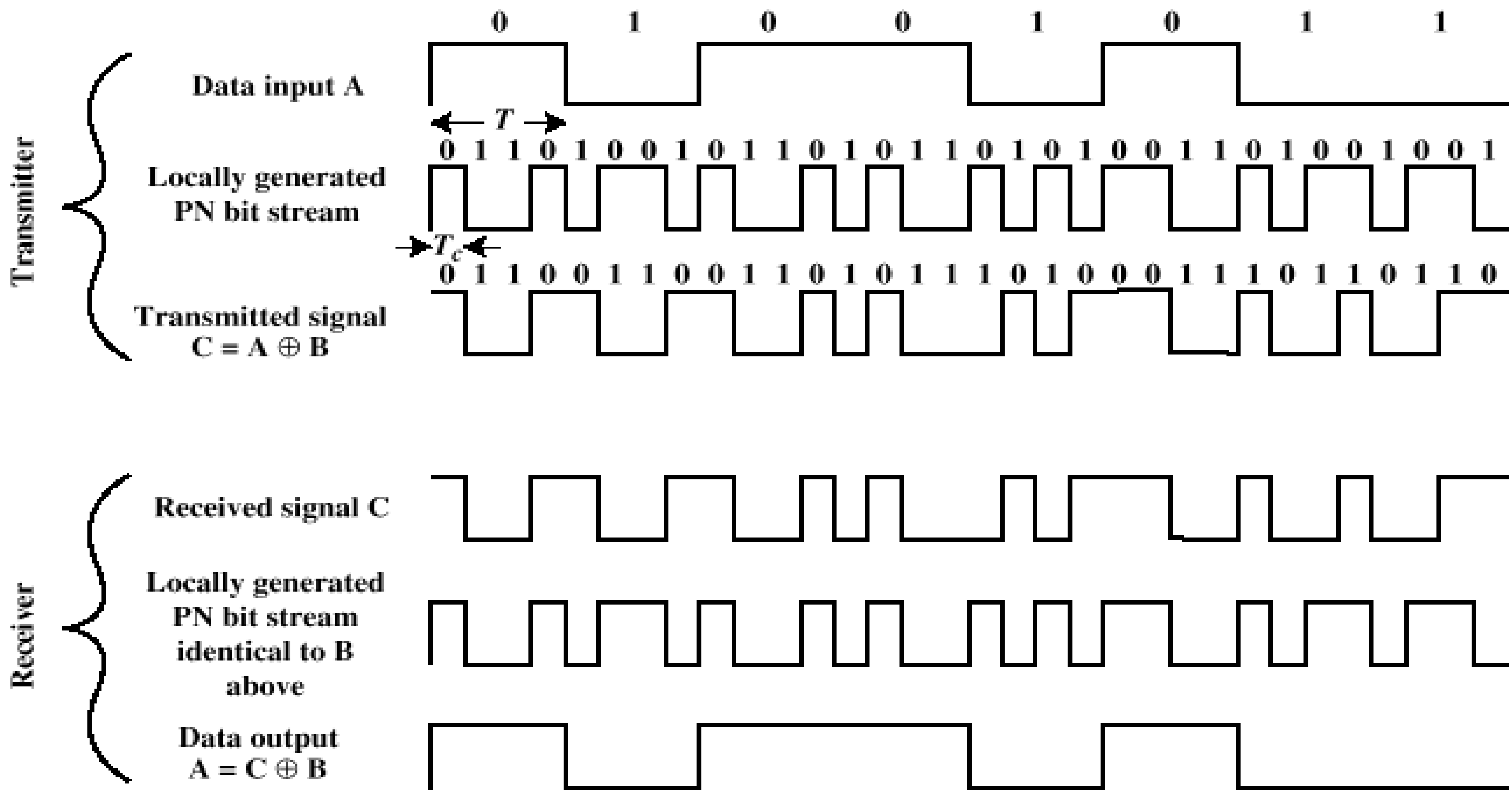
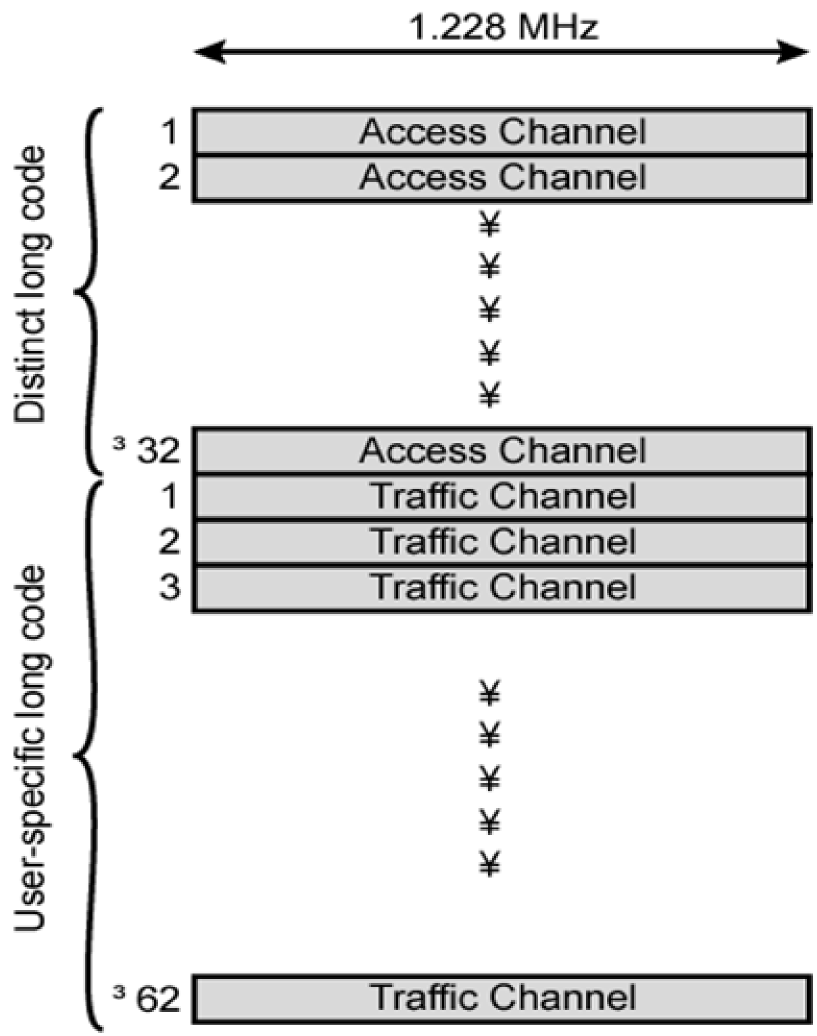


Figure 7.6 Example of Direct Sequence Spread Spectrum

IS-95 CDMA Logical Channels (Reverse Link) [Stallings 02]

- Traffic Channels
  - Carry traffic
  - Up to 62 TCs
- Access Channel
  - Used to initiate a call
  - Register on the system
  - Respond to paging
  - Up to 32 ACs



(b) Reverse channels

The IS-95 Reverse Channels [Stallings 02]

- There is no spreading of the data symbols using orthogonal codes
- Instead, the orthogonal codes are used for waveform encoding
  - Employs an orthogonal modulation scheme that consumes bandwidth but reduces the error rate performance of the system
  - Mapping used in IS-95 for Walsh codes of length 64
    - W = b0 + 2b1+4b2 + 8b3 + 16b4 + 32b5
    - b5 is the most recent bit (from the input)
  - For instance, if the input six bits are: 111010
    - input b0 = 1, input b1 =1, input b2 = 1, input b3 = 0, input b4 = 1, input b5 = 0)
    - the Walsh code selected is:

    1+2xl +4x1 + 8x0+ 16 xl +32x0=23   i.e., W23 is transmitted

Waveform Encoding Example - Walsh Code of length 8 [PK 02]

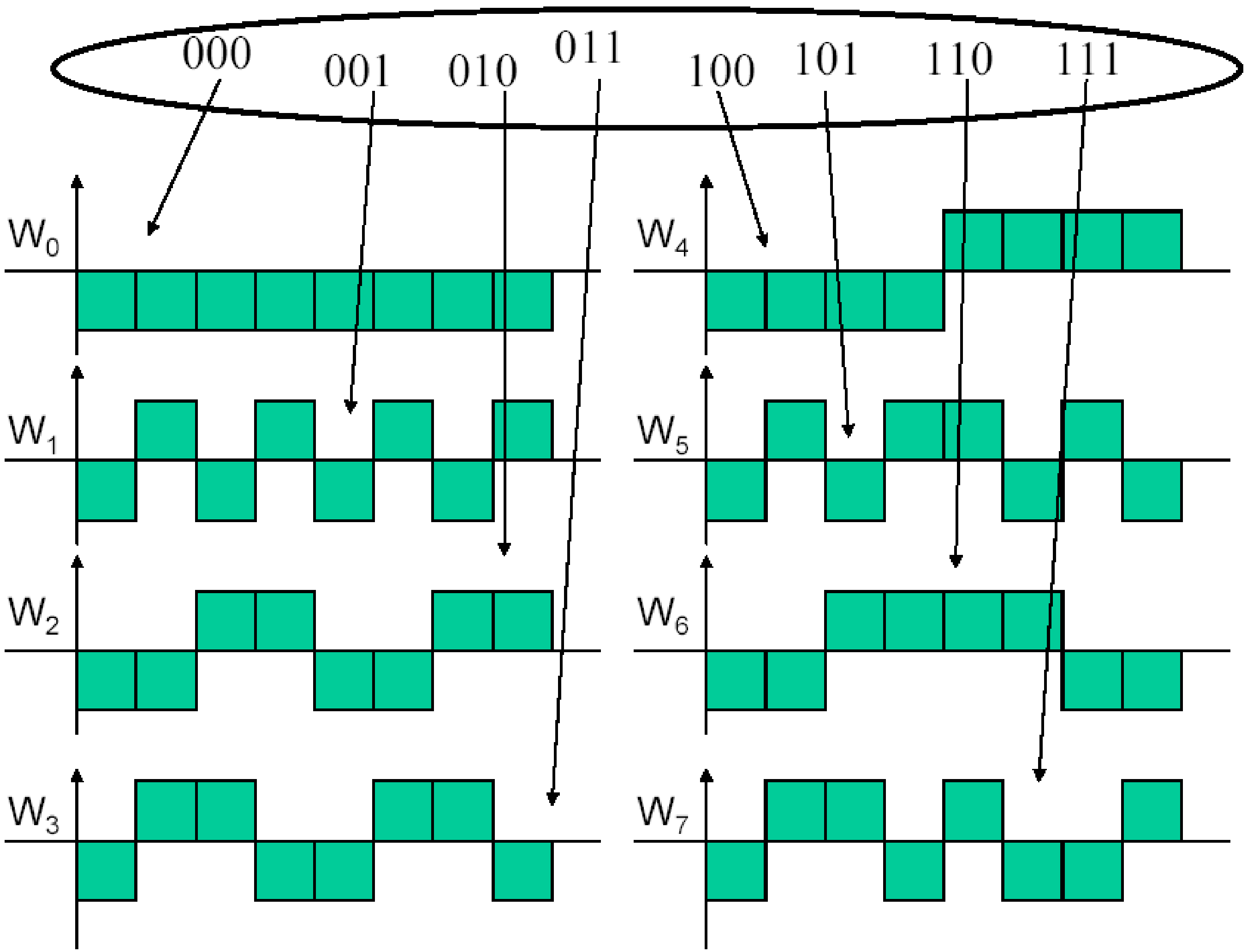
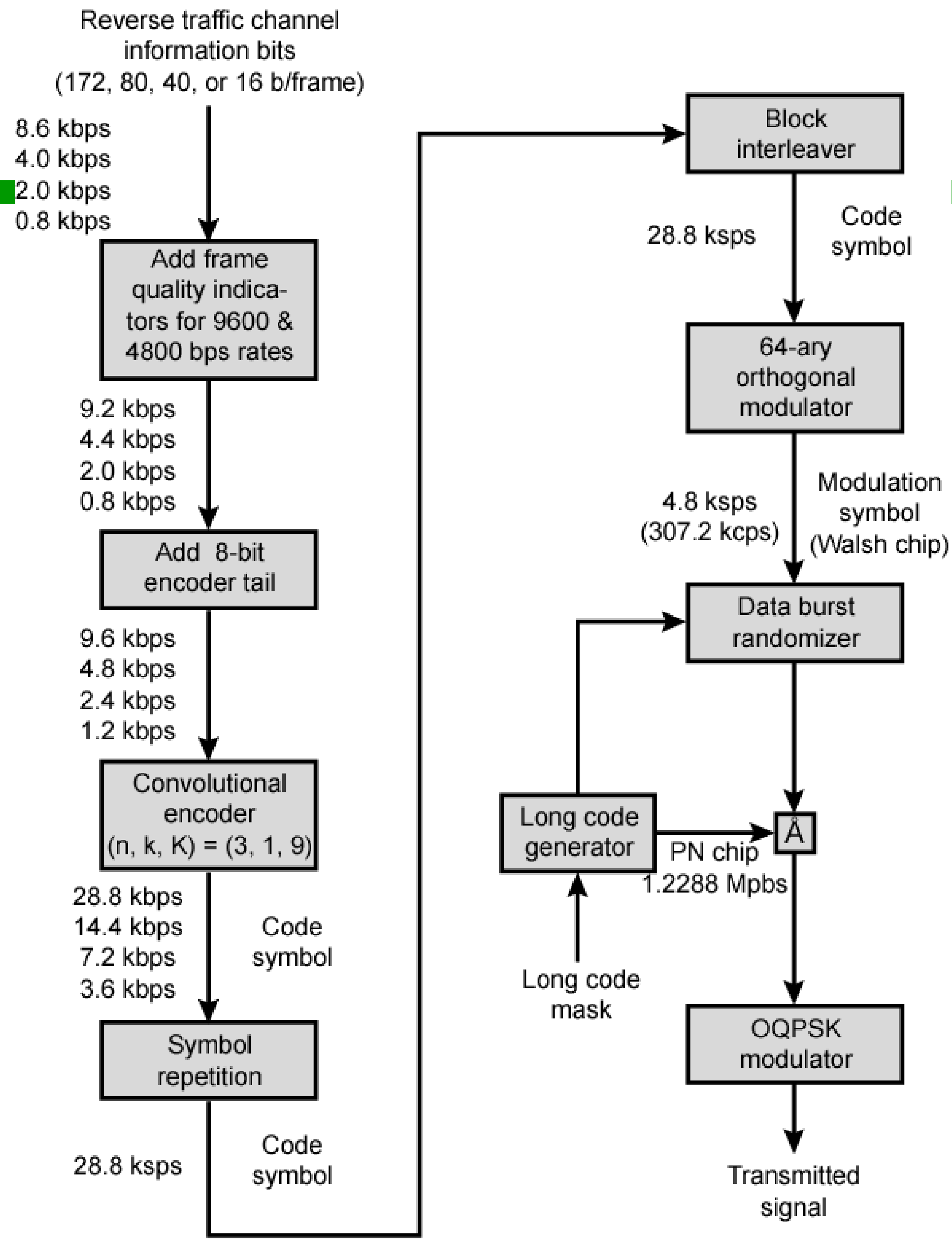


Figure 8.11: Mapping data bits to Walsh encoded symbols

$$W = b0 + 2b1 + 4b2$$

RTC Processing [Stallings 02]



Reverse Traffic Channel Processing Steps

- Time frame 20ms
- Speech is encoded at a rate of 8550 bps
- Additional bits added for error detection (9.6kbps)
- Data transmitted in 20ms blocks with forward error correction provided by a convolutional encoder (1/3) (28.8kbps)
- Data interleaved in blocks to reduce effects of errors
- Walsh block error-correction coding (spread factor 64/6)
  - data are grouped in units of 6 bits
  - Each 6-bit unit serves as an index to select a row of the 64 x 64 Walsh matrix ($2^6 = 64$), and that row is substituted for the input
  - 28.8kbps times 64/6 = 307.2kbps
- Data burst randomiser to reduce interference from other mobile stations
- DS-SS function spreads the 307.2 kbps to a rate of 1.2288 Mbps (factor of 4) user unique long code Digital bit stream modulated onto the carrier using OQPSK modulation scheme

IS-95B

- IS-95b brought improvements over IS-95a
  - Mobile assisted hard handoff
    - Mobile scans pilot channels of other BSs before making handoff, reducing large failure rate
  - Power control step size reduced from 1dB to 0.25dB offering greater accuracy
  - Access performance improved :
    - Mobiles are now allowed to scan for better pilot during call set up and perform handoffs during call set ups
  - A new handoff algorithm with dynamic add/drop thresholds reduces soft handoff time
  - Support for High Speed Data up to 64kbps occupying up to 8 traffic channels

Class Quiz

- **How is IS95 architecture from GSM one?**
- **How is the cell capacity is determined in CDMA?**
- **What is the rake receiver?**
- **How is the handover organised in IS95?**
- **How is the spreading code used in the forward and reverse channels, respectively.**

References

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