Digital Wireless Technologies

Introduction

- 2G technologies (GSM & CDMA) are still around but will “sunset” by 2019
- 1992, analog technologies (AMPS, TACS, NMT) were in use
- Popularity of cell phones demanded more capacity and efficient spectrum usage
- The solution was the introduction of digital-radio technology
- First attempt in 1992 → IS-54 (aka D-AMPS)
- Then by mid-1990s we had
  - IS-136 (aka TDMA), evolved form of IS-54
  - GSM
  - CDMA
- GSM later evolved into UMTS
- CDMA evolved into cdma2000
- Now all have merged into LTE

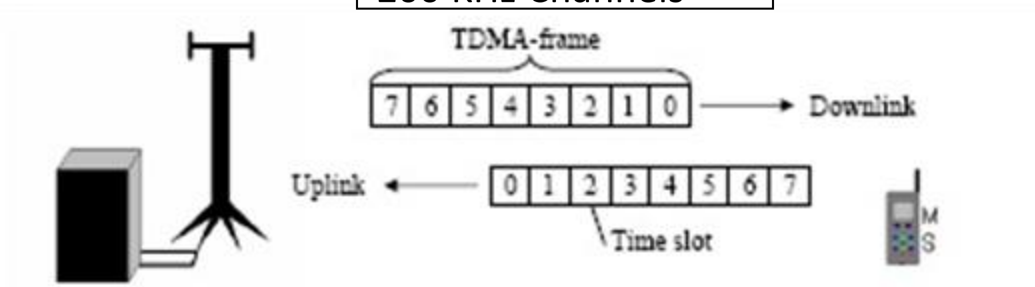
Digital Wireless: Advantages over Analog Cellular Systems

- Digital offers larger *capacity*
- Digital network equipment *costs* lesser---*lighter devices*
- Digital sound is *cleaner*---White noise introduced for pauses during CDMA calls
- Digital systems are more *secure*---difficult to hack, eavesdrop, or clone
- Digital networks exhibit lesser handover dropped calls
- Digital technology offer better signal quality estimation---BER and FER
- Repeaters are used instead of amplifiers---no additive noise
- TDM can be used instead of FDM
- Conversion to digital signaling allows use of more efficient digital switching techniques

Global System for Mobile Communication (GSM) Technology

- TDMA based technology
- Originally named after Groupe Special Mobile
- GSM channel can transport up to eight calls simultaneously
- 200/8 = 25 KHz, which is less than 30 KHz of AMPS channel

200 KHz Channels



FREQUENCY BAND

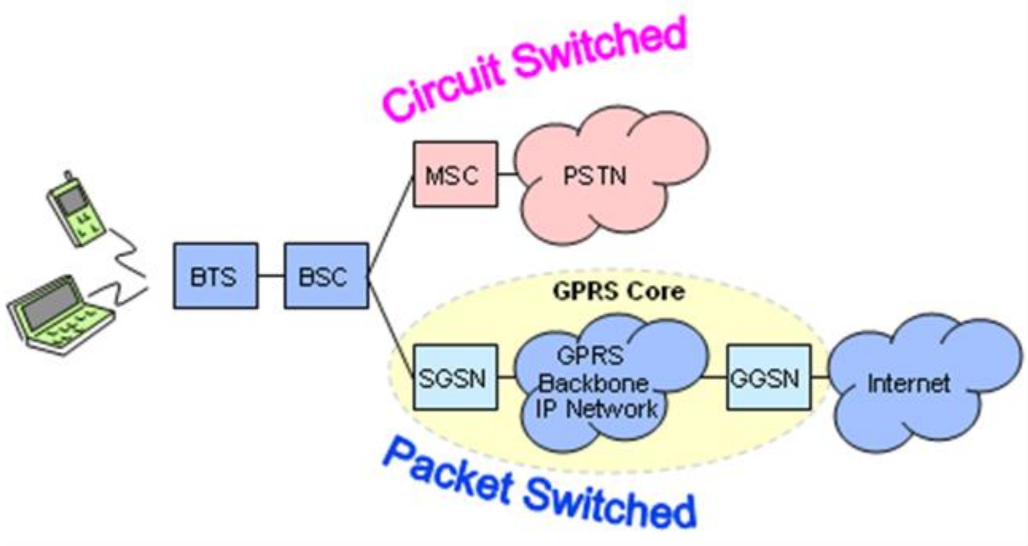
	GSM 900	GSM 1800	GSM 1900
Uplink	890 - 915 MHz	1710 – 1785 MHz	1850 – 1910 MHz
Downlink	935 – 960 MHz	1805 – 1880 MHz	1930 – 1990 MHz

Frequency Bands

GSM Adjunct Systems

The GSM standard defines the use of multiple ancillary systems in conjunction

- G*ateway MSC* (GMSC): Calls from other networks (i.e., the PSTN) will first terminate into the GMSC
- *Gateway GPRS Support Node* (GGSN): gateway between the GSM systems, and other external packet data networks such as other cellular data networks or IP networks
- *Service GPRS Support Node* (SGSN), mediates access to network resources on behalf of mobile subscribers and implements the packet scheduling
- Short Message Service Center (SMSC): Processes text messages



And Now!

- Spread Spectrum

Spread Spectrum - Transmitter

- Input is fed into a channel encoder
  - Produces analog signal with narrow bandwidth
- Signal is *further* modulated using sequence of digits
  - Spreading code or spreading sequence composed of Pseudonoise, or pseudo-random number
- Resulting in increased bandwidth of signal

Spread Spectrum - Receiver

- On receiving end, digit sequence is used to demodulate the spread spectrum signal

- Signal is fed into a channel decoder to recover data

Spread Spectrum

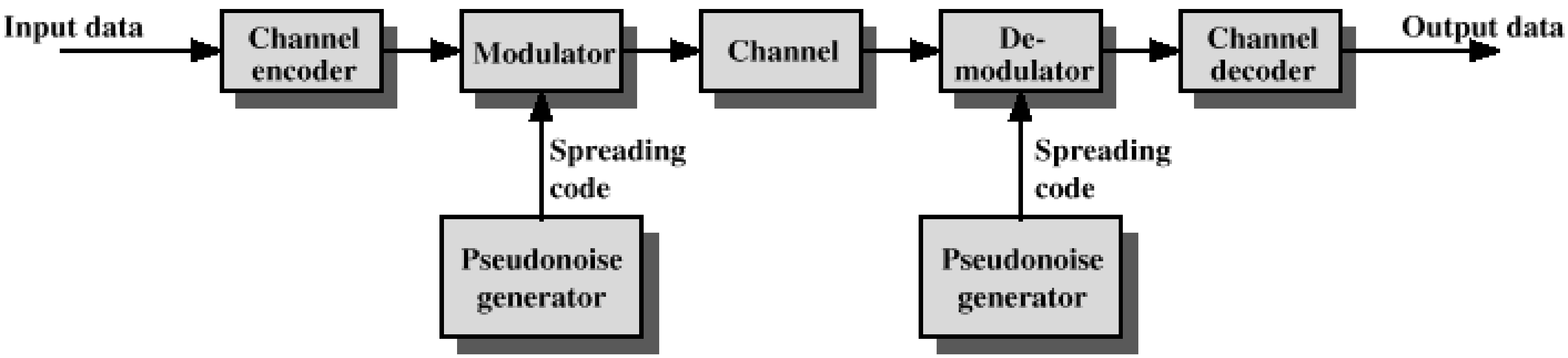


Figure 7.1 General Model of Spread Spectrum Digital Communication System

Spread Spectrum - Why

- Resistance to noise and multipath distortion
- Data hiding and encryption
- Concurrent transmission for several users

Frequency Hoping Spread Spectrum (FHSS)

- Transmission over seemingly random frequencies
  - A number of channels allocated for the FH signal
  - Width of each channel = bandwidth of input signal
- Signal hops from frequency to frequency
  - At fixed intervals
  - Transmitter operates in one channel at a time
  - Bits are transmitted using some encoding scheme
  - At each successive interval, a new carrier frequency is selected

Ref: https://en.wikipedia.org/wiki/Hedy_Lamarr

Frequency Hoping Spread Spectrum

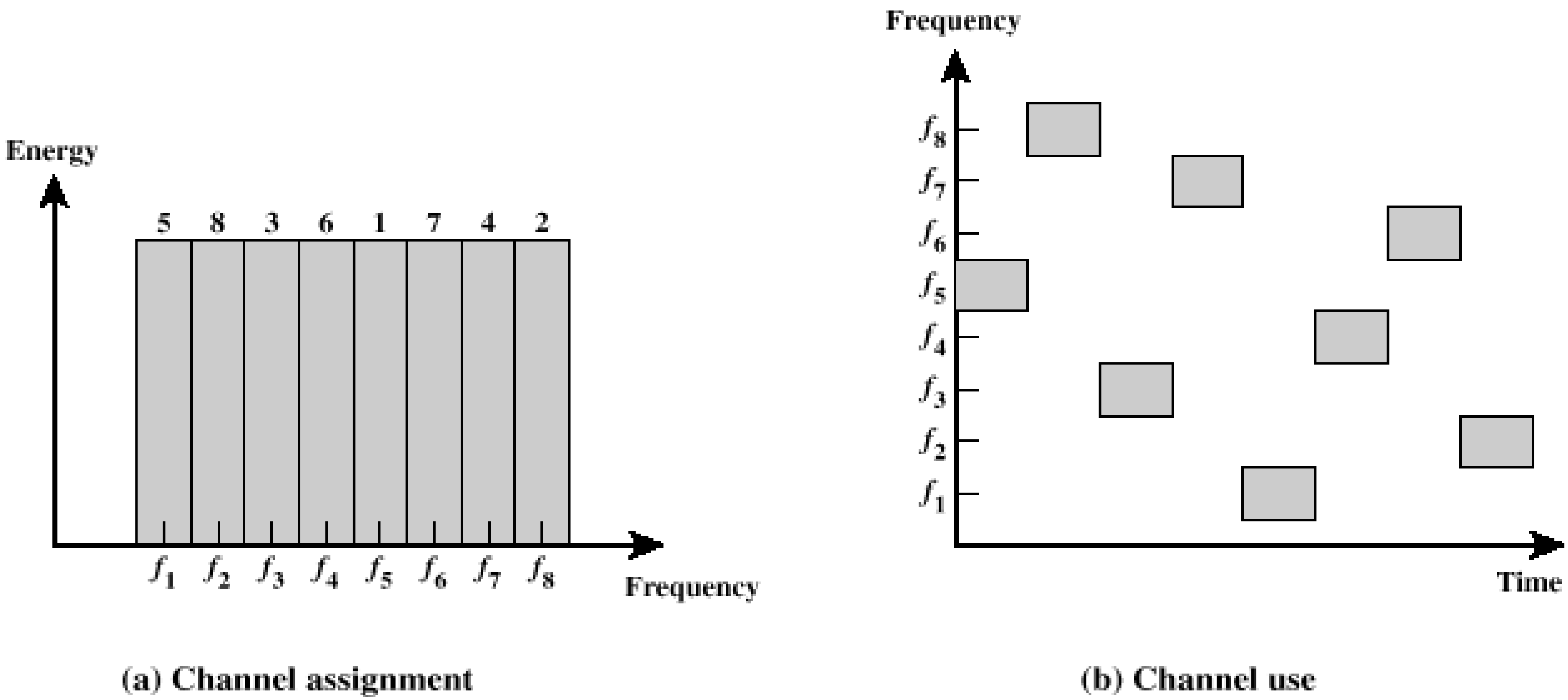
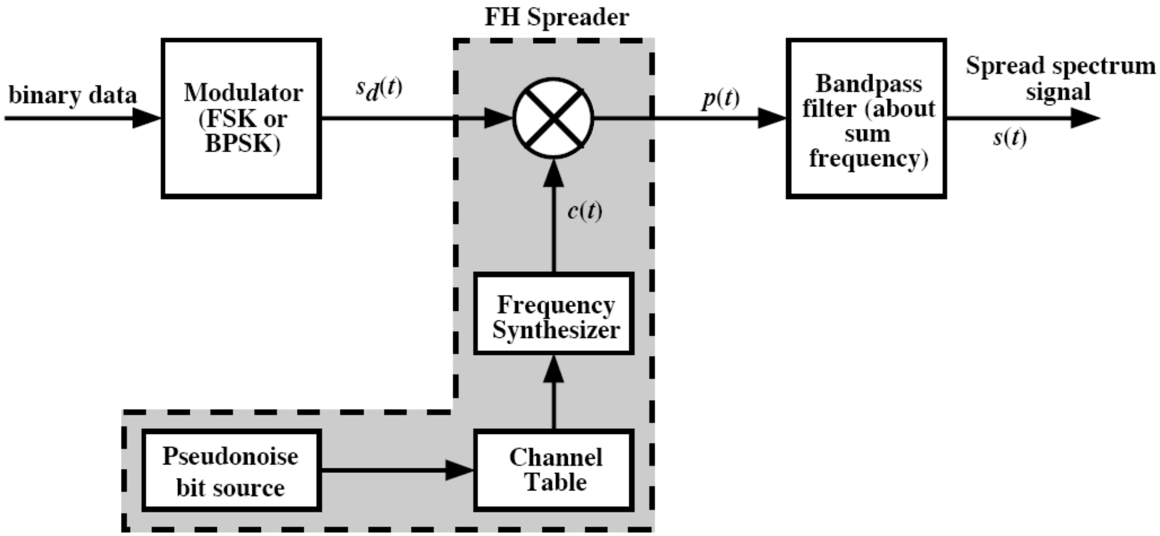


Figure 7.2 Frequency Hopping Example

Implementation of FHSS



- $s_d(t) = A\cos(2\pi f_1 t)$
- $p(t) = A\cos(2\pi f_1 t)\cos(2\pi f_i t)$

  $=0.5A\cos(2\pi(f_1+f_i)t)+0.5A\cos(2\pi(f_1-f_i)t)$

Frequency Hoping Spread Spectrum

- Channel sequence dictated by *pseudo-random* sequences
- Receiver hops in synchronization with transmitter
- Advantages
  - Eavesdroppers hear only unintelligible blips
  - Attempts to jam signal on one frequency succeed only at knocking out a few bits

FHSS Performance Considerations

- Large number of frequencies used
- Resistant to interference and jamming
  - Jammer must jam all frequencies
  - With fixed power, this reduces the jamming power in any one frequency band

Direct Sequence Spread Spectrum (DSSS)

- Each bit in original signal is represented by multiple *chips* in the transmitted signal
- Spreading code spreads signal across a wider frequency band
  - Spread is in direct proportion to number of chips used
- One technique combines digital information stream with the spreading code bit stream using exclusive-OR (Figure 7.6)

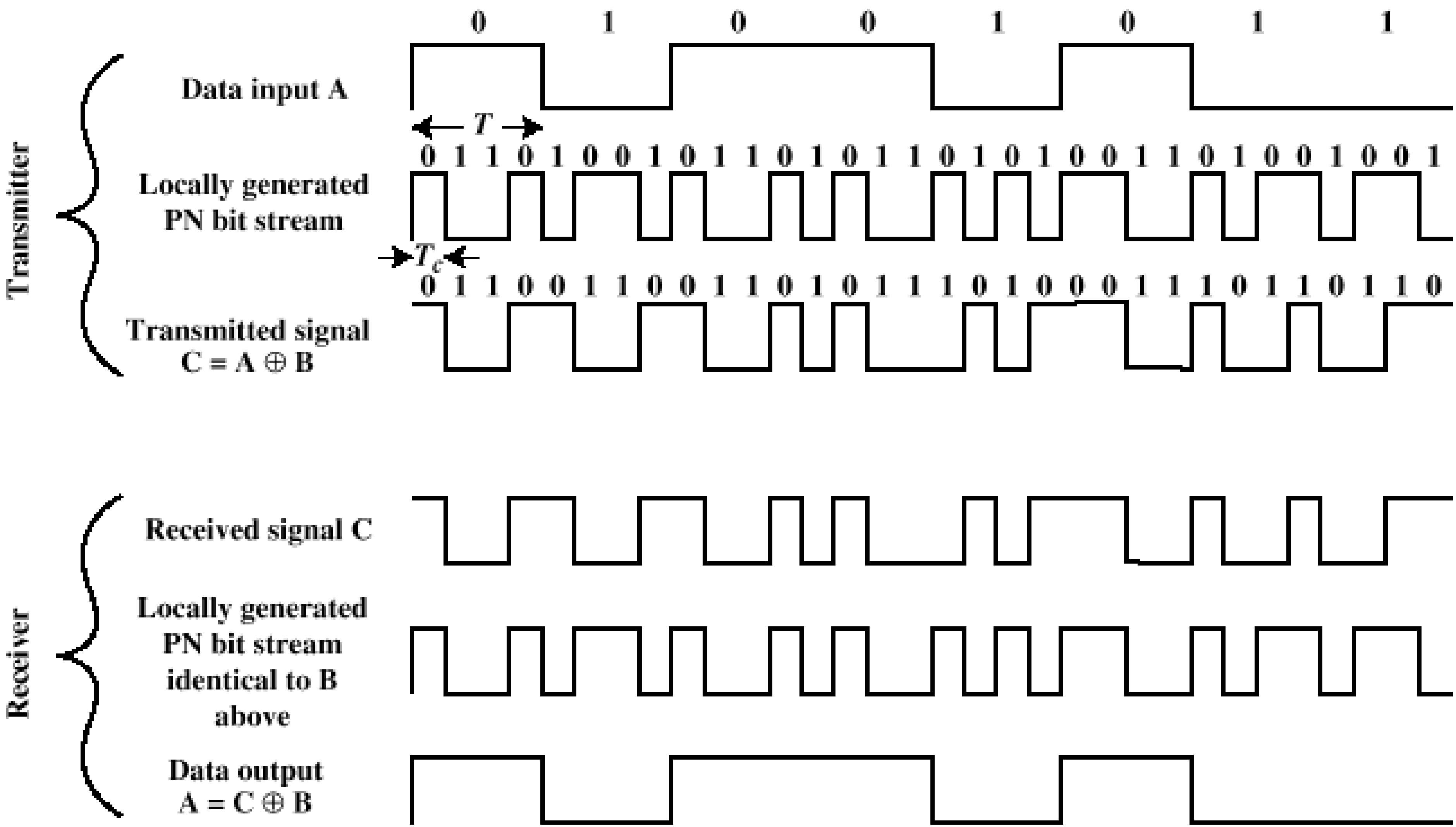


Figure 7.6 Example of Direct Sequence Spread Spectrum

DSSS Using BPSK

- Multiply BPSK signal,

$$s_d(t) = A\, d(t) \cos(2\pi f_c t)$$

  by $c(t)$ [takes values +1, -1] to get

$$s(t) = A\, d(t)c(t) \cos(2\pi f_c t)$$

  - A = amplitude of signal
  - f_c = carrier frequency
  - d(t) = discrete function [+1, -1]
- At receiver, incoming signal multiplied by $c(t)$
  - Since, $c(t) \cdot c(t) = 1$, incoming signal is recovered

DSSS Using BPSK

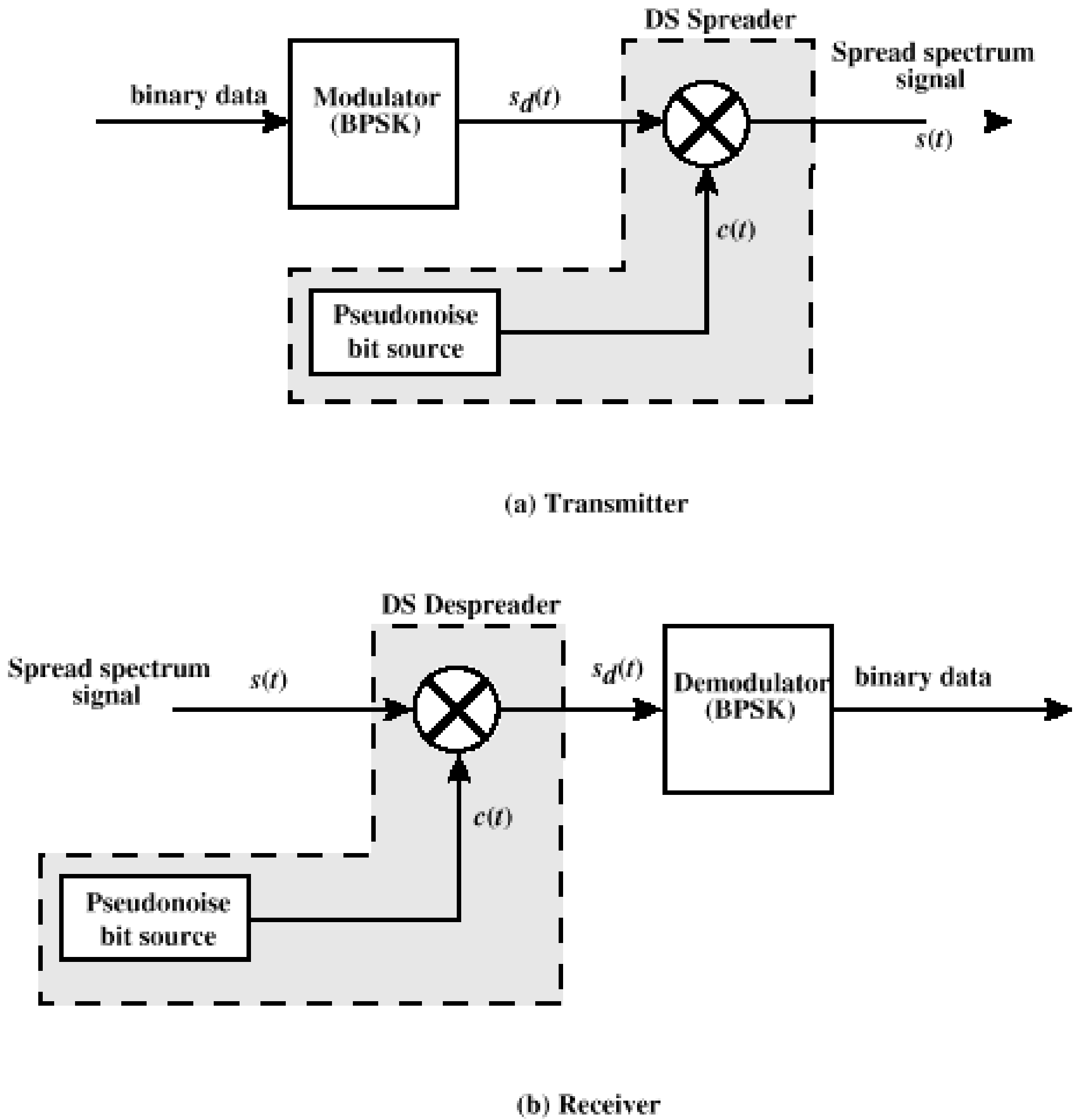


Figure 7.7 Direct Sequence Spread Spectrum System

Code-Division Multiple Access (CDMA)

- Basic Principles of CDMA
  - *D* = rate of data signal
  - Break each bit into *k chips*
    - Chips are a user-specific fixed pattern
  - Chip rate of new channel = *kD*

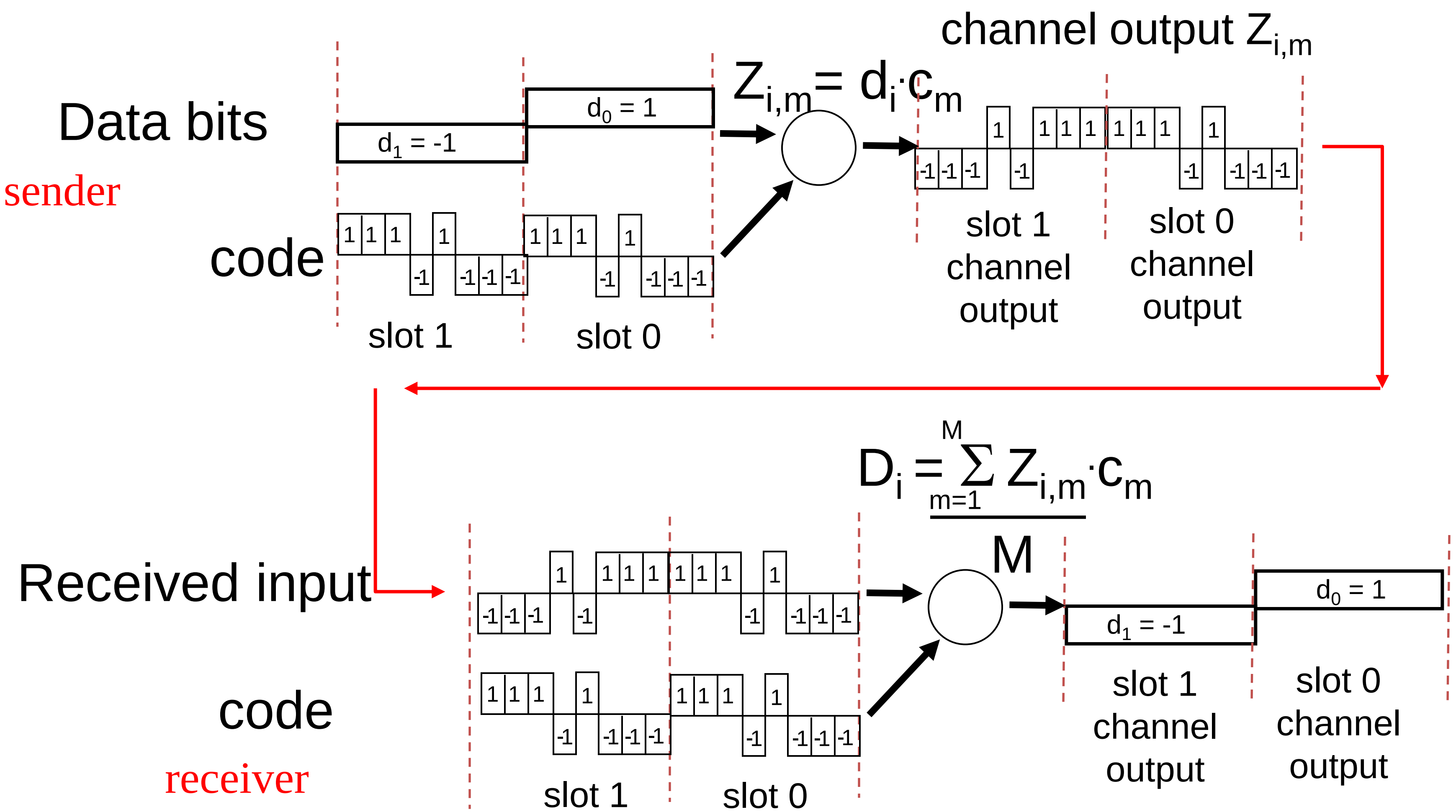
CDMA Example

- If *k*=6 and code is a sequence of 1s and -1s
  - For a ‘1’ bit, following chip pattern is sent out
    - <c1, c2, c3, c4, c5, c6>
  - For a ‘0’ bit, complement of the code is sent
    - <-c1, -c2, -c3, -c4, -c5, -c6>
- Receiver knows sender’s code and performs electronic decode function

$$S_u(d) = d1 \times c1 + d2 \times c2 + d3 \times c3 + d4 \times c4 + d5 \times c5 + d6 \times c6$$

    - <*d*1, *d*2, *d*3, *d*4, *d*5, *d*6> = received chip pattern
    - <*c*1, *c*2, *c*3, *c*4, *c*5, *c*6> = sender’s code

CDMA Encode/Decode



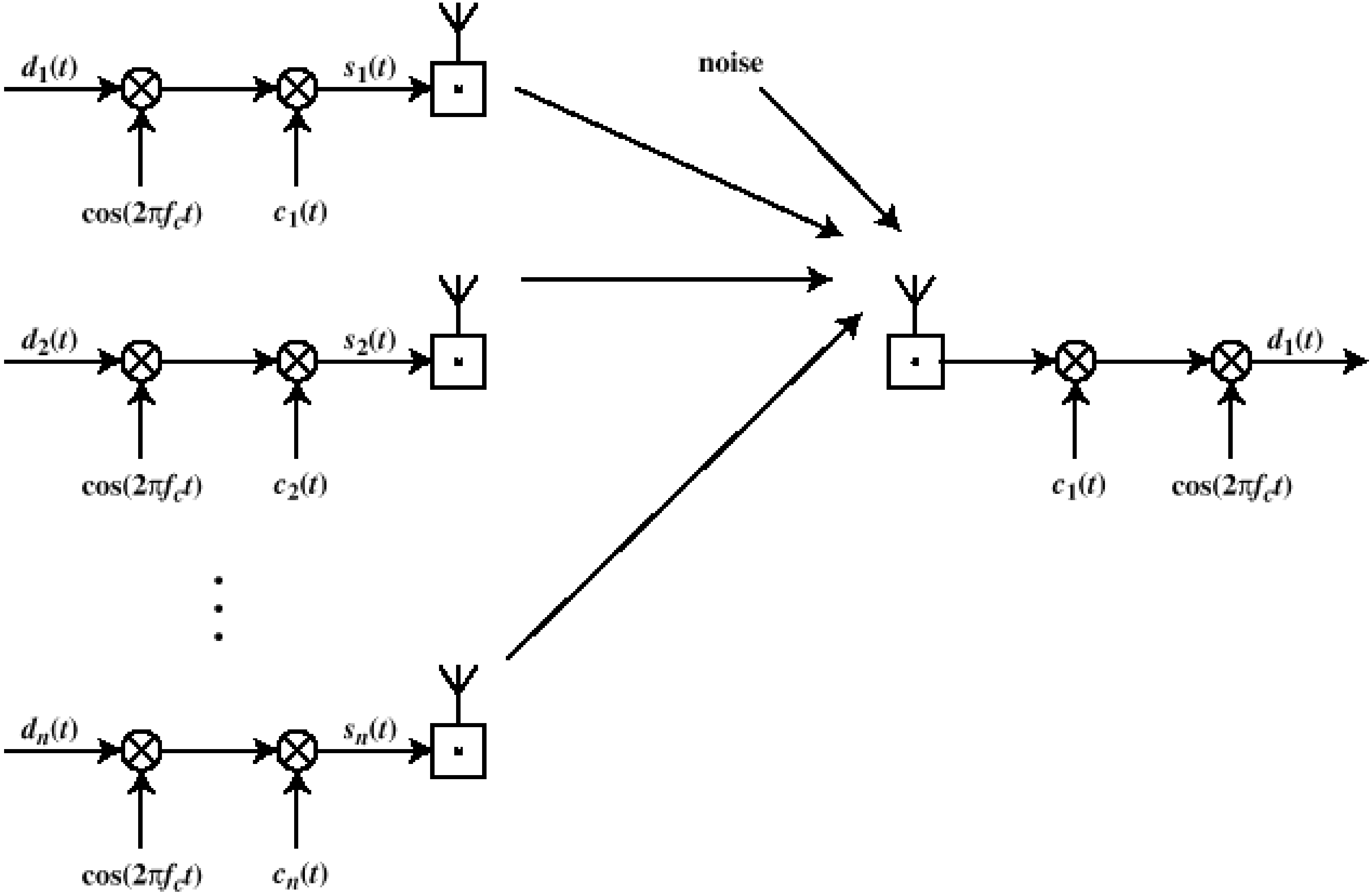


Figure 7.11 CDMA in a DSSS Environment

Categories of Spreading Sequences

- Spreading Sequence Categories
  - PN sequences
  - Orthogonal codes
- For FHSS systems
  - PN sequences most common
- For DSSS systems not employing CDMA
  - PN sequences most common
- For DSSS CDMA systems
  - PN sequences
  - Orthogonal codes

PN Sequences

- PN generator produces periodic sequence that appears to be random
- PN Sequences
  - Generated by an algorithm using initial seed
  - Sequence isn’t statistically random but will pass many test of randomness
  - Sequences referred to as pseudorandom numbers or pseudonoise sequences
  - Unless algorithm and seed are known, the sequence is very difficult to predict

Important Properties for Randomness

- Randomness
  - Uniform distribution
    Occurrence of each value has same probability
    - Balance property
      In a long sequence the fraction of binary 1's approaches 1/2
    - Run property
      Run is a sequence of all 1's (or 0's)
      one-half of the runs of length 1; one-fourth of length 2; one-eighth of run 3, and so on
  - Independence
    No one value can be inferred from the others
  - Correlation property
    Shifted versions of a sequence do not correlate

Orthogonal Codes

- Orthogonal codes
  - All pairwise cross correlations are zero
  - For CDMA application
    Used for channelization on the downlink
  - Each mobile user, on the uplink, uses one sequence in the set as a spreading code
- Types
  - Walsh codes
  - Orthogonal variable-length spreading factor (OVSF) codes

Walsh Codes

- Set of Walsh codes of length n consists of the n rows of an $n \times n$ Walsh matrix:

n = dimension of the matrix

$$W_{2n} = \begin{bmatrix} W_n & W_n \\ W_n & \overline{W_n} \end{bmatrix}$$

$$W_1 = (0)$$

(a) 1×1

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

(b) 2×2

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

(c) 4×4

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

(d) 8×8

Walsh Codes

- Every row is orthogonal to every other row and to the logical not of every other row
- Requires tight synchronization
  - Cross correlation between different shifts of Walsh sequences is not zero

Typical Multiple Spreading Approach

- Spread data rate by an orthogonal code (channelization code)
  - Provides mutual orthogonality among all users in the same cell
- Further spread result by a PN sequence (scrambling code)
  - Provides mutual randomness (low cross correlation) between users in different cells

Q & A

谢谢
THANK YOU