Spread Spectrum

Spread Spectrum

- 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
  - Generated by pseudonoise, or pseudo-random number generator
- Effect of modulation is to increase bandwidth of signal to be transmitted
- 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

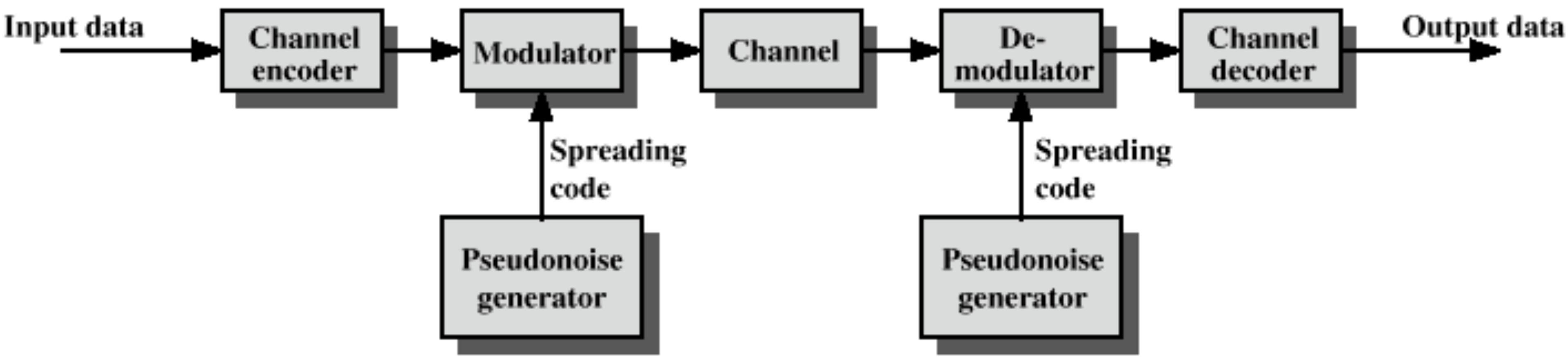


Figure 7.1 General Model of Spread Spectrum Digital Communication System

Spread Spectrum

- What can be gained from apparent waste of spectrum?
  - Immunity from various kinds of noise and multipath distortion
  - Can be used for hiding and encrypting signals
  - Several users can independently use the same higher bandwidth with very little interference

Frequency Hoping Spread Spectrum (FHSS)

- Signal is broadcast over seemingly random series of radio frequencies
  - A number of channels allocated for the FH signal
  - Width of each channel corresponds to 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

Frequency Hoping Spread Spectrum

- Channel sequence dictated by spreading code
- Receiver, hopping between frequencies in synchronization with transmitter, picks up message
- Advantages
  - Eavesdroppers hear only unintelligible blips
  - Attempts to jam signal on one frequency succeed only at knocking out a few bits

Frequency Hopping Spread Spectrum

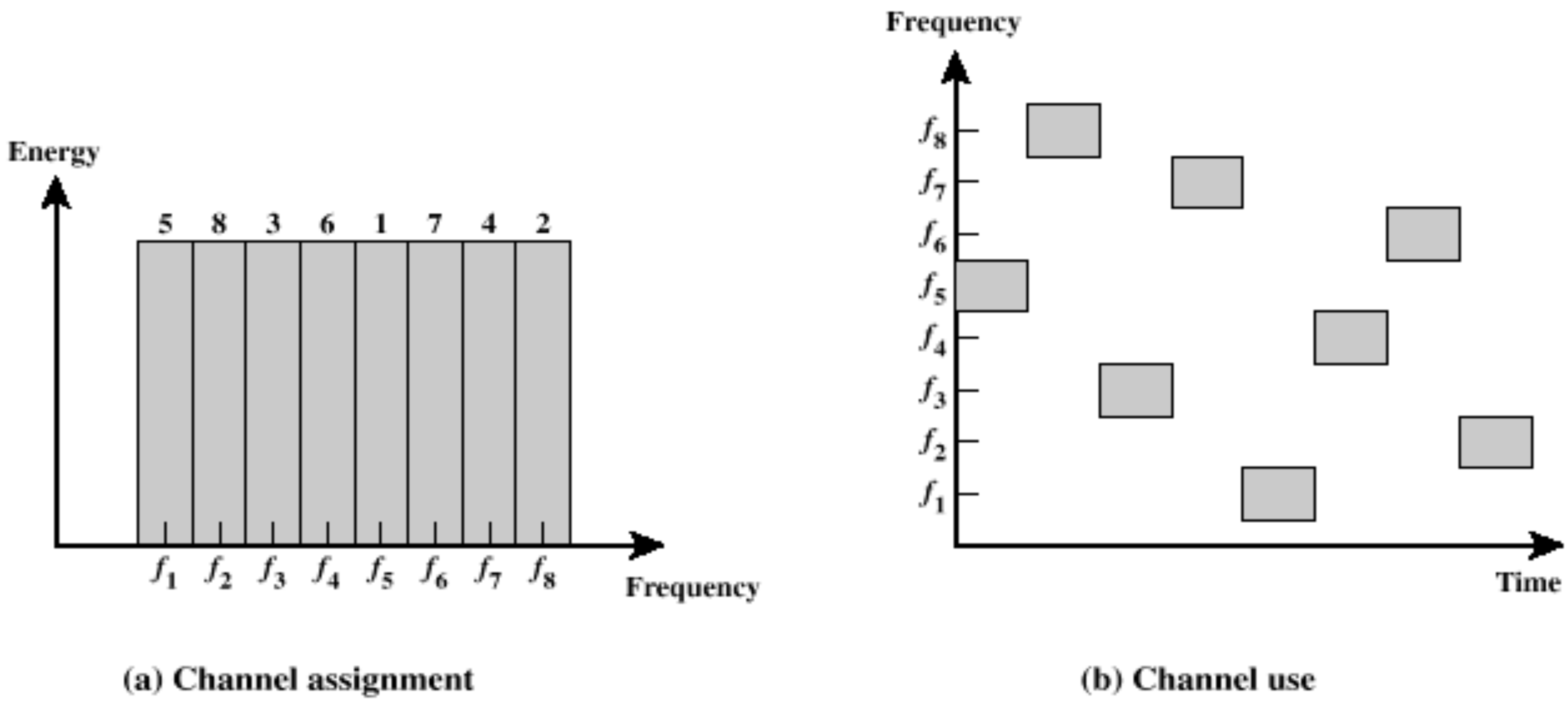


Figure 7.2 Frequency Hopping Example

FHSS Using MFSK

- MFSK signal is translated to a new frequency every T_c seconds by modulating the MFSK signal with the FHSS carrier signal
- For data rate of R:
  - duration of a bit: $T = 1/R$ seconds
  - duration of signal element: $T_s = LT$ seconds
- $T_c \geq T_s$ - slow-frequency-hop spread spectrum
  - Cheaper to implement but less protection against noise/jamming
  - Popular technique for wireless LANs
- $T_c < T_s$ - fast-frequency-hop spread spectrum
  - More expensive to implement, provides more protection against noise/jamming

FHSS Performance Considerations

- Large number of frequencies used
- Results in a system that is quite resistant to 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 bits in the transmitted signal
- Spreading code spreads signal across a wider frequency band
  - Spread is in direct proportion to number of bits used
- One technique combines digital information stream with the spreading code bit stream using exclusive-OR

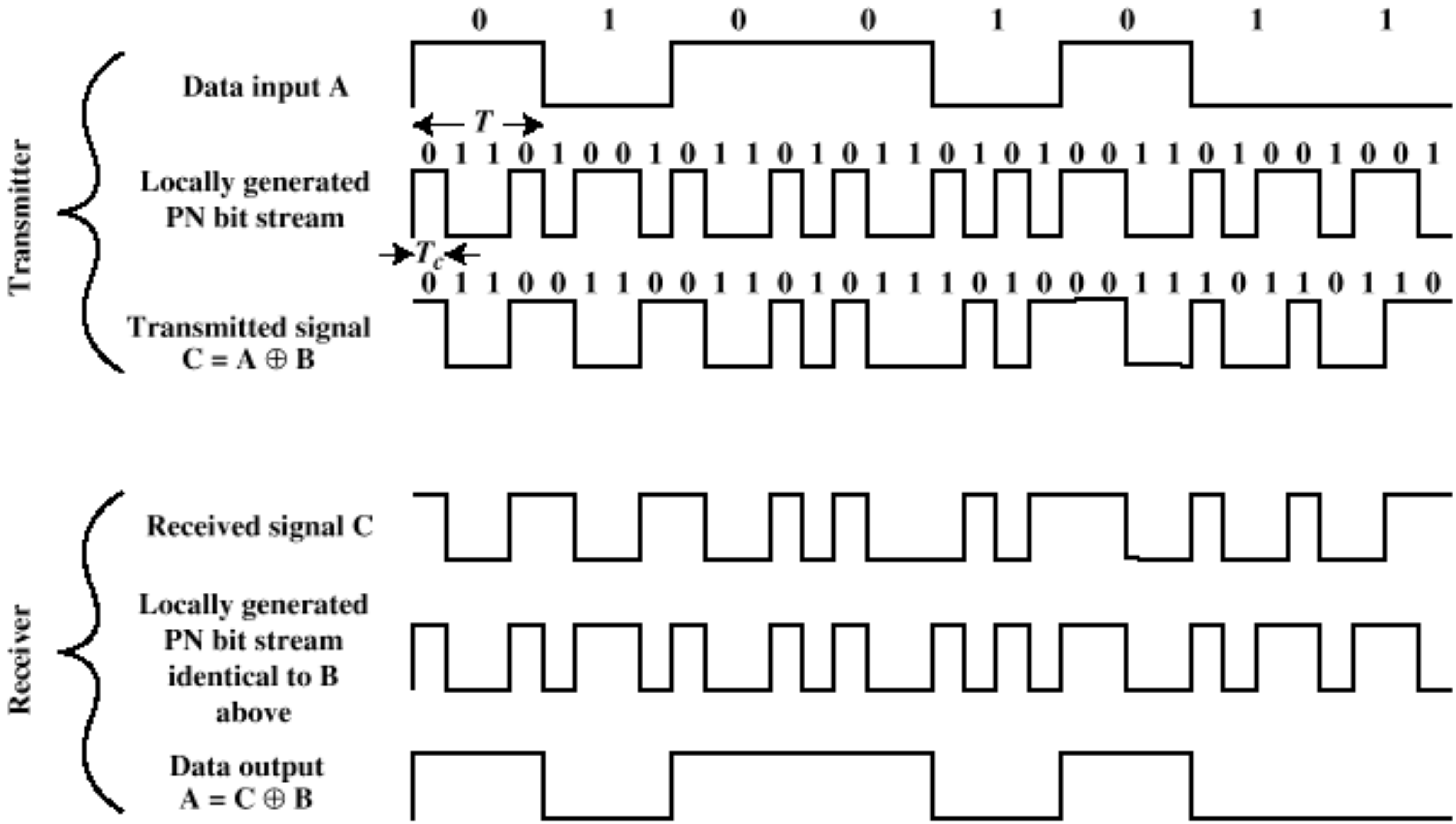


Figure 7.6 Example of Direct Sequence Spread Spectrum

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, $c(t)$ x $c(t)$ = 1, incoming signal is recovered

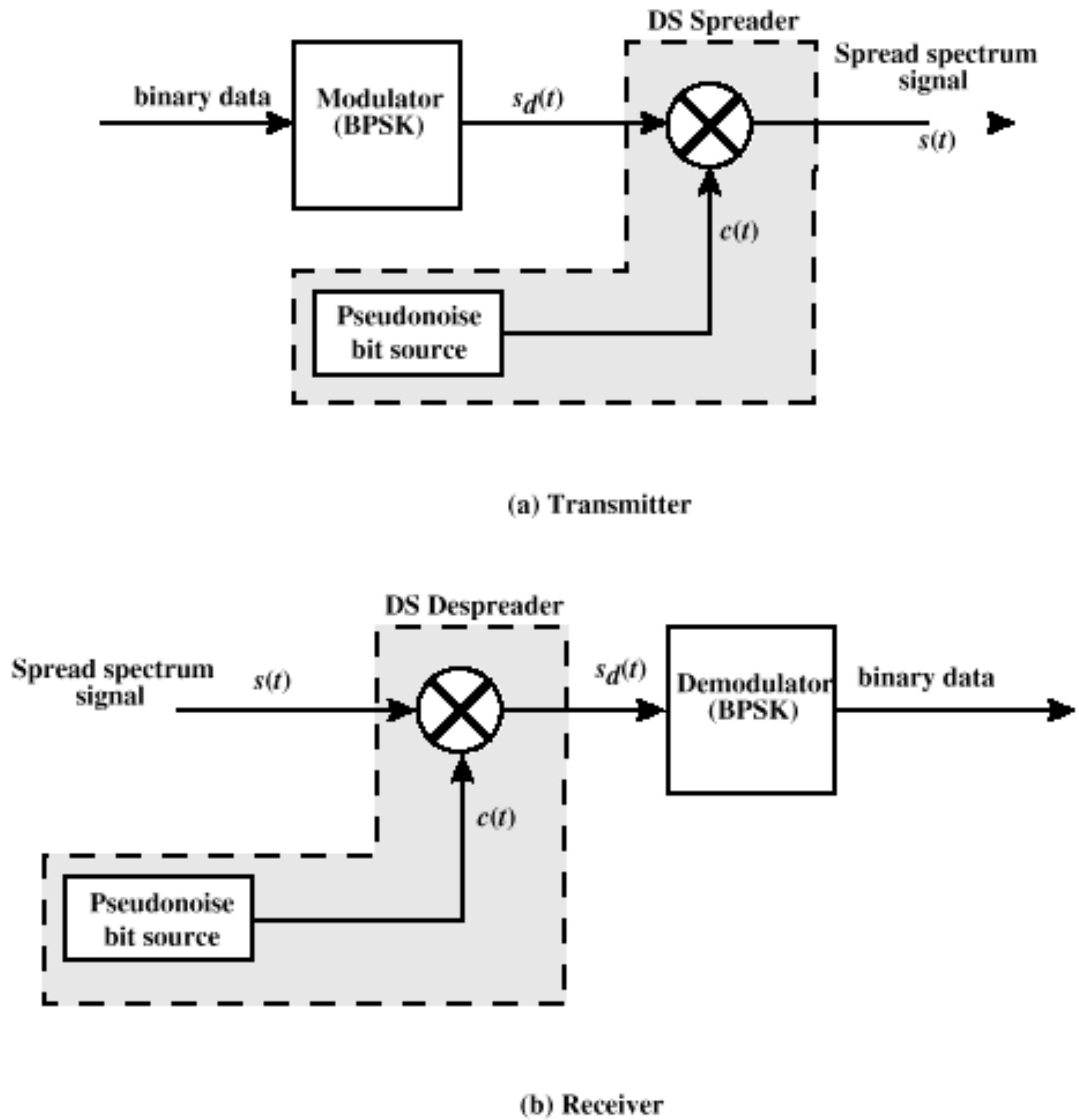


Figure 7.7 Direct Sequence Spread Spectrum System

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 data rate of new channel = kD

CDMA Example

- If k=6 and code is a sequence of 1s and -1s
  - For a '1' bit, A sends code as chip pattern
    - <c1, c2, c3, c4, c5, c6>
  - For a '0' bit, A sends complement of code
    - <-c1, -c2, -c3, -c4, -c5, -c6>
- Receiver knows sender's code and performs electronic decode function

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

  - <d1, d2, d3, d4, d5, d6> = received chip pattern
  - <c1, c2, c3, c4, c5, c6> = sender's code

CDMA Example

- User A code = <1, –1, –1, 1, –1, 1>
  - To send a 1 bit = <1, –1, –1, 1, –1, 1>
  - To send a 0 bit = <–1, 1, 1, –1, 1, –1>
- User B code = <1, 1, –1, – 1, 1, 1>
  - To send a 1 bit = <1, 1, –1, –1, 1, 1>
- Receiver receiving with A’s code
  - (A’s code) x (received chip pattern)
    - User A ‘1’ bit: 6 -> 1
    - User A ‘0’ bit: -6 -> 0
    - User B ‘1’ bit: 0 -> unwanted signal ignored

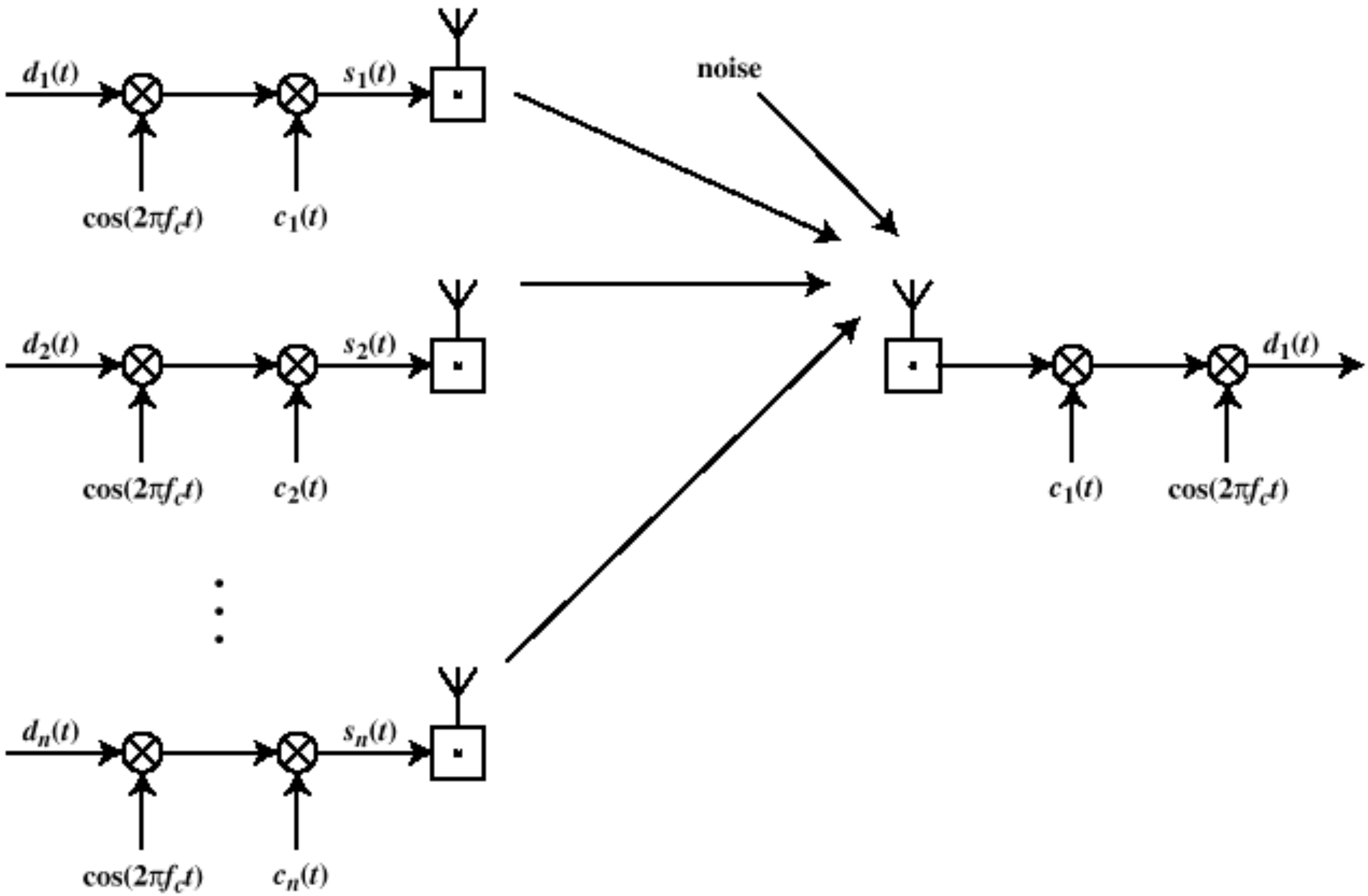


Figure 7.11 CDMA in a DSSS Environment

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 impractical to predict

Important PN Properties

- Randomness
  - Uniform distribution
    - Balance property
    - Run property
  - Independence
  - Correlation property
- Unpredictability

Linear Feedback Shift Register Implementation

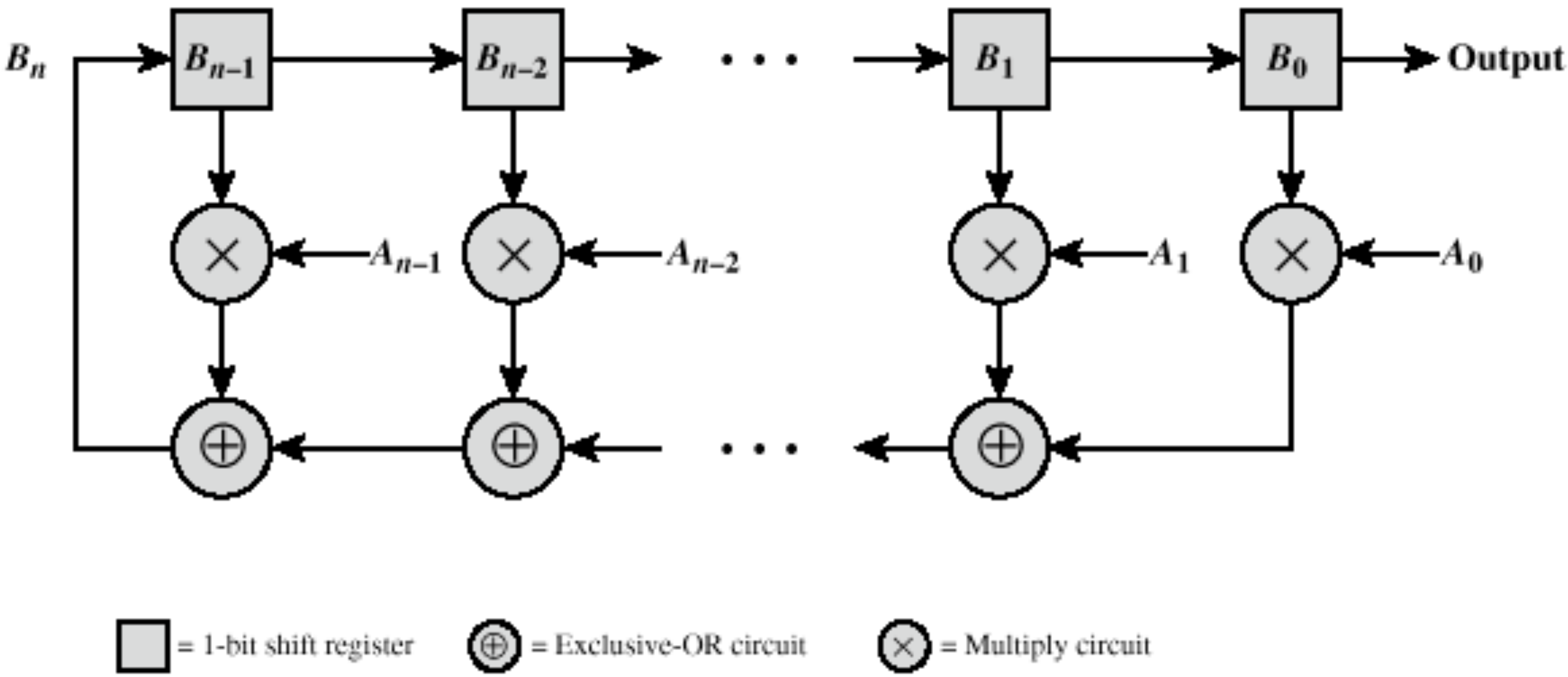


Figure 7.12 Binary Linear Feedback Shift Register Sequence Generator

Properties of M-Sequences

- Property 1:
  - Has 2^{n-1} ones and 2^{n-1}-1 zeros
- Property 2:
  - For a window of length n slid along output for N (=2^{n-1}) shifts, each n-tuple appears once, except for the all zeros sequence
- Property 3:
  - Sequence contains one run of ones, length n
  - One run of zeros, length n-1
  - One run of ones and one run of zeros, length n-2
  - Two runs of ones and two runs of zeros, length n-3
  - 2^{n-3} runs of ones and 2^{n-3} runs of zeros, length 1

Properties of M-Sequences

- Property 4:
  - The periodic autocorrelation of a ±1 m-sequence is

$$R(\tau) = \begin{cases} 1 & \tau = 0, N, 2N, \ldots \\ -\dfrac{1}{N} & \text{otherwise} \end{cases}$$

Definitions

- Correlation
  - The concept of determining how much similarity one set of data has with another
  - Range between –1 and 1
    - 1 The second sequence matches the first sequence
    - 0 There is no relation at all between the two sequences
    - -1 The two sequences are mirror images
- Cross correlation
  - The comparison between two sequences from different sources rather than a shifted copy of a sequence with itself

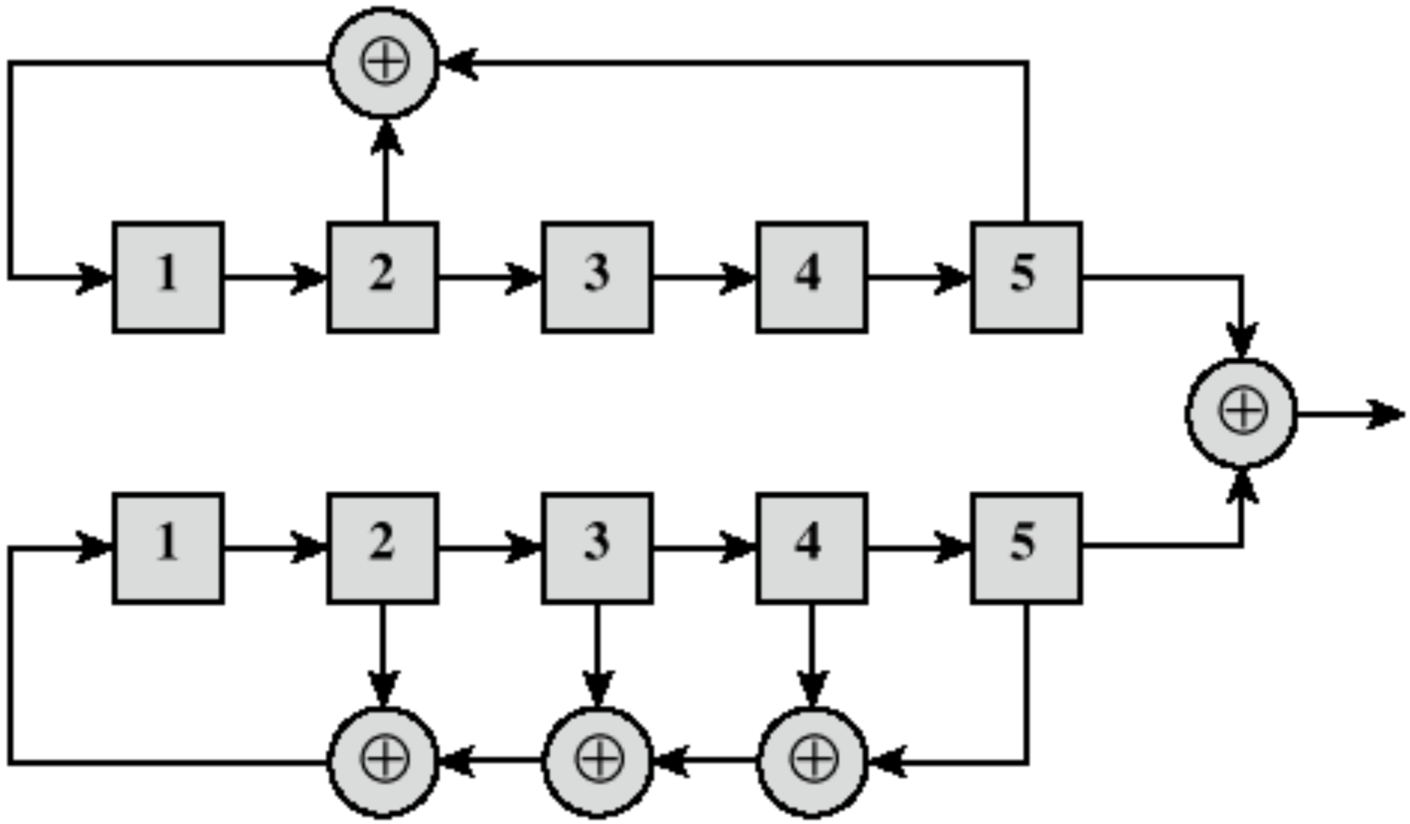
Advantages of Cross Correlation

- The cross correlation between an m-sequence and noise is low
  - This property is useful to the receiver in filtering out noise
- The cross correlation between two different m-sequences is low
  - This property is useful for CDMA applications
  - Enables a receiver to discriminate among spread spectrum signals generated by different m-sequences

Gold Sequences

- Gold sequences constructed by the XOR of two m-sequences with the same clocking
- Codes have well-defined cross correlation properties
- Only simple circuitry needed to generate large number of unique codes
- In following example (Figure 7.16a) two shift registers generate the two m-sequences and these are then bitwise XORed

Gold Sequences



(a) Shift-register implementation

Orthogonal Codes

- Orthogonal codes
  - All pairwise cross correlations are zero
  - Fixed- and variable-length codes used in CDMA systems
  - For CDMA application, each mobile user uses one sequence in the set as a spreading code
    - Provides zero cross correlation among all users
- Types
  - Walsh codes
  - Variable-Length Orthogonal codes

Walsh Codes

- Set of Walsh codes of length *n* consists of the n rows of an *n* X *n* Walsh matrix:
  - o $W_1 = (0)$

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

    - n = dimension of the matrix
  - o Every row is orthogonal to every other row and to the logical not of every other row
  - o 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