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

(a) Channel assignment
(b) Channel use

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: $T = \frac{1}{R}$ seconds
  - duration of signal element: $T_s = LT$ seconds
- $T_c \geq T_s$ - slow-frequency-hop spread spectrum
- $T_c < T_s$ - fast-frequency-hop spread spectrum
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, \( c(t) \times c(t) = 1 \), incoming signal is recovered
Figure 7.7 Direct Sequence Spread Spectrum System
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
    - \( <c_1, c_2, c_3, c_4, c_5, c_6> \)
  - For a ‘0’ bit, A sends complement of code
    - \( <-c_1, -c_2, -c_3, -c_4, -c_5, -c_6> \)
- Receiver knows sender’s code and performs electronic decode function
  \[
  S_u(d) = d_1 \times c_1 + d_2 \times c_2 + d_3 \times c_3 + d_4 \times c_4 + d_5 \times c_5 + d_6 \times c_6
  \]
  - \( <d_1, d_2, d_3, d_4, d_5, d_6> = \) received chip pattern
  - \( <c_1, c_2, c_3, c_4, c_5, c_6> = \) sender’s code
CDMA 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>
  - To send a 0 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 tests 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

\[ B_n \rightarrow B_{n-1} \rightarrow B_{n-2} \rightarrow \ldots \rightarrow B_0 \rightarrow \text{Output} \]

\[ A_{n-1} \rightarrow A_{n-2} \rightarrow \ldots \rightarrow A_0 \]

\( \square \) = 1-bit shift register \quad \( \oplus \) = Exclusive-OR circuit \quad \( \times \) = Multiply circuit

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

\[ R(\tau) = \begin{cases} 
1 & \tau = 0, N, 2N, \ldots \\
-\frac{1}{N} & \text{otherwise}
\end{cases} \]
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 $n \times n$ Walsh matrix:
  - $W_1 = (0)$
  - $W_{2n} = \begin{pmatrix} W_n & W_n \\ W_n & \overline{W}_n \end{pmatrix}$

  - $n =$ dimension of the matrix

- 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