English words like 'technology' stem from a Greek root beginning with the letters $\tau\epsilon\chi$...; and this same Greek word means *art* as well as technology.

Donald Knuth, *The $\TeX$ Book*

TELE303/404 Mobile Systems

Lecture 5 – Spread Spectrum

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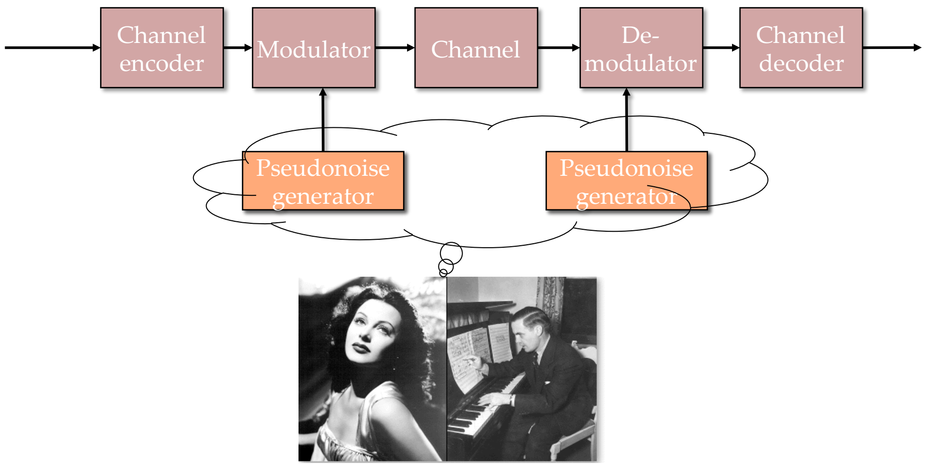
Road Map

- Last Lecture:
  - ASK, FSK, PSK
    - BFSK, BPSK, MFSK
  - QAM
  - PCM, DM
- This Lecture:
  - Spread Spectrum
  - Advantages
  - Implementations
  - CDMA

Spread Spectrum: Overview

Spread Spectrum - Diagram



Spread Spectrum

- Input is fed into a channel encoder
  - Produces analog signal with narrow bandwidth
- Signal is further modulated using sequence of digits
  - *aka* **spreading code** or spreading sequence or **chip**
  - Generated by pseudo-noise, or pseudo-random number generator
- Effect of modulation is to increase bandwidth of signal to be transmitted

Spread Spectrum

- On receiving end, digit sequence is used to demodulate the spread spectrum signal
- Signal is fed into a channel decoder to recover data
- Two types of SS:
  - Frequency hopping (FHSS)
  - Direct sequence (DSSS)

Waste of 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
  - Allows random access

Approach I: FHSS

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Approach I – Frequency Hopping

- Frequency hopping 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

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Frequency Hopping Spread Spectrum

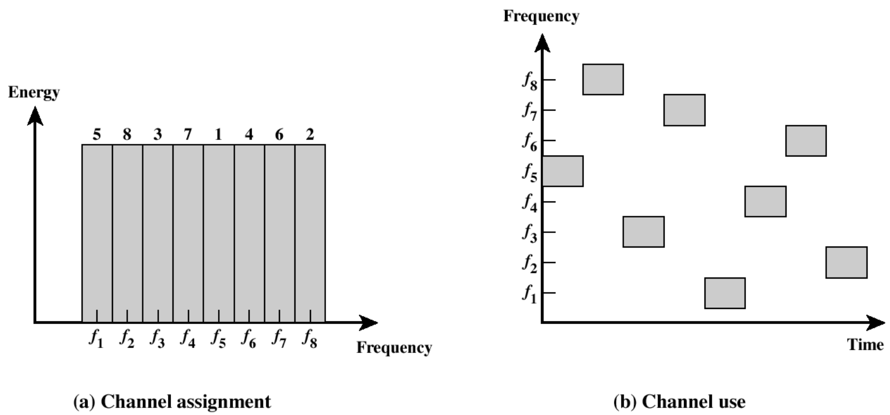

Figure 7.2 Frequency Hopping Example

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Frequency Hopping 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

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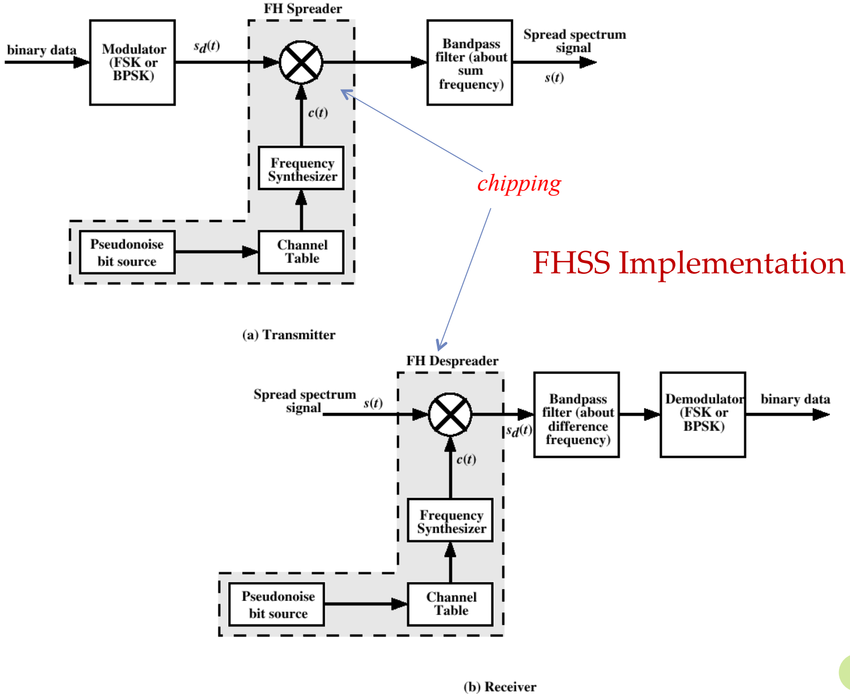
FHSS Implementation



BFSK + FHSS

BFSK:

$$s_d(t) = A\cos(2\pi(f_0 + 0.5(b_i + 1)\Delta f)t)$$

Bipolar: 1 or -1

Sender Chipping: f_i

$$f_0 + 0.5(b_i + 1)\Delta f + f_i$$

Receiver Chipping: f_i

BFSK restored: $[f_0 + 0.5(b_i + 1)\Delta f + f_i] - f_i$

$= f_0 + 0.5(b_i + 1)\Delta f$

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
- Compare T_c with T_s (duration of signal element)
  - $T_c \geq T_s$ - slow-frequency-hop spread spectrum
  - $T_c < T_s$ - fast-frequency-hop spread spectrum

Review: Multiple Frequencies (MFSK)

- More than two frequencies are used in FSK
- More bandwidth efficient
- Used for frequency hopping in spread spectrum

$$s_i(t) = A\cos 2\pi f_i t \qquad 1 \leq i \leq M$$

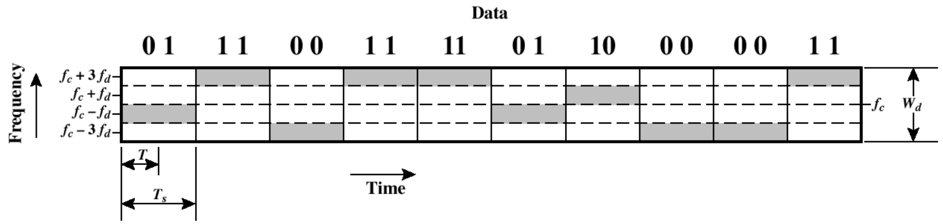


Fig. 6.4 MFSK Frequency Use (M=4)

Slow FHSS

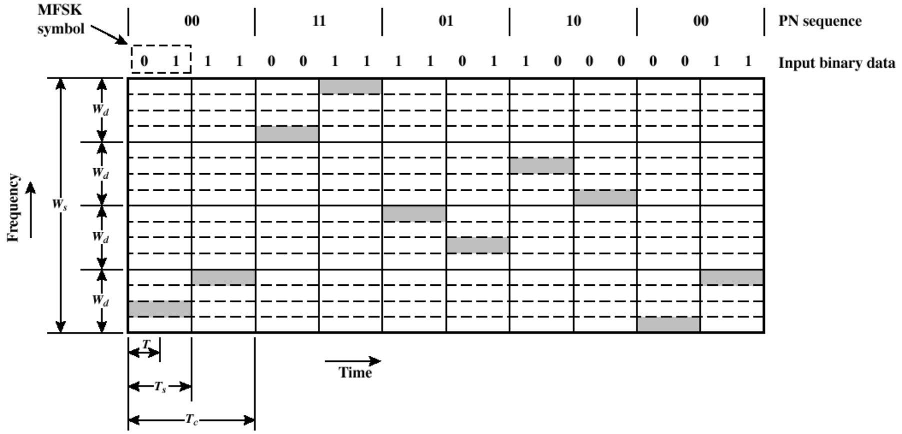
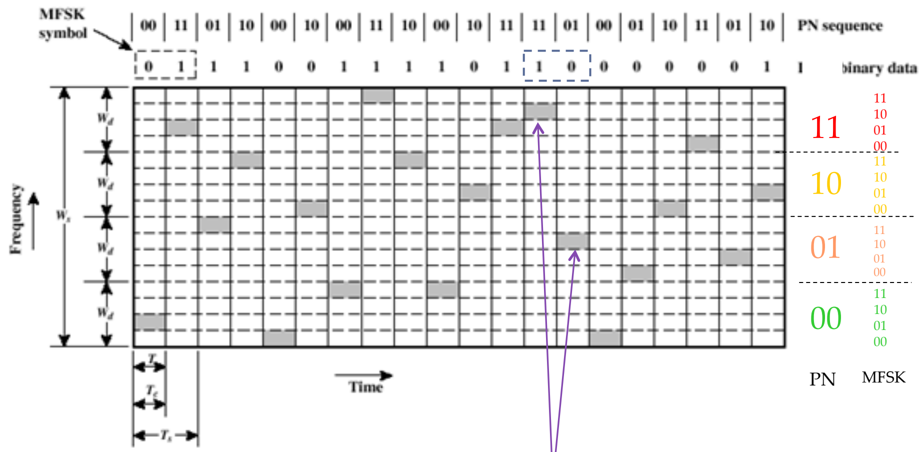


Figure 7.4 Slow Frequency Hop Spread Spectrum Using MFSK (M = 4, k = 2)

Fast FHSS



Channel table look-up by PNs (11 & 01) & MFSK symbol (10)

Approach II: DSSS

Approach II - Direct Sequence

- 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)

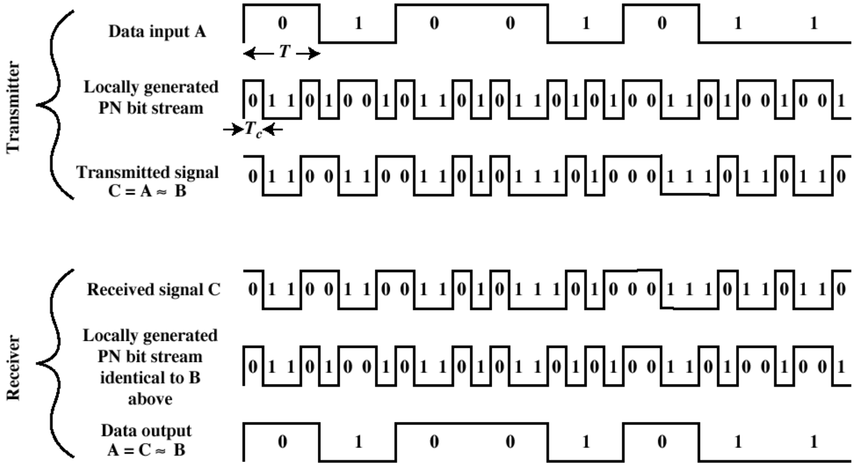


Figure 7.6 Example of Direct Sequence Spread Spectrum

DSSS Using BPSK

- Multiply BPSK signal $s_d(t) = Ad(t)\cos(2\pi f_c t)$
  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 $c(t)$: $s_d(t) = s(t)\, c(t)$
  - Since $c(t) \times c(t) = 1$, incoming signal is recovered

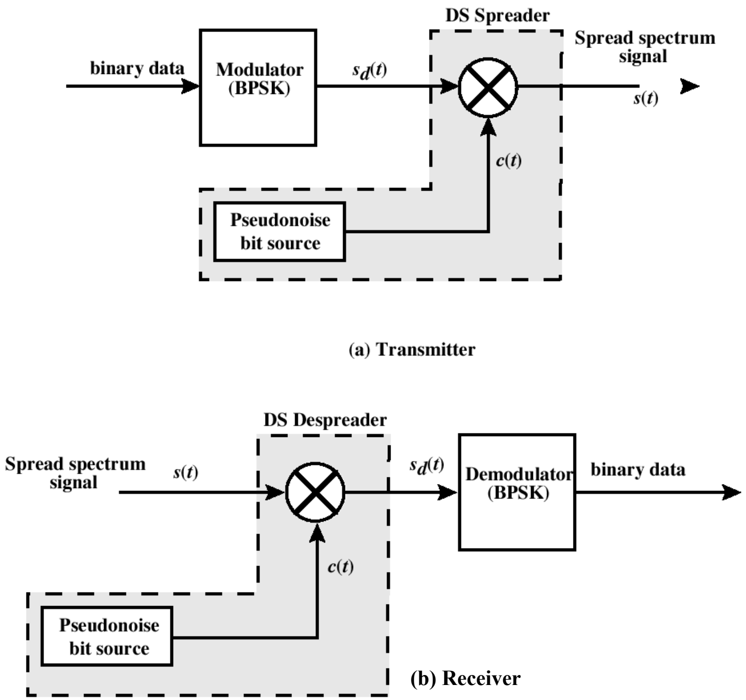
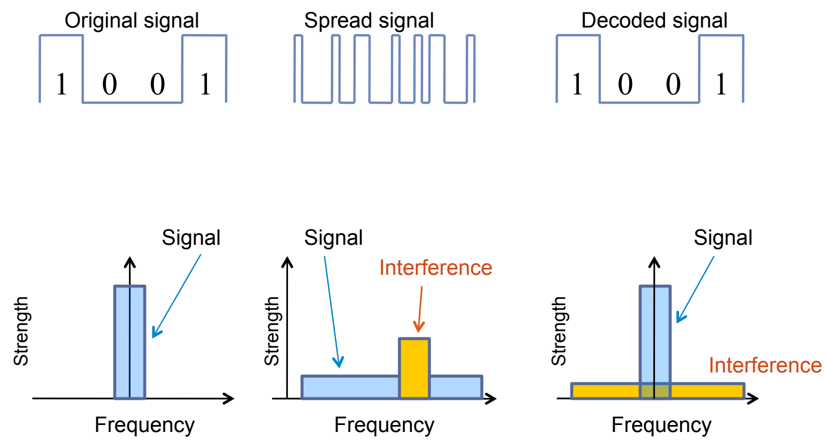


Figure 7.7 DSSS System

Coping with Jamming



CDMA

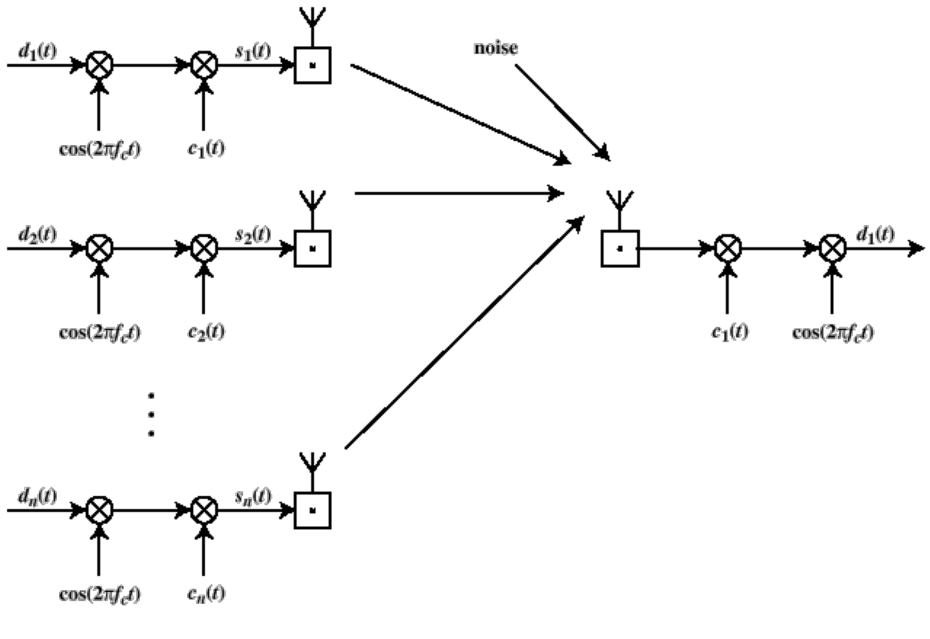


Figure 7.11 CDMA in a DSSS Environment

Code-Division Multiple Access

- CDMA: a multiplexing technique used with spread spectrum
- Senders employ different spreading sequences in their SS
- SS can be FH or DS, or both (hybrid)
- Question: How to make good spreading sequences?
  - Robust to eavesdropping / jamming
  - Allowing multiple users with little interference
  - Allowing self-clocking

CDMA Example

- Code is a sequence of 1s and -1s, length=6
  - 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>
  - o To send a 1 bit = <1, –1, –1, 1, –1, 1>
  - o To send a 0 bit = <–1, 1, 1, –1, 1, –1>
- User B code = <1, 1, –1, – 1, 1, 1>
  - o To send a 1 bit = <1, 1, –1, –1, 1, 1>
- Receiver receiving with A's code
  - o (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

Spread Spectrum

- Frequency hopping
  - o Carrier frequency hopping according to chips
  - ☹ Potential frequency collisions; faster hardware required
- Direct sequence
  - o Signals multiplied by PN codes (chips)
  - ☹ **Near-far effect**: when interfering transmitter gets much closer to the receiver than the intended transmitter.
  - o Requires adaptive power control

Categories of Spreading Sequences

- Spreading Sequence Categories
  - o PN sequences
  - o Orthogonal codes
- For FHSS systems
  - o PN sequences most common
- For DSSS systems
  - o PN sequences
  - o Orthogonal codes

Recap

- Spread spectrum
- FHSS and DSSS
- CDMA
- Readings
  - o Chapter 9
  - o Piazza/ Resources/Readings

- Next Lecture:
  - o More on CDMA
  - o Medium Access Control