Chapter 9: Spread Spectrum
Spread Spectrum

• Important encoding method for wireless communications
• Spread data over wide bandwidth
• Makes jamming and interception harder
• Frequency hoping
  — Signal broadcast over seemingly random series of frequencies
• Direct Sequence
  — Each bit is represented by multiple bits in transmitted signal
  — Chipping code
Spread Spectrum Concept

• Input fed into channel encoder
  — Produces narrow bandwidth analog signal around central frequency

• Signal modulated using sequence of digits
  — Spreading code/sequence
  — Typically generated by pseudonoise/pseudorandom number generator

• Increases bandwidth significantly
  — Spreads spectrum

• Receiver uses same sequence to demodulate signal

• Demodulated signal fed into channel decoder
General Model of Spread Spectrum System
Spread Spectrum Advantages

- Immunity from various noise and multipath distortion
  - Including jamming
- Can hide/encrypt signals
  - Only receiver who knows spreading code can retrieve signal
- Several users can share same higher bandwidth with little interference
  - Cellular telephones
  - Code division multiplexing (CDM)
  - Code division multiple access (CDMA)
Pseudorandom Numbers

- Generated by algorithm using initial seed
- Deterministic algorithm
  - Not actually random
  - If algorithm good, results pass reasonable tests of randomness
- Need to know algorithm and seed to predict sequence
Frequency Hopping Spread Spectrum (FHSS)

- Signal broadcast over seemingly random series of frequencies
- Receiver hops between frequencies in sync with transmitter
- Eavesdroppers hear unintelligible blips
- Jamming on one frequency affects only a few bits
Basic Operation

- Typically $2^k$ carriers frequencies forming $2^k$ channels
- Channel spacing corresponds with bandwidth of input
- Each channel used for fixed interval
  - 300 ms in IEEE 802.11
  - Some number of bits transmitted using some encoding scheme
    - May be fractions of bit (see later)
    - Sequence dictated by spreading code
Frequency Hopping Example

(a) Channel assignment

(b) Channel use
Frequency Hopping Spread Spectrum System (Transmitter)
Frequency Hopping Spread Spectrum System (Receiver)
Slow and Fast FHSS

- Frequency shifted every $T_c$ seconds
- Duration of signal element is $T_s$ seconds
- Slow FHSS has $T_c \geq T_s$
- Fast FHSS has $T_c < T_s$
- Generally fast FHSS gives improved performance in noise (or jamming)
Slow Frequency Hop Spread Spectrum Using MFSK (M=4, k=2)

MFSK = Multiple FSK

M is the number of different signal elements, frequencies to encode data, $2^k$ is the number of channels, each of width $W_d$
Fast Frequency Hop Spread Spectrum Using MFSK (M=4, k=2)
FHSS Performance Considerations

- Typically large number of frequencies used
  - Improved resistance to jamming
Direct Sequence Spread Spectrum (DSSS)

• Each bit is represented by multiple bits using spreading code

• Spreading code spreads signal across wider frequency band
  — In proportion to number of bits used
  — e.g., 10 bit spreading code spreads signal across 10 times bandwidth of 1 bit code

• One method:
  — Combine input with spreading code using XOR
    • Input bit 1 inverts spreading code bit
    • Input zero bit doesn’t alter spreading code bit
  — Data rate equal to original spreading code

• Performance similar to FHSS
Direct Sequence Spread Spectrum Example

Transmitter

Data input A

Locally generated PN bit stream

Transmitted signal $C = A \oplus B$

Receiver

Received signal $C$

Locally generated PN bit stream identical to $B$ above

Data output $A = C \oplus B$
Direct Sequence Spread Spectrum Transmitter

![Diagram of Direct Sequence Spread Spectrum Transmitter](image)
Direct Sequence Spread Spectrum Receiver

[Diagram showing a spread spectrum signal being spread using a pseudonoise bit source, then despread and demodulated into binary data]
Direct Sequence Spread Spectrum Using BPSK Example

(a) $d(t)$

(b) $s_d(t)$

(c) $c(t)$

(d) $s(t)$
Approximate Spectrum of DSSS Signal

(a) Spectrum of data signal

(b) Spectrum of pseudonoise signal

(c) Spectrum of combined signal
Code Division Multiple Access (CDMA)

- Multiplexing Technique used with spread spectrum
- Start with data signal rate $D$
  - Called bit data rate
- Break each bit into $k$ chips according to fixed pattern specific to each user
  - User’s code
- New channel has chip data rate $kD$ chips per second
- E.g. $k=6$, three users (A,B,C) communicating with base receiver R
  - Code for A = $<1,-1,-1,1,-1,1>$
  - Code for B = $<1,1,-1,-1,1,1>$
  - Code for C = $<1,1,-1,1,1,-1>$
CDMA Example

Code

Message "1101" Encoded

User A

User B

User C
CDMA Explanation

- Consider A communicating with base
- Base knows A’s code
- Assume communication already synchronized
- A wants to send a 1
  - Send chip pattern <1,-1,-1,1,-1,1>
    - A’s code
- A wants to send 0
  - Send chip pattern <-1,1,1,-1,1,-1>
    - Complement of A’s code
- Decoder ignores other sources when using A’s code to decode
  - Orthogonal codes
CDMA for DSSS

- $n$ users each using different orthogonal PN sequence
- Modulate each users data stream
  - Using BPSK
- Multiply by spreading code of user
CDMA in a DSSS Environment

\[ d_1(t) \rightarrow \cos(2p_1 f_c t) \rightarrow c_1(t) \rightarrow s_1(t) \rightarrow \text{noise} \]

\[ d_2(t) \rightarrow \cos(2p_2 f_c t) \rightarrow c_2(t) \rightarrow s_2(t) \rightarrow \text{noise} \]

\[ d_n(t) \rightarrow \cos(2p_n f_c t) \rightarrow c_n(t) \rightarrow s_n(t) \rightarrow \text{noise} \]
Seven Channel CDMA Encoding and Decoding

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<tr>
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<th>Data value</th>
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<tr>
<td>(6)</td>
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</tr>
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Individual channel waveforms

Channel 0 code

Composite signal

positive number = 1  negative number = 0
Summary

- looked at use of spread spectrum techniques, e.g.,
  - FHSS
  - DSSS
  - DSSS
  - CDMA