Spread Spectrum

Last updated: 5/5/2011
Overview

☐ Notes
Frequency Bands (ISM and U-NII)

- Differ in output frequency and power

- The FCC has specified two basic band categories for license free use
  - ISM
  - UNII

- Industrial, Scientific, and Medical (ISM)
  - 915 MHz
    - Obsolete and expensive
  - 2.4 GHz
    - Used by 802.11, 802.11b, and 802.11g
    - FCC specifies use from 2.4000 GHz to 2.4835 GHz
  - 5.8 GHz
    - 5.725 GHz to 5.875 GHz
    - Not used by 802.11, especially 802.11a

- Unlicensed National Information Infrastructure (UNII)
  - Lower band (UNII-1)
    - 5.15 GHz to 5.25 GHz
    - 40 mW output power
  - Middle band (UNII-2)
    - 5.25 GHz to 5.35 GHz
    - 200 mW output power
  - Upper band (UNII-3)
    - 5.725 GHz to 5.825 GHz
    - 800 mW output power
White Space Frequency Bands (2010)

- White space refers to the 6-MHz channels left unused by TV broadcasters in the 54- to 698-MHz range—channels 2 through 51
- In any given local region, TV stations are assigned frequencies several channels apart from one another to prevent interference
- White space refers to the unused gaps
- Also known as WiFi on steroids
  - like television signals – can range for miles and travel through obstructing entities that would block a standard wireless broadband signal

<table>
<thead>
<tr>
<th>CHANNEL</th>
<th>FREQUENCY RANGE (MHz)</th>
<th>CHANNEL</th>
<th>FREQUENCY RANGE (MHz)</th>
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<tr>
<td>VHF LOW-BAND</td>
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<td>2</td>
<td>54 to 60</td>
<td>24</td>
<td>530 to 536</td>
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<td>3</td>
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<td>76 to 82</td>
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<td>6</td>
<td>82 to 88</td>
<td>28</td>
<td>554 to 560</td>
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<td>FM BROADCAST</td>
<td>88 to 108</td>
<td>29</td>
<td>560 to 566</td>
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<td>118 to 135</td>
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<td>HAM RADIO</td>
<td>144 to 148</td>
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<td>572 to 578</td>
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<td>MOBILE/MARINE</td>
<td>150 to 173</td>
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<td>186 to 192</td>
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<td>692 to 698</td>
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Modulation Techniques

- Spread Spectrum Modulation
  - Used to transmit analog or digital signals
  - The basic idea is to transmit over wide bandwidth
    - Low power peak with bandwidth
  - Used in wireless communications
  - Typically requires no FCC licensing (cheap) – narrow-band signals often require FCC licensing

- Advantages
  - Less susceptible to ISI (overlapping data bits due to multipath)
  - Cannot be jammed using narrow-band

- Applications
  - Military communications; cordless phones, cell phone systems, GPS, Bluetooth, WLAN. WPAN
Delay Spread

- Resulted due to Intersymbol Interference (ISI)
  - A form of multipath
  - Can cause errors
- The idea of SS is to tolerate large delay spread
Spread Spectrum Modulation Techniques - Background

Frequency Hopping
- Invented in 1940 by Hedy Lamarr

Direct Sequence
- More recent type of SSM
Spread Spectrum Modulation - Background

- Initially developed by military (hard to decode or jam)
- Used in military for the past 50 years
- Its commercial use started in 1980
**Spread Spectrum Model**

- 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 (PN) generator
- Effect of modulation is to increase bandwidth of signal to be transmitted and lowering the peak power
Spread Spectrum Model

- 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

An analog signal with narrow bandwidth is used in Spread Spectrum. The bandwidth of the signal is increased due to modulation using a pseudonoise, or pseudo-random number (PN) generator. The same spread code as the transmitted signal is used during decoding to recover the original signal.
Spread Spectrum

- What can be gained from apparent waste of spectrum?
- Immunity from various kinds of noise and multipath distortion (ISI)
- Can be used for hiding and encrypting signals
- Several users can independently use the same higher bandwidth with very little interference (multiplexing, e.g., CDMA)
Spread Spectrum Types

- Frequency Hoping Spread Spectrum (FHSS)
- Direct Sequence Spread Spectrum (DSSS)
- Other types:
  - OFDM (recognized as spread spectrum)
  - HR-DSSS (high-rate DSSC)
Frequency Hoping Spread Spectrum (FHSS)

- Signal is broadcasted 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 Hoping Spread Spectrum

Channels allocated for the FH signal

Width of each channel corresponds to bandwidth of input signal

Channel sequence dictated by spreading code

Signal hops from frequency to frequency at fixed intervals

Receiver will be hopping between frequencies in synchronization with transmitter
Frequency Hoping Spread Spectrum

Multiple users can be using the same channel

Number of available channels = $2^k - K = \text{available carriers}$
FHSS

- Requires synchronization
- Frequency hopping is time dependent
- **Orthogonal** hopping sequence
  - Resulting in high throughput
- The energy is spread over wide range
  - Jamming requires large power over the entire range of frequencies
- The hopping sequence must be known to RX (spread key)

Dwell time – narrow band (0.4 SEC)
FHSS Parameter Setting

- Hop pattern (random)
  - Hopping order

- Hop index (how to generate the random number; hopping must be orthogonal)
  - Sequence number

- How to perform the synchronization
  - Using a Beacon frequency

- Dwell time (msec)
  - The smaller the more spreading impact

- Hope time (micro-second)
  - Overhead time (f1 changing to f2)

- Hoping channel
  - No wider than 1 MHz (FCC)
  - Use all channels equally
  - Number of hops per band (80.11 75 hops)

- Frequencies of operation
  - U-NII or ISM

- Output power
  - FCC or IEEE compliant (IEEE is more stringent!)
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
- $T_c < T_s$ - fast-frequency-hop spread spectrum

M frequencies to represent each symbol (in MFSK)
Each PN is modulated with $k$ symbols
$2^k$ frequencies are required using FHSS
MFSK bandwidth will be $W_d = M f_d$ (fd is the frequency spacing)
Total bandwidth using FHSS will be $W_s = 2^k W_d$
FHSS Using BFSK
- Example

- Assume BFSK: $f_0$ and $f_0 + \Delta f$
  - If transmit $+1 \rightarrow f_0$
  - If transmit $-1 \rightarrow f_0 + \Delta f$

- The modulator is simply a multipliers
  - $C(t) = \cos(2\pi f_i t)$; $f_i$ is the frequency at the $i$th bit

- Hence, during the $i$th bit interval, the frequency of the transmitted signal will be $f_0 + f_i$ or $f_0 + f_i + \Delta f$

Refer to your notes! (C & D)
Multiple Frequency-Shift Keying (MFSK) - Example

Assume $M=4 \rightarrow$ 4 frequencies
20 bit stream: we send 2 bits per frequency
Note: $T_s = 2T_b = \text{Symbol period}$
Total BW = $2M.f_d$
Wideband frequency $\rightarrow$ less power per symbol!
$k = 2 \; \text{;} \; 2^4$ codes  
$T_c > T_s \rightarrow T_s = 4T_c$  
Each signal element generates one tone  
$W_s = 4xW_d$
Fast Frequency-Hop SS Using MFSK M=4; k=2 (Tc<Ts)

More hoping → even harder to jam!
Resistance to noise and Jamming

- 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

Refer to your notes! (B)
Signal Spectrum

Original Data

PN signal

Combined signal

Signal Energy

frequency

-1/T 1/T

-1/Tc 1/Tc

-1/T - 1/Tc 1/T + 1/Tc
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 – It is not fixed.
- One technique combines digital information stream with the spreading code bit stream using **exclusive-OR**.

| 1 ⊕ 1 = 0 | 0 ⊕ 0 = 0 |
| 1 ⊕ 0 = 1 | 0 ⊕ 1 = 1 |
Direct Sequence Spread Spectrum (DSSS)

When 1, the code will be the complement of PN. Must be the same exact PN; synchronized!

Recovered signal after demodulation.

Figure 7.6 Example of Direct Sequence Spread Spectrum
Figure 7.7 Direct Sequence Spread Spectrum System

Note the difference:

Refer to your notes! (C & D)
Direct Sequence Spread Spectrum (DSSS) – Spectrum
DSSS in 802.11 / 802.11b

Understanding DSSS
DSSS Using BPSK

Modulate then Spread!

Tc<T
Note that PN changing (k=3)

In this case the final spread code is being subject to BPSK modulation
Comparing Spread Spectrum Techniques

- **OFDM**
  - Preferable over DSSS
  - More expensive than DSSS
  - Less expensive than FHSS
  - Data rate of 54 Mbps
  - Longer range than DSSS at similar data rates up to 54 Mbps

- **FHSS**
  - Resistant but not immune to narrowband interference
  - Harder to find
  - More expensive
  - Co-location advantage over DSSS
  - Data rate of 1 or 2 Mbps
  - Longest range

- **DSSS**
  - Less resistant to narrowband interference
  - Least expensive
  - Do not co-locate with OFDM
  - Data rate of 11 Mbps
  - 5.5 Mbps actual throughput
  - Medium range when at 11 Mbps

Most expensive/Most used/ISM
Review of Multiplexing Techniques

☐ Notes
Comparison wireless air interface technology
Review - TDMA

**Time Division Multiple Access (TDMA)**

- Each user can use *all* available frequencies, for a limited period. The user must not transmit until its next turn.
- High bit rates required, therefore possible problems with intersymbol-interference.
- Flexible allocation of resources (multiple time slots).
- Used in second generation digital networks, such as GSM (Europe), and D-AMPS (USA).
FDMA (Frequency Division Multiple Access)

- Each user is assigned a unique frequency for the duration of their call.
- Severe fading and interference can cause errors.
- Complex frequency planning required. Not flexible.
- Used in analogue systems, such as TACS (Europe), and AMPS (USA).
Code-Division Multiple Access (CDMA)

- Cellular wireless air interface technology
- Developed by Qualcomm in 1989
- First deployed commercially in 1995
- Considered as the main infrastructure for 3G and 4G systems
- Evolution of CDMA
  - CdmaOne (2G CDMA)
  - Cdma2000 (3G CDMA)
Code-Division Multiple Access (CDMA) - Basics

- Multiple-access technology
  - It is based on spread spectrum digital techniques
  - Allows separation of signals, which are concurrent in time and frequency
  - The signal appears on the entire wideband spectrum
  - At the receiver all other signals are rejected except the desired signal
CDMA

Frequency Hopping
Code Division Multiple Access (FH-CDMA)

- Each user regularly hops frequency over the available spectrum.
- Users are distinguished from each other by a unique hopping pattern (or code).
- Interference is randomised.
- Used in Bluetooth™
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
    - The chip has \( k \) bits
  - Chip data rate of the new CDMA channel = \( kD \)

- Example:
  - Assume the incoming data rate is 10 Mbps. How long does it take to receive 1101?
  - Using CDMA, the chip has 6 bits. What is the total bit rate for the generated CDMA signal?
CDMA General Operation

- 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
  - $<d_1, d_2, d_3, d_4, d_5, d_6>$ = received chip pattern
  - $<c_1, c_2, c_3, c_4, c_5, c_6>$ = sender’s code

$$S_u(d) = d_1 \times c_1 + d_2 \times c_2 + d_3 \times c_3 + d_4 \times c_4 + d_5 \times c_5 + d_6 \times c_6$$
CDMA Example

- User A code: \( c=<1, -1, -1, 1, -1, 1> \)
  - 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
  - \((A’s \ code) \times (received \ chip \ pattern)\)
    - User A ‘1’ bit: 6 \( \rightarrow \) 1
    - User A ‘0’ bit: -6 \( \rightarrow \) 0
    - User B ‘1’ bit: 0 \( \rightarrow \) unwanted signal ignored

\[
S_u(d) = d1 \times c1 + d2 \times c2 + d3 \times c3 + d4 \times c4 + d5 \times c5 + d6 \times c6
\]
CDMA General Operation –
Power Level
Cell Phone Communications Using CDMA

Forward Link: a composite signal which is transmitted to all users and differentiated by codes.

CDMA in which each channel is assigned a unique code which is orthogonal to codes used by other users.

http://www.celltrek.com/sub03_technologies/sub03_08.php
Example

Chips pattern
For user 1 (user 1 code)

Coded output of
user 1

Transmitted signal
containing the data
from all 4 users

Received
signal

Decoded
signal for
user 1

1 if Power is +
0 if power is -

http://www.dpunkt.de/mobile/code/cdma.html
References


2. **CDMA Coding Demo Applet**  
   Jörg Roth  
   German applet that demonstrates CDMA multiple access coding. Allows user to see the process of coding/decoding in real time. Excellent demo, site is in German language.

3. Digital modulation direct sequence, Code Division Multiple Access (DS-CDMA), frequency hopping Code Division Multiple Access (FH-CDMA), Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), pdf file


5. A very good applet:  
Questions –

☐ Chapter 7: 1-7 & 14
References

- Digital Society:
  http://www.digitalsociety.org/2011/01/wi-fi-was-never-a-substitute-for-wireless-carriers/