CHAPTER 17

Wireless Transmission Techniques

MIMO Antennas

• Multiple-input-multiple-output
• Has become a key technology in evolving high-speed wireless networks
• Exploits the space dimension to improve wireless systems in terms of capacity, range, and reliability
• Cornerstone of emerging broadband wireless networks
MIMO Principles
• Two types of transmission schemes:

Spatial diversity
- The same data is coded and transmitted through multiple antennas, which effectively increases the power in the channel proportional to the number of transmitting antennas.
- Improves SNR for cell edge performance.
- There is a high probability that if one antenna is suffering a high level of fading, another antenna has sufficient signal level.

Spatial multiplexing
- A source data stream is divided among the transmitting antennas.
- Gain in channel capacity is proportional to the available number of antennas at the transmitter or receiver, whichever is less.
- Can be used when transmitting conditions are favorable and for relatively short distances.
Multiple-User MIMO

- **MU-MIMO**
- Extends the basic MIMO concept to multiple endpoints, each with multiple antennas
- Advantage is that the available capacity can be shared to meet time-varying demands
- Used in both Wi-Fi and 4G cellular networks
Applications of MU-MIMO

- **Uplink – Multiple Access Channel, MAC**
  - Multiple end users transmit simultaneously to a single base station

- **Downlink – Broadcast Channel, BC**
  - The base station transmits separate data streams to multiple independent users

  - **MIMO-MAC**
    - Systems outperform point-to-point MIMO, particularly if the number of receiver antennas is greater than the number of transmit antennas at each user
    - A variety of multiuser detection techniques are used to separate the signals transmitted by the users

  - **MIMO-BC**
    - Used to enable the base station to transmit different data streams to multiple users over the same frequency band
    - More challenging to implement
    - Techniques employed involve processing of the data symbols at the transmitter to minimize interuser interference

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**Figure 17.3** Orthogonal Frequency Division Multiplexing
OFDM Advantages

- If the data stream is protected by a forward error-correcting code frequency selective fading is easily handled
- Overcomes intersymbol interference (ISI) in a multipath environment
- QPSK is a common modulation scheme used with OFDM
- Signal processing involves two functions:
  - Fast Fourier transform (FFT)
    - Algorithm that converts a set of uniformly spaced data points from the time domain to the frequency domain
  - Inverse fast Fourier transform (IFFT)
    - Reverses the FFT operation
    - Has the effect of ensuring that the subcarriers do not interfere with each other
Figure 17.5 OFDM and OFDMA

Figure 17.6 Simplified Block Diagram of OFDMA and SC-FDMA

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFT</td>
<td>Discrete Fourier transform</td>
</tr>
<tr>
<td>IDFT</td>
<td>Inverse discrete Fourier transform</td>
</tr>
<tr>
<td>FFT</td>
<td>Fast Fourier transform</td>
</tr>
<tr>
<td>IFFT</td>
<td>Inverse fast Fourier transform</td>
</tr>
<tr>
<td>EQ</td>
<td>Subcarrier equalization</td>
</tr>
<tr>
<td>CP</td>
<td>Cyclic prefix</td>
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</tbody>
</table>

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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**

[Diagram showing the spread spectrum system with input data, channel encoder, modulator, channel, demodulator, channel decoder, and output data.]
**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 $A$: 0 1 0 0 1 0 0 1 1
- Locally generated PN bit stream $T$: 0 1 1 0 0 1 1 0 1 0 1 0 1 1 0 1 0 0 1 1 0 1 0 1 1 0
- Transmitted signal $C = A \oplus B$: 0 1 1 0 1 0 1 0 0 0 1 1 1 1 0 1 1 0 1 0 0 1 1 0 0 1

**Receiver**
- Received signal $C$: 0 1 1 0 1 0 1 0 0 0 1 1 1 1 0 1 1 0 1 0 0 1 1 0 0 1
- Locally generated PN bit stream identical to $B$ above
- Data output $A = C \oplus B$: 0 1 0 0 0 1 0 1 1

Direct Sequence Spread Spectrum Transmitter

- Binary data
- Modulator (BPSK)
- DS Spreader
- Spread spectrum signal
- Pseudonoise bit source
Direct Sequence Spread Spectrum Receiver

Direct Sequence Spread Spectrum Using BPSK Example

(a) \( x(t) \) data

(b) \( s(t) \)

(c) \( c(t) \) spreading code

(d) \( s_d(t) \)
**Approximate Spectrum of DSSS Signal**

- Spectrum of data signal
- Spectrum of pseudonoise signal
- 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

- 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
Seven Channel CDMA Encoding and Decoding

<table>
<thead>
<tr>
<th>Channel number</th>
<th>Data value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
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<tr>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

Individual channel waveforms

Channel 0 code

Composite signal

positive number = 1
negative number = 0

Summary

- MIMO antennas
  - MIMO principles
  - Multiple-user MIMO
- OFDM
- OFDMA
- SC-FDMA
- Spread spectrum
- Direct sequence spread spectrum
  - DSSS using BPSK
  - DSSS performance considerations
- Code division multiple access
  - Basic principles
  - CDMA for DSSS