Research Trends on High Throughput Wireless Communication Systems

Lecture 3

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Room: B405
LECTURE INFORMATION

- **Lecturer**
  - Assistant Prof. Tran Thi Hong, Computing Architecture Lab

- **Slide**
  - I will upload lecture slides here: [http://arch.naist.jp/~hong/](http://arch.naist.jp/~hong/)

- **Score**

<table>
<thead>
<tr>
<th>Pass (合格)</th>
<th>Attend at least 3 classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Pass (不合格)</td>
<td>Attend less than 3 classes</td>
</tr>
</tbody>
</table>

- **Contact**
  - Room: B405
  - Email: hong@is.naist.jp
Lecture Contents

- Lecture 1+2: Fundamental of Communication System
- Lecture 3+4: Research Trends on High Throughput communication systems
LOOP ANTENNA FOR VHF COMMUNICATION

- **Question:** How to build antenna for marine communication? Because antenna size must be very large.
- **Answer:** Loop antenna.
RESEARCH TRENDS ON HIGH THROUGHPUT COMMUNICATION SYSTEM (1)
Lecture Contents

- WiFi: High Efficient Wireless HEW 802.11ax
- Cognitive Radio
- Massive MIMO
- Milliwave Communication
- LiFi Communication
**WiFi Evolution (1)**

HEW: High Efficiency Wireless
## Wi-Fi Evolution (2)

- **DSSS**: Direct-sequence spread spectrum
- **OFDM**: Orthogonal frequency division multiplexing

<table>
<thead>
<tr>
<th>Standard</th>
<th>Throughput</th>
<th>Symbol modulation</th>
<th>Carrier Freq. (GHz)</th>
<th>Max Subcarrier Modulation</th>
<th>Max Bandwidth</th>
<th>No. of Streams</th>
<th>Channel</th>
<th>Subcarrier Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11b</td>
<td>11 M</td>
<td>DSSS</td>
<td>2.4GHz</td>
<td></td>
<td></td>
<td>1</td>
<td>SISO</td>
<td>312.5 KHz</td>
</tr>
<tr>
<td>802.11a</td>
<td>54M</td>
<td><strong>OFDM</strong></td>
<td>5GHz</td>
<td>64QAM</td>
<td>20 MHz</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>802.11g</td>
<td>54M</td>
<td></td>
<td>2.4GHz</td>
<td>64QAM</td>
<td>20 MHz</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>802.11n</td>
<td>600M</td>
<td></td>
<td>2.4/5 GHz</td>
<td>64QAM</td>
<td>40 MHz</td>
<td>4</td>
<td>MIMO</td>
<td></td>
</tr>
<tr>
<td>802.11ac</td>
<td>6.9G</td>
<td></td>
<td>5GHz</td>
<td>256QAM</td>
<td>160 MHz</td>
<td>8</td>
<td>MU-MIMO, SDMA</td>
<td></td>
</tr>
<tr>
<td>802.11ax</td>
<td>HEW</td>
<td></td>
<td>2.4/5 GHz</td>
<td><strong>1024 QAM</strong></td>
<td>160 MHz</td>
<td></td>
<td>MU-MIMO, OFDMA</td>
<td>78.125 KHz</td>
</tr>
</tbody>
</table>

- **SISO**: Single Input Single Output
- **MIMO**: Multiple Input Multiple Output
- **MU-MIMO**: Multiuser MIMO
- **SDMA**: Spatial Division Multiple Access
- **OFDMA**: Orthogonal Frequency Division Multiple Access
DISCUSSION

What are the challenges when increasing channel bandwidth?
What are the challenges when implementing high order subcarrier modulation (1024-QAM)?
WiFi’s OFDM Symbols

Data are divided into OFDM symbols. Each symbol is transmitted in 4us.

OFDM: Orthogonal Frequency Division Multiplexing

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>#Subchannel Per OFDM symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 MHz</td>
<td>64</td>
</tr>
<tr>
<td>40 MHz</td>
<td>256</td>
</tr>
<tr>
<td>80 MHz</td>
<td>512</td>
</tr>
</tbody>
</table>
**WiFi’s PHY Frame Formats**

- **Legacy mode** (*11a/g compatibility*)
  
<table>
<thead>
<tr>
<th>8us</th>
<th>8us</th>
<th>4us</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-STF</td>
<td>L-LTF</td>
<td>L-SIG</td>
</tr>
<tr>
<td>DATA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Mixed mode** (*High Throughput mode*)
  
<table>
<thead>
<tr>
<th>8us</th>
<th>8us</th>
<th>4us</th>
<th>8us</th>
<th>4us</th>
<th>4us per LTF</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-STF</td>
<td>L-LTF</td>
<td>L-SIG</td>
<td>HT-SIG</td>
<td>HT-STF</td>
<td>HT-LTFs</td>
</tr>
<tr>
<td>DATA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

L: Legacy
HT: High Throughput
STF: Short Training Field
LTF: Long Training Field
SIG: Signal field
**WiFi’s PHY Block Diagrams**

- Detect data frame
- Estimate the transmitted data
- Correct the Error bits

### Transmitter
- PSDU GEN
- Scrambler
- MUX
- BCC
- Interleave
- Mapper
- Pilot
- MUX
- IFFT
- GII
- Window
- TX Filter
- Noisy Channel

### Receiver
- De-Scrambler
- Viterbi Dec.
- De-Interleave
- Demapper
- Data Detect
- Phase Track
- FFT
- GIR
- CFO
- AGC
- Window
- RX Filter

### Additional Components
- Preamble Memory
- Channel Est.
- Frame Sync.
OFDM (1)

- To transmit multiple signals over the channel, we modulate these signals into different ranges of frequency.
- Each range of carrier frequency is called as a subchannel, or subcarrier
- To avoid interference among subcarriers, there should be space between two adjacent subcarriers.

→ Frequency spectrum usage is not effective.
OFDM (2)

- OFDM (Orthogonal Frequency Division Multiplexing) is a multi-subcarrier symbol’s modulation scheme.
- Each subcarrier of OFDM symbol is modulated by conventional modulation such as BPSK, QPSK, etc.
- Purpose: Make signal power of subcarriers are orthogonal to each other
OFDM (3)

- Advantages:
  - High spectral efficiency

- Disadvantages:
  - Sensitive to Doppler shift
  - High peak-to-average-power ratio (PAPR)
  - Processing is high complex
**Subcarrier Spacing**

<table>
<thead>
<tr>
<th>BW</th>
<th>#Subcarriers 11a/n/ac</th>
<th>#Subcarriers 11ax</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 MHz</td>
<td>64</td>
<td>256</td>
</tr>
<tr>
<td>40 MHz</td>
<td>128</td>
<td>512</td>
</tr>
<tr>
<td>80 MHz</td>
<td>256</td>
<td>1024</td>
</tr>
<tr>
<td>160 MHz</td>
<td>512</td>
<td>2048</td>
</tr>
</tbody>
</table>
What are the challenges when reducing subcarrier spacing by 1/4?
MIMO System

\[ X = [x_1 \ x_2]: \text{transmitted data} \]
\[ N = [n_1 \ n_2]: \text{Noise} \]
\[ H = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}: \text{Channel Impulse Response} \]
\[ Y = [y_1 \ y_2]: \text{Received data} \]

\[ Y = H.X + N \]
\[ \Rightarrow X = H^{-1} Y \]
Wi-Fi’s PHY Block Diagrams
4x4 MIMO: Transmitter
WiFi’s PHY Block Diagrams
4x4 MIMO: Receiver
DISCUSSION

What are the challenges of MIMO system?
MU-MIMO & SDMA (1)

- Beam forming

SDMA: Spatial Division Multiple Access
MU-MIMO & SDMA (2)

- Beam forming

SDMA: Spatial Division Multiple Access

How to remove these interferences?
MU-MIMO & SDMA (3)

- Beam forming

SDMA: Spatial Division Multiple Access
OFDM VS. OFDMA IN MU-MIMO

Frequency (sub channel)

OFDM
symbol

user1  user2  user3  user4

OFDMA
symbol

Frequency (sub channel)
COGNITIVE RADIO (1)

- Help unlicensed user (secondary user) can use licensed spectrum of licensed user (primary user)
Cognitive Radio (2)

- **Cognitive radio (CR)** is a radio that can be **programmed** and **configured dynamically** to use the best wireless channels.

- **Functions of CR:**
  - Spectrum sensing $\rightarrow$ detect unused spectrum
    - Transmitter detection based sensing
    - Receiver detection based sensing
    - Cooperative detection based sensing
  - Dynamic Spectrum management
    - Dynamic spectrum allocation
    - Dynamic spectrum sharing
  - Power Control: deal with interference in sharing spectrum communication
  - Etc.
Cognitive Radio (3)
OFDM, MIMO, MU-MIMO, OFDMA, cognitive radio are not only advanced cutting edge technologies in WiFi communication, but also in mobile communication (LTE Advanced)
Massive MIMO (1)

- Massive MIMO is a communication system that the base station uses a large number of antennas (hundreds, thousands) for transferring data.
Massive MIMO (2)
MASSIVE MIMO (3)
MASSIVE MIMO (4)

- Challenges:
  - The complexity in channel estimation increases with increase in the number of antennas.
  - Loop interference increases with increase in the spatial antennas.
  - Training symbols for channel estimation depends on the number of transmitting antennas. Increase in number of training symbols decreases overall throughput.
  - Etc.
NEXT LECTURE: RESEARCH TRENDS ON HIGH THROUGHPUT COMMUNICATION SYSTEM (2)

- Miliwave Communication
- LiFi Communication
- MAC’s advanced cutting edge techniques