IEEE 802.11n PHY Overview and Channel Models

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802.11n Physical Layer Overview

802.11n Channel Modeling and Test
The Indoor Wireless LAN Channel

- Environment characterized by high multipath
- Reflections off everything
  - Walls, floors, ceilings, furniture, people…
- Direct ray is rare except for short range
- Until now multipath was a problem that limited operating range
- Now MIMO technology actually uses multipath to achieve gains in operating range
802.11n MIMO Radio Systems

- Data is organized into spatial streams that are transmitted simultaneously

- **SISO**: Single-Input/Single-Output; **MIMO**: Multi-Input/Multi-Output
  - Refers to the streams between a set of transmit and receive antennas

- There’s a propagation path between each transmit and receive antenna (a “MIMO path”)
  - $N$ transmit antennas
  - $M$ receive antennas
  - Total of $N \times M$ paths

- Hence MIMO system characterization: “4x4”, “2x2”, “2x3”, etc.
MIMO Techniques for Increased Performance

- **Spatial Multiplexing**
  - Use multiple transmit and receive antennas to send *more than one data stream* simultaneously (multiple “spatial streams”)
  - Yields higher effective PHY rates
  - Channel responses for each MIMO path must be sufficiently decorrelated

- **Beamforming**
  - Use multiple transmit and receive antennas to transmit *the same data stream* to improve signal reception
  - Think of it as transmitter and receiver diversity
  - Yields longer range

- **How can a receiver make sense of this?**
  - A lot of DSP and matrix math
IEEE 802.11 WLAN Roadmap

1Q06  2Q06  3Q06  4Q06  1Q07  Q07  3Q07  4Q07

- 802.11k Radio Measurement
- 802.11r Fast Roaming
- 802.11n High Speed
- 802.11p Vehicle
- 802.11u Interworking
- 802.11s Mesh
- 802.11T Test

IEEE Standards Board Approval (expected)

http://grouper.ieee.org/groups/802/11/802.11_Timelines.htm
• Goals of the EWC
  – Accelerate the IEEE 802.11n development
  – Promote a technology specification for interoperability of next-generation wireless local area networking (WLAN) products

• Membership includes 27 Wi-Fi industry leaders

• Applications include
  – PC and networking equipment
  – Handheld
  – Consumer electronics
EWC Specifications

• The PHY (physical layer) interfaces to the MAC (medium access control) through the TX vector and the RX vector.

EWC_MAC_spec_V10  EWC_PHY_spec_V101
EWC PHY Specification Summary

- Mixed-mode interoperability with 802.11a/b/g networks – provides enhanced performance while maintaining communication with legacy devices
- PHY transmission rates up to 600Mbps – supports applications requiring high data rates (such as transmitting multiple HDTV streams), and reduces battery drain by minimizing the time required to send and receive data streams
- Enhanced efficiency MAC with frame aggregation – brings actual throughput closer to the raw PHY rate, providing end users with at least 100 Mbps application level bandwidth
- Use of 2.4GHz and 5GHz unlicensed bands – matches the frequency plan of existing 802.11 devices
- 20MHz and 40MHz channel support – can double the wireless spectrum over legacy 802.11 networks to enhance performance
- Enhanced range via multiple antennas and advanced coding – provides for a wider coverage area with consistent wireless speeds
# 40MHz Channel Allocation in the 5GHz Band

<table>
<thead>
<tr>
<th>Regulatory domain</th>
<th>Band (GHZ)</th>
<th>$N_{\text{control_ch}}$</th>
<th>Center Frequency (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Extension=1</td>
<td>Extension=1</td>
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<tr>
<td>United States</td>
<td>U-NII lower band (5.15-5.25)</td>
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<td></td>
<td></td>
<td>132</td>
<td>136</td>
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<tr>
<td>United States</td>
<td>U-NII upper band (5.725-5.825)</td>
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<td>153</td>
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<td></td>
<td></td>
<td>157</td>
<td>161</td>
</tr>
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</table>

Channel center frequency = (5000 + 5*n) MHz, where n=0..200
# 40MHz Channel Allocation in the 2.4GHz Band

The channel center frequency is given by the formula:

$$\text{Channel center frequency} = (2407 + 5*n) \text{ MHz}, \text{ where } n=1..11$$

<table>
<thead>
<tr>
<th>Regulatory domain</th>
<th>$N_{\text{control_ch}}$</th>
<th>Center Frequency (MHz)</th>
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<tr>
<td></td>
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<tr>
<td>Canada</td>
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<td>Europe</td>
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<td></td>
<td>5</td>
<td>9</td>
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<td></td>
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<td>10</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>11</td>
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</table>
PHY Operating Modes

The PLCP (PHY Layer Convergence Protocol) Frame Format

- **Legacy**
  - L-STF: Legacy Short Training Field
  - L-LTF: Legacy Long Training Field
  - L-SIG: Legacy Signal Field
  - Data

- **Mixed Mode**
  - L-STF
  - L-LTF
  - L-SIG
  - HT-SIG
  - HT-STF
  - HT-LTF's
  - Data

- **Green Field**
  - L-STF
  - HT-LTF
  - HT-SIG
  - HT-LTF's
  - Data

L-STF: Legacy Short Training Field; L-LTF: Legacy Long Training Field; L-SIG: Legacy Signal Field

HT-SIG: High Throughput Signal Field; HT-STF: High Throughput Short Training Field; HT-LTF1: First High Throughput Long Training Field

HT-LTF’s: Additional High Throughput Long Training Fields

Data – The data field includes the PSDU (PHY Sub-layer Data Unit)
MIMO Performance Gains Come with Complexity Cost

• Existing standards
  – 11b (DSSS-CCK) – 1, 2, 5.5, 11 Mbps in 2.4 GHz band
  – 11a (OFDM) – 6, 9, 12, 18, 24, 36, 48, 54 Mbps in 5 GHz band
  – 11g – both 11b and 11a rates in 2.4 GHz band

• 802.11n – 6 to 600 Mbps in 2.4 and 5 GHz bands

• MIMO introduces concept of Modulation and Coding Scheme – “MCS”

• Each MCS is determined by a different set of parameters:
  – Modulation, coding rate, # spatial streams, # FEC encoders

• More than one MCS may have the same effective PHY rate!
  – Modem algorithms should select optimum under current channel conditions
Some Example MCS’s from EWC spec

- Note MCS 1 and 8 are same PHY rates; likewise MCS 21 and 28

<table>
<thead>
<tr>
<th>MCS Index</th>
<th>Modulation</th>
<th>Code Rate</th>
<th>Spatial Streams</th>
<th>FEC Coders</th>
<th>PHY Rate 20 MHz</th>
<th>PHY Rate 40 MHz</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>BPSK</td>
<td>1/2</td>
<td>1</td>
<td>1</td>
<td>6.5</td>
<td>13.5</td>
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<tr>
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<td>QPSK</td>
<td>1/2</td>
<td>1</td>
<td>1</td>
<td>13</td>
<td>27</td>
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<tr>
<td>7</td>
<td>64-QAM</td>
<td>5/6</td>
<td>1</td>
<td>1</td>
<td>65</td>
<td>135</td>
</tr>
<tr>
<td>8</td>
<td>BPSK</td>
<td>1/2</td>
<td>2</td>
<td>1</td>
<td>13</td>
<td>27</td>
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<tr>
<td>14</td>
<td>64-QAM</td>
<td>3/4</td>
<td>2</td>
<td>1</td>
<td>117</td>
<td>243</td>
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<tr>
<td>21</td>
<td>64-QAM</td>
<td>2/3</td>
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<td>2</td>
<td>156</td>
<td>324</td>
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<tr>
<td>28</td>
<td>16-QAM</td>
<td>3/4</td>
<td>4</td>
<td>2</td>
<td>156</td>
<td>324</td>
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<tr>
<td>31</td>
<td>64-QAM</td>
<td>5/6</td>
<td>4</td>
<td>2</td>
<td>260</td>
<td>540</td>
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<tr>
<td>31*</td>
<td>64-QAM</td>
<td>5/6</td>
<td>4</td>
<td>2</td>
<td>288.89</td>
<td>600</td>
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</tbody>
</table>

* This MCS uses a shorter guard interval (GI) – 400 ns vs. 800 – to increase throughput
Transmit Block Diagram
802.11n Physical Layer Overview

802.11n Channel Modeling and Test
MIMO Multipath Channel

- Multipath reflections come in “clusters”
- Each cluster is caused by a specific group of reflectors
- Reflections in a cluster arrive at a receiver all from the same general direction (mostly)
- On this picture one can imagine three or four major clusters
- Statistics of clusters are key to MIMO system operation and a critical part of channel emulation for MIMO
The TGn Channel Models

- Six models agreed on for evaluation of TGn proposals
  - Models A through F

- Tapped delay line model (FIR filter)

- Models assume linear antenna arrays for Tx and Rx
  - Determines spatial correlation between MIMO paths
  - $\frac{1}{2}$, 1 and 4 wavelength element spacing

- Doppler spectrum assumes reflectors moving in environment at 1.2 km/h
  - Corresponds to about 6 Hz in 5 GHz band, 3 Hz in 2.4 GHz band
  - “Bell” shaped spectrum

- Number of clusters varies from 2 to 6
Example 2x2 Unidirectional MIMO Channel Model

- Time-varying FIR filter weights
  - Spatially correlated: $H_{11}$ correlated with $H_{12}$, etc., according to antenna spacing and cluster statistics
  - Time correlated according to the Doppler model
Basic Model Parameters

- Delay spread is a function of the size of the modeled environment
- Average distance to first wall determines whether there is a direct ray in the model
  - Rician component on 1st tap for shorter distances
  - No Rician (100% diffuse Rayleigh) for longer distances
- Number of clusters represents number of independent propagation paths modeled

<table>
<thead>
<tr>
<th>Parameters</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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<tbody>
<tr>
<td>Avg 1st Wall Distance (m)</td>
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<td>5</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>30</td>
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<td>RMS Delay Spread (ns)</td>
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<td>50</td>
<td>100</td>
<td>150</td>
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<td>Maximum Delay (ns)</td>
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<td>200</td>
<td>390</td>
<td>730</td>
<td>1050</td>
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<tr>
<td>Number of Taps</td>
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<td>9</td>
<td>14</td>
<td>18</td>
<td>18</td>
<td>18</td>
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<tr>
<td>Number of Clusters</td>
<td>N/A</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
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</table>
Bidirectional Emulator needed for TGn

- Some proposed MCS’s require feedback from the receiver
  - Channel state info derived from ACKs and used to select best MCS
- Channel emulator must be bidirectional, with channel state synchronized
4X4 MIMO Multipath Bi-directional Channel Emulator Block Diagram

Bold path = 4 RF Lines
Channel Emulator Requirements

• 4x4 MIMO
• Bi-Directional
• Support for IEEE TGn Channel Models: A-F
• Programmable attenuation helps test signal range (60 dB of range)
• Minimal configuration requirements
  – Channel model selection
  – TX and RX Antenna spacing parameters
  – Channel of operation
  – Attenuator setting
• 2.4 - 2.5, and 4.9 – 5.850 GHz bands with 40 MHz channels
Channel Emulator Test Setup

- Isolate DUTs from one another to avoid signal coupling via paths other than the channel emulator
- Sensitivity of MIMO devices is -80 dBm or better
Throughput vs. Channel Model and Path Loss

- Measure throughput vs. channel model and path loss
- Verify performance needed by new video applications
- Compare competing products
References

• “TGn Channel Models,” V. Erceg et al, IEEE 802.11 document 11-03/0940r4