Understanding High Speed 802.11n Wireless Networks in Depth

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Agenda

- The Role of IEEE and WFA
- 802.11n Technology Prerequisites
- MIMO
- 40MHz Channels
- Packet Aggregation
- Backward Compatibility
- Cisco and Intel Collaboration
The Role of the IEEE and the WFA

- 802.11n was a 7-years endeavor at the IEEE
- The High Throughput Study Group – Sept 11, 2002
- 802.11n Task Group – Sept 11, 2003
- WFA first began certifying the interop of draft 2.0 802.11n devices in June 2007
- IEEE 802.11n ratification on Sept 11 2009
802.11n Technology

■ Goal:

To dramatically increase the effective throughput of 802.11 devices available to end-user apps, not to simply build a radio capable of higher bit rates.

■ Every aspect of 802.11 introducing overhead needs to be minimized as far as possible …

■ Not only faster PHY layer, but also more efficient MAC layer

  Reliability and bit rate are increased by MIMO
  The bit rate increased by 40-MHz operation
  Frame aggregation – higher throughput for apps
  Robust backward compatibility
802.11n Advantages

Throughput

Increased Bandwidth for emerging and existing applications

Reliability

Reduced Retries permitting low latency and delay sensitive applications such as voice

Predictability

Reduced dead spots permitting consistent connectivity for every application
Technical Elements of 802.11n

- MIMO
- 40Mhz Channels
- Packet Aggregation
- Backward Compatibility
MIMO (Multiple Inputs Multiple Outputs)

- MIMO is heart of 802.11n
- 802.11n it is mandatory requirement to have at least two receivers and one transmit per band
  
  Optional to support up to four TXs and four RXs
- Ability to use multiple transmit antennas to improve SNR of the signal at the receiver
- Ability to use multiple receive antennas to improve SNR of the signal at the receiver – MIMO Equalization
- Ability to send two or more signals – spatial streams → spatial division multiplexing
- MRC—Maximum ratio combining (MIMO Equalizer for a single spatial stream)

Note: MIMO provides improvements for non-802.11n clients
Comparing SISO and MIMO Signal Reception

- One radio chain
- Switches between antennas
  - Either A or B
- Multipath degrades

- Three radio chains
- Aggregates all antennas
  - A and B and C
- Multipath improves
- Better immunity to noise
- Better SNR than SISO
MIMO Radio Terminology

- **TxR:S**
  
  Transmit Antennas x Receive Antennas : Spatial Streams

- T – Transmit Antennas

- R – Receive Antennas

- S – Spatial Streams (1 = 150Mbps, 2 = 300Mbps)

- The 1250 and 1140 are 2x3:2
  
  Two Transmit, Three Receive, Two Spatial Streams

- **NOTE**: Beware the taxonomy… vendors claiming 3x3 and 4x4 MIMO systems still only do 2 spatial streams!
Maximum Ratio Combining (MIMO Equalizer)

MIMO (Multiple Input, Multiple Output)

**Without MRC**
Multiple Signals Sent; One Signal Chosen

**With MRC**
Multiple Signals Sent and Combined at the Receiver *Increasing Fidelity*

Maximum Ratio Combining (MIMO Equalizer)
Maximum Ratio Combining

- Performed at receiver (either AP or client, complement to transmit beamforming)
- Combines multiple received signals
- Increases receive sensitivity
- Works with both 11n and non-11n clients
- MRC is like having multiple ears to receive the signal
Illustration of Three Multipath Reflections to SISO AP

Multipath Reflections of Original Signal

Signal Each Antenna Sees Due to Multipath Effect

Radio Switches to Best Signal with Least Multipath Effect
Illustration of Three Multipath Reflections to MIMO AP with MRC

The DSP Adjusts the Received Signal Phase So They Can Be Added Together

The Resulting Signal Is Addition of Adjusted Receive Signals

Multipath Reflections of Original Signal
Spatial Multiplexing

MIMO (Multiple Input, Multiple Output)

Information Is Split and Transmitted on Multiple Streams

Transmitter and Receiver Participate

Concurrent Transmission on Same Channel

Increases Bandwidth

Requires 11n Client

40Mhz Channels
Packet Aggregation
Backward Compatibility

Performance
SISO Data Transmission

Time Period 1

Data
The quick brown fox...
Radio
The
Radio
Data

Time Period 2

Data
quick brown fox...
Radio
quick
Radio
Data
The quick
MIMO Spatial Multiplexing
Data Transmission

Time Period 1

Data

The quick brown fox...

TX Radio

The

quick

RX Radio

Data

The quick

Time Period 2

Data

brown fox...

TX Radio

brown

fox

TX Radio

RX Radio

Data

The quick brown fox...
More Efficient Spectrum Utilization with MIMO Spatial Multiplexing

The data is broken into two streams transmitted by two transmitters at the same frequency.

I Can Recognize the Two Streams Transmitted at the Same Frequency Since the Transmitters Have Spatial Separation Using My Three RX Antennas with My Multipath and Math Skills.
Technical Elements of 802.11n

- MIMO
- 40Mhz Channels
- Packet Aggregation
- Backward Compatibility
40-MHz Channels

Moving from 2 to 4 Lanes

40-MHz = 2 aggregated 20-MHz channels—takes advantage of the reserved channel space through bonding to gain more than double the data rate of 2 20-MHz channels
Double Wide Channel – 40MHz Support

- **802.11n** supports 20 or 40 MHz wide channels
  - 40 MHz wide channels recommended only for 5 GHz
- Consists of a primary channel and a secondary channel also referred to as extension channel
  - Second channel must be adjacent
  - Can be above or below primary
  - Protection provided for 20 MHz wide client use
40 MHz-Wide Channel

- Spectrum Expert Trace for 40 MHz-wide channel channel 36 primary and channel 40 extension
Technical Elements of 802.11n

- MIMO
- 40Mhz Channels
- Packet Aggregation
- Backward Compatibility
Aspects of 802.11n

Carpooling Is More Efficient Than Driving Alone

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<thead>
<tr>
<th>Without Packet Aggregation</th>
<th>With Packet Aggregation</th>
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<td>802.11n Overhead</td>
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802.11n Overhead

Packet

Packet

Packet
Packet Aggregation

- All 11n devices must support receiving of either packet aggregation method A-MPDU or A-MSDU
- A-MPDU packet aggregation is what 1250 and 1140 will use for packet aggregation with block acknowledge
Technical Elements of 802.11n

- MIMO
- 40Mhz Channels
- Packet Aggregation
- Backward Compatibility
Aspects of 802.11n

11n Operates in Both Frequencies

802.11ABG Clients Interoperate with 11n AND Experience Performance Improvements
802.11n HT-mix PHY

To provide legacy co-existence all 11n transmissions today use a mixed mode PHY that encapsulates the HT PHY in the Legacy PHY when transmitting at HT rates.

- Legacy devices degrade 11n device performance based on duty cycle they use in the spectrum.
Backward Compatibility & Co-Existence

- Co-existence of ABG/N APs
- Benefits of 11n accrue to ABG clients (ClientLink)

MIMO benefits ABG clients on the AP receive side from MRC
Backward Compatibility & Co-Existence

- Mixed mode experiences slight performance impact due to ABG clients
- 11n clients still transmit at full performance
- Move 11n clients to 5GHz, keep legacy clients at 2.4GHz
  - Use Cisco BandSelect to automatically move dual-band clients to 5GHz
802.11n Data Rates
MCS—Modulation and Coding Scheme

- 802.11a/b/g used data rates
- 802.11n defines MCS rates
- 77 MCS rates are defined by standard
- 1140 and 1250 support 16 (MCS 0-15)
  Eight are mandatory
- Best MCS rate is chosen based on channel conditions
- MCS specifies variables such as
  Number of spatial stream, modulation, coding rate, number of forward error correction encoders, number data subcarriers and pilot carriers, number of code bits per symbol, guard interval
# MCS Chart

<table>
<thead>
<tr>
<th>MCS Index</th>
<th>Modulation</th>
<th>Spatial Streams</th>
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Maximum with 1 spatial stream

Maximum with 2 spatial streams
A Few More 802.11n Features Used to Increase Performance

- Beam forming
- Reduced inter-frame spacing
- Reduced guard interval
  From 800ns to 400ns between ‘symbols’
- QAM 64
Cisco Next-Generation Wireless Portfolio

- **Cisco Aironet 1140 Series**
  - Carpeted Indoor Environments
  - Easy to Deploy-Sleek design with integrated antennas
  - 802.11n performance with efficient 802.3af power
  - Blends seamlessly into the environment

- **Cisco Aironet 1250 Series**
  - Rugged Indoor Environments
  - Versatile RF coverage with external antennas
  - Flexible power options for optimal RF coverage
11a/g to 11n Access Point Migration

Indoor Environments
Integrated Antennas

Rugged Environments
Antenna Versatility
## 1140 vs 1250 Positioning

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<th>1140</th>
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<tr>
<td>Deployment</td>
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<td>Antennas</td>
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<td>Power Options</td>
<td>PoE, AC, Pwr Injector</td>
<td>PoE*, ePoE, AC, Pwr Injector</td>
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</tbody>
</table>

* 1250 runs on PoE with reduced performance
Cisco and Intel:

Collaborative 802.11n Leadership and Testing
Why Cisco/Intel is different

Dedicated office building for testing enterprise WLAN

Intel and Cisco engineers working together

Application level testing vs. standards compliance

Robots provide 24*7 testing, accurate results

Virtual Tour:
http://ciscointelalliance.com/wireless_mobility/collab_mov.aspx
Line of Sight (LoS), Non-Line of Sight (NLoS) Tests

Customer Challenges:

- Reliable and predictable performance needed for enterprise apps to operate effectively on WLANs
- Applications require increasing amounts of bandwidth

Customer Impact:

- 802.11n delivers 5X to 9X the level of application layer throughput in comparison to 802.11a/g

Test Methodology:

- Application layer testing with TCP traffic
- Multiple locations tested in an office environment

802.11n Offers Superior Throughput and Coverage
Non-Line of Sight (NLoS)—Test Results

TCP Throughput (5GHz)

Average of 9X throughput increase comparing 802.11n vs. 802.11a

802.11n Offers Superior Throughput and Coverage
Non-Line of Sight (NLoS)—Test Results

802.11n Offers Superior Throughput and Coverage

Average of 5X throughput increase comparing 802.11n vs. 802.11g
Client Density Testing – Test results

Customer Challenges

- Highly dense client environments exist in many organizations
- Have historically proved challenging with shared media like wireless.

Customer Impact: 802.11n delivers a more predictable, reliable even in circumstances of high client density / contention.

- Can easily support difficult environments like carpeted enterprise, education, hospitality, etc.
- Peak throughput 195 Mbps, Average 182 Mbps
Mixed Mode Testing

Customer Challenges

- Customers will not immediately be able to upgrade their client infrastructure to be 802.11n capable.
- An 802.11n infrastructure must be able to handle both “legacy” clients in addition to 802.11n clients.

Customer Impact: Consistent client performance is offered across all test runs (~2Mbps per legacy client, ~25Mbps per 11n client).

“Legacy” 802.11a/b/g clients will not impact your 802.11n network.

11n Performance is Not Impacted by Existing 11abg
Enterprise Client Roaming

Customer Challenges

- Applications require consistent, predictable network performance, even when the client is roaming.
- There is no “standard” client roaming algorithm.

Customer Impact: Cisco and Intel have collaborated to focus on optimizing roaming for enterprise applications.

- Throughput remains consistent across roaming resulting in a stable platform for enterprise applications.
- Customers using Cisco infrastructure with Intel clients will deliver the best throughput and roaming in the industry.
Enterprise Roaming
Non-optimized, Inconsistent Results

Iteration 1
Iteration 2
Iteration 3
Iteration 4
Iteration 5
Enterprise Roaming
Optimized, Consistent Results

Iteration 1
Iteration 2
Iteration 3
Iteration 4
Iteration 5

Consistent roams across multiple iterations. This is good for mission critical applications.
MIMO vs. SISO ‘Dead Spot’ Assessment
### SISO vs. MIMO Dead Spot Comparison

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- Each square represents a slight position change
- Number is percentage of maximum throughput
- 802.11n provides more predictability through MRC
Cisco 11n Access Point Comparison

- For 2.4GHz, both APs deliver 100Mbps TCP throughput for each traffic direction.
- For a 5GHz (40MHz) channel, both APs deliver above 175Mbps TCP throughput and a peak of ~195Mbps.
Intel 11n Client Comparison

The 5100 is a 1x2:2 radio chipset meaning it can receive at 300Mbps data rate but only send at a maximum of 150Mbps.

The 5300 is a 3x3:3 radio chipset supporting a full 300Mbps in both upstream and downstream directions.
Additional Resources

For

- Cisco/Intel Testing Whitepaper
  

- Cisco/Intel Collaboration Video
  
  http://www.youtube.com/watch?v=8WPBMBz9n7A