Cisco Expo
2009
November 25-26, Bratislava, Slovakia

# 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 increased 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

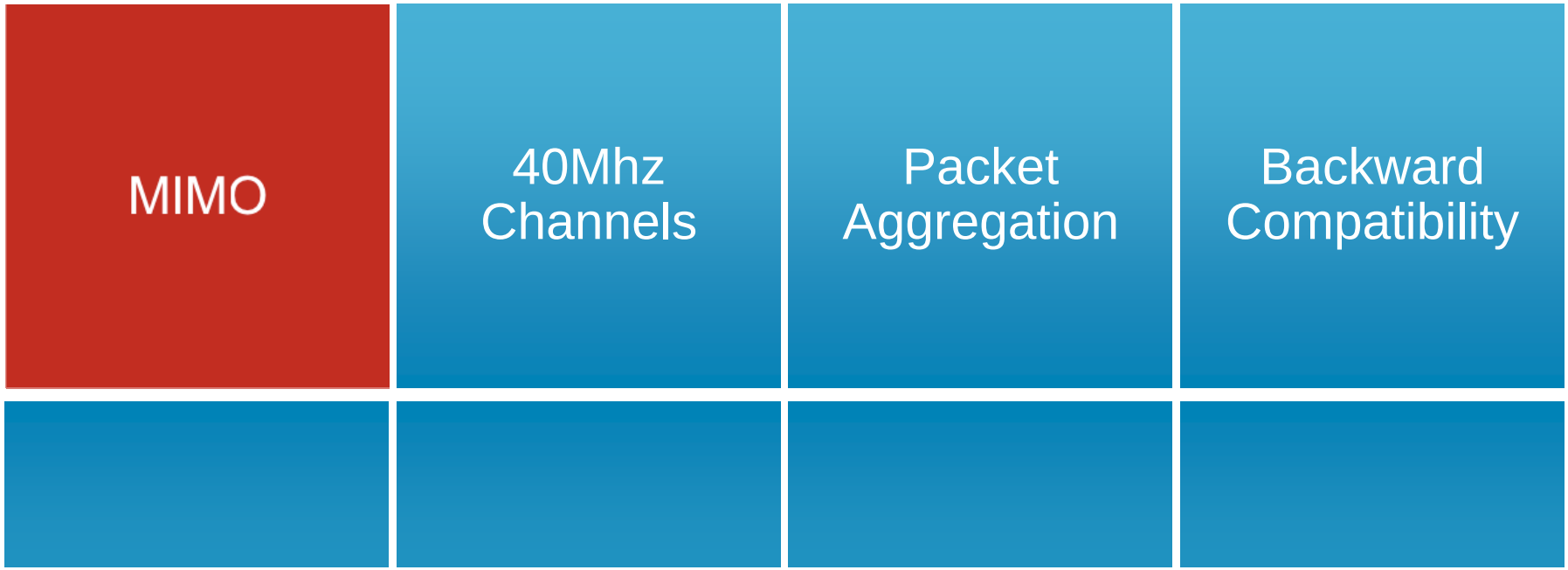

Increased Bandwidth for emerging and existing applications

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

Reduced dead spots permitting consistent connectivity for every application

# Technical Elements of 802.11n

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



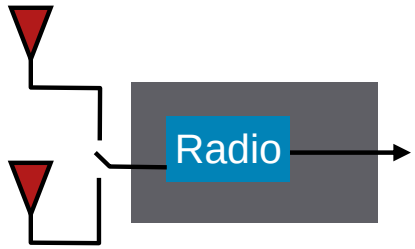
# MIMO (Multiple Inputs Multiple Outputs)

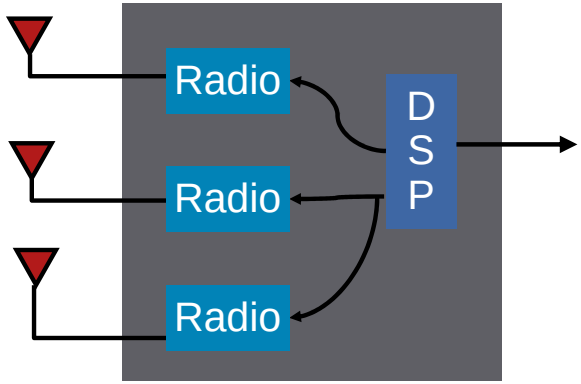
- MIMO is heart of 802.11n
- 802.11n it is mandatory requirement to have at least two receivers and one transmit per band

  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 *

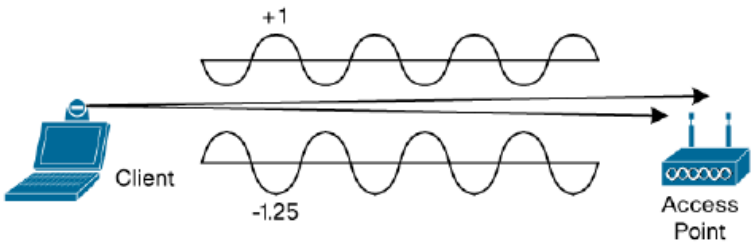
# Comparing SISO and MIMO Signal Reception




- 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!

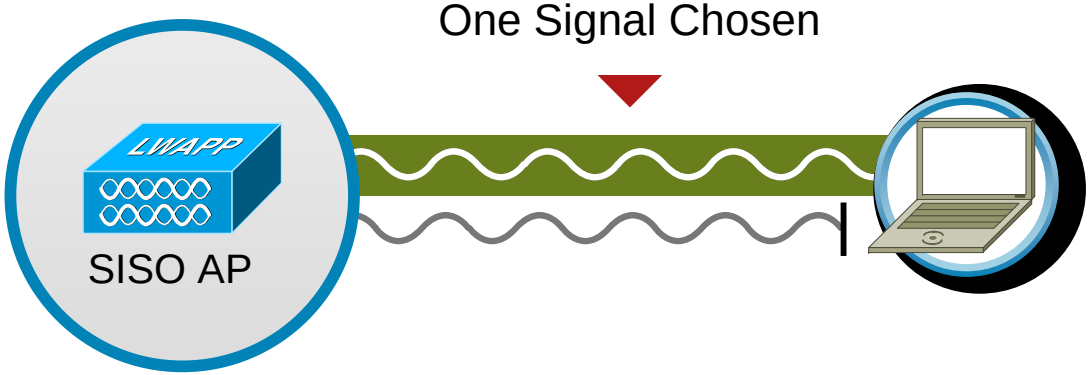
# Maximum Ratio Combining (MIMO Equalizer)



## MIMO (Multiple Input, Multiple Output)

**Without MRC**

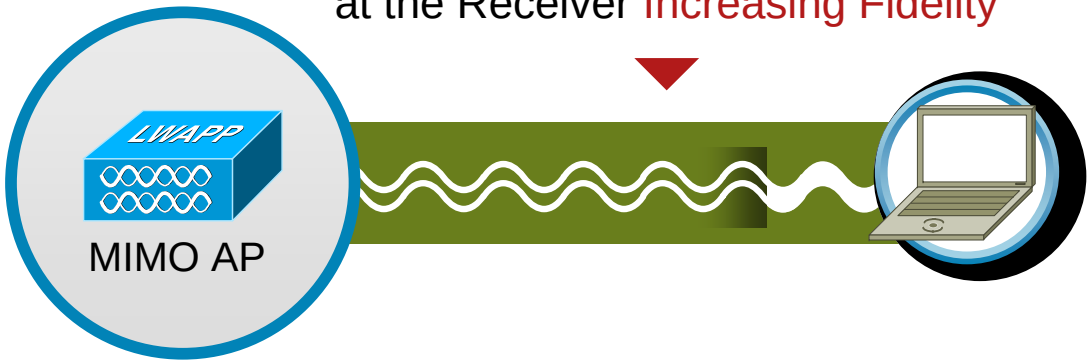
Multiple Signals Sent;
One Signal Chosen




Performance

**With MRC**

Multiple Signals Sent and Combined
at the Receiver Increasing Fidelity

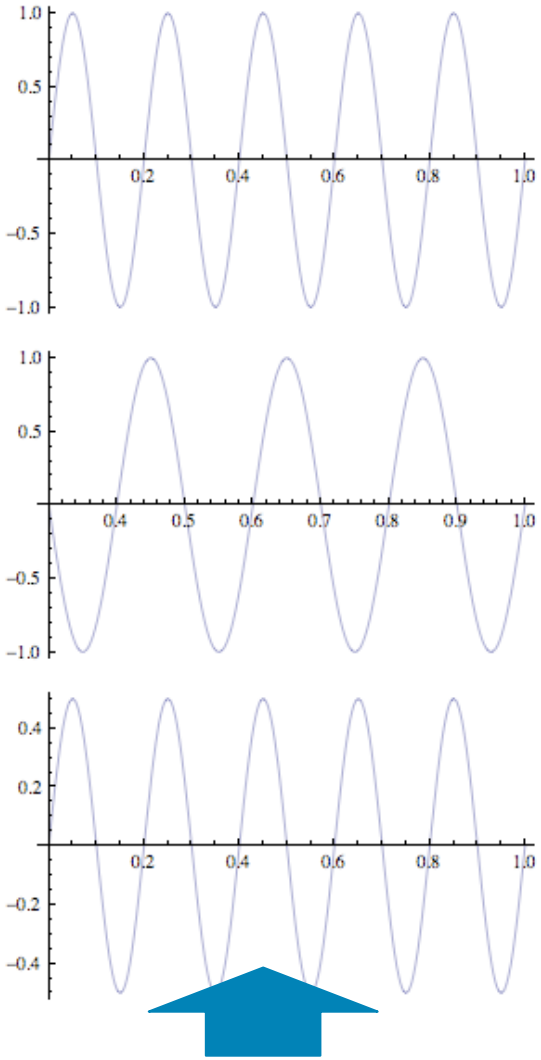



Performance

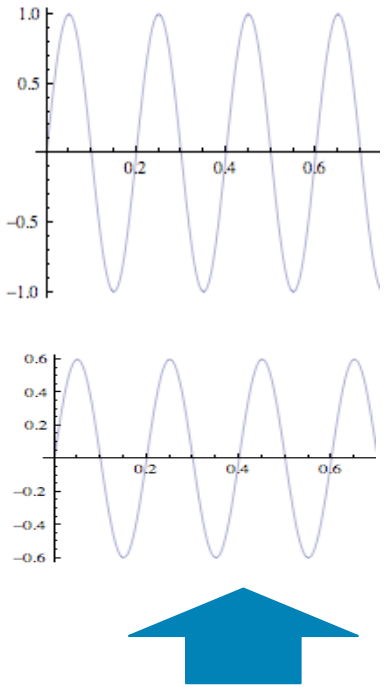
# Maximum Ratio Combining

- 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

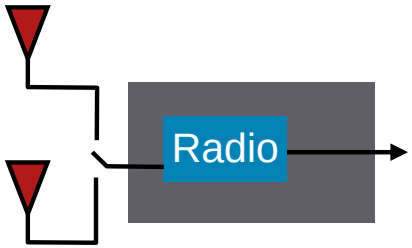
# Illustration of Three Multipath Reflections to SISO AP

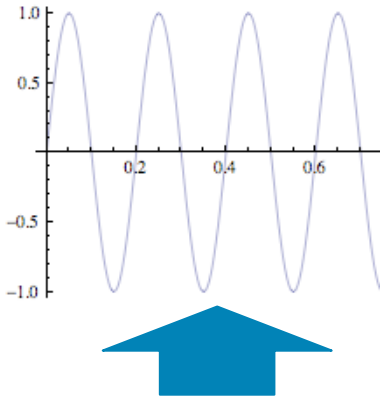


**Multipath Reflections of Original Signal**



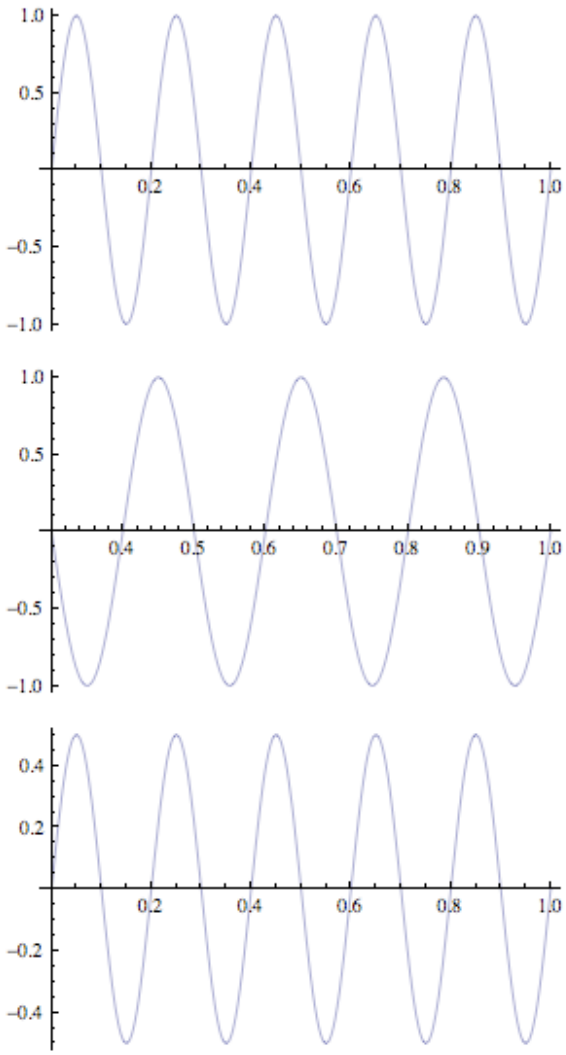
**Signal Each Antenna Sees Due to Multipath Effect**



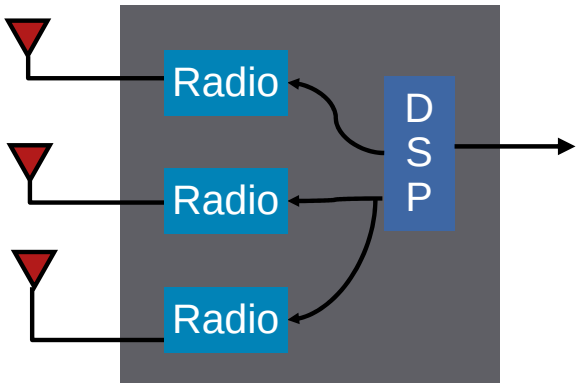



**Radio Switches to Best Signal with Least Multipath Effect**

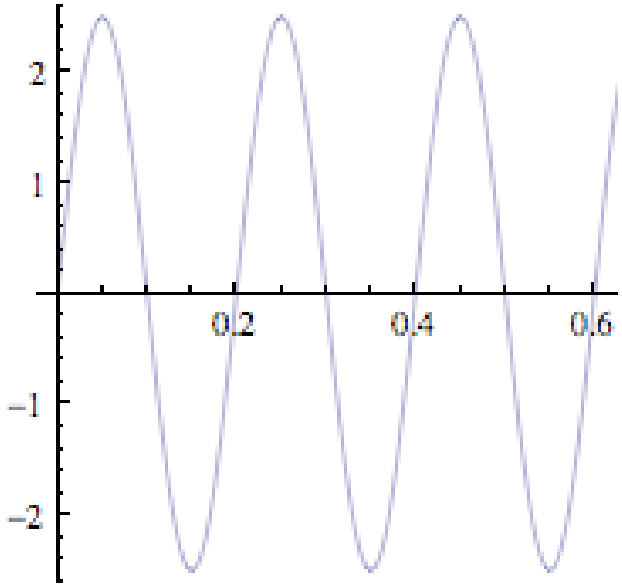
# Illustration of Three Multipath Reflections to MIMO AP with MRC




**Multipath Reflections of Original Signal**




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



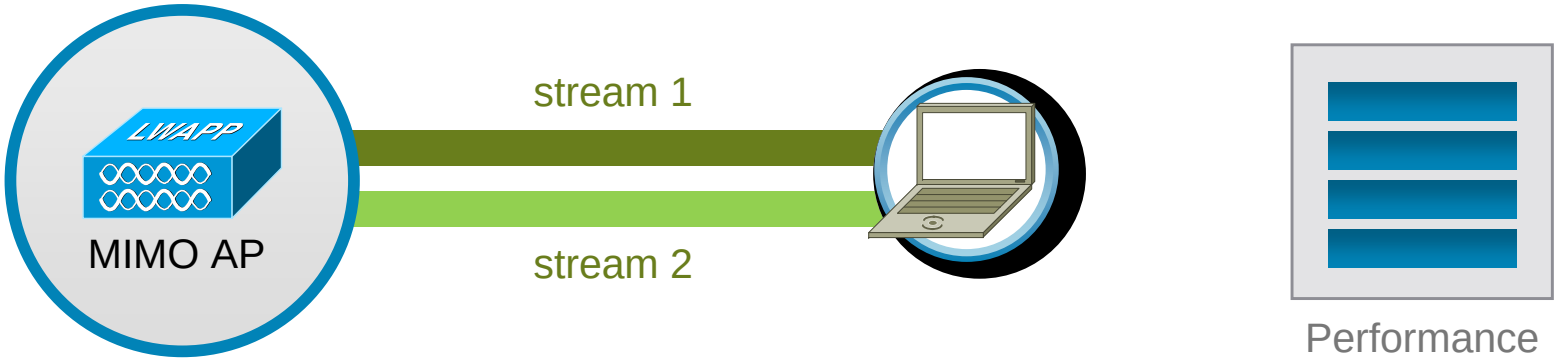

**The Resulting Signal Is Addition of Adjusted Receive Signals**

# Spatial Multiplexing

40Mhz Channels | Packet Aggregation | Backward Compatibility

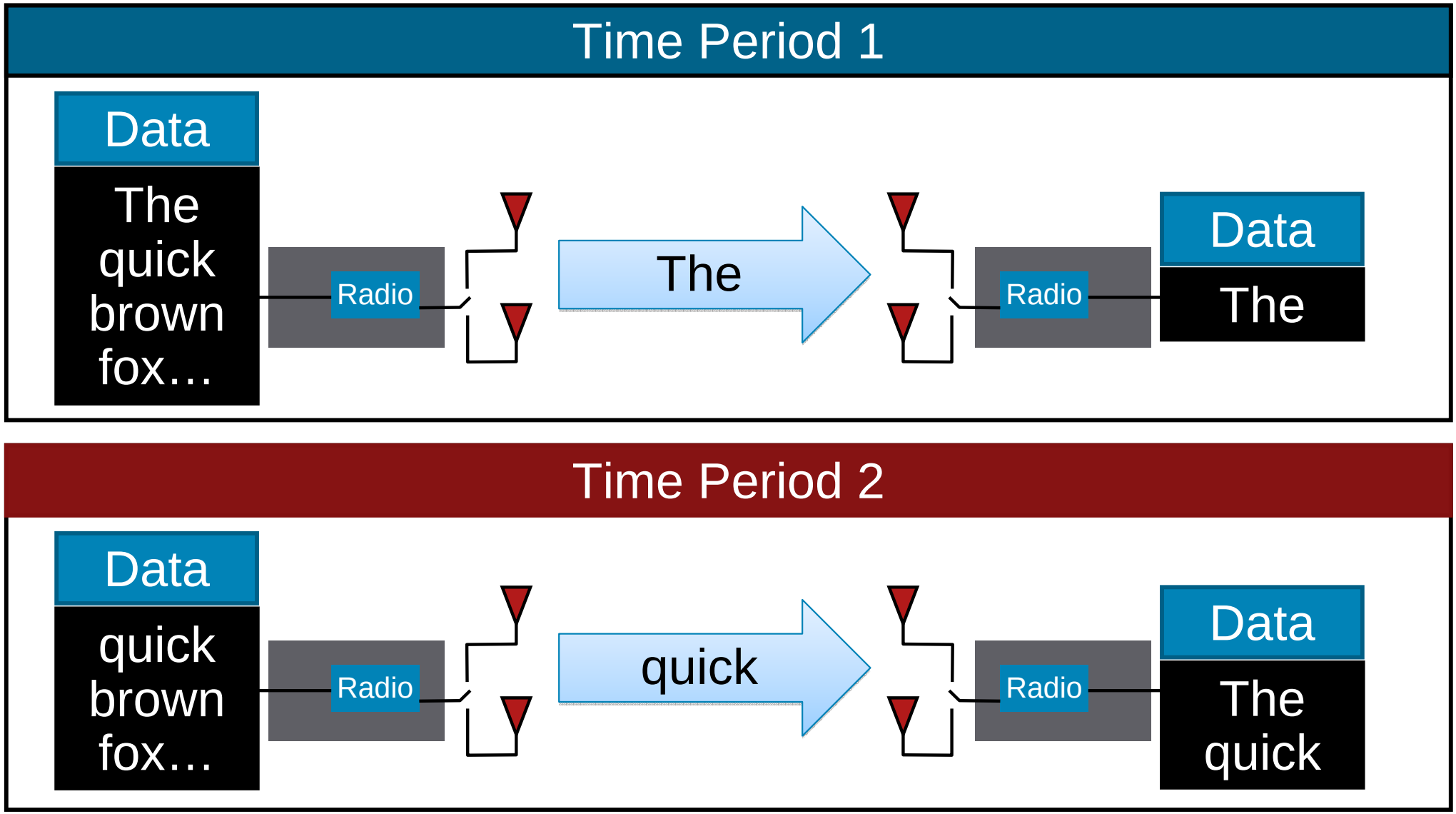
## MIMO (Multiple Input, Multiple Output)

Information Is Split and Transmitted on Multiple Streams

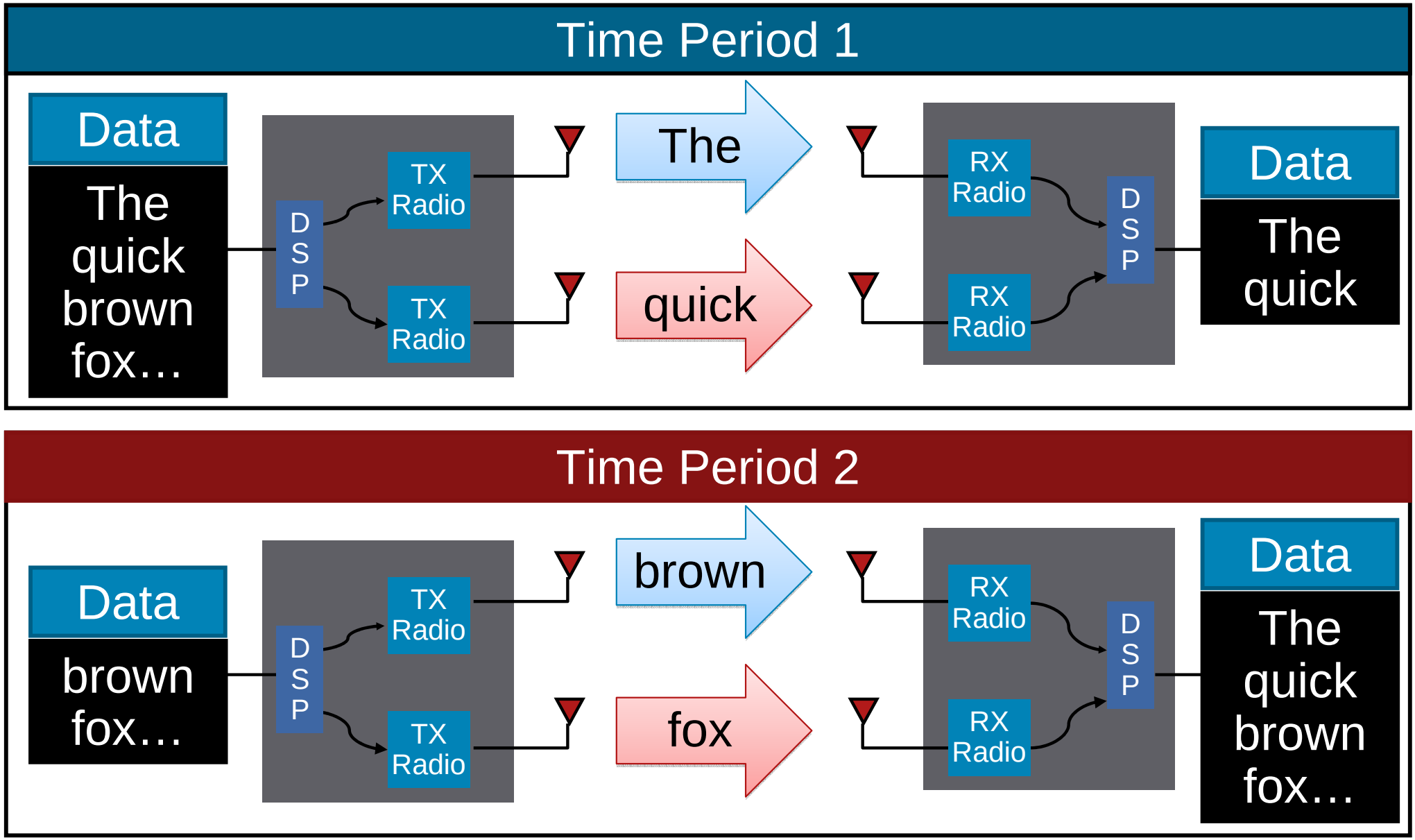



| | | | |
|---|---|---|---|
| Transmitter and Receiver Participate | Concurrent Transmission on Same Channel | Increases Bandwidth | Requires 11n Client |

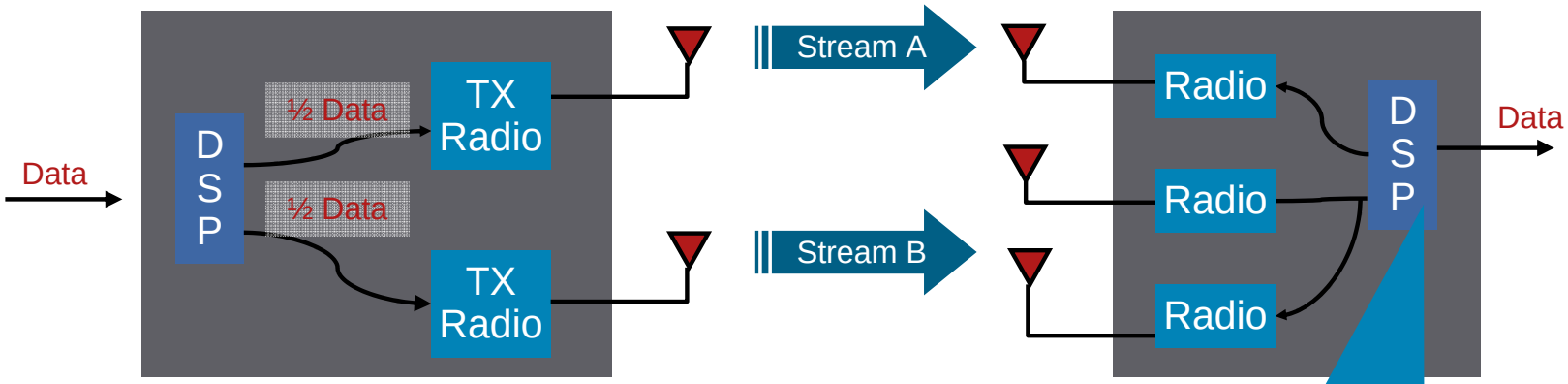
# SISO Data Transmission



# MIMO Spatial Multiplexing Data Transmission



# More Efficient Spectrum Utilization with MIMO Spatial Multiplexing

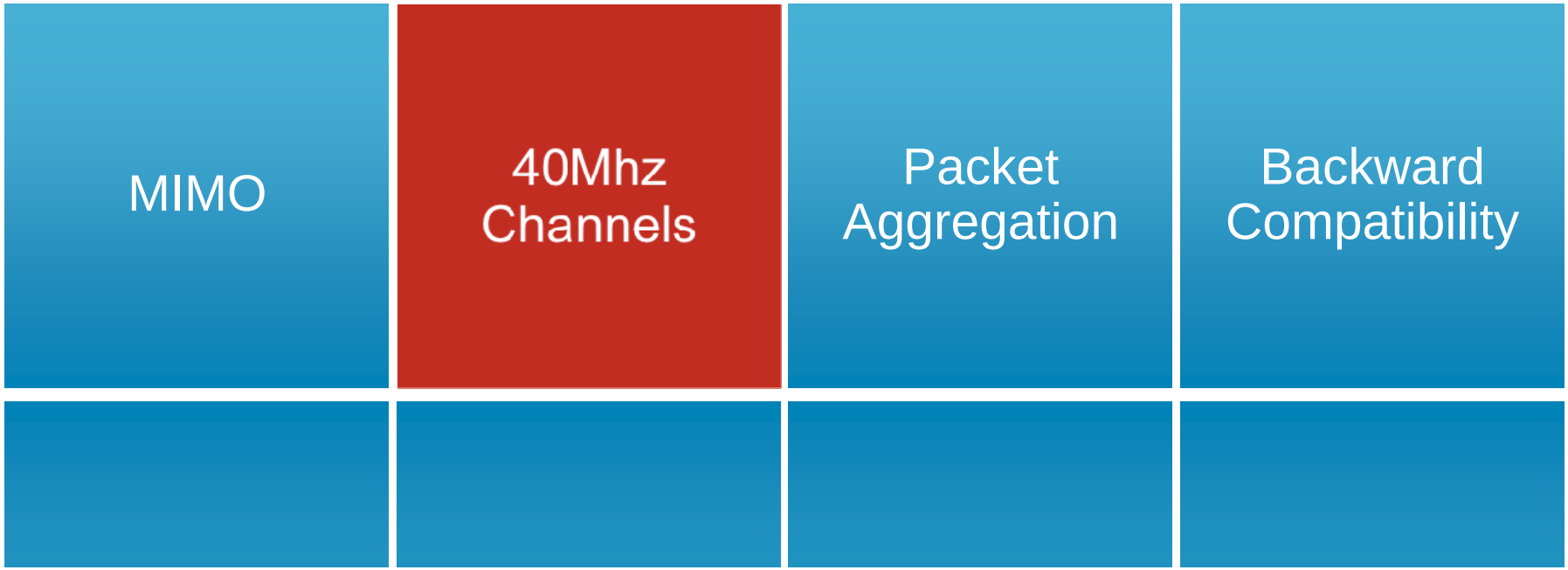



- The data is broken into two streams transmitted by two transmitters at the same frequency

**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 |
|---|---|---|---|

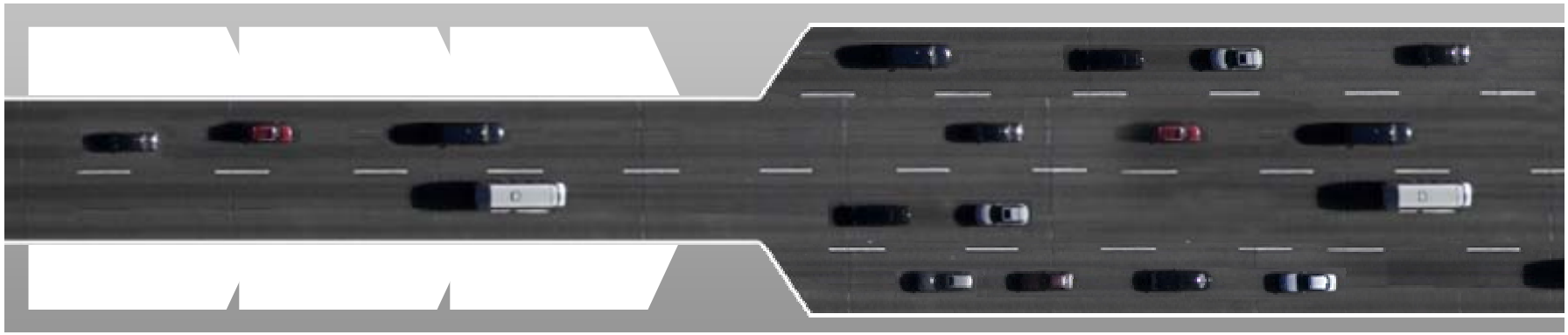


# 40-MHz Channels



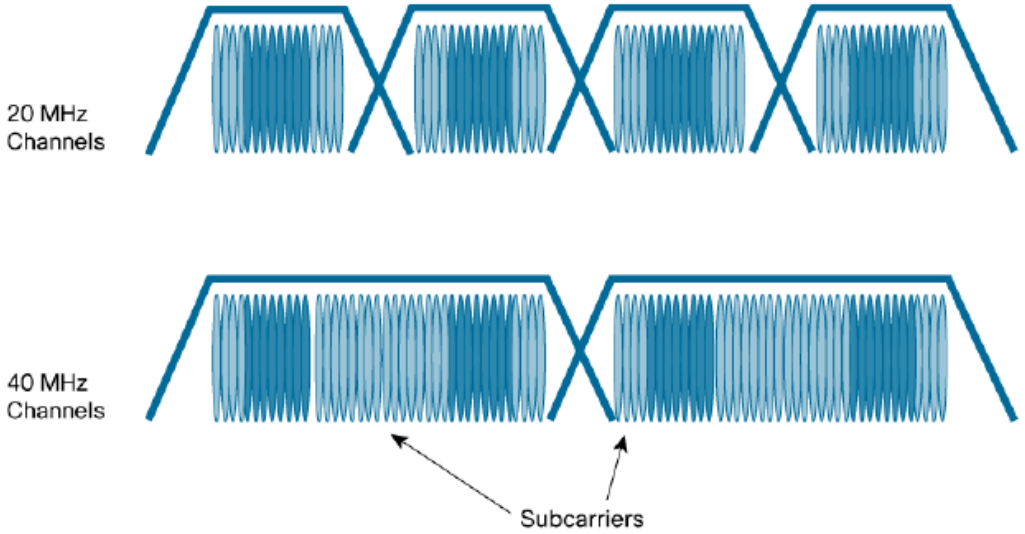
## 40Mhz Channels

Moving from 2 to 4 Lanes



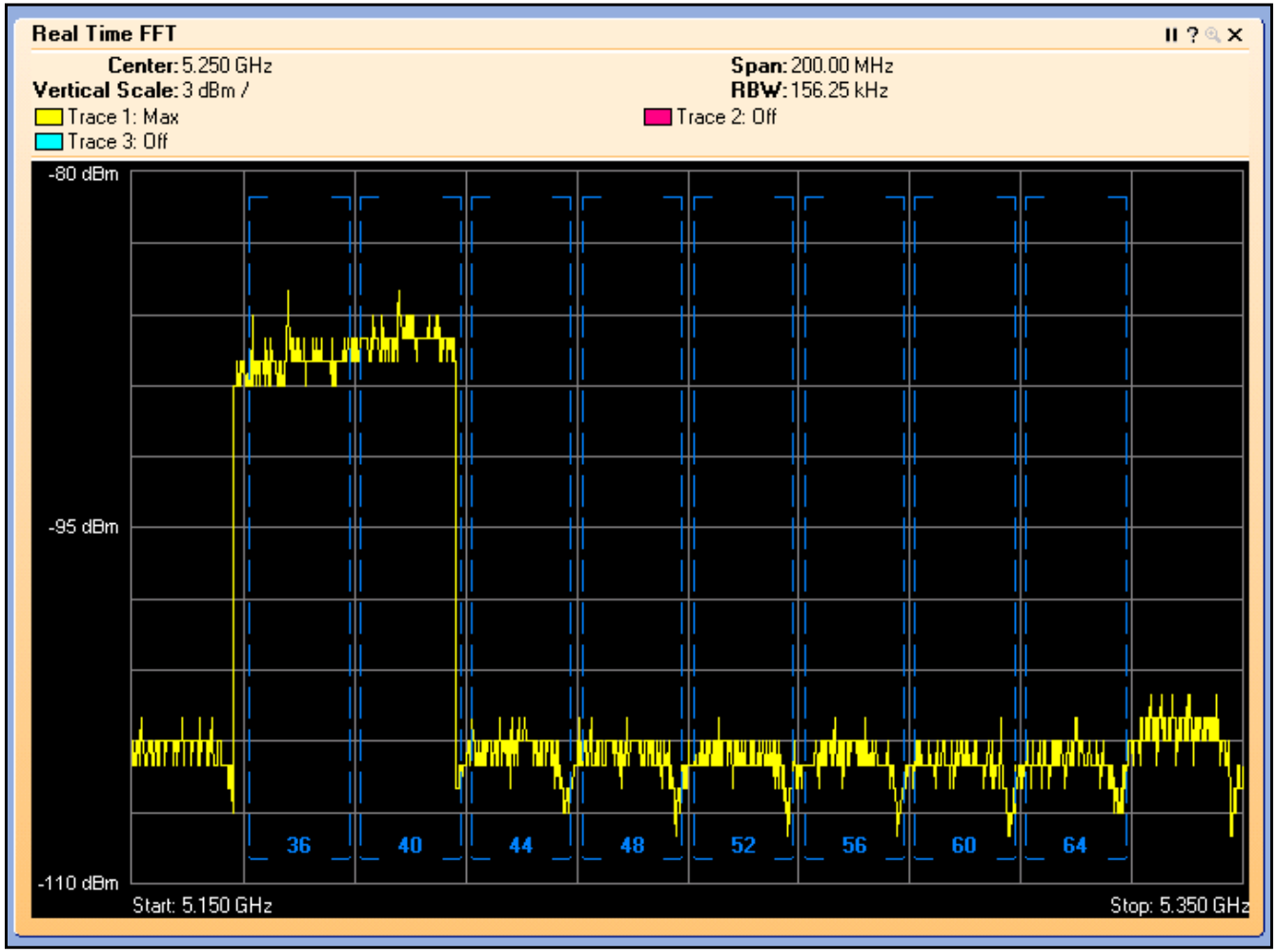
- 40-MHz = 2 aggregated 20-MHz channels—takes advantage of the reserved channel space through bonding to gain more than double the data rate of 2 20-MHz channels

# 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

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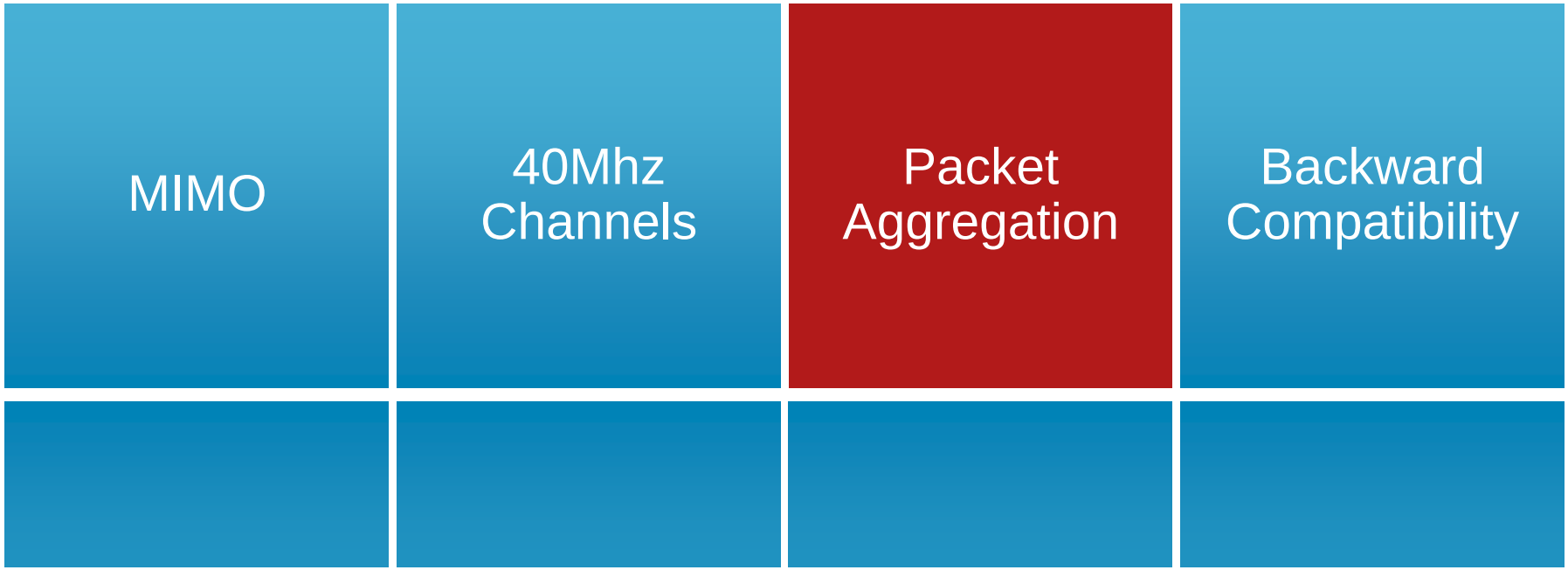
|---|---|---|---|

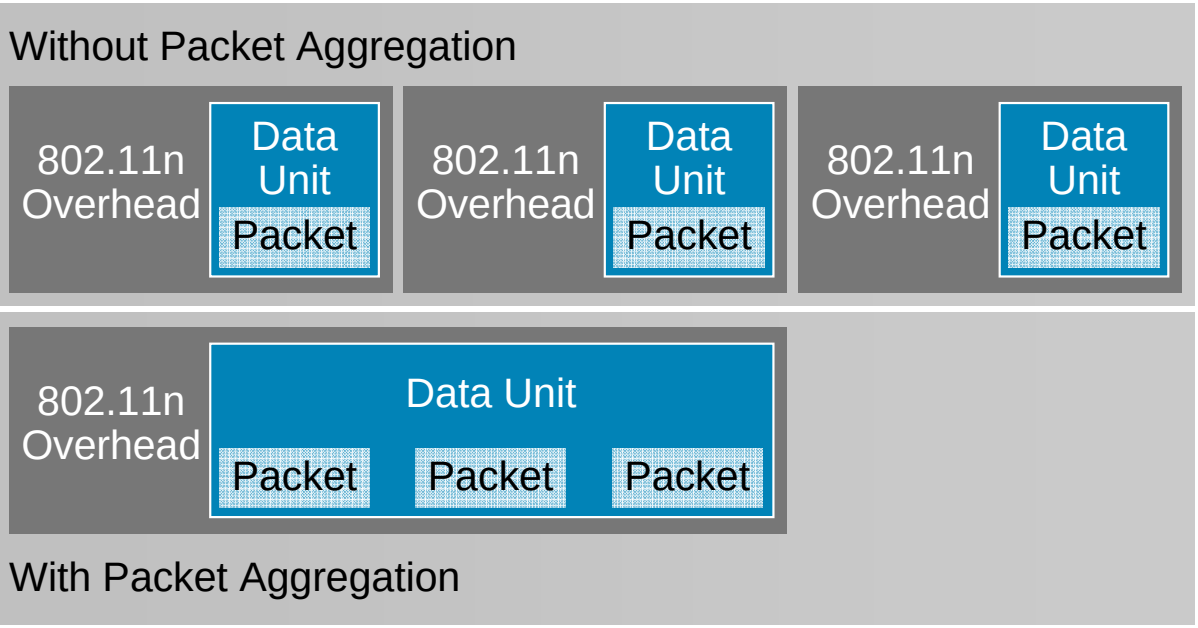


# Aspects of 802.11n

MIMO | 40Mhz Channels | Packet Aggregation | Backward Compatibility

## Packet Aggregation

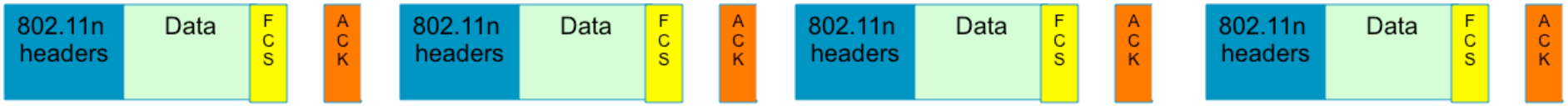
### Carpooling Is More Efficient Than Driving Alone



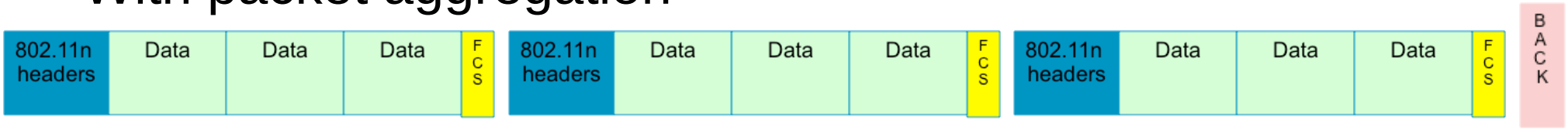
# Packet Aggregation

- 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

Without packet aggregation

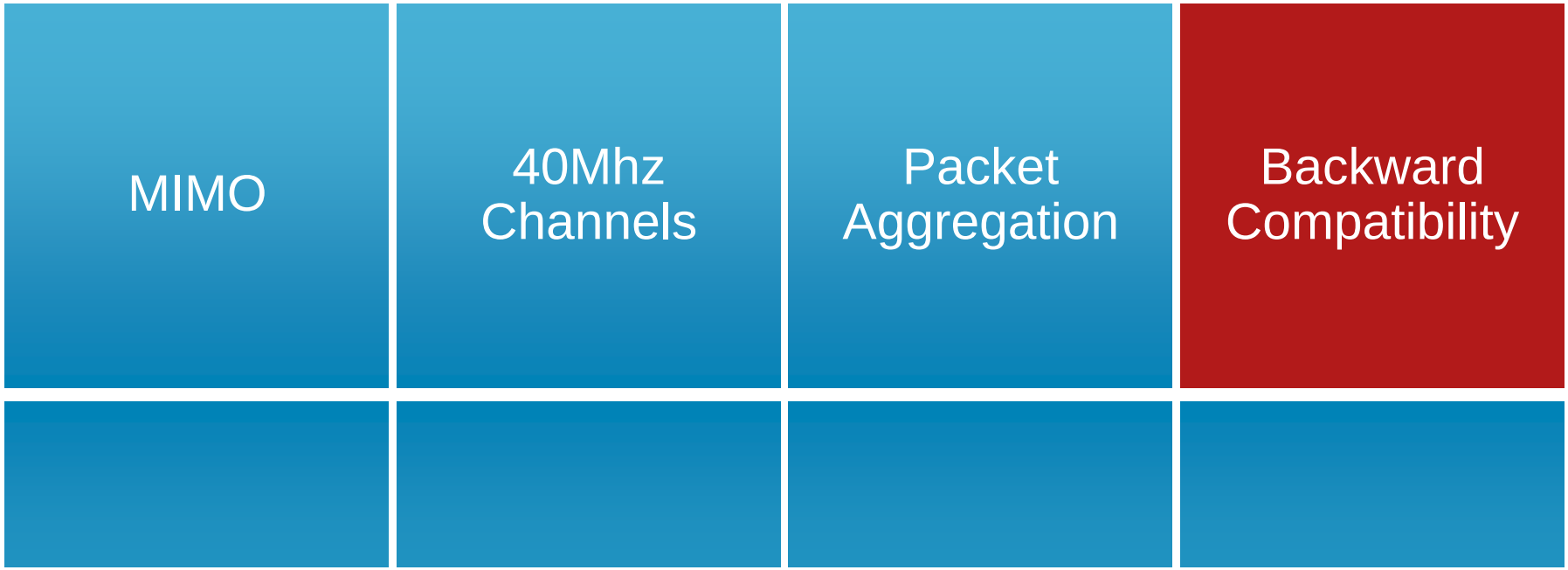



With packet aggregation



# Technical Elements of 802.11n

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



# Aspects of 802.11n

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

## Backward Compatibility

2.4GHz

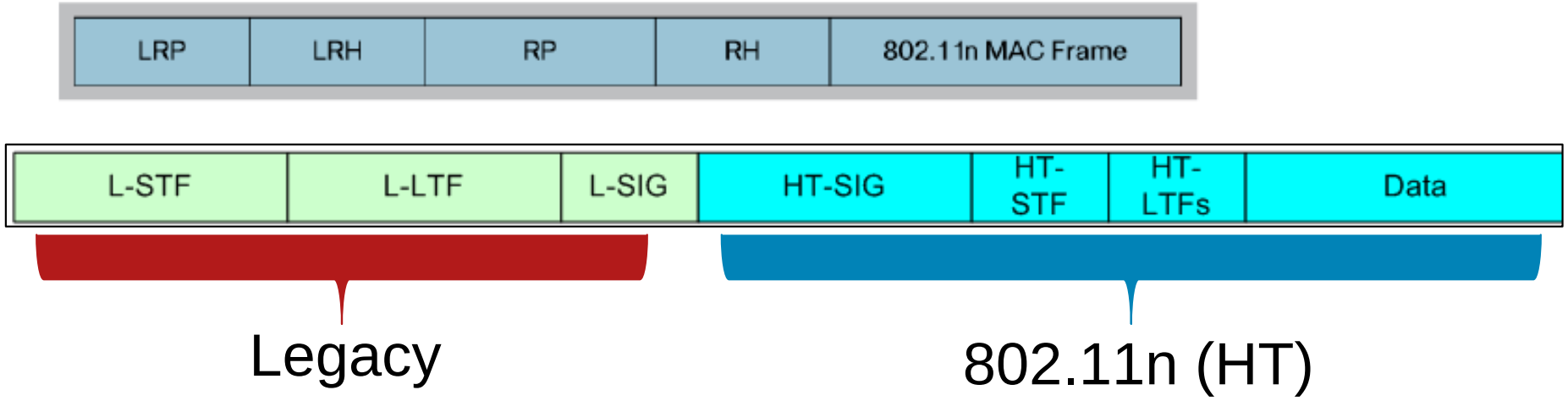
5GHz

11n Operates in Both Frequencies

802.11ABG Clients Interoperate with 11n AND Experience Performance Improvements

# 802.11n HT-mix PHY

LRP = Legacy Radio Preamble
LRH = Legacy Rapid Header
RP = 11n Radio Preamble
RH = 11n Radio Header

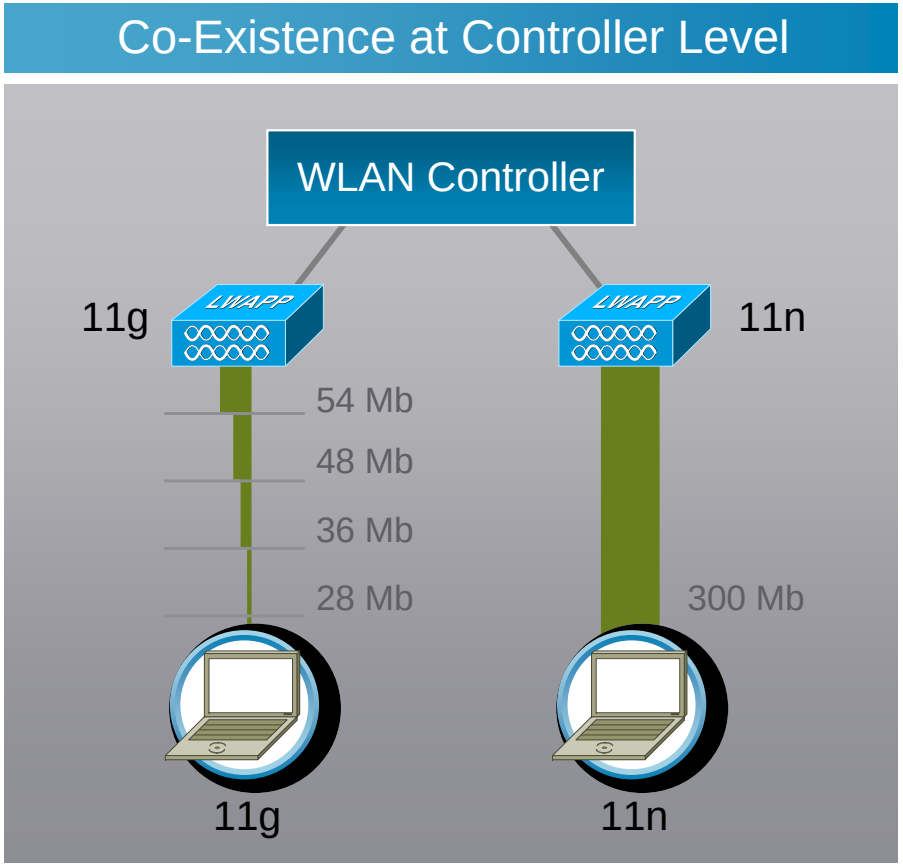


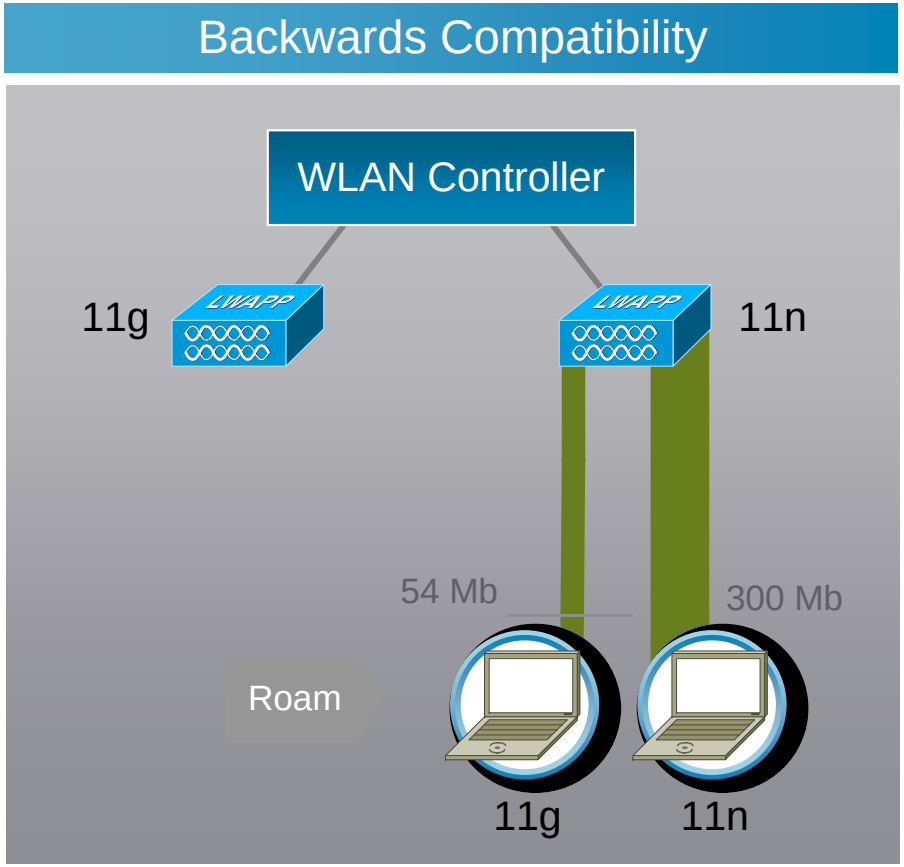

- To provide legacy co-existence all 11n transmissions today use a mixed mode PHY that encapsulates the HT PHY in the Legacy PHY when transmitting at HT rates
- Legacy devices degrade 11n device performance based on duty cycle they use in the spectrum

# Backward Compatibility & Co-Existence

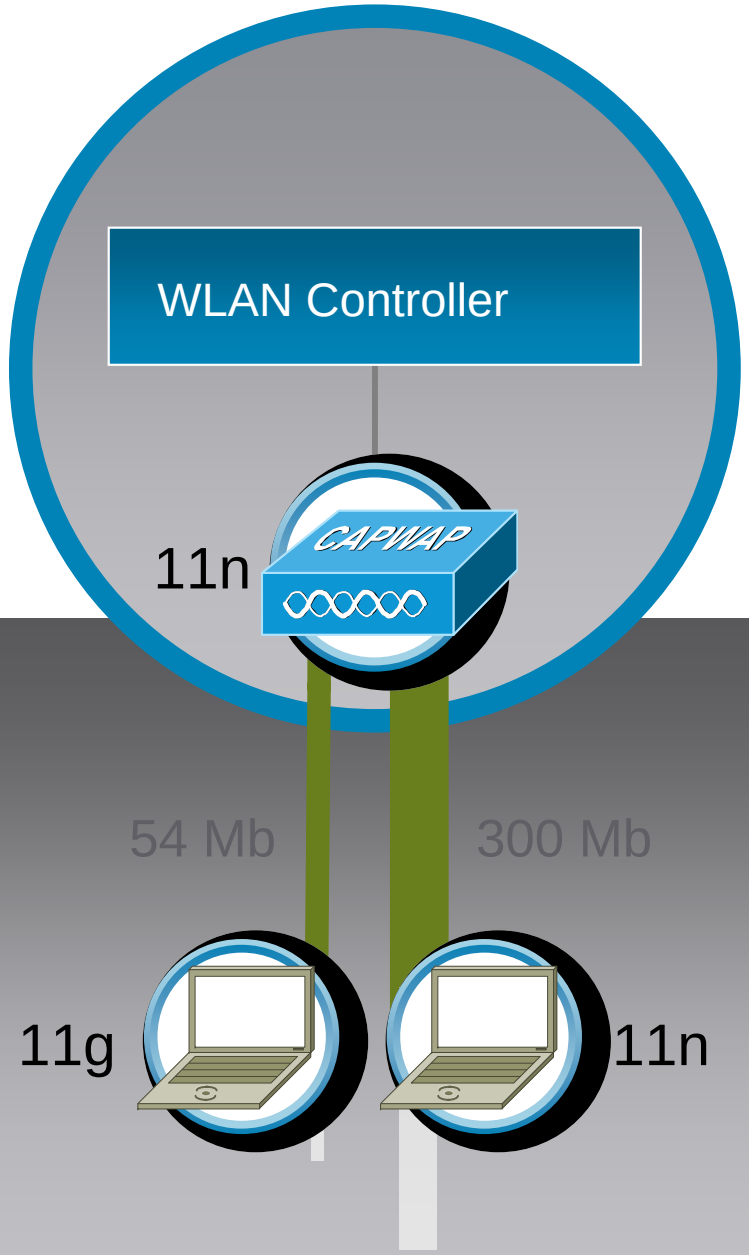
- Co-existence of ABG/N APs
- Benefits of 11n accrue to ABG clients (ClientLink)

  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

| MCS Index | Modul-ation | Spatial Streams | 802.11n Data Rate | | | |
|---|---|---|---|---|---|---|
| | | | 20 MHz | | 40 MHz | |
| | | | L-GI | S-GI | L-GI | S-GI |
| 0 | BPSK | 1 | 6.5 | 7.2 | 13.5 | 15 |
| 1 | QPSK | 1 | 13 | 14.4 | 27 | 30 |
| 2 | QPSK | 1 | 19.5 | 21.7 | 40.5 | 45 |
| 3 | 16-QAM | 1 | 26 | 28.9 | 54 | 60 |
| 4 | 16-QAM | 1 | 39 | 43.3 | 81 | 90 |
| 5 | 64-QAM | 1 | 52 | 57.8 | 108 | 120 |
| 6 | 64-QAM | 1 | 58.5 | 65 | 122 | 135 |
| 7 | 64-QAM | 1 | **65** | **72.2** | **135** | **150** |
| 8 | BPSK | 2 | 13 | 14.4 | 27 | 30 |
| 9 | QPSK | 2 | 26 | 28.9 | 54 | 60 |
| 10 | QPSK | 2 | 39 | 43.3 | 81 | 90 |
| 11 | 16-QAM | 2 | 52 | 57.8 | 108 | 120 |
| 12 | 16-QAM | 2 | 78 | 86.7 | 162 | 180 |
| 13 | 64-QAM | 2 | 104 | 116 | 216 | 240 |
| 14 | 64-QAM | 2 | 117 | 130 | 243 | 270 |
| 15 | 64-QAM | 2 | **130** | **144** | **270** | **300** |

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

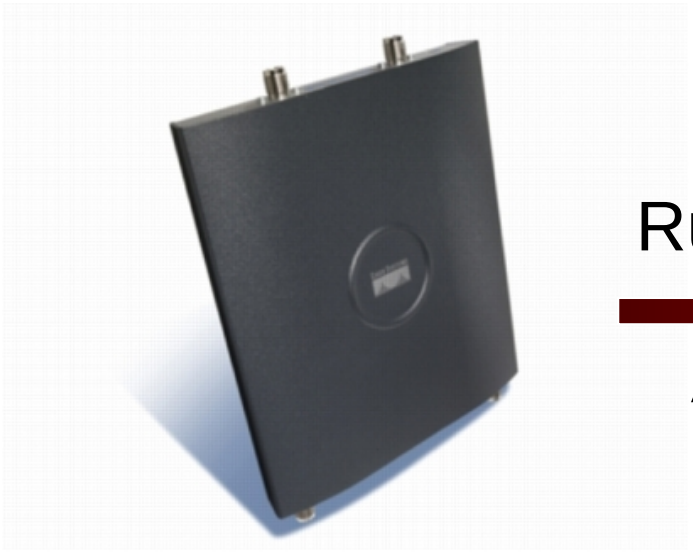
- **Cisco Aironet 1140 Series**
  - Carpeted Indoor Environments
  - Easy to Deploy-Sleek design with integrated antennas
  - 802.11n performance with efficient 802.3af power
  - Blends seamlessly into the environment

- **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

| | 1140 | 1250 |
|---|---|---|
| |  |  |
| Deployment | Indoor | Ruggedized |
| Antennas | Integrated | External (RP-TNC) |
| Wired Uplink | Gigabit | Gigabit |
| Power Options | PoE, AC, Pwr Injector | PoE*, ePoE, AC, Pwr Injector |

* 1250 runs on PoE with reduced performance

# Cisco and Intel:

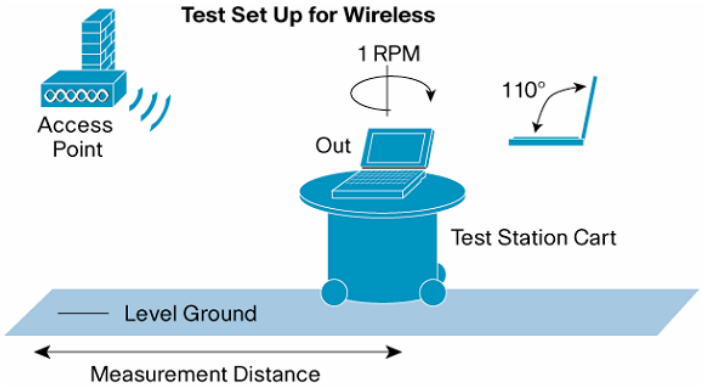
## Collaborative 802.11n Leadership and Testing

# 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

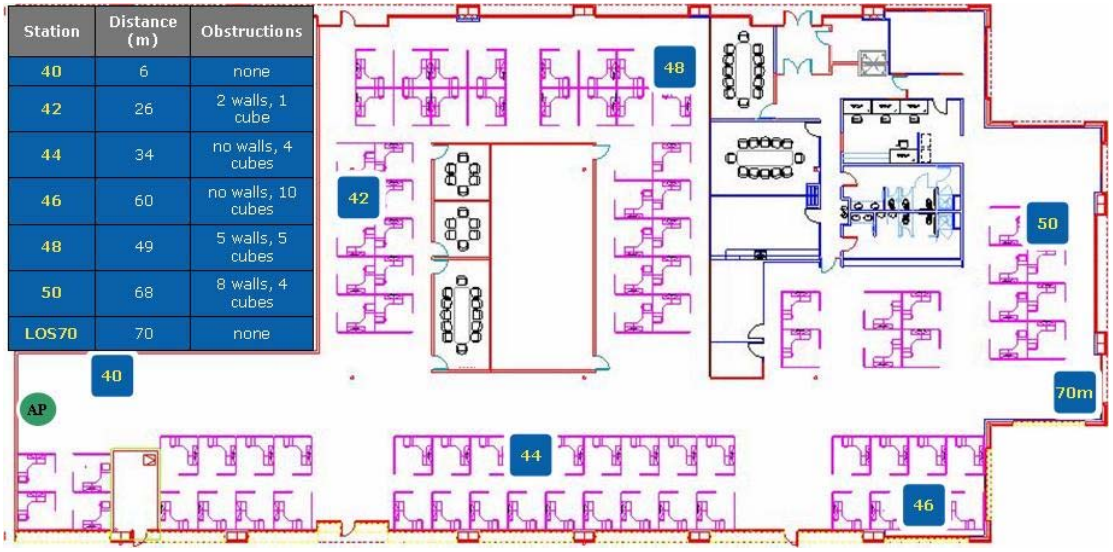
## Customer Impact:

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

## Test Methodology:

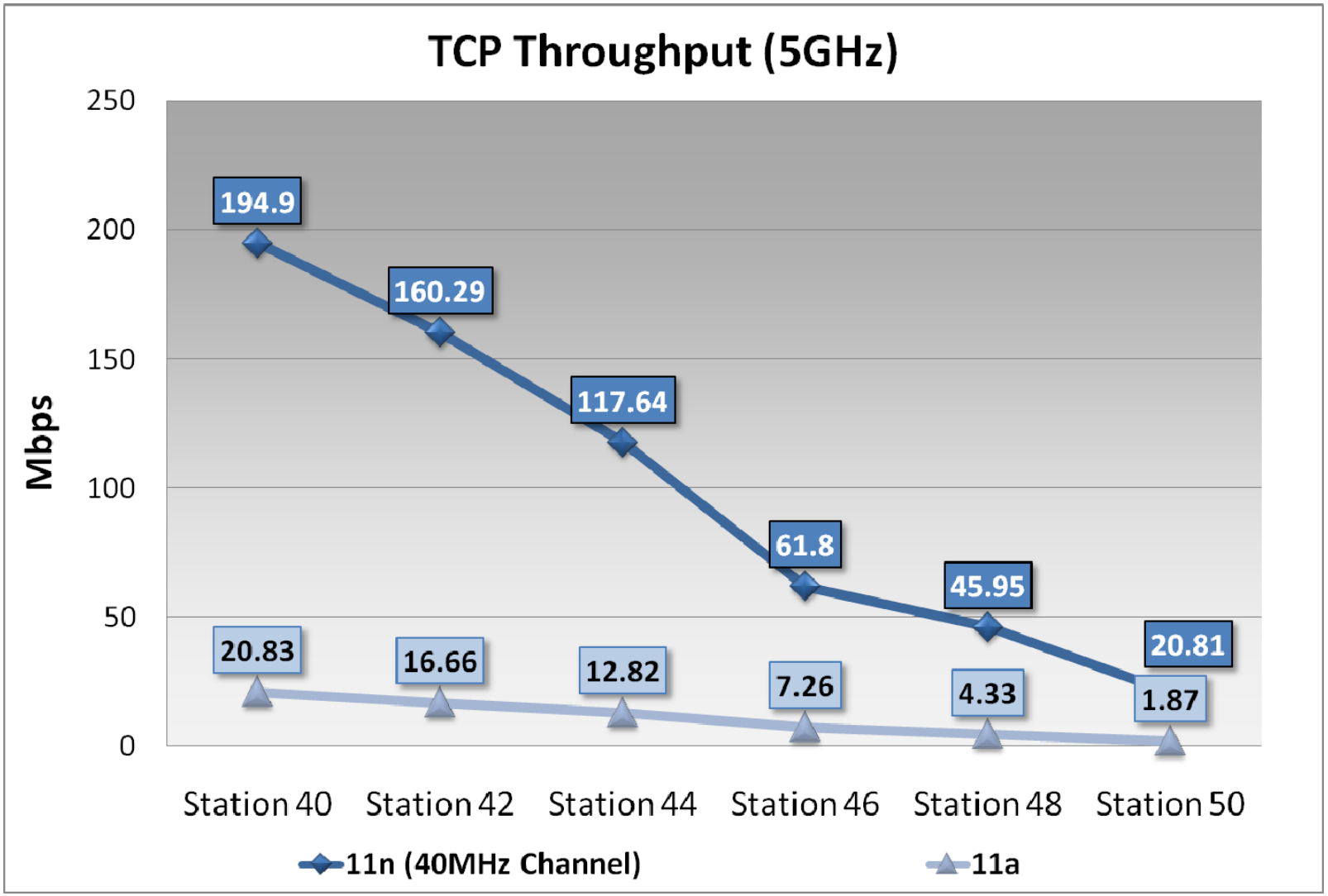
- Application layer testing with TCP traffic
- Multiple locations tested in an office environment

| Station | Distance (m) | Obstructions |
|---|---|---|
| 40 | 6 | none |
| 42 | 26 | 2 walls, 1 cube |
| 44 | 34 | no walls, 4 cubes |
| 46 | 60 | no walls, 10 cubes |
| 48 | 49 | 5 walls, 5 cubes |
| 50 | 68 | 8 walls, 4 cubes |
| LOS70 | 70 | none |




**802.11n Offers Superior Throughput and Coverage**

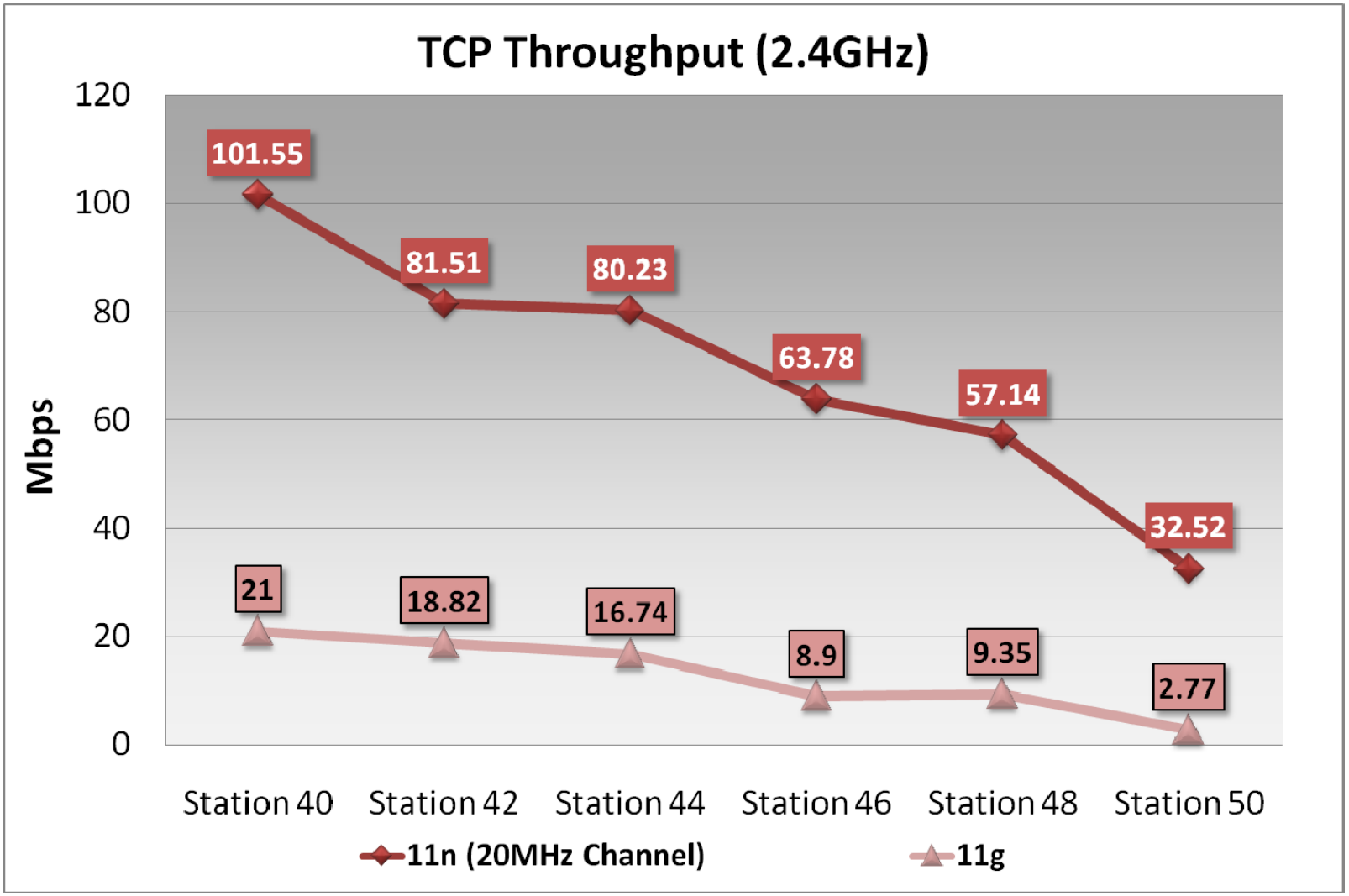
# Non-Line of Sight (NLoS)—Test Results




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



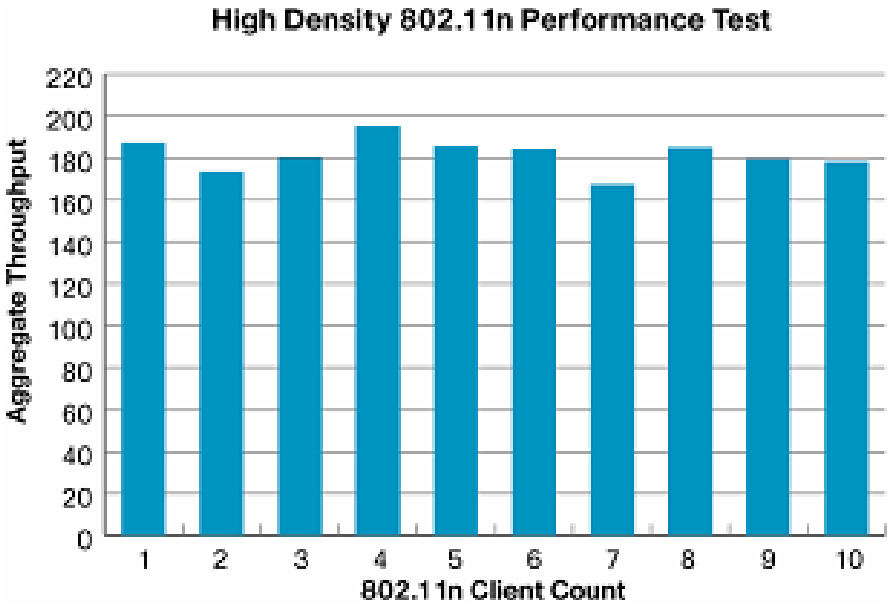

Average of **5X** throughput increase comparing 802.11n vs. 802.11g

**802.11n Offers Superior Throughput and Coverage**

# 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

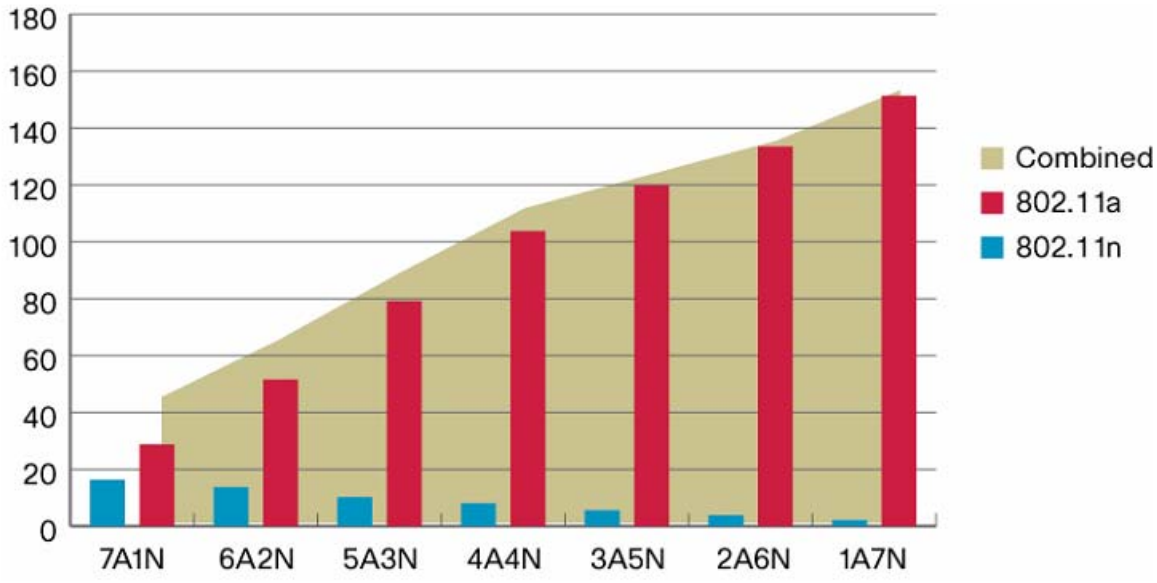
**Constant Aggregate Throughput as Client Density Increases**

# 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.

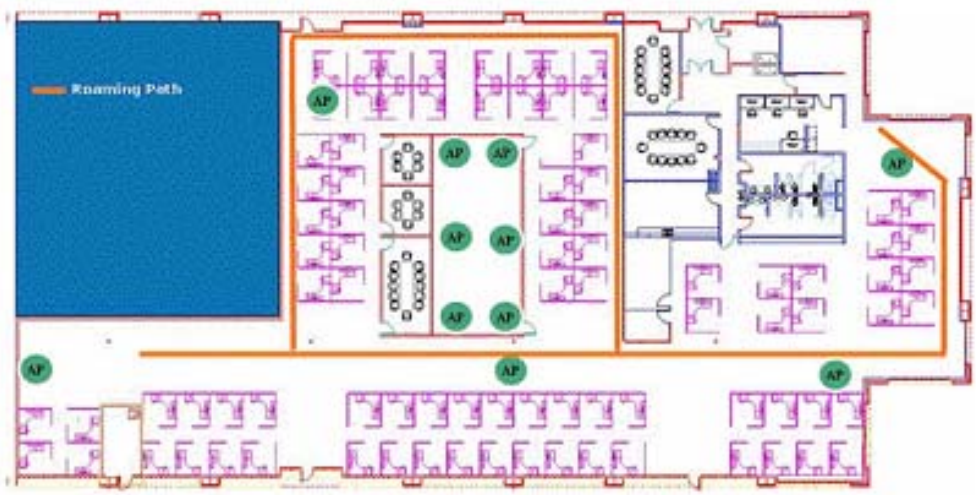



**11n Performance is Not Impacted by Existing 11abg**

# Enterprise Client Roaming

## Customer Challenges

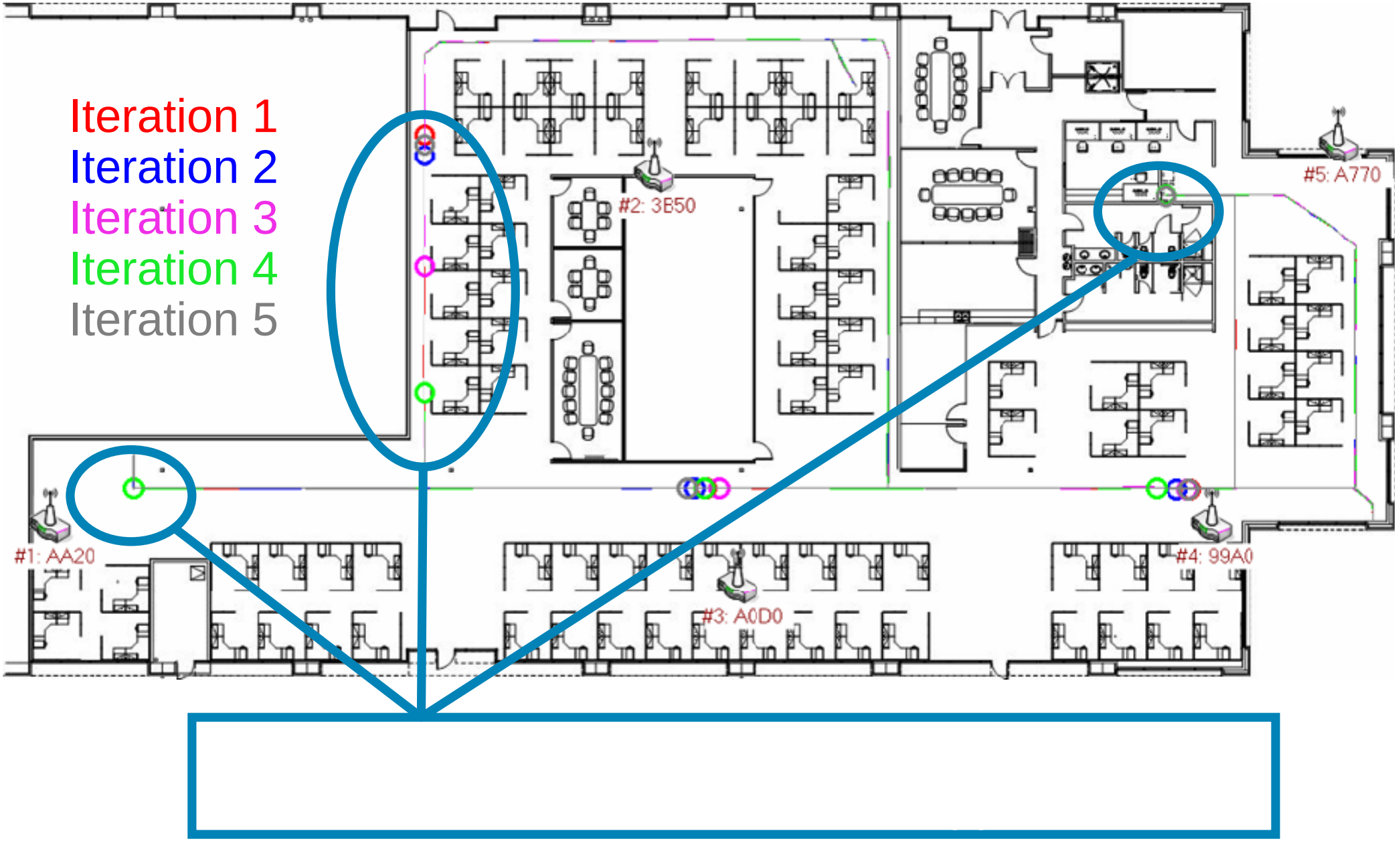
- Applications require consistent, predictable network performance, even when the client is roaming.
- There is no “standard” client roaming algorithm.



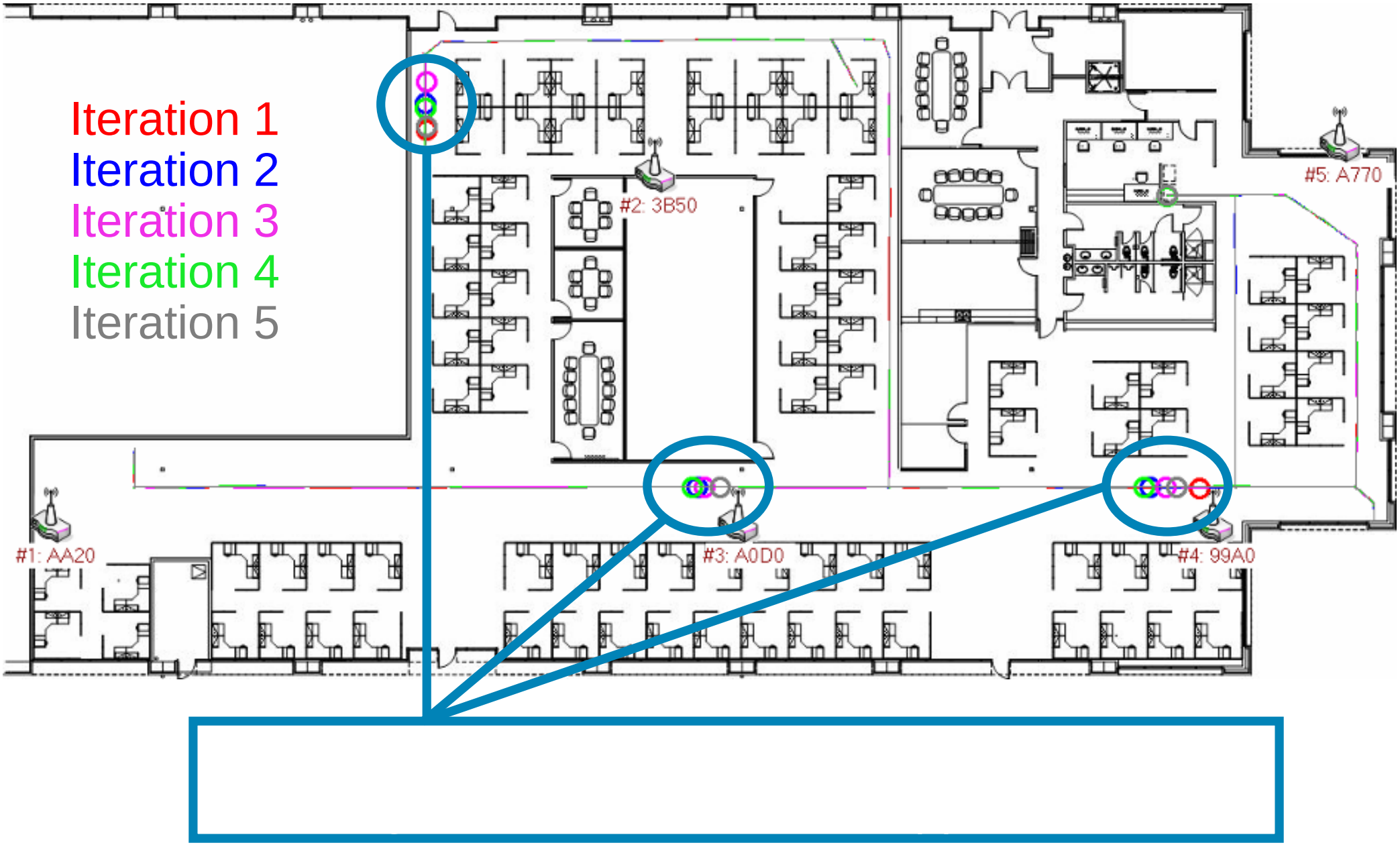

- **Customer Impact:** Cisco and Intel have collaborated to focus on optimizing roaming for enterprise applications.
- Throughput remains consistent across roaming resulting in a stable platform for enterprise applications.
- Customers using Cisco infrastructure with Intel clients will deliver the best throughput and roaming in the industry.

# Enterprise Roaming

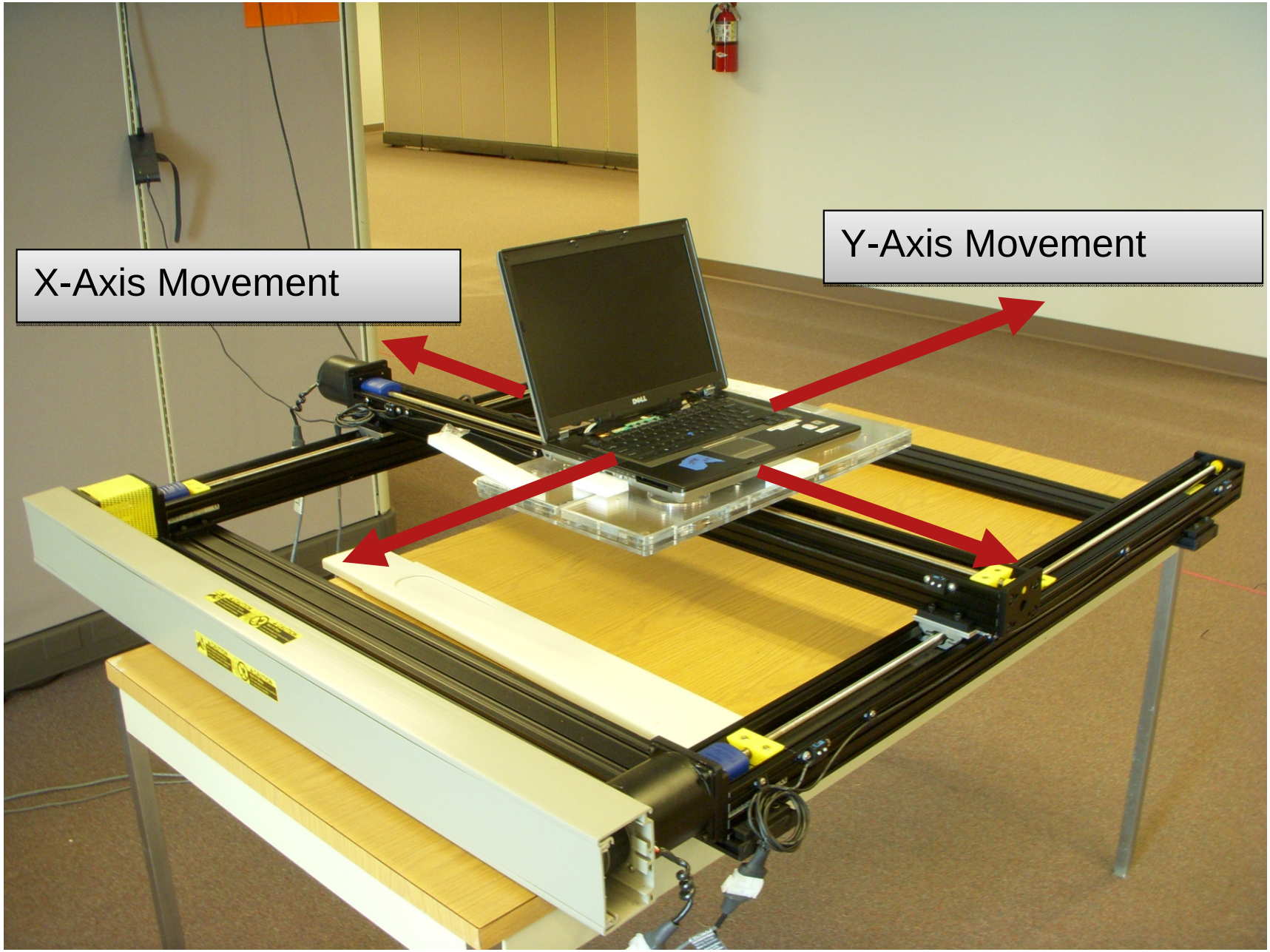
## Non-optimized, Inconsistent Results



# Enterprise Roaming
## Optimized, Consistent Results



# MIMO vs. SISO 'Dead Spot' Assessment



# SISO vs. MIMO Dead Spot Comparison

## 1240 with Intel 3945ABG

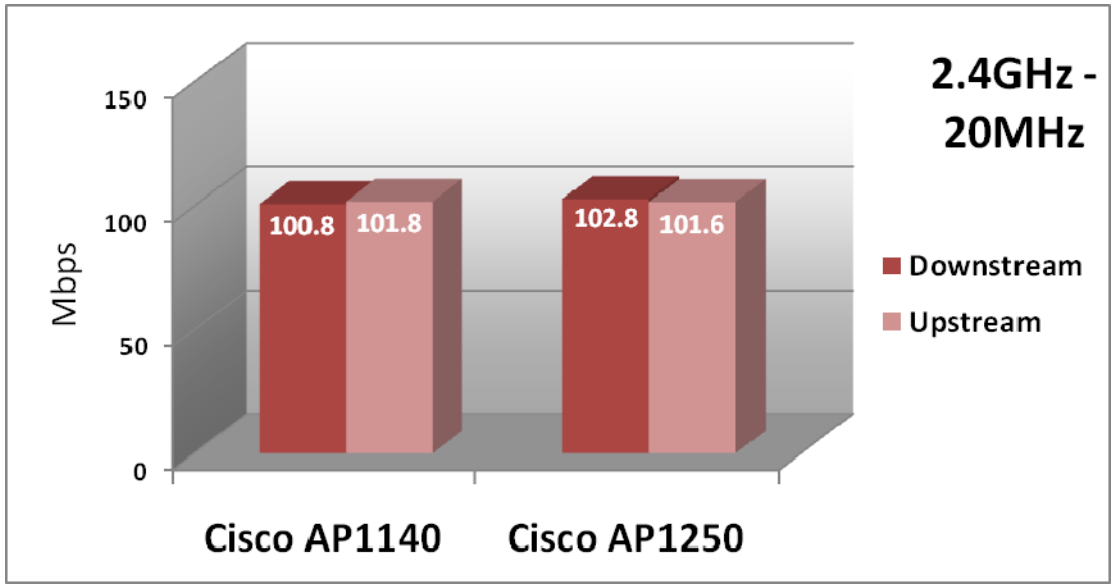
| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 82 | 77 | 39 | 83 | 80 | 83 | 88 | 78 | 71 | 65 | 64 | 80 | 25 | 64 |
| 38 | 52 | 54 | 48 | 71 | 85 | 85 | 52 | 70 | 69 | 89 | 66 | 91 | 68 |
| 67 | 89 | 71 | 81 | 48 | 80 | 69 | 56 | 72 | 45 | 45 | 86 | 91 | 89 |
| 70 | 75 | 70 | 49 | 85 | 55 | 56 | 88 | 62 | 78 | 69 | 75 | 73 | 93 |
| 58 | 67 | 80 | 62 | 70 | 90 | 69 | 65 | 91 | 69 | 55 | 69 | 70 | 61 |
| 57 | 69 | 67 | 71 | 90 | 70 | 21 | 71 | 69 | 68 | 53 | 68 | 92 | 67 |
| 70 | 89 | 74 | 66 | 67 | 69 | 58 | 68 | 88 | 65 | 68 | 87 | 90 | 91 |
| 28 | 90 | 31 | 90 | 57 | 69 | 90 | 75 | 64 | 71 | 89 | 89 | 88 | 83 |
| 44 | 72 | 75 | 82 | 69 | 28 | 41 | 34 | 42 | 41 | 52 | 68 | 67 | 71 |
| 43 | 81 | 39 | 54 | 69 | 92 | 42 | 90 | 67 | 74 | 92 | 61 | 61 | 70 |
| 69 | 90 | 72 | 61 | 41 | 89 | 53 | 88 | 56 | 46 | 69 | 71 | 67 | 69 |
| 74 | 96 | 59 | 87 | 67 | 90 | 68 | 75 | 62 | 38 | 69 | 64 | 59 | 100 |
| 56 | 56 | 85 | 25 | 32 | 50 | 50 | 62 | 87 | 67 | 47 | 67 | 74 | 68 |
| 63 | 68 | 85 | 86 | 82 | 33 | 84 | 88 | 83 | 72 | 59 | 43 | 87 | 49 |

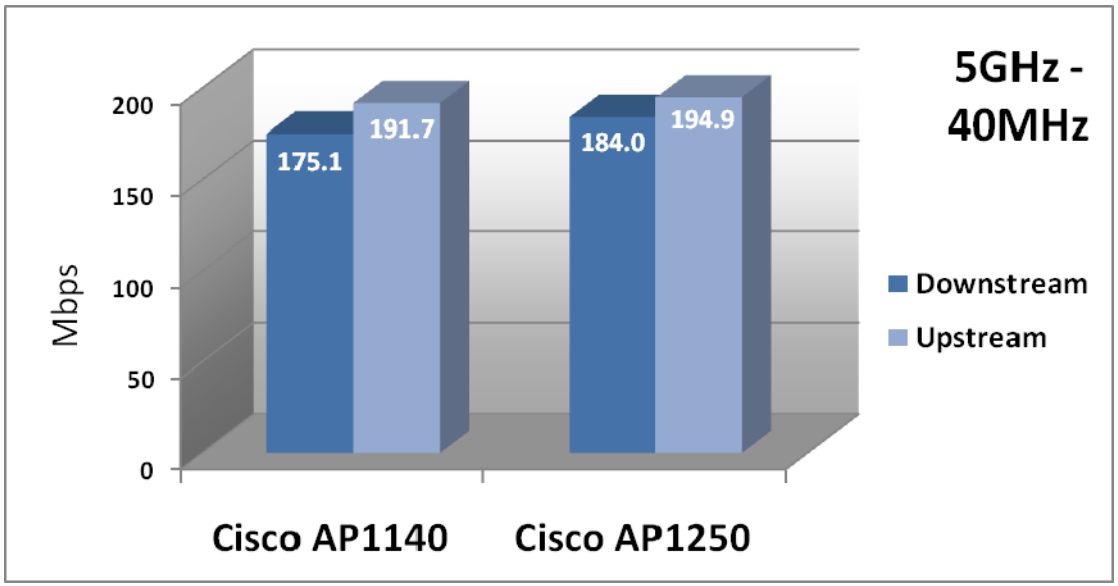
## 1250 with Intel 5300AGN

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92 | 90 | 96 | 84 | 92 | 90 | 90 | 89 | 89 | 84 | 88 | 89 | 91 | 95 |
| 90 | 90 | 92 | 89 | 90 | 94 | 98 | 93 | 91 | 90 | 89 | 86 | 92 | 92 |
| 98 | 91 | 96 | 96 | 98 | 92 | 90 | 92 | 92 | 90 | 90 | 90 | 95 | 92 |
| 91 | 97 | 91 | 97 | 92 | 91 | 89 | 91 | 90 | 95 | 91 | 96 | 90 | 99 |
| 97 | 92 | 91 | 92 | 90 | 94 | 90 | 91 | 89 | 90 | 91 | 90 | 90 | 97 |
| 98 | 92 | 90 | 85 | 94 | 91 | 99 | 88 | 91 | 90 | 97 | 95 | 97 | 93 |
| 92 | 92 | 89 | 89 | 95 | 91 | 86 | 94 | 92 | 91 | 97 | 91 | 92 | 98 |
| 99 | 97 | 90 | 99 | 97 | 93 | 94 | 90 | 93 | 92 | 90 | 93 | 94 | 99 |
| 96 | 96 | 97 | 95 | 95 | 94 | 89 | 90 | 90 | 97 | 96 | 90 | 97 | 98 |
| 96 | 98 | 99 | 91 | 97 | 92 | 95 | 91 | 96 | 98 | 97 | 95 | 93 | 98 |
| 98 | 93 | 91 | 99 | 96 | 89 | 96 | 91 | 91 | 92 | 93 | 97 | 93 | 100 |
| 91 | 96 | 91 | 89 | 92 | 93 | 91 | 91 | 96 | 94 | 92 | 93 | 99 | 97 |
| 96 | 97 | 96 | 98 | 96 | 98 | 96 | 96 | 98 | 96 | 99 | 97 | 98 | 98 |
| 98 | 98 | 98 | 98 | 92 | 98 | 96 | 95 | 90 | 91 | 96 | 98 | 98 | 99 |

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

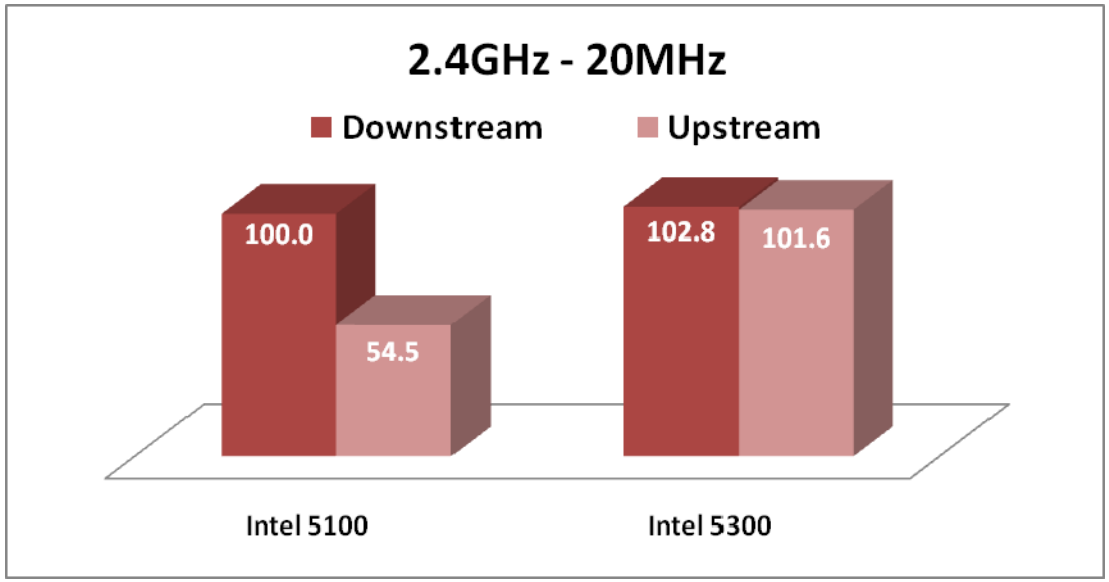
# Cisco 11n Access Point Comparison

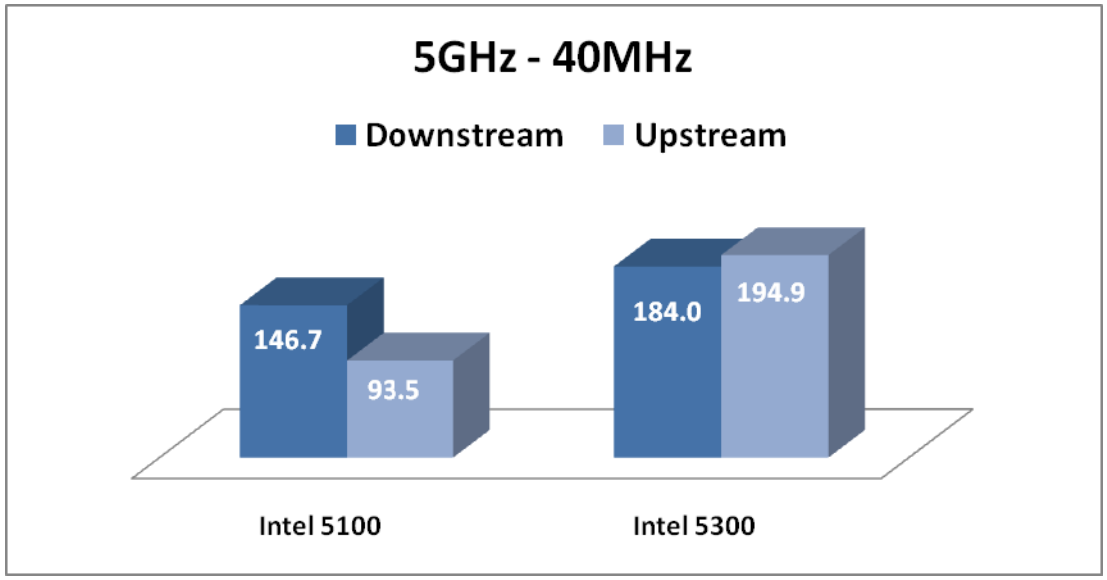



- For 2.4GHz, both APs deliver 100Mbps TCP throughput for each traffic direction.
- For a 5GHz (40MHz) channel, both APs deliver above 175Mbps TCP throughput and a peak of ~195Mbps.

# 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

  http://www.cisco.com/en/US/solutions/collateral/ns340/ns394/ns348/ns767/white_paper_c11-492743.pdf

- Cisco/Intel Collaboration Video

  http://www.youtube.com/watch?v=8WPBMBz9n7A