Evolutions in 802.11 Design

High-Density, Capacity Planning and Survey Methodologies

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#wifitrek

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Introduction

- Solutions Architect for Dimension Data; Consulting Systems Engineer for Wireless Practice
- 6 years at Cisco in Wireless Networking Business Unit on the Wireless Escalation team
  - Duke University, Bank of America, Target, Apple, NYSE, and Stanford University

- Authored the Voice over Wireless LAN Troubleshooting located on CCO
- Technical Editor for the Cisco Press book entitled, "Designing and Deploying 802.11n Wireless Networks - First Edition" along with Tom Carpenter and authored by Jim Geier.
- B.S. in Computer Engineering and M.S. Degree in Information Assurance

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Agenda

- High Density Use Cases
- 802.11n vs. 802.11ac
- SU-MIMO vs. MU-MIMO
- MU-MIMO, TxBF and Antenna Selection
- Spectrum Use / Reuse
- Capacity Planning
- Customer Scenario
  - Calculating Total System Throughput (TST)
  - Per Device Throughput (PDT)
  - General Capacity Planning
- Wireless LAN Best Practices for High Density

High-Density Use Cases

- As the industry evolves, users always seem to find a way to exhaust the available spectrum.
- High-Density deployments have become very prevalent for:
  - University Lecture Halls and Classrooms
  - Auditoriums
  - Conference Centers
  - Stadiums
  - Malls and Retail Venues
  - Theme Parks

802.11n vs. 802.11ac

Key Differences

	802.11n	802.11ac Enhancements
Channel Widths	20 and 40 MHz channel-width	Increased channel-widths to 80 &160 MHz
Frequency Bands	2.4 GHz and 5 GHz frequency bands	Available only in 5 GHz.
Modulation	BPSK, QPSK, 16, 64 QAM	Adds 256-QAM (Tighter Modulation) Adds two more bits on each carrier increasing it from 6 to 8, increasing capacity for 11ac by 33%
Beamforming	Many types of (optional, proprietary) implicit beamforming	Supports ONLY (NDP) null data packet explicit beamforming Facilitates about a 3 dB performance gain.
Spatial Streams (PHY Data Rate)	Up to 4x4:4 spatial streams (600 Mbps at 40 MHz)	Up to 4x4:4 SS (Wave 1) spatial streams (1.3 Gbps at 80 MHz) Supports client devices up to 2SS Up to 8x8:4SS (Wave 2) spatial str4eams (3.467 Gbps at 160 MHz) Supports client devices up to 4SS
Frame Aggregation	Selective use of A-MPDU, A-MSDU, and A-MPDU of A-MSDU	Requires every 802.11ac transmission to be sent as an A-MPDU aggregate. Utilizes larger A-MSDU values thus reducing TxOP's
MIMO Mode	SU-MIMO – Transmits to a single client.	MU-MIMO (Wave 2) – Transmits downlink to Multiple Users simultaneously.

Source: Wikipedia

802.11ac - MCS Rates

Theoretical throughput for a single spatial stream (in Mbit/s)										
MCS index	Modulation type	Coding rate	20 MHz channels		40 MHz channels		80 MHz channels		160 MHz channels	
			800 ns GI	400 ns GI	800 ns GI	400 ns GI	800 ns GI	400 ns GI	800 ns GI	400 ns GI
0	BPSK	1/2	6.5	7.2	13.5	15	29.3	32.5	58.5	65
1	QPSK	1/2	13	14.4	27	30	58.5	65	117	130
2	QPSK	3/4	19.5	21.7	40.5	45	87.8	97.5	175.5	195
3	16-QAM	1/2	26	28.9	54	60	117	130	234	260
4	16-QAM	3/4	39	43.3	81	90	175.5	195	351	390
5	64-QAM	2/3	52	57.8	108	120	234	260	468	520
6	64-QAM	3/4	58.5	65	121.5	135	263.3	292.5	526.5	585
7	64-QAM	5/6	65	72.2	135	150	292.5	325	585	650
8	256-QAM	3/4	78	86.7	162	180	351	390	702	780
9	256-QAM	5/6	N/A	N/A	**180**	**200**	**390**	**433.3**	**780**	**866.7**

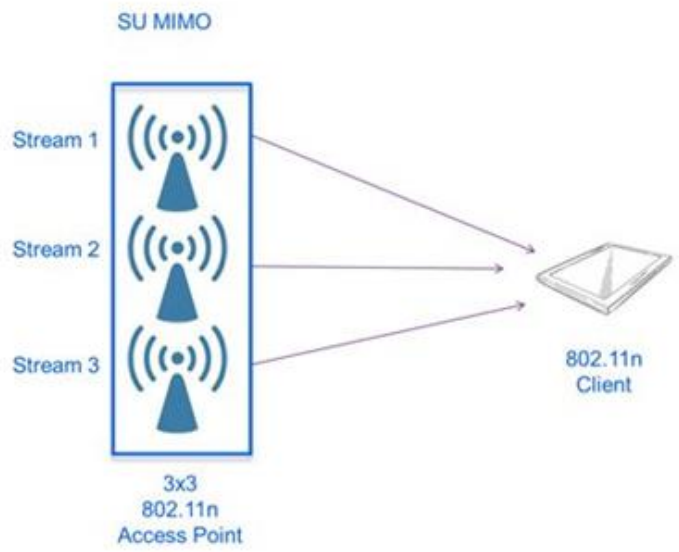
Very Specific Design Criteria

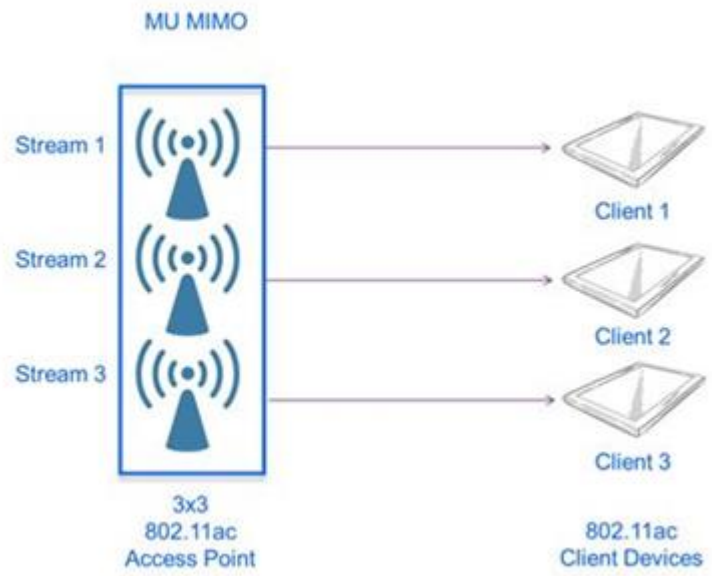
MIMO and Antenna Selection

Source: Cisco

SU-MIMO (11n) vs. MU-MIMO (11ac)

- SU-MIMO (802.11n) limits transmissions to a single station.
- MU MIMO (802.11ac – Wave 2) transmits “x” number of streams to multiple clients



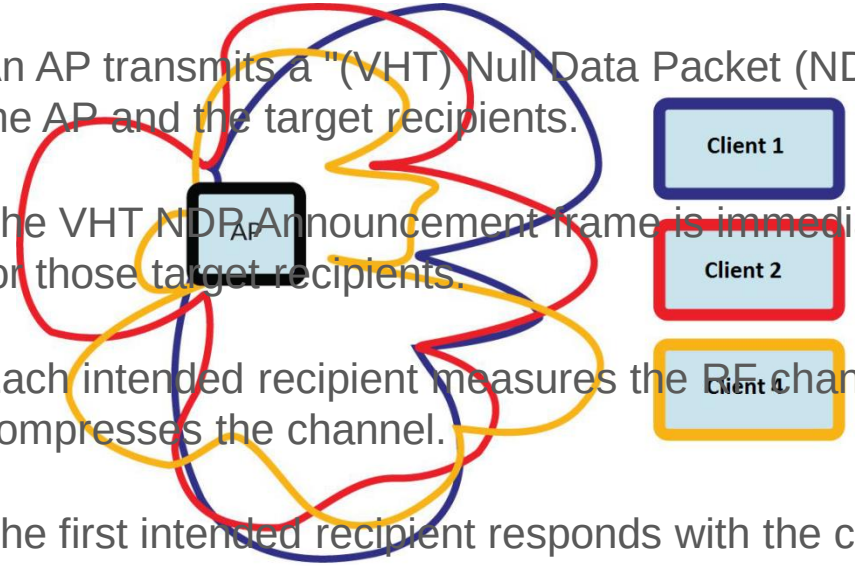


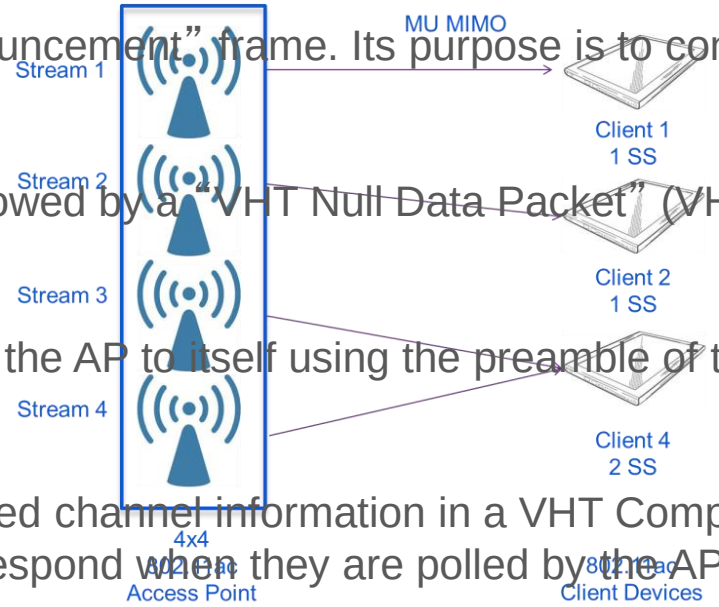
Source: Cisco

MU-MIMO – Multi-User MIMO

NDP (explicit) TxBF Beamforming

Here is how Explicit Beam forming helps





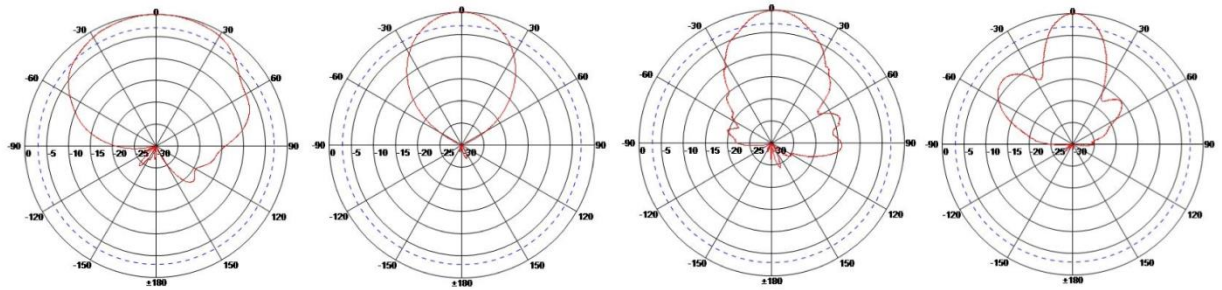
1. An AP transmits a "(VHT) Null Data Packet (NDP) Announcement" frame. Its purpose is to contain the address of the AP and the target recipients.
2. The VHT NDP Announcement frame is immediately followed by a "VHT Null Data Packet" (VHT NDP) intended for those target recipients.
3. Each intended recipient measures the RF channel from the AP to itself using the preamble of the VHT NDP and compresses the channel.
4. The first intended recipient responds with the compressed channel information in a VHT Compressed Beamforming frame immediately, and other recipients respond when they are polled by the AP.
5. The AP receives the compressed beamforming frame from the first beamformee, then after a SIFS the AP sends the beamforming report poll frame to the next client, who responds after SIFS and so on.

Source: Terrawave

Patch, Panel or Sector Antennas

Antenna Selection

- **802.11n/ac 2.4/5 GHz 10/11 dBi Panel Antenna with N-Style Jack Connector**
  - Aerohive AP 170
  - Aruba AP 134
  - Aruba AP 224
  - Cisco AP 2602e
  - Cisco AP 3602e
  - Cisco AP 3702e
  - Meraki AP MR66
  - Motorola AP 7131
  - Motorola AP 8132



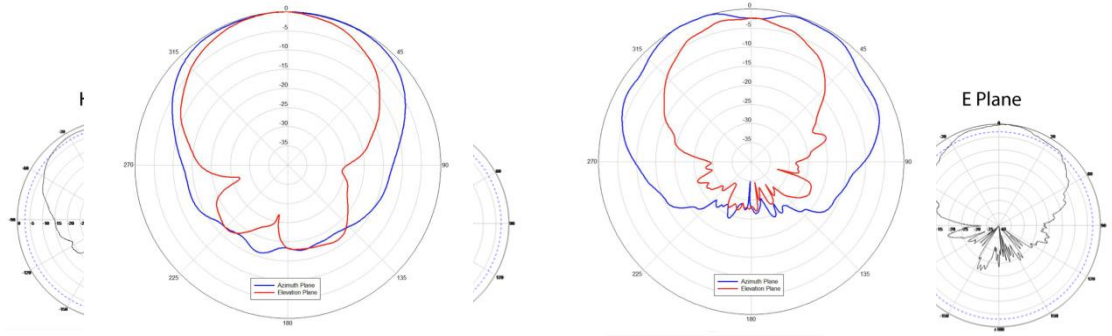
2.4 GHz: H-Plane | 2.4 GHz: E-Plane | 5 GHz: H-Plane | 5 GHz: E-Plane

Source: Terrawave and Cisco Live

Indoor Patch Antennas

Cisco Live

- 802.11n/ac 2.4/5 GHz 6/8 dBi Quad Patch Antenna with RPTNC Connector
  - Cisco Aironet 2.4 GHz/5 GHz 6 dBi MIMO Patch Antenna (AIR-ANT2560P4M-R)
    - Cisco AP 2702e
    - Cisco AP 3702e



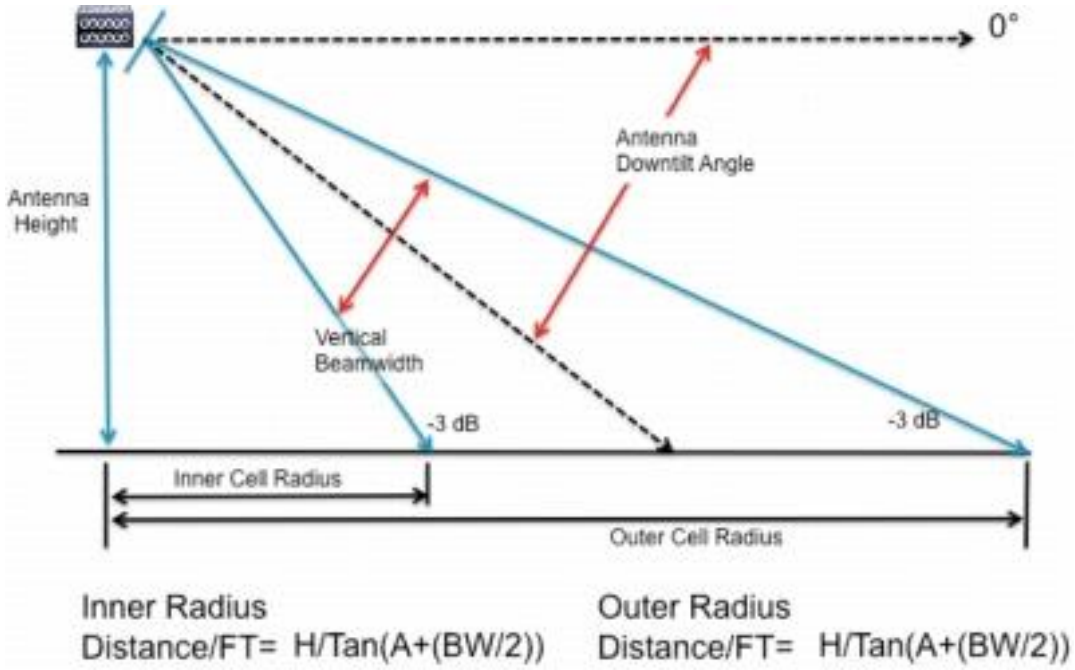
Source: Cisco

Directional Antennas and Downtilt

Inner and Outer Cell Radius

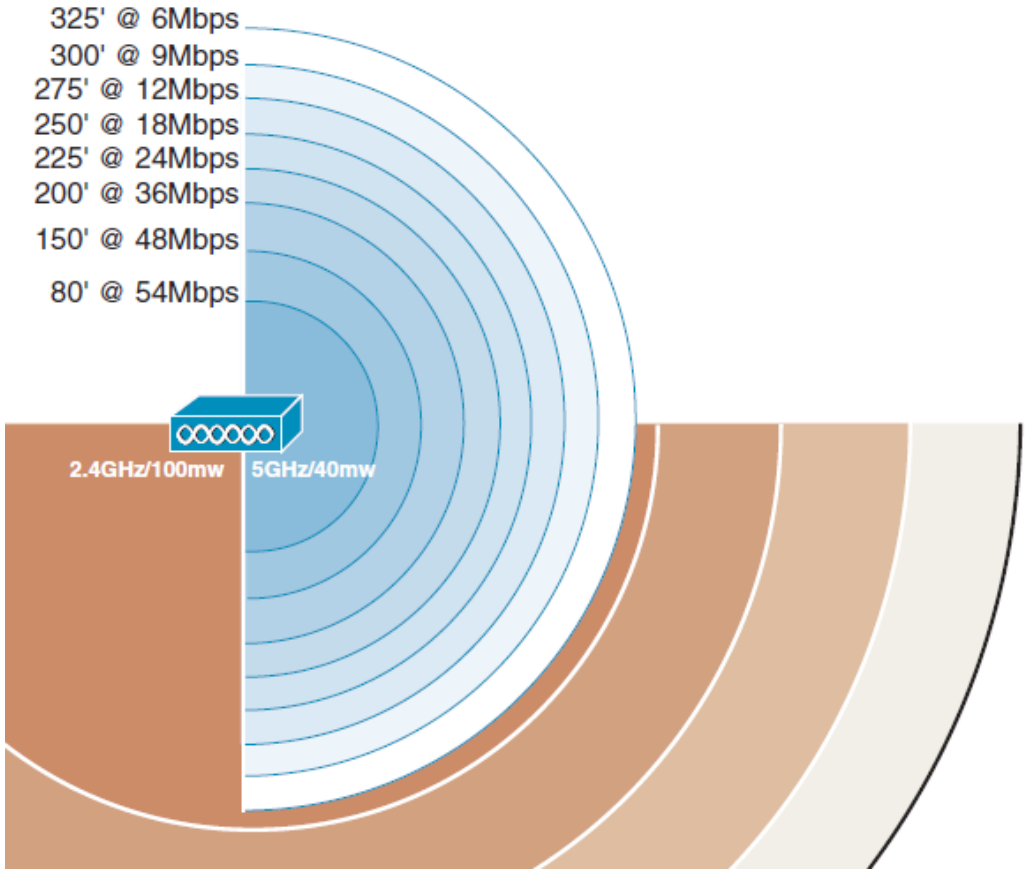
The values for the formula above are:

- H = height of the antenna
- A = downtilt angle
- BW = the 3 dB horizontal beamwidth of the antenna



Data Rate vs. Coverage

Source: Cisco

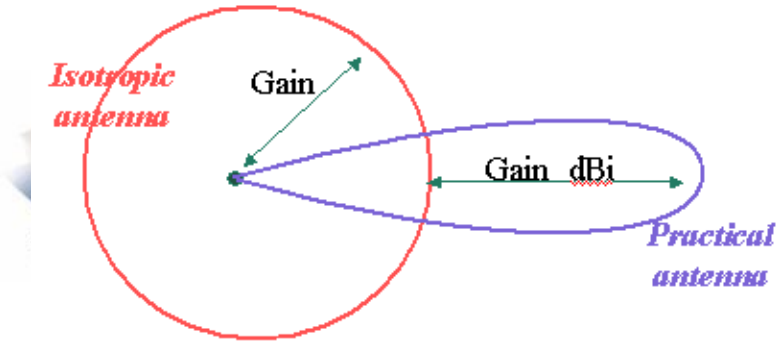


Understanding EIRP

While coverage is important, BYOD devices can only transmit at about 13dB

6 dB rule for antennas: Every 6 dB doubles RF range

For Example: 40 mW (17 dBm) on 5 GHz+ 6 dBi Antenna = Tx Power of 126 mW



Source: Wikipedia

MU-MIMO – Theoretical Examples

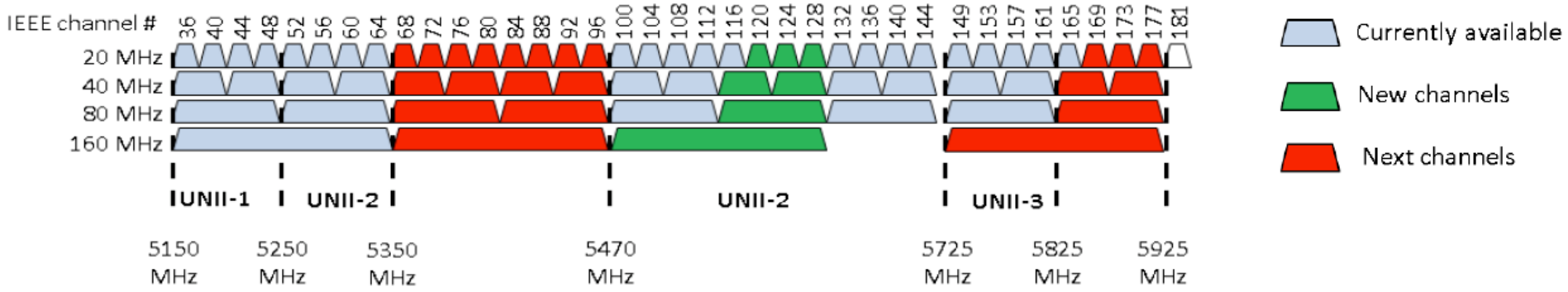
AP to Client Scenario	Device Type	PHY Rate	Aggregate Capacity
(1) antenna AP / (1) antenna STA, 80 MHz	Handheld	433 Mbit/s	433 Mbit/s
(2) antenna AP / (2) antenna STA, 80 MHz	Tablet, Laptop	867 Mbit/s	867 Mbit/s
(1) antenna AP / (1) antenna STA, 160 MHz	Handheld	867 Mbit/s	867 Mbit/s
(2) antenna AP / (2) antenna STA, 160 MHz	Tablet, Laptop	1.69 Gbit/s	1.69 Gbit/s
(4) antenna AP (4) singe antenna STAs, 160 MHz (MU-MIMO)	Handheld	867 Mbit/s to each STA	3.39 Gbit/s
Hypothetical Scenarios (8x8:8SS) (8) antenna AP, 160 MHz (MU-MIMO) ▪ (1) four-antenna STA (4SS) ▪ (1) two-antenna STA (2SS) ▪ (2) one-antenna STA (2SS)	Digital TV, Set-top Box, Tablet, Laptop, PC, Handheld	▪ 3.39 Gbit/s to four-antenna STA ▪ 1.69 Gbit/s to two-antenna STA ▪ 867 Mbit/s to each one-antenna STA	6.77 Gbit/s
(8) antenna AP, (4) 2-antenna STAs, 160 MHz (MU-MIMO)	Digital TV, tablet, laptop, PC	1.69 Gbit/s to each STA	6.77 Gbit/s

Spectrum Use/Reuse

Source: Cisco

Wireless Spectrum Management

Reforming 5 GHz to optimize for 11ac



More non-overlapping channels enabling better 802.11ac experience

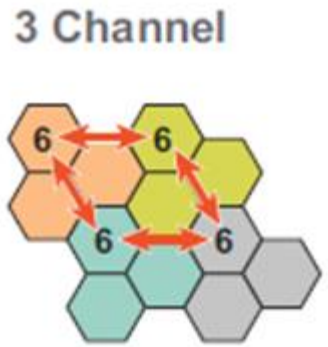
- Reclaim channels between 120 through 128.
- Increase capacity by allowing channels 68-96, 120-128, 169-177
- Use DFS channels for High Density
- All major OS's (Mac OS, Windows, Windows Phone, IOS and Android) all support DFS channels.

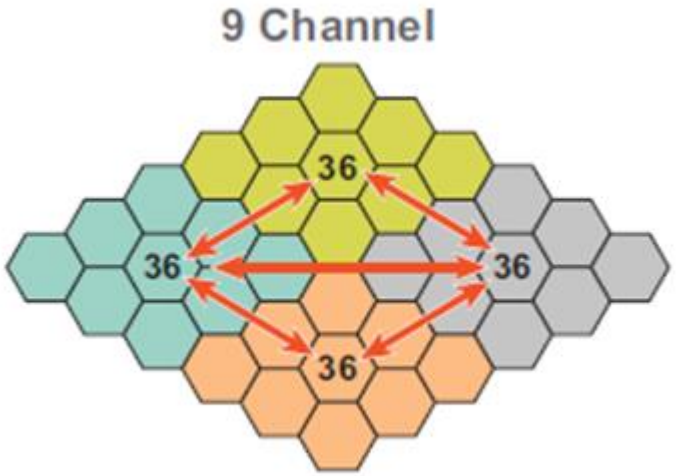
Channel–Width (MHz)	Currently Available	New / Next Channels
20	22	37
40	10	18
80	5	9
160	1	4

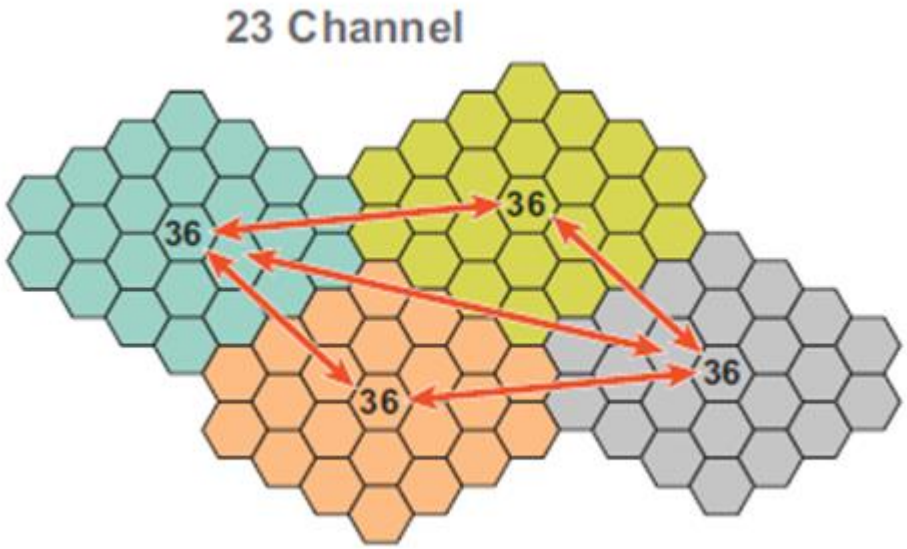
Source: Aruba

Spatial Use / Reuse

Increased Re-use Distance







Spatial Reuse at 20 MHz.

- 3 Channel (1, 6, 11) as in 2,.4 GHz
- 9 Channel (Non-DFS)
- 23 Channel (DFS)

Larger Segmentation of same channel cells.

Spatial Reuse at 40 and 80 MHz.

- 40 MHz – 10 Channels
- 80 MHz – 5 Channels

Fewer channels limits distance between same channel cells

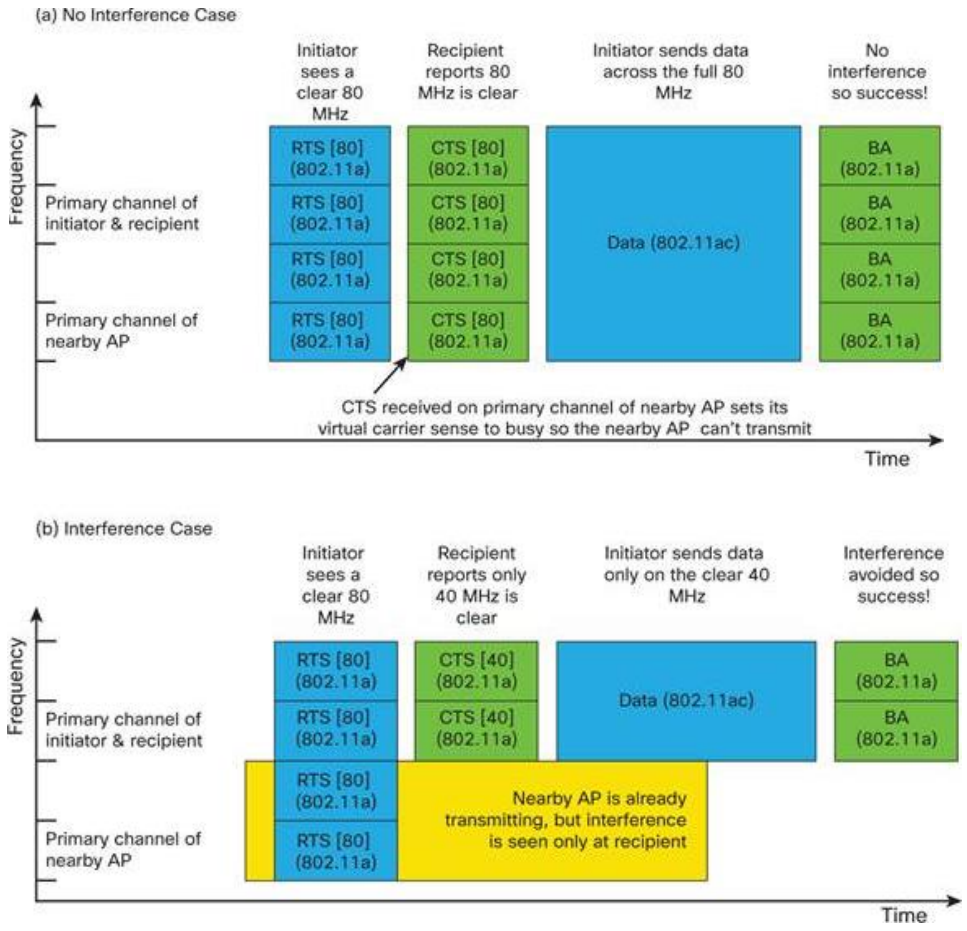
Source: Cisco

RTS/CTS with Bandwidth Signaling

802.11ac

- No Interference
  1. Initiator sees that 80 MHz is clear
  2. Recipient reports that 80 MHz is clear
  3. Initiator sends data across the full 80 MHz
  4. Results in successful transmission

- Interference
  1. Initiator sees that 80 MHz is clear
  2. Recipient reports that only 40 MHz is clear
  3. Initiator sends data only on the clear 40 MHz
  4. Interference avoided resulting in successful transmission



Customer Scenario

Customer Scenario – Apple Store

- Assumptions
  - Cisco Wireless LAN Deployment → 3702e Access Point (4x4:3SS) 11n/ac
  - Application / Throughout SLA: 2 Mbps Per Client Minimum
  - Short-Guard Interval (400 ns)
  - Throughput is exhausted at 80% Channel Utilization
  - Pre-Deployment Survey - Client Inventory

Device Type	Chipset Type	Frequency Band	Channel-Width	Spatial Streams	PHY Rate (256 QAM)	PHY Rate (64 QAM)
MacBook Pro (2014)	Broadcom	2.4, 5 GHz	HT80, MIMO	3SS	1.3 Gbps	975 Mbps
iPad Air 2	Broadcom	2.4, 5 GHz	HT80, MIMO	2SS	866.7 Mbps	650 Mbps
iPhone 6	Broadcom	2.4, 5 GHz	HT80	1SS	433.3 Mbps	325 Mbps

Actual TCP/IP Throughput is 40-50% of PHY Rate

Gathering Requirements

1. What is the Per Device Throughput Requirement or SLA?
2. What type of client stations does the customer have in their environment and how many spatial streams do their devices support?
3. How many devices are capable of utilizing 5 GHz vs. 2.4 GHz?
4. What is the Associated Device Count (ADC)?
5. What is the current Device Duty Cycle on the WLAN?
6. How many SSID's does the customer have in their deployment?
7. What type of AP does the customer have or intend to deploy?
8. What are the channel-widths supported by the Wireless LAN?

Pre-Deployment Assessment

Site Survey Methodologies

Pre-Deployment

- Predictive Site Survey – Planning Tools
  - Defines Coverage and Cell Edge
  - Approx PHY Rate
- Active Survey (Associated)
  - PHY Rate / TCP/IP Throughput
  - Retry Rates, Packet Loss
  - Specific Client, RSSI, SNR

Post Deployment

- Passive Site Survey (Not-Associated)
  - Coverage Validation
  - RSSI, SNR, SSID's
- Spectrum Analysis
  - Measures FFT Duty Cycle
  - FFT DC displays signal > 20 dB above noise floor

Cell Edge Design Example (Data Only):

Initial Site Survey

- 17 dBm (5 GHz) and 20 dBm (2.4 GHz)
- -67 at 60 and 75 ft respectively

Cell Edge Design Example (BYOD Only):

Remediation

- Utilize 6 dB rule.
- Reduce Tx Power to 11 dBm (5 GHz) and 14 dBm (2.4 GHz)
- -67 at 30 and 37.5 ft respectively

Capacity Planning

…a practical approach to High Density

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Source: Aruba

Calculating Total System Throughput

Capacity of an 11ac Channel

TST = Channels * Average Channel Throughput * Reuse Factor

Step 1 – Channel Table

Channel Type	5-GHz Channels (USA)
Non-DFS	9
DFS	11
Total	20

Step 2 – Unimpaired Throughput

Spatial Streams	50 Concurrent Clients	75 Concurrent Clients	100 Concurrent Clients
1SS Device	50 Mbps	38 Mbps	30 Mbps
2SS Device	100 Mbps	72 Mbps	50 Mbps
3SS Device	158 Mbps	118 Mbps	78 Mbps

Step 3 – Impairment Percentage (Subjective)

Venue	5 GHz	2.4 GHz
Apple Store	10%	25%
Non-DFS	100 = 90 Mbps	100 = 75 Mbps
DFS	50 = 45 Mbps	50 = 37.5 Mbps

Step 4 – Calculate Total Spectrum Throughput

Venue	Reuse Factor	5 GHz – TST	2.4 GHz - TST
Apple Store Non-DFS Plan	1	9 * 90 Mbps * R = 810 Mbps	3 * 75 = 225 Mbps
Apple Store DFS Plan	1	20 * 45 Mbps * R = 900 Mbps	3 * 37.5 = 112.5 Mbps

Source: Aruba

Calculating Per Device Throughput

PDT = Total System Throughput / (Associated Device Capacity * Duty Cycle)

- Associated Device Capacity – Percentage of users with an active Wi-Fi device * average number of Wi-Fi devices per person. Calculations should be performed per frequency.
- Device Duty Cycle – Average percent of time that a given user attempts to transmit.

#	Venue	Users	Adoption Rate	Devices Per Person	ADC	Band Split (5 / 2.4 GHz)	Duty Cycle	5 GHz - TST	2.4 GHz - TST
1	Apple Store	250	50%	1.65	206	90 / 10	20%	810	225
250 Users * 50% Adoption (125) * Devices Per User = 206 (ADC)						185 / 21 Users		810 / (185 * .20) **22 Mbps PDT**	225 / 21 * .20 **56 Mbps PDT**

- User duty cycle is subjective, as an example we will utilize 20% to represent email, web browsing, and social networking.

Source: Revolution Wi-Fi

Capacity Planning

802.11n

802.11n Equation

Throughput Req. / (50% of Link Data Rate) = Per Client Airtime * # of Clients / 80% Channel Utilization = AP Radios

Applied

- 2 Mbps / 202.5 = .99% * 103 Clients = 101.97.
- 2 Mbps / 67.5 = 2.96% * 103 Clients = 304.88.
- (101.97 + 304.88) 406.85 / 80%CU = 508.65 or (6) 5 GHz AP Radios

Client Device	Application or Throughput SLA	Device Quantity	Application Throughput	2.4 GHz Band			5 GHz Band			Client Link Data Rate	TCP/IP Throughput
				Assoc.	Active	Airtime	Assoc.	Active	Airtime		
Laptop (11n, 3SS, 40 MHz)	2 Mbps PDT	1	2 Mbps	0	0	0%	1	1	0.99%	405.0	202.5
Tablet (11n, 1SS, 40 MHz)	2 Mbps PDT	1	2 Mbps	0	0	0%	1	1	2.96%	135	67.5

Source: Revolution Wi-Fi

Capacity Planning

802.11n vs. 802.11ac

Client Device	Application / Throughput SLA	Device Qty	Application Throughput	5 GHz Band			Client Link Data Rate	TCP/IP Throughput
				Assoc.	Active	Airtime		
Laptop (11n, 3SS, 40 MHz)	2 Mbps PDT	1	2 Mbps	1	1	0.99%	405.0	202.5
Laptop (11ac, 3SS, 80 MHz)	2 Mbps PDT	1	2 Mbps	1	1	0.82%	405.0	202.5
Tablet (11n, 1SS, 40 MHz)	2 Mbps PDT	1	2 Mbps	1	1	2.96%	135	67.5
Tablet (11ac, 1SS, 80 MHz)	2 Mbps PDT	1	2 Mbps	1	1	2.47%	135	67.5

2 Mbps / 67.5 = .0296 (2.96.%) * 80 Clients \ 80% Channel Utilization = 2.96; which is equal to (3) 5 GHz AP Radio

Source: Revolution Wi-Fi

Air Time Correlations – 20, 40 and 80 MHz

Application Throughput vs. Spatial Streams

Client Device	Application or Throughput SLA	Device Quantity	Application Throughput	5 GHz Band (80 Mhz)		
				Assoc.	Active	Airtime
Smart Phone (11ac, 1SS, 80 MHz)	250 Kbps per-device throughput SLA	1	250 Kbps	1	1	0.32%
Smart Phone (11ac, 1SS, 80 MHz)	500 Kbps per-device throughput SLA	1	500 Kbps	1	1	0.64%
Smart Phone (11ac, 1SS, 80 MHz)	1 Mbps per-device throughput SLA	1	1 Mbps	1	1	1.28%
Smart Phone (11ac, 1SS, 80 MHz)	**2 Mbps per-device throughput SLA**	**1**	**2 Mbps**	**1**	**1**	**2.56%**
Laptop (11ac, 2SS, 80 MHz)	250 Kbps per-device throughput SLA	1	250 Kbps	1	1	0.08%
Laptop (11ac, 2SS, 80 MHz)	500 Kbps per-device throughput SLA	1	500 Kbps	1	1	0.16%
Laptop (11ac, 2SS, 80 MHz)	1 Mbps per-device throughput SLA	1	1 Mbps	1	1	0.32%
Laptop (11ac, 2SS, 80 MHz)	**2 Mbps per-device throughput SLA**	**1**	**2 Mbps**	**1**	**1**	**0.64%**

Wireless LAN Best Practices

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Source: Cisco

Cisco Unified Wireless LAN Controller

- General Guidelines
  - Channel Plans
    - 20 MHz for most Deployments
    - 40 MHz for some Single-Floor Deployments where CCI can be mitigated
  - Data Rates
    - 2.4 GHz. MBR 24 Mbps
    - 5 GHz. MBR 12 - 24 Mbps
    - Disable all Lower Data Rates
  - Transmit Power Control
    - Power 11 dB (14 mW)
    - Transmit Power Throttling and DTPC
  - Cell Edge Design
    - -65 to -67 Cell Edge
    - SNR 25 or Better

Optimizes Cell Size

- High-Density Features
  - RF Profiles > Data Rates > RRM > High Density
  - Band Select / Client Load-Balancing (except VoWLAN
  - Dynamic Band Width Allocation (DBA)
  - Air Time Fairness (ATF)
  - Rx-SOP
- QoS (802.1p) and/or WMM
  - LB-CAC
- Encryption (802.11n)
  - WPA2-AES CCMP
  - Required for 802.11n HT rates
- Mobility
  - 5 GHz (20 % Cell Overlap)
  - 2.4 GHz. (10-15%)

Source: Cisco

Dynamic Bandwidth Allocation (WLAN)

Before
Complex configuration and inefficient use of spectrum

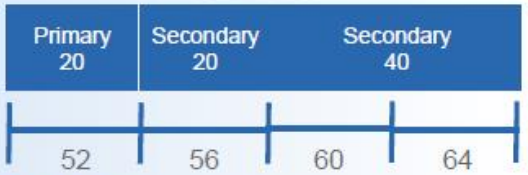
80 MHz Channel
52/56/60/64

Interference impacts 80 MHz…what can I use?

Radio Resource Management (RRM) selects channel only

Difficult to find non-overlapping channels

After
Automatic and intelligent use of spectrum



- 80-MHz channel 52/56/60/64
- Interference is impacting **only** channel 60
- 3x20 MHz channels still available or 1x40 MHz and 1x20 MHz

RRM selects channel and channel width

Automatic detection of non-overlapping channels

Source: Cisco

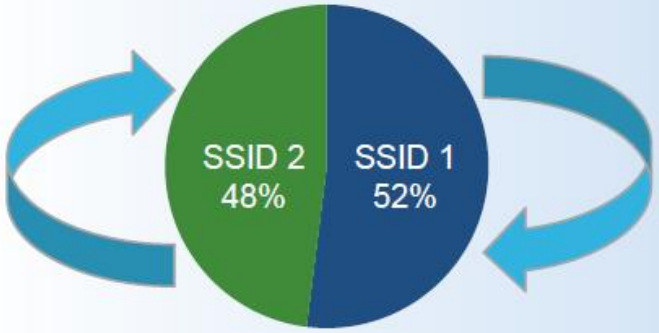
Air Time Fairness (ATF)

Before

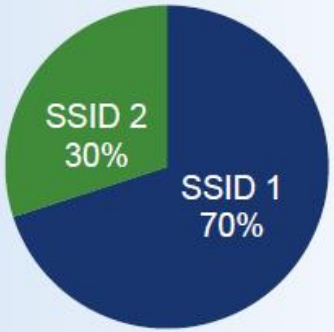
Rate limiting can only specify a bit rate (throughput) limit. There is no way to limit the duration that the bit rate will use.

After

Air time is allocated per SSID, per realm, per client. There is now better control over how air time is shared.



Gain the Ability to Meet SLAs

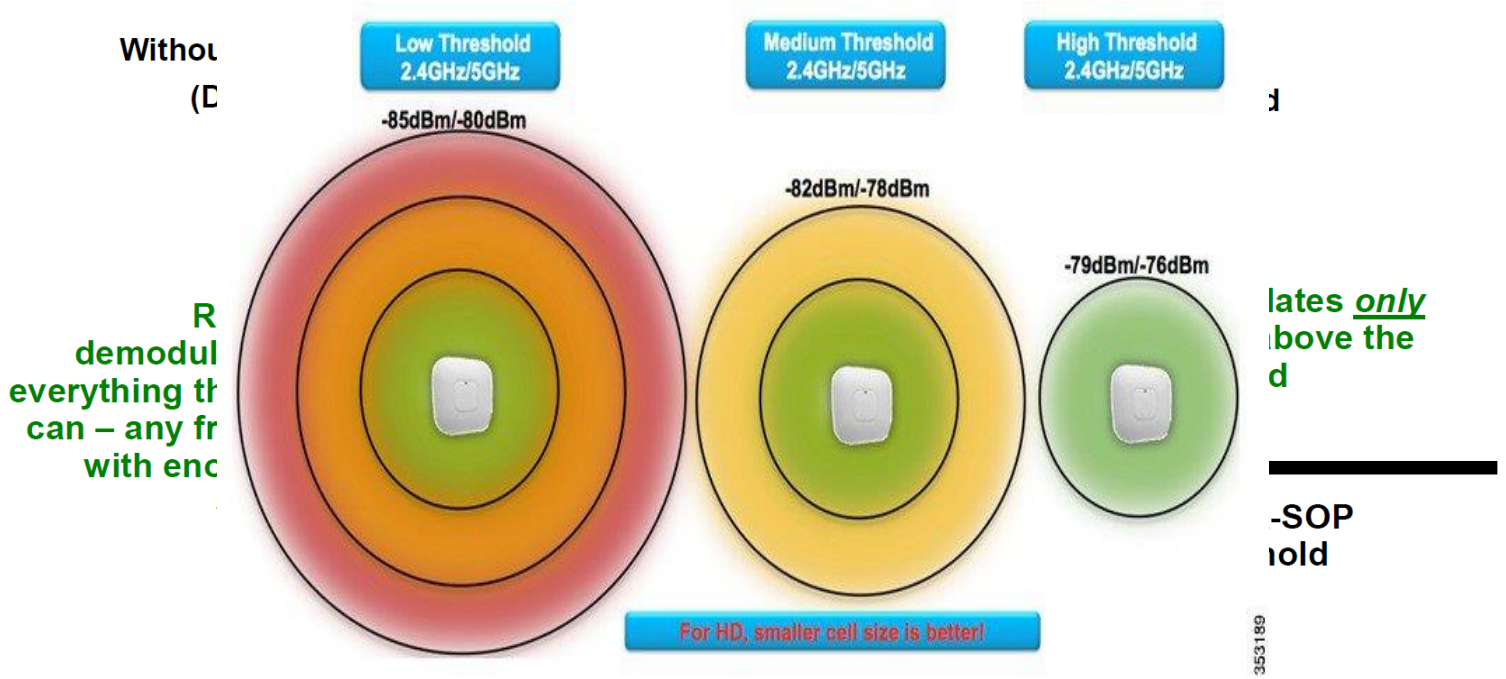


Bandwidth rate unpredictable	Client-dependent fluctuation	Not time-based

Time-based	Automatic calculation on availability	Ongoing recalculation

Source: Cisco

Receive Sensitivity Threshold (Rx-SOP)



802.11 Band	High Threshold	Medium Threshold	Low Threshold	Auto
5 GHz	-76 dBm	-78 dBm	-80 dBm	Use Radio Default
2.4 GHz.	-79 dBm	**-82 dBm** -20 dBm to -81 dBm	-85 dBm	Use Radio Default

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