Understanding 802.11ac

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Agenda

- Why 802.11ac
- Overview 802.11ac Wave1 main features
- Look into MU-MIMO/256-QAM/channels
- 802.11ac Wave 2 considerations

Session Agenda – Objectives

- Basic understanding of 802.11ac fundamentals including:
  - MU-MIMO,
  - Channel bonding,
  - 256-QAM Modulation
  - Beamforming

Why is 802.11ac important?

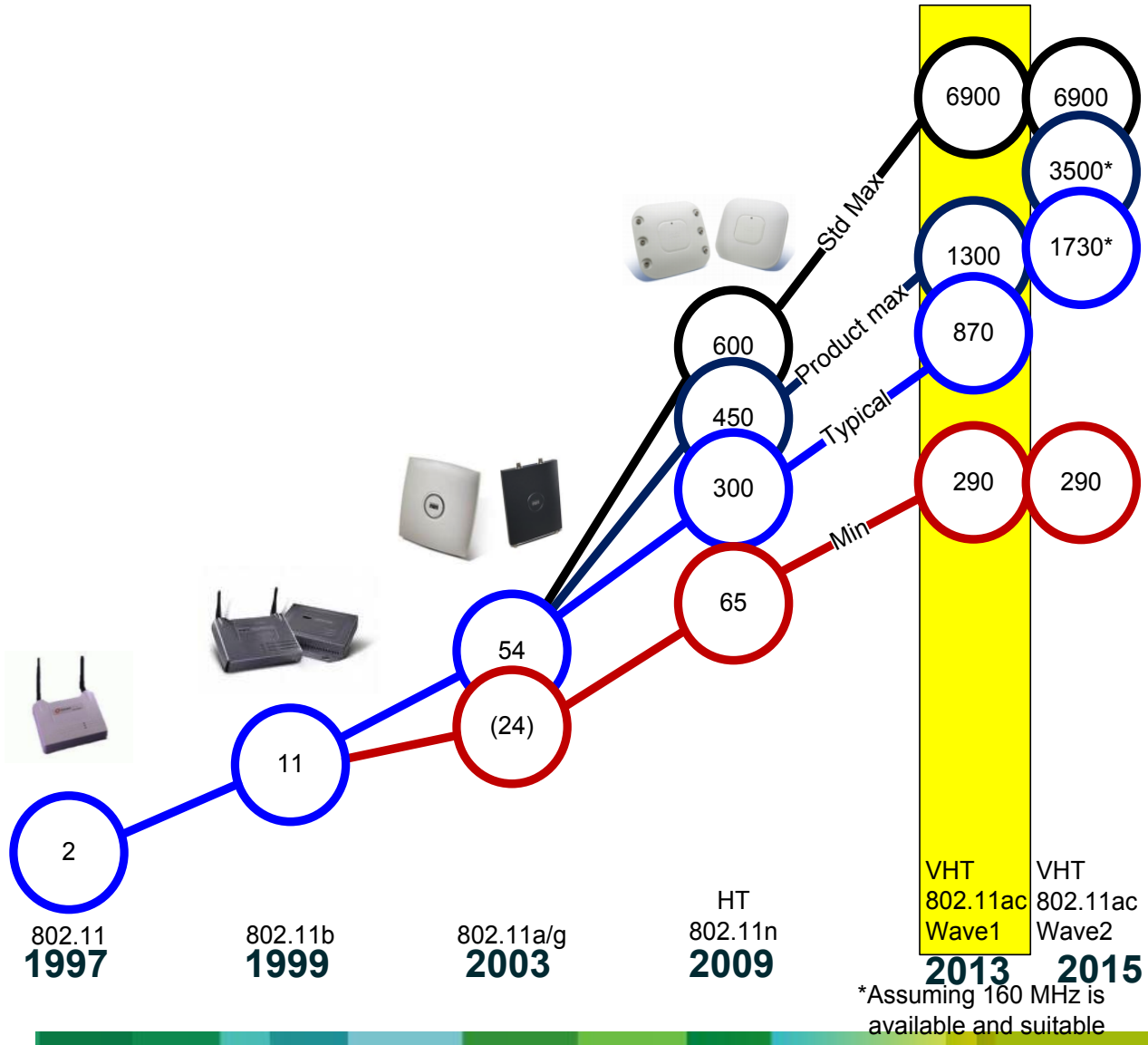
This section will guide you in understanding 802.11ac Wave-1 and Wave-2

802.11ac devices have started to emerge especially mobile devices so there is a customer need for improved performance

Access Point
802.11ac 5GHz
802.11n 2.4GHz

New .11ac clients starting to emerge

Fact: 802.11ac is here - is your network ready?



1997 – 2 mbps of data rate = 1 SD video flow max.
(level 2: 352x288, 30 img/sec, Extended profile H.264)

2013 – 870 mbps = 400+ SD video flows, or 50+ HD video flows
(Level 3.1: 1280×720, 30 img/sec, Extended profile – 14mbps peak)

IEEE 802.11ac – The Next Generation in Wi-Fi

What is 802.11ac?

- Most efficient Wi-Fi standard to date
- Optimized for high bandwidth applications
- Backwards compatible with 802.11n and .11a
- Provides better coverage in dense environments
- Optimized for better client battery life

What Are the Features?

- Wider Channels and More Spatial Streams than 802.11n
- Data rates Up to 1.3 Gbps (Wave 1) & 2.6/3.5 Gbps (Wave 2)
- Operates in 5GHz Band only
- Multi-user MIMO mode

What to expect with 802.11ac when deployed on your network?

- **Noticeably faster connectivity enabling an enhanced Quality of Experience for the end user**
- **Wired-like experience at higher speed**
- **Significantly better client battery life**
- **Much higher client density because of greater efficiency for the entire cell**

So let's talk about 802.11ac – Wave1

The Wi-Fi Alliance (WFA) is looking at Wave 1 today with the main features implemented being:

- **Faster modulation 256-QAM (optional)**
- **Channel Bonding 80 MHz (mandatory)**
- **Ability to receive 1,2 & 3 Spatial Streams tested**
  - **2SS is mandatory for non-battery-powered APs**
  - **Only 1SS is mandatory for battery powered AP's and clients**
- **WFA's focus is on 80 MHz, 1-3SS and 256-QAM**

802.11ac is happening in stages Referred to as "Wave-1 and Wave-2

Broadcom 4360 in the newest Macbooks

Wi-Fi CERTIFIED™ ac

BEST LIST FOR IDENTIFYING NEW 802.11AC HARDWARE
http://wikidevi.com/wiki/List_of_802.11ac_Hardware

802.11ac Fundamentals

Operating in the 5GHz Band Only	• Avoids the crowded 2.4GHz Band • Allows for wider Channels
Wider RF Channels: 80MHz and 160MHz	• More potential bandwidth available
Number of Spatial Streams: 1 to 8	• Expect 3SS (Spatial Streams) initially with future implementation going to 4SS
Modulation: 256 QAM	• ~30% more efficient
MU-MIMO (Multi-User MIMO) Support	• APs can transmit to multiple downstream clients simultaneously
Data Rates	• From a minimum of 290Mbps up to 6.9Gbps theoretical maximum

802.11n “Things that never really got much traction”

- **Greenfield header**

  (pure 802.11n, for networks with no 802.11a/b/g stations) by the way this is a bad idea as you want to be a good RF neighbor. FYI - **Greenfield is not supported in 802.11ac.**

- **4 Spatial streams for up to 600 Mbps**

  (assuming bonded 40 MHz and short 400ns GI) just too many issues (lack of clients, PoE considerations etc.) **11ac 3-SS Wave-1**

- **Channel bonding in 2.4 GHz for enterprise**

  (just not enough channels) as you can only do so much on 2.4 GHz as there isn’t that much spectrum. **802.11ac is 5 GHz only**

- **Explicit beam-forming**

  (clients really didn’t support this) **Supported with .11ac**

- **Dual CTS protection**

  (AP send to CTS when using Space Time Block Coding, STBC, which extends the range of the cell: one CTS for non-STBC stations (short range), and one CTS for STBC stations (longer range) **New protections added with .11ac**

802.11ac Wave-1 and Wave-2

* The 802.11ac specification will be brought to market in 2 phases or "Waves"
* Each Wave of 802.11ac will require new chip sets

Feature	Wave 1 – 2013	Wave 2 – 2014/2015 Features still in Discussions			
PHY Rate	1.3 Gbps	1.3 Gbps	1.73 Gbps	2.6 Gbps	3.5 Gbps
# of Spatial Streams	3	3	4	3	4
Modulation	256 QAM	256 QAM	256 QAM	256 QAM	256 QAM
Channel Width	20, 40, 80 MHz	20, 40, 80 MHz	20, 40, 80 MHz	20, 40, 80, 80+80, 160 MHz	20, 40, 80, 80+80, 160 MHz
MIMO	Single User	Multi User	Multi User	Multi User	Multi User
802.11 protocol support	a, n, ac	a, n, ac	a, n, ac	a, n, ac	a, n, ac
Ethernet Uplink	GbE	GbE and 10GbE			

So let's talk about 802.11ac - How is it like .11n?

802.11ac (Wave-1) introduces 256-QAM

Faster throughput happens when you can use more complex Modulation Coding Schemes (MCS) rates

MCS	Coding	Modulation	Streams
MCS0	1/2	BPSK	1
MCS1	1/2	QPSK	1
MCS2	3/4	QPSK	1
MCS3	1/2	16-QAM	1
MCS4	3/4	16-QAM	1
MCS5	2/3	64-QAM	1
MCS6	3/4	64-QAM	1
MCS7	5/6	64-QAM	1

802.11n 1-ss MCS up to 64-QAM
64-QAM uses 6 bits per symbol

MCS	Coding	Modulation	Streams
0	1/2	BPSK	1
1	1/2	QPSK	1
2	3/4	QPSK	1
3	1/2	16-QAM	1
4	3/4	16-QAM	1
5	2/3	64-QAM	1
6	3/4	64-QAM	1
7	5/6	64-QAM	1
8	3/4	256-QAM	1
9	5/6	256-QAM	1

802.11ac 1-ss MCS supports 256-QAM
256-QAM uses 8 bits per symbol (up to 4x faster)

Just one more EYECHART

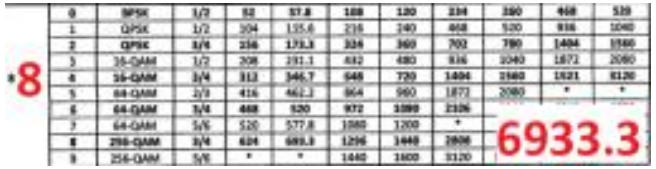
For Your Reference

802.11ac (Wave-2)
Up to 8 spatial streams.

.11ac MCS rates (unlike 802.11n) don't exceed 0-9 -- but rather **it is 0-9** and then you **call out how many Spatial Streams** so a chart like this is quite extensive.

Depicted to the right are only streams 2 & 3 out of the 8 possible spatial streams.

1 stream (80MHz) is 433 Mbps
2 stream (80MHz) is 866 Mbps
3 stream (80MHz) is 1300 Mbps

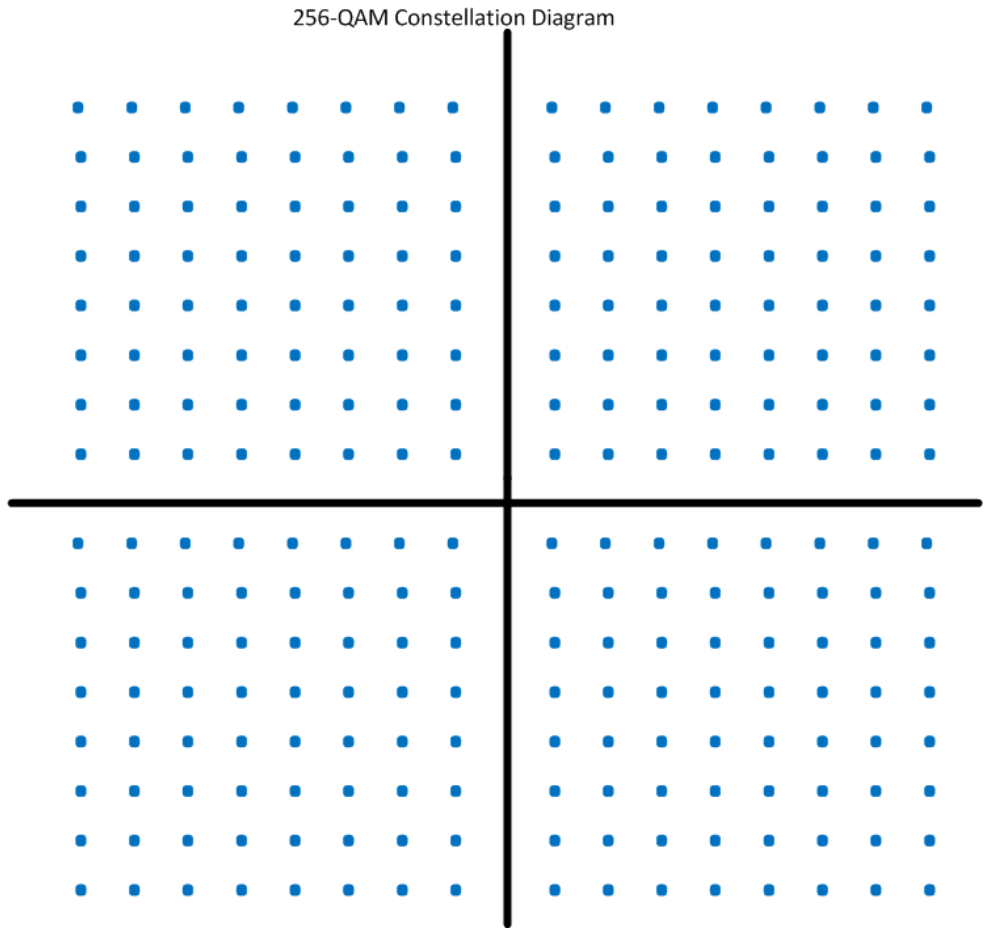


802.11ac Data Rates

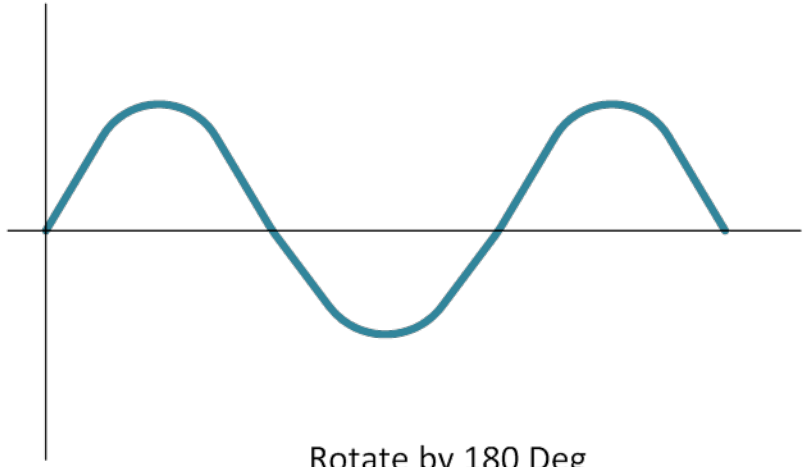
* RATE NOT SUPPORTED

Spatial Streams	MCS Index	Modulation	Coding	Mb/s 20 MHz Guard 800ns	20 MHz Interval 400ns	40 MHz Guard 800ns	40 MHz Interval 400ns	80 MHz Guard 800ns	80 MHz Interval 400ns	160 MHz Guard 800ns	160 MHz Interval 400ns
2	0	BPSK	1/2	13	14.4	27	30	58.5	65	117	130
	1	QPSK	1/2	26	28.9	54	60	117	130	234	260
	2	QPSK	3/4	39	43.3	81	90	175.5	195	351	390
	3	16-QAM	1/2	52	57.8	108	120	234	260	468	520
	4	16-QAM	3/4	78	86.7	162	180	351	390	702	780
	5	64-QAM	2/3	104	115.6	216	240	468	520	936	1040
	6	64-QAM	3/4	117	130	243	270	526.5	585	1053	1170
	7	64-QAM	5/6	130	144.4	270	300	585	650	1170	1300
	8	256-QAM	3/4	156	173.3	324	360	702	780	1404	1560
	9	256-QAM	5/6	*	*	360	400	780	866.7	1560	1733.3
3	0	BPSK	1/2	19.5	21.7	40.5	45	87.8	97.5	175.5	195
	1	QPSK	1/2	39	43.3	81	90	175.5	195	351	390
	2	QPSK	3/4	58.5	65	121.5	135	263.3	292.5	526.5	585
	3	16-QAM	1/2	78	86.7	162	180	351	390	702	780
	4	16-QAM	3/4	117	130	243	270	526.5	585	1053	1170
	5	64-QAM	2/3	156	173.3	324	360	702	780	1404	1560
	6	64-QAM	3/4	175.5	195	364.5	405	*	*	1579.5	1755
	7	64-QAM	5/6	195	216.7	405	450	877.5	975	1755	1950
	8	256-QAM	3/4	234	260	486	540	1053	1170	2106	2340
	9	256-QAM	5/6	260	288.9	540	600	1170	1300	*	*

What is 256-QAM?



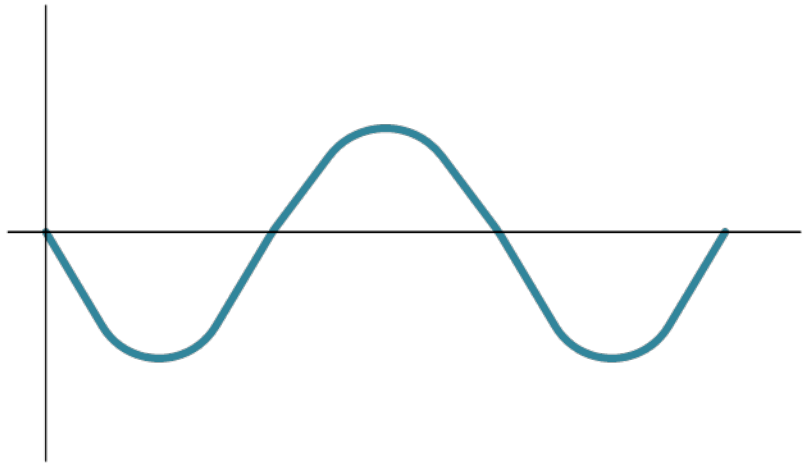
BPSK
1 Bit per Modulation Symbol



= 0

Rotate by 180 Deg

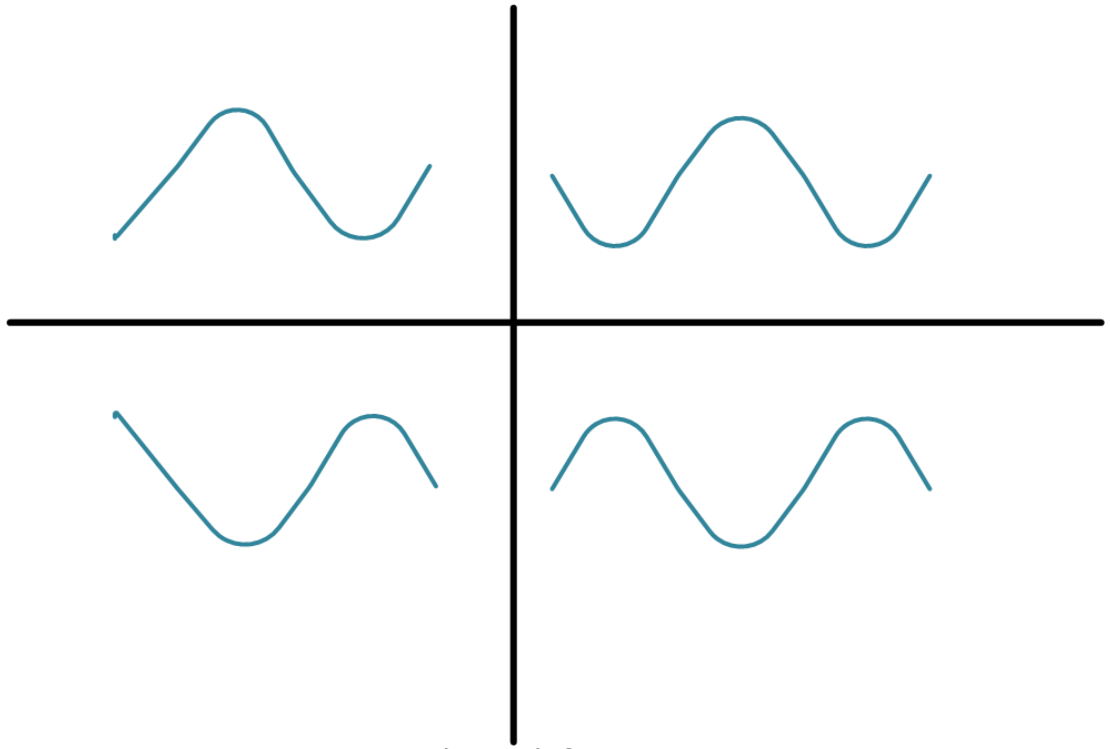
180 Deg Phase Shift



= 1

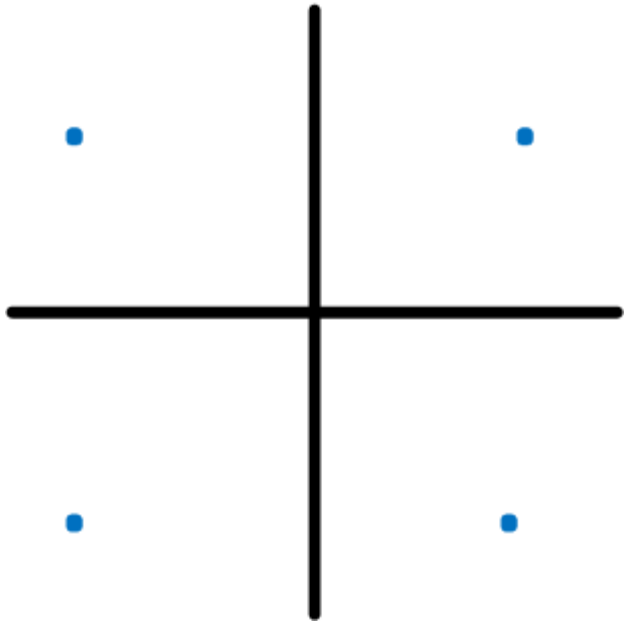
BPSK - Binary Phase Shift Keying

QPSK
2 Bits per Modulation Symbol



4 Phase Shifts over
360 Degrees

0	**0**
0	1
1	0
1	1



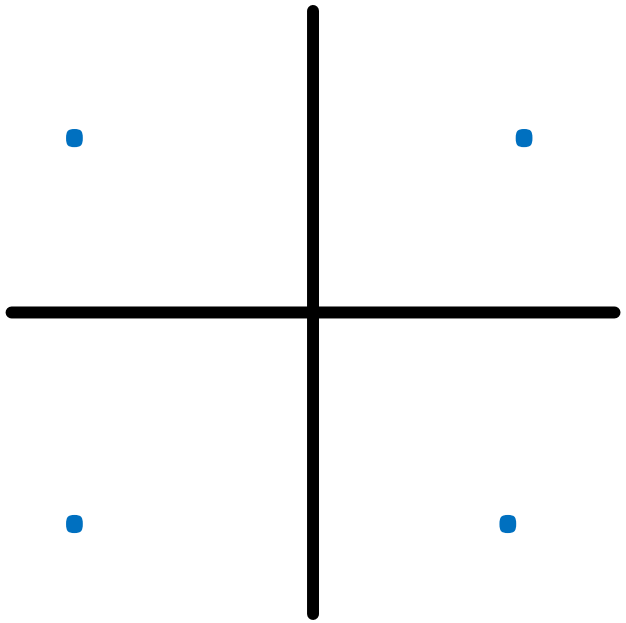
QPSK - Quadrature Phase Shift Keying

Data Rates with Modulation

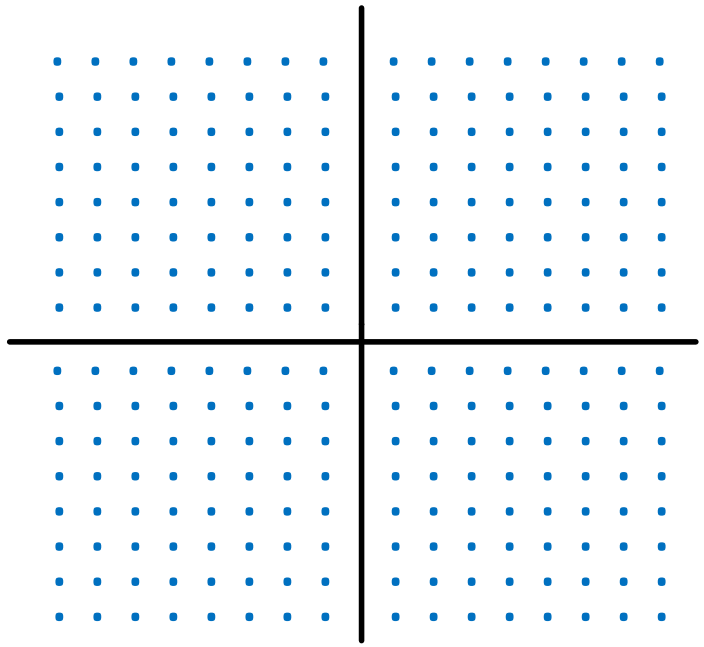
Modulation	BPSK	QPSK	16QAM	64QAM	256QAM
Bits per Modulation Symbol	1	2	4	6	8

Constellation diagrams

BPSK

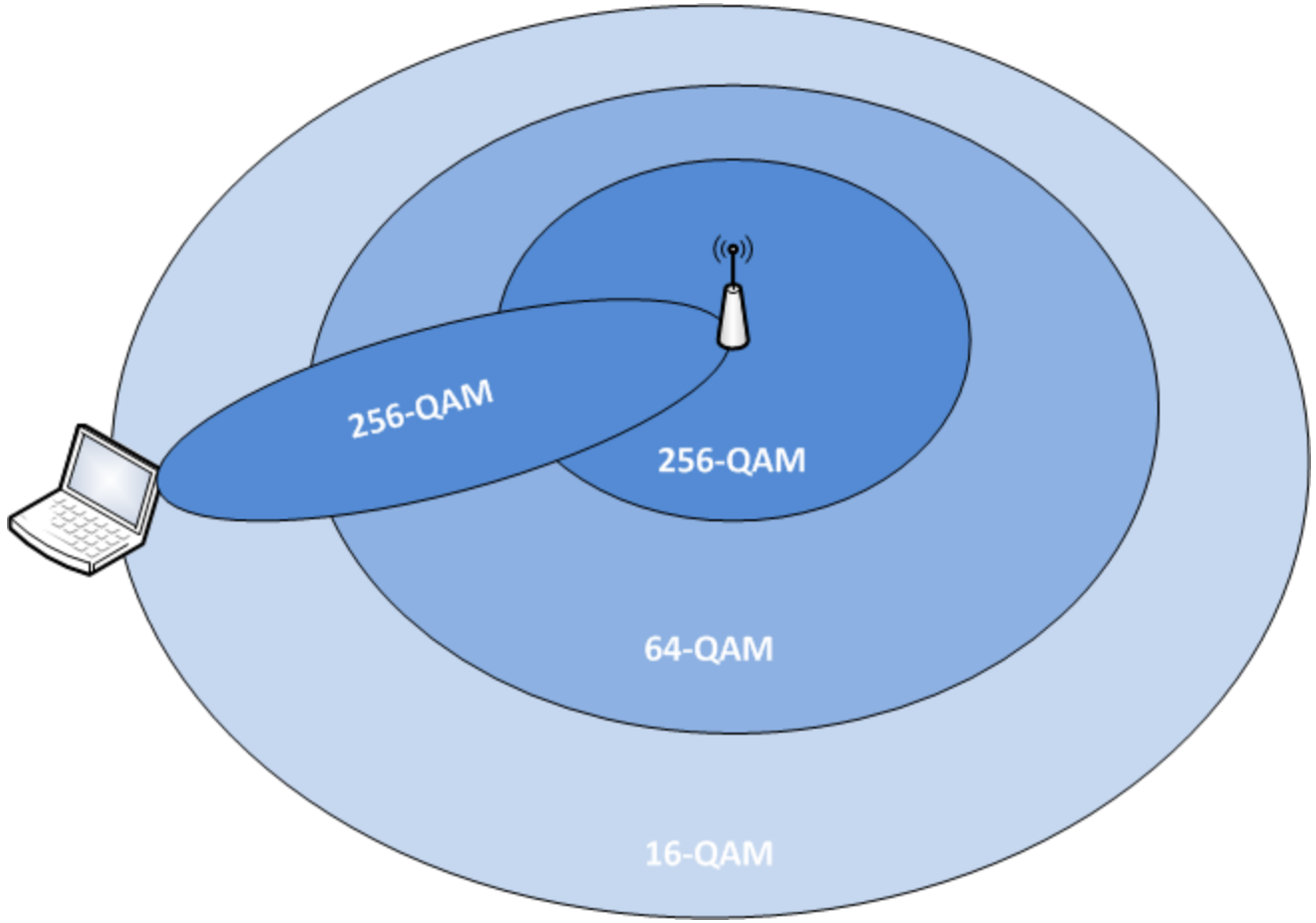


256-QAM



256-QAM has to the potential to be more prone to a greater BER
Improved via Beam forming

Beam Forming in 801.11ac



Beamforming – What did and didn't happen
Review – Beamforming 802.11n and now 802.11ac

	802.11n (EBF) Enhanced Beam Forming	Client Link 2.0 (CVBF) Cisco Vector Beam Forming
WLAN Client		
Works for Multiple Spatial Stream HT Clients	Not yet	All
Works for 1 SS HT Clients	Not yet	All
Works for Legacy Clients (11 a/g)	None	All
General Requirements/Dependencies		
Requires Client Cooperation/Support	Yes	No
Requires Use of Channel Time for Sounding	Yes	No
Can be Used w/ Clients Currently on Market	No	All 11a/g/n

EBF Enhanced Beam-forming didn't make it in 802.11n but it's now in 802.11ac
Lots of channel sounding mechanisms and the industry could not decide at the time which one to use so everything was proprietary

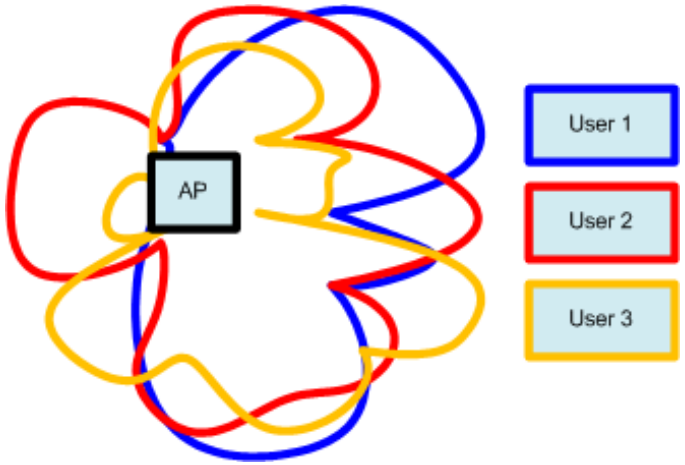
This got a lot better with 802.11ac after a single sounding method was agreed upon.
Note: EBF changed to ECBF Explicit Compressed Beam Forming

How about Multi-User MIMO (**MU-MIMO**)

Does it work? Any caveats?

- **802.11ac MU MIMO is like 802.11n MIMO, except instead of one client, there are up to four clients**
  - **AP does pre-coding for all the clients within the Multi-User group simultaneously**
  - **In MU pre-coding, when AP beam-forms space-time streams to one client, it simultaneously null-steers those space-time streams to the rest.**
  - **All users' MPDUs are padded to the same number of OFDM symbols**
- **MU-MIMO is technically risky and challenging:**
  - **Needs precise channel estimation (CSI) to maintain deep nulls**
  - **Precise channel estimation adds overhead**
  - **Rate adaptation is more difficult**
  - **Throughput benefits are sensitive to MU grouping**

WFA Wave 2 certification:
- MU-MIMO

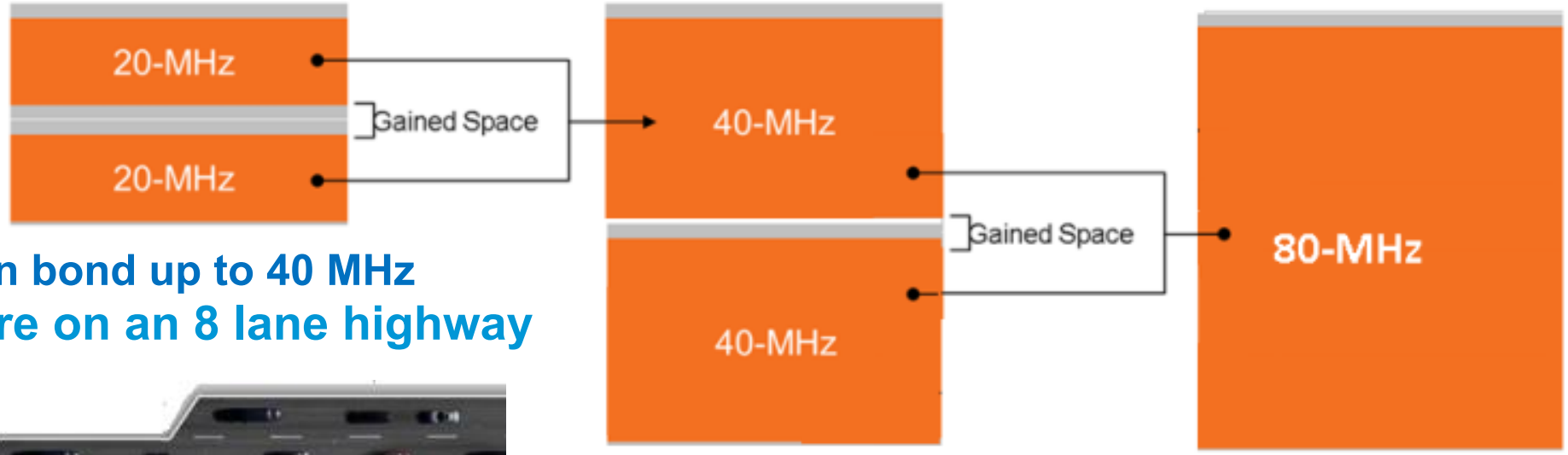


Null-steering:To send data to user 1, the AP forms a strong beam toward user 1, shown as the top-right lobe of the blue curve. At the same time the AP minimizes the energy for user 1 in the direction of user 2 and user 3. This is called "null steering" and is shown as the blue notches. Same logic applies to red and yellow beams.

Channel Bonding

So let's talk about 802.11ac - How is it like .11n?

Wave-1 allows up to 80 MHz channel bonding



802.11n can bond up to 40 MHz

Now we are on an 8 lane highway

802.11ac can bond up to 80 MHz (Wave-1)

***up to 160 MHz (Wave-2)**

Suggested Guidelines on Channel Bonding

20 MHz mode is suggested if…

- you have lots of voice clients.
- you have lots of non-11n capable 5 GHz clients
- you will be deploying a transition of mixed 11a & 11n infrastructure

40 MHz (Bonded channel) mode is suggested if…

- You have few voice clients (less than 10 per AP)
- You expect to have predominantly 11n clients that support 40 MHz operation.
- You are doing bandwidth-intensive file transfers such as video downloads, wireless backups, etc.

So why is channel bonding so important?

MCS rates @ 1 Spatial Stream in Mbps

MCS	Modulation	Ratio	20 MHz channel	40 MHz channel	80 MHz channel WAVE-1
			400 ns GI	400 ns GI	400 ns GI
0	BPSK	1/2	7.2	15	32.5
1	QPSK	1/2	14.4	30	65
2	QPSK	3/4	21.7	45	97.5
3	16-QAM	1/2	28.9	60	130
4	16-QAM	3/4	43.3	90	195
5	64-QAM	2/3	57.8	120	260
6	64-QAM	3/4	65	135	292.5
7	64-QAM	5/6	72.2	150	325
8	256-QAM	3/4	86.7	180	390
9	256-QAM	5/6	N/A	200	433.3

New Phones such as the HTC One & Samsung S 4 have support for 802.11ac Wave-1

More than 1-SS requires that the client have more radios which draw more power.

The goal is to enable devices to have more throughput with less battery draw

Most mobile devices will use 1-SS

Tablets & laptops can use 2-SS or more

Channel Bonding Wave-1 and Wave-2

.11ac MCS Rates @ 1-spatial stream -- (Wave1) typically supports up to 3-ss

For Your Reference

MCS	Modulation	Ratio	20 MHz channel		40 MHz channel		80 MHz channel WAVE-1		160 MHz channel WAVE-2	
			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

802.11ac Wave 1 Potential Throughput @ 80 MHz

faster connectivity = shorter active radio time = better battery life

802.11ac Performance Table

BW (MHz)	# Spatial Streams	MCS (QAMr5/6)	PHY Rate (Mbps)	MAC Thru-put (Mbps)*
80	1	64	290	175
80	1	64	330	200
80	1	256	430	260
80	2	64	650	390
80	2	256	870	520
80	3	64	980	590
80	3	256	1300	780
80	4	256	1700	1020
80	8	256	3500	2100

1x1

Smartphones from 260 Mbps*

2x2

Tablets from 520 Mbps*

2x2
3x3

High End Laptops from 780 Mbps*

BYOD CONTINUES

Single GbE port on the AP3600 - More than sufficient bandwidth from the full duplex GbE port on the AP3600

*** Assumes 60% MAC efficiency and 256 QAM connection with the AP**

Not all Clients will be created equal – early chip drops and quality of components make a difference - mileage will vary

Rate & Range, Environment and Deployment will impact coverage and quality

Client cell sizes similar between .11n and .11ac

There are so many data-rates in .11ac

Using the internal .11n radio on the Access Point, we performed a quick cell size characterization with .11n rates using several .11n clients.

When we switched to .11ac clients, and the .11ac radio, it performed similar @40 MHz with clients having a cell size similar to the .11n clients.

Take-away .11n/11ac are similar rate/ range but of course @80 MHz and 256-QAM, you get a significant data-rate boost

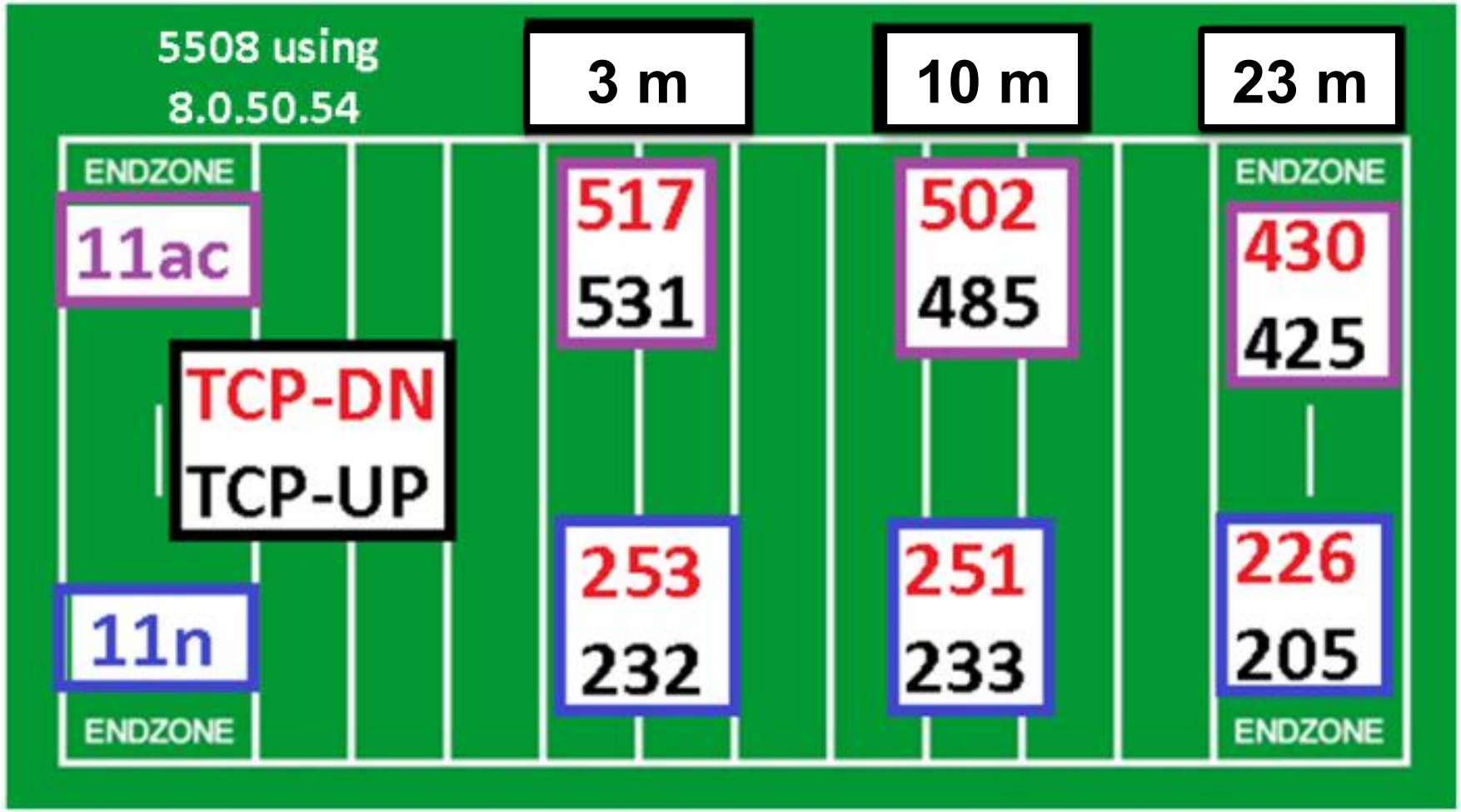
Cisco facility in Richfield Ohio for RF testing

Any Rate over Range data?
Comparing 802.11ac versus 802.11n using 3-SS clients

11ac client
Dell E6430 with
Broadcom 3-ss

Vs.

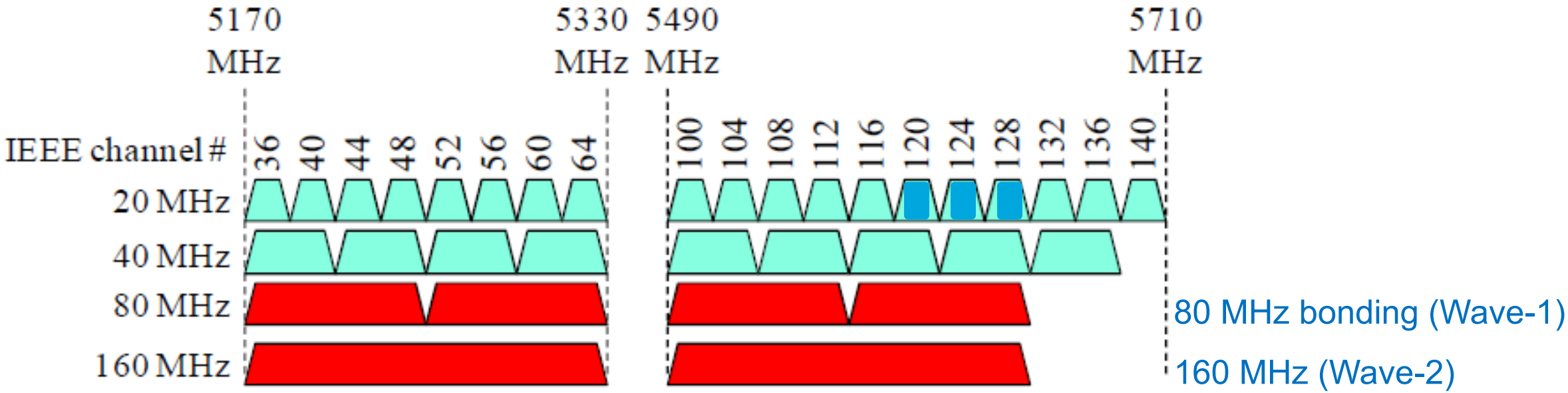
11n client
Apple 3-ss
Macbook Pro



(Take-away) 802.11ac client @ 3-ss is able to get twice the speed than 802.11n

Channel Allocation and Bonding

ETSI channel allocation plan

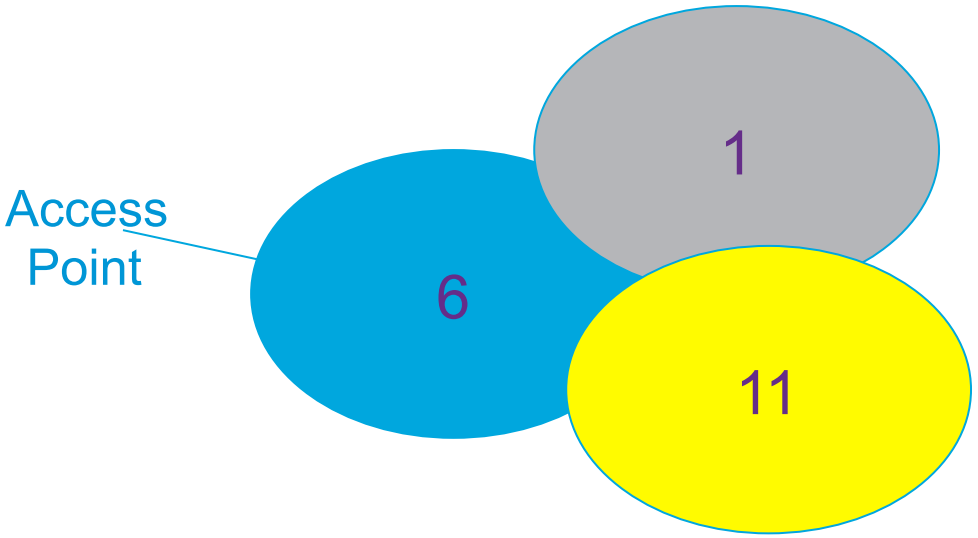


Note: Efforts are underway globally to expand the number of channels in the 5 GHz band.

Channel Allocation and Bonding

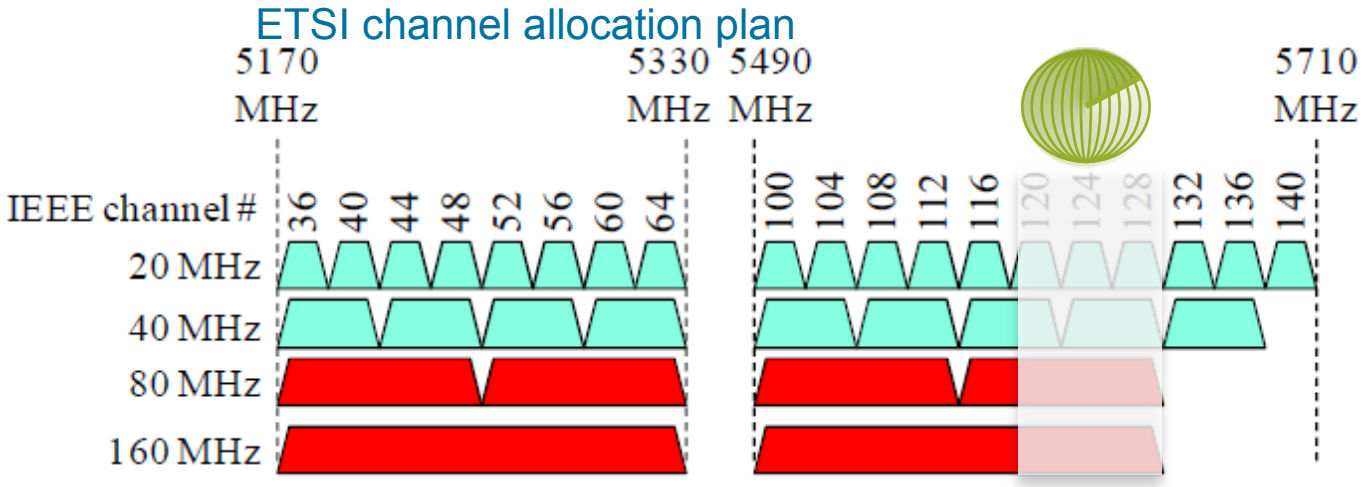
Neighboring APs use different channels to reduce interference.

On 2.4 GHz, the “Reuse cluster” size is equal to 3



802.11b / 802.11g / 802.11n

On 5 GHz, the “Reuse cluster” size varies depending on channel width:



802.11a / 802.11n / 802.11ac

80 MHz bonding (Wave-1)

160 MHz (Wave-2)

802.11ac and Wave-2

What are likely to be the minimum requirements?

(Wave-2) Minimum requirements for enterprise will likely include: 256-QAM, 3-SS and 160 MHz

- **For Wave 2, initially it is expected that 160 MHz devices will appear with 1-3SS (typical) with perhaps 4-SS supported with likely data rates of 867-2600 Mbps.**
- **Data rates up to 3.5 Gbps PHY and over 2 Gbps MAC**
- **Will require faster than GigE speeds requiring either 10GbE or perhaps two GbE cables / hybrid**

Future proofing new installations (cabling considerations)

- **A single GbE cable is fine for (Wave-1)**
- **Wave-2 will exceed GbE speeds so for now, it is recommended for new installs requiring Wave-2 that you pull two CAT6a cables until this standard is better defined.**
- **A pair of CAT6a cables allows you to fall back to using 2 GbE ports for some iterations of (Wave-2) if required. If the second cable isn't needed it can be used to bring the console port back.**
- **CAT5e cables may be used or one of each for cost savings but not for 10GbE.**

Higher Education Use Case

- BYOD to address client adoption –

  Students are typically early adopters of latest gadgets, such as laptops, smartphone, tables

- High concentration of devices connecting to the network
- Desire to connect to student network
- Education seeing dramatic increase of wireless demand
- Better spectrum use to 5GHz rather than a crowded 2.4GHz band

Contact Details:

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Thank you.