

The background is a vibrant, abstract graphic featuring a rainbow color palette. On the left, there are horizontal, wavy bands of color transitioning from red at the top to blue at the bottom. On the right, a bright white light source emits a series of sharp, triangular rays of color in a radial pattern, also using the rainbow spectrum. The overall effect is energetic and celebratory.

cisco *Live!*

Let's go

#CiscoLiveAPJC



The bridge to possible

Wireless Network Design for Demanding Applications

A Client Perspective

Mark Krischer
Principal Wireless Architect
BRKEWN-2926

CISCO *Live!*

#CiscoLiveAPJC

Cisco Webex App

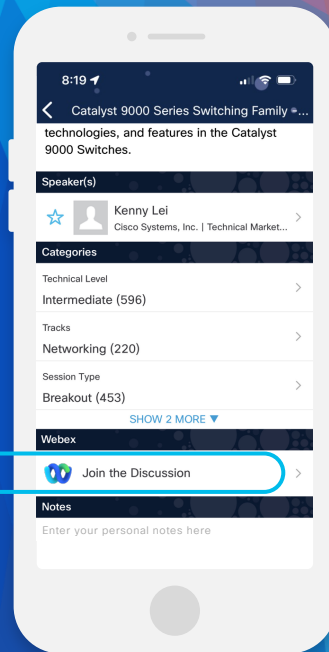
Questions?

Use Cisco Webex App to chat with the speaker after the session

How

- 1 Find this session in the Cisco Live Mobile App
- 2 Click “Join the Discussion”
- 3 Install the Webex App or go directly to the Webex space
- 4 Enter messages/questions in the Webex space

Webex spaces will be moderated by the speaker until December 22, 2023.

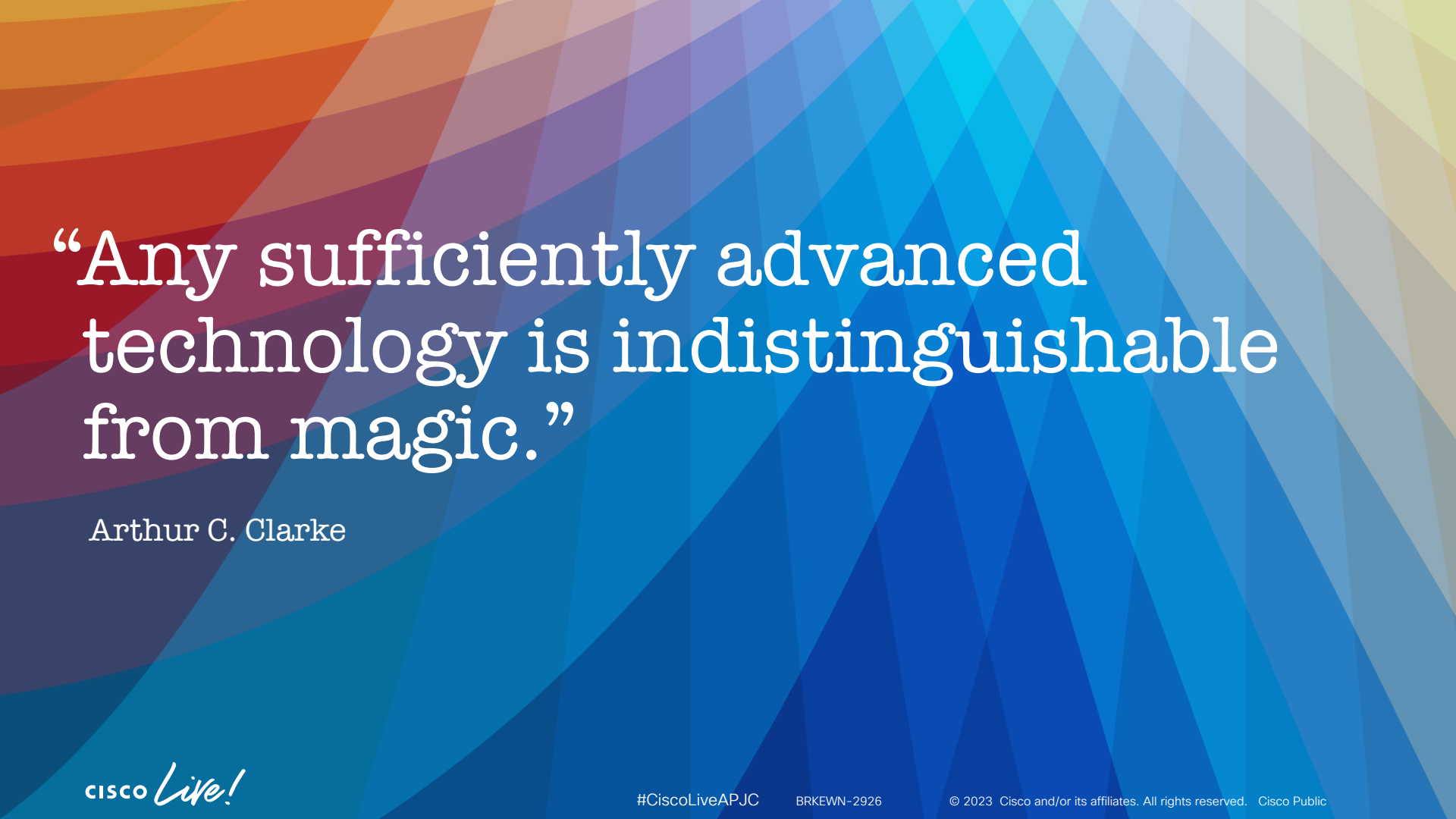


<https://ciscolive.ciscoevents.com/ciscolivebot/#BRKXXX-xxxx>

Agenda

- Wireless Fundamentals
- Designing the Network from the Client Perspective
- Optimising for Client Roaming Behaviour
- Optimising for Low Latency Applications





“Any sufficiently advanced
technology is indistinguishable
from magic.”

Arthur C. Clarke

Radio Frequency Fundamentals

- Frequency and Wavelength

- $f = c / \lambda$

- c = the speed of light in a vacuum

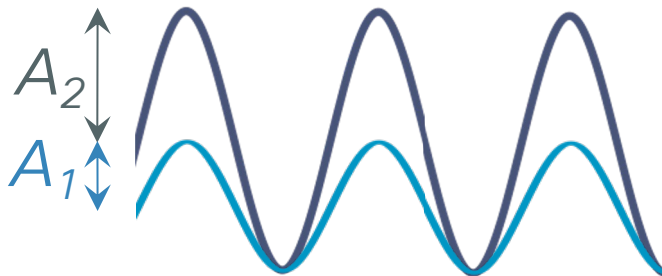
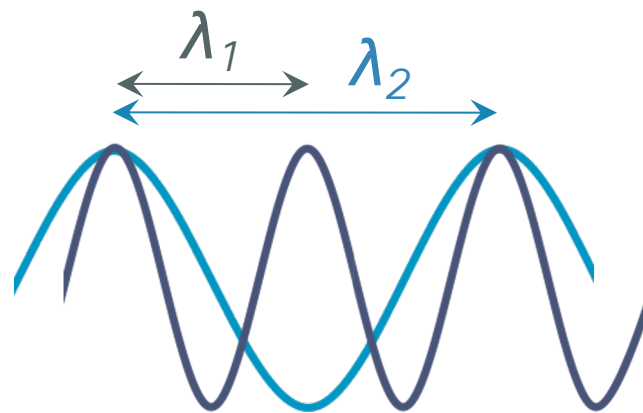
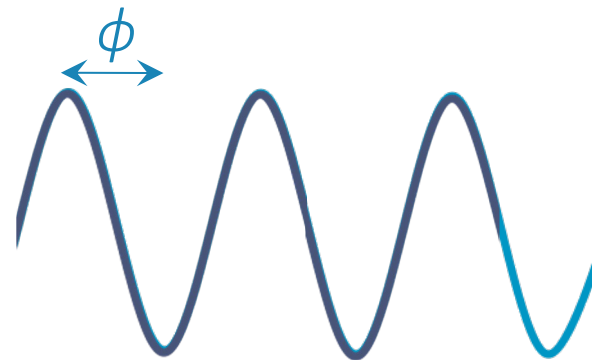
- 2.4 GHz = 12.5 cm

- 5.0 GHz = 6 cm

- 6.0 GHz = 5 cm

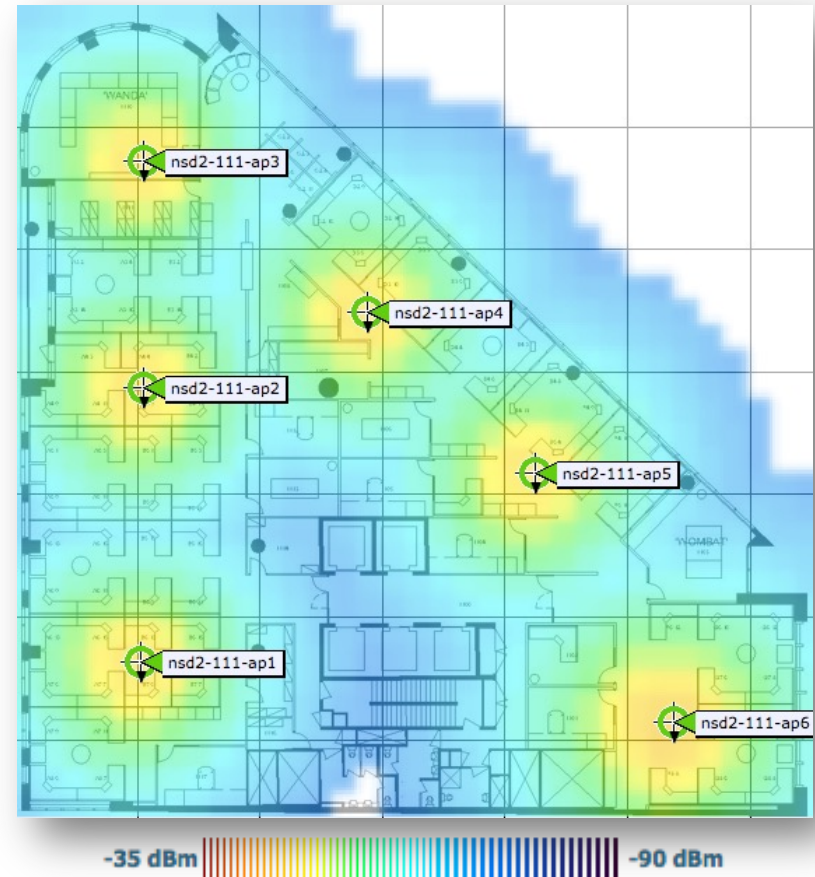
- Amplitude

- Phase



RF Mathematics

- dB is a logarithmic ratio of values (voltages, power, gains, losses)
- We add gains
- We subtract losses
- dBm is a power measurement relative to 1 mW
- dBi is the forward gain of an antenna compared to isotropic antenna



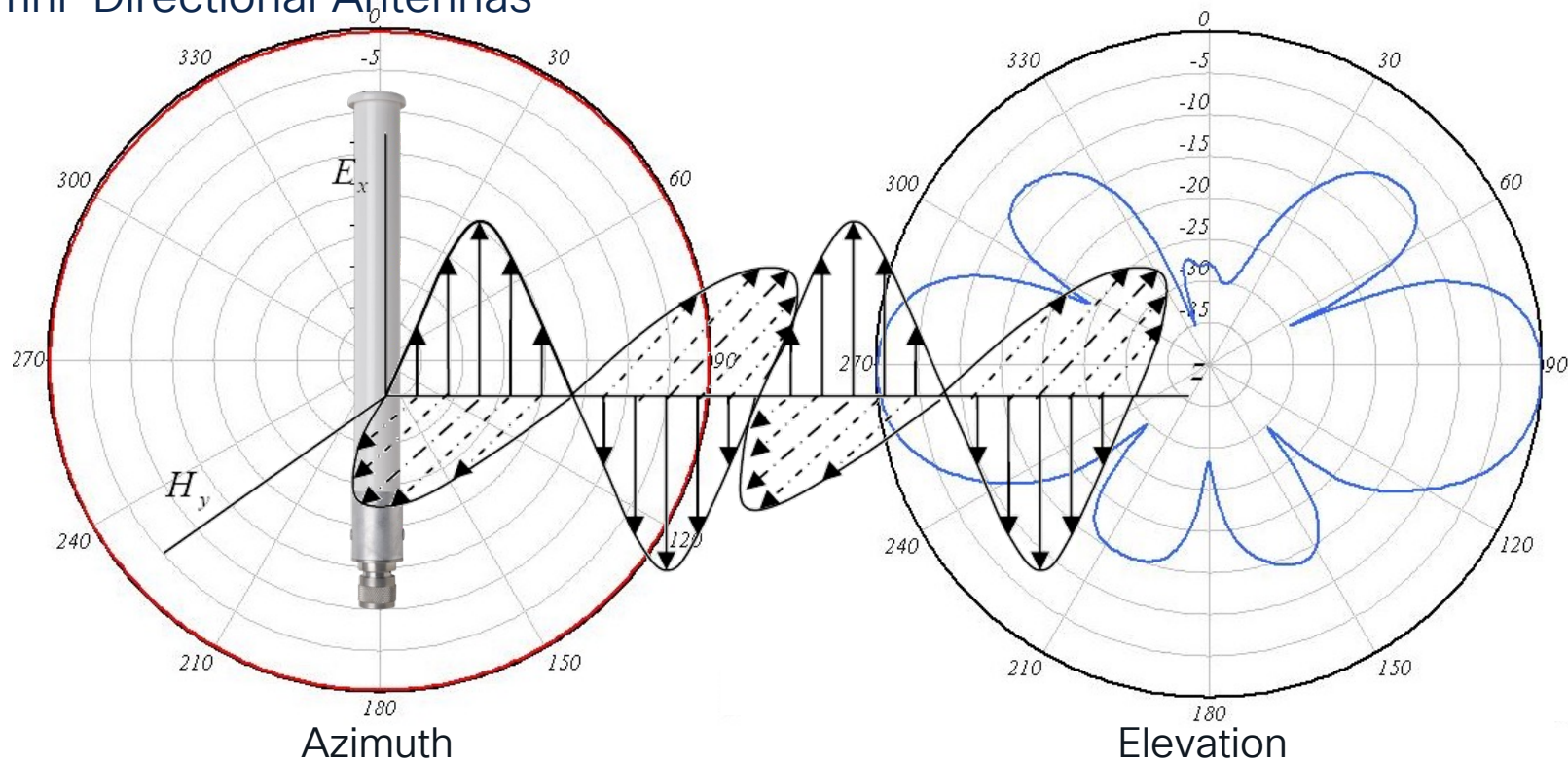
Interference and Signal to Noise Ratio

- Any RF signals other than what we want is interference
- SNR is a ratio
- The signal strength is a result of
 - Transmit power
 - Receive sensitivity
- Two Levers
 - Increase the signal
 - Or decrease the noise

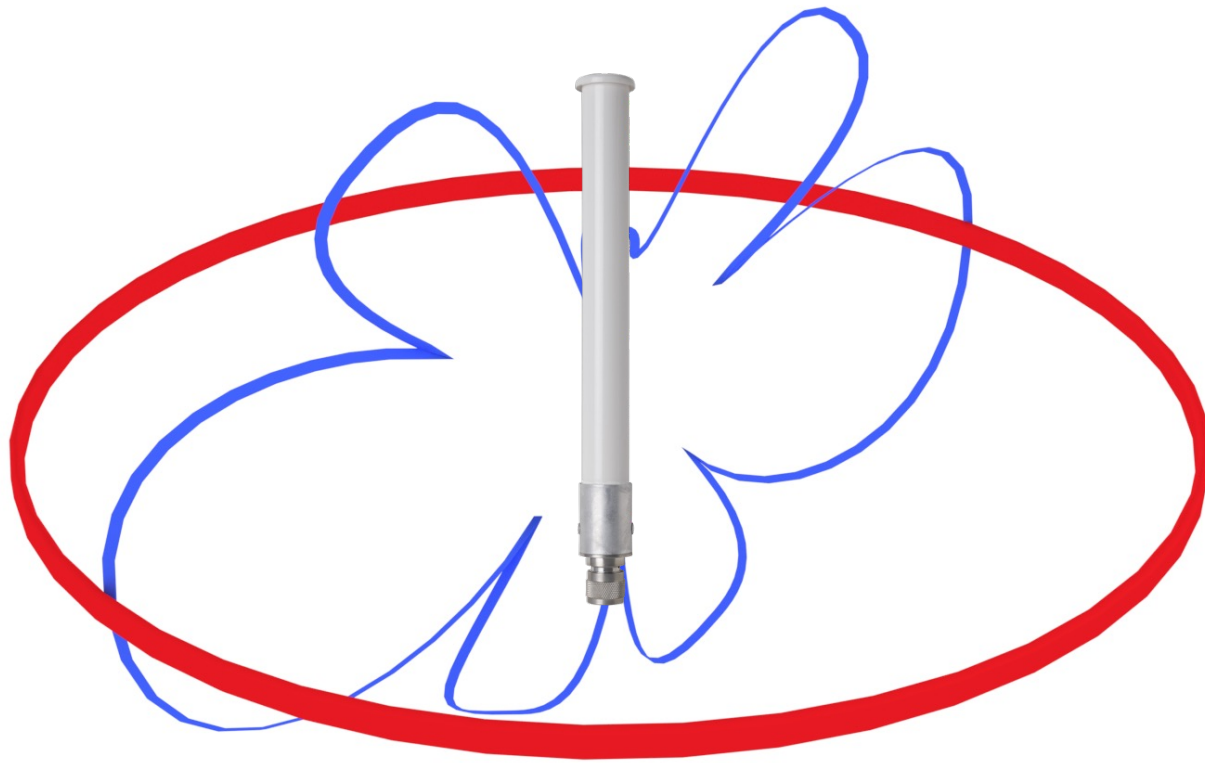


Antenna Design

Omni-Directional Antennas

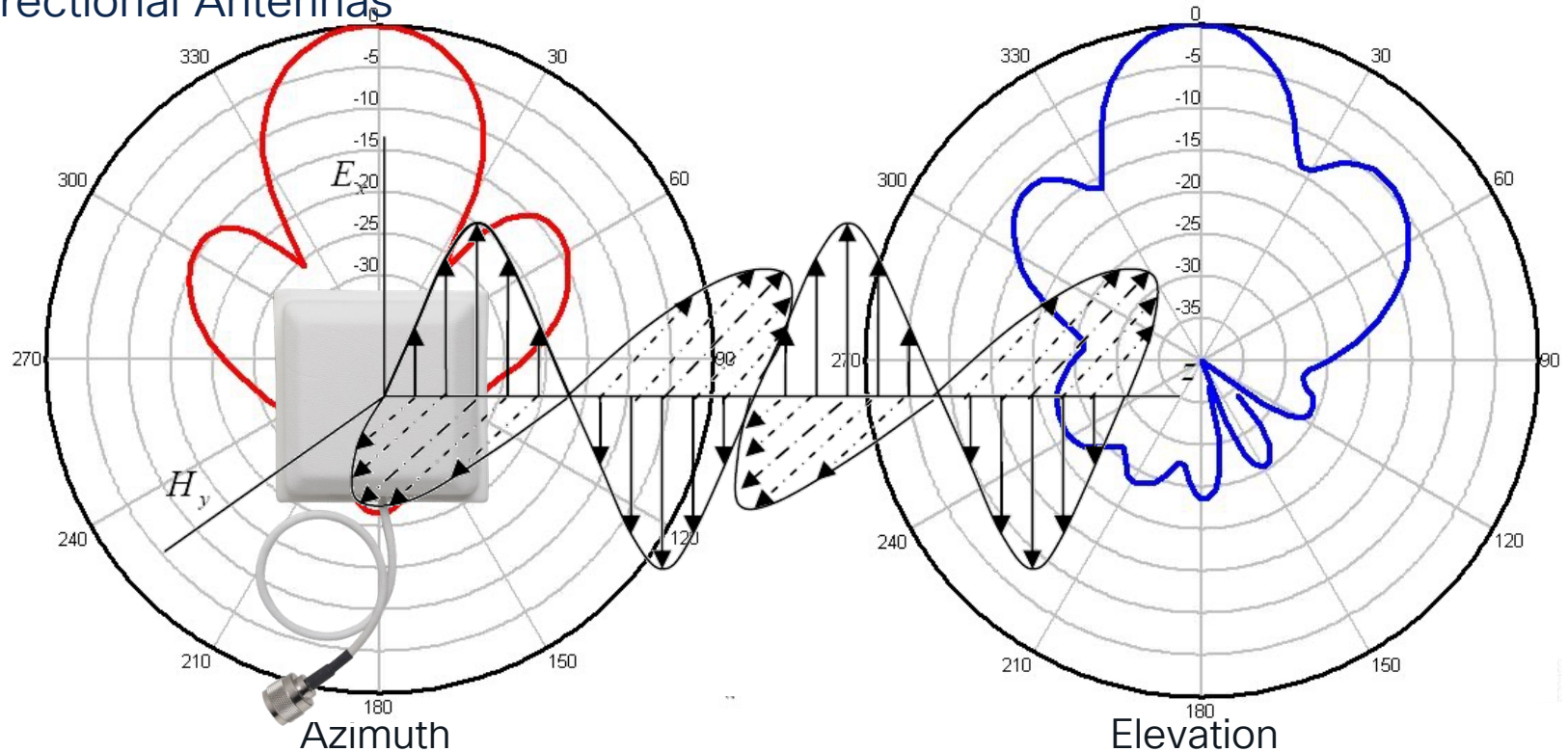


Azimuth and Elevation Planes



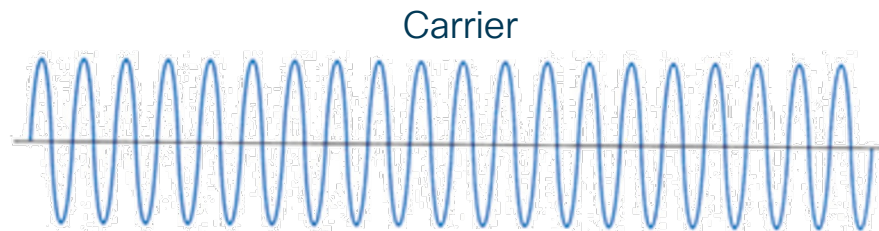
Antenna Design

Directional Antennas



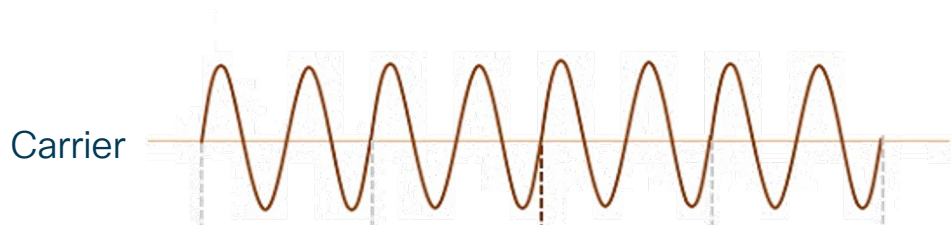
Digital Modulation Techniques

- Three basic methods
 1. Modulate the Amplitude
 2. Modulate the Frequency
 3. Modulate the Phase

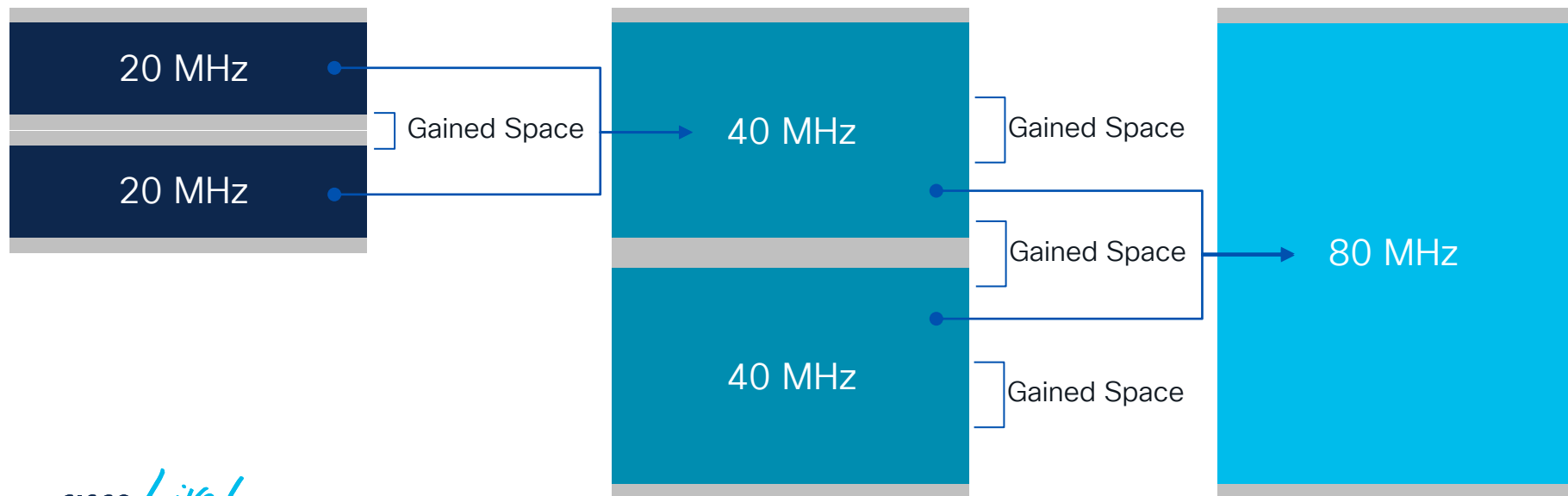


Digital Modulation Techniques

- Quadrature Phase Shift Keying (QPSK)
 - Each possible shift represents 2 bits
- Quadrature Amplitude Modulation (QAM)
 - Symbols are a combination of amplitude and phase
 - High Spectral Efficiency
 - Difficult to demodulate in the presence of noise



Channel Aggregation



Wi-Fi Spectrum

2.4 GHz Channels

80 MHz

Wavelength 12.5cm - 4.9" to 12.0cm - 4.7"

ISM Band	2407 + 5 X Ch. Number		
Channel	1	6	11
Center Freq	2.412	2.437	2.462

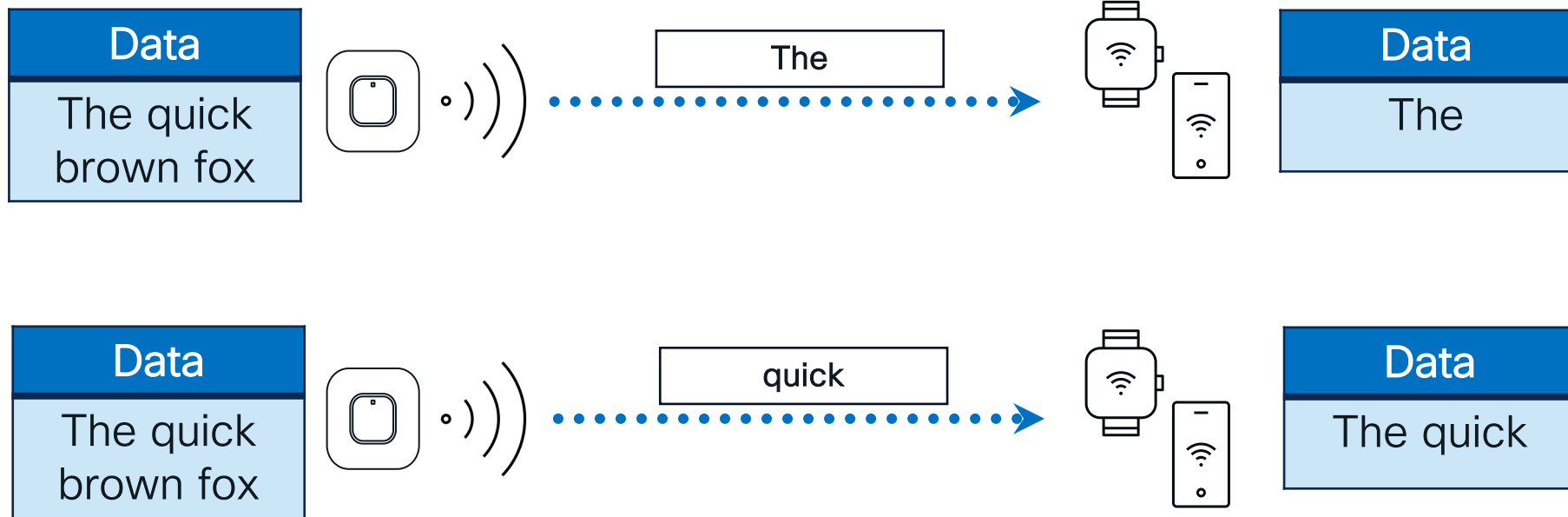
5 GHz Channels

500 MHz

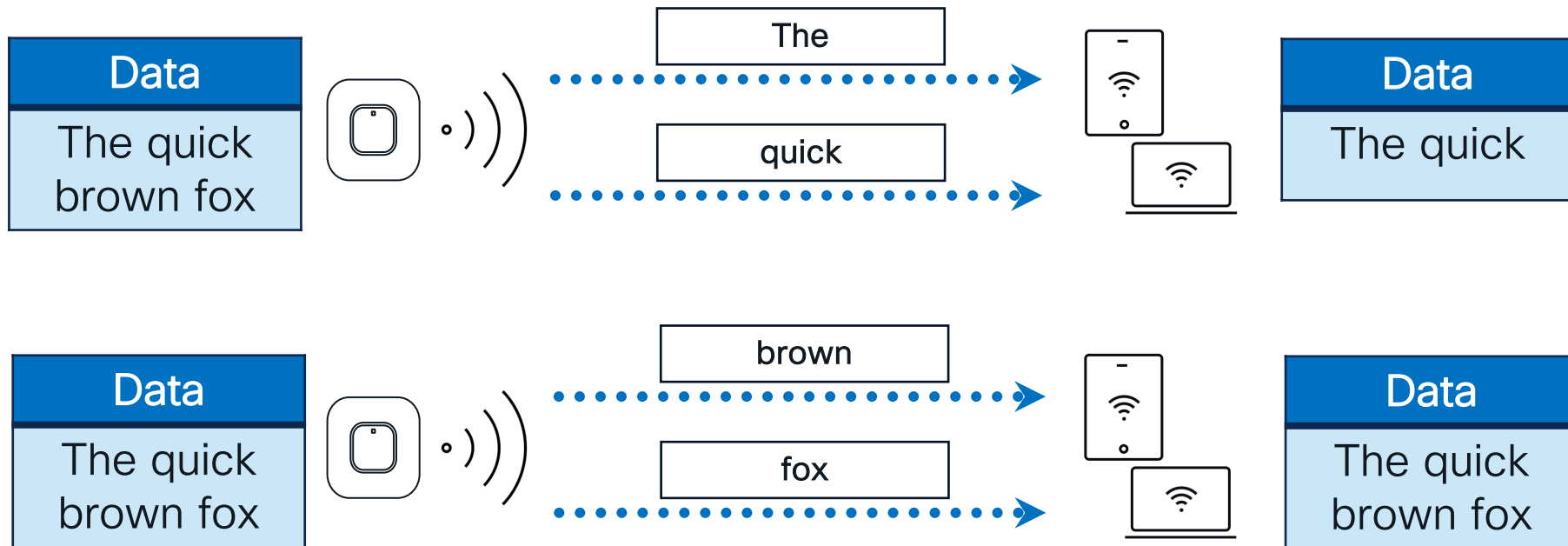
Wavelength 5.8cm - 2.3" to 5.1cm - 2.0"

Radio Band		DFS Channels												DFS Channels												Qty	
Center Freq		U-NII-1				U-NII-2a				TDDr								U-NII-3									
		5.180	5.200	5.220	5.240	5.260	5.280	5.300	5.320	5.500	5.520	5.540	5.560	5.580	5.600	5.620	5.640	5.660	5.680	5.700	5.720	5.740	5.760	5.780	5.800	5.820	Qty
25	20 MHz	36	40	44	48	52	56	60	64	100	104	108	112	116	120	124	128	132	136	140	144	149	153	157	161	165	25
11	40 MHz	38			46	54	62			102		110		118		126		134		142		151		159			11
8	80 MHz			42			58				106				122				138				155				8
2	160 MHz				50								114														2
		165 was GSM, now U-NII-3																									

Spatial Multiplexing



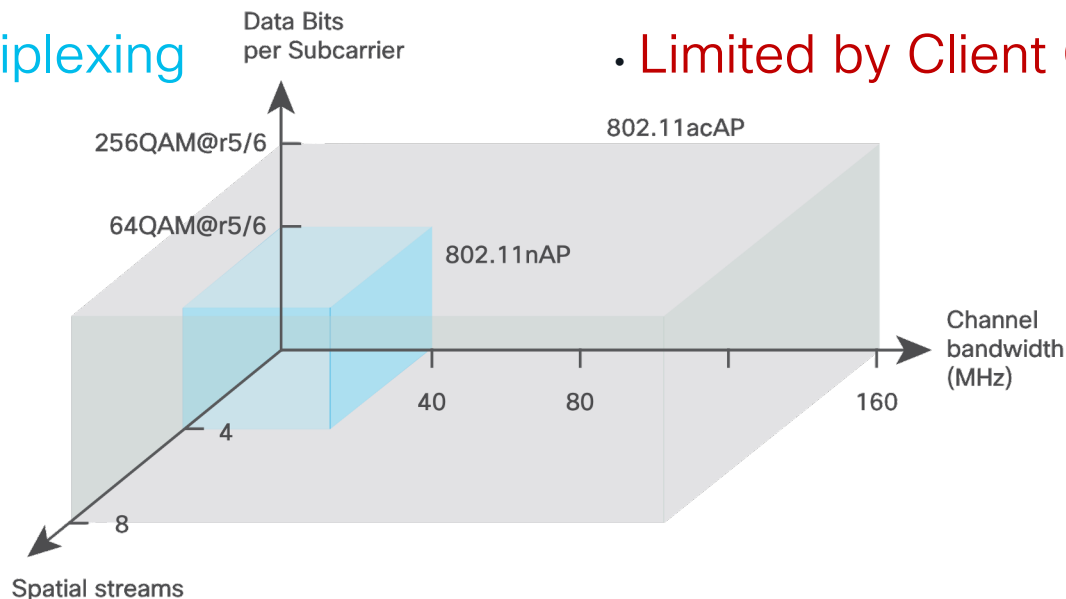
Spatial Multiplexing



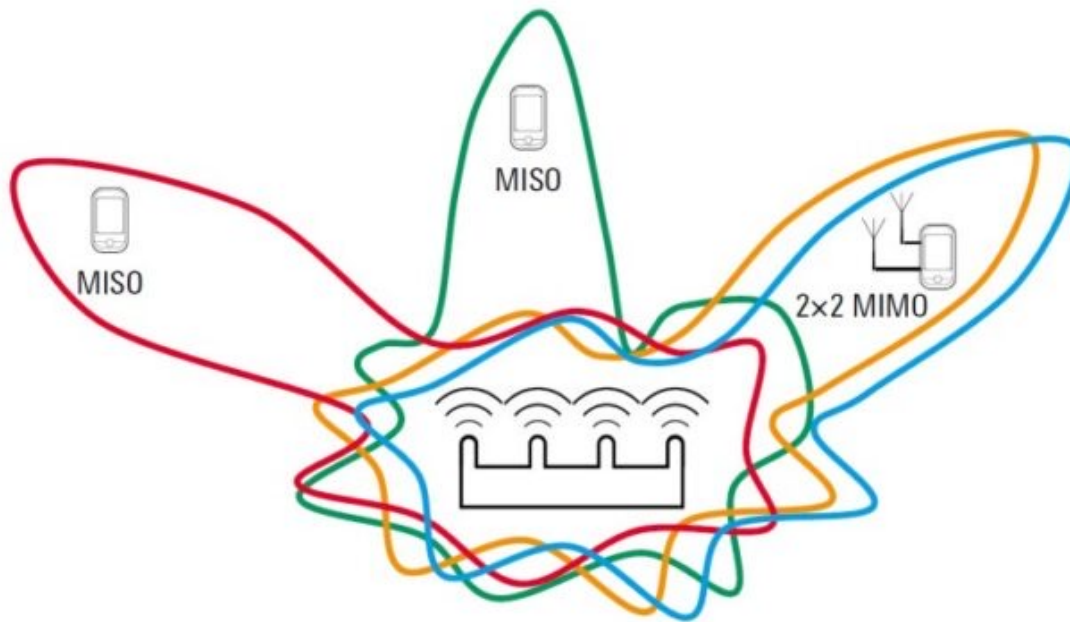
Three Dimensions to Wi-Fi Performance

- Digital Modulation
- Channel Aggregation
- Spatial Multiplexing

- Limited by SNR
- Limited by Spectrum Availability
- Limited by Client Capability



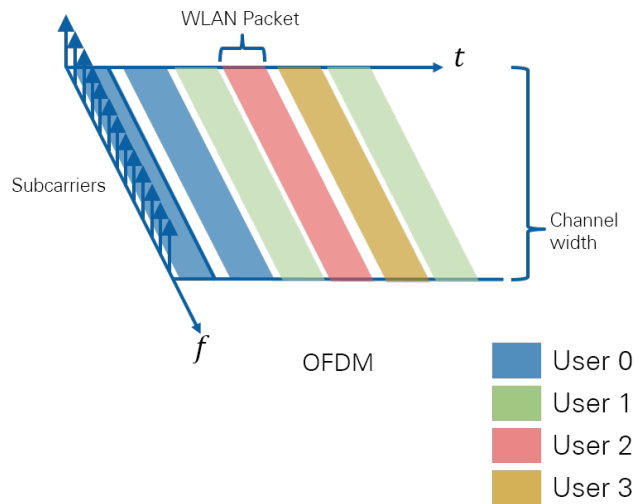
Multi-User MIMO



Multi-Carrier Modulation

- Orthogonal Frequency Division Multiplexing (OFDM)
 - Combines modulation and multiplexing techniques to further improve spatial efficiency
 - The transmission channel is divided into subchannels or subcarriers
 - To avoid overlap between subcarriers, they are orthogonal (at 90° angle) to one another
 - Modulation techniques such as QPSK or QAM are then used in each subcarrier

Improving Spectrum Efficiency



Different Perspectives

AP

AP understands its own RF environment and the success of downstream traffic

AP sees client upstream data rate and the 'retry' bit, but can only infer why there is a difference

AP has visibility of neighbouring cells their client load

Client

Client has limited awareness of other clients in the cell

Client has limited awareness of neighbouring cells

Client has no awareness of cell edge location or next cell conditions

Providing the AP with the Client Perspective

What is this client?

- Form factor (phone/tablet/laptop)
- Hardware chipset
- Software OS/drivers

What is the client's perspective?

- AP RSSI
- Neighbour AP RSSI
- Retries

Where did the client go?

- 802.11 “standard” reasons
- User intervention
- Upper layer reasons

What does the AP know?

- Neighbour list
- AP load

Client Analytics

- On a Cisco Network, after association, client sends an unsolicited, encrypted action frame with vendor-specific subtype

- Apple

- Platform (“iPhone 15”)
- OS (“iOS 17.1.1”)

- Samsung

- Platform (“Galaxy 22 Ultra”)
- OS (“Android 14.1”)
- Manufacturer Build (“Samsung v5.917”)
- SP Build (“AT&T v4.1.17”)

- Intel (AX200 and later)

- Hardware model (“AX210”)
- Driver version (“iOS 17.1.1”)
- OS (“Win 11.0.12”)
- AC/DC voltage (“AC”)

4 matching clients

Status	Description	Last seen	Usage	Device type, OS	IPv4 address	Policy
Wireless	Karas-MacBook-Air-3	Apr 24 15:03	811.8 MB	Mac OS X	192.168.10.17	Normal
Wireless	DAHUCABY-M-C9V9	Apr 24 15:03	1.70 GB	Apple iPhone	192.168.10.7	Normal
Wireless	iPhone-3	Apr 24 15:03	4.40 GB	iPhone 13, iOS15.6.1	192.168.10.15	Normal
Wireless	DH-iPad-Air					

FYI

Status	last seen Nov 25 20:44
SSID	blizzard
Access point	SFO12-3-AP22 topology
Splash	N/A
User	ksahin@cisco.com (802.1X login)
Device type, OS	Apple iPad Pro, iOS17.1.1
Capable Wi-Fi standards	802.11ax - 2.4, 5, and 6 GHz, 802.11r, Fastlane capable details
Tools	history packet capture disconnect client

Detail Information Jan 3, 2023 11:52 AM

Device Info	Connectivity	RF	iOS Analytics
Information			
Device Type	iPad Pro (11 inch) (2nd gen)		
Operating System	iOS 13.5.1		
User Name	--		
Host Name	WTMEs-iPad		
MAC Address	3C:7D:0A:CC:D1:DF		
IPv4 Address	10.70.1.95		
IPv6 Address	fe80::cf8:8ee:9011:c255		
Status	Connected		
VLAN ID	70		
Association Protocol	Wi-Fi 6		
Protocol Capability	Wi-Fi 6		

MacOS: supported on Intel platforms since 2918, added to Mx platforms in June 2023
Samsung details are not supported in Meraki Dashboard yet

802.11 Reason Codes

- 802.11 says “why” one side terminates the connection
 - ~70 possible reasons
 - Reasons are only “L1 or L2”
 - No OS or upper layer event considered
 - No user action considered

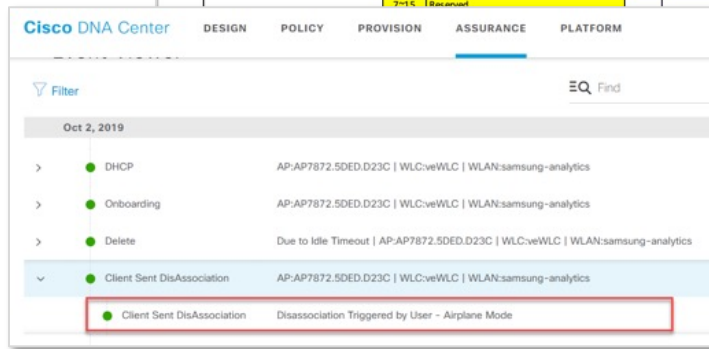
Table 9-49—Reason codes

Reason code	Name	Meaning
0		Reserved
1	UNSPECIFIED_REASON	Unspecified reason
2	INVALID_AUTHENTICATION	Previous authentication no longer valid
3	LEAVING_NETWORK_DEAUTH	Deauthenticated because sending STA is leaving (or has left) the BSS
4	REASON_INACTIVITY	Disassociated due to inactivity
5	NO_MORE_STAS	Disassociated because AP is unable to handle all currently associated STAs
6	INVALID_CLASS2_FRAME	Class 2 frame received from nonauthenticated STA
7	INVALID_CLASS3_FRAME	Class 3 frame received from nonassociated STA

Understanding Client Behaviour

- Apple, Intel and Samsung clients will send additional reason codes upon disassociation
- Apple adds 9 upper layer reasons
 - DHCP failed
 - EAP timed out
 - 802.1X failed
 - Device is idle
 - Captive portal security failed
 - Decryption failed
 - Wi-Fi interface disabled
 - User triggered disassociation
 - AP triggered disassociation
- Samsung enhances the Apple reason codes with more details

STEP 1 Reason [15:8]		Additional Reason Code [15:0]		STEP 3 Reason [3:0]		AP	STA
0	Reserved	0-15	Reserved	0-15	Reserved		
1	User Triggered Disconnect	0	Unspecified	0	Unspecified		
		1	Power Off or Wi-Fi Off		1: Sent but not acked		
		2	Connect to other AP		2: Not received (Sent and acked well)		
		3	Remove AP profile		3: Received but something wrong		
		4	Airplane mode On		4-15: Reserved		
		5-15	Reserved				
2	L2 Connection	0	Unspecified				
		1	Association				
		2-15	Reserved				
3	4-Way Handshake	0	Unspecified				
		1	M1 for 4-Way Handshake				
		2	M2 for 4-Way Handshake				
		3	M3 for 4-Way Handshake				
		4	M4 for 4-Way Handshake				
		5	M1 for Groupkey Handshake				
		6	M2 for Groupkey Handshake				
		7-15	Reserved				
4	DHCP Fail	0	Unspecified				
		1	Time Out				
		2	Time out after Roaming				
		3	Lease Expired (no response for renew)				
		4	Nak in renew				
		5	Renew lease wrong IP				
		6	Internal error				
		7-15	Reserved				



iOS and Samsung Analytics

▼ Detail Information Jan 3, 2023 11:52 AM

Device Info Connectivity RF iOS Analytics

Information

Device Type	iPad Pro (11 inch) (2nd gen)
Operating System	iOS 13.5.1
User Name	--
Host Name	WTMEs-iPad
MAC Address	3C:7D:0A:CC:D1:DF
IPv4 Address	10.70.1.95
IPv6 Address	fe80::cf8:8ee:9011:c255
Status	Connected
VLAN ID	70
Association Protocol	Wi-Fi 6
Protocol Capability	Wi-Fi 6

Device Info Connectivity RF iOS Analytics

Neighbor APs (6)

Search Table

BSSID	AP Name	Channel	RSSI (dBm)	Location	Time
AC:4A:56:AE:92:CD	Assurance_9130_3	48	-49	Global/San Jose/Building 14/F	
A4:53:0E:7D:42:AD	SJC14-TME-AP10	52	-80	Global/San Jose/Building 14/F	
6C:8D:77:2E:04:2D	SJC14-F1-9164-3	100	-75	Global/San Jose/Building 14/F	
10:F9:20:FD:68:8D	SJC14-F1-9166-1	116	-61	Global/San Jose/Building 14/F	

6 Records Show Records: 10 < 1 >

The diagram illustrates a mobile device (represented by a smartphone icon) connected to five access points (APs). The connections are shown with dashed lines and labeled with their RSSI values in dBm. The APs and their RSSI values are:

- SJC14-TME-AP9 (10:B3:C6:24:B7:4D) with -54 dBm
- SJC14-TME-AP10 (A4:53:0E:7D:42:AD) with -80 dBm
- SJC14-F1-9166-1 (10:F9:20:FD:68:8D) with -61 dBm
- SJC14-F1-9164-3 (6C:8D:77:2E:04:2D) with -75 dBm
- Assurance_9130_3 (AC:4A:56:AE:92:CD) with -49 dBm

Cisco DNA Center DESIGN POLICY PROVISION ASSURANCE PLATFORM

Filter EQ Find

Oct 2, 2019

- > DHCP AP:AP7872.5DED.D23C | WLC:veWLC | WLAN:samsung-analytics
- > Onboarding AP:AP7872.5DED.D23C | WLC:veWLC | WLAN:samsung-analytics
- > Delete Due to Idle Timeout | AP:AP7872.5DED.D23C | WLC:veWLC | WLAN:samsung-analytics
- ▼ Client Sent DisAssociation AP:AP7872.5DED.D23C | WLC:veWLC | WLAN:samsung-analytics
 - Client Sent DisAssociation Disassociation Triggered by User - Airplane Mode

Intel Device Analytics

FYI

Station Information

Reports: Hardware model, OS version, driver version, manufacturer, voltage, system model

Helps troubleshoot and identify Intel devices based on their specific attributes

Low RSSI

Reports: When RSSI is below -75dBm for 5 mins, Last Reported Time

Identify sticky client issues and understand why a roam has not triggered

Neighboring APs

Reports: Top 5 APs based on RSSI, Roaming Reasons, Missed Beacons and 11v Recommendations

Provides a client-side view of the network and the reason for a roam

Temporary Disconnects

Reports: When a client disconnection is due to a Missed Beacon

Helps understand why a client has disconnected from the network

Unknown APs

Reports: Reports a list of APs not part of Neighboring AP report

Helps troubleshoot issues with non-valid IEs and see why AP is not responding

Failed APs

Reports: Reports invalid IEs in Beacons, Probe Responses and Association Responses

Used to identify and flag rogue BSSIDs

Intel Connectivity Analytics

Detail InformationJun 2, 2022 3:19 PM

Device InfoConnectivityRFIntel Connectivity Analytics

Information

Device Type	Dell Inc. Inspiron 5406 2n1
Operating System	Windows 10
User Name	--
Host Name	OTA-wind11-156-USDT
MAC Address	A4:6B:B6:40:37:51
IPv4 Address	40.235.10.11
IPv6 Address	2000:40:235:0:352b:c7c7:c720:322b (7)
Status	Connected
VLAN ID	2435
Association Protocol	Wi-Fi 6E
Protocol Capability	Wi-Fi 6E
L3 Virtual Network	--

Connection Information

Detail InformationDec 17, 2020 10:16 AM

Device InfoConnectivityRFIntel Connectivity Analytics

Roam EventsView All Roam Events in Event Viewer

Reason Code: Low RSSISelected AP: AP9120.1234BSSID: 6C:B2:AE:C7:AB:00RSSI: -50 dBm

The diagram illustrates a device (labeled 'OTA-wind11-156-USDT') connected to several access points (APs). The connections are color-coded: red for -80 dBm and green for -34 dBm. The APs shown are AP9120.1234 (BSSID: 6C:B2:AE:C7:AB:00), AP9120.1236 (BSSID: 6C:B2:AE:C7:AB:00), AP9120.1238 (BSSID: 6C:B2:AE:C7:AB:00), and AP9120.1239 (BSSID: 6C:B2:AE:C7:AB:00).

Last 5 Reported ErrorsView All Reported Errors in Event Viewer

Last 5 Temporary Disconnection ReportsView All Temporary Disconnection Reports

Last 5 Low RSSI ReportsView All Low RSSI Reports

> June 11, 11:56 AM10 Access Points

> June 11, 10:58 AM8 Access Points

June 11, 11:53 AMAccess Point: AP9120.1236BSSID: 6C:B2:AE:C7:AB:00

June 11, 11:50 AMAccess Point: AP9120.1236

June 11, 10:34 AMAccess Point: AP9120.1239BSSID: 6C:B2:AE:C7:AB:00RSSI: -80 dBm

June 11, 10:17 AM

Event ViewerEQ Find

FilterExportGo to Global Event Viewer

Event is Roam Report

May 9, 2022

>	Intel	Roam Report	9:25:35.935 PM	RSSI: -47 dBm AP: OTA-9136B-17E0 Reason Code Low RSSI Type: Device Analytics - Intel
>	Intel	Roam Report	8:55:33.628 PM	RSSI: -47 dBm AP: OTA-9136B-17E0 Reason Code Better AP Type: Device Analytics - Intel
>	Intel	Roam Report	8:25:32.200 PM	RSSI: -47 dBm AP: OTA-9136B-17E0 Reason Code Other Type: Device Analytics - Intel
>	Intel	Roam Report	7:55:30.066 PM	RSSI: -47 dBm AP: OTA-9136B-17E0 Reason Code 11v force Type: Device Analytics - Intel
>	Intel	Roam Report	7:25:28.241 PM	RSSI: -47 dBm AP: OTA-9136B-17E0 Reason Code Other Type: Device Analytics - Intel
>	Intel	Roam Report	7:25:28.241 PM	RSSI: -47 dBm AP: OTA-9136B-17E0 Reason Code Other Type: Device Analytics - Intel
>	Intel	Roam Report	6:55:27.112 PM	RSSI: -46 dBm AP: OTA-9136B-17E0 Reason Code Low RSSI Type: Device Analytics - Intel
>	Intel	Roam Report	6:25:26.366 PM	RSSI: -47 dBm AP: OTA-9136B-17E0 Reason Code Better AP Type: Device Analytics - Intel
>	Intel	Roam Report	5:55:24.129 PM	RSSI: -46 dBm AP: OTA-9136B-17E0 Reason Code Other Type: Device Analytics - Intel

Showing 1 - 9 of 48

FYI

Minimum Software Support Matrix

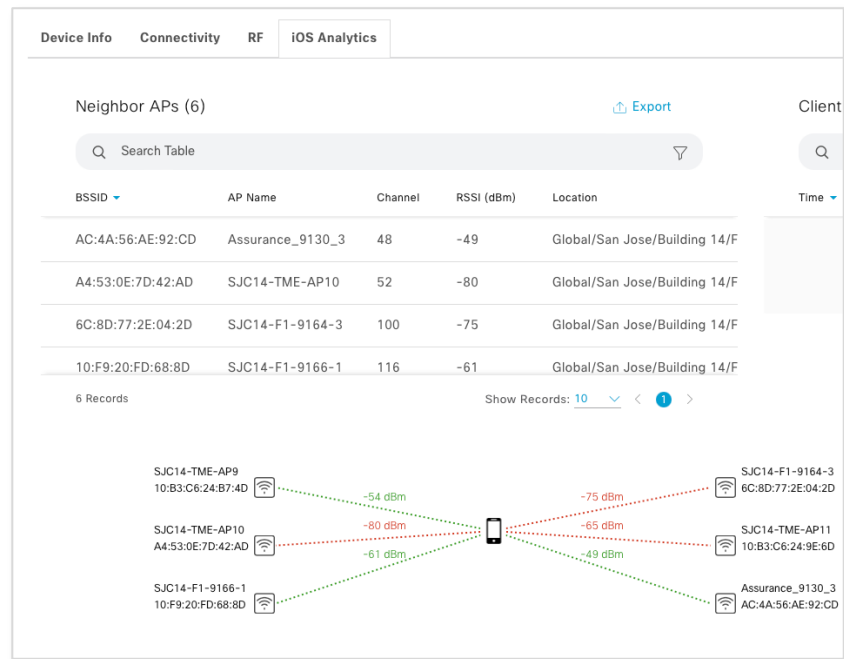
	Meraki	WLC Type	WLC Version	Catalyst Center
Intel Connectivity Analytics	MR29	IOS XE	17.6.1	2.3.3
		AireOS	N/A	N/A
Apple Analytics	MR27	IOS XE	16.12.1s	2.2.1
		AireOS	8.5	2.2.1
Samsung Analytics	MR31*	IOS-XE	17.1.1	2.2.1
		AireOS	N/A	N/A

Intel Hardware and Software Matrix

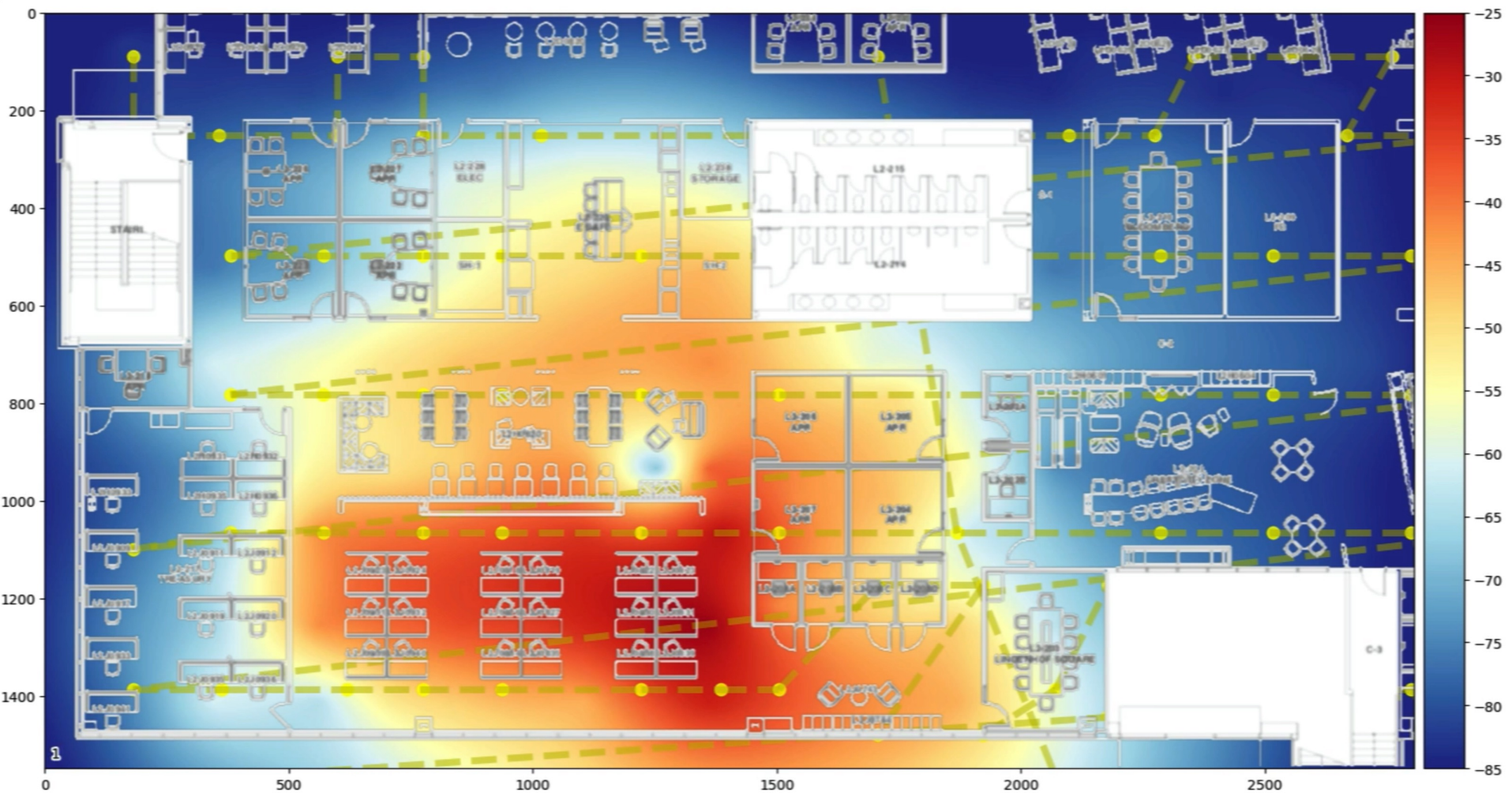
Cisco Access Point Hardware		Intel Chipset	
All Wave 2, Catalyst Wi-Fi 6/6E APs		AX200, AX201, AX210, AX211, AX411	
Cisco IOS XE WLC Software	Cisco AireOS WLC Software	Cisco Catalyst Center	Intel Driver Software
17.6.1	N/A	2.3.3	22.50.1
Cisco IOS XE WLC Hardware			
Embedded Wireless Controller on the AP and Switch			
C9800-CL			
C9800-L			
C9800-40			
C9800-80			

The Client Perspective of the Network

- Apple
 - After sending client details, iOS/macOS device sends an 802.11k unsolicited beacon report with a list of BSSID/channel/RSSI for the current SSID
- Intel
 - After sending client details, Intel clients sends an unsolicited 802.11k beacon report
 - AP can ask for an updated report, or instruct client to perform an active or passive scan
- Samsung
 - After receive client details, the AP automatically requests an 802.11k beacons report
 - AP can ask for an updated report, or instruct client to perform an active or passive scan



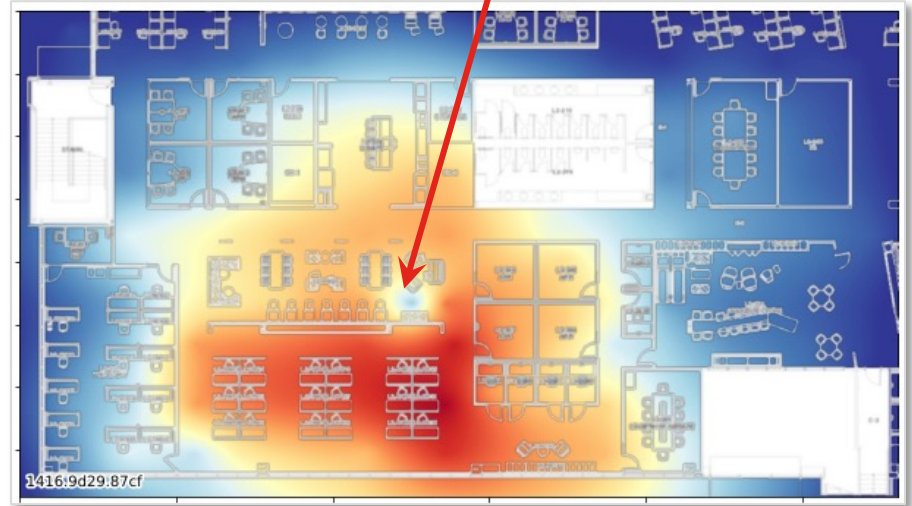
Samsung details are not yet supported in Meraki Dashboard



Mapping the RF Environment

- Using any recent Samsung Galaxy or Intel client, trigger a solicited 802.11k beacon report

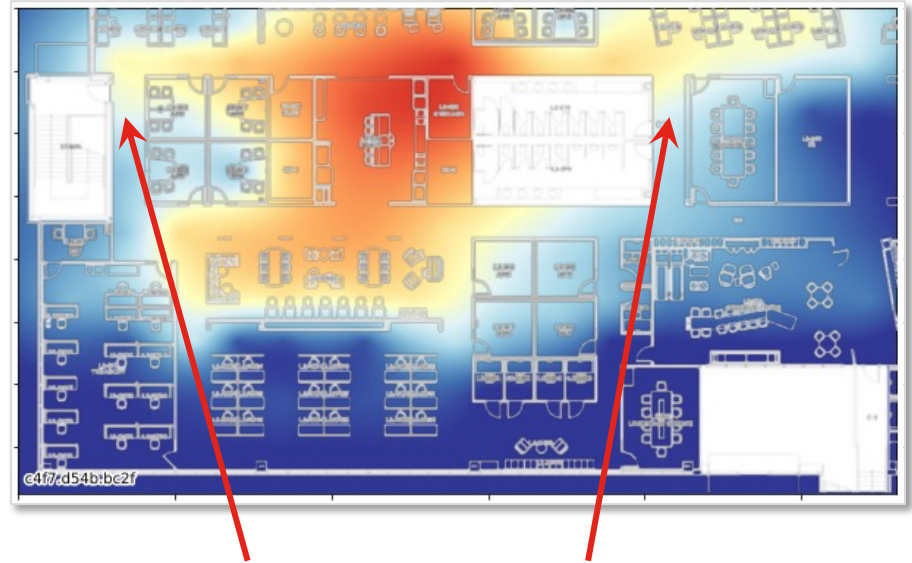
Fast fading coverage gap behind a pillar



Source code available at <https://github.com/jhenry-github/floor-heatmap>

Mapping the RF Environment

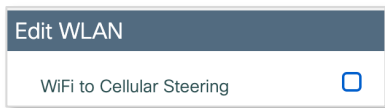
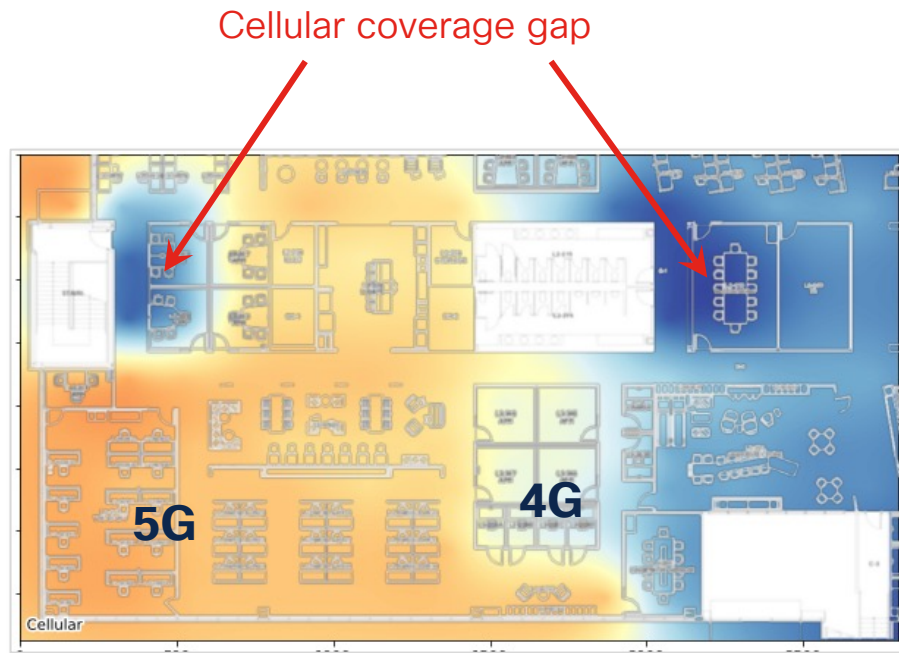
- Using any recent Samsung Galaxy or Intel client, trigger a solicited 802.11k beacon report
 - Intel clients also send “Bad Coverage” and “Temporary disconnection” reports
 - “I hear you, but RSSI below -75 dBm for x minutes”
 - “Moved to you, but lost contact with AP1 at -X dBm Y minutes ago”



Signal drops as client turns the corner

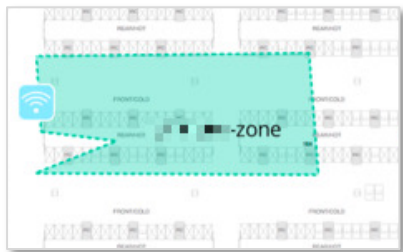
Mapping the RF Environment

- Using any recent Samsung Galaxy or Intel client, trigger a solicited 802.11k beacon report
- Samsung clients also send cellular signal in addition to Wi-Fi
 - Map indoor cellular coverage
 - Automatically push Samsung clients to cellular at the Wi-Fi domain edge



Why it Matters

- Better Troubleshooting
 - 96% of STAs disconnecting in this zone are Galaxy S23 running Android 14



- Proactive maintenance
 - Day 0 issue affects Android 14
 - Identify which devices run this version

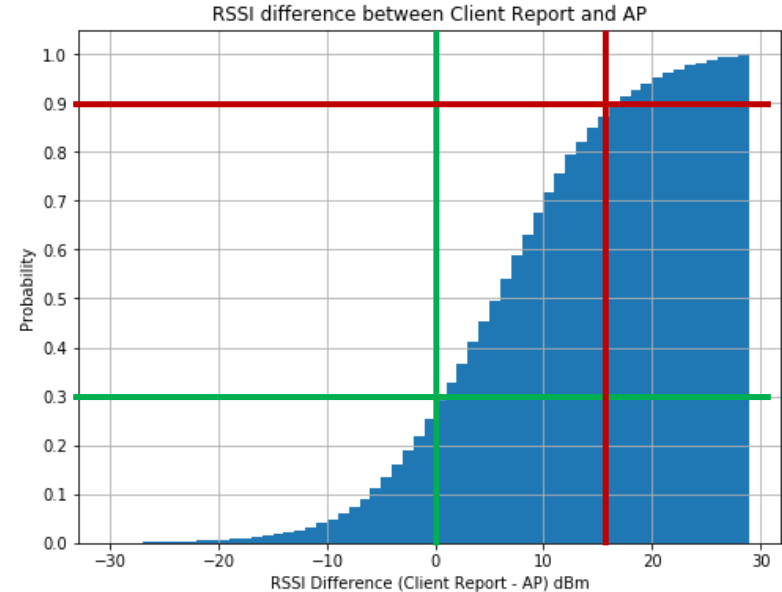
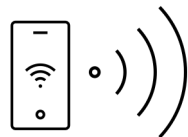
- Roaming Issues
 - iPhone 15 roams here
 - Short connection drops reported



- Galaxy S23 roams here
- No issues reported

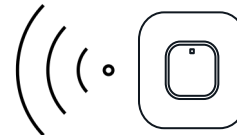
Device Disparity

- Six months aggregated view of the network designed “from the ceiling”
 - AP power set with “AP to AP” in mind (max tx power)
 - RSSI seen by the AP is lower than that seen by Client
- RSSI difference is significant
 - 50% of the time the RSSI is 6 dB less
 - 90% of the time the RSSI is 15 dB less

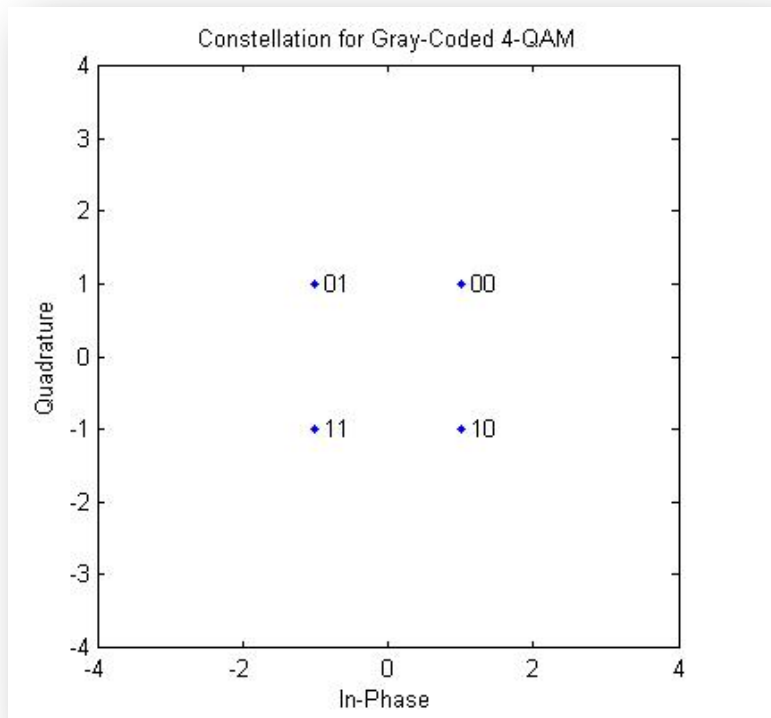


I see you at
-56 dBm

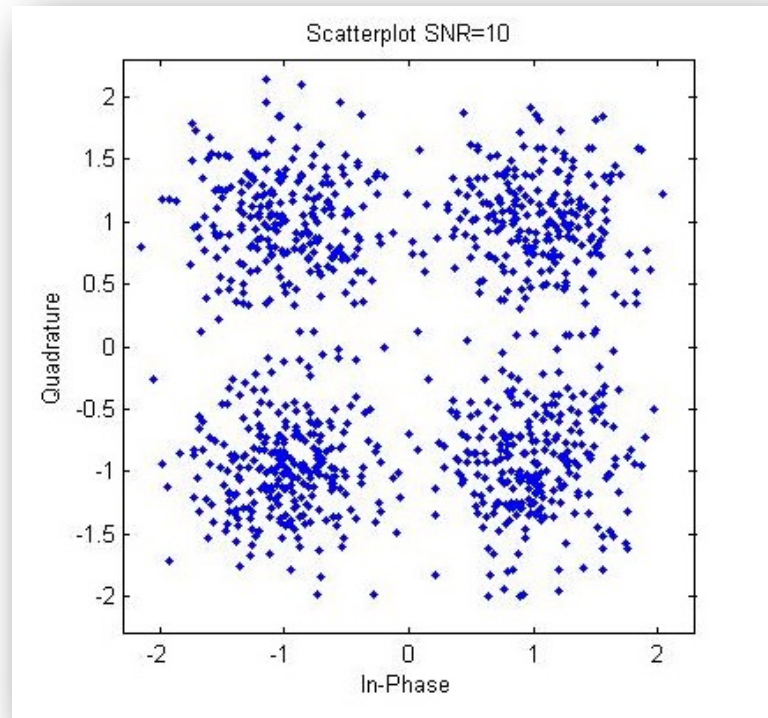
I see you at
-62 dBm



Modulation, SNR and Data Rates

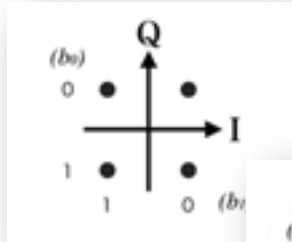


4-QAM

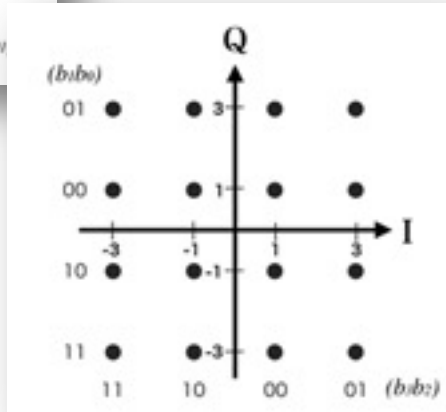


SNR=10

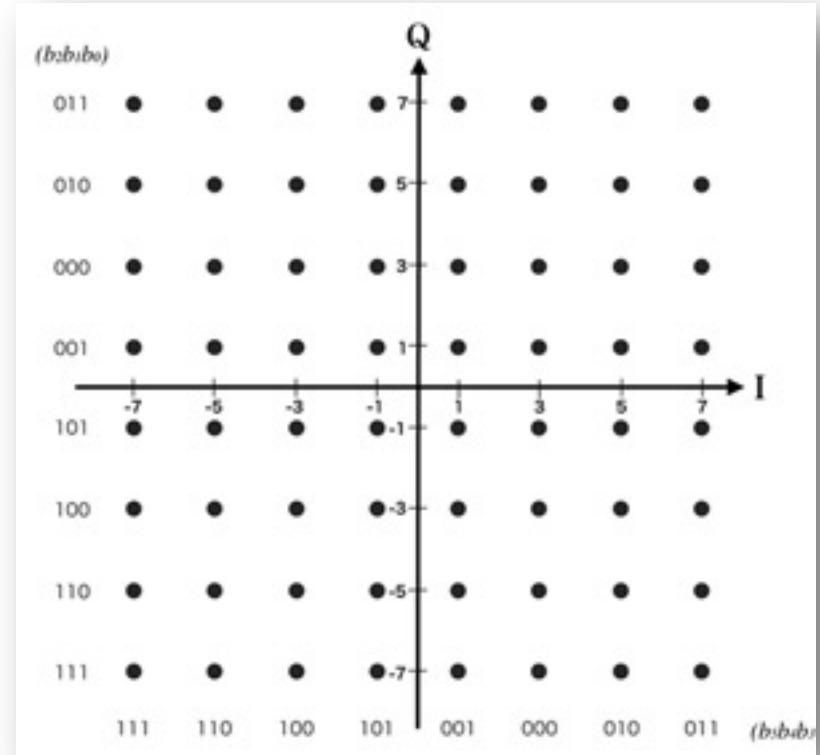
Rate vs Range and the Laws of Physics



4-QAM

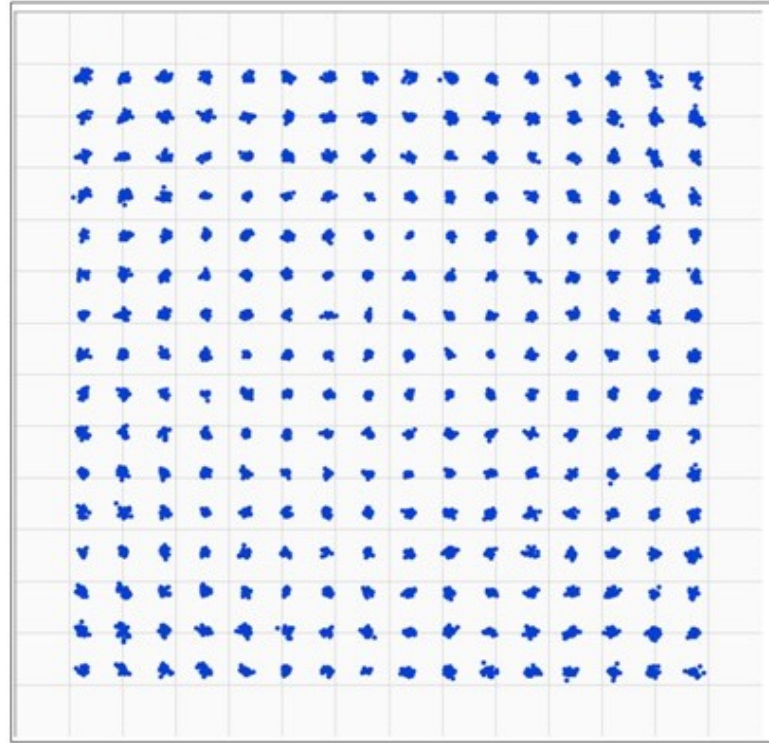


16-QAM



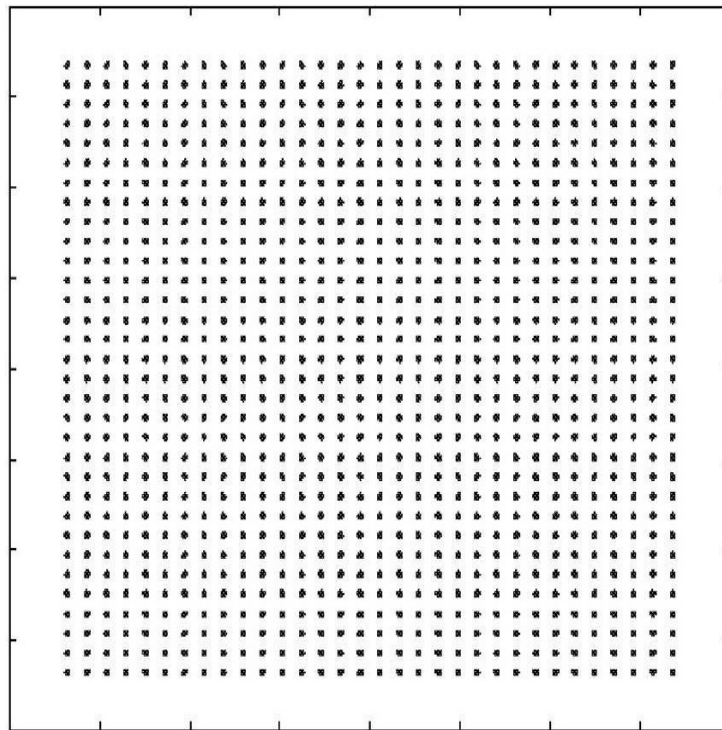
64-QAM

Rate vs Range and the Laws of Physics



256-QAM (8 bits/symbol)

Rate vs Range and the Laws of Physics

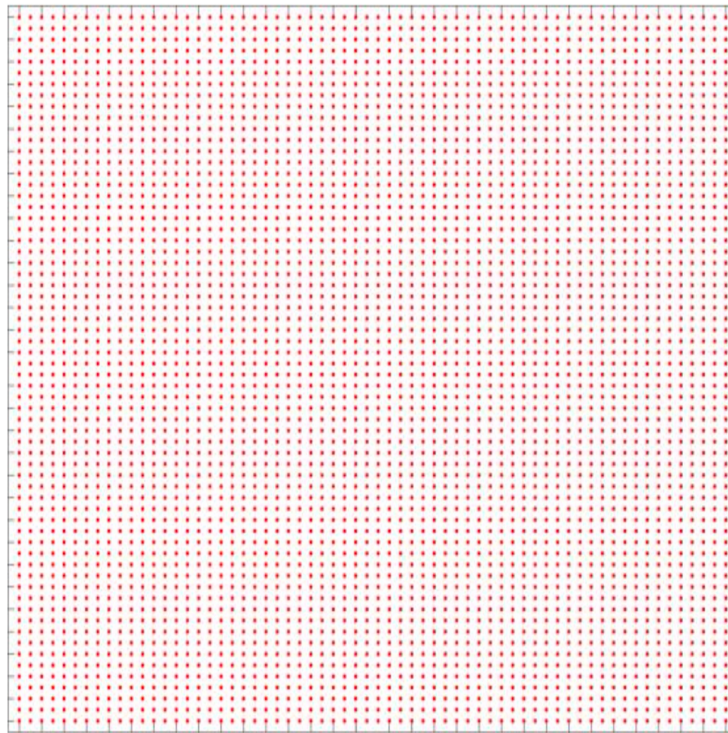


1024-QAM (10 bits/symbol)

Relationship Between Modulation and SNR

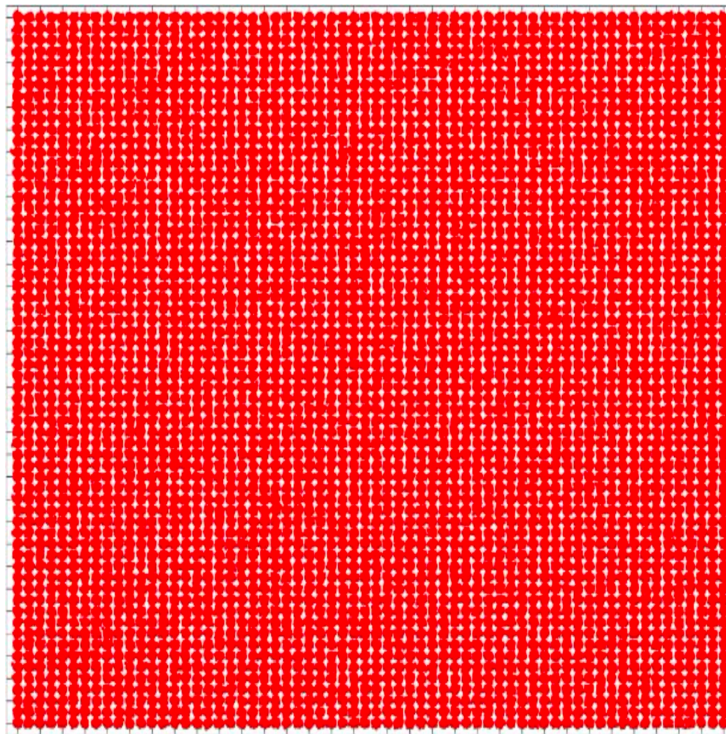
Protocol and Channel Width	MCS Value Achieved by Clients at Various Signal to Noise Ratio (SNR) Levels													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
IEEE 802.11b 20 MHz	None	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2	MCS 2
IEEE 802.11g 20 MHz	None	None	MCS 0	MCS 0	MCS 1	MCS 2	MCS 2	MCS 2	MCS 2	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4
IEEE 802.11n 20 MHz	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3
IEEE 802.11n 40 MHz	None	None	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2
IEEE 802.11ac 20 MHz	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3
IEEE 802.11ac 40 MHz	None	None	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2
IEEE 802.11ac 80 MHz	None	None	None	None	None	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1
IEEE 802.11ac 160 MHz	None	None	None	None	None	None	None	None	None	None	None	MCS 0	MCS 0	MCS 0

Improved Data Rates



4096-QAM (12 bits/symbol)

Increased Sensitivity to Noise



SNR=43

Implications of Poor Cell Design

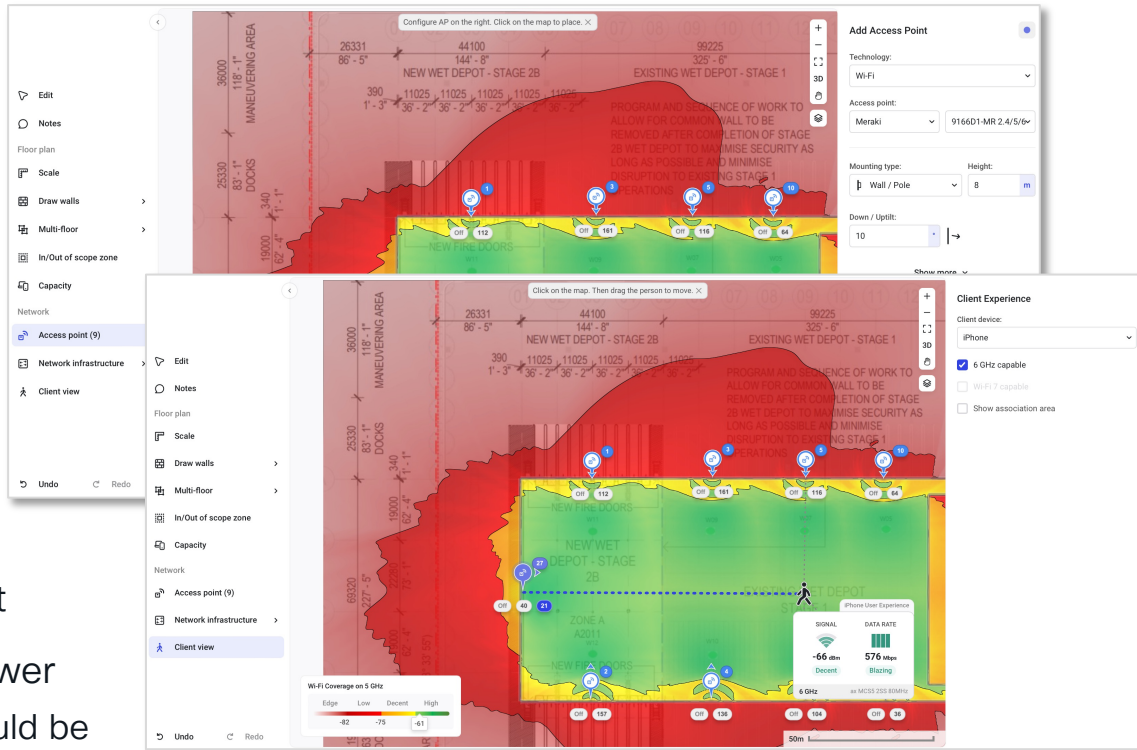
17	0.039879000	172.31.255.101	172.31.255.103	UDP	1420	34	-35 55 dB	54.0	Source port: 50857	Destination port: search-agent
18	0.040266000	172.31.255.101	172.31.255.103	UDP	1420	34	-35 55 dB	54.0	Source port: 50857	Destination port: search-agent
19	0.040648000	172.31.255.101	172.31.255.103	UDP	1420	34	-34 56 dB	54.0	Source port: 50857	Destination port: search-agent
20	0.041938000	172.31.255.101	172.31.255.103	UDP	1420	34	-34 56 dB	54.0	Source port: 50857	Destination port: search-agent
21	0.042217000	172.31.255.101	172.31.255.103	UDP	1420	34	-29 61 dB	36.0	Source port: 50857	Destination port: search-agent
22	0.043444000	172.31.255.101	172.31.255.103	UDP	1420	34	-29 61 dB	12.0	Source port: 50857	Destination port: search-agent
23	0.043445000		Cisco_0a:04:2e (RA)	802.11	40		-45 45 dB	12.0	Acknowledgement, Flags=.....C	
24	0.043850000	172.31.255.101	172.31.255.103	UDP	1420	34	-34 56 dB	54.0	Source port: 50857	Destination port: search-agent
25	0.044245000	172.31.255.101	172.31.255.103	UDP	1420	34	-34 56 dB	54.0	Source port: 50857	Destination port: search-agent
26	0.044641000	172.31.255.101	172.31.255.103	UDP	1420	34	-34 56 dB	54.0	Source port: 50857	Destination port: search-agent
27	0.045023000	172.31.255.101	172.31.255.103	UDP	1420	34	-35 55 dB	54.0	Source port: 50857	Destination port: search-agent
28	0.045750000	172.31.255.101	172.31.255.103	UDP	1420	34	-29 61 dB	36.0	Source port: 50857	Destination port: search-agent
29	0.046223000	172.31.255.101	172.31.255.103	UDP	1420	34	-29 61 dB	36.0	Source port: 50857	Destination port: search-agent
30	0.047450000	172.31.255.101	172.31.255.103	UDP	1420	34	-29 61 dB	12.0	Source port: 50857	Destination port: search-agent
31	0.047450000		Cisco_0a:04:2e (RA)	802.11	40		-47 43 dB	12.0	Acknowledgement, Flags=.....C	

- Based on received AP signal strength, client transmits at 54 Mbps
- Client signal strength at the AP is too low, and AP does not send the acknowledgement
- Client continues to decrease the data rate and retransmit
- AP finally acknowledges the packet has been received at 12Mbps

Wireless Network Design

Planning Tools

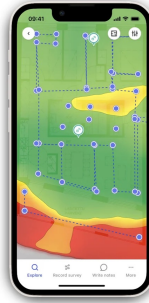
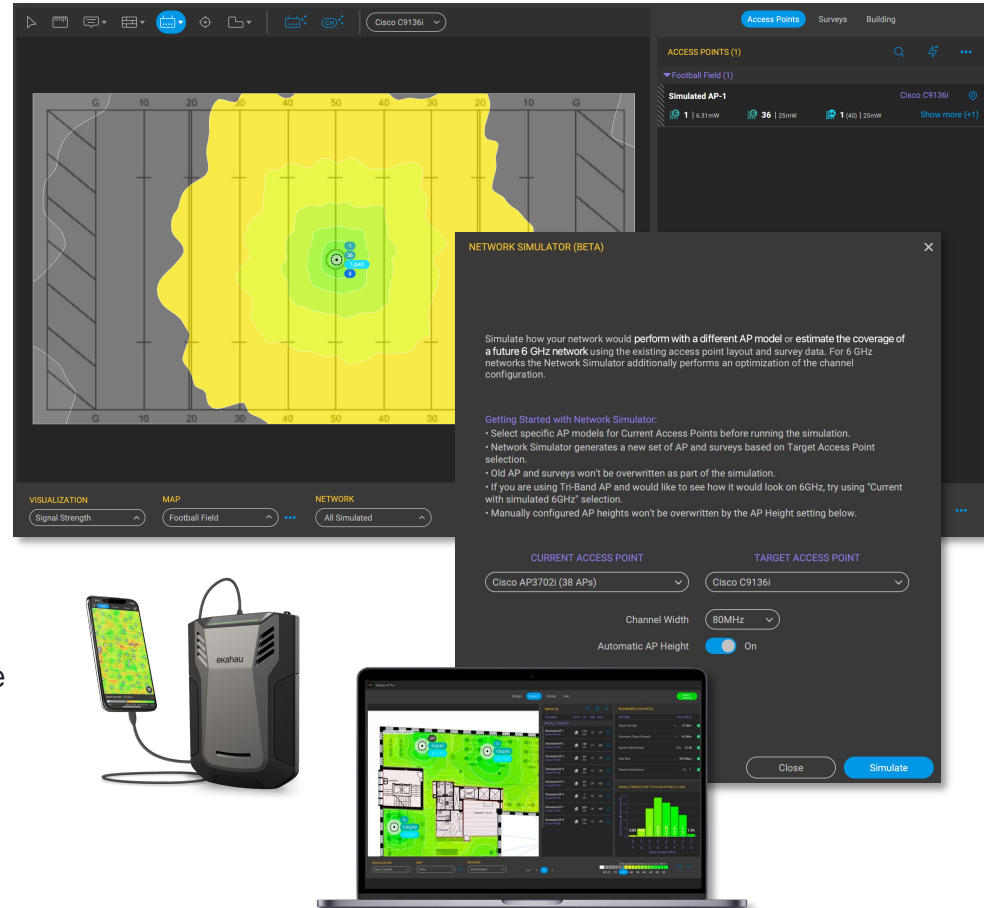
- All models are wrong
- Some of them are useful
- Planning tools can help develop a preliminary design and identify potential deployment issues
- The model MUST be calibrated to ensure what you see is what you get
- Always remain conservative with power
 - Middle to lower end of the range should be selected
 - Many tools default to high power and can be very misleading
 - Coverage and capacity should be balanced



- Catalyst Center and Meraki Dashboard both support both Ekahau and Hamina project file import

Site Surveys

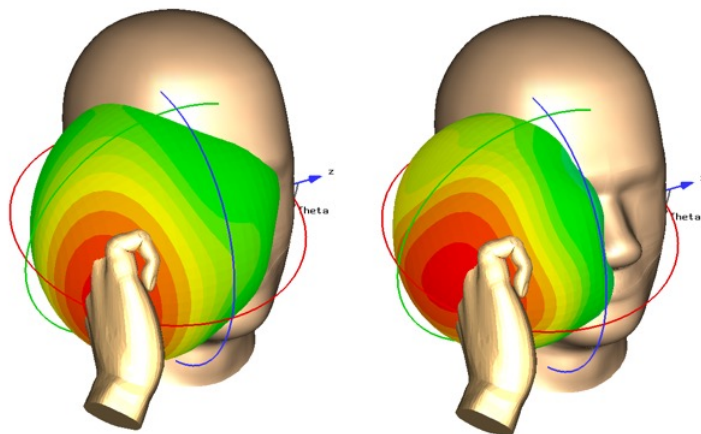
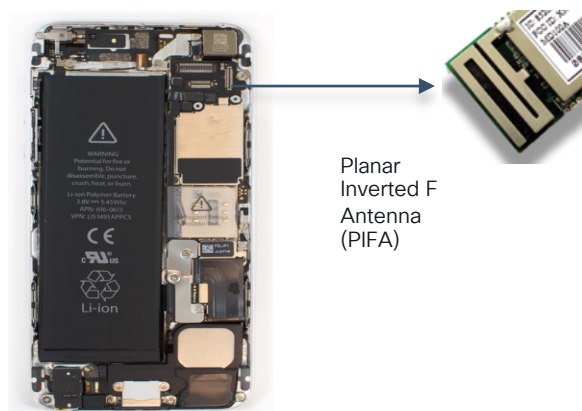
- Always verify predicted coverage with actual measurements
- Consider underlying requirements
 - Number of Users
 - Application Types
 - Location accuracy
- AP placement considerations
 - Consider environmentals
 - Characterise the -66 dBm edges
 - For location a minimum of three AP should be able to hear the device with a signal strength of -75 dBm or higher
- Understand existing spectrum use



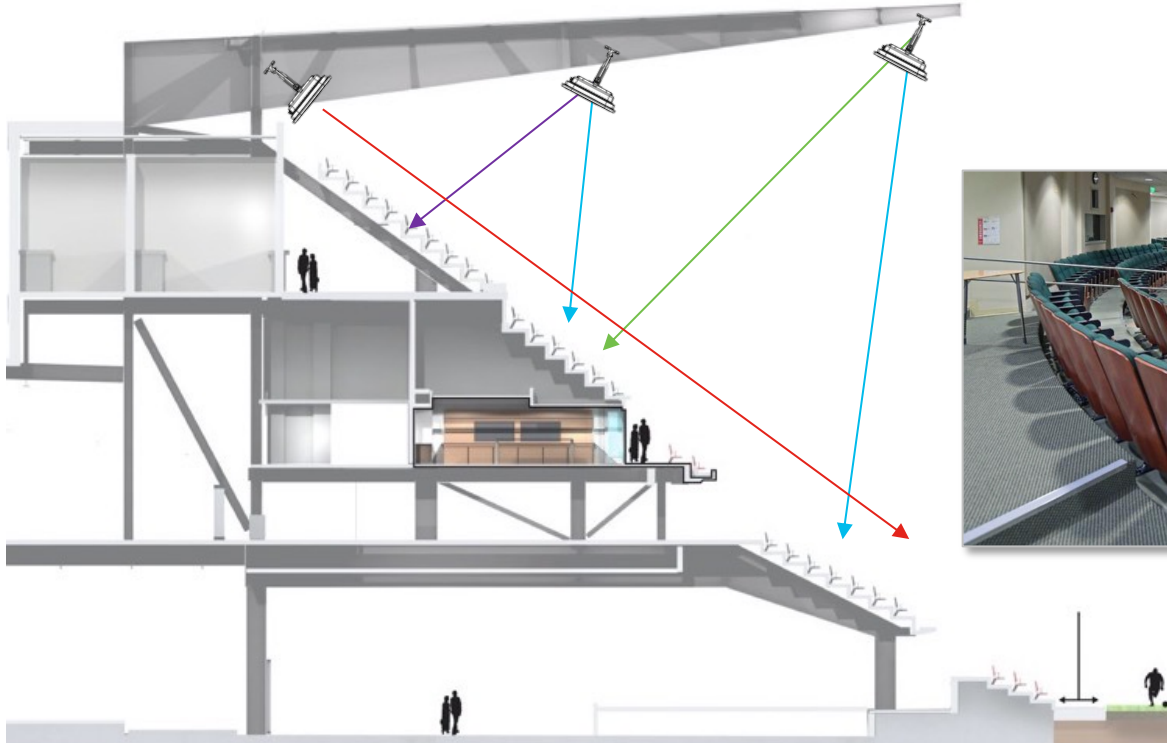
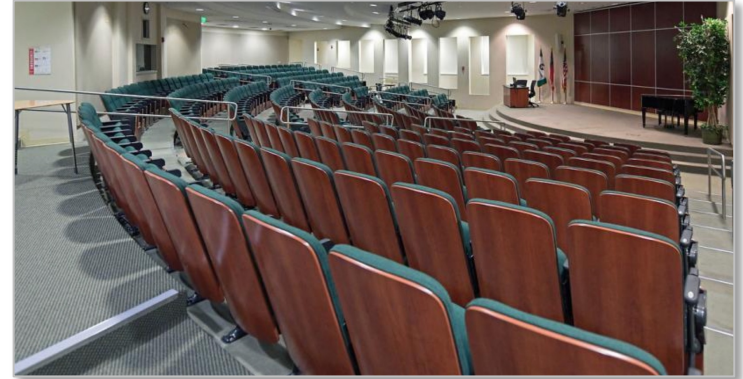
Spot the Difference



Client Position and Attenuation



Antenna Positioning and Coverage



6GHz Device Classes



Low Power Indoor

- Indoor Only
- Integrated Antenna Required
- Can use up to 1200 MHz
- Wired Power



Standard Power

- Indoor or Outdoor
- Integrated or External Antenna
- UNII-5 and UNII-7 Only
- Requires AFC



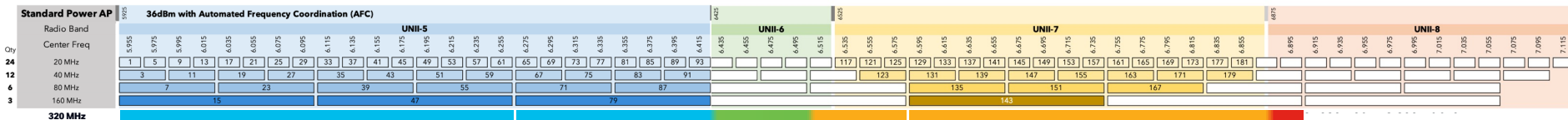
Very Low Power

- Mobile Indoor or Outdoor
- Limited Range
- UNII-5 and UNII-7 Only
- Does not require AFC



Client Devices

- Indoor or Outdoor
- Only Indoor under control of LPI AP
- 6 dBm lower power than AP



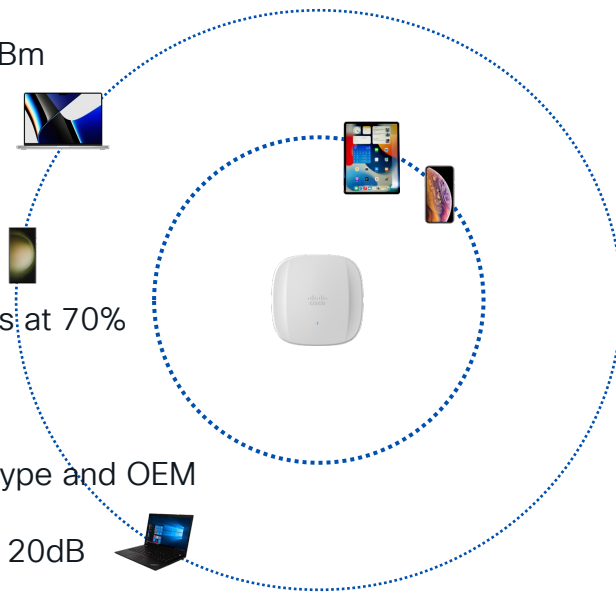
Client Roaming Logic

iOS devices start scanning at -70dBm
Roam to AP if 8dB better when active
Roam to AP if 12dB better when idle

macOS devices start scanning at -75dBm
Roam to AP if 12dB better

Samsung devices start scanning at -75dBm
Samsung devices start scanning at -65dBm if channel utilisation is at 70%
Roam to AP if 10dB better

Intel laptops scanning trigger depends on the antenna type and OEM
Typically between -65dBm and -75dBm
Roaming aggressiveness also varies, between 5dB and 20dB

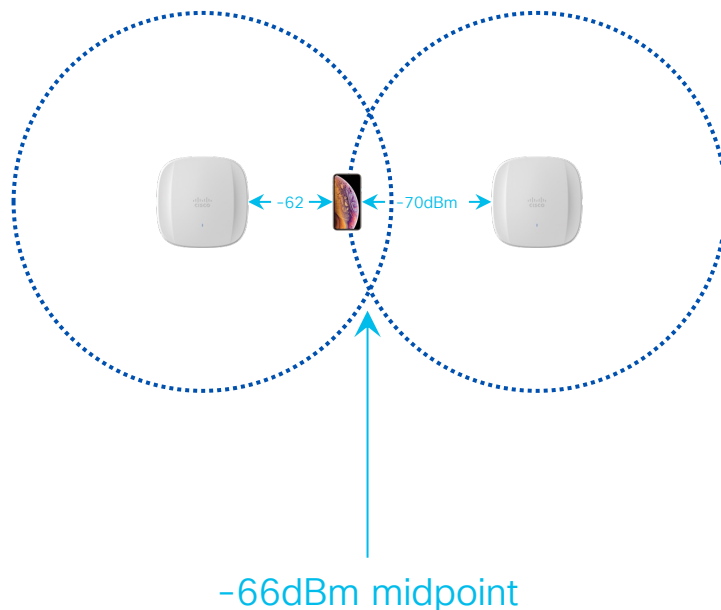


Mac OS Roaming Logic: <https://support.apple.com/en-us/HT206207>

Samsung Roaming Logic: <https://docs.samsungknox.com/admin/knox-platform-for-enterprise/kbas/kba-115013403768.htm>

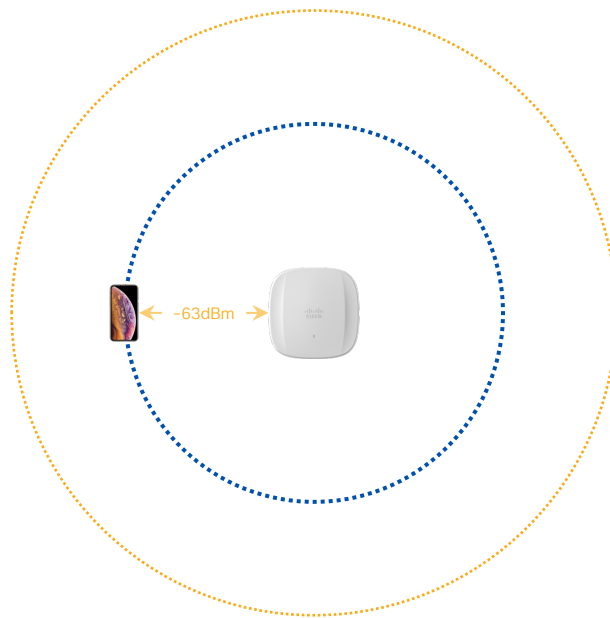
Cell Edge is Defined from the Client Perspective

- If the average client starts to look for a new AP at -70dBm , it better find one at -62dBm



Cell Edge is Defined from the Client Perspective

- If the average client starts to look for a new AP at -70dBm, it better find one at -62dBm
- Beware of 5GHz to 2.4GHz roams
 - At similar power, a 2.4GHz signal will be heard at 7dBm better than 5GHz



Cell Edge is Defined from the Client Perspective

- If the average client starts to look for a new AP at -70dBm, it better find one at -62dBm
- Beware of 5GHz to 2.4GHz roams
 - At similar power, a 2.4GHz signal will be heard at 7dBm better than 5GHz
 - Reduce 2.4GHz transmit power to maintain similar coverage



Designing for Cell Overlap

- The 6dB Rule
 - Half the distance = +6dB
 - Twice the distance = -6dB

← Distance $d/2$
-60dBm →



Distance d
-66dBm



Distance $2d$
-72dBm

Radio Resource Management

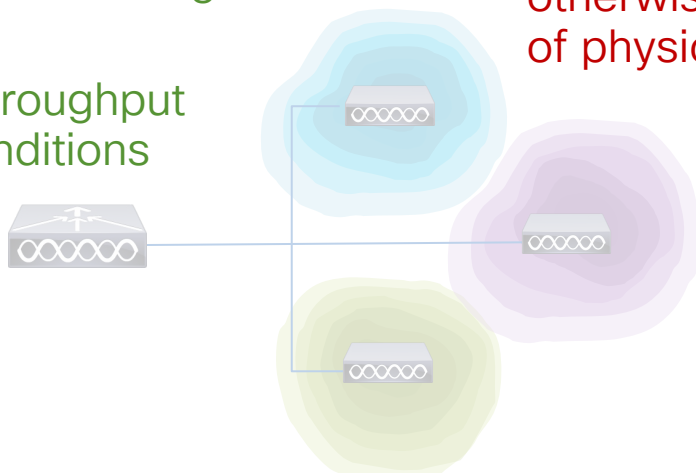
Dynamic Channel Allocation · Dynamic Bandwidth Selection · Transmit Power Control · Coverage Hole Detection

• What It Does

- Dynamically balances the RF environment and mitigates changes
- Monitor and maintain coverage for all clients
- Provides optimal throughput under changing conditions

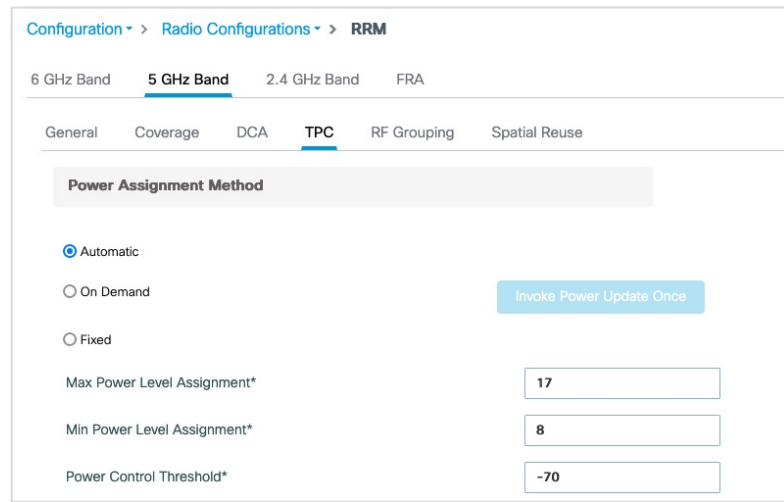
• What It Doesn't Do

- Substitute for a site survey
- Correct a poor RF design
- Manufacture spectrum or otherwise counteract the laws of physics...



Cell Edge as Defined by the AP Transmit Power

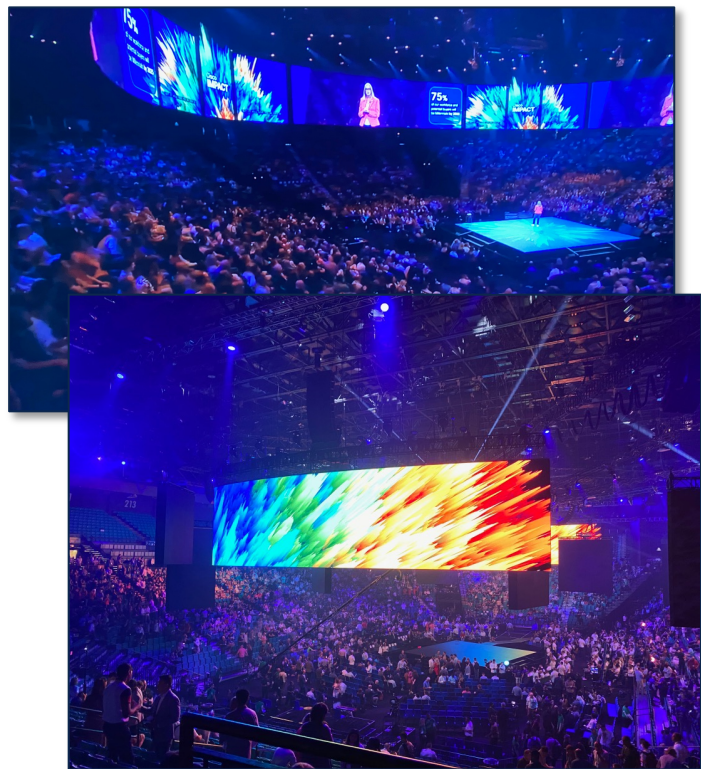
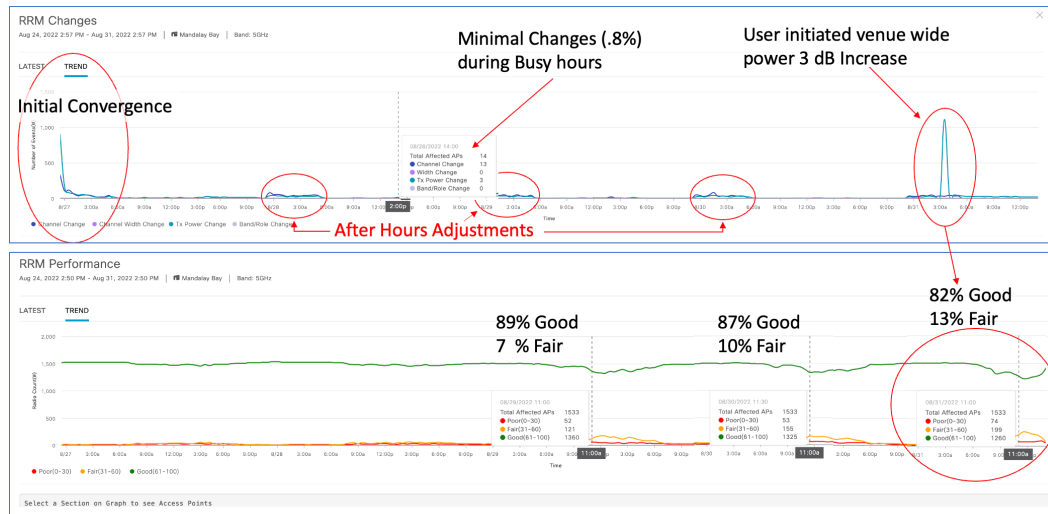
- Client Power Levels
 - Laptops: 20-23dBm
 - Modern Phones and Tablets: 17dBm
 - Older and Cheaper Phones: 11-14dBm
- The ideal AP max power level should be set to match your worst client max power
 - Assume a 3dB margin
 - For most modern clients assume the worst value to be 14dBm
 - Resulting in AP max power level of 17dBm



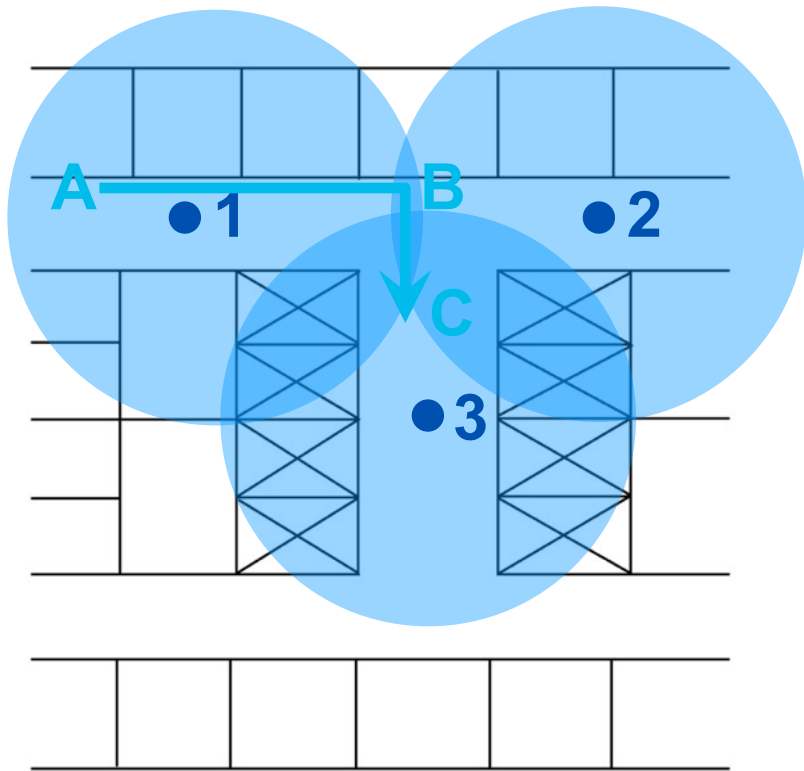
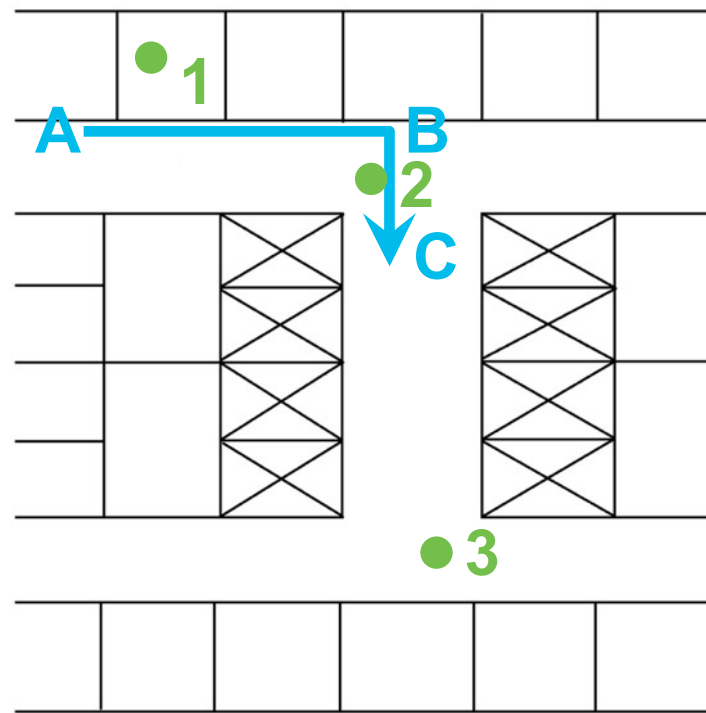
The screenshot shows the Cisco RRM configuration interface. The breadcrumb trail is Configuration > Radio Configurations > RRM. The '5 GHz Band' is selected under the 'Radio Configurations' section. The 'TPC' (Transmit Power Control) tab is active. Under 'Power Assignment Method', the 'Automatic' option is selected. There is a button labeled 'Invoke Power Update Once'. Below this, three input fields are shown: 'Max Power Level Assignment*' with a value of 17, 'Min Power Level Assignment*' with a value of 8, and 'Power Control Threshold*' with a value of -70.

Power Assignment Method	
☒ Automatic	
☐ On Demand	Invoke Power Update Once
☐ Fixed	
Max Power Level Assignment*	17
Min Power Level Assignment*	8
Power Control Threshold*	-70

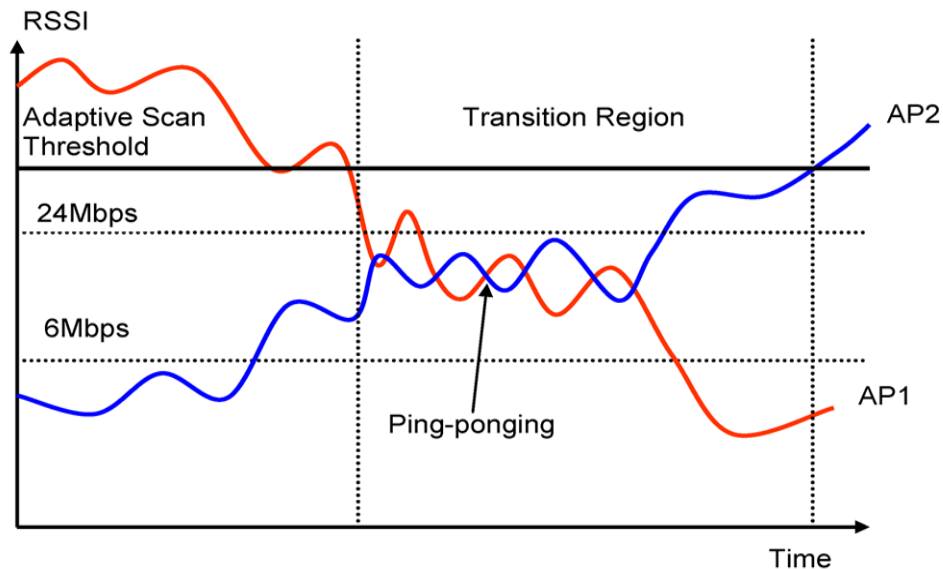
Enhancing RF Management with AI/ML



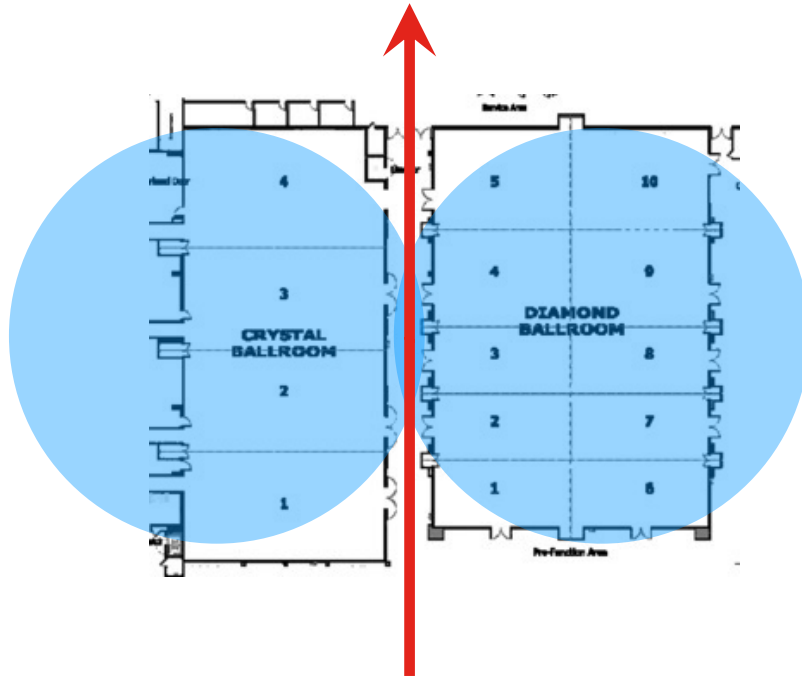
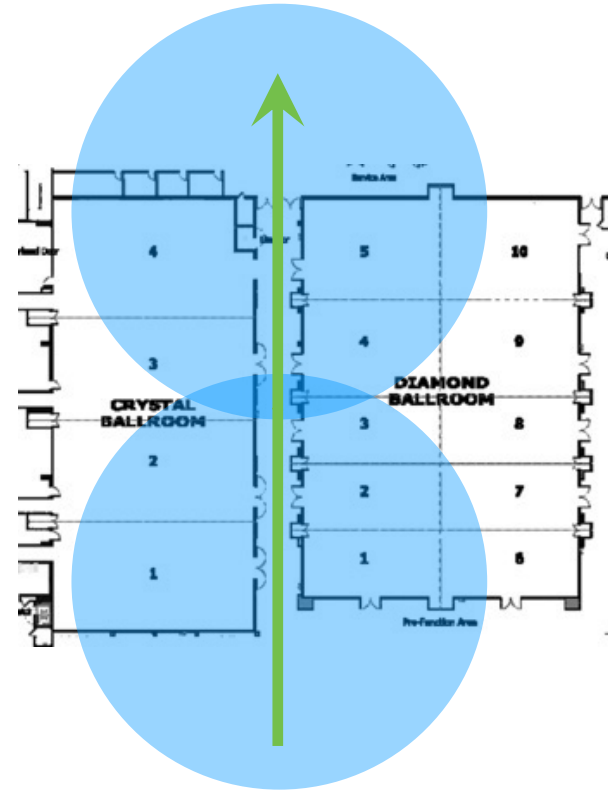
AP Placement and Roaming Optimisation



Avoiding Ping Pong Zones



Avoiding Ping Pong Zones



BSS Transition with 802.11k and 802.11v / MBO

- 802.11k
 - Provides a list of the neighbouring APs
 - Reduces the number of channels the client needs to scan
- 802.11v
 - Solicited Request
 - Unsolicited Request
 - AP load too high
 - Client RSSI to low
 - DFS event



Enabling Support

- Individually 802.11k & 802.11v
 - No downsides or impacts
- Enable Device Analytics
 - Advertise Support
 - Samsung Analytics
- Advertise PC Analytics Support
 - Intel Analytics
- Share Data with Client
 - Samsung onboard AI/ML optimiser
- Enable 11k client scan reports for Samsung and Intel clients

Edit WLAN

Max Client Connections

Per WLAN: 0

Per AP Per WLAN: 0

Per AP Radio Per WLAN: 200

Assisted Roaming (11k)

Prediction Optimization: ☐

Neighbor List: ☒

Dual Band Neighbor List: ☐

DTIM Period (in beacon intervals)

5 GHz Band (1-255): 1

2.4 GHz Band (1-255): 1

11v BSS Transition Support

BSS Transition: ☒

Dual Neighbor List: ☐

BSS Max Idle Service: ☒

BSS Max Idle Protected: ☐

Directed Multicast Service: ☒

Configuration of '11v BSS Disassociation Imminent' is supported from Command Line Interface (CLI) only

Device Analytics

Advertise Support: ☒

Advertise PC Analytics Support: ☒

Share Data with Client: ☒

11k Beacon Radio Measurement

Client Scan Report

On Association: ☒

On Roam: ☒

Device Analytics

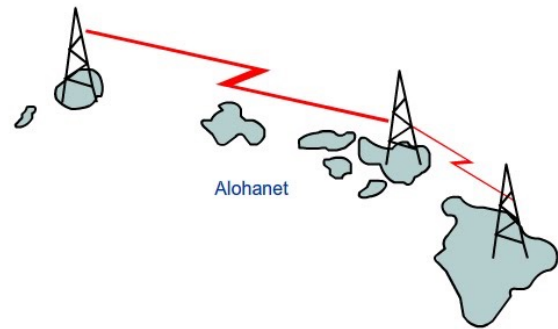
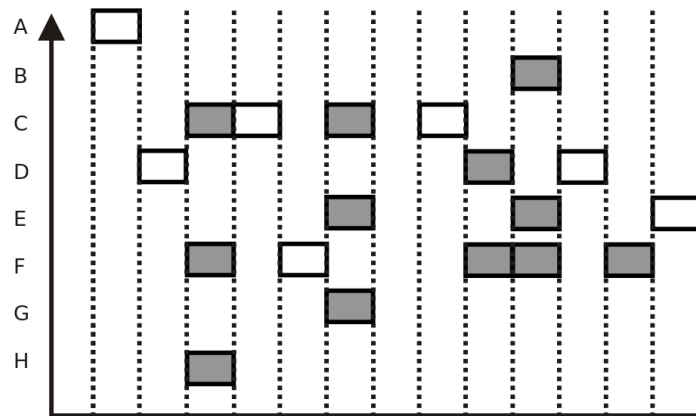
FYI

		Intel	Apple	Samsung
What is the client type?	Catalyst 9800	Device Analytics > Advertise PC Analytics support	Automatic	Device Analytics > Advertise support
	Meraki Dashboard	Automatic Cannot be disabled	Automatic Cannot be disabled	
How does the client see the network?	Catalyst 9800	Automatic at (re)association if PC Analytics is enabled Also sent dynamically	Automatic at (re)association	Automatic at (re)association if Device Analytics is enabled Also sent dynamically
	Meraki Dashboard	Automatic Cannot be disabled	Automatic Cannot be disabled	
Why did the client leave?	Catalyst 9800	Automatic if Advertise PC Analytics support enabled	Automatic	Automatic if Device Analytics is enabled
	Meraki Dashboard	Automatically on, cannot be turned off	Automatically on, cannot be turned off	
For better client experience	Catalyst 9800	Enable 802.11k/v and Device Analytics > Share Data with Client. Cisco sends the STA info about AP to tune its algorithms to understand what is a good AP		
	Meraki Dashboard			

Carrier Sense Multiple Access / Collision Detection

FYI

- Pure ALOHA
 - If you have data, send it
 - If you receive data while sending, there is a message collision and you must retransmit
- Slotted ALOHA
 - Stations only send at start of timeslot
 - Reduces collisions
- Clear Channel Assessment
 - Energy detection
 - Hidden Node Problem

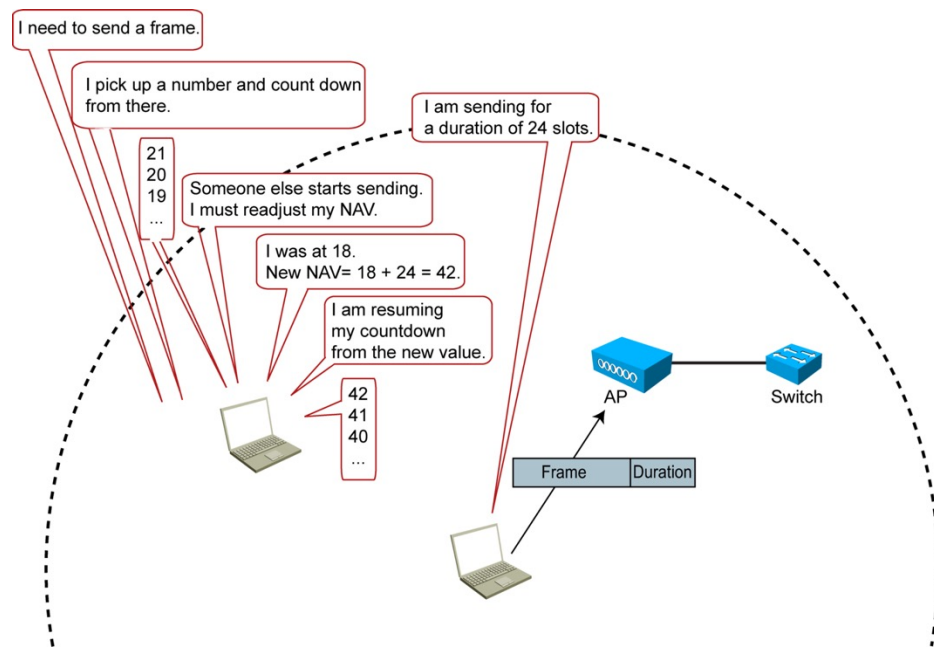


Slotted ALOHA protocol (shaded slots indicate collision)

Carrier Sense Multiple Access / Collision Avoidance

FYI

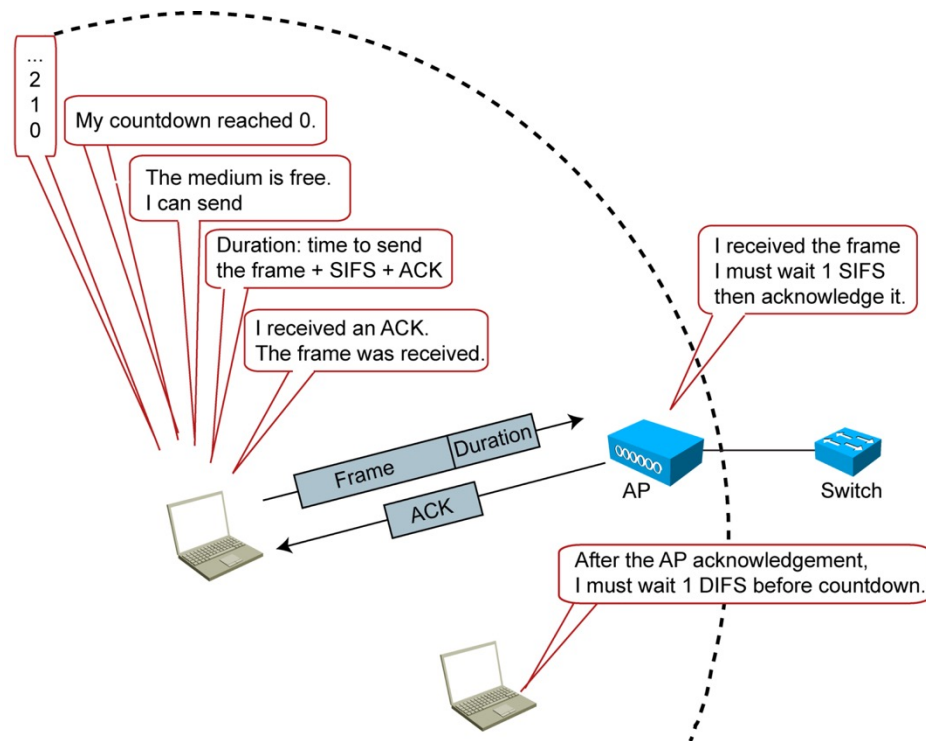
- Back-off Timer
 - Random number for countdown
- Contention Window (CW)
 - Backoff timer range
 - CWMin → CWMax
 - Differentiated back-off times to implement priorities
- Network Allocation Vector (NAV)
 - Total wait time before sending
 - Adjusted on energy detect



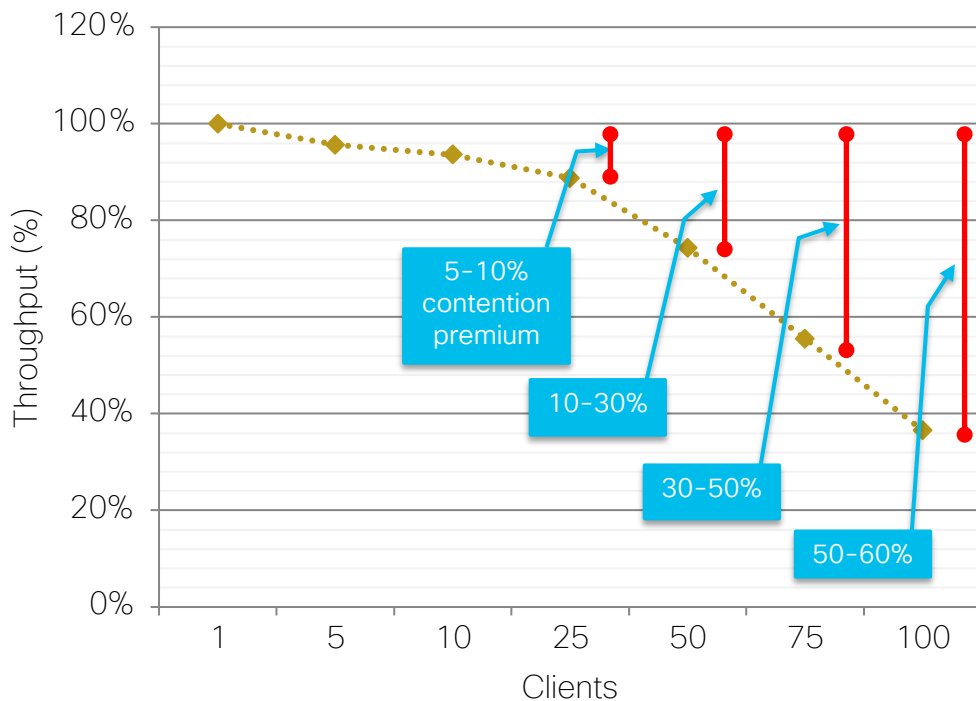
Carrier Sense Multiple Access / Collision Avoidance

FYI

- Short Interframe Space (SIFS)
 - Silence between unicast frame and ACK
- Acknowledgement (ACK)
 - Acknowledgement frame sent by receiver to confirm receipt of the packet
- Distributed Interframe Space (DIFS)
 - Silence between transmissions
- Arbitration Interframe Space (AIFS)
 - DIFS equivalent for 802.11e QoS



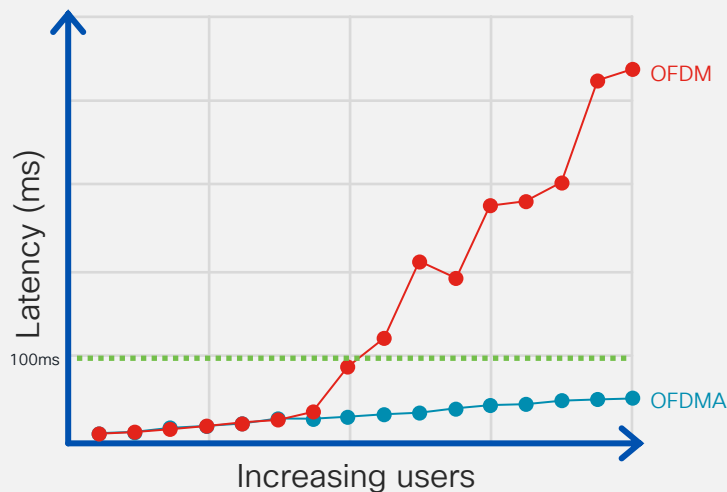
The Contention Breaking Point



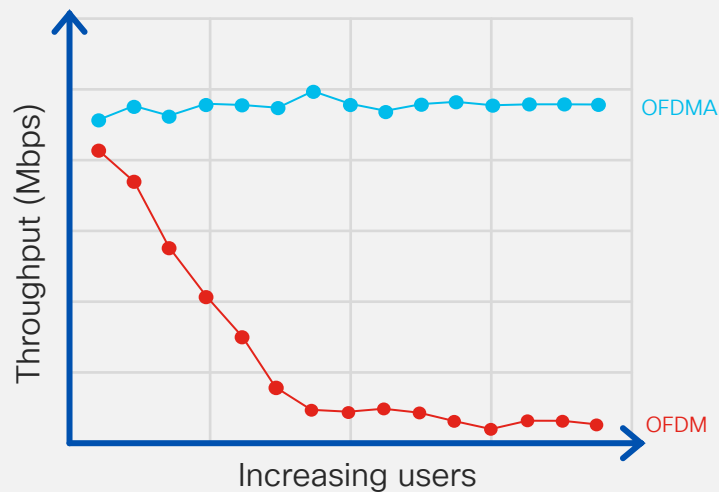
- As more clients associate and transmit, WLAN contention increases for all clients
- Retries and back off windows increase
- Each station spends more and more time in the “waiting and listening” state
- This results in a significant decrease in per-station performance

Deterministic Wireless

Linear **Voice** delay

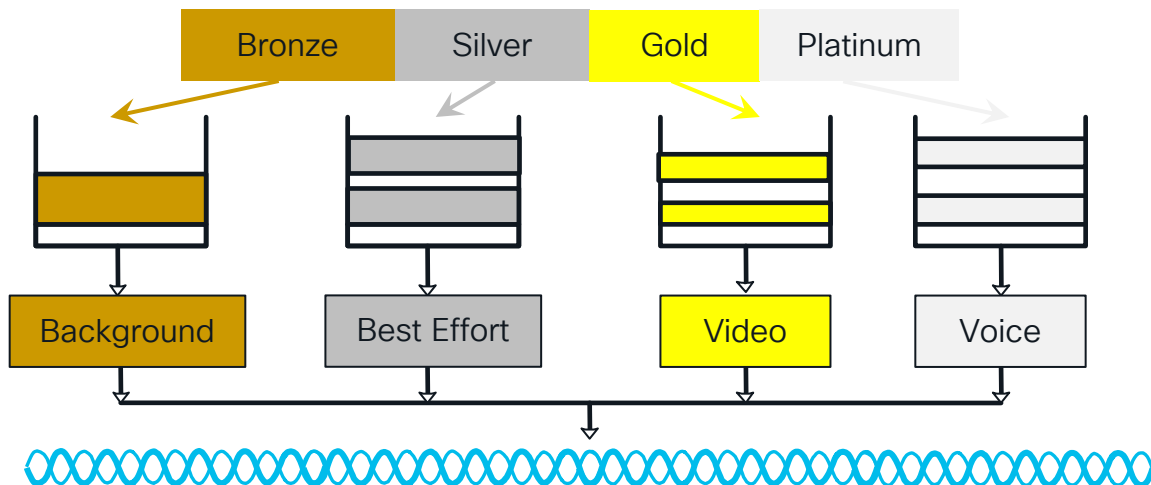


Consistent **Data** throughput



QoS Enhancements with 802.11e / WMM

- Enhanced Distributed Channel Access (EDCA)
 - EDCA established 4 queues known as Access Categories
 - Each AC queue maintains different
 - Arbitration Inter Frame Spacing (AIFS) timers
 - Contention Window sizes
 - CW_{min} and CW_{max}



IP DSCP to 802.11e User Priority Mapping



Internet Engineering Task Force (IETF)
Request for Comments: 8325
Category: Standards Track
ISSN: 2070-1721

T. Szigeti
J. Henry
Cisco Systems
F. Baker
February 2018

Mapping Diffserv to IEEE 802.11

Abstract

As Internet traffic wireless endpoints, aligned between wireless mappings from DiffServ 802.11 User Priority offered by the IETF treatment between wireless

IETF DiffServ Service Class	PHB	Reference	IEEE 802.11 User Priority	Access Category
Network Control (reserved for future use)	CS7	REC 2474	7 OR 0	AC_VO (Voice) OR AC_BE (Best Effort)
Network Control	CS6	REC 2474	7 OR 0	AC_VO (Voice) OR AC_BE (Best Effort)
Telephony	EF	REC 3246	6	AC_VO (Voice)
VOICE-ADMIT	VA	REC 5865	6	AC_VO (Voice)
Signaling	CS5	REC 2474	5	AC_VI (Video)
Multimedia Conferencing	AF41 AF42 AF43	REC 2597	4	AC_VI (Video)
Real-Time Interactive	CS4	REC 2474	4	AC_VI (Video)
Multimedia Streaming	AF31 AF32 AF33	REC 2597	4	AC_VI (Video)
Broadcast Video	CS3	REC 2474	4	AC_VI (Video)
Low-Latency Data	AF21 AF22 AF23	REC 2597	3	AC_BE (Best Effort)
OAM	CS2	REC 2474	0	AC_BE (Best Effort)
High-Throughput Data	AF11 AF12 AF13	REC 2597	0	AC_BE (Best Effort)
Standard	DF	REC 2474	0	AC_BE (Best Effort)
Low-Priority Data	CS1	REC 3662	1	AC_BK (Background)



IETF Traffic Class	PHB
Network Control	CS6
Voice (46), Voice-Admit(44)	EF,VA
Signaling	CS5
Multimedia Conferencing	AF4x
Real-time Interactive	CS4
Multimedia Streaming	AF3x
Broadcast Video	CS3
Low Latency Data	AF2x
OAM	CS2
High Throughput Data	AF1x
Standard (Best Effort)	DF
Low Priority Data	CS1

AC	UP
AC_VO	7
AC_VO	6
AC_VI	5
AC_VI	4
AC_VI	4
AC_VI	4
AC_VI	4
AC_BE	3
AC_BE	0
AC_BE	0
AC_BE	0
AC_BK	1

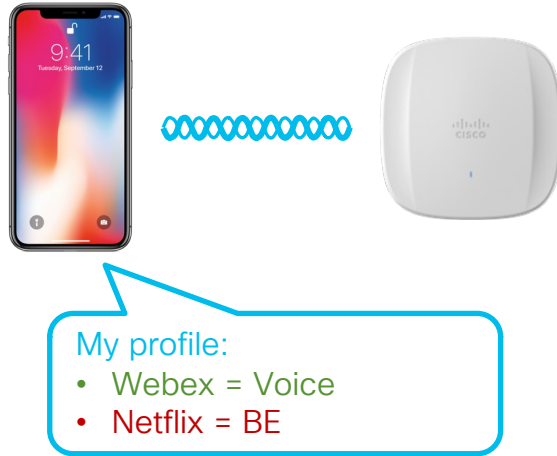
Voice

Video

Best Effort

Background

FastLane

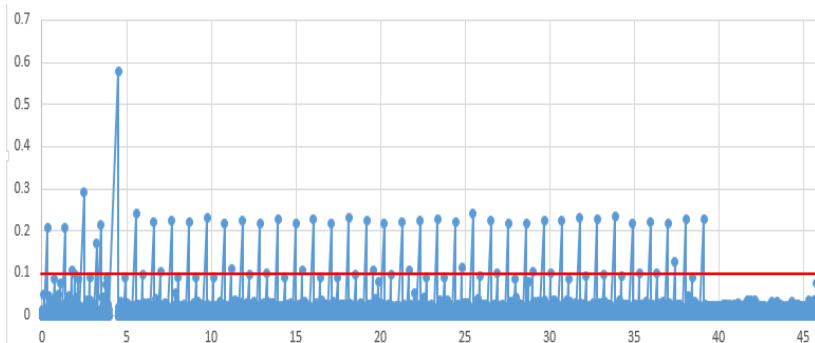


- Apple devices and Cisco network identify each other and confirm capabilities
- Administrators can provision Apple iOS devices with a QoS profile
 - Without a profile, QoS is applied for all applications
- On a non-Cisco network QoS Profile is not considered
 - Applications can only mark 802.11e UP and *not* IP DSCP

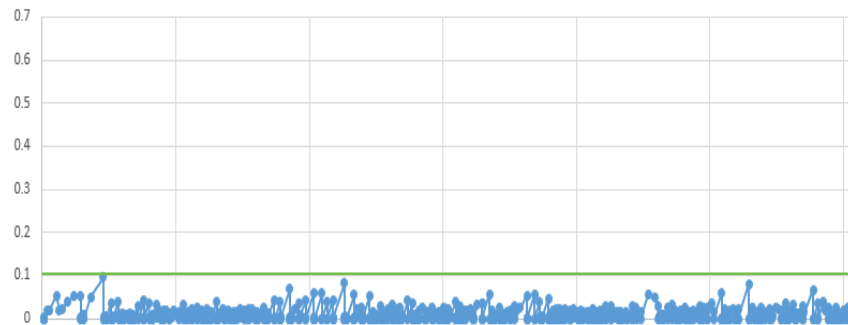
QoS Prioritisation in Congested Environments

FYI

- One voice packet sent every 20ms with 75% congestion
- Measuring the interval between voice packets upstream



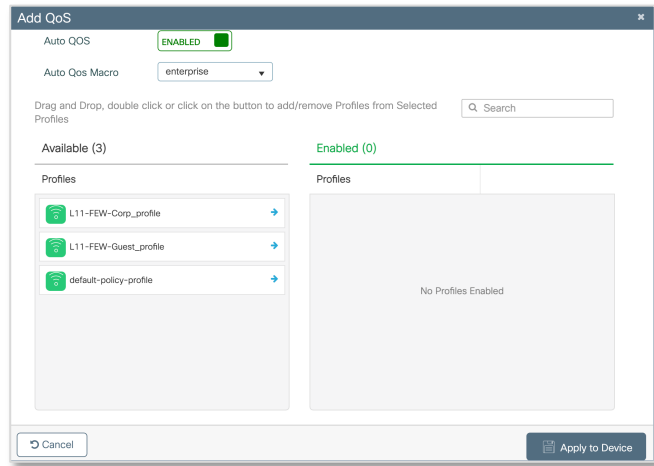
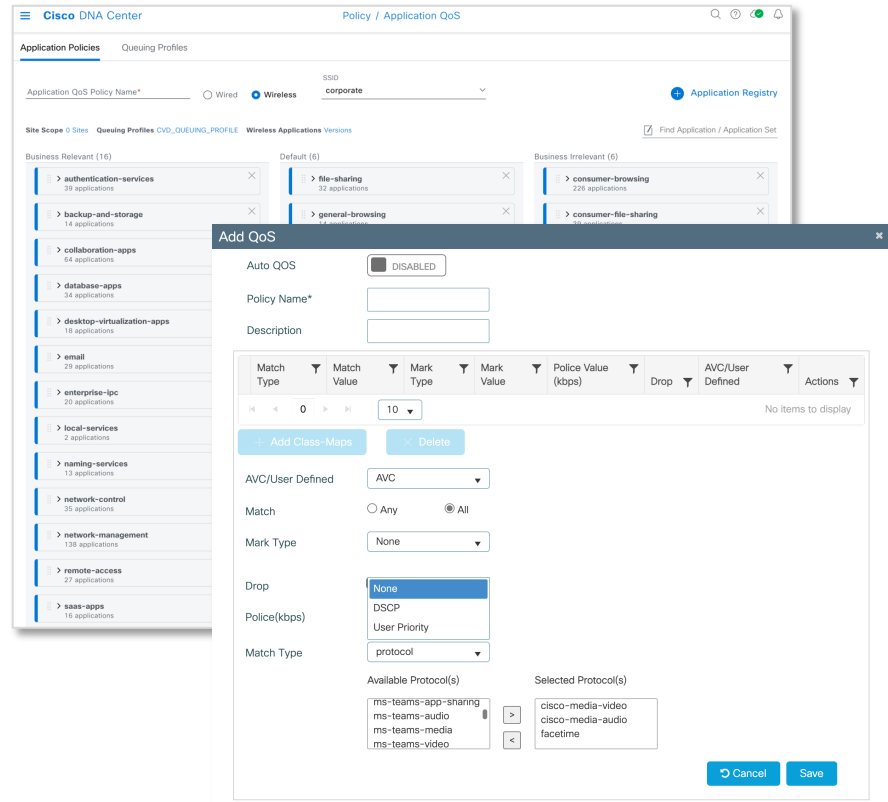
Without FastLane



With FastLane

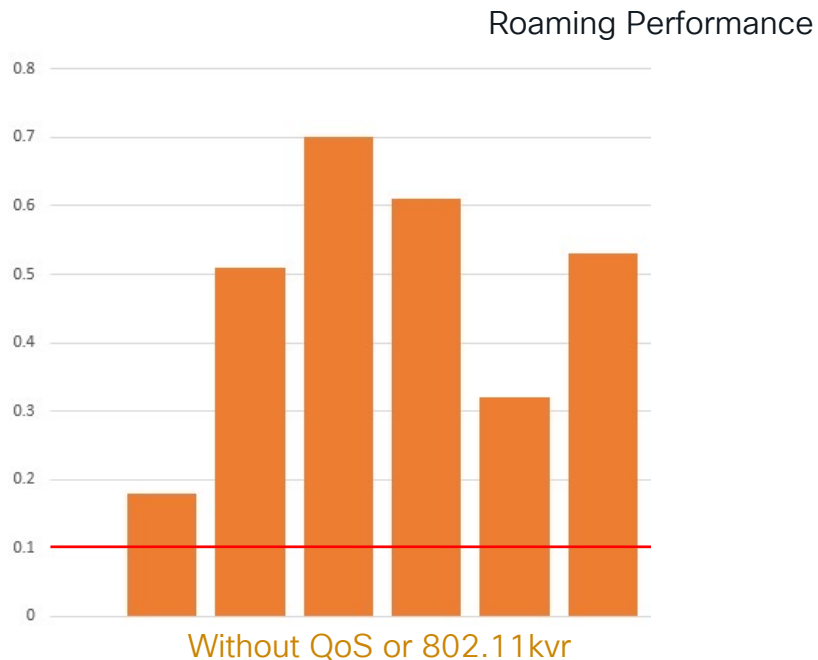
Application Visibility and Control (AVC)

- AVC provides traffic visibility and ensures that marking stays consistent in both directions



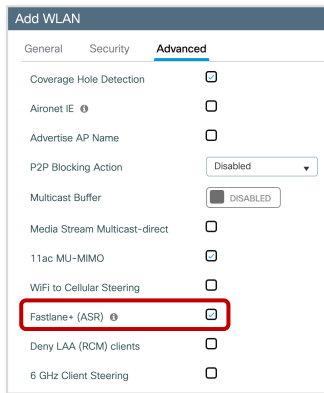
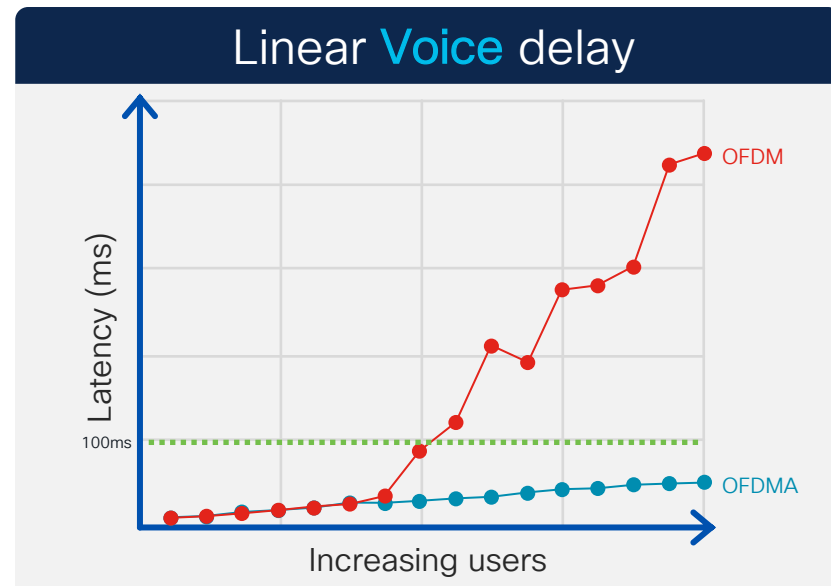
Putting it All Together

- Measuring time interval between last packet on previous AP and first packet on next AP for voice call while roaming

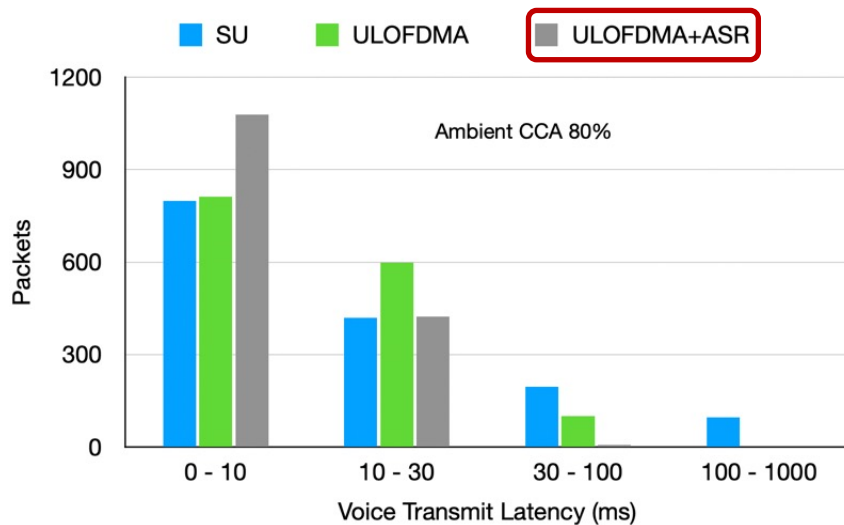
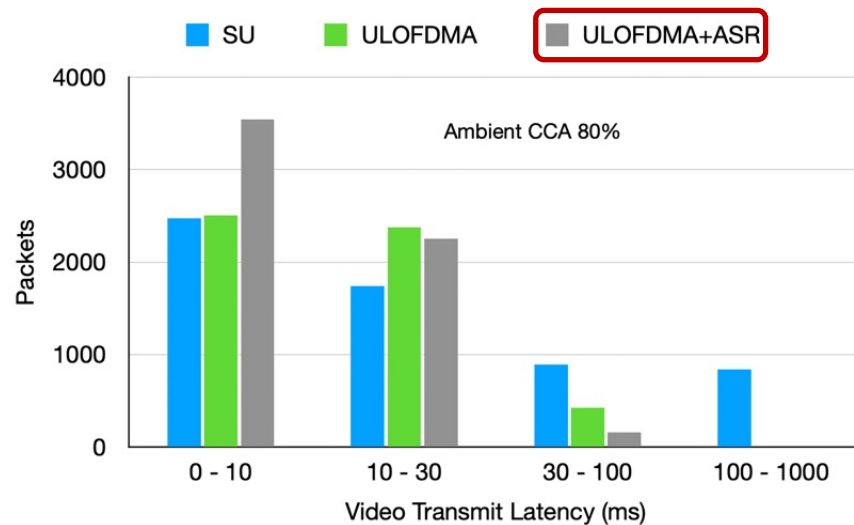


One More Thing

- Client sends a periodic Buffer Status Report (BSR) with the amount of traffic in the buffer for each QoS queue
- FastLane+ allows for the client to send an Advanced Scheduling Request (ASR) to reserve bandwidth resources for latency-sensitive real-time voice and video applications



FastLane+ Advanced Scheduling Requests



Wireless Network Design

- Two levers for improving signal quality
 - Increase the signal
 - Decrease the noise
- Three dimensions to Wi-Fi performance
 - Channel Aggregation
 - Digital Modulation
 - Spatial Multiplexing
- Design with your clients in mind
 - Use Client Analytics to improve troubleshooting
 - APs set to max transmit power is an indication something is wrong
 - Consider client transmit power
 - Ensure cell overlap to facilitate roaming
 - Understand how APs hear each other along roaming pathways
 - Enable available features to support real-time applications



The bridge to possible

Thank you

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The background is a vibrant, abstract graphic featuring a rainbow color palette. On the left, there are horizontal, wavy bands of color transitioning from red at the top to blue at the bottom. On the right, a bright white light source emits a series of sharp, triangular rays of color in a radial pattern, also using the rainbow spectrum. The overall effect is energetic and celebratory.

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Let's go

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