Understanding RF in a Wireless First World

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Principal Wireless Architect

BRKEWN-2048

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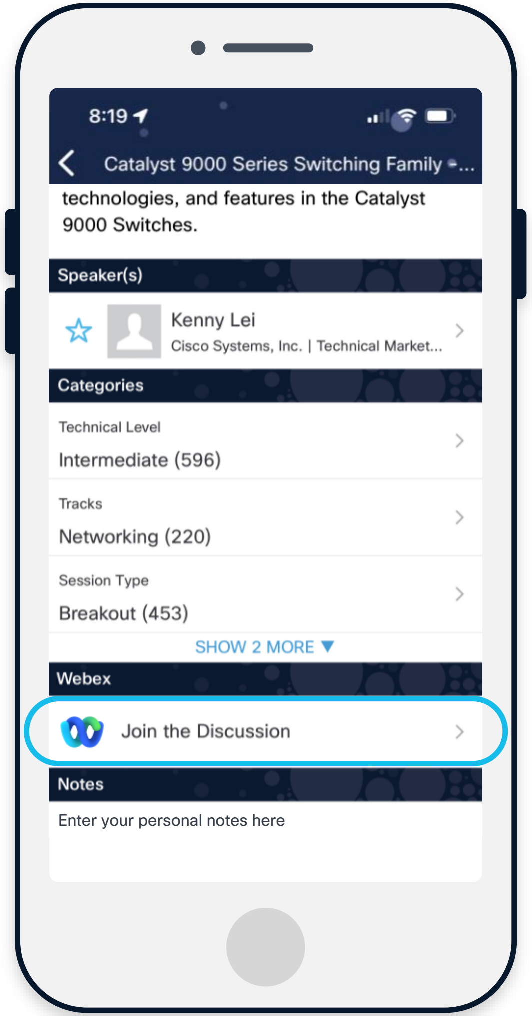


Agenda

- RF Fundamentals
  - Three Dimensions of Wireless Performance
  - Wi-Fi 6 and Wi-Fi 7 Enhancements
- Implications for Wireless Network Design
  - Optimizing for Client Roaming Behavior
  - RF Planning and Site Surveys
  - Optimizing for Low Latency Applications

RF Fundamentals

“Any sufficiently advanced technology
is indistinguishable from magic.”

Arthur C. Clarke

Electromagnetic Spectrum

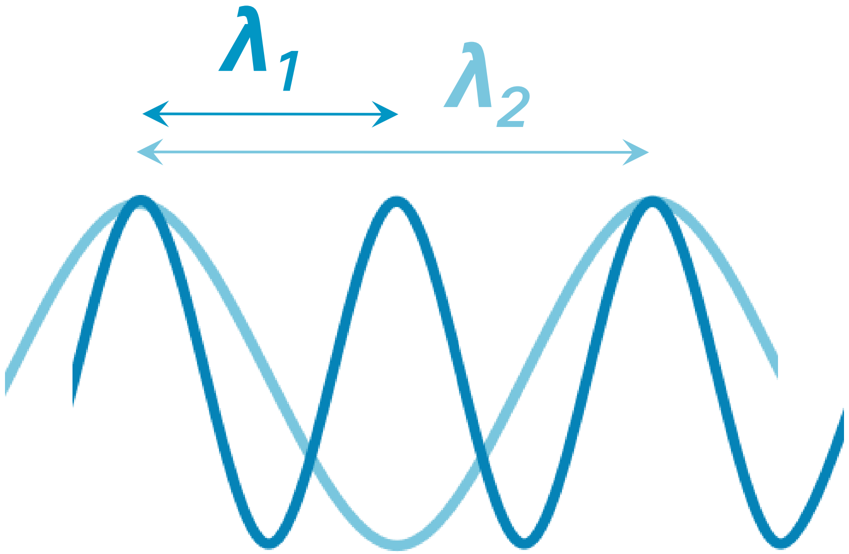
FYI

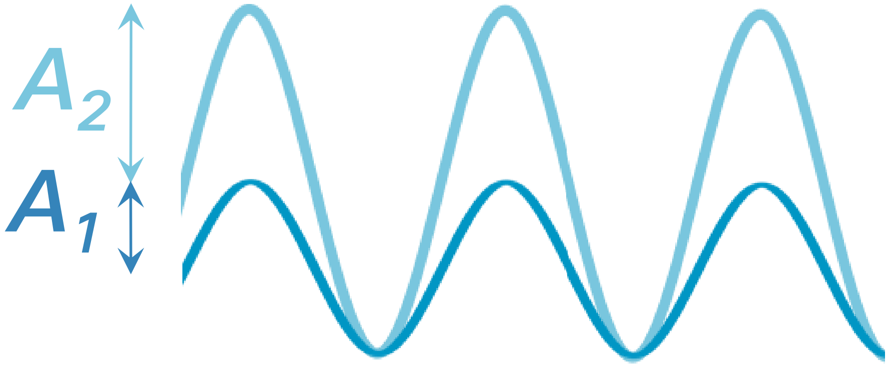
- Microwaves
- Radio Waves
- Infrared Radiation
- Visible Light
- Ultraviolet Radiation
- X-Rays
- Gamma Rays

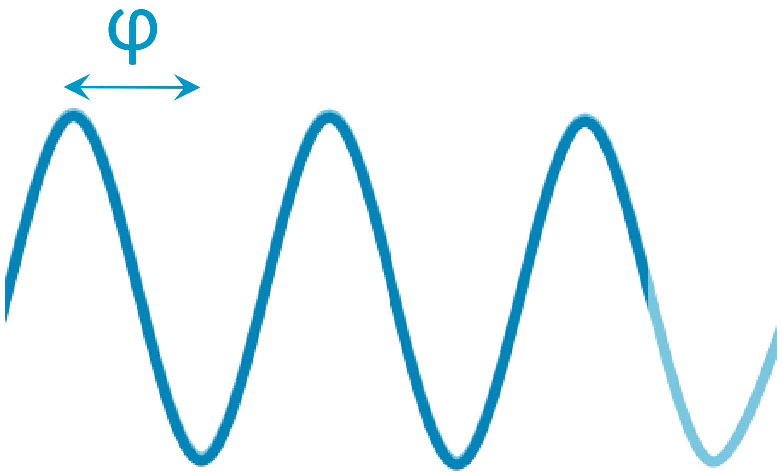
Color	Frequency	Wavelength
Violet	668-789 THz	380-450nm
Blue	606-668 THz	450-495nm
Green	526-606 THz	495-570nm
Yellow	508-526 THz	570-590nm
Orange	484-508 THz	590-620nm
Red	400-484 THz	620-750nm

Radio Frequency Fundamentals

- Frequency and Wavelength
  - $f = c / \lambda$
    - c = the speed of light in a vacuum
  - 2.45GHz = 12.3cm = 4.84”
  - 5.0GHz = 6cm = 2.36”
  - 6.0GHz = 5cm = 1.97”
- Amplitude
- Phase

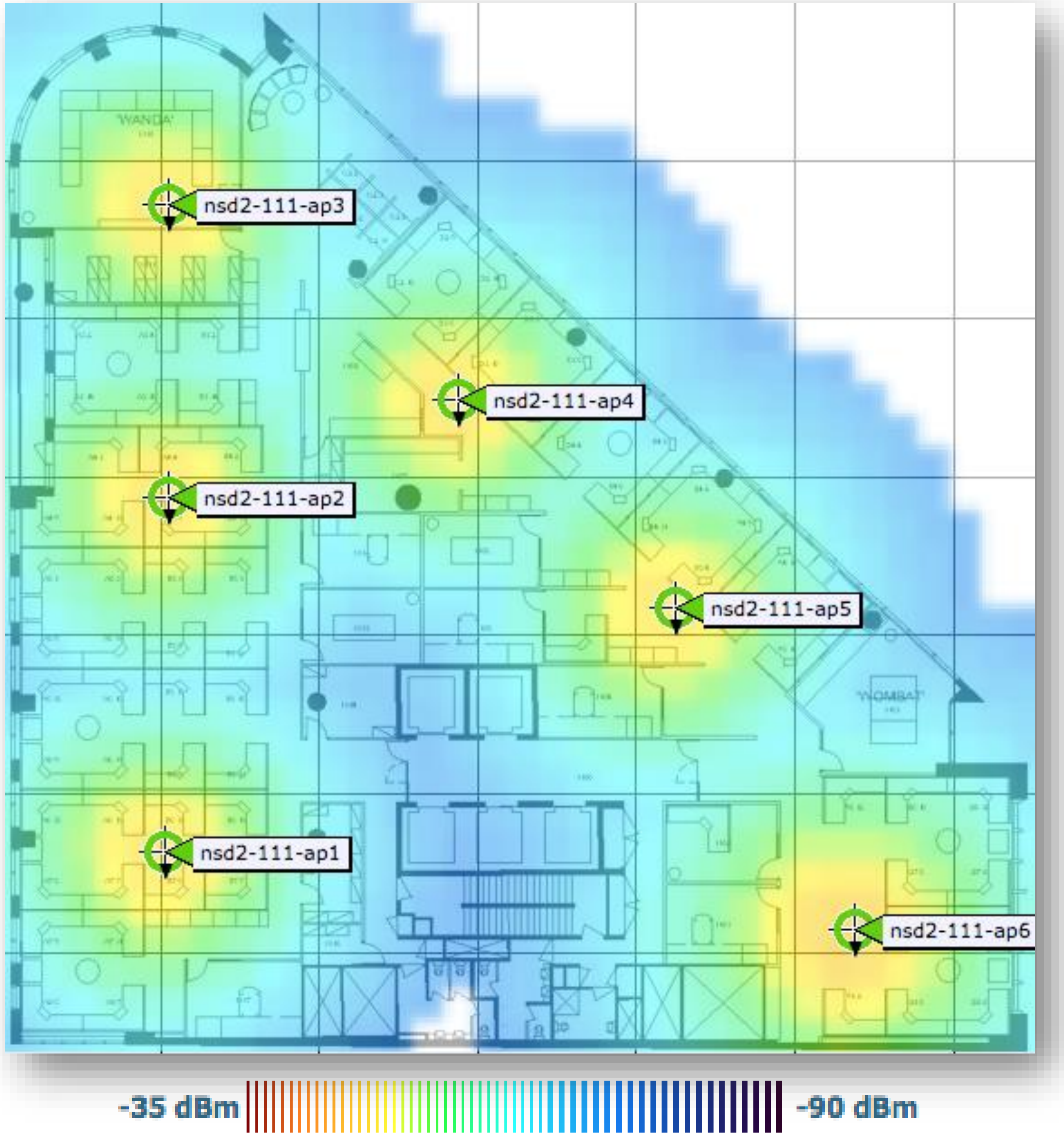






RF Mathematics

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

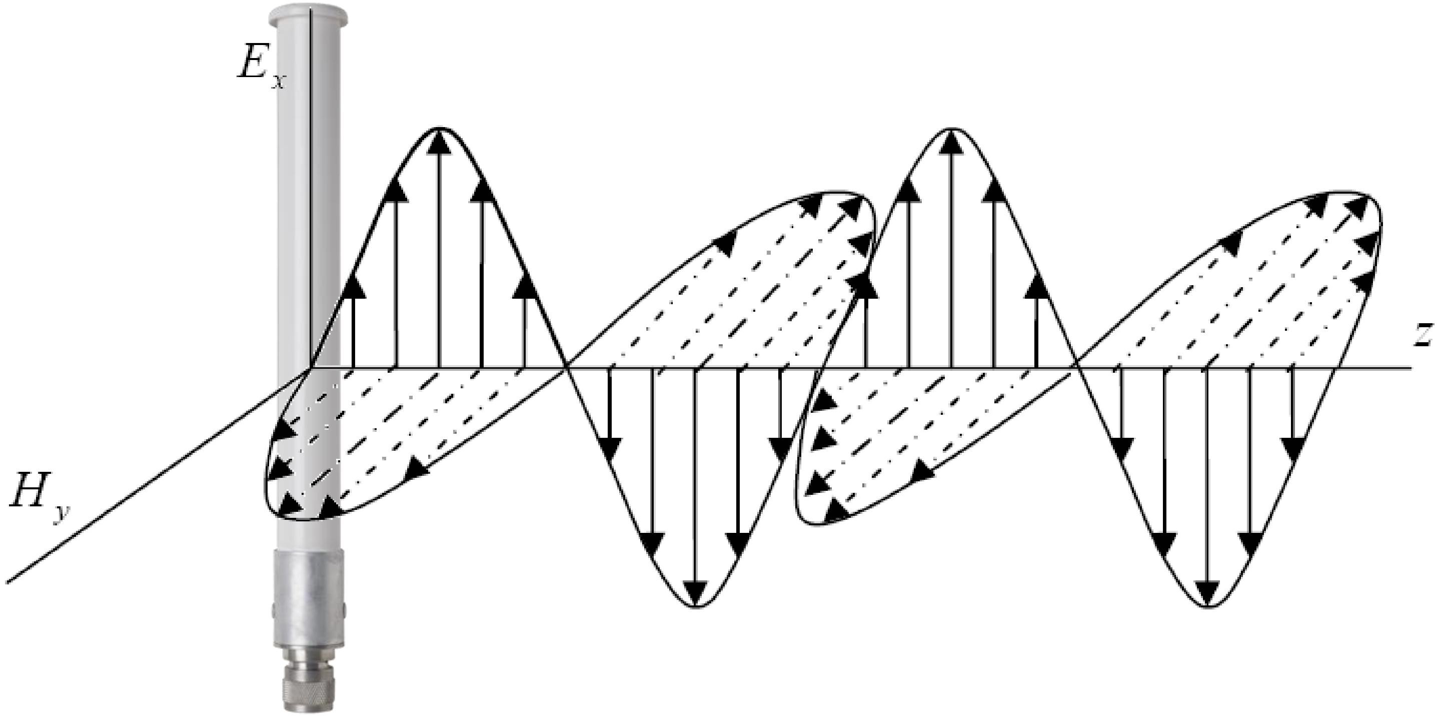


Interference and Signal to Noise Ratio

- 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

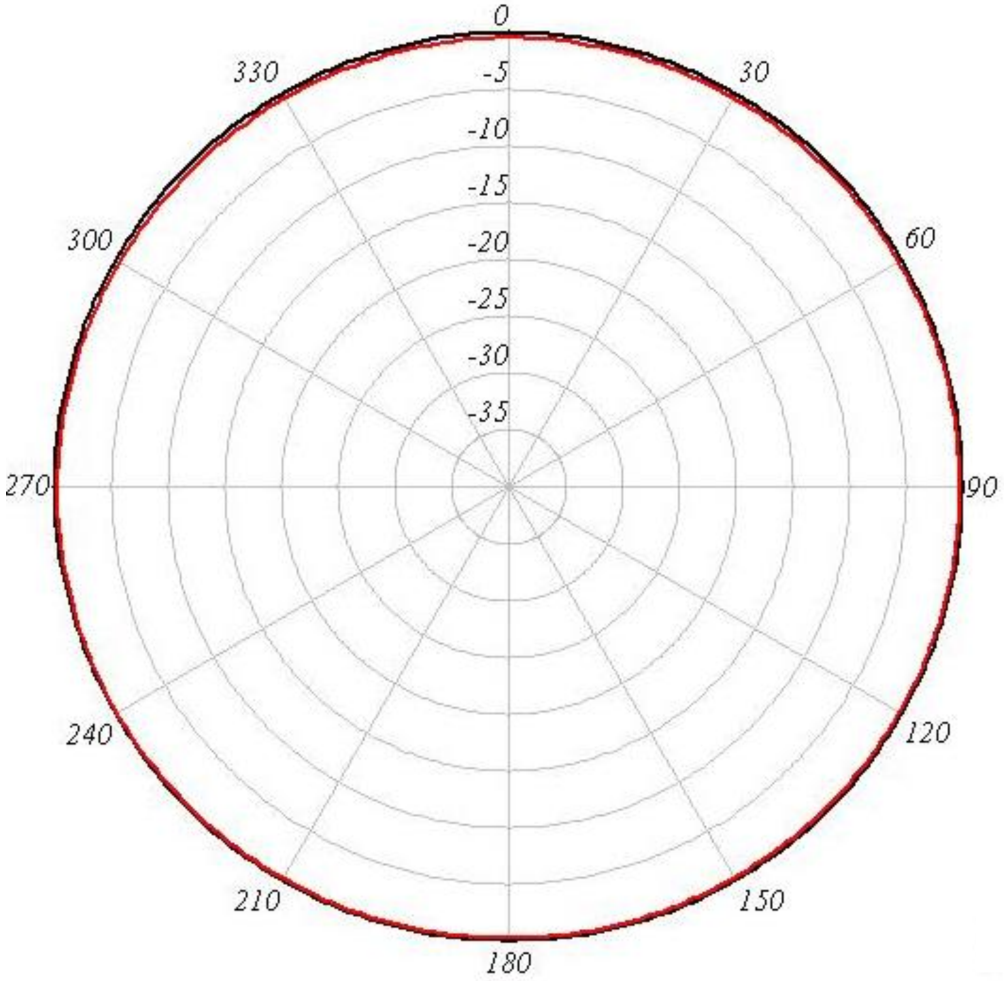
Antenna Design

Omnidirectional Antenna

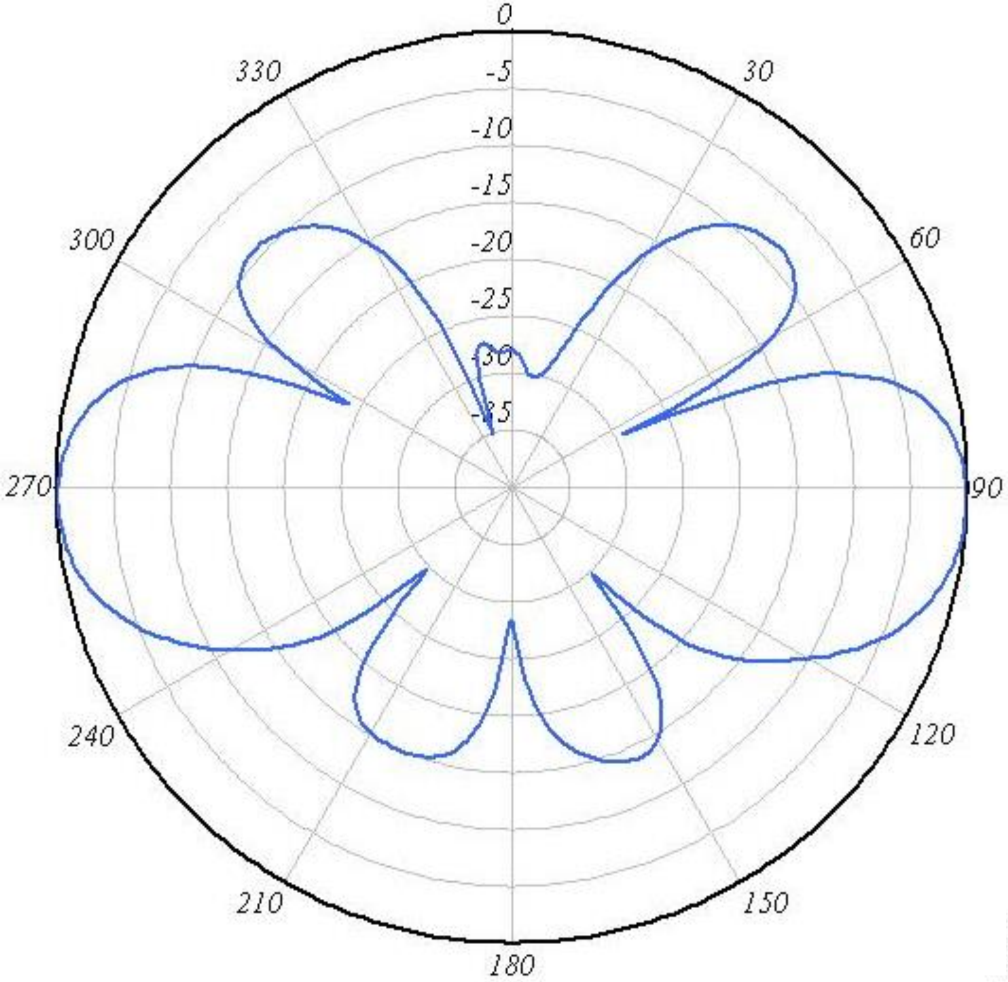


Antenna Design

Omnidirectional Antenna

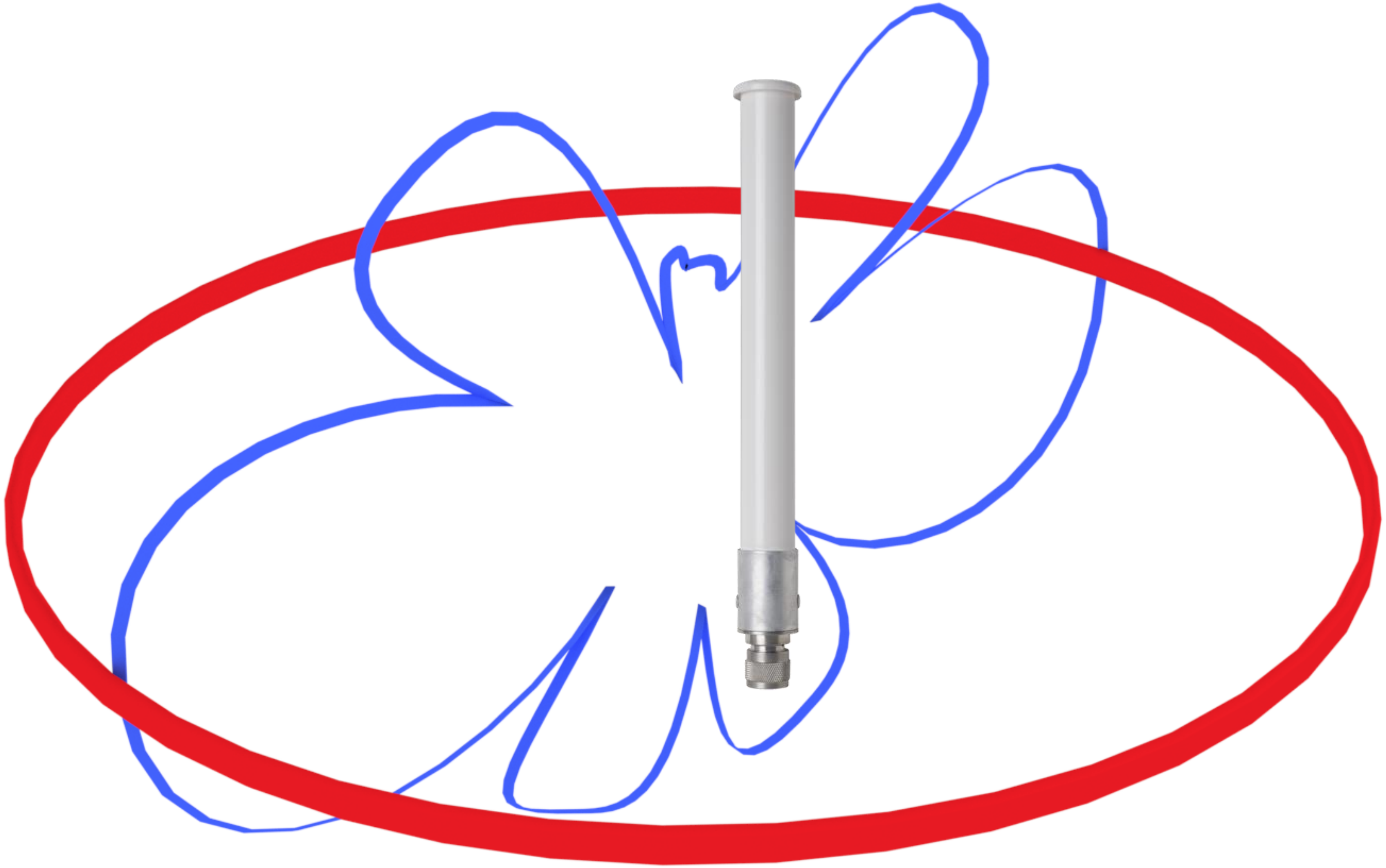


Azimuth



Elevation

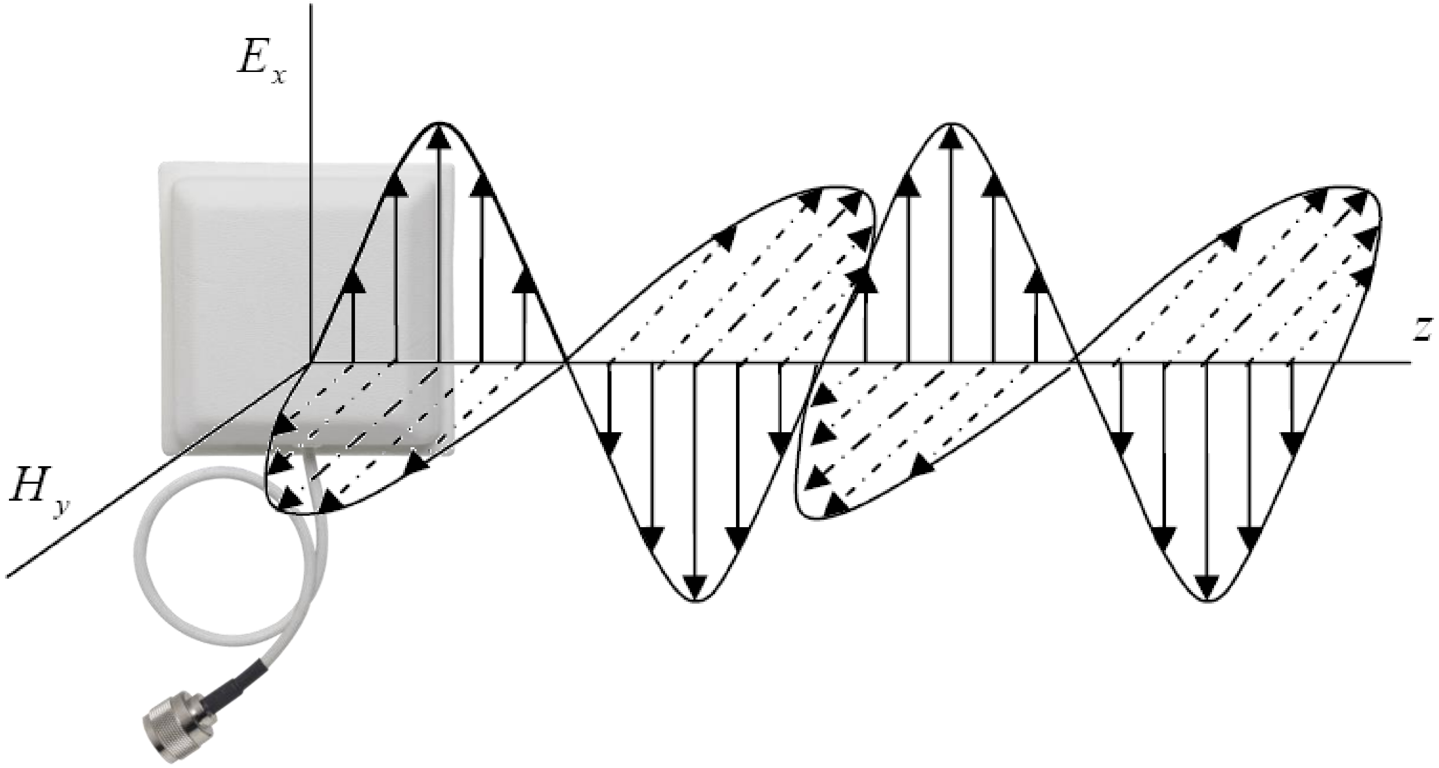
Azimuth and Elevation Planes



FYI

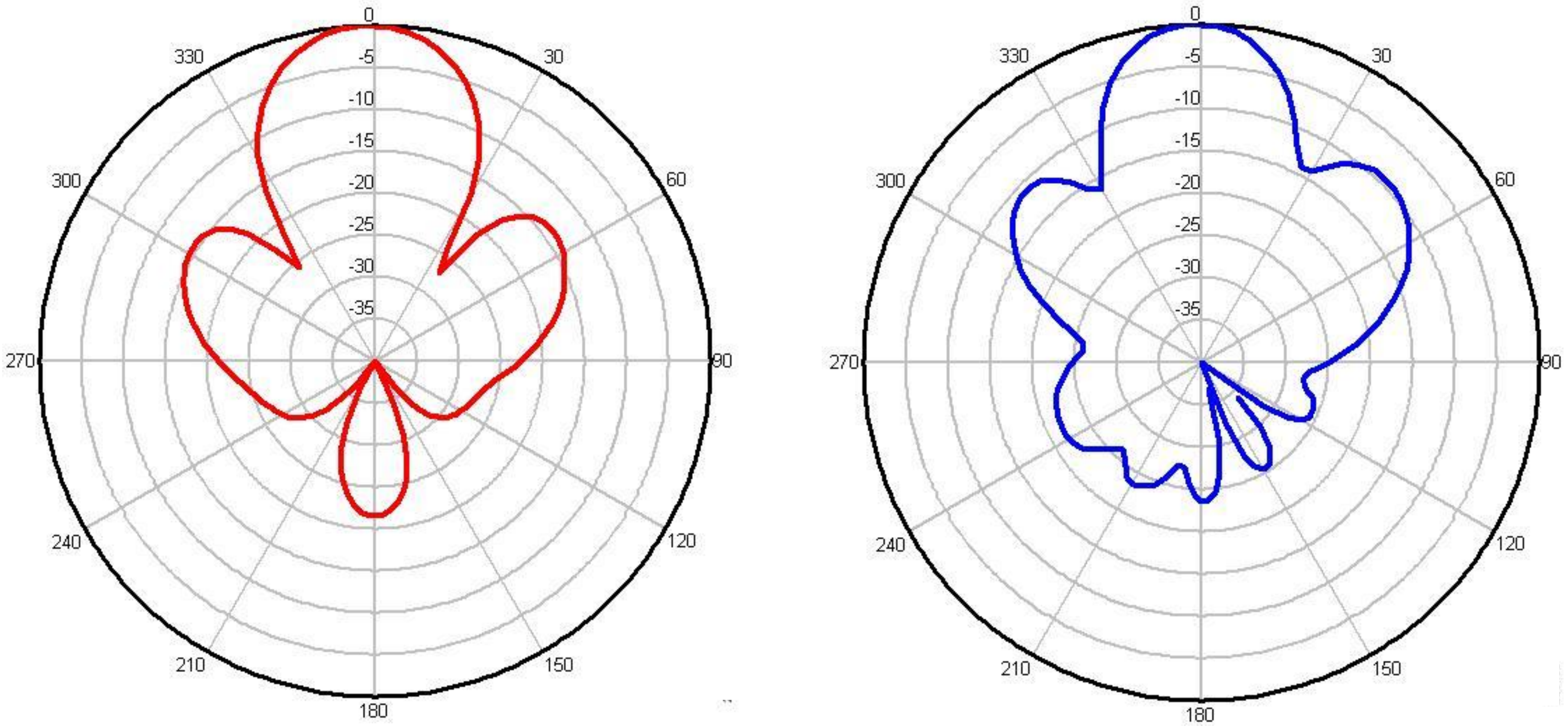
Antenna Design

Directional Antennas



Antenna Design

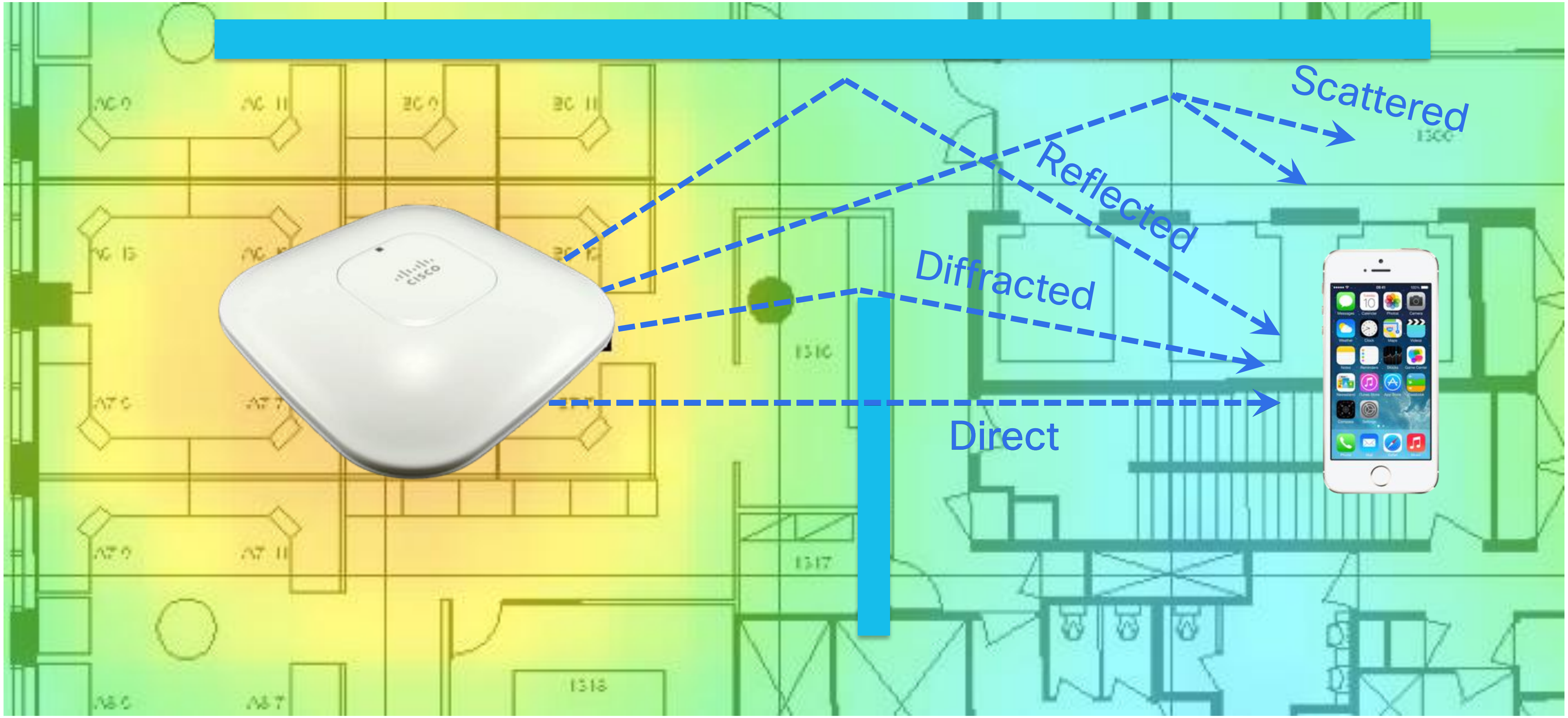
Directional Antennas



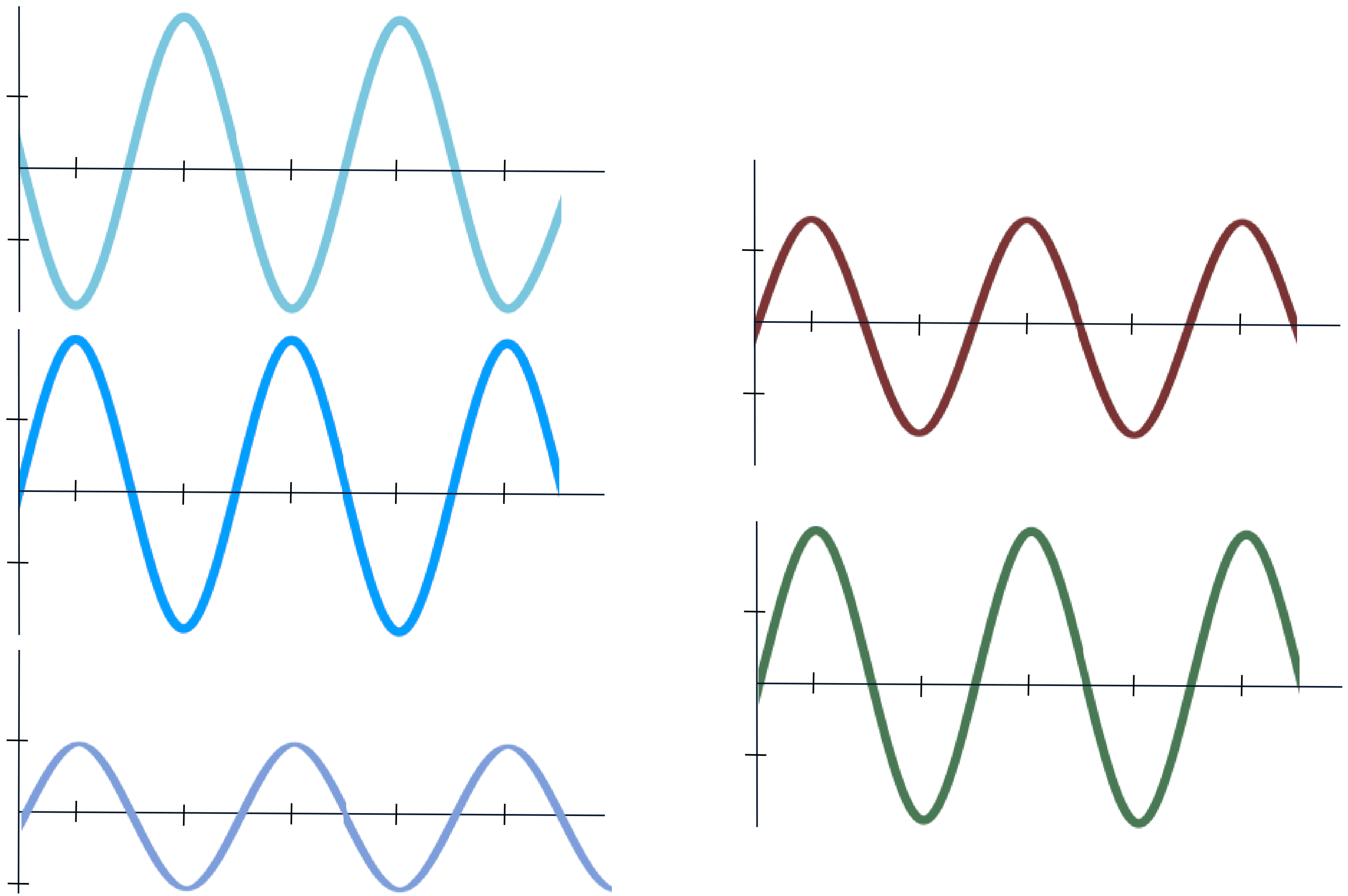
Azimuth

Elevation

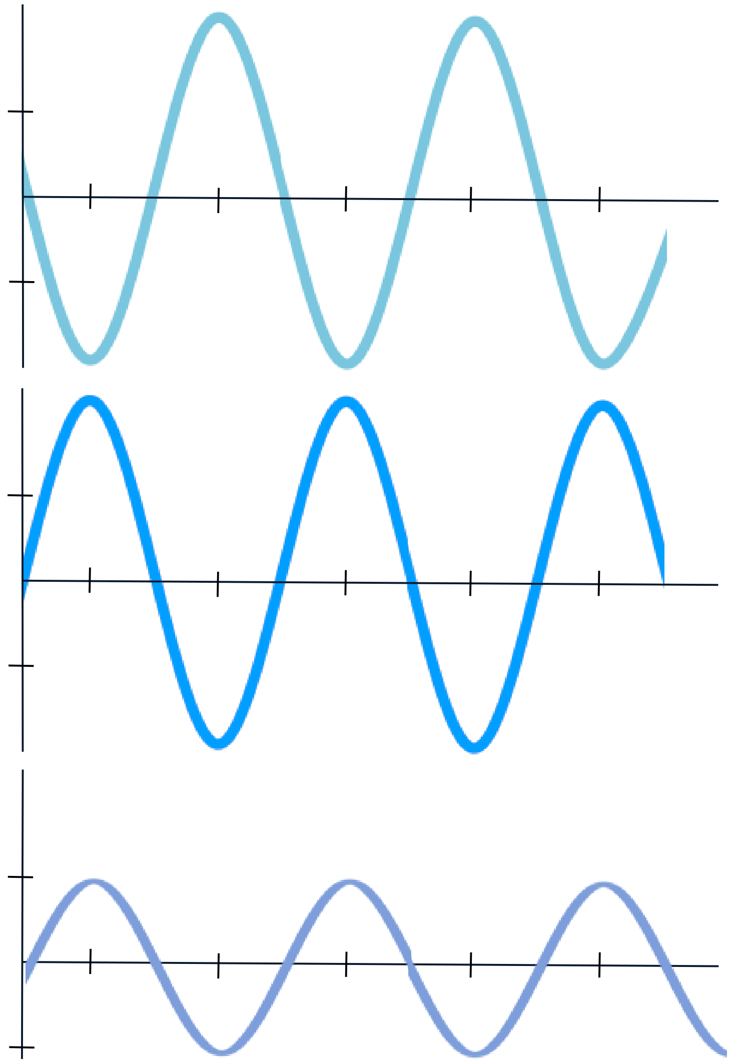
Multipath Propagation

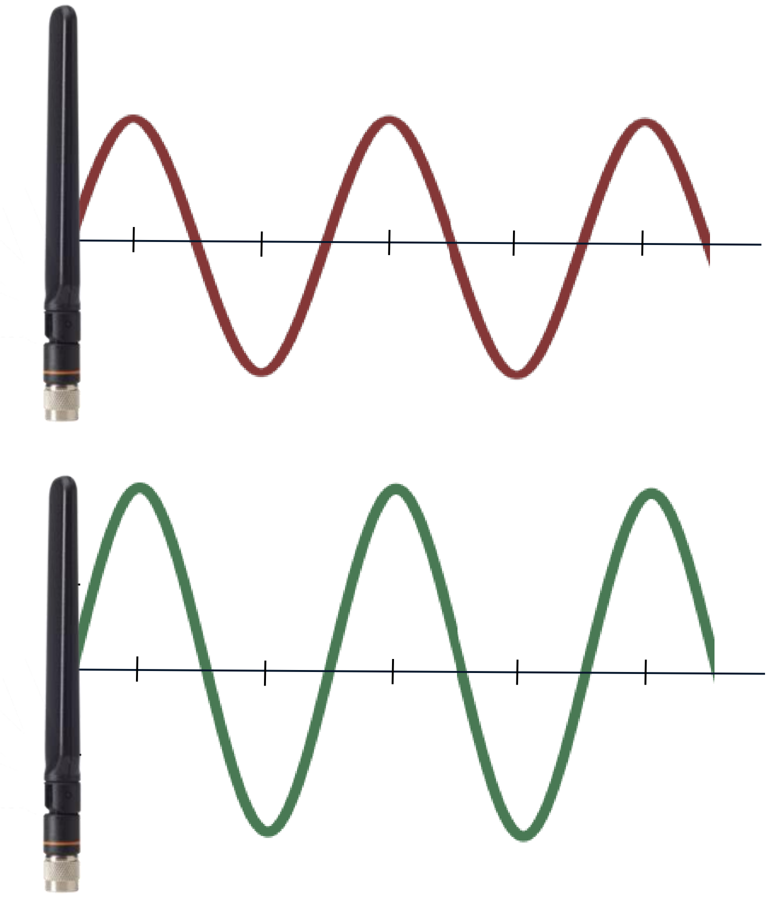


Destructive and Constructive Interference

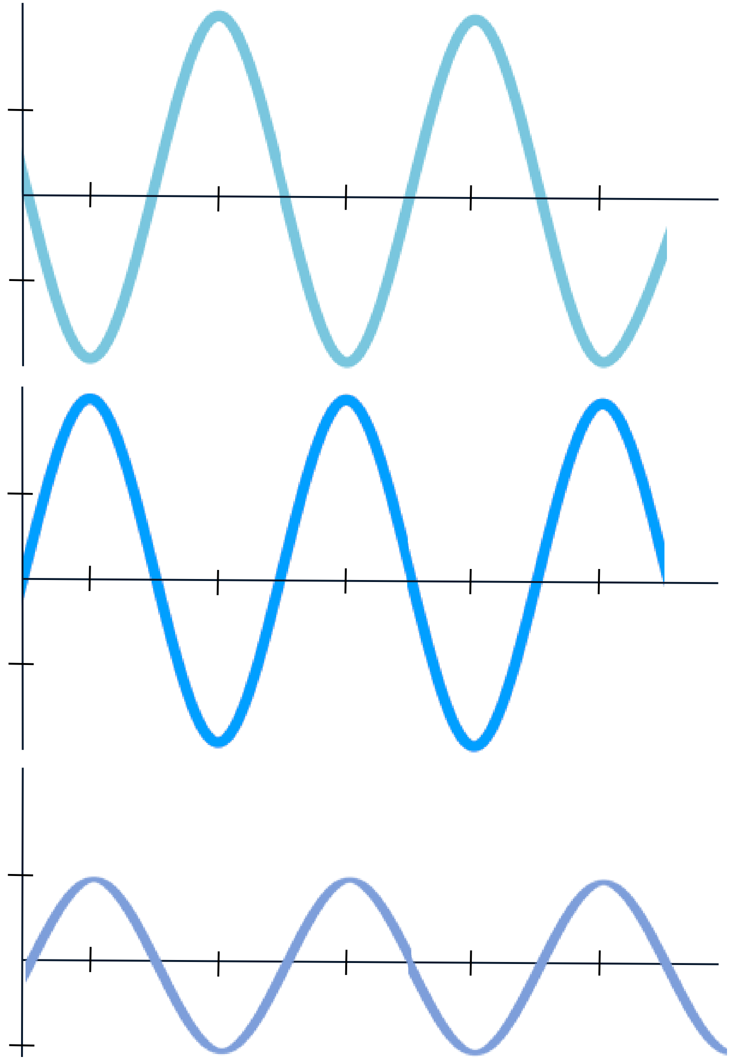


Antenna Diversity

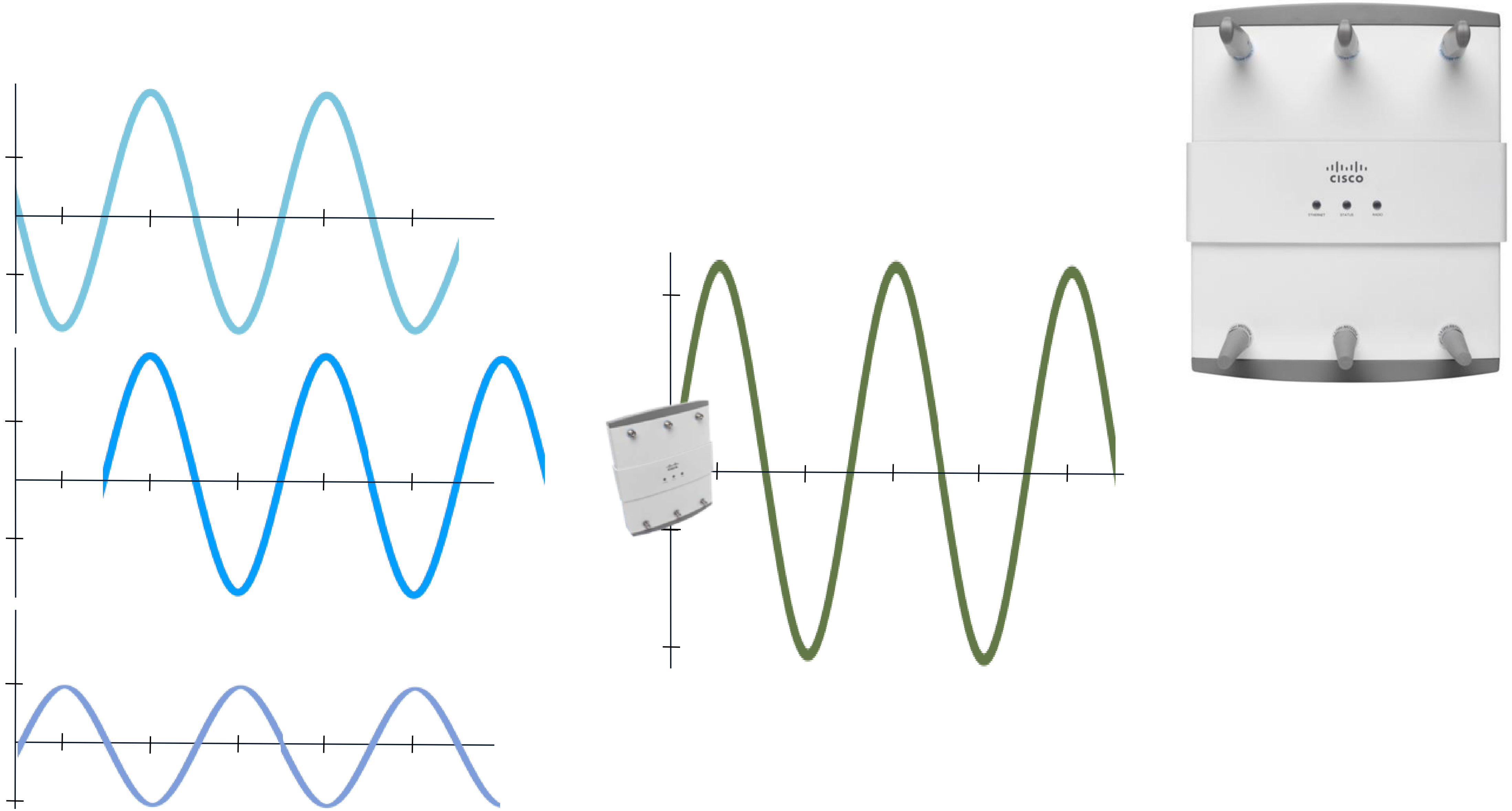




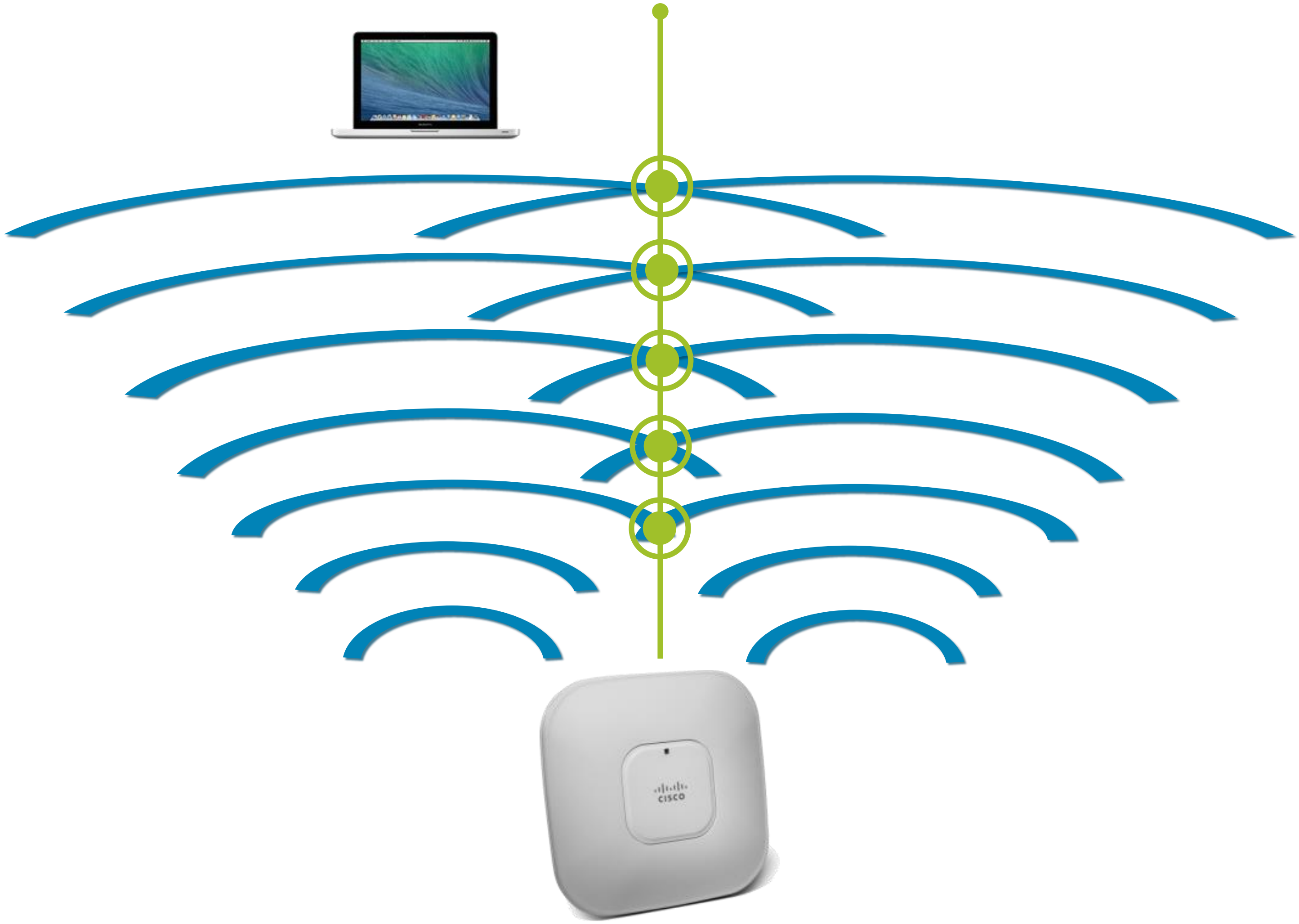
Diversity Combining



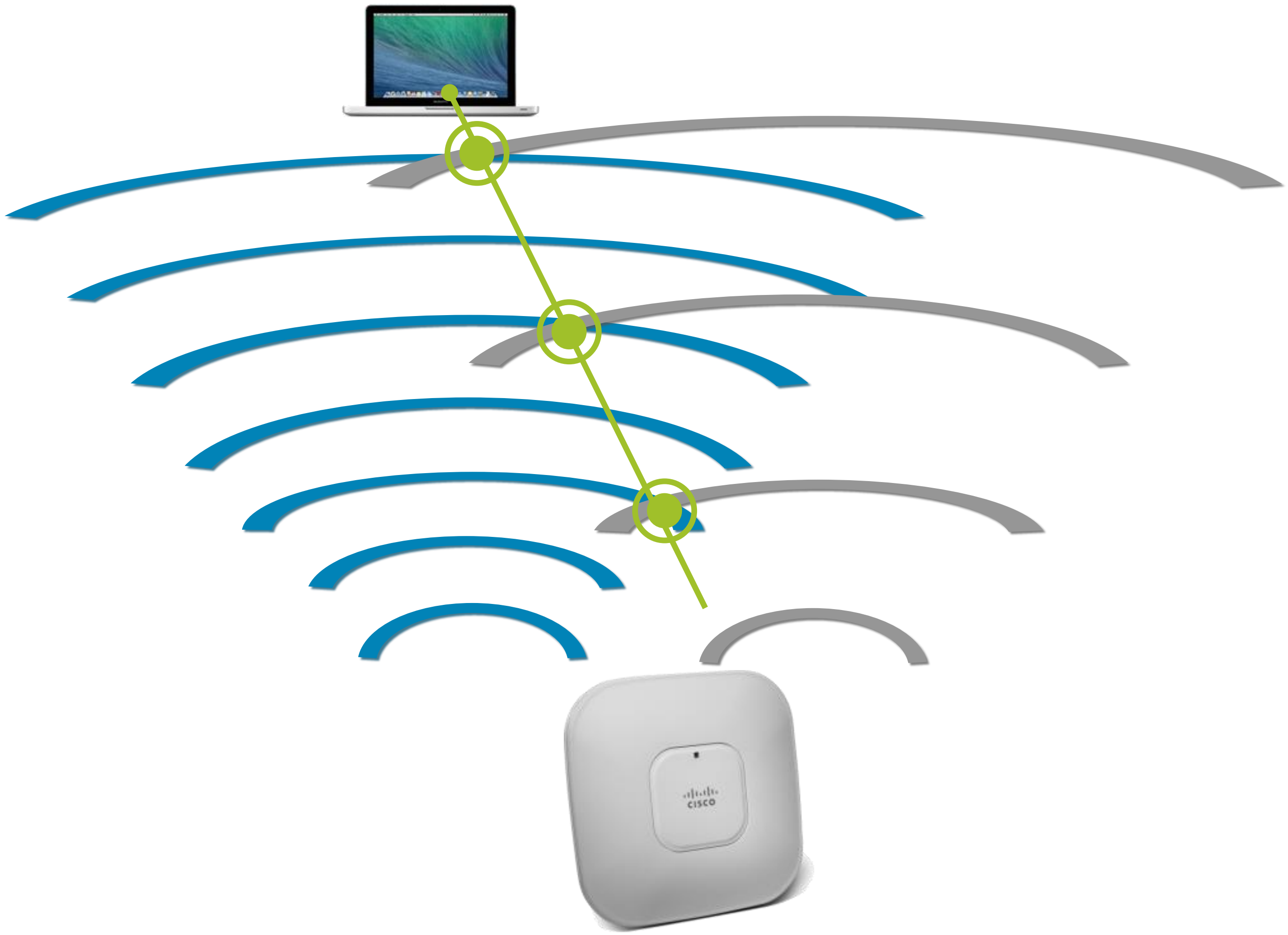
Diversity Combining



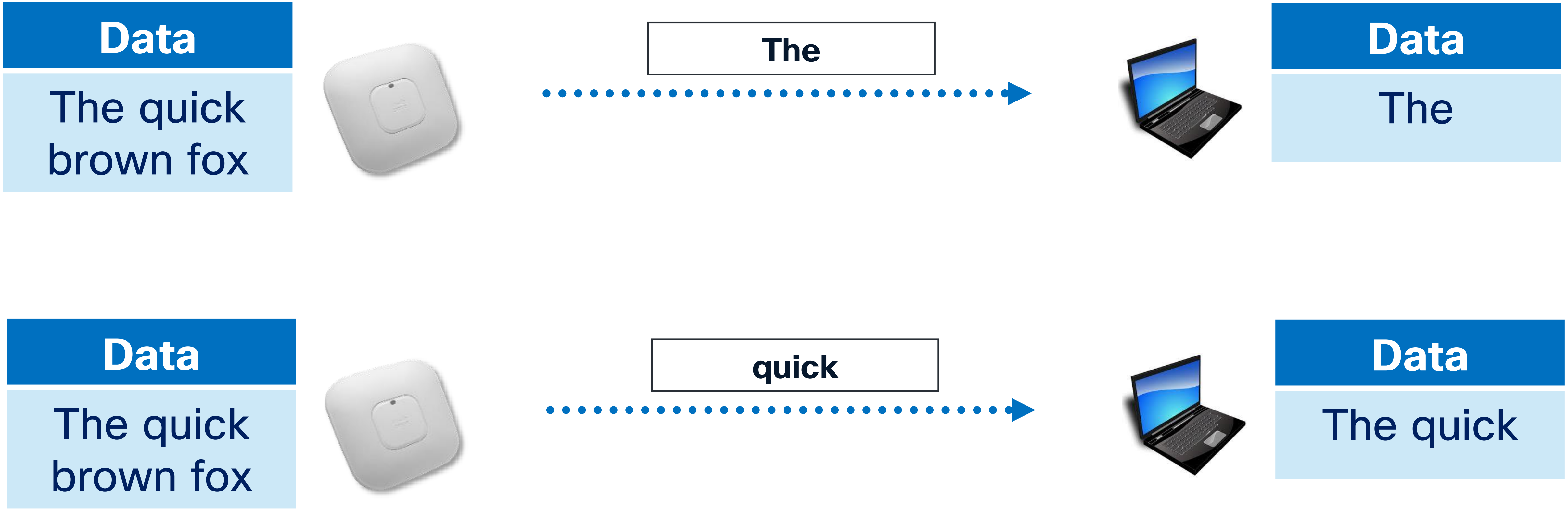
Transmit Beamforming



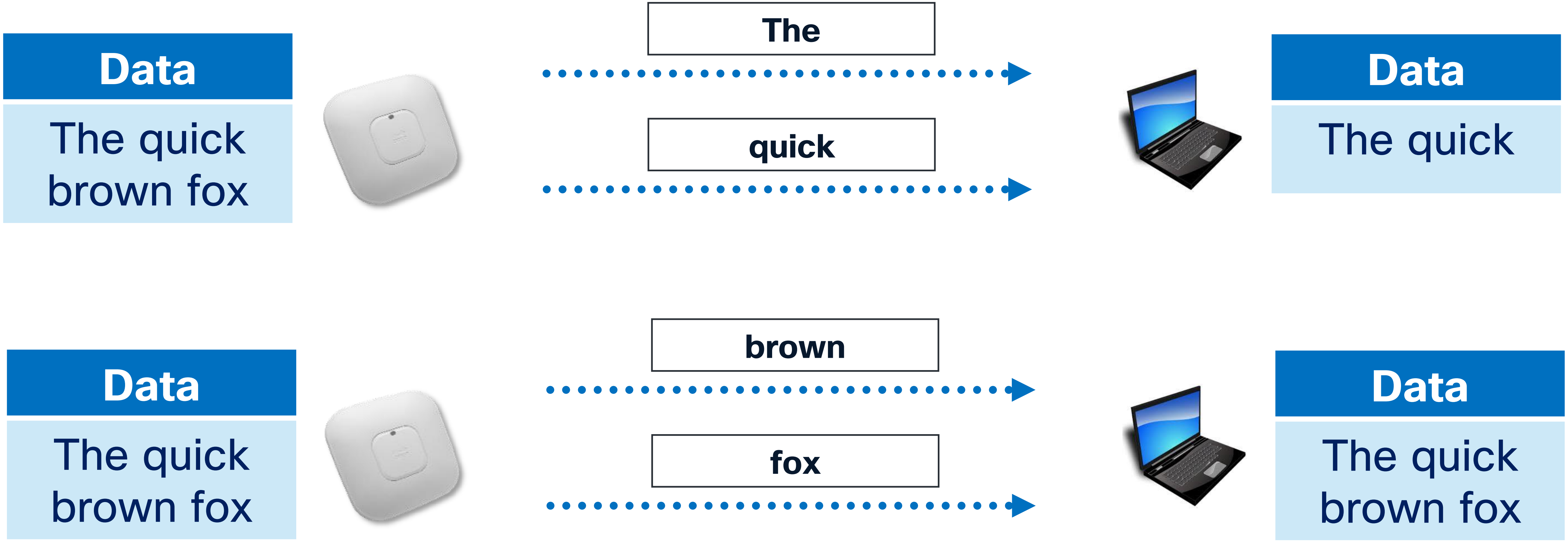
Transmit Beamforming



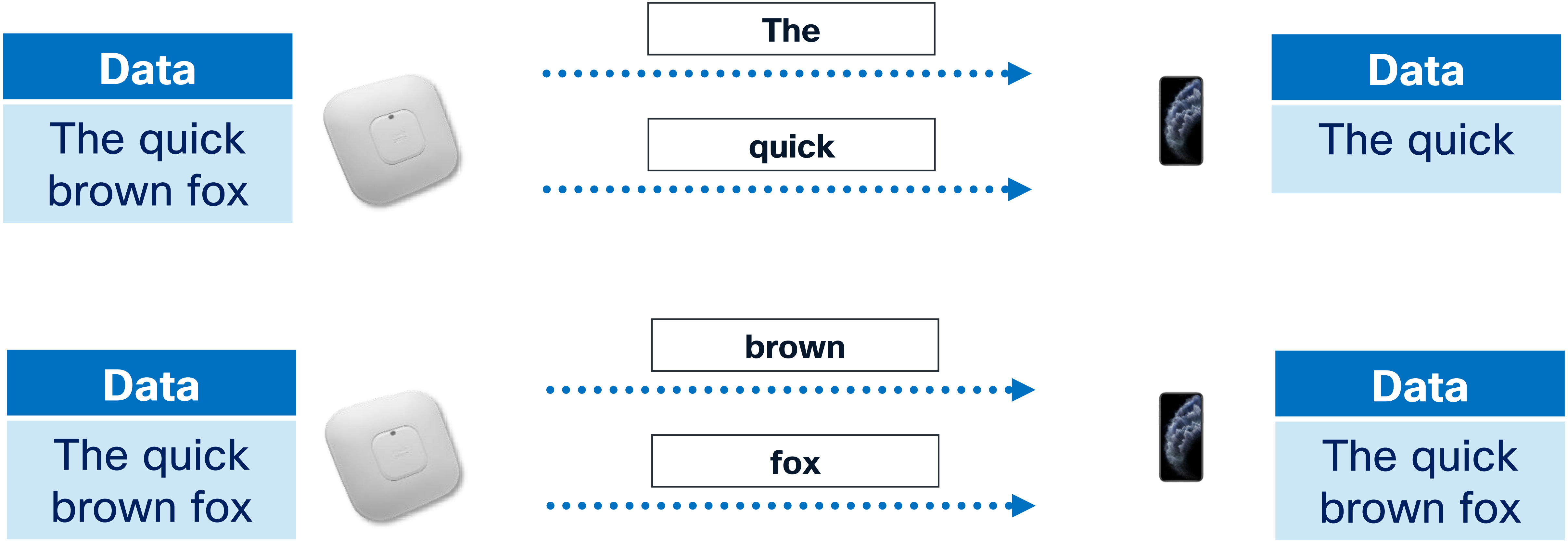
Spatial Multiplexing



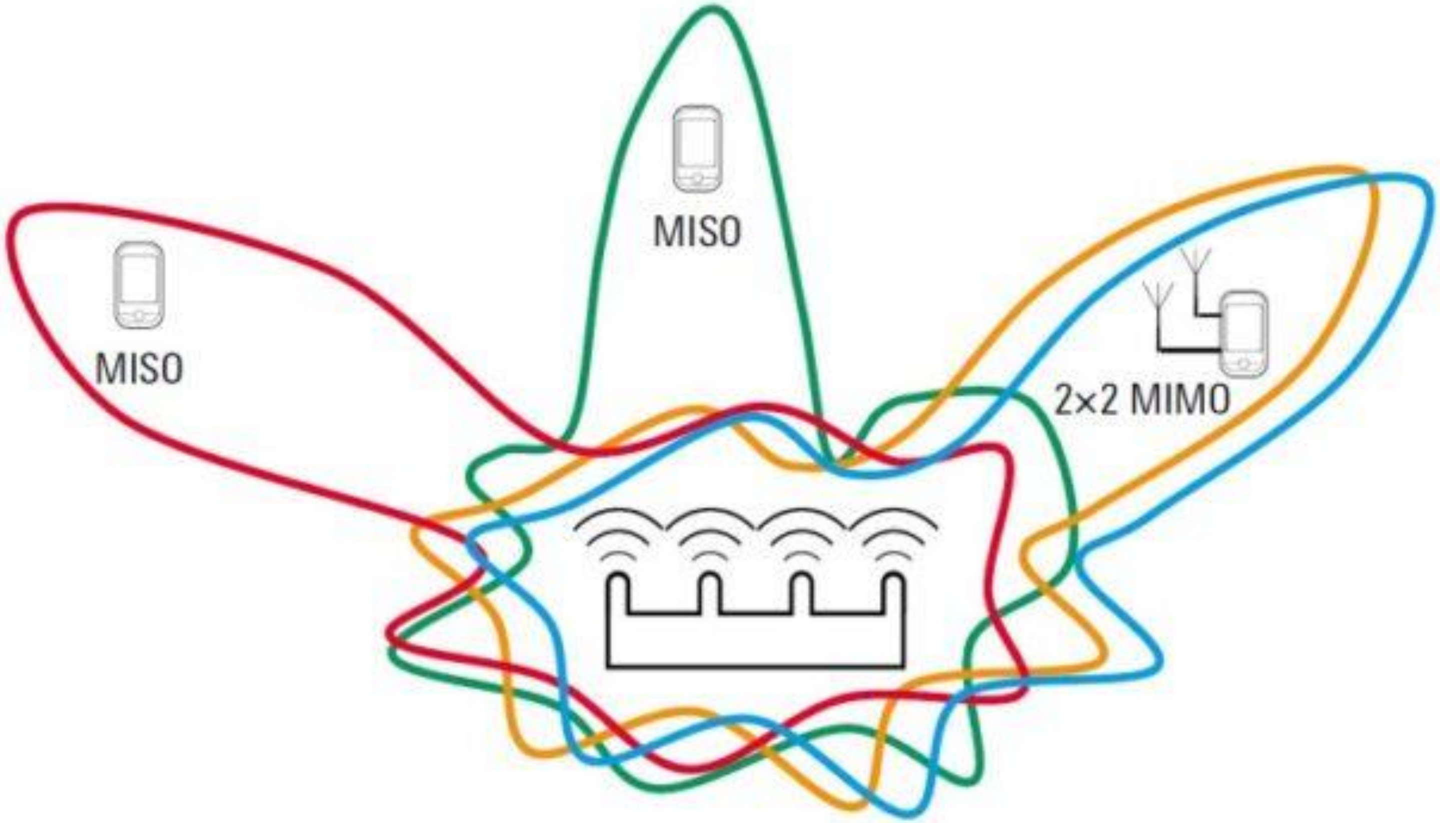
Spatial Multiplexing



Spatial Multiplexing



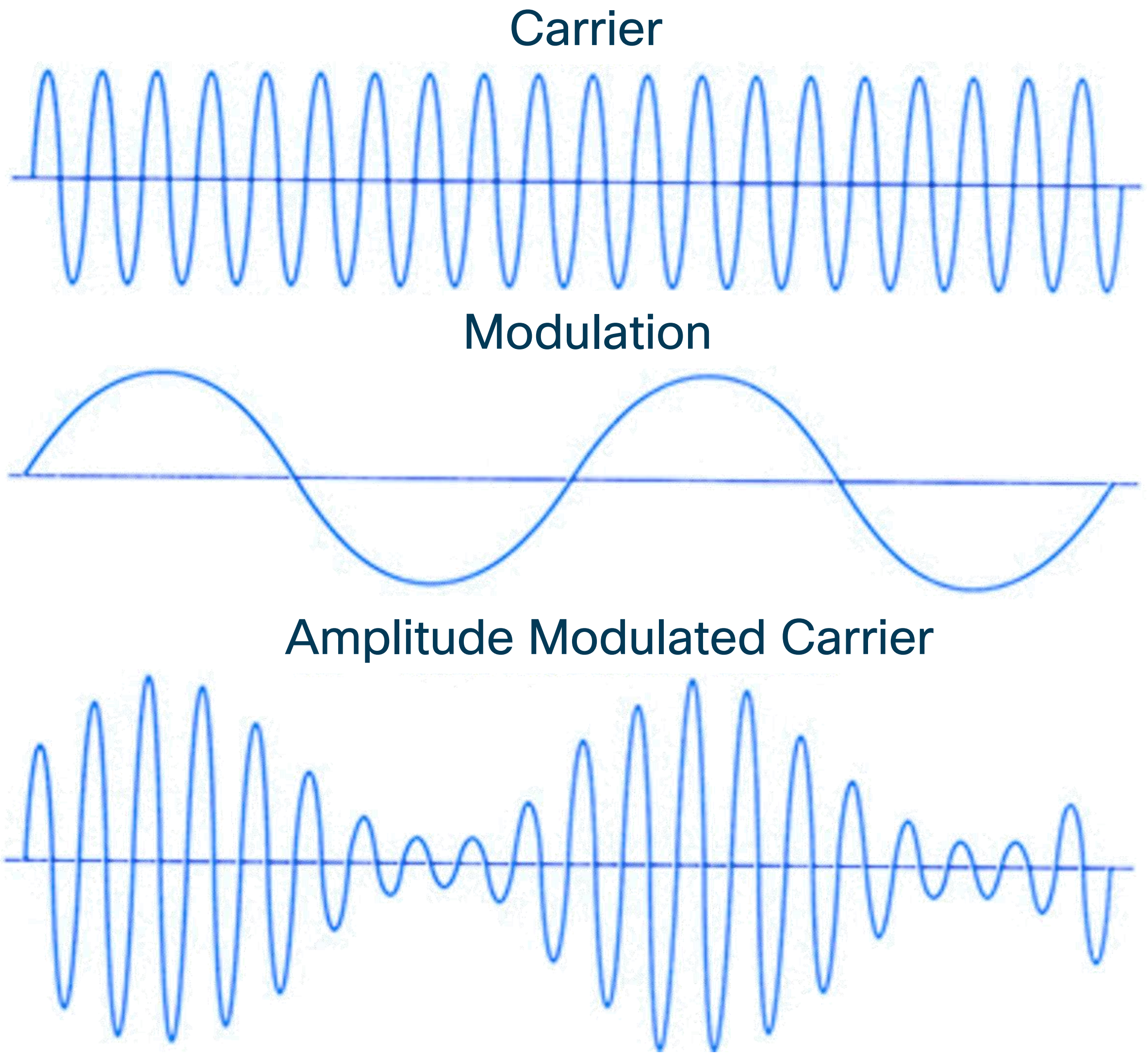
Multi-User MIMO



Digital Modulation Techniques

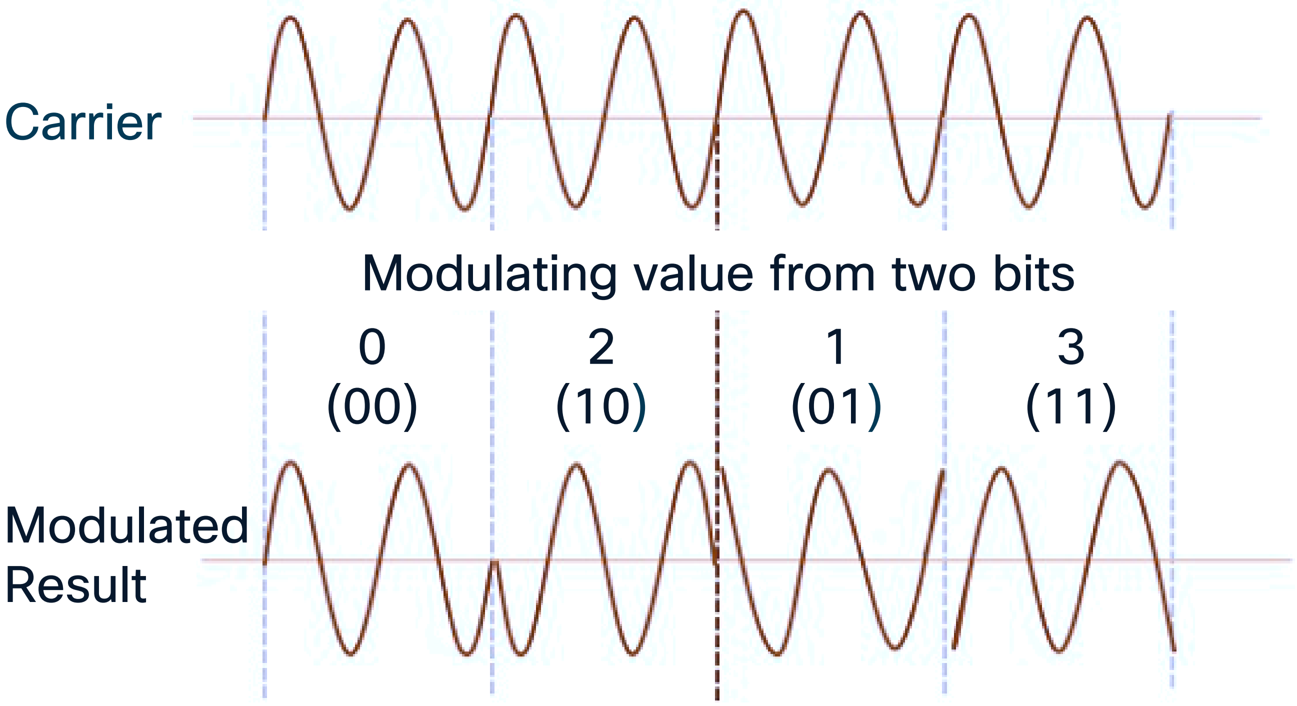
Three basic methods

1. Modulate the Amplitude
2. Modulate the Frequency
3. Modulate the Phase

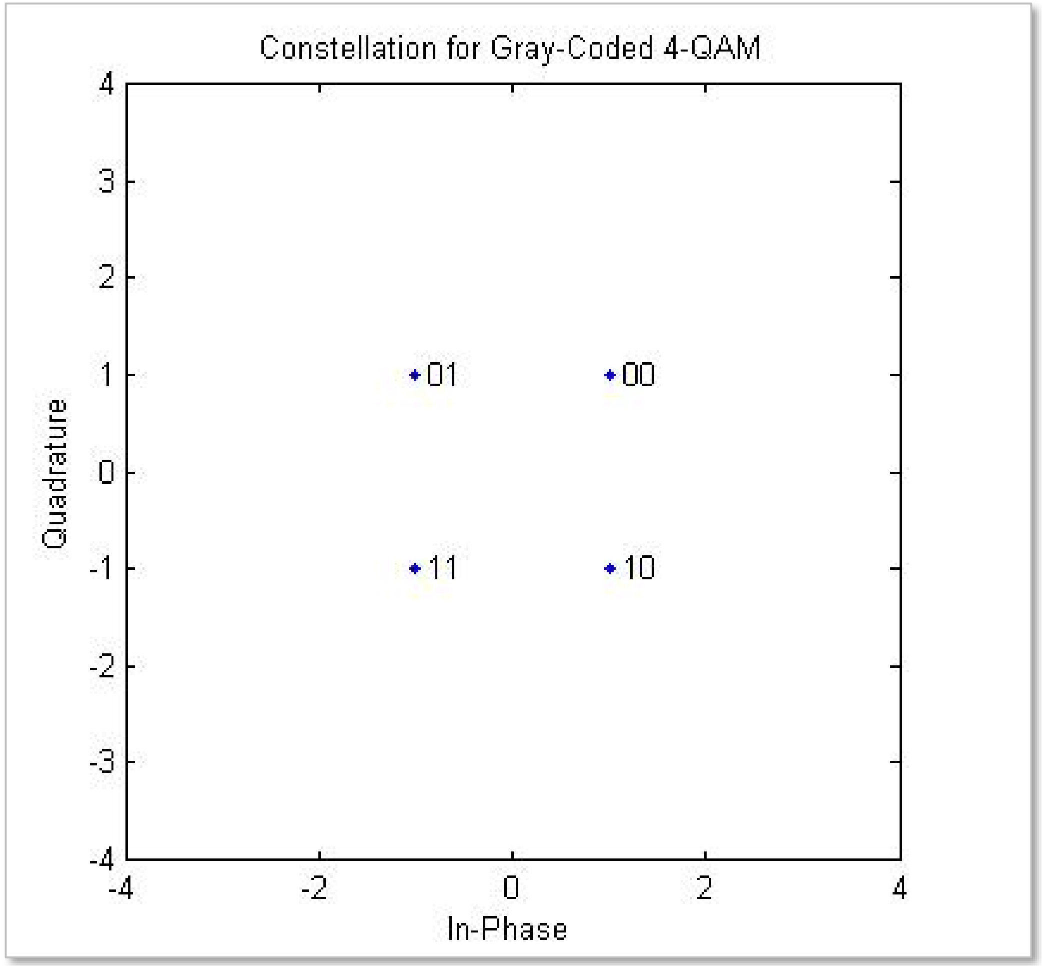


Digital Modulation Techniques

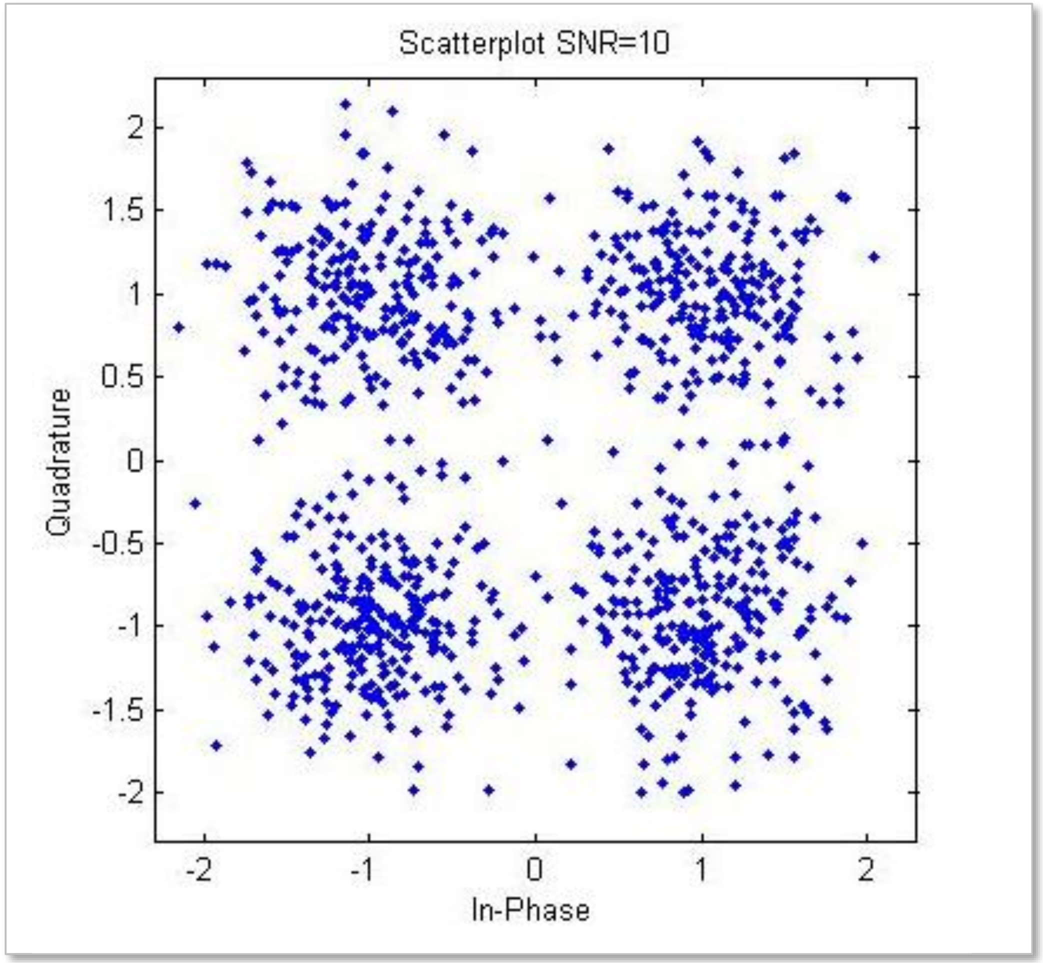
- Quadrature Phase Shift Keying (QPSK)
  - Each possible shift represents 2 bits
- Quadrature Amplitude Modulation (QAM)
  - Symbols are a combination of amplitude and phase
  - High Spectral Efficiency
  - Difficult to demodulate in the presence of noise



Modulation, SNR and Data Rates

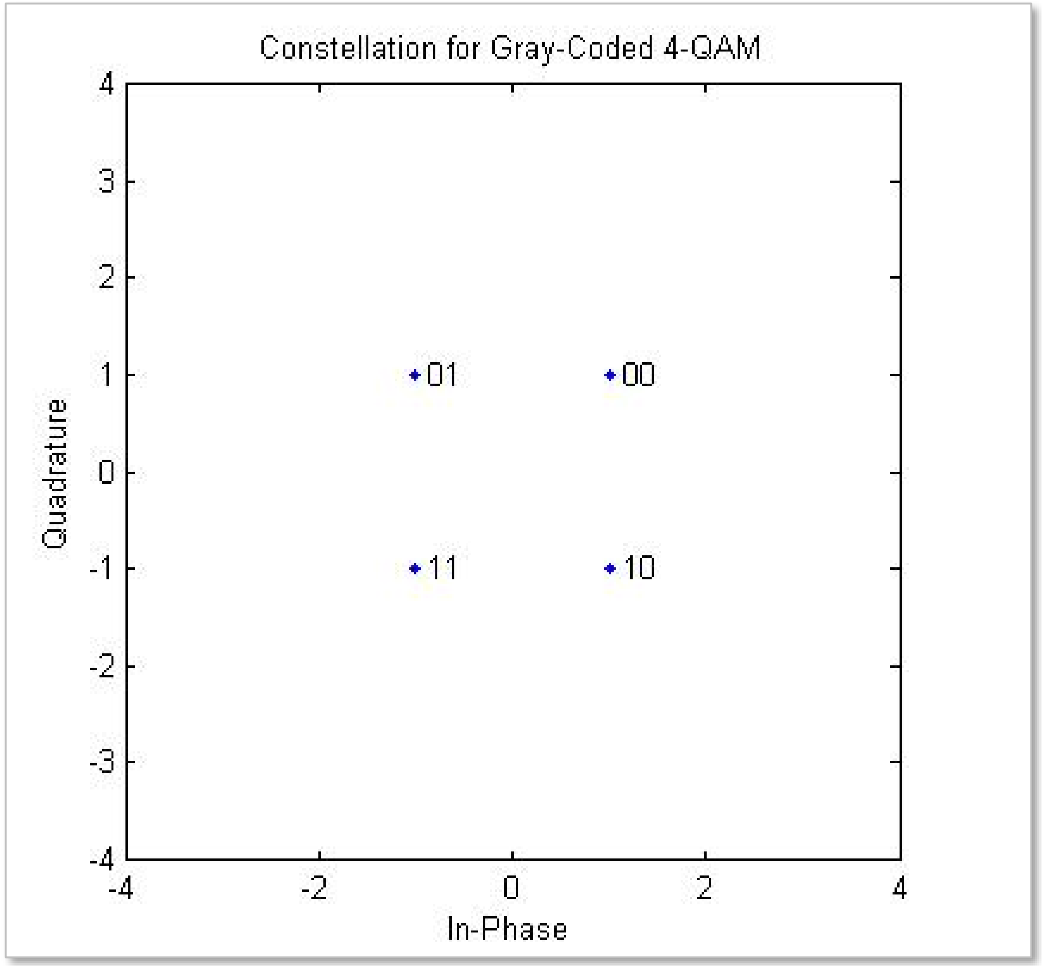


4-QAM

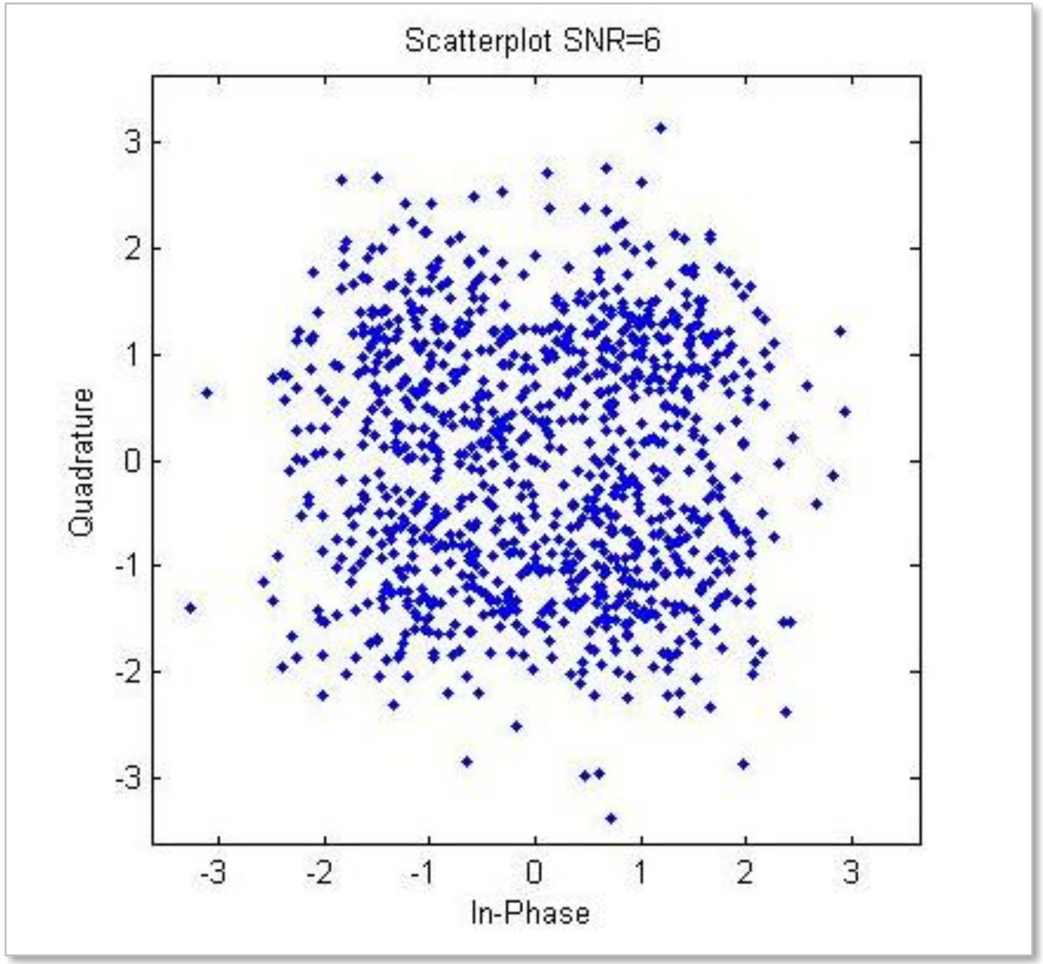


SNR=10

Modulation, SNR and Data Rates



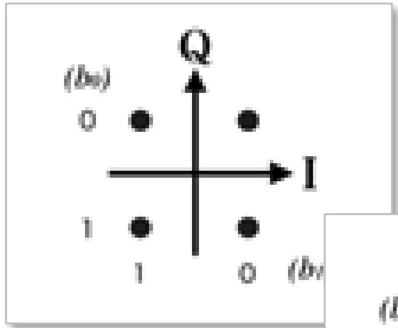
4-QAM



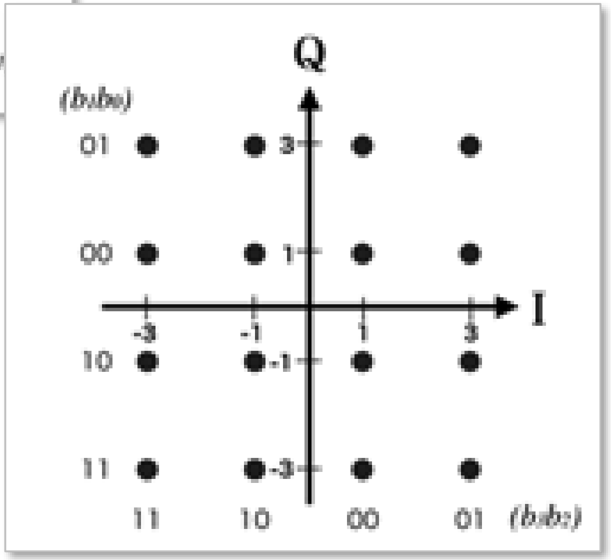
SNR=6

Rate vs Range and the Laws of Physics

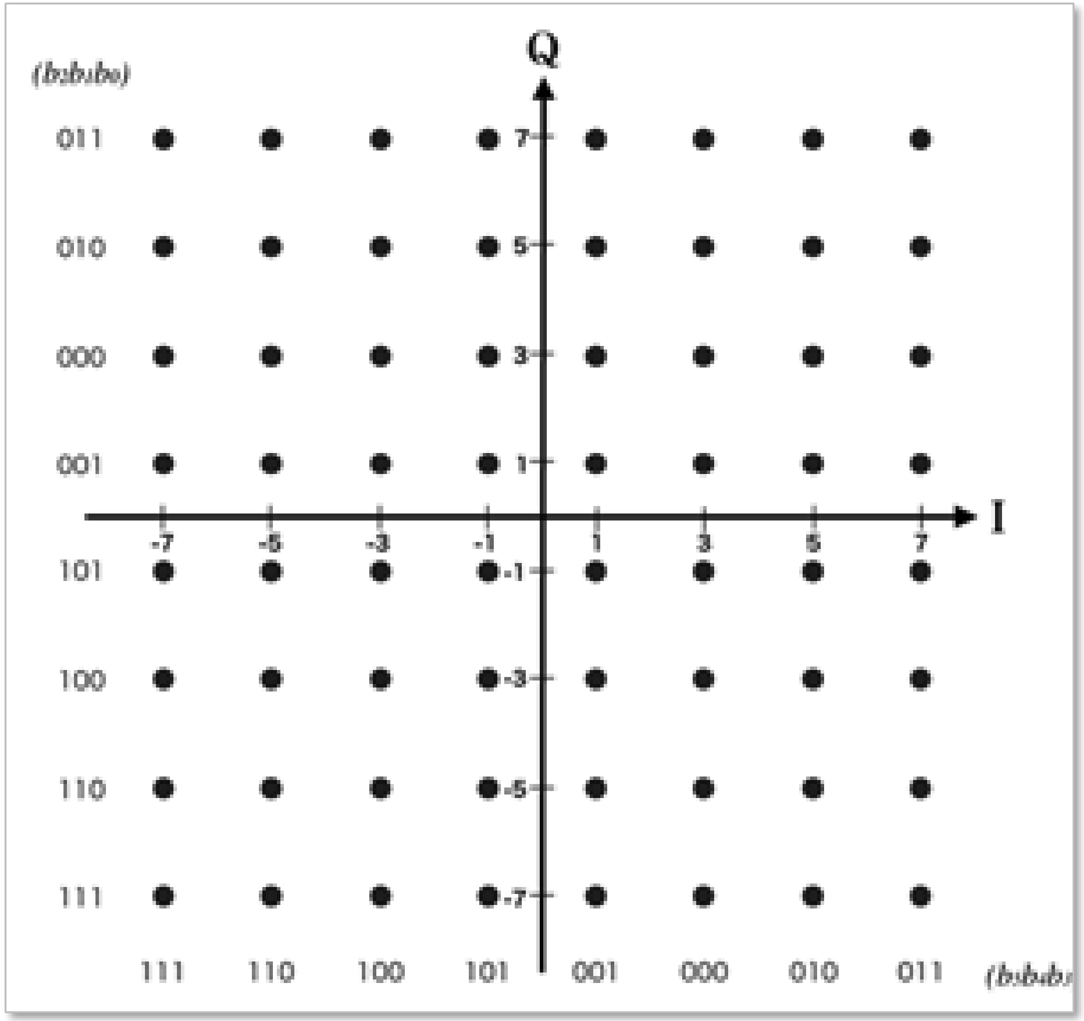
FYI



4-QAM

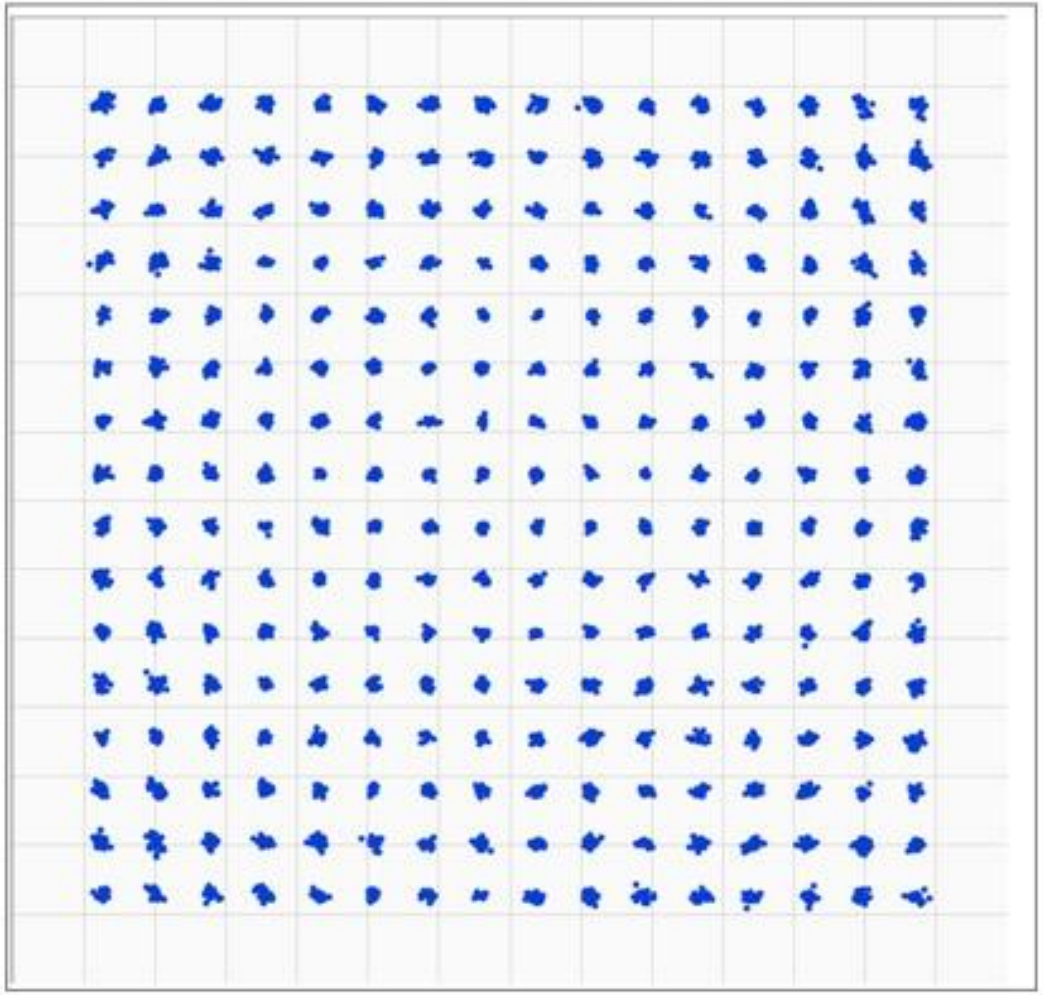


16-QAM



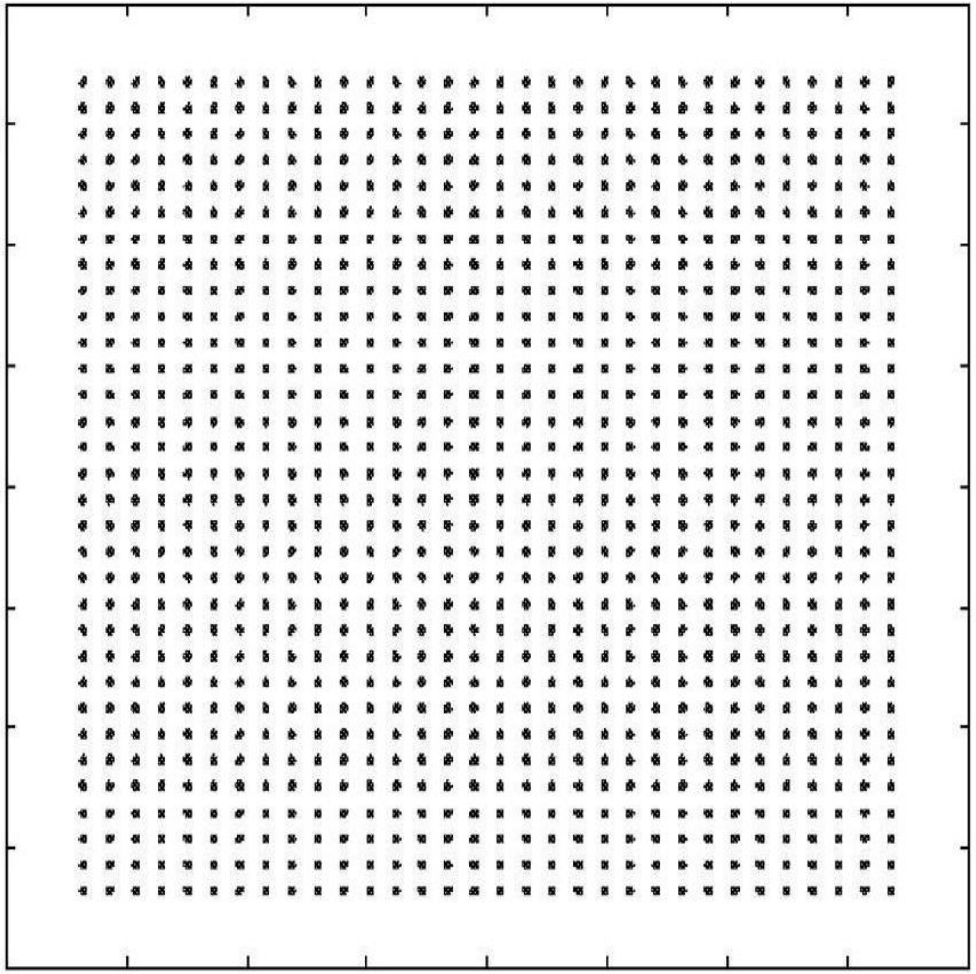
64-QAM

Rate vs Range and the Laws of Physics



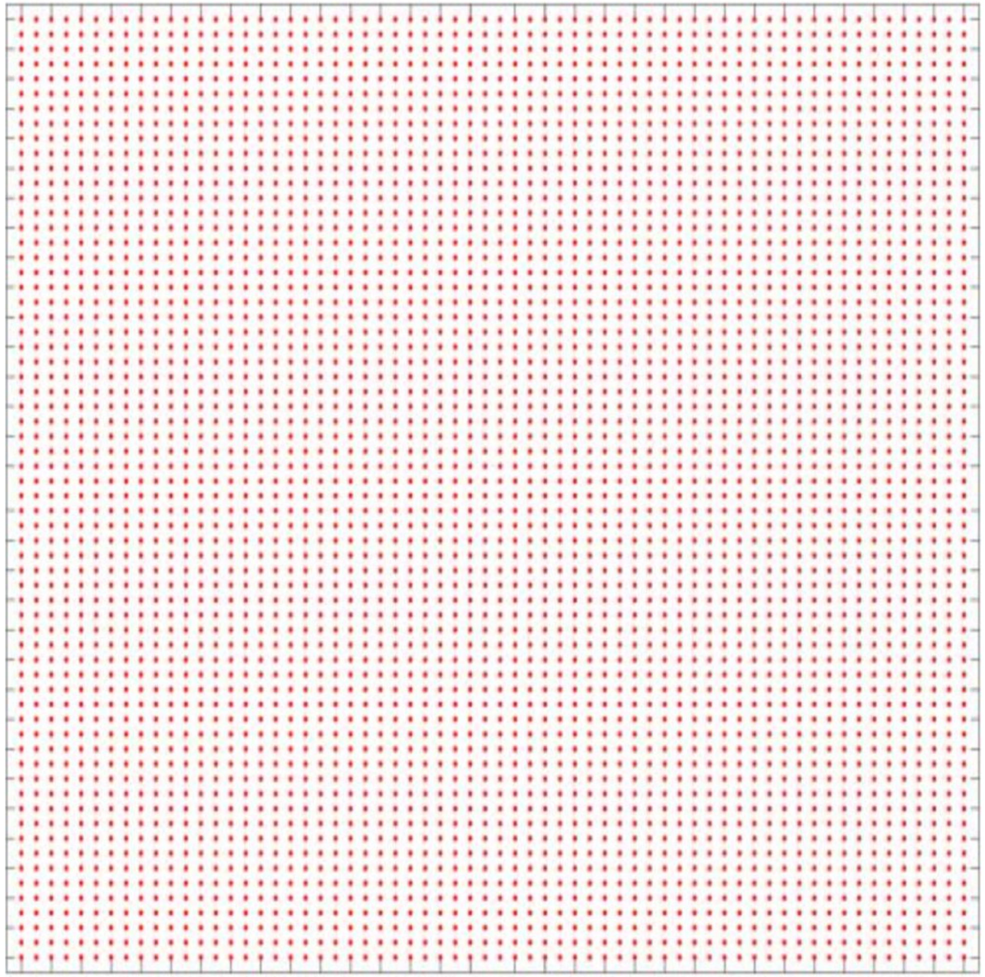
256-QAM (8 bits/symbol)

Rate vs Range and the Laws of Physics



1024-QAM (10 bits/symbol)

Rate vs Range and the Laws of Physics

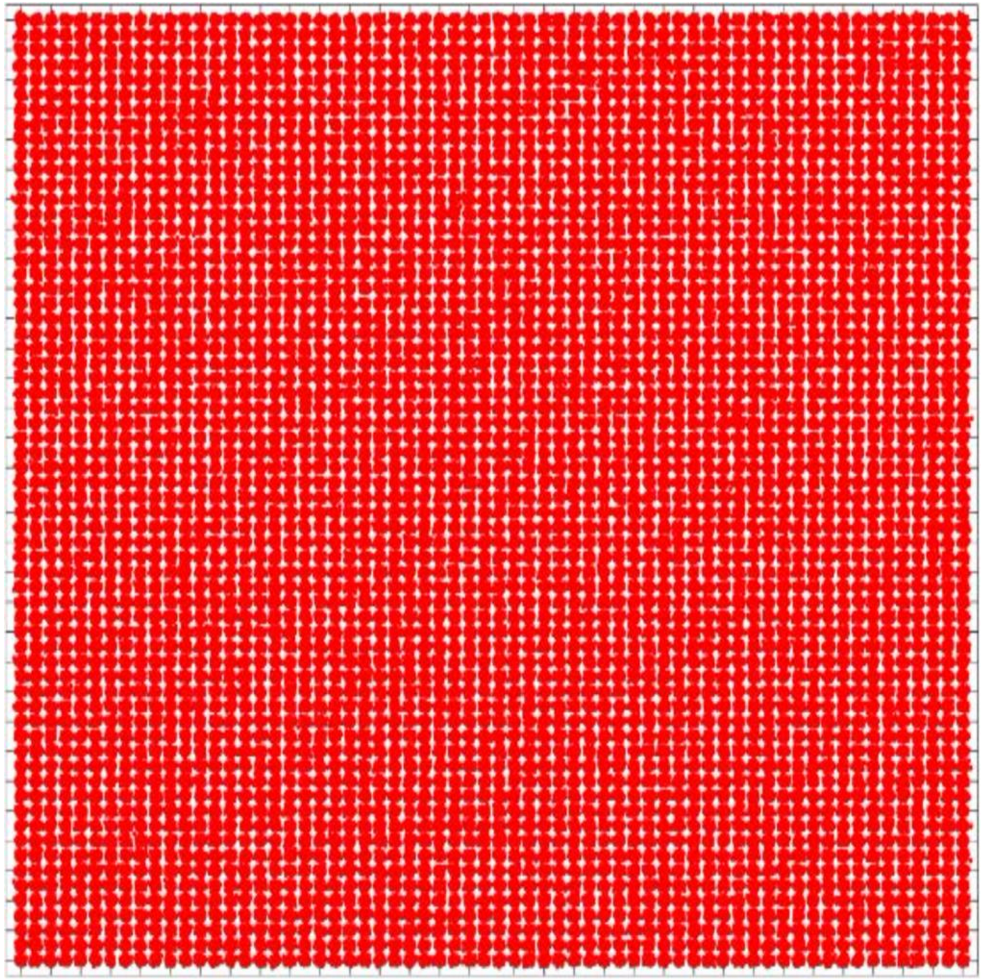


4096-QAM (12 bits/symbol)

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	
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	MC
IEEE_802.11ag 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	MC
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	MC
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	MC
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	MC
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	MC
IEEE_802.11ac 80 MHz	None	None	None	None	None	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MC
IEEE_802.11ac 160 MHz	None	None	None	None	None	None	None	None	None	None	None	MCS 0	MCS 0	MC

Increased Sensitivity to Noise



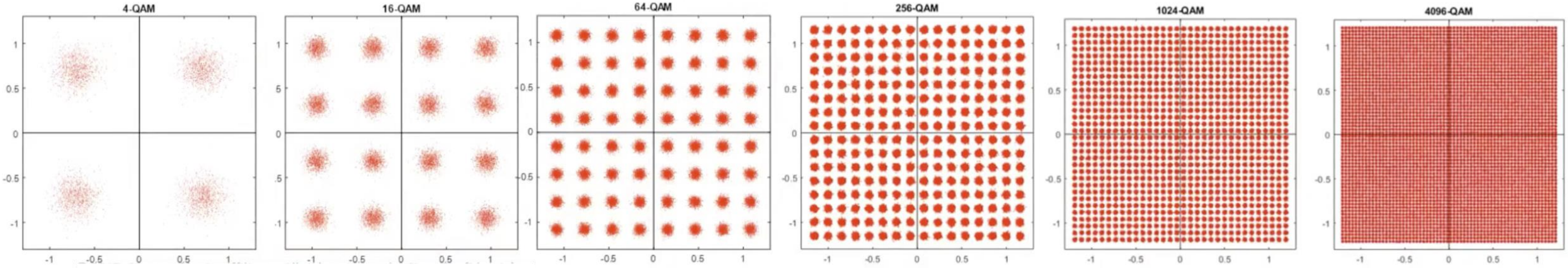
SNR=43

Increasing Throughput and Decreasing Range

FYI

Each increment in constellation size reduces range by approx. 50%

Incremental data rate	+100%	+50%	+33%	+25%	+20%
Relative Range	80	40	20	10	5



Wi-Fi4	Wi-Fi5	Wi-Fi6	Wi-Fi7

Implications of Poor Cell Design

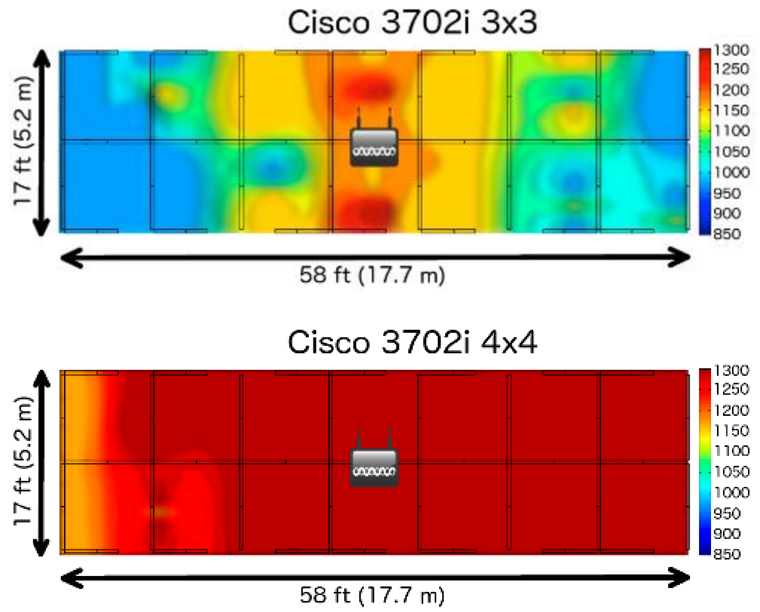
FYI

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

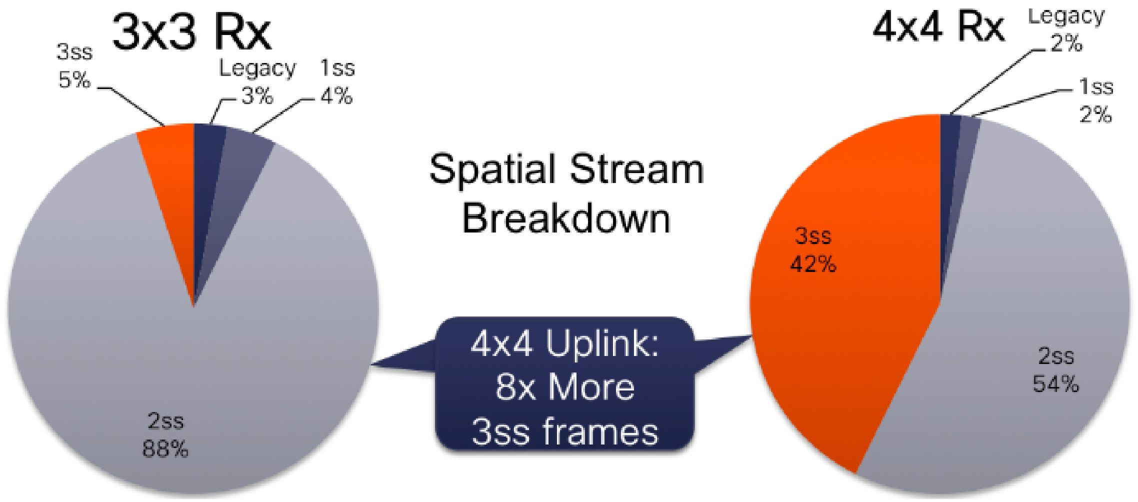
Transmit and Receive Diversity

- Transmit Diversity improves signal strength at the client



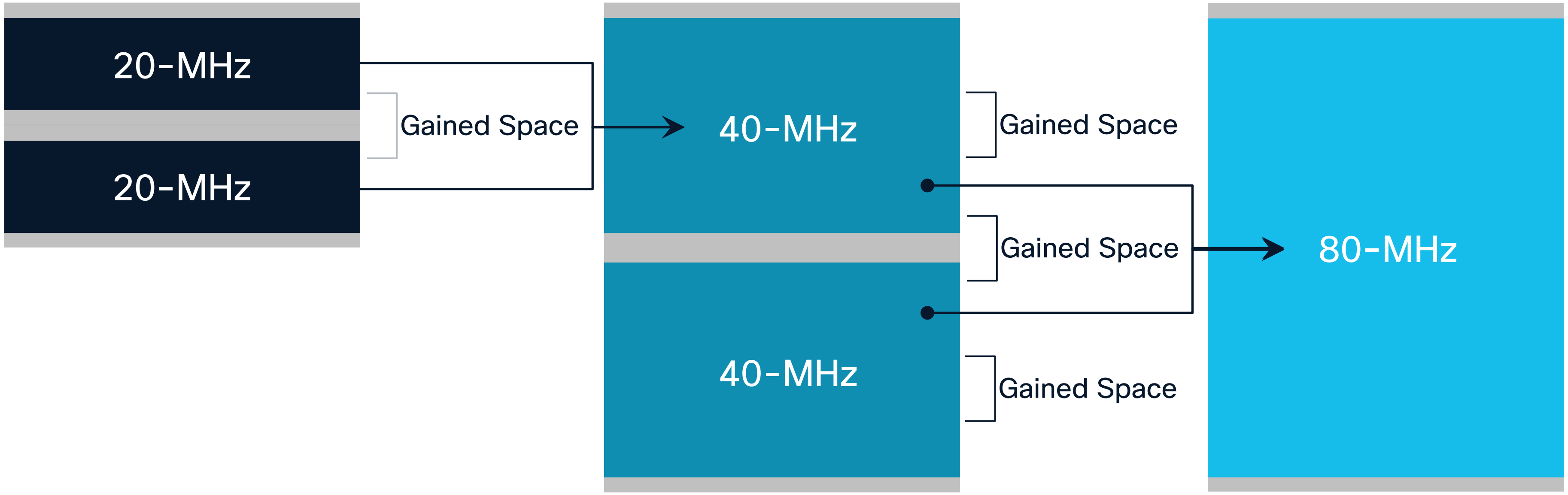
- Results in a 15% improvement by making MCS m8/m9 usable

- Receive Diversity improves ability to receive 3SS frames from the client



- N+1 is necessary to deliver spatial multiplexing benefits

Channel Aggregation



Wi-Fi Spectrum

2.4 GHz Channels

80 MHz

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

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

5 GHz Channels

500 MHz

Frequency	*5000 + 5 X Ch. Number*

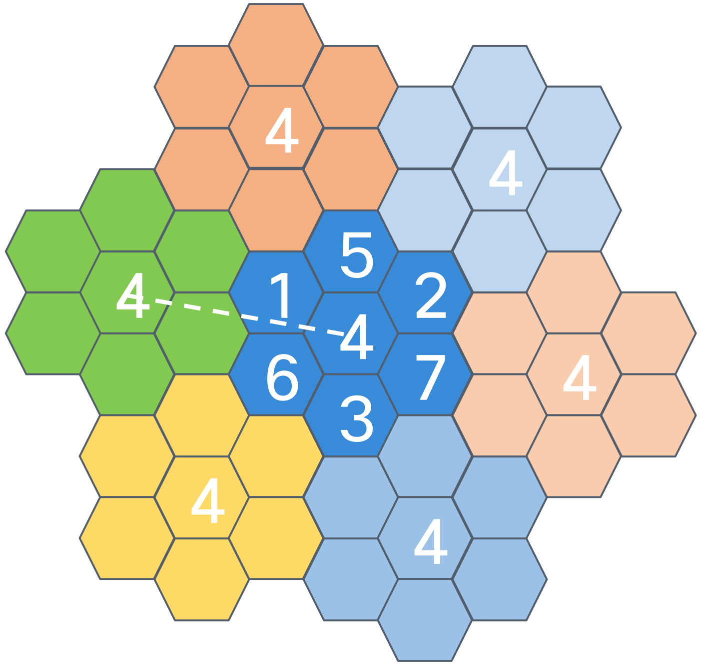
Wavelength 5.8cm - 2.3" to 5.1cm - 2.0"

Qty	**Radio Band**	**U-NII-1**				**U-NII-2a** (DFS Channels)			
	Center Freq	5.180	5.200	5.220	5.240	5.260	5.280	5.300	5.320
25	**20 MHz**	36	40	44	48	52	56	60	64
11	**40 MHz**	38		46		54		62	
5	**80 MHz**	42				58			
2	**160 MHz**	50							

Radio Band	**U-NII-2c (Extended)** (DFS Channels)												**U-NII-3**					Qty
						TDWR												
Center Freq	5.500	5.520	5.540	5.560	5.580	5.600	5.620	5.640	5.660	5.680	5.700	5.720	5.745	5.765	5.785	5.805	5.825	
20 MHz	100	104	108	112	116	120	124	128	132	136	140	144	149	153	157	161	165	**25**
40 MHz	102		110		118		126		134		142		151		159			**11**
80 MHz	106				122				138				155					**5**
160 MHz	114												*165 was ISM, now U-NII-3*					**2**

wirelessLAN PROFESSIONALS

Wi-Fi Spectrum



2.4 GHz Channels

80 MHz

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

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

5 GHz Channels

500 MHz

Frequency *5000 + 5 X Ch. Number* ***Wavelength*** ***5.8cm - 2.3" to 5.1cm - 2.0"***

Qty	Radio Band	U-NII-1				U-NII-2a (DFS Channels)				U-NII-2c (Extended) (DFS Channels)					TDWR							U-NII-3					Qty
	Center Freq	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	5.745	5.765	5.785	5.805	5.825	
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
5	80 MHz	42				58				106				122				138				155					5
2	160 MHz	50								114												*165 was ISM, now U-NII-3*					2

6 GHz Channels

1,200 MHz

FCC - USA *5950 + 5 X Ch. Number* ***Wavelength*** ***5.1cm - 2.0" to 4.2cm - 1.6"***

Low Power Indoor — 5dBm/MHz - Net EIRP 18dBM

5925 / 6425 / 6525 / 6875 / 7125

UNII-5

Qty	Center Freq	5.955	5.975	5.995	6.015	6.035	6.055	6.075	6.095	6.115	6.135	6.155	6.175	6.195	6.215	6.235	6.255	6.275	6.295	6.315	6.335	6.355	6.375	6.395	6.415
59	20 MHz	1	5	9	13	17	21	25	29	33	37	41	45	49	53	57	61	65	69	73	77	81	85	89	93
29	40 MHz	3		11		19		27		35		43		51		59		67		75		83		91	
14	80 MHz	7				23				39				55				71				87			
7	160 MHz	15								47								79							

UNII-6 / UNII-7

Radio Band	UNII-6					UNII-7																
Center Freq	6.435	6.455	6.475	6.495	6.515	6.535	6.555	6.575	6.595	6.615	6.635	6.655	6.675	6.695	6.715	6.735	6.755	6.775	6.795	6.815	6.835	6.855
20 MHz	97	101	105	109	113	117	121	125	129	133	137	141	145	149	153	157	161	165	169	173	177	181
40 MHz	99		107		115		123		131		139		147		155		163		171		179	
80 MHz	103				119				135				151				167				183	
160 MHz	111								143								175					

UNII-8

Radio Band		UNII-8												Qty
Center Freq		6.895	6.915	6.935	6.955	6.975	6.995	7.015	7.035	7.055	7.075	7.095	7.115	
20 MHz	185	189	193	197	201	205	209	213	217	221	225	229	233	59
40 MHz	187		195		203		211		219		227			29
80 MHz			199				215							14
160 MHz			207											7

Standard Power AP — 36dBm with Automated Frequency Coordination (AFC)

5925 / 6425 / 6525 / 6875

UNII-5

Qty	Center Freq	5.955	5.975	5.995	6.015	6.035	6.055	6.075	6.095	6.115	6.135	6.155	6.175	6.195	6.215	6.235	6.255	6.275	6.295	6.315	6.335	6.355	6.375	6.395	6.415
24	20 MHz	1	5	9	13	17	21	25	29	33	37	41	45	49	53	57	61	65	69	73	77	81	85	89	93
12	40 MHz	3		11		19		27		35		43		51		59		67		75		83		91	
6	80 MHz	7				23				39				55				71				87			
3	160 MHz	15								47								79							

UNII-6 / UNII-7

Radio Band	UNII-6					UNII-7																
Center Freq	6.435	6.455	6.475	6.495	6.515	6.535	6.555	6.575	6.595	6.615	6.635	6.655	6.675	6.695	6.715	6.735	6.755	6.775	6.795	6.815	6.835	6.855
20 MHz						117	121	125	129	133	137	141	145	149	153	157	161	165	169	173	177	181
40 MHz							123		131		139		147		155		163		171		179	
80 MHz									135				151				167					
160 MHz									143													

UNII-8

Radio Band	UNII-8											
Center Freq	6.895	6.915	6.935	6.955	6.975	6.995	7.015	7.035	7.055	7.075	7.095	7.115

320 MHz

wirelessLAN PROFESSIONALS

6GHz Device Classes

Low Power Indoor

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

Client Devices

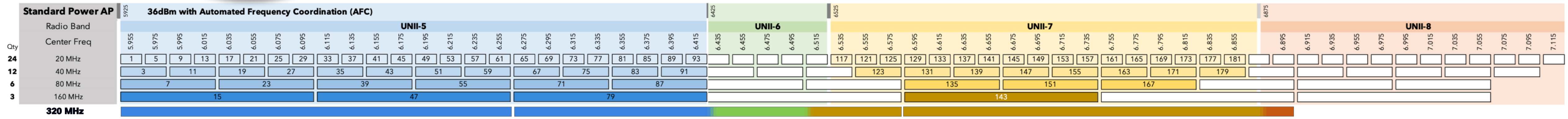
- Indoor or Outdoor
- Only Indoor under control of LPI AP
- 6 dBm lower power than AP

Very Low Power

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

Standard Power

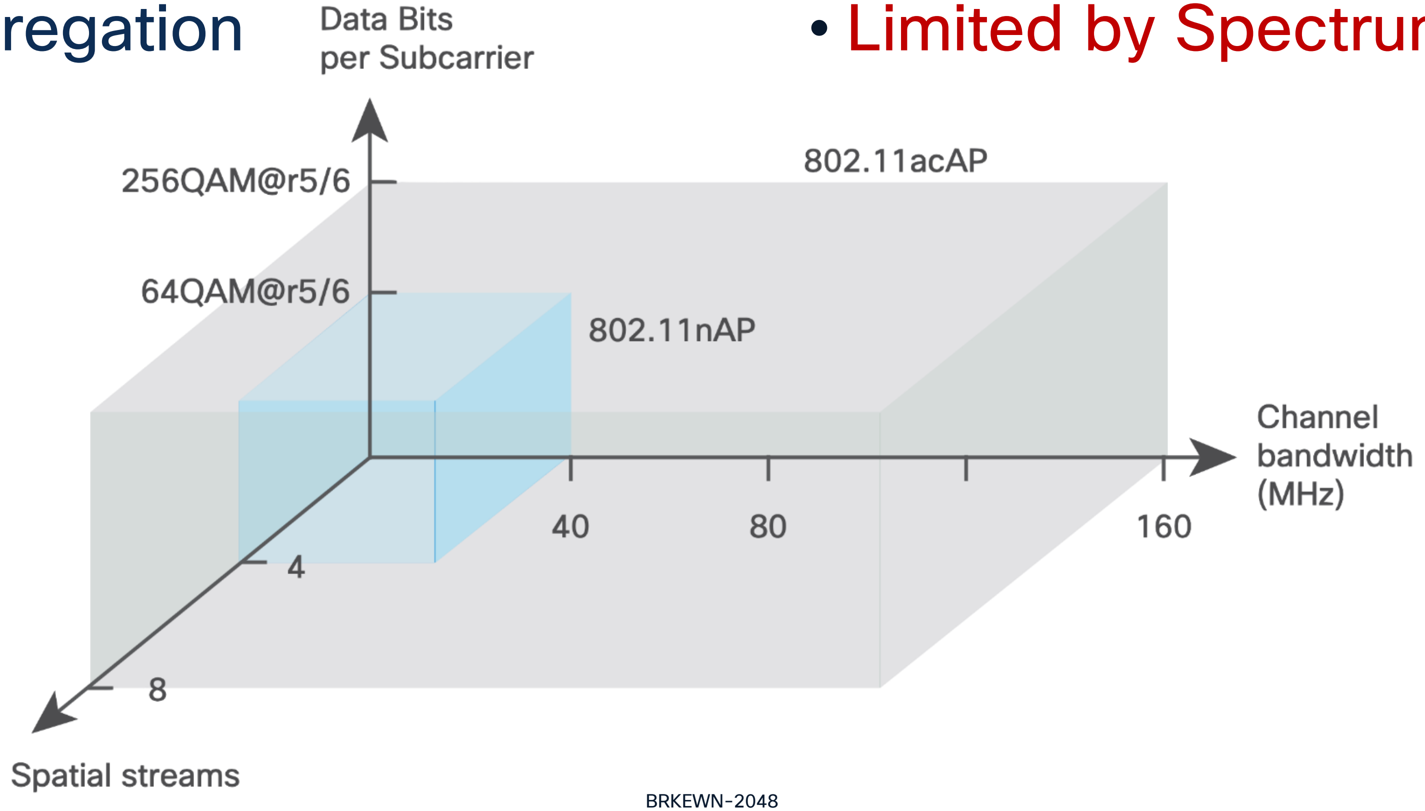
- Indoor or Outdoor
- Integrated or External Antenna
- UNII-5 and UNII-7 Only
- Requires AFC



Three Dimensions to Wi-Fi Performance

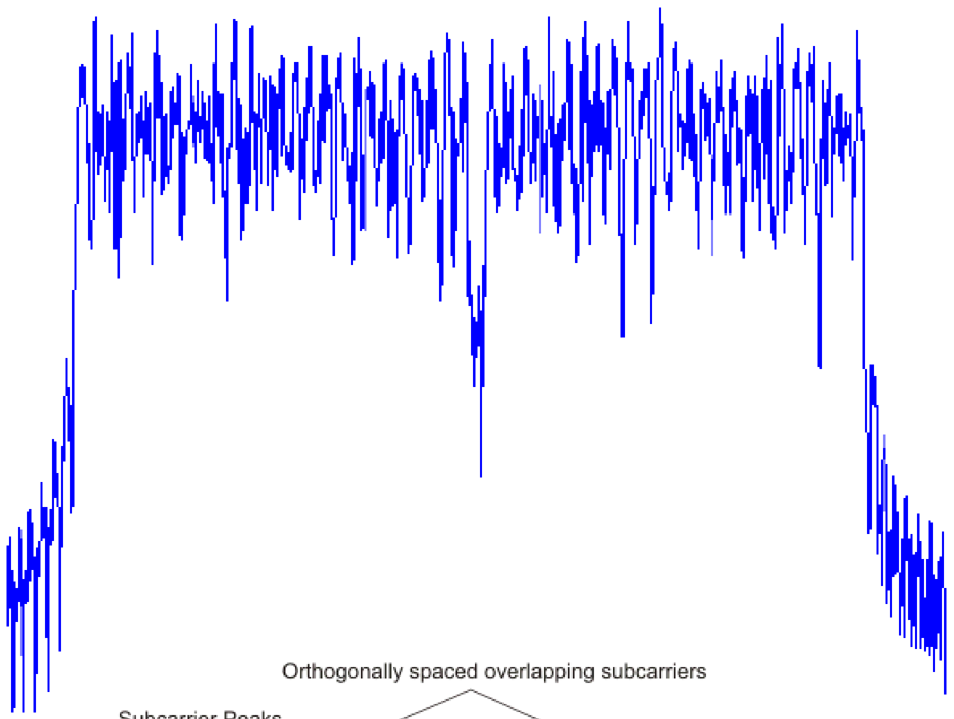
- Digital Modulation
- Spatial Multiplexing
- Channel Aggregation

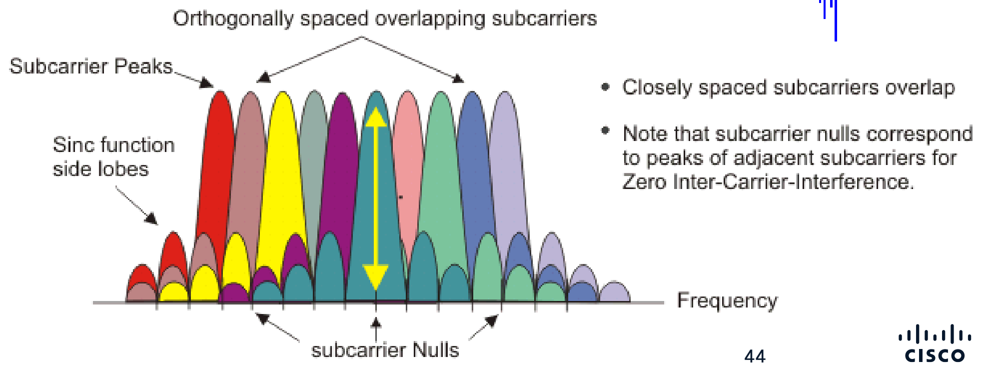
- Limited by SNR
- Limited by Client Capability
- Limited by Spectrum Availability



Multi-Carrier Modulation

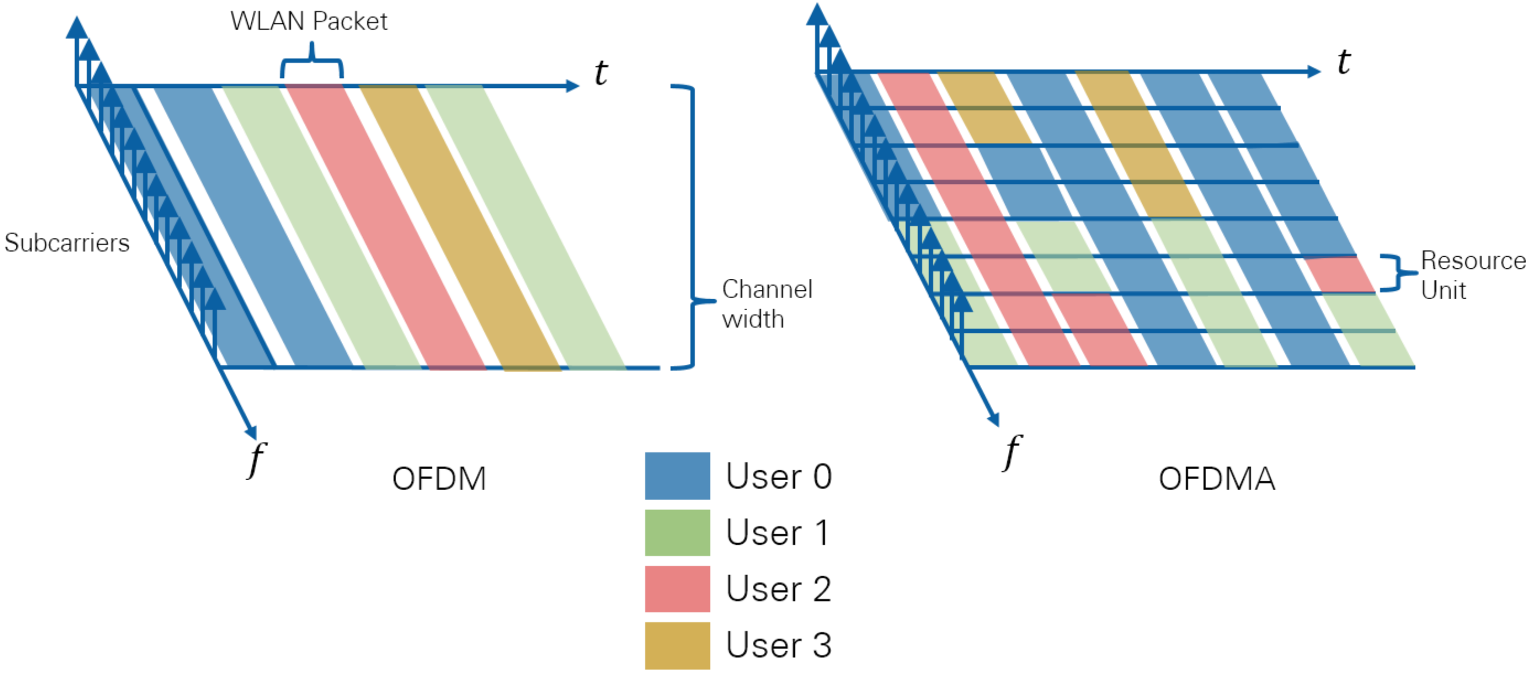
- Orthogonal Frequency Division Multiplexing (OFDM)
  - Combines modulation and multiplexing techniques to further improve spatial efficiency
  - The transmission channel is divided into subchannels or subcarriers
  - To avoid overlap between subcarriers, they are orthogonal (at 90˚ angle) to one another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





Improving Spectrum Efficiency

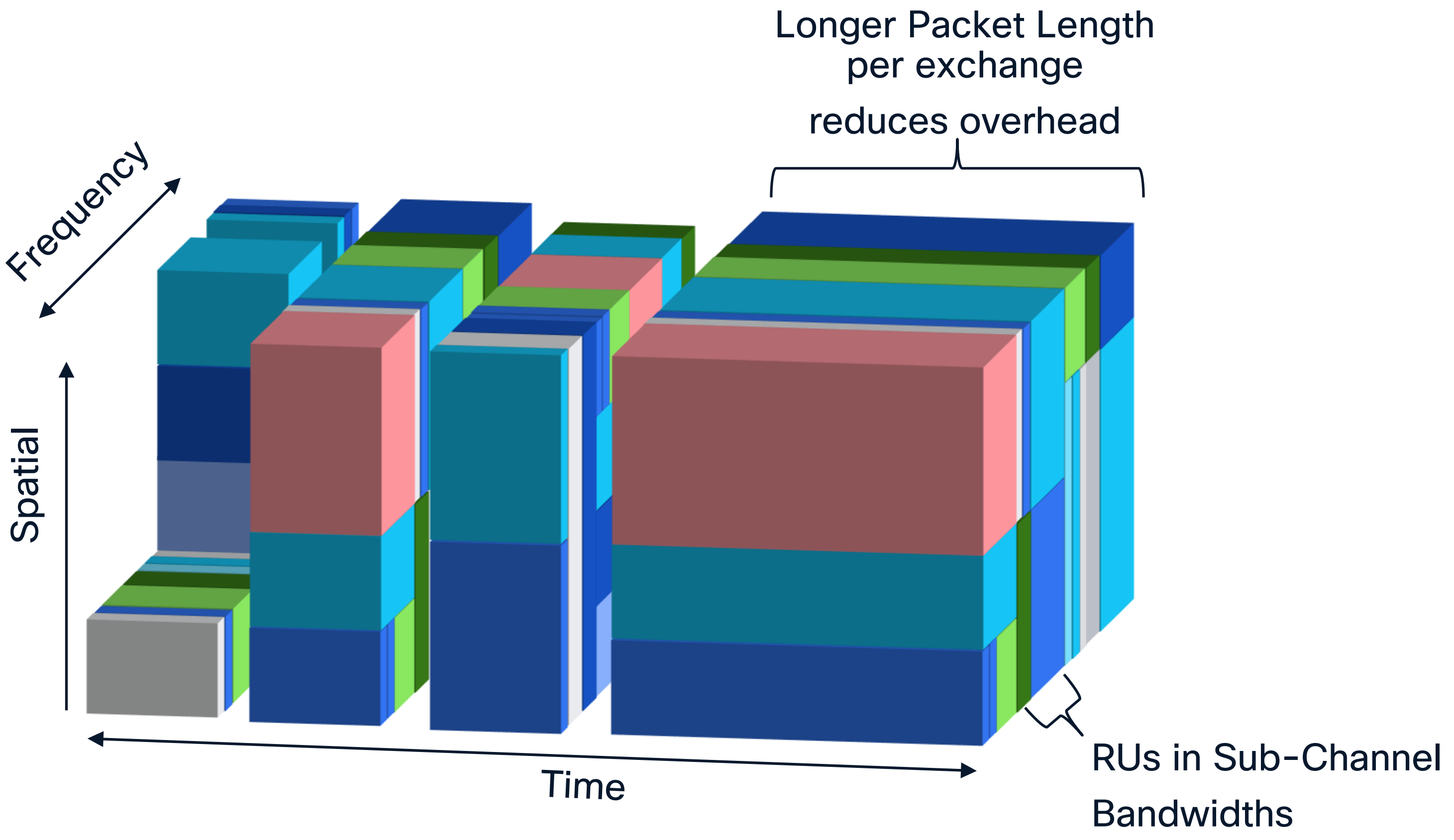
Orthogonal Frequency Division Multiple Access



OFDMA Concepts

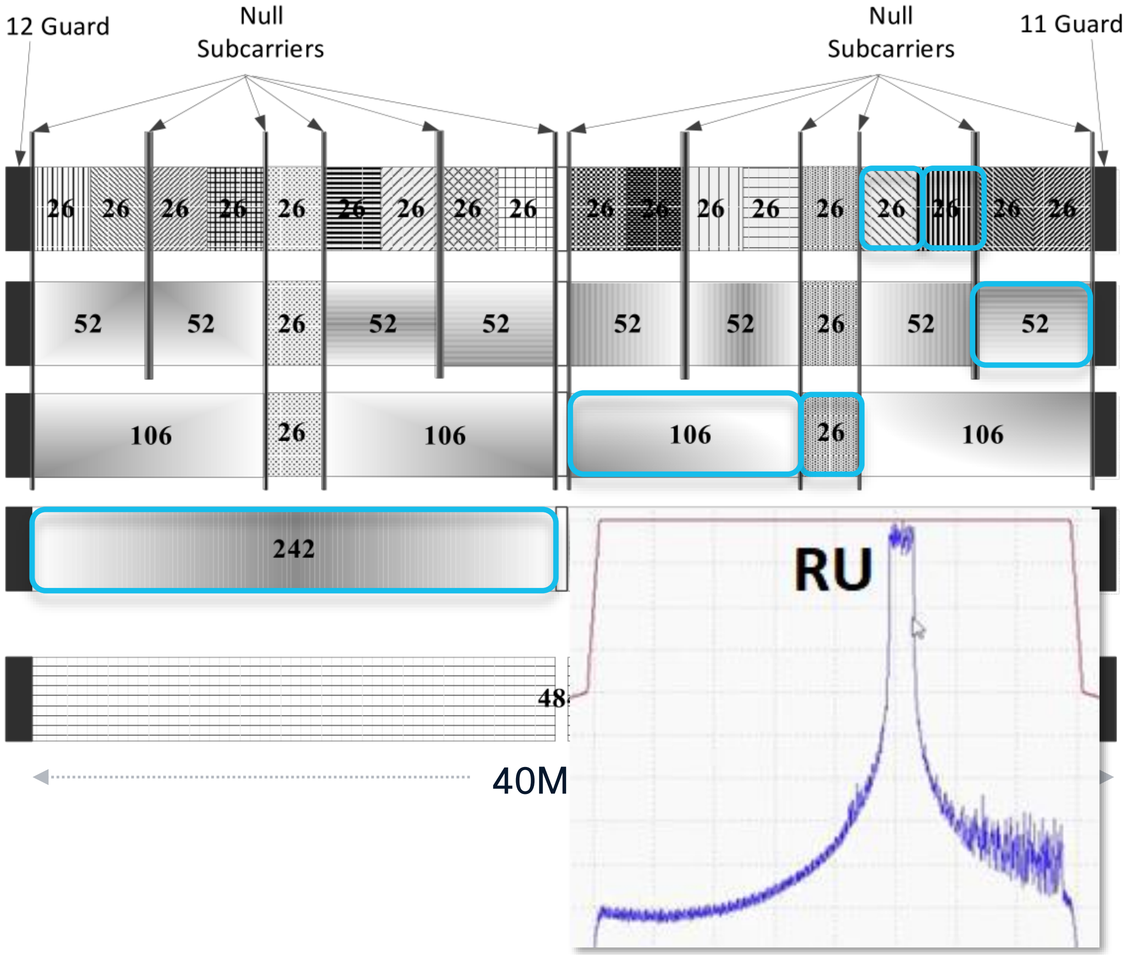
FYI

- Spatial Dimension
  - Multi-User
- Frequency Dimension
  - Sub-Channel Bandwidths
- Time Dimension
  - Scheduled Transmissions
- Variable Frequency Bandwidth per receiver
- Variable MCS per receiver



Resource Units

Orthogonal Frequency Division Multiple Access

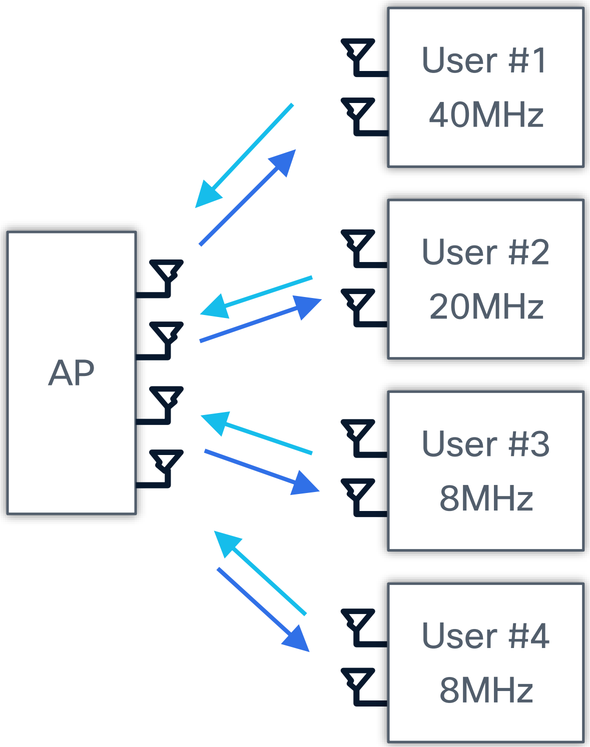


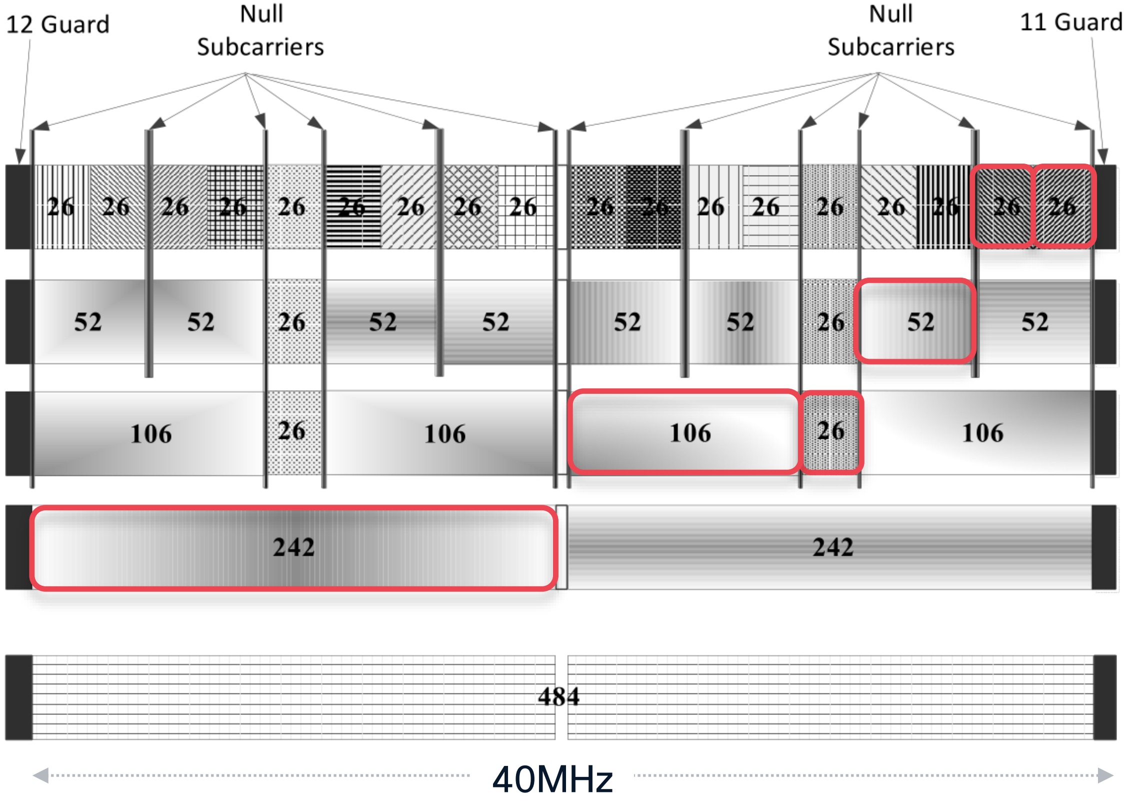
Resource Units

DL and UL OFDMA

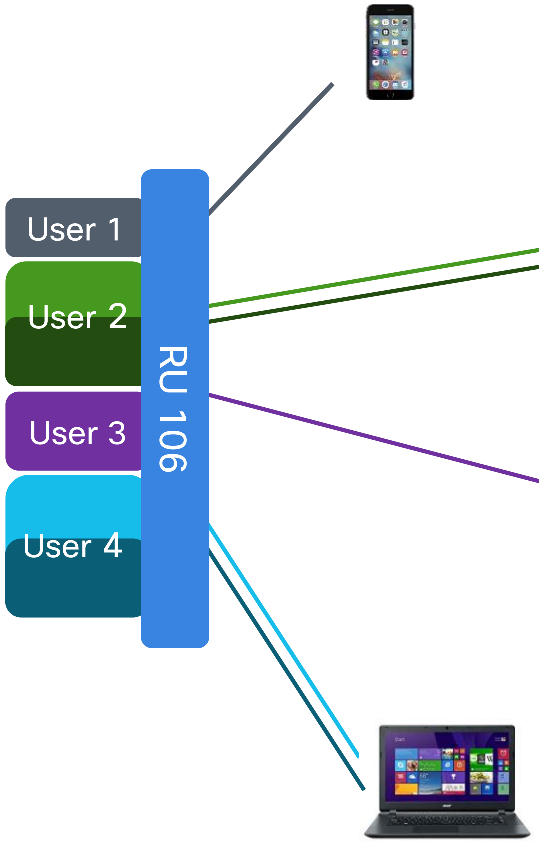
FYI

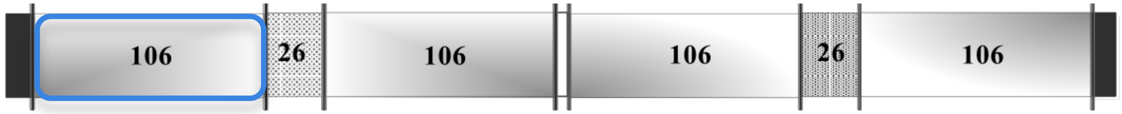
- Users can be assigned different Resource Unit bandwidths
  - 2MHz
  - 4MHz
  - 8MHz
  - 20MHz
  - 40MHz
  - 80MHz
  - 160MHz





OFDMA and MU-MIMO

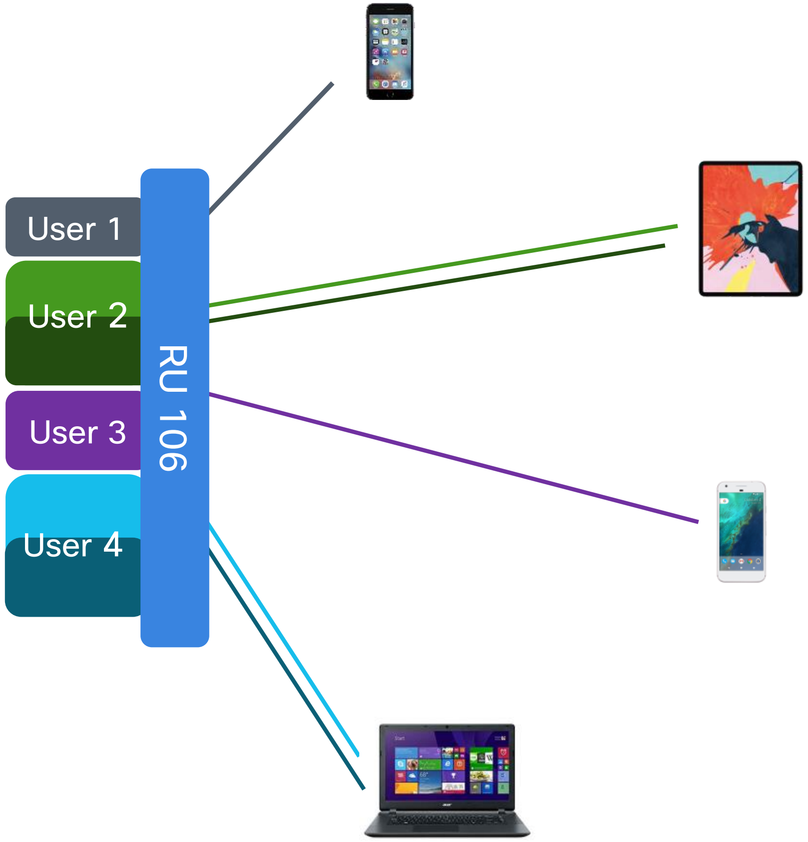


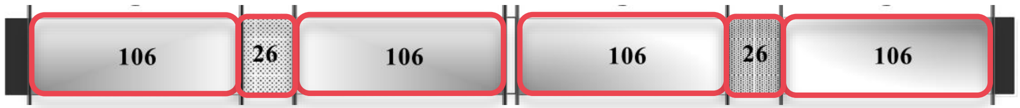


OFDMA and MU-MIMO

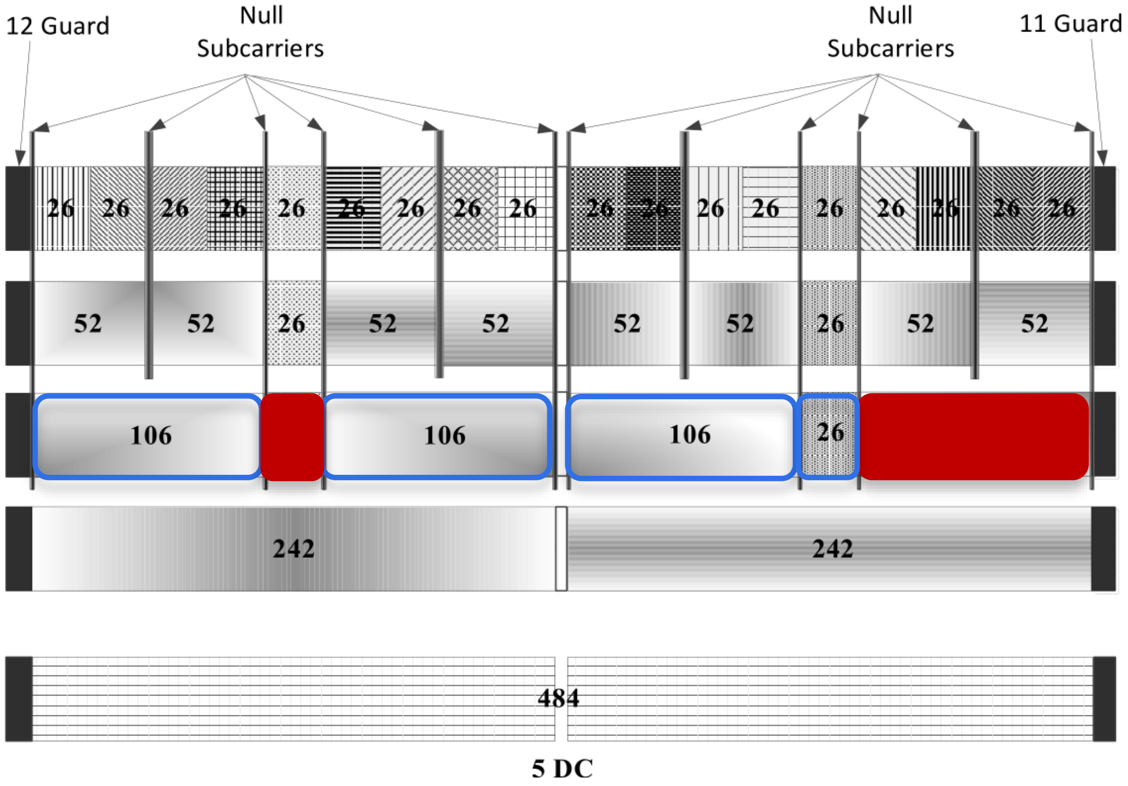
FYI

- Within OFDMA – any RU 106 or larger can multiplex up to 8 SS split between users
  - DL/UL MU-MIMO
- Within the same 802.11ax frame, some RUs can be SU and others MU
- A 40 MHz BW signal has 4x RU106





Puncturing

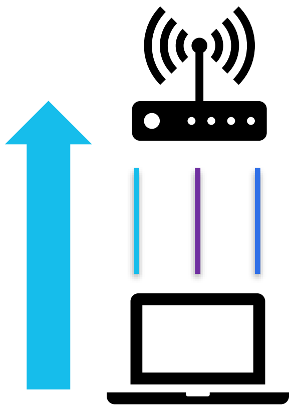


12 Guard
Null Subcarriers
Null Subcarriers
11 Guard
26 26 26 26 26 26 26 26 26 26 26 26 26 26 26 26 26 26
52 52 26 52 52 52 52 26 52 52
106 106 106 26
242 242
484
5 DC

Multi-Link Operation

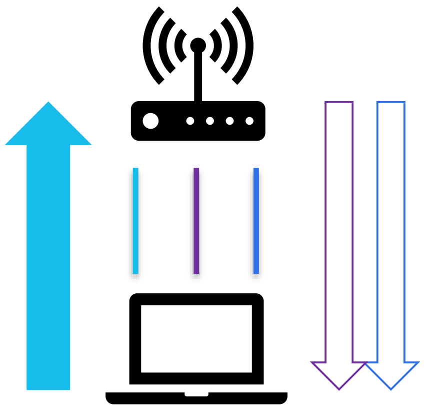
Single Radio

MLSR



Only one link fully operational at a given time

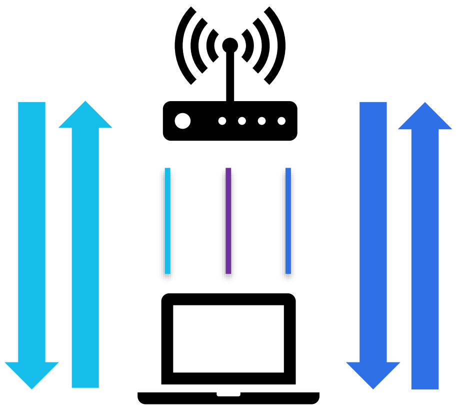
EMLSR



Only one link fully operational at a given time with the ability to **listen** on the other links

Multi Radio

MLMR STR



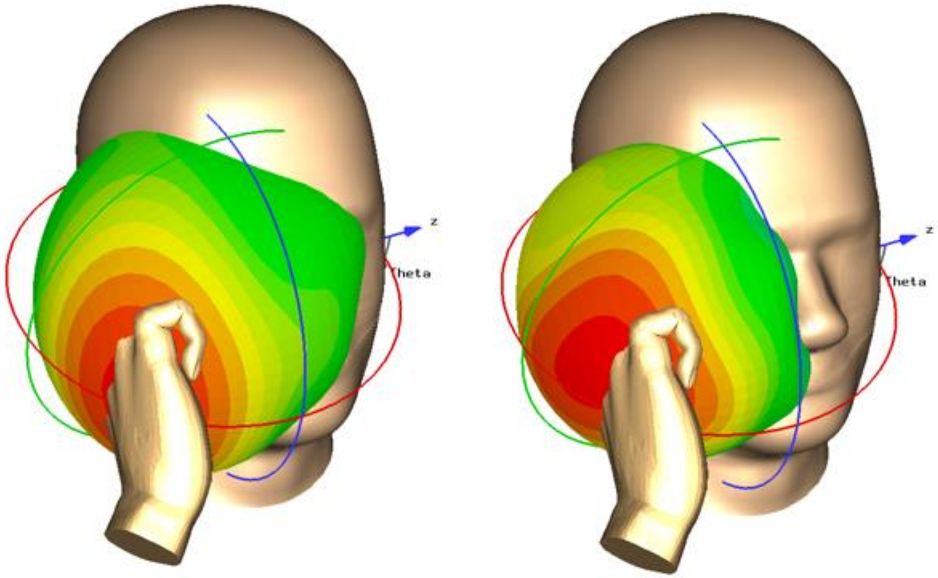
Each link operating independently

Implications for Wireless Network Design

Spot the Difference

Client Position and Attenuation

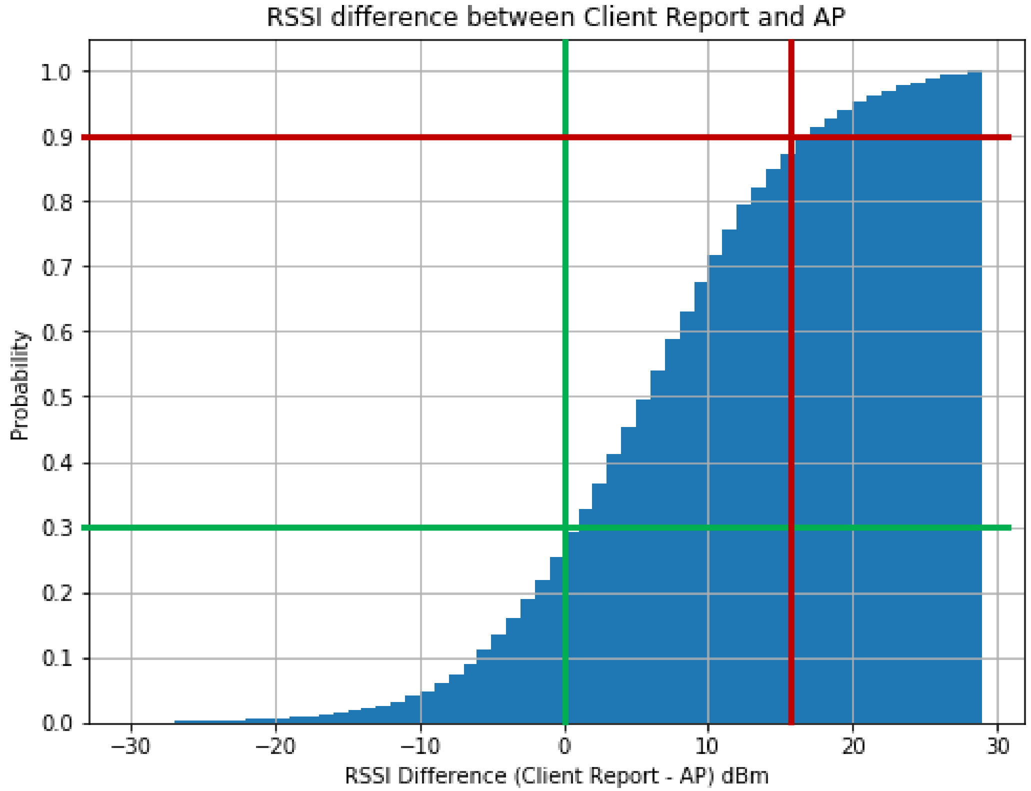
FYI

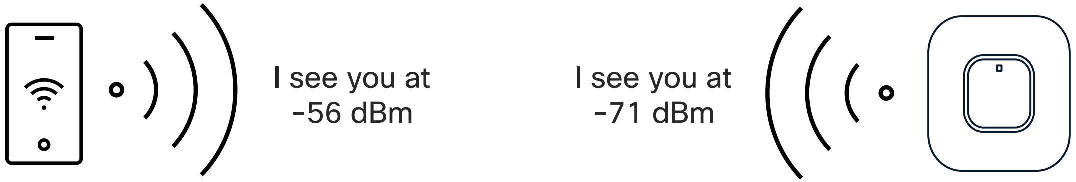


Planar
Inverted F
Antenna
(PIFA)

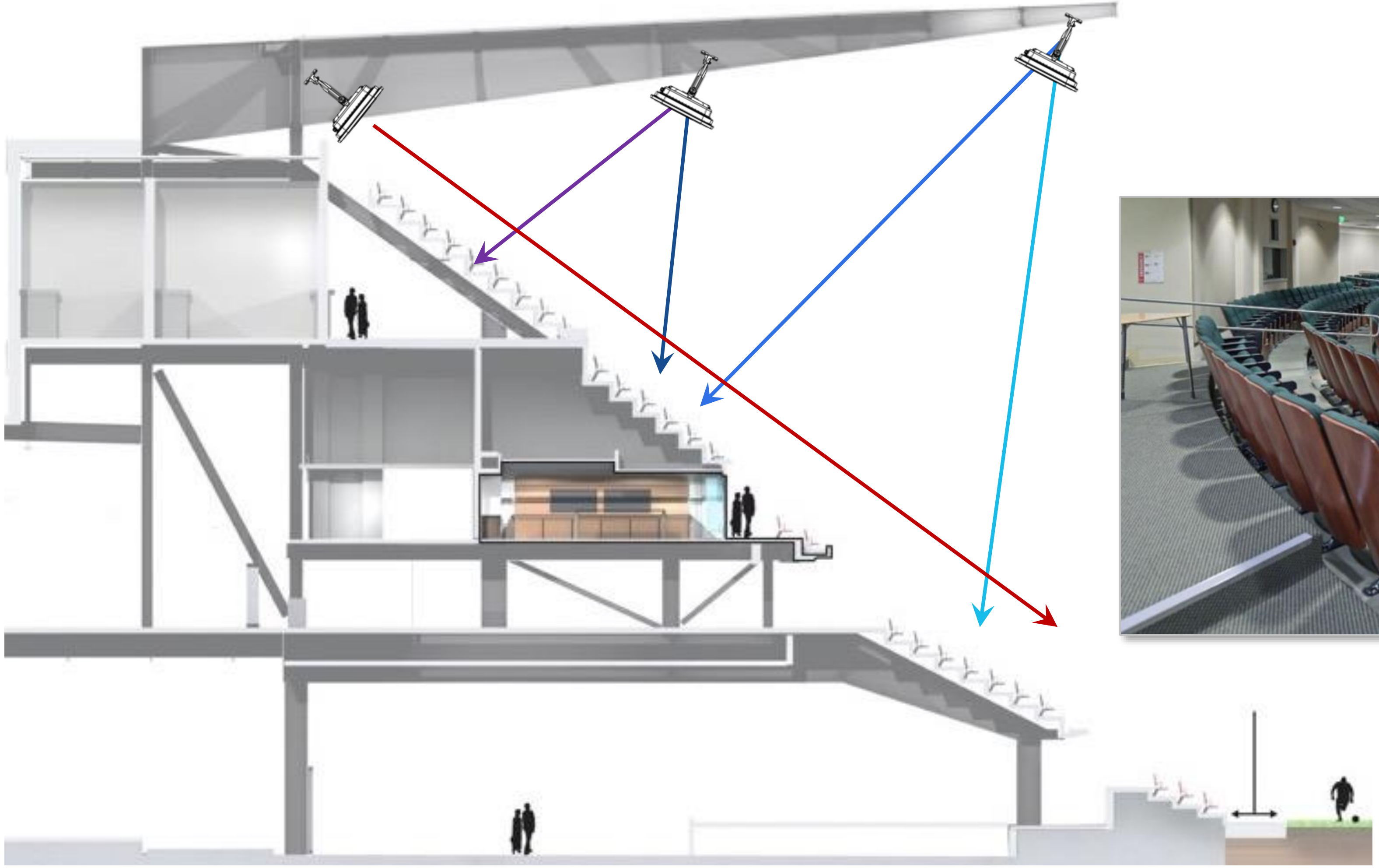
Device Disparity

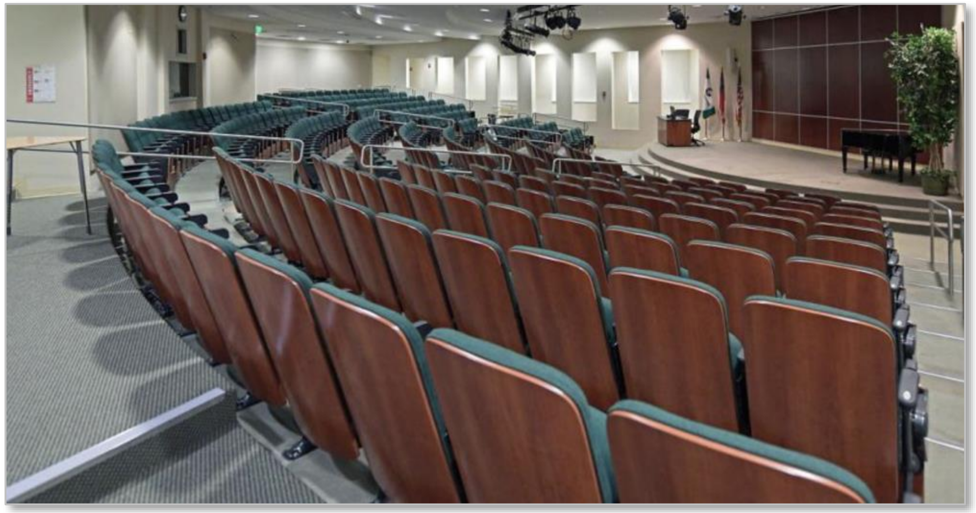
- Six months aggregated view of the network designed “from the ceiling”
  - AP power set with “AP to AP” in mind (max tx power)
  - RSSI seen by the AP is lower than that seen by Client
- RSSI difference is significant
  - 50% of the time the RSSI is 6 dB less
  - 90% of the time the RSSI is 15 dB less





Antenna Positioning and Coverage



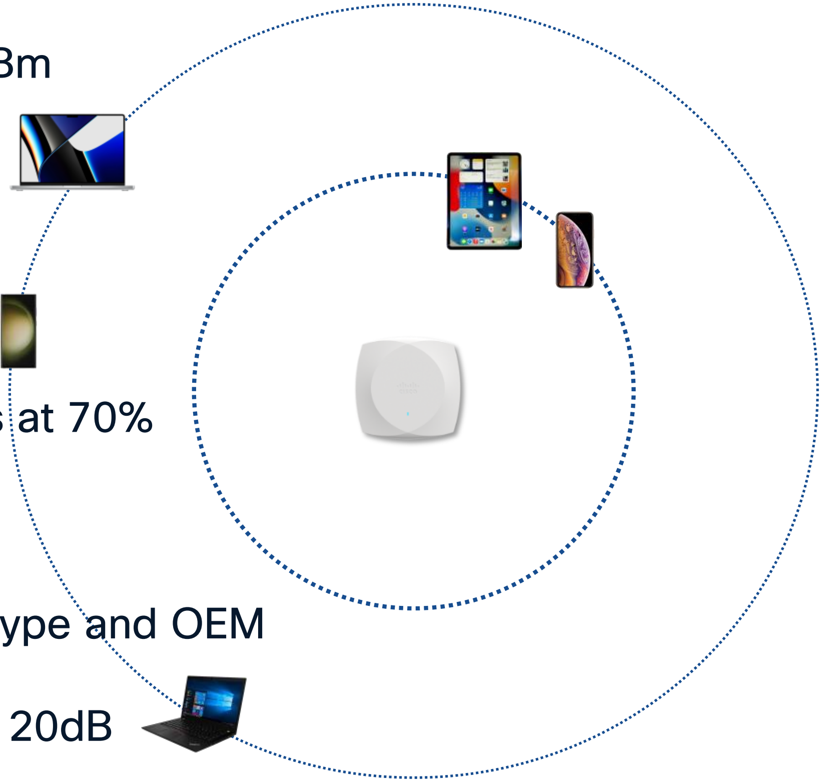


Client Roaming Logic

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 utilization is at 70%
Roam to AP if 10dB better

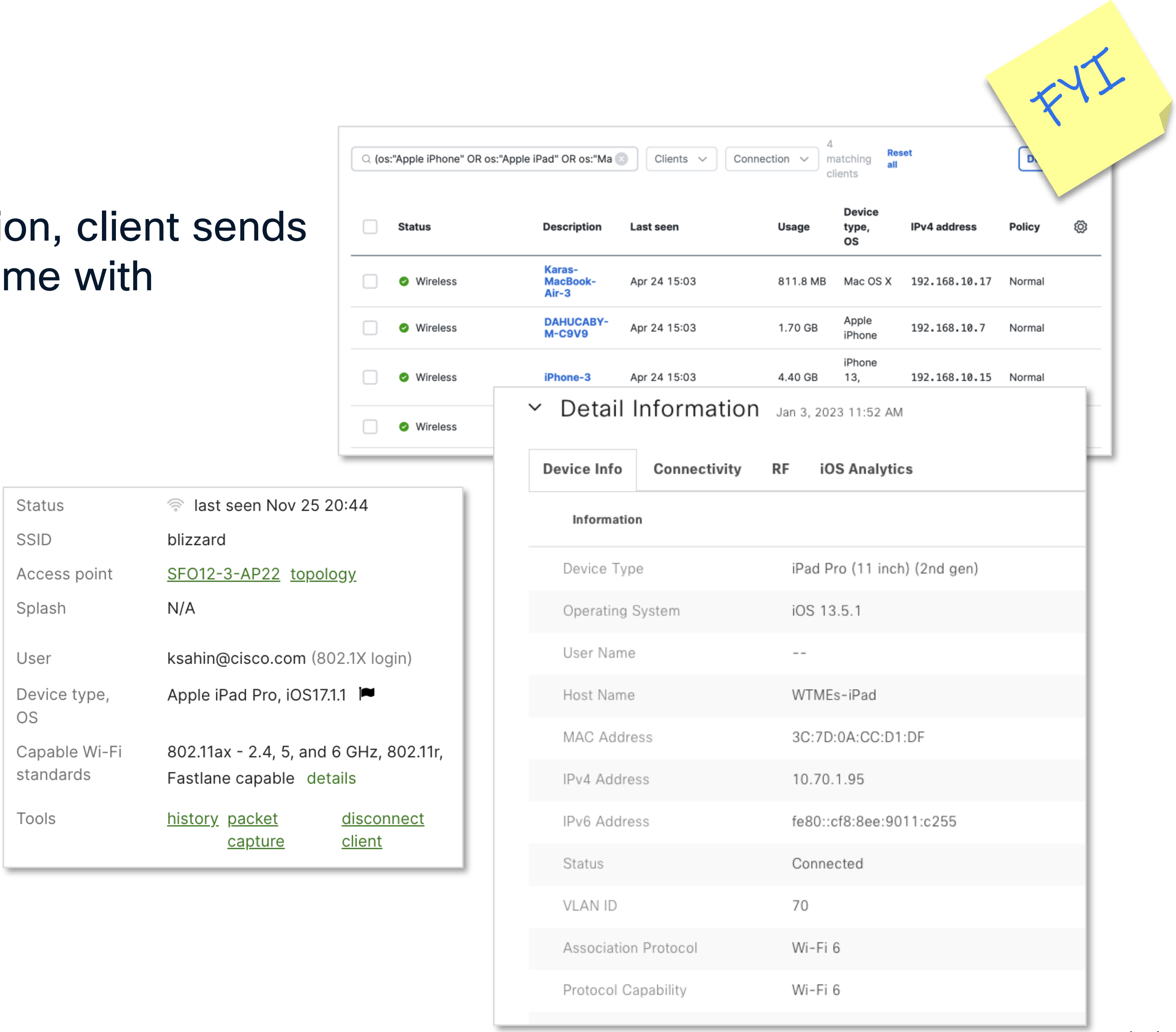


Intel laptops scanning trigger depends on the antenna type and OEM
Typically between -65dBm and -75dBm
Roaming aggressiveness also varies, between 5dB and 20dB

https://support.apple.com/en-us/HT206207
https://docs.samsungknox.com/admin/knox-platform-for-enterprise/kbas/kba-115013403768.htm

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”)



802.11 Reason Codes

FYI

- 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

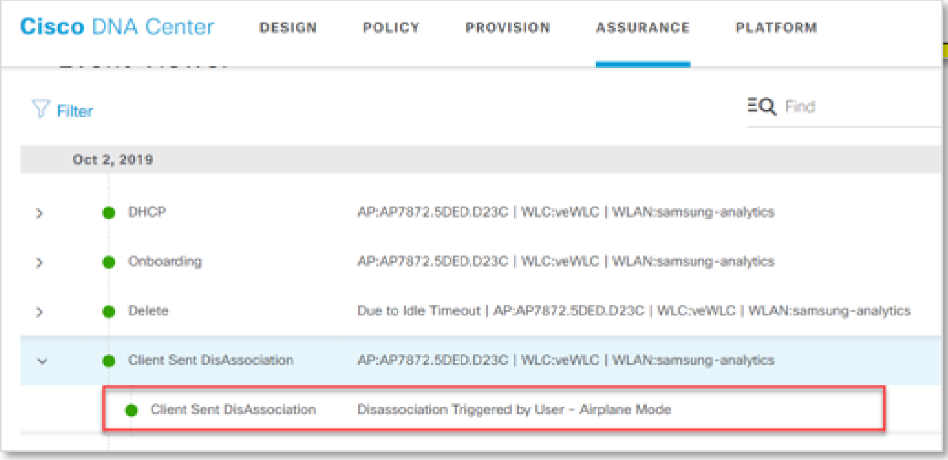
Reason code	Name	Meaning
0		Reserved
1	UNSPECIFIED_REASON	Unspecified reason
2	INVALID_AUTHENTICATION	Previous authentication no longer valid
3	LEAVING_NETWORK_DEAUTH	Deauthenticated because sending STA is leaving (or has left) the BSS
4	REASON_INACTIVITY	Disassociated due to inactivity
5	NO_MORE_STAS	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

FYI

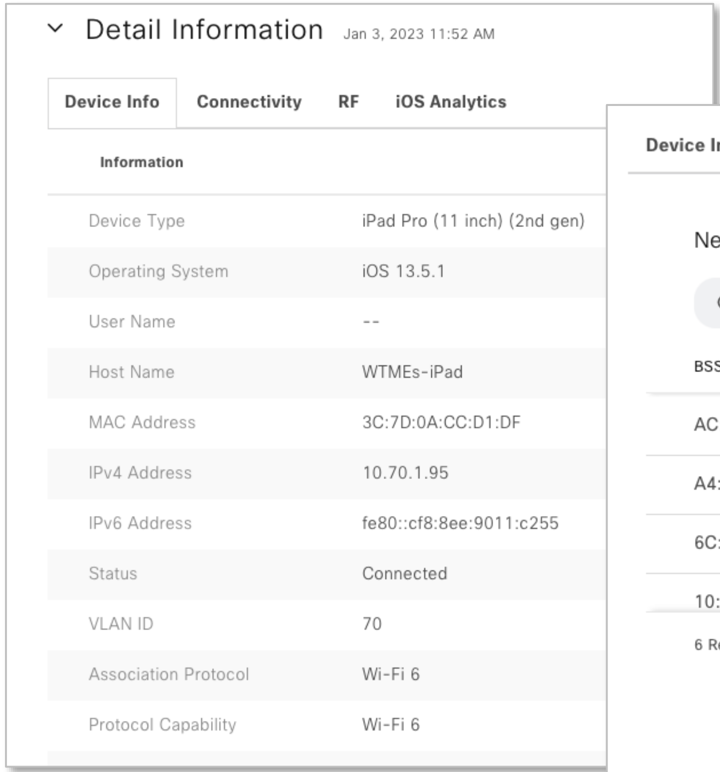
- Apple, Intel and Samsung clients will send additional reason codes upon disassociation
- Apple adds 9 upper layer reasons
  - DHCP failed
  - EAP timed out
  - 802.1X failed
  - Device is idle
  - Captive portal security failed
  - Decryption failed
  - Wi-Fi interface disabled
  - User triggered disassociation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

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



iOS and Samsung Analytics

FYI

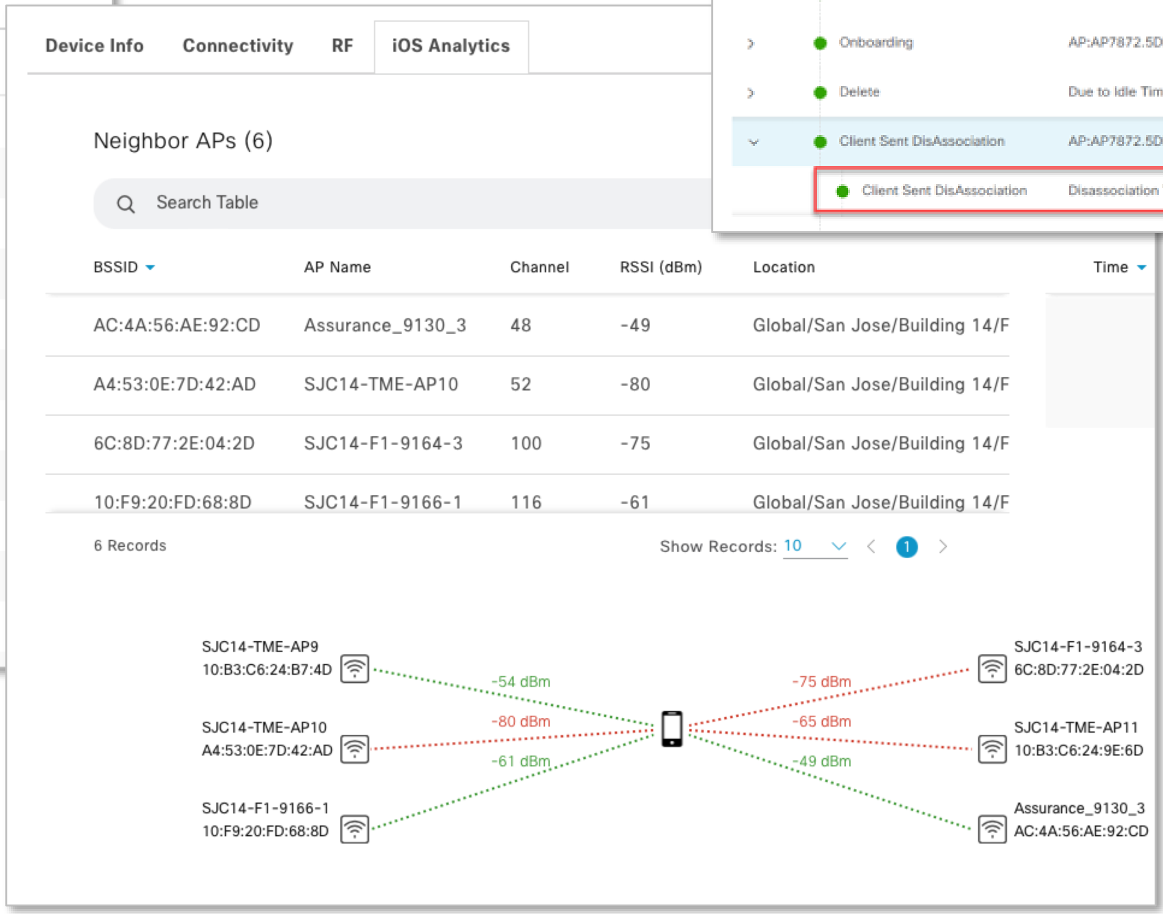


Detail Information Jan 3, 2023 11:52 AM

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



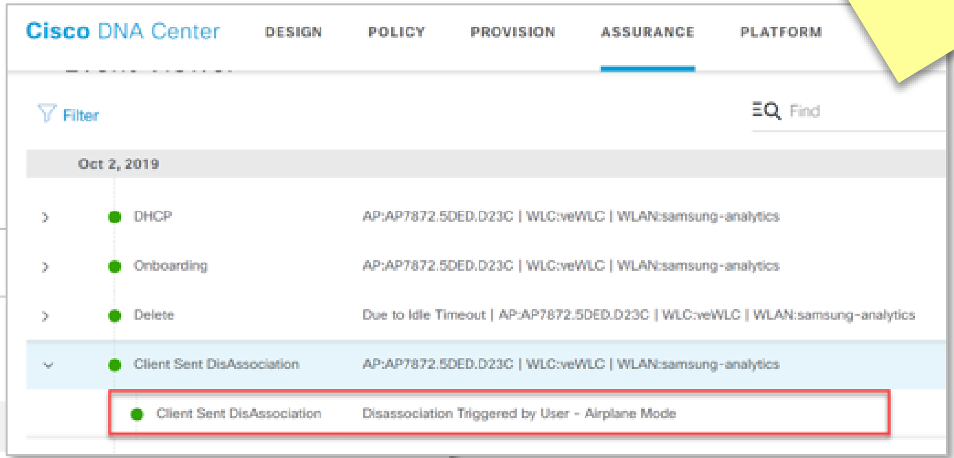
Device Info | Connectivity | RF | iOS Analytics

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



Cisco DNA Center | DESIGN | POLICY | PROVISION | ASSURANCE | PLATFORM

Filter 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

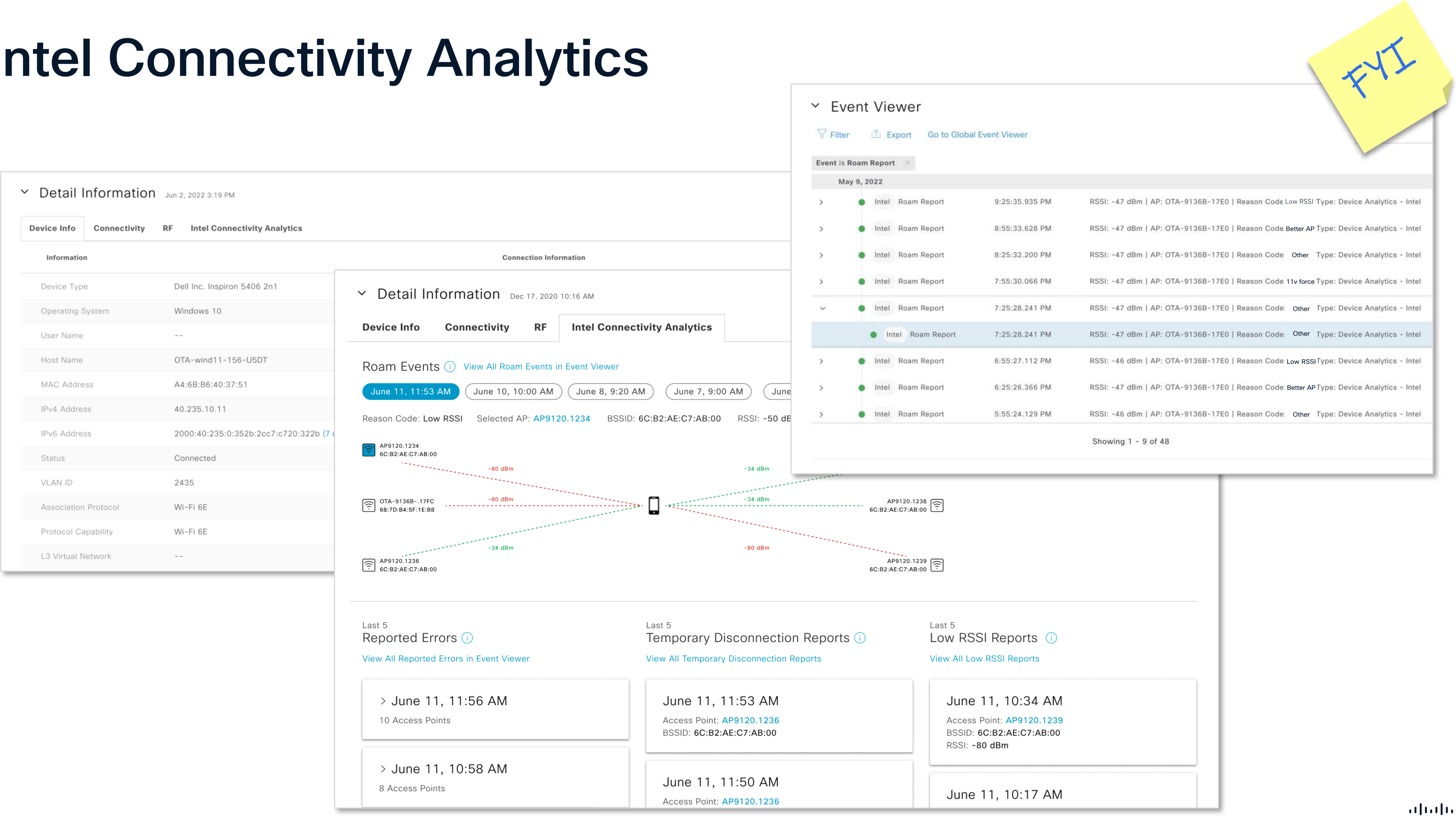
Helps troubleshoot issues with non-valid IEs and see why AP is not responding

Failed APs

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

Used to identify and flag rogue BSSIDs

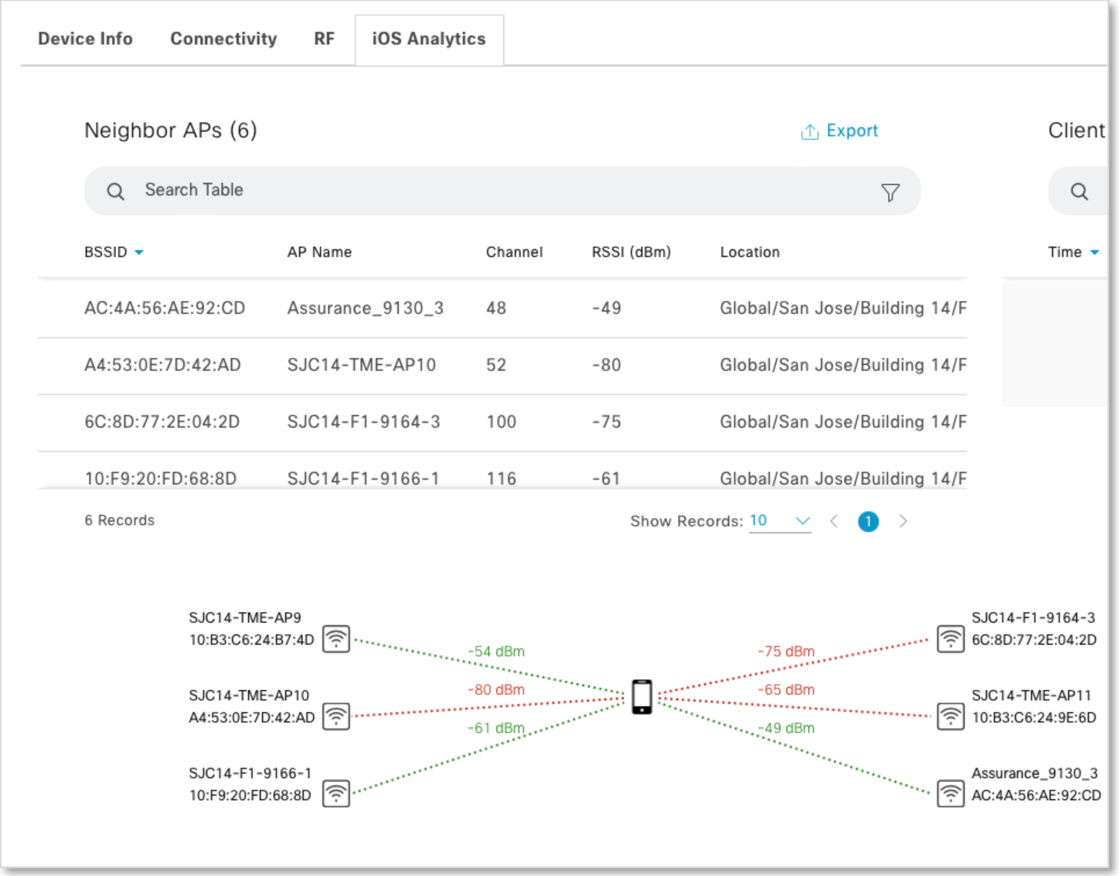
Intel Connectivity Analytics



The Client Perspective of the Network

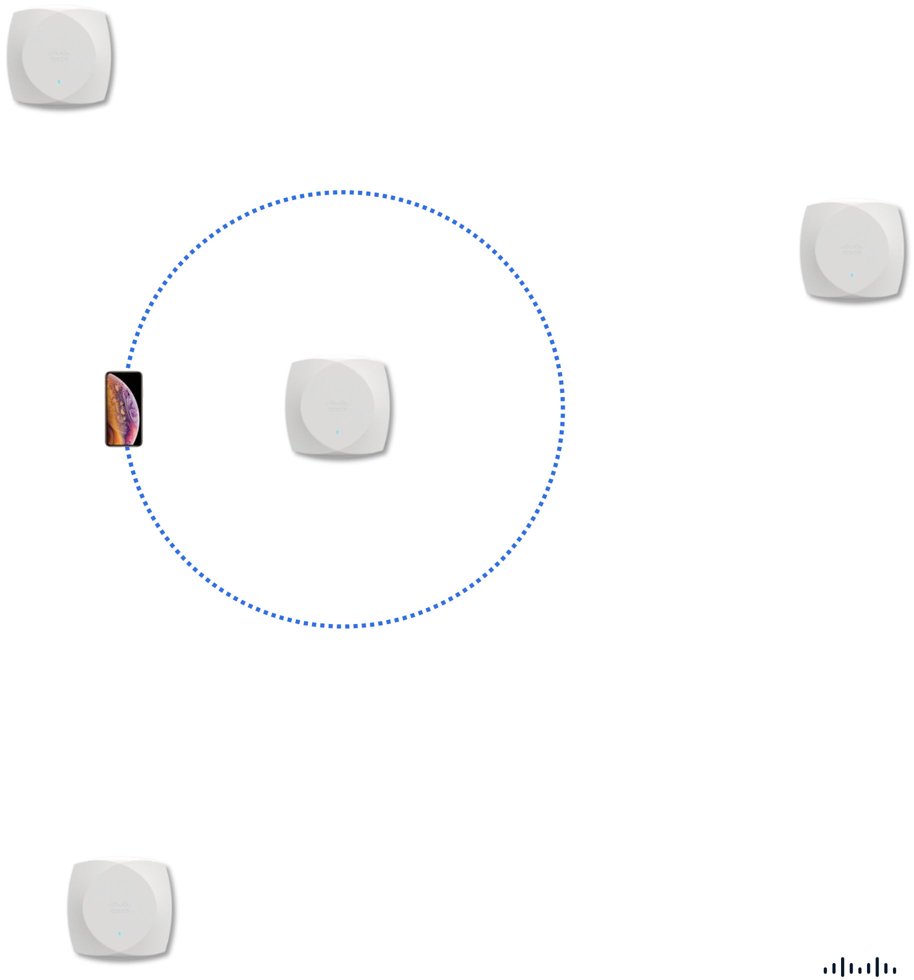
FYI

- 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



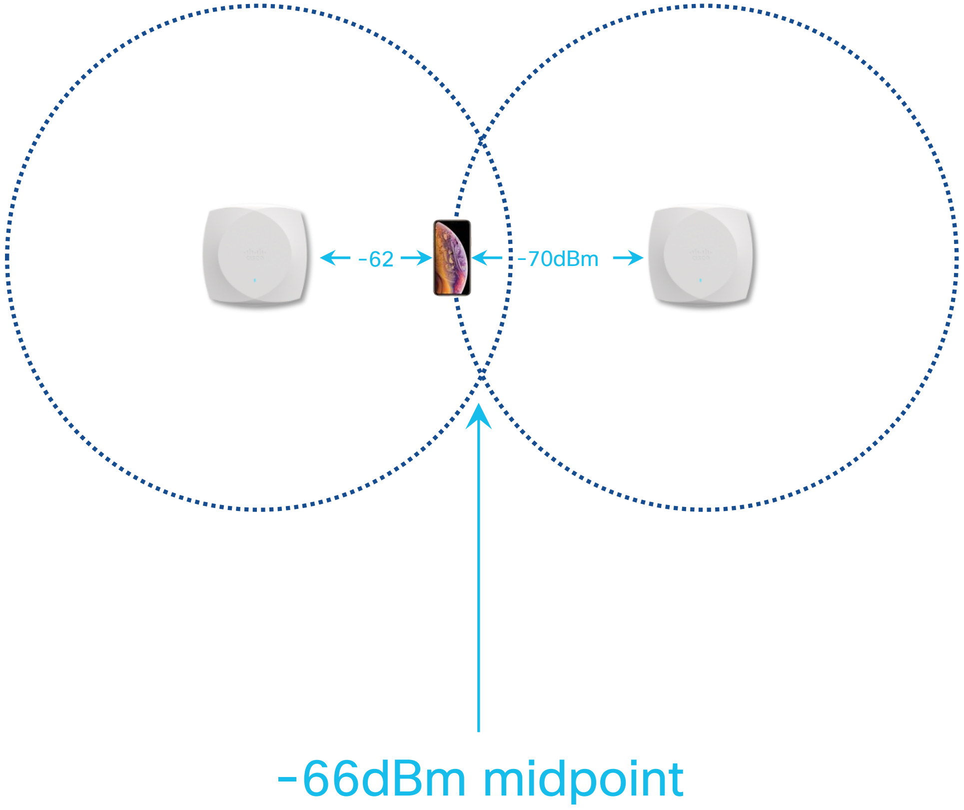
BSS Transition with 802.11k and 802.11v

- 802.11k (Neighbour and Beacon Report)
  - Provides a list of the neighbouring APs
  - Reduces the number of channels the client needs to scan
- 802.11v (BSS Transition Management)
  - Solicited Request
  - Unsolicited Request
    - AP load too high
    - Client RSSI to low
    - DFS event
  - High Priority Request
  - Disassociation Imminent



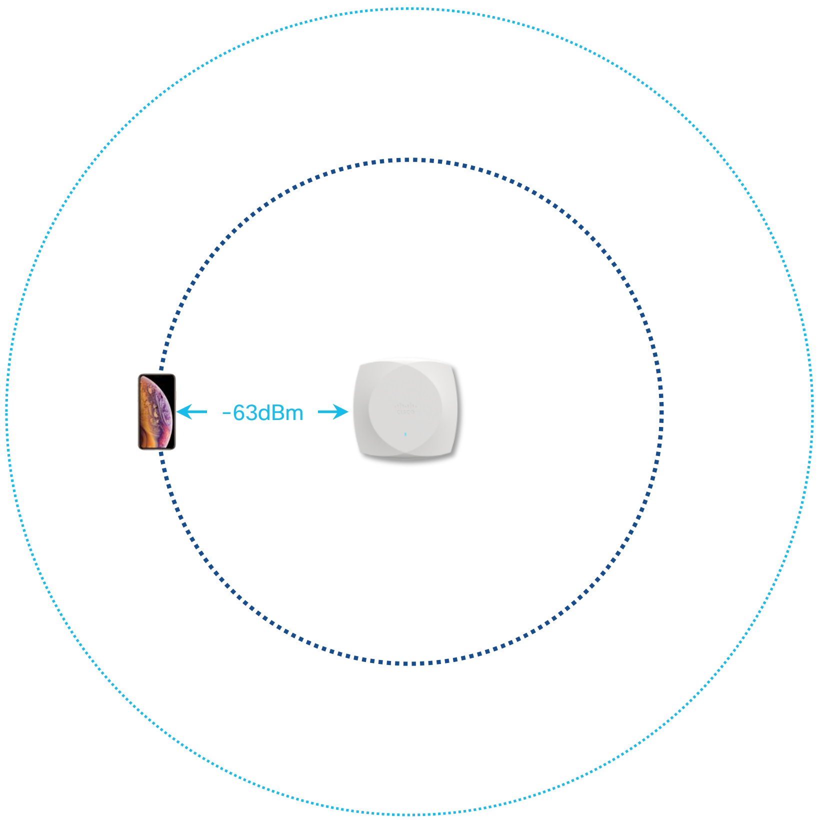
Cell Edge is Defined from the Client Perspective

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



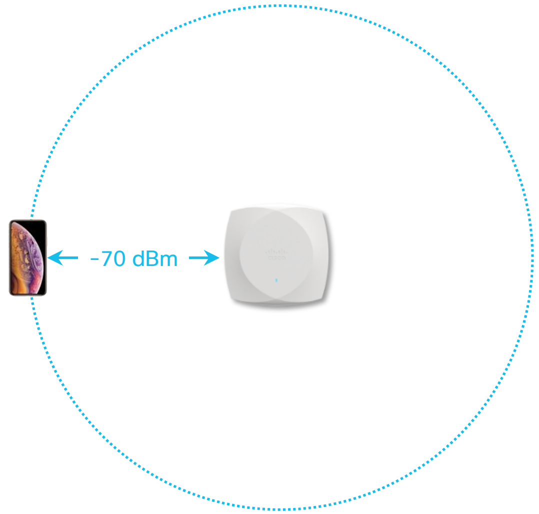
Cell Edge is Defined from the Client Perspective

- 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

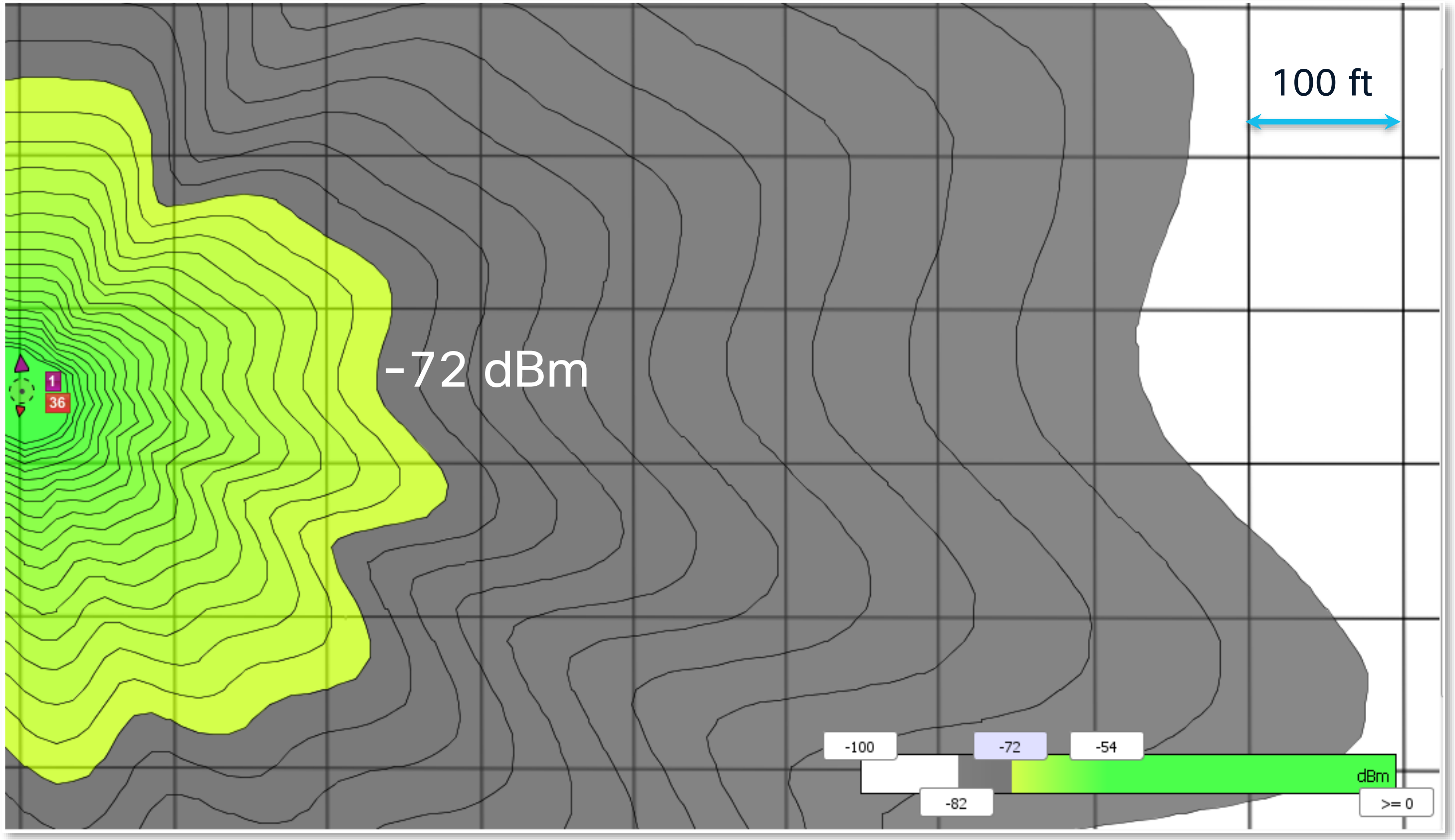


Designing for Cell Overlap

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

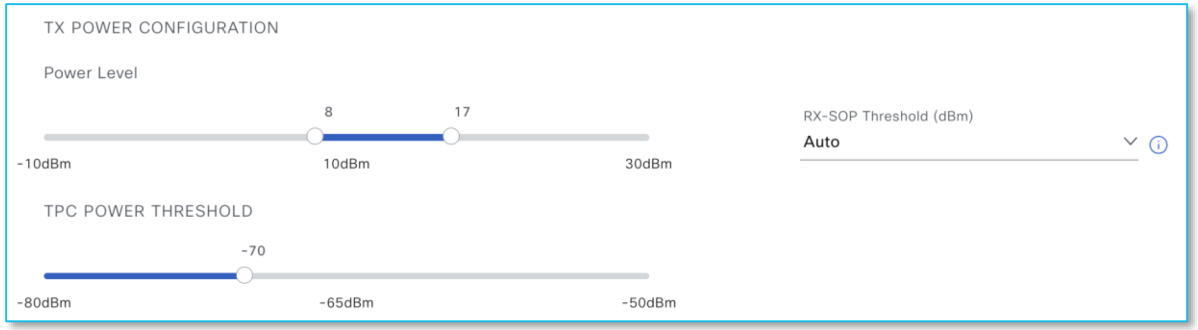
Managing the Cell Edge

- High Gain Directional Antennas
- Mandatory Data Rates
- Using Tx Power
  - Cutoff -82 dBm
  - Cutoff -76 dBm
  - Cutoff -72 dBm
- Receiver Start of Packet (RX-SOP)



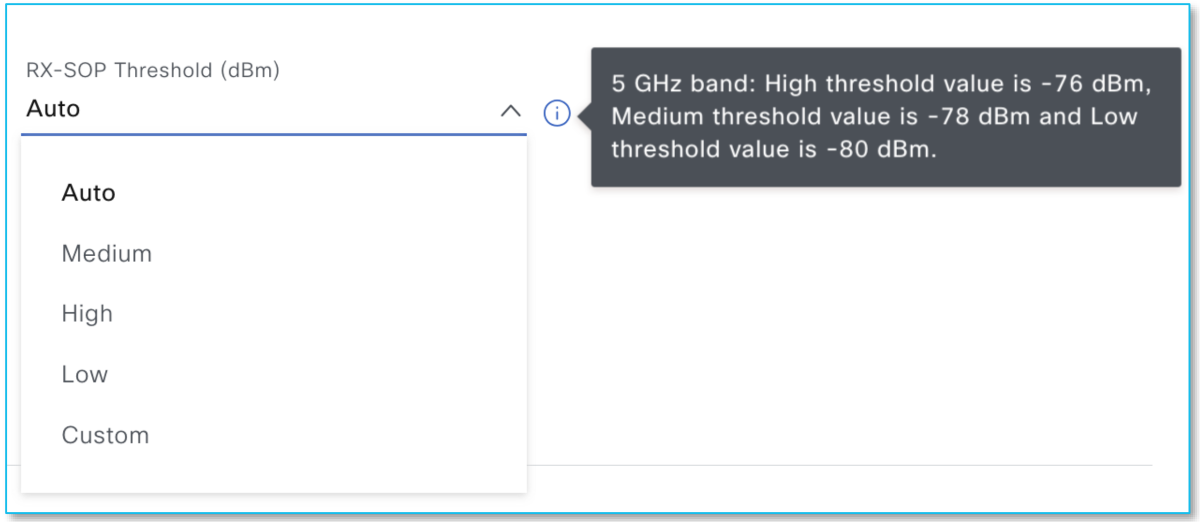
Cell Edge as Defined by the AP Transmit Power

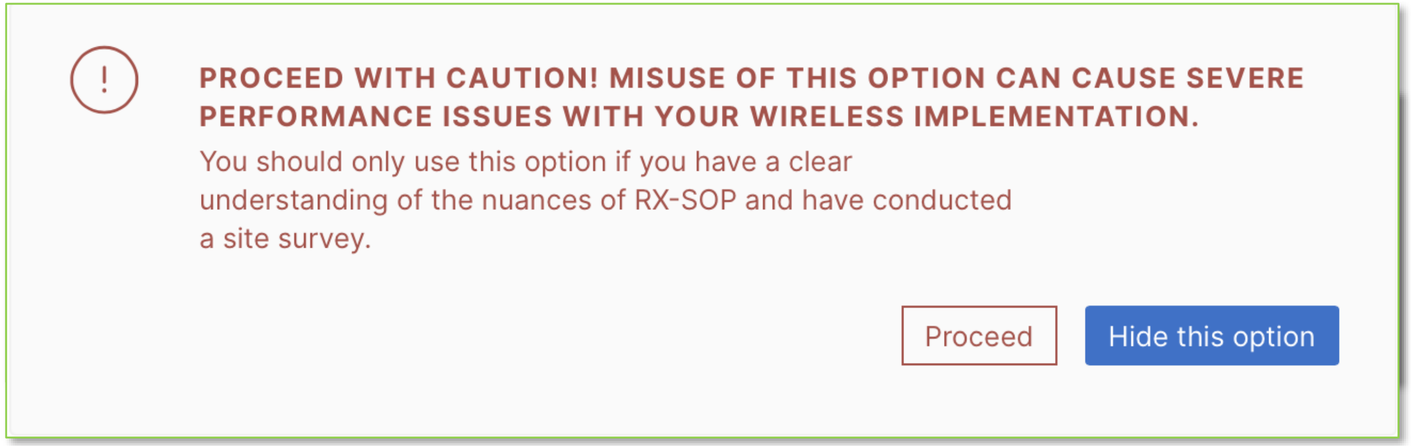
- Client Power Levels
  - Laptops: 20-23dBm
  - Modern Phones and Tablets: 17dBm
  - Older and Cheaper Phones: 11-14dBm
- The ideal AP max power level should be set to match your worst client max power
  - Assume a 3dB margin
  - For most modern clients assume the worst value to be 14dBm
  - Resulting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



Cell Edge as Defined by Receiver Start of Packet

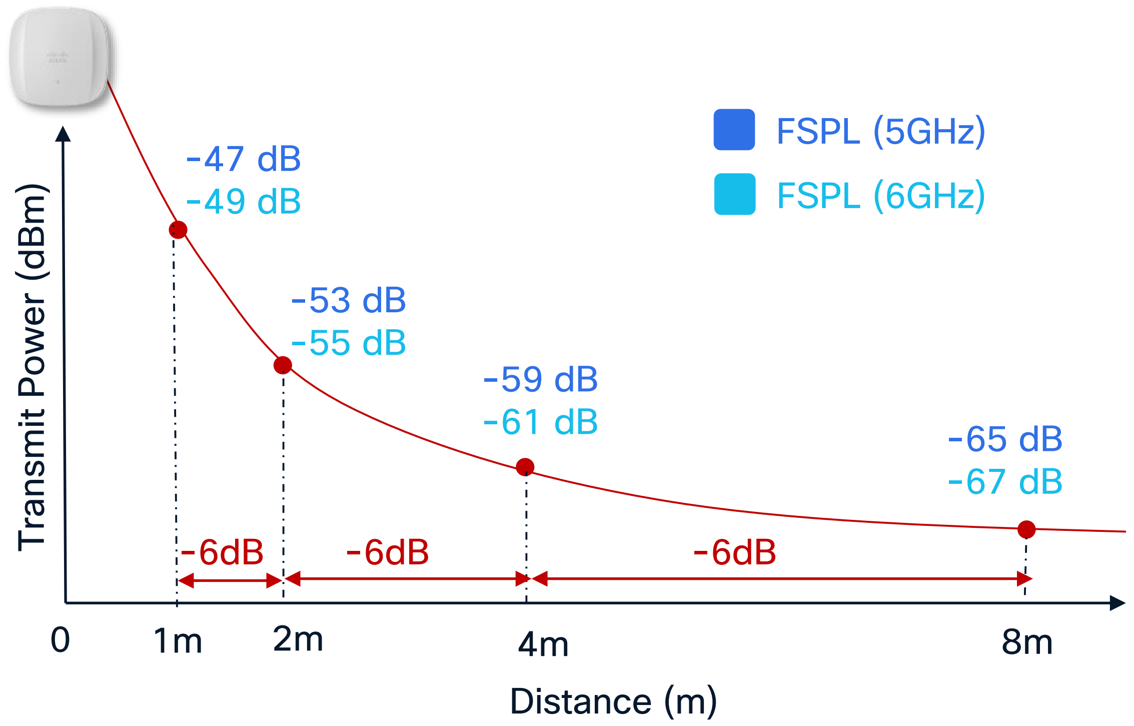
- RX-SOP Threshold
  - Determines the signal level in dBm at which the AP will demodulate and decode a packet
  - Increase RX-SOP
    - Decrease radio sensitivity
    - Reduce cell size
  - Auto setting uses the radio default threshold
  - Custom can be used for fine tuning in very specific areas





Designing for 6GHz

- There is a 2-3dB difference in attenuation between 5GHz and 6GHz signals
- Higher transmit power is necessary to balance 5GHz and 6GHz cells
- For existing networks at 5GHz, transmit power level is typically 11-15 dBm (PL3/4) depending on density
- This leaves room for 6GHz transmit power to be increased to match the existing cell coverage

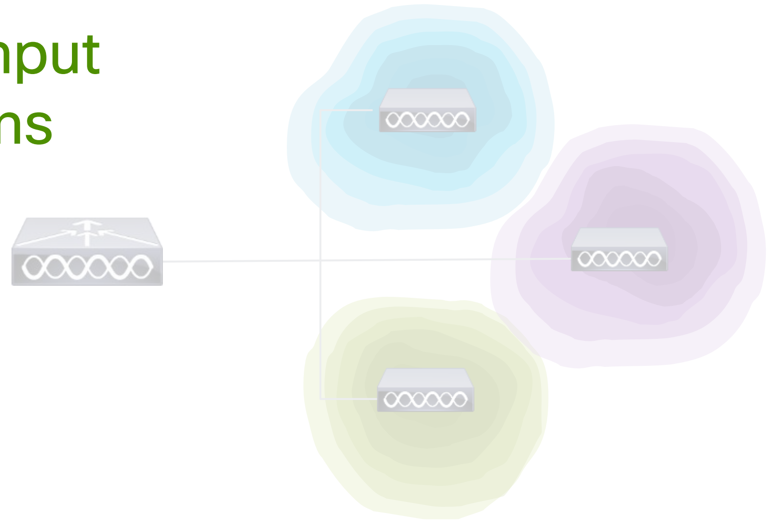


Radio Resource Management and AutoRF

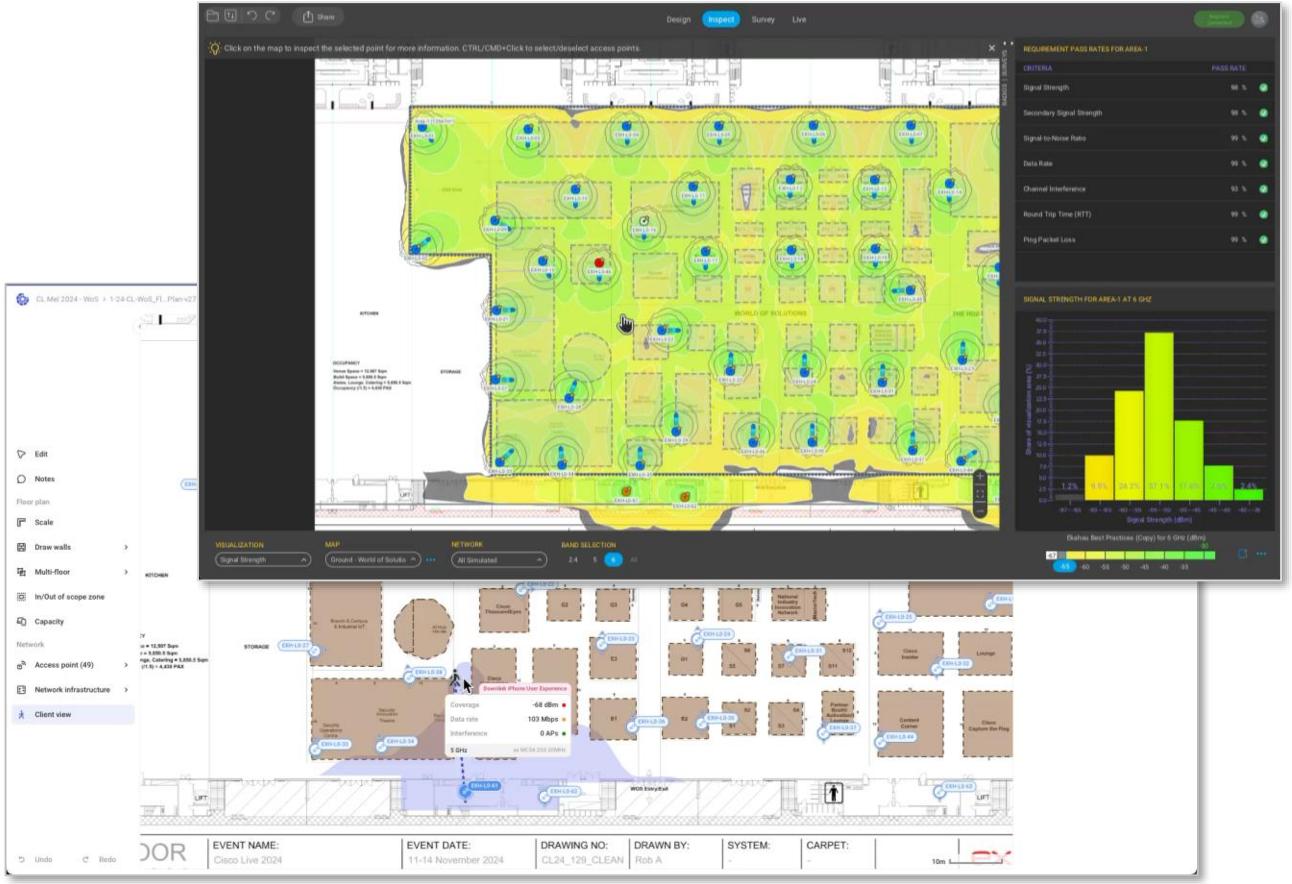
Dynamic Channel Allocation · Dynamic Bandwidth Selection · Transmit Power Control · Coverage Hole Detection

- 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...



RF Planning Tools

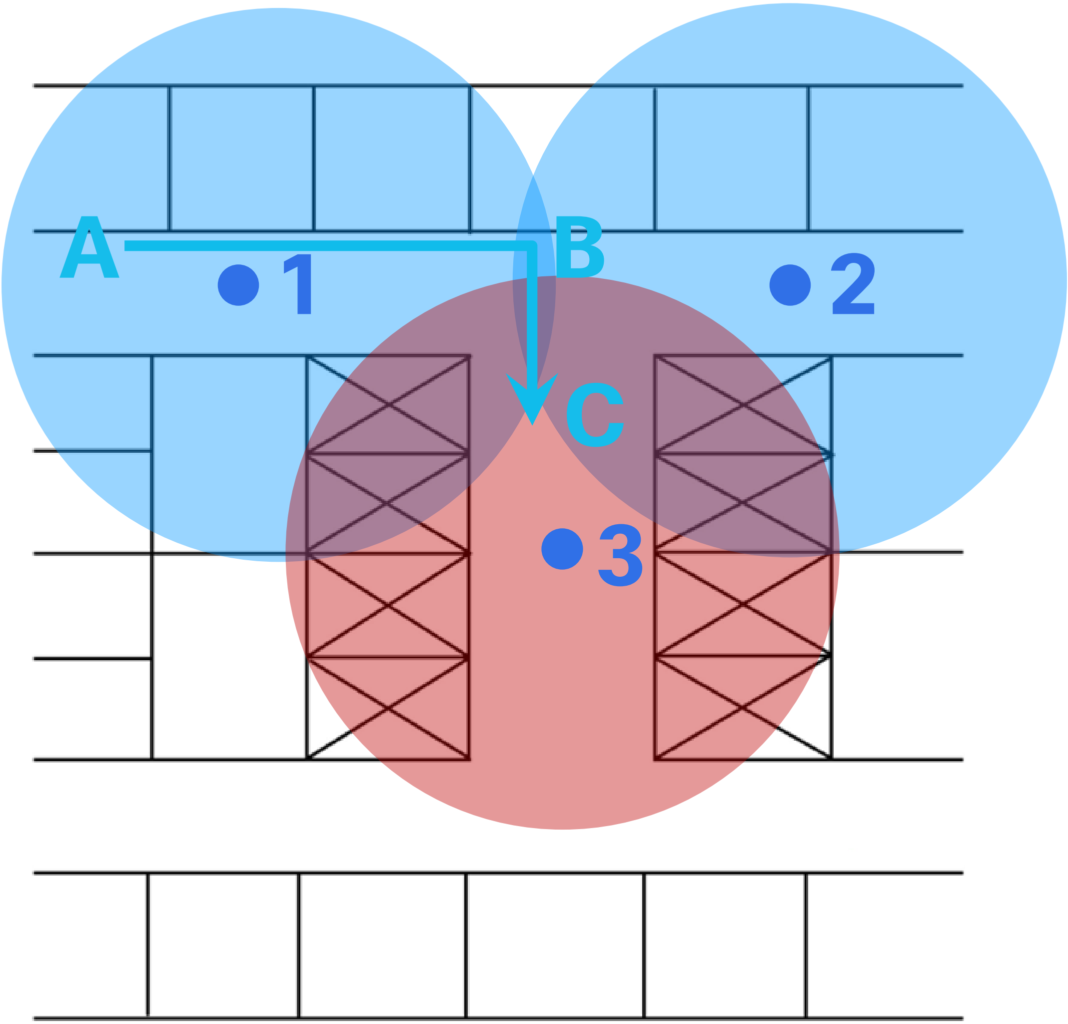


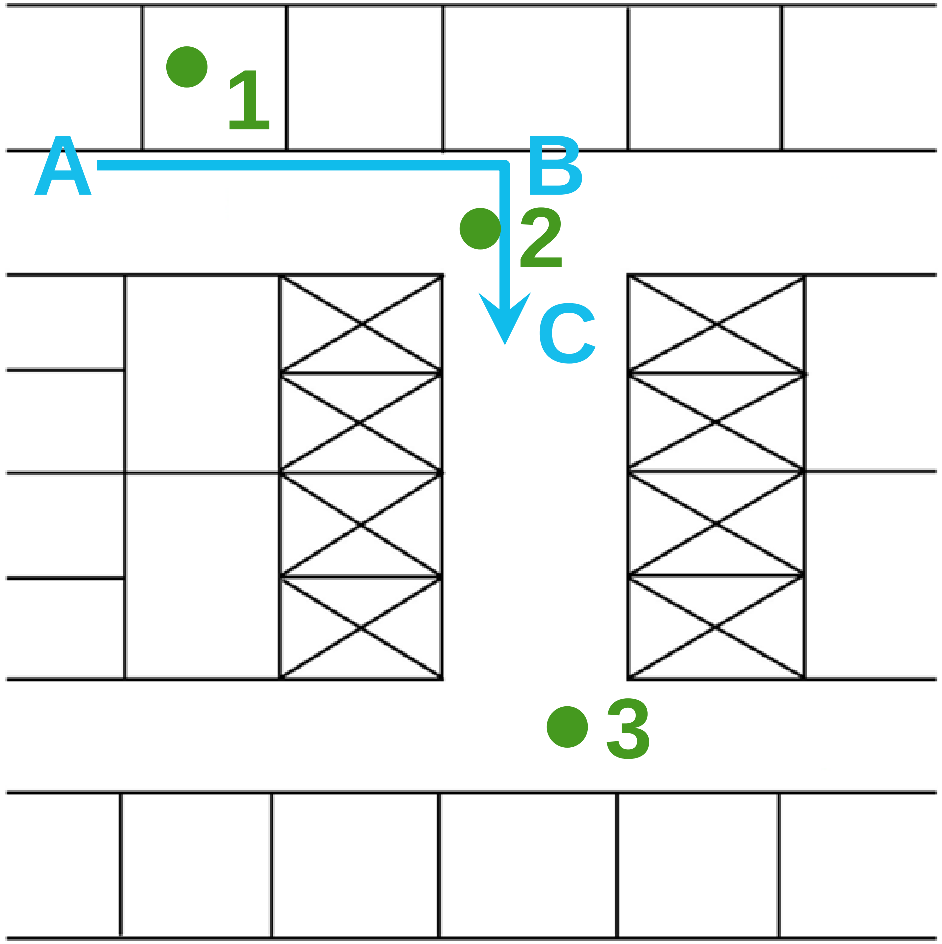
- All models are wrong
- Some of them are useful
- Planning tools can help develop a preliminary design and identify potential deployment issues
- The model MUST be calibrated to ensure what you see is what you get
- Always remain conservative with power
  - Middle to lower end of the range should be selected
  - Coverage and capacity should be balanced
- Catalyst Center and Meraki Dashboard support Ekahau and Hamina project file import

Site Surveys

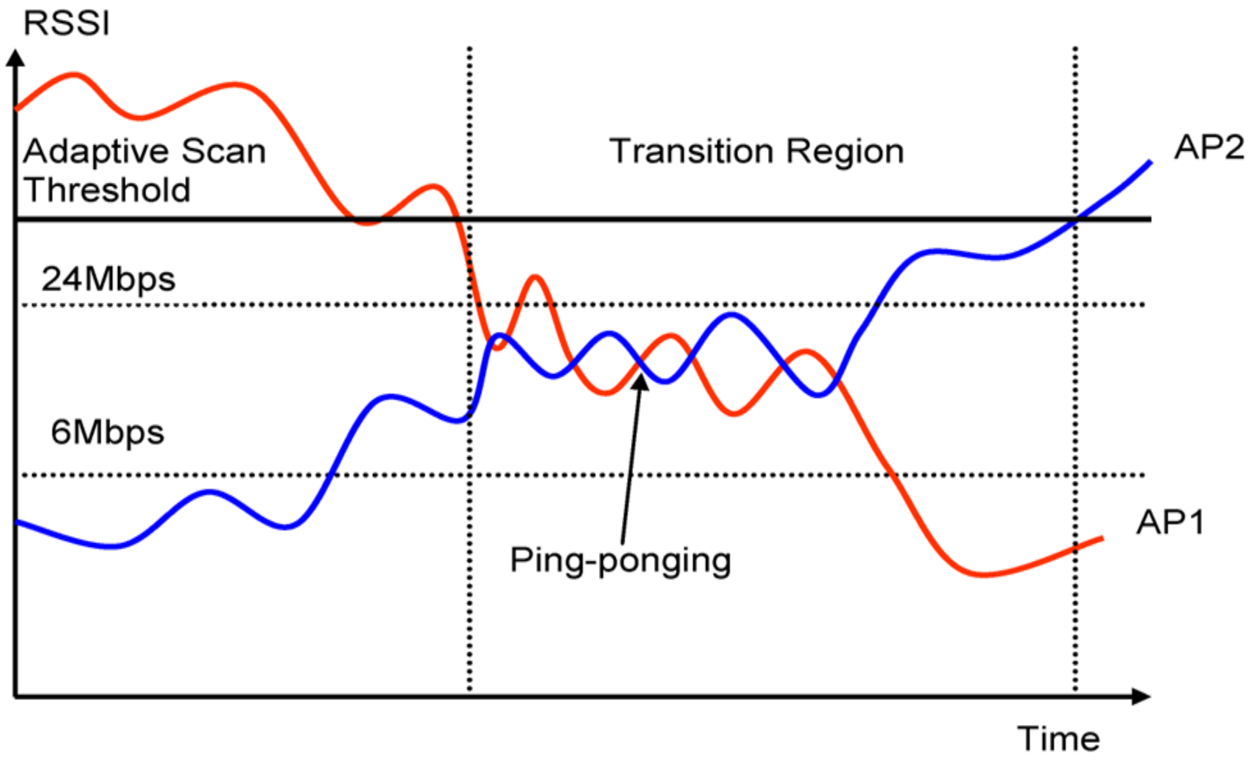
- Always verify predicted coverage with actual measurements
- Consider underlying requirements
  - Number of Users
  - Application Types
  - Location accuracy
- AP placement considerations
  - Consider environmentals
  - Characterize the -67 dBm edges
  - For location a minimum of three AP should be able to hear the device with a a signal strength of -75 dBm or higher
- Understand existing spectrum use

AP Placement and Roaming Optimisation

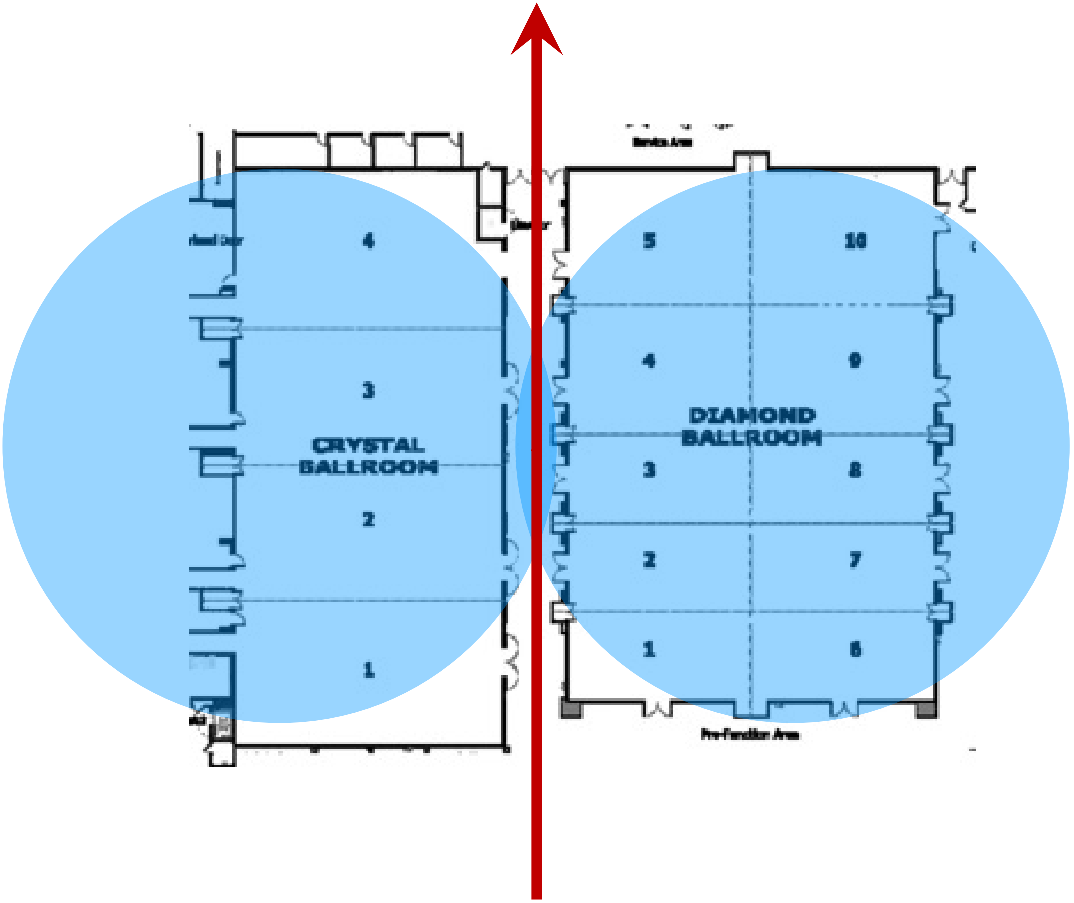


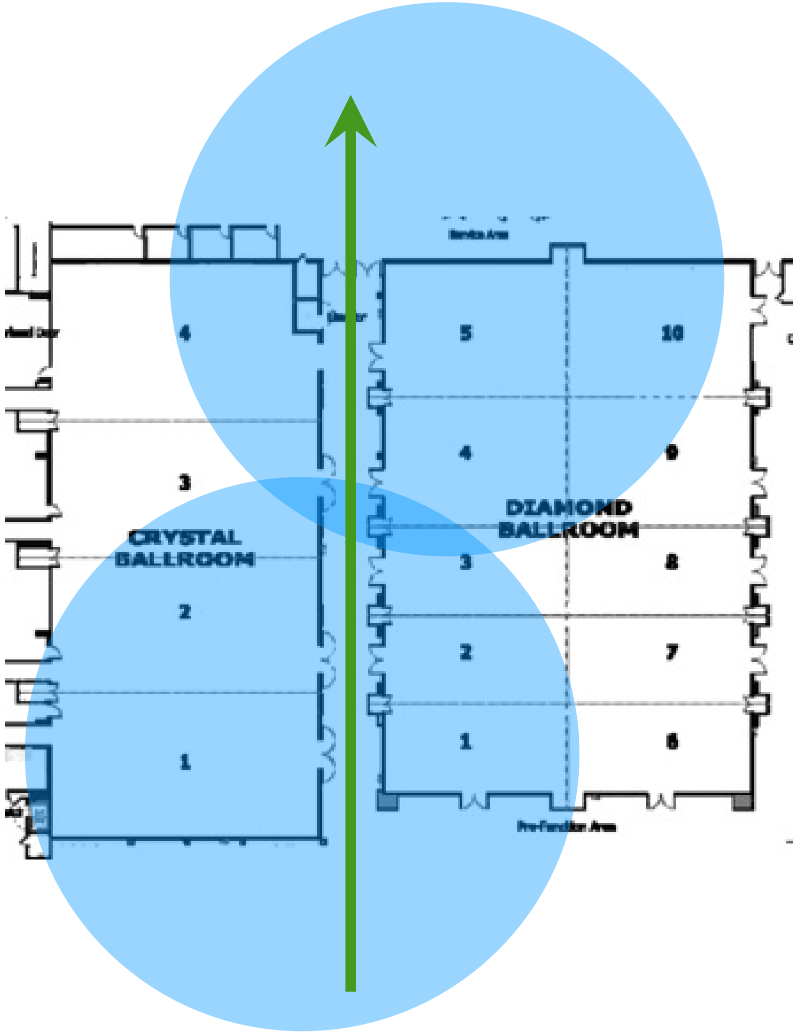


Avoiding Ping Pong Zones



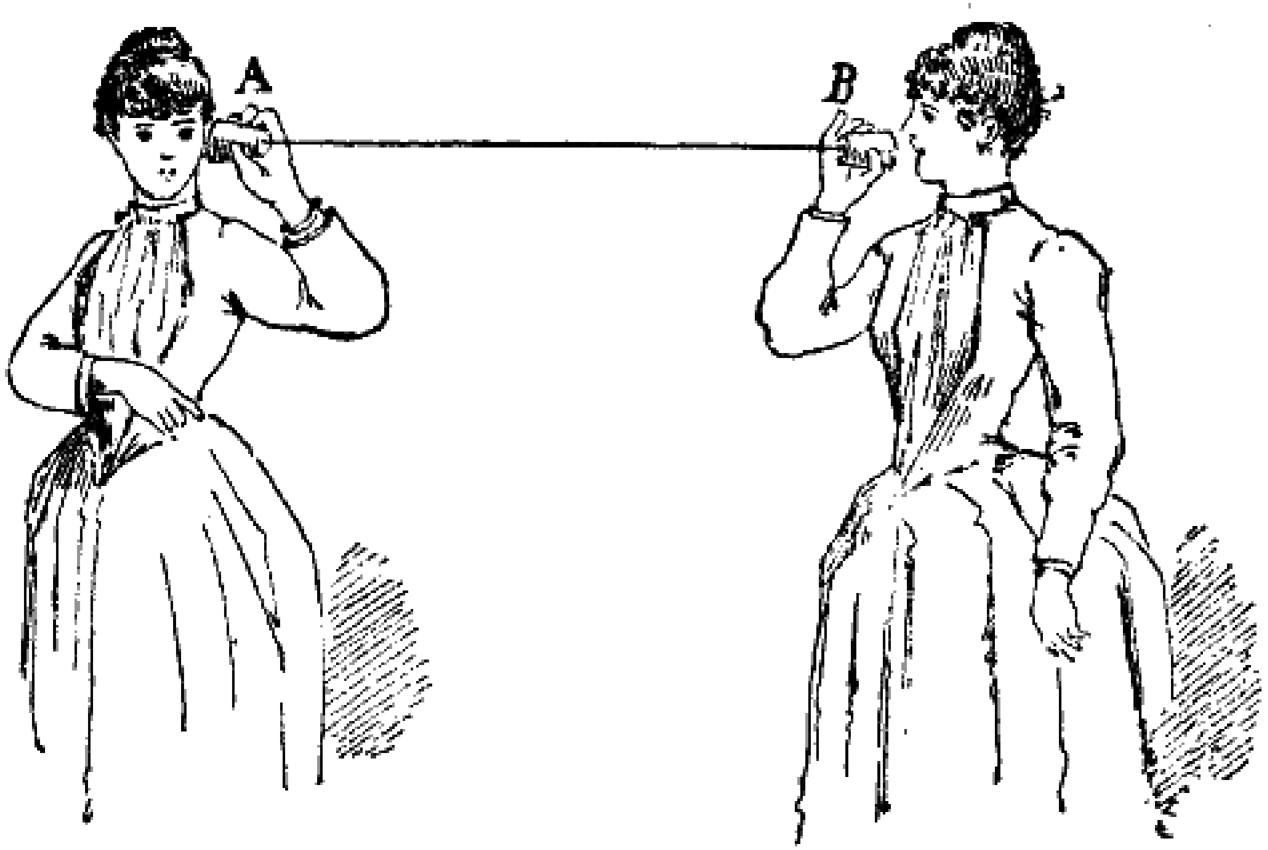
Avoiding Ping Pong Zones





FYI

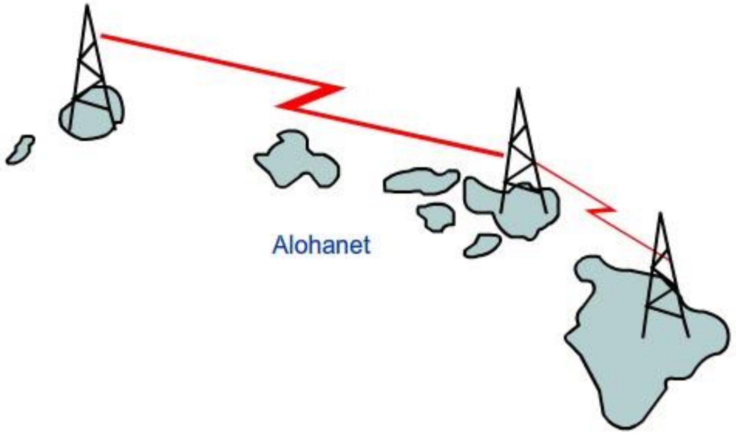
Listen Before Talk

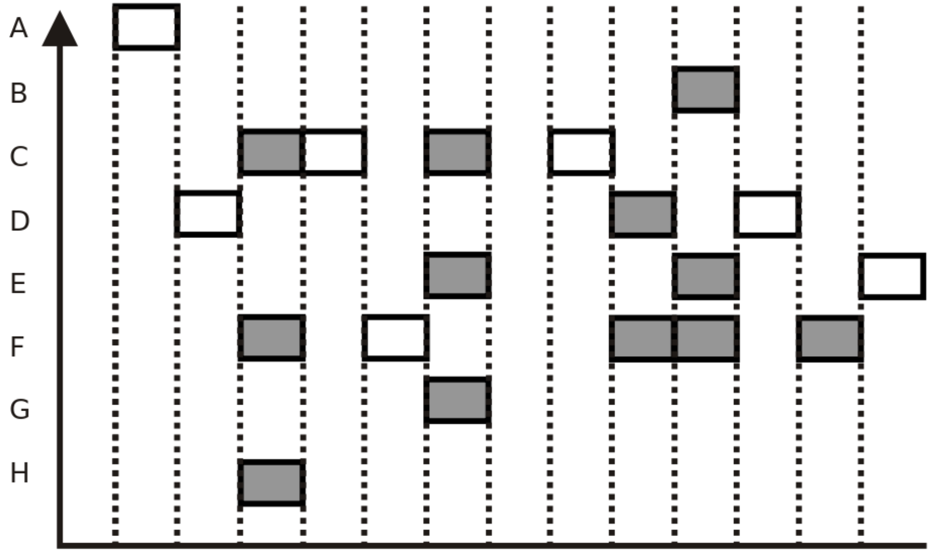


Carrier Sense Multiple Access / Collision Detect

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

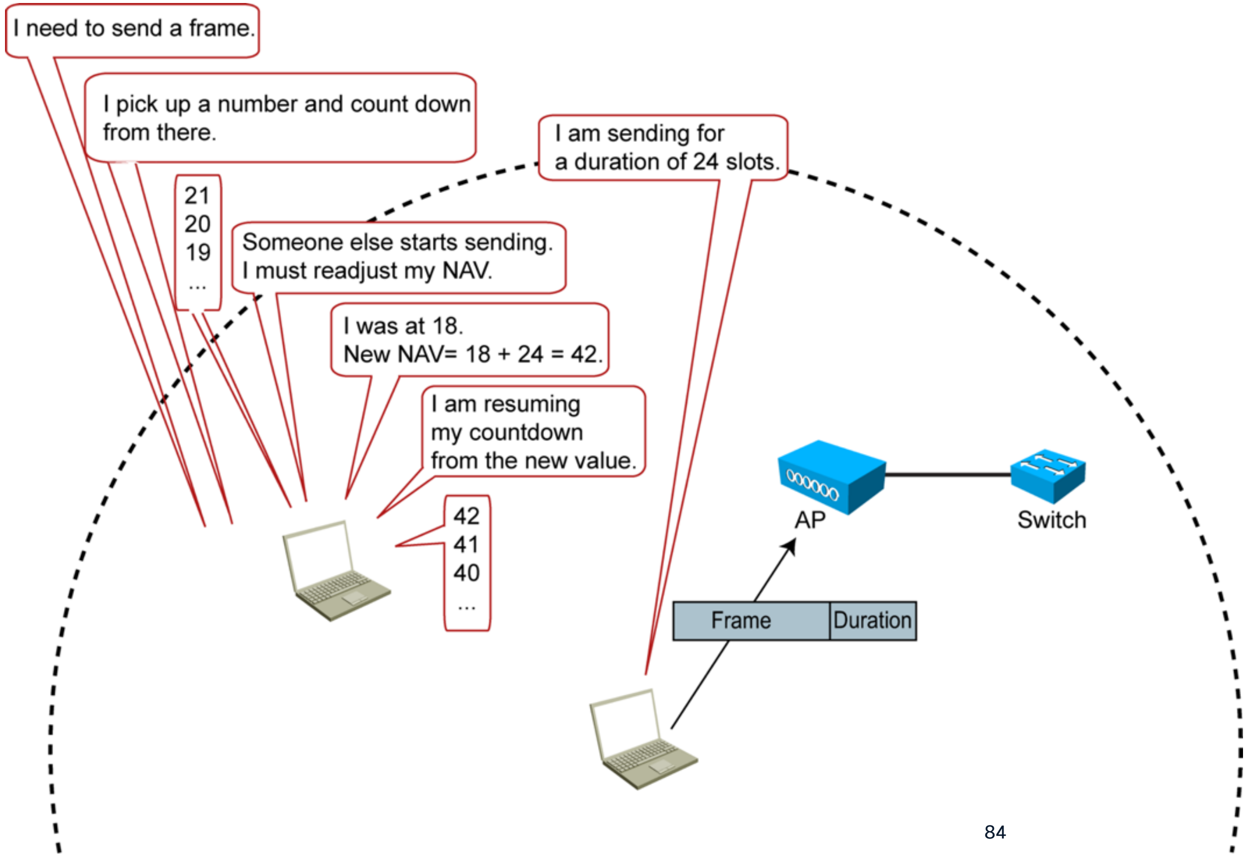




Slotted ALOHA protocol (shaded slots indicate collision)

Carrier Sense Multiple Access / Collision Avoidance

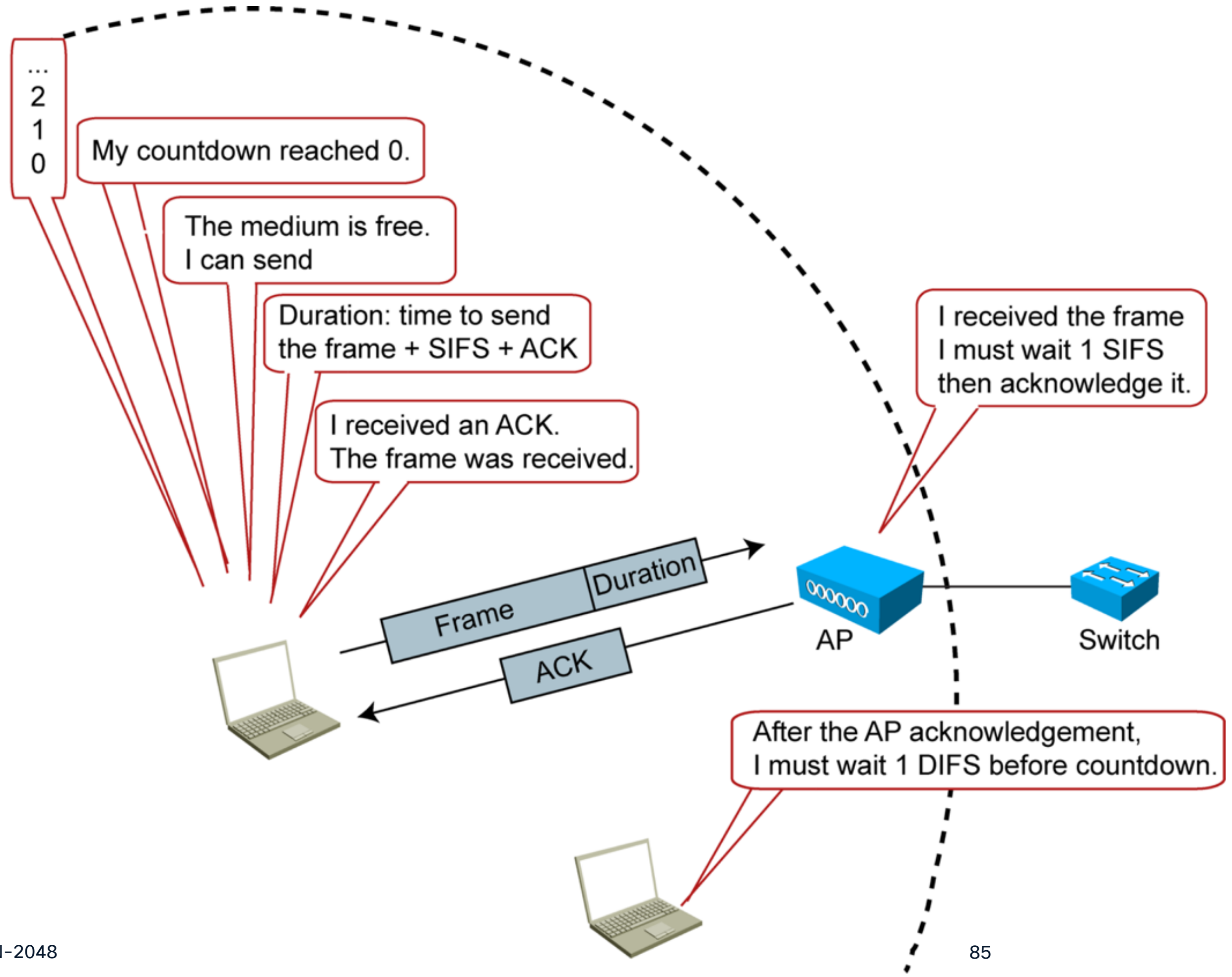
- Back-off Timer
  - Random number for countdown
- Contention Window (CW)
  - Backoff timer range
  - CWMin → CWMax
  - Differentiated back-off times to implement priorities
- Network Allocation Vector (NAV)
  - Total wait time before sending
  - Adjusted on energy detect



Carrier Sense Multiple Access / Collision Avoidance

FYI

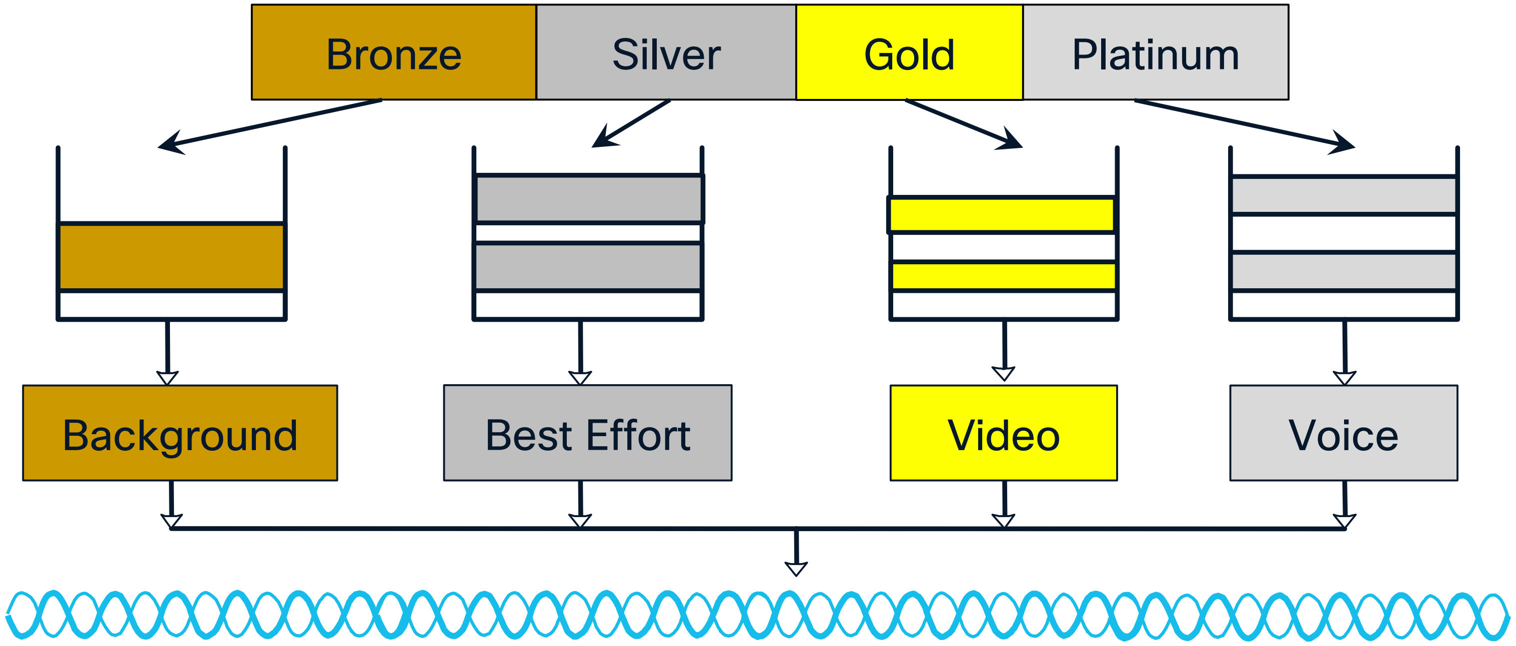
- Short Interframe Space (SIFS)
  - Silence between unicast frame and ACK
- Acknowledgement (ACK)
  - Acknowledgement frame sent by receiver to confirm receipt of the packet
- Distributed Interframe Space (DIFS)
  - Silence between transmissions
- Arbitration Interframe Space (AIFS)
  - DIFS equivalent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



Quality of Service

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

FYI

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 wir
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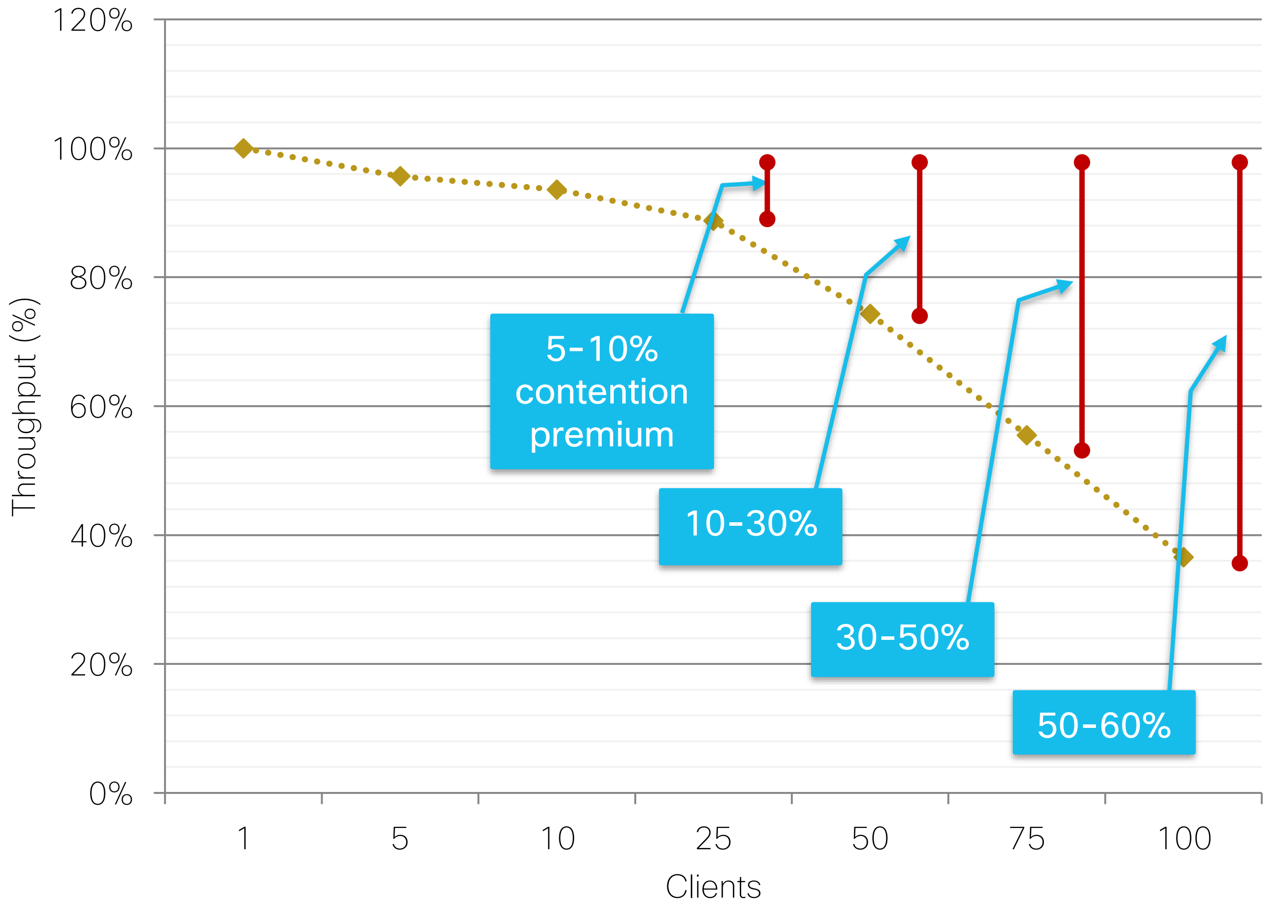
mappings from Diffe
802.11 User Priorit
offered by the IETF
treatment between w

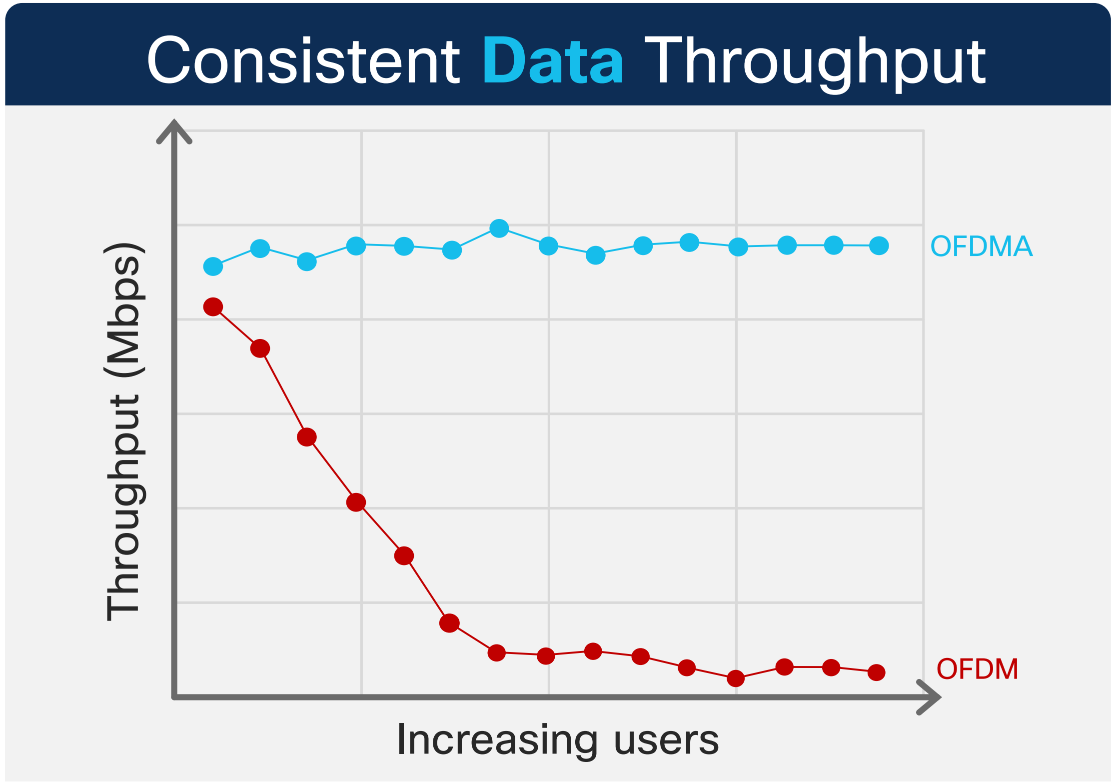
IETF Diffserv Service Class	PHB	Reference RFC	IEEE 802.11 User Priority	IEEE 802.11 Access Category
Network Control (reserved for future use)	CS7	RFC 2474	7 OR 0	AC_VO (Voice) OR AC_BE (Best Effort) See Security Considerations-Sec.8
Network Control	CS6	RFC 2474	7 OR 0	AC_VO (Voice) OR AC_BE (Best Effort) See Security Considerations
Telephony	EF	RFC 3246	6	AC_VO (Voice)
VOICE-ADMIT	VA	RFC 5865	6	AC_VO (Voice)
Signaling	CS5	RFC 2474	5	AC_VI (Video)
Multimedia Conferencing	AF41 AF42 AF43	RFC 2597	4	AC_VI (Video)
Real-Time Interactive	CS4	RFC 2474	4	AC_VI (Video)
Multimedia Streaming	AF31 AF32 AF33	RFC 2597	4	AC_VI (Video)
Broadcast Video	CS3	RFC 2474	4	AC_VI (Video)
Low-Latency Data	AF21 AF22 AF23	RFC 2597	3	AC_BE (Best Effort)
OAM	CS2	RFC 2474	0	AC_BE (Best Effort)
High-Throughput Data	AF11 AF12 AF13	RFC 2597	0	AC_BE (Best Effort)
Standard	DF	RFC 2474	0	AC_BE (Best Effort)
Low-Priority Data	CS1	RFC 3662	1	AC_BK (Background)

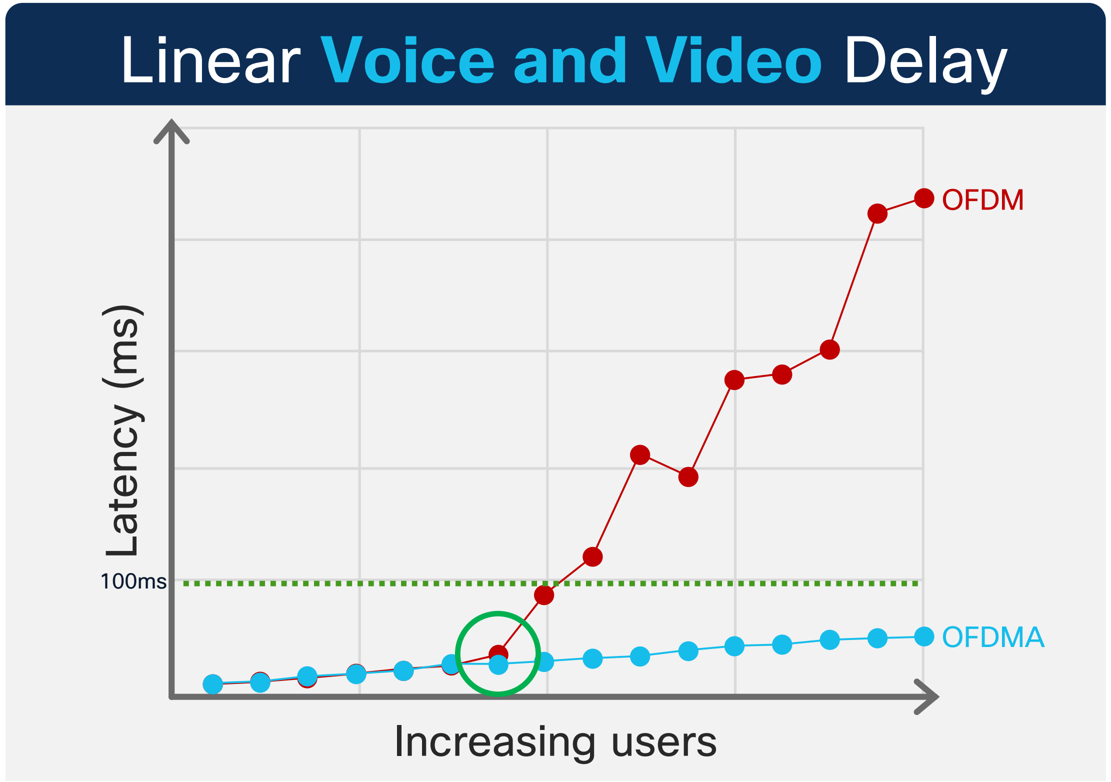
IETF Traffic Class	PHB	AC	UP	
Network Control	CS6	AC_VO	7	Voice
Voice (46), Voice-Admit(44)	EF,VA	AC_VO	6	
Signaling	CS5	AC_VI	5	Video
Multimedia Conferencing	AF4x	AC_VI	4	
Real-time Interactive	CS4	AC_VI	4	
Multimedia Streaming	AF3x	AC_VI	4	
Broadcast Video	CS3	AC_VI	4	
Low Latency Data	AF2x	AC_BE	3	Best Effort
OAM	CS2	AC_BE	0	
High Throughput Data	AF1x	AC_BE	0	
Standard (Best Effort)	DF	AC_BE	0	
Low Priority Data	CS1	AC_BK	1	Background

The Contention Breaking Point



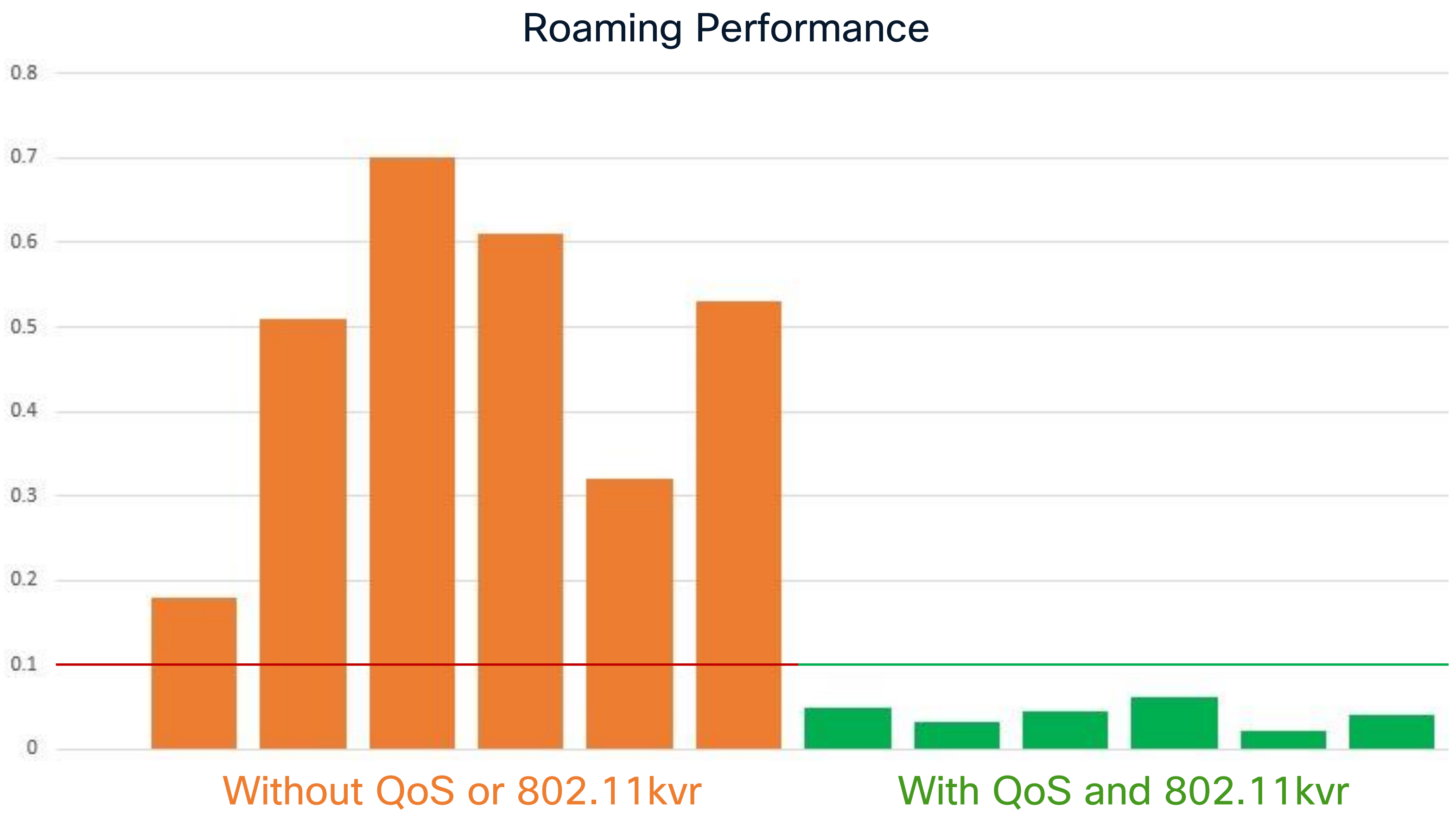
Deterministic Wireless



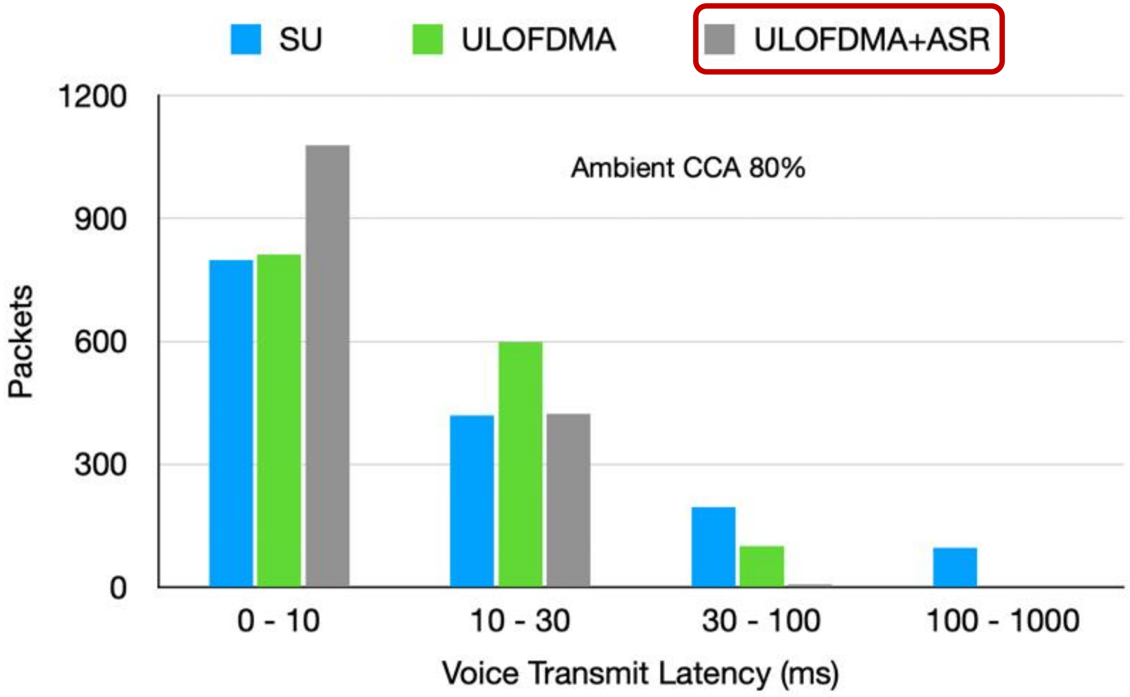


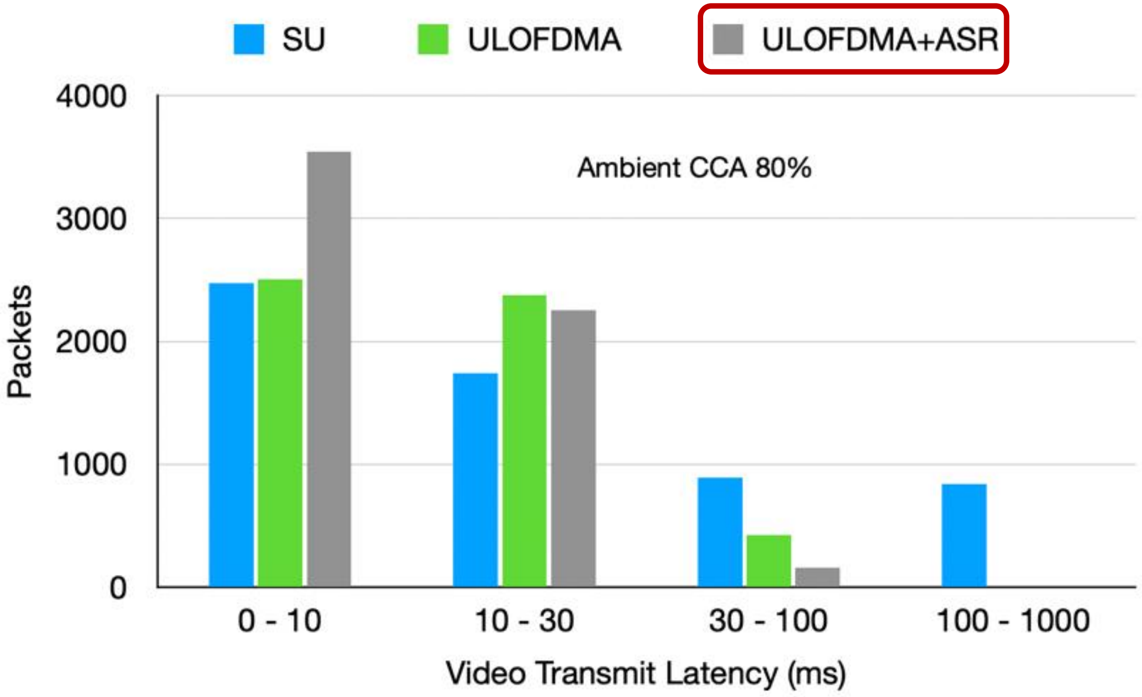
Putting it All Together

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

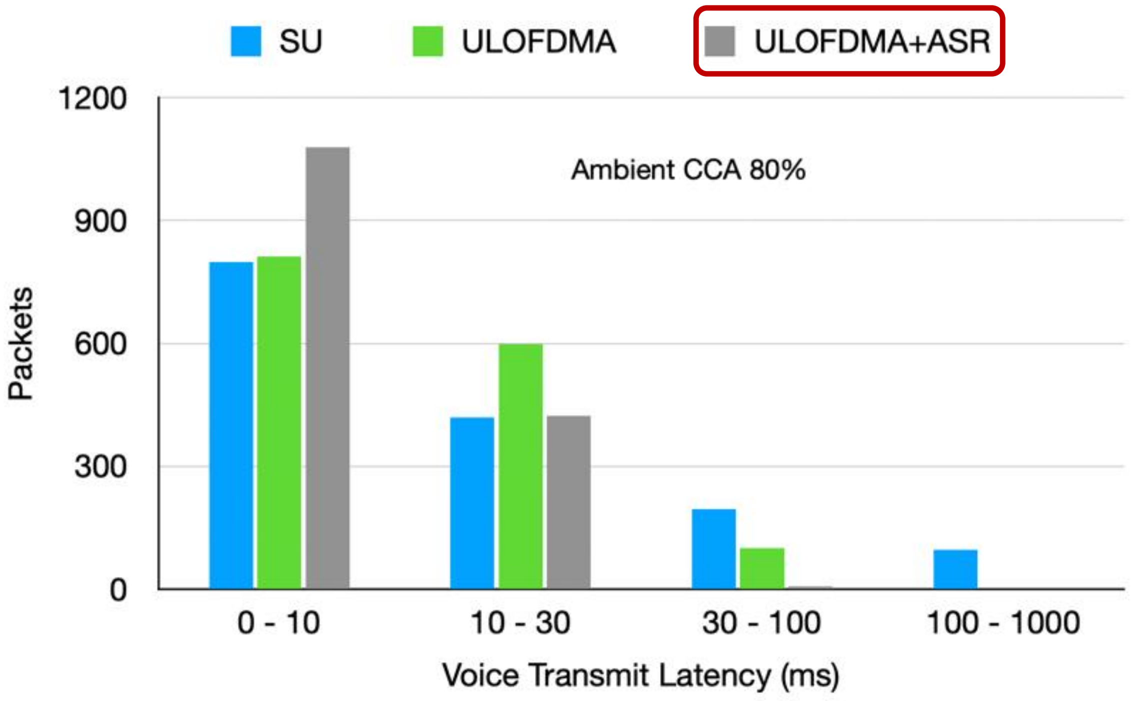


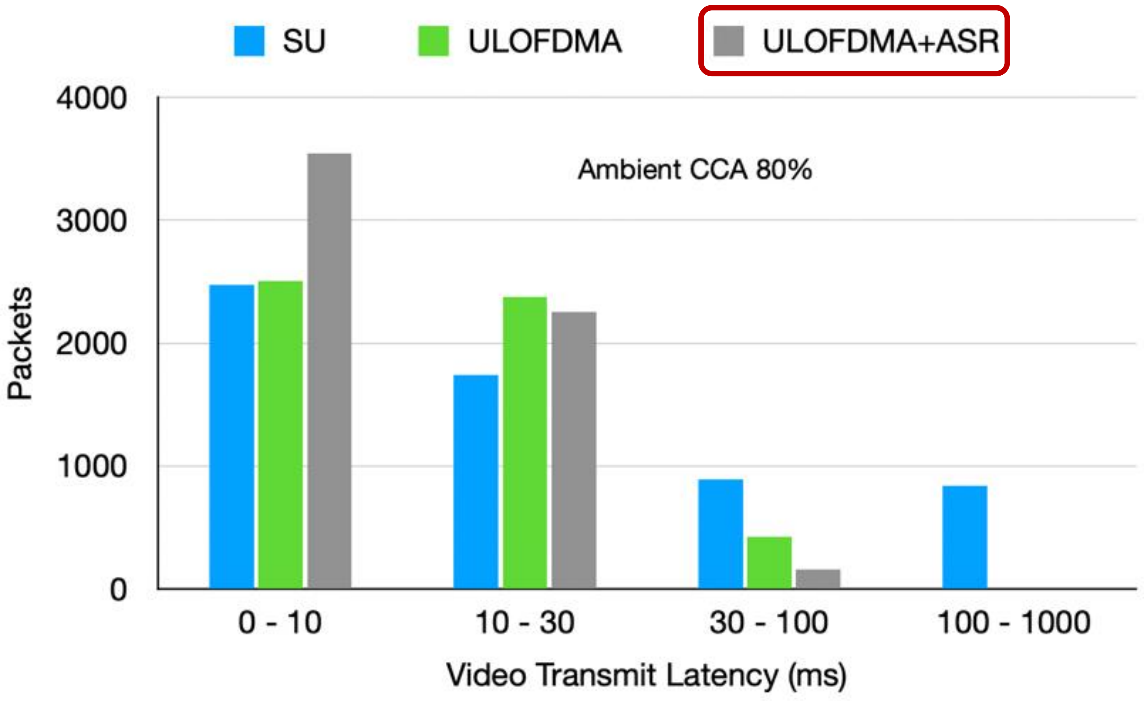
FastLane+ Advanced Scheduling Requests



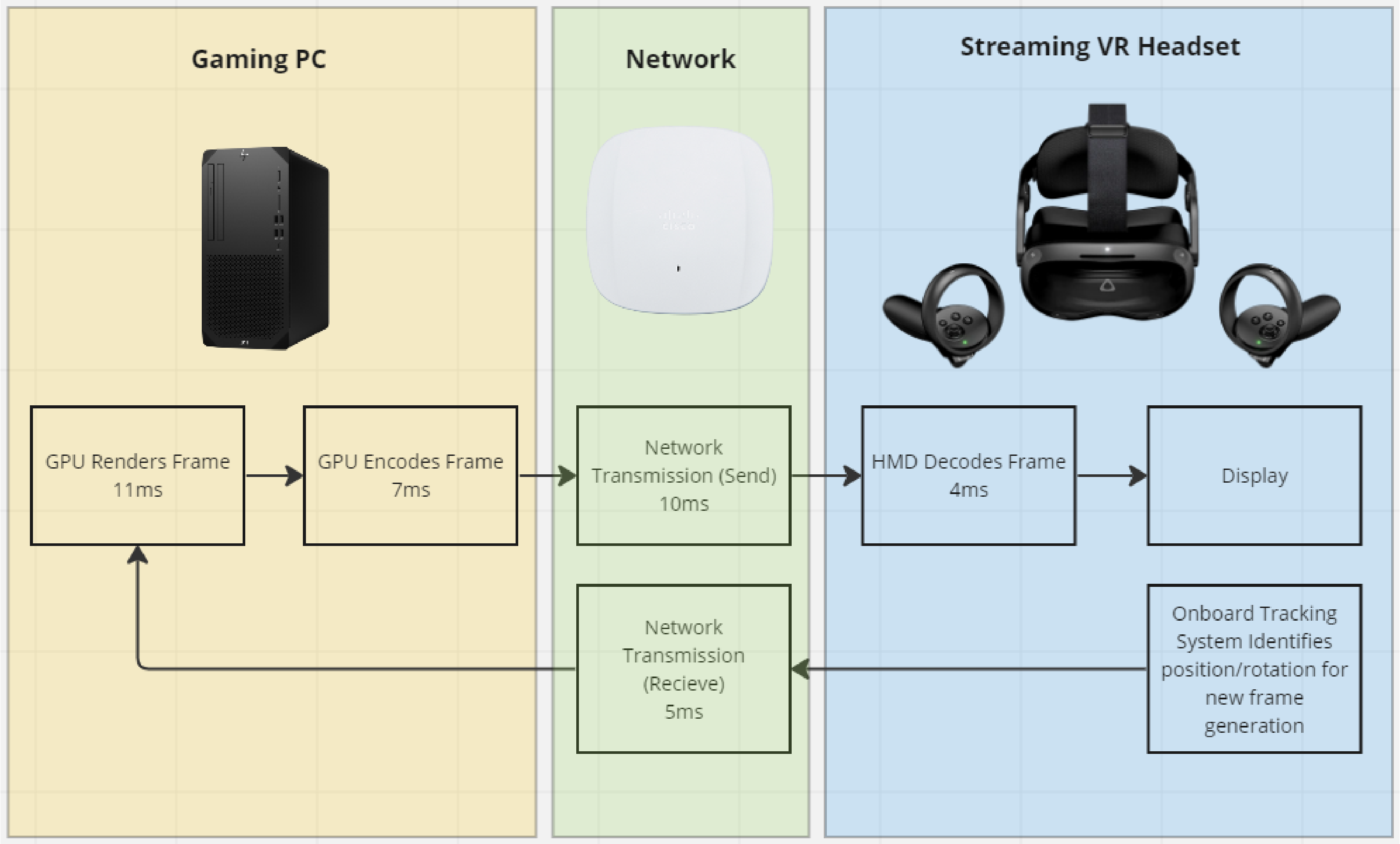


Triggered UL Access Optimisation



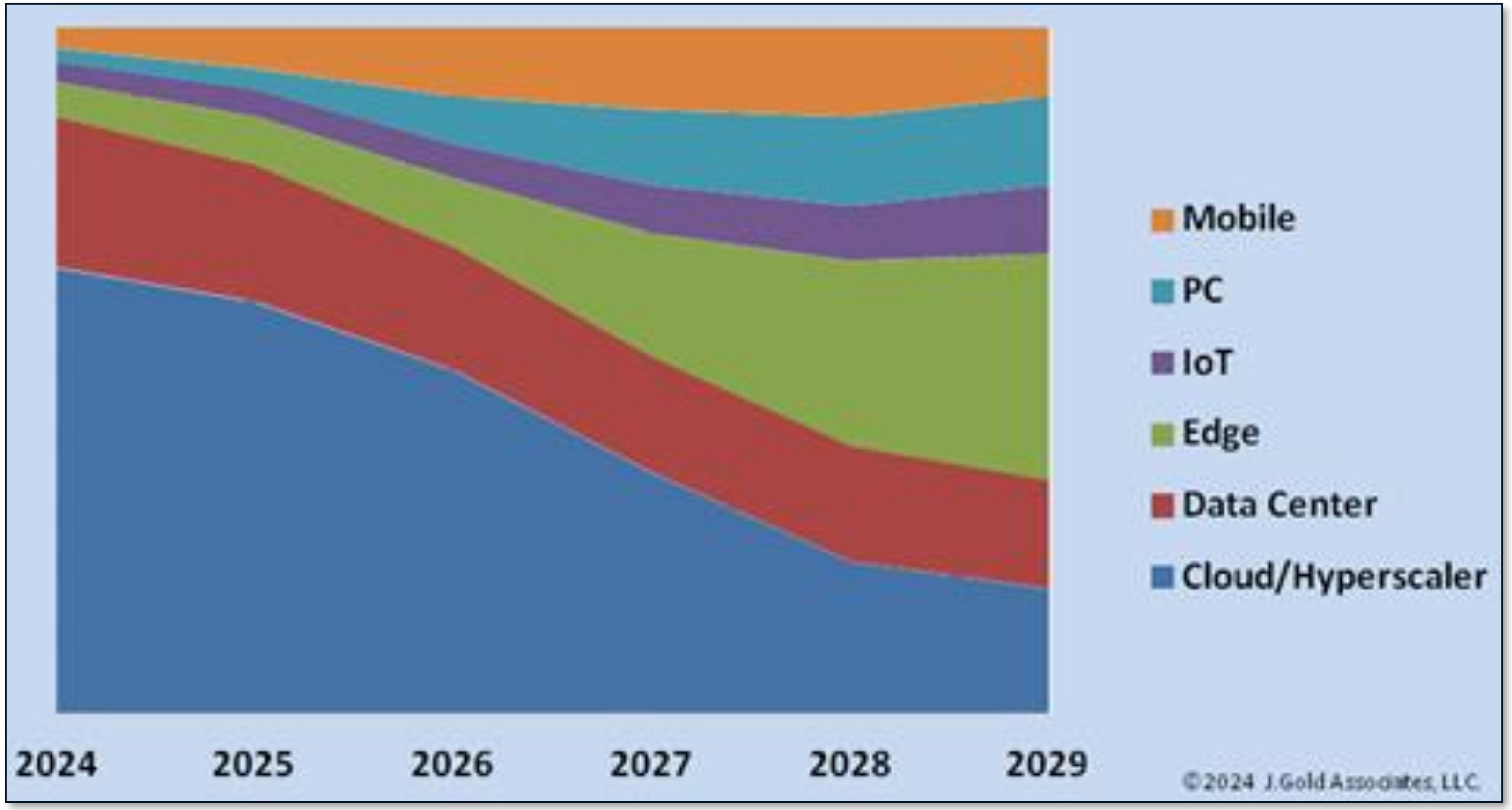


Designing for Virtual Reality



Designing for AI Workloads at the Edge

Percentage of AI Workloads by System Type



Wireless Network Design

- Two levers for improving signal quality
  - Increase the signal
  - Decrease the noise
- Three dimensions to Wi-Fi performance
  - Digital Modulation
  - Spatial Multiplexing
  - Channel Aggregation
- Design with your clients in mind
  - Consider device disparity
  - APs set to max transmit power is an indication something is wrong
  - Ensure cell overlap to facilitate roaming
  - Understand how APs hear each other along roaming pathways
  - Enable available features to support seamless roaming and real-time applications
- Planning tools and site surveys are critical to success

Thank you

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