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The bridge to possible

High Density Wi-Fi Design, Deployment, and Optimization

Matt Swartz - Cisco Customer Experience, Distinguished Engineer, CCIE #13232
Josh Suhr - Cisco Customer Experience, Principal Architect, CCIE #39980

BRKEWN-2087

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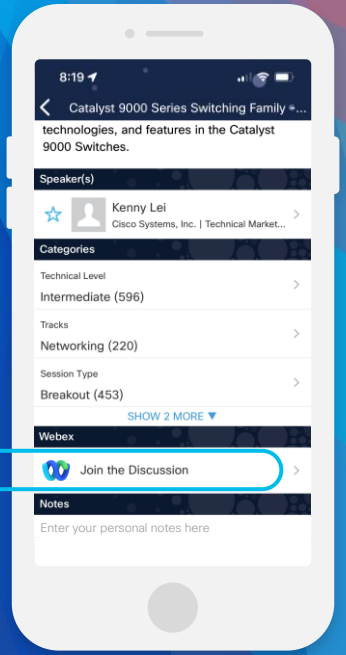


https://ciscolive.ciscoevents.com/ciscolivebot/#BRKEWN-2087

Agenda

- Designing RF for High Client Densities
- HD Wi-Fi Configuration Tips
- HD Wi-Fi Engineering Toolkit

Josh Suhr

Principal Architect, Cisco CX

CCIE #39980 (Wireless)

First HD WiFi Project: Sporting Kansas City, 2011

Husband, recent dad, soccer fan, beer & pizza connoisseur

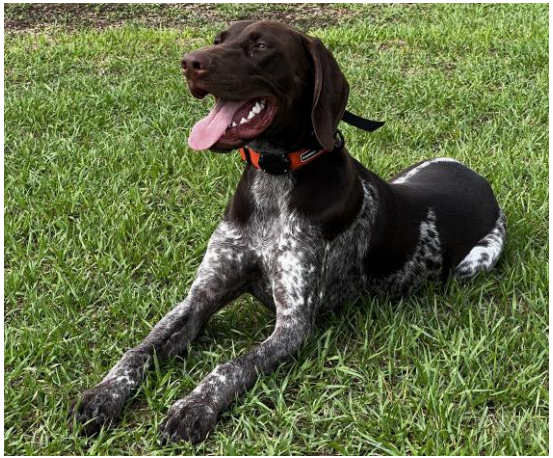
Matt Swartz

Distinguished Engineer, Cisco CX

CCIE #13232 (R/S, Wireless)

First HD WiFi Project: New York Yankees, 2008

Husband, dad, mountain biker, beer connoisseur

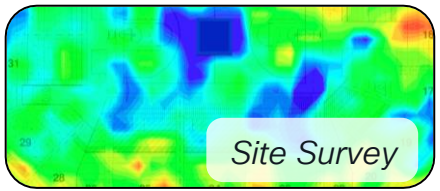


Key Trends in High Density Wi-Fi

- Wi-Fi 6 – new hardware and HD improvements
- Software-defined antenna (C9104)
- 6GHz / Wi-Fi 6E – more spectrum!!!
- More devices per user
- Auto authentication & OpenRoaming

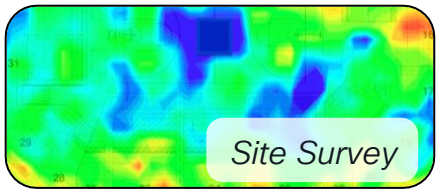
Designing for the 3 Key RF Relationships

1 AP to Client



Designing for the 3 Key RF Relationships

1 AP to Client



2 Client to AP

Device Type	iPhone 12
Device OS	iOS 15.4.1
Client Performance	Signal Strength: -66 dBm Signal Quality: 30 dB Ch BW(Negotiated/Capable): 20 MHz/80 MHz
Capabilities	802.11a
Fabric Status	Disabled

WLC UI / CLI

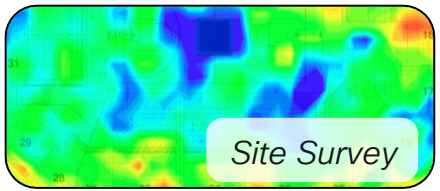
Designing for the 3 Key RF Relationships

Name	Slot	Channel	Power Level	Power dBm	Neigh. Name	Neigh. Slot	Neigh. Channel	Neigh. Power	Compensated Power
AP12	1	112	6	4	AP1	1	52	-42	-57
AP12	1	112	6	4	AP2	1	144	-51	-66
AP12	1	112	6	4	AP3	1	120	-53	-65
AP12	1	112	6	4	AP4	1	100	-53	-65
AP12	1	112	6	4	AP5	1	124	-57	-66
AP12	1	112	6	4	AP6	1	60	-61	-73
AP12	1	112	6	4	AP7	1	136	-62	-74
AP12	1	112	6	4	AP8	1	44	-69	-69
AP12	1	112	6	4	AP9	1	104	-79	-85
AP12	1	112	6	4	AP10	1	60	-80	-89
AP12	1	112	6	4	AP11	1	153	-81	-84

WCAE

3 AP to AP

1 AP to Client



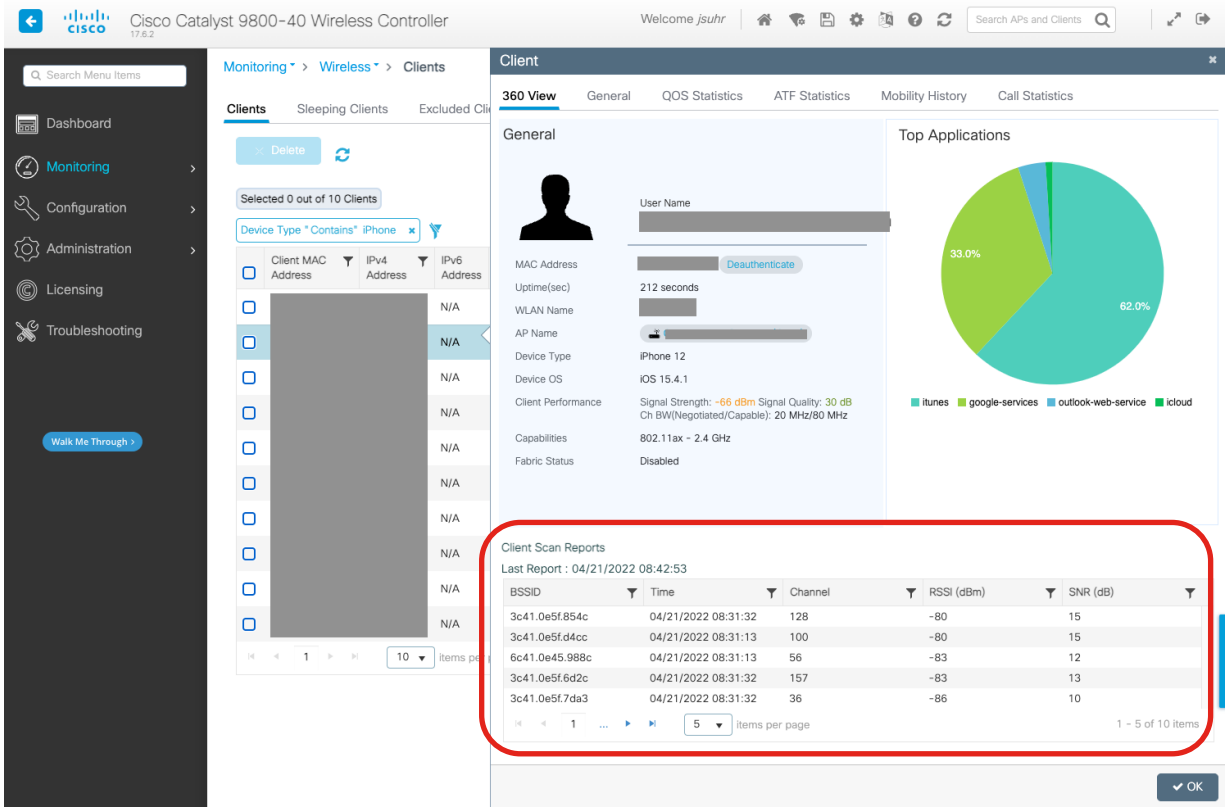
2 Client to AP

Device Type	iPhone 12
Device OS	iOS 15.4.1
Client Performance	Signal Strength: -66 dBm Signal Quality: 30 dB Ch BW(Negotiated/Capable): 20 MHz/80 MHz
Capabilities	802.11ax - 2.4 GHz
Fabric Status	Disabled

WLC UI / CLI

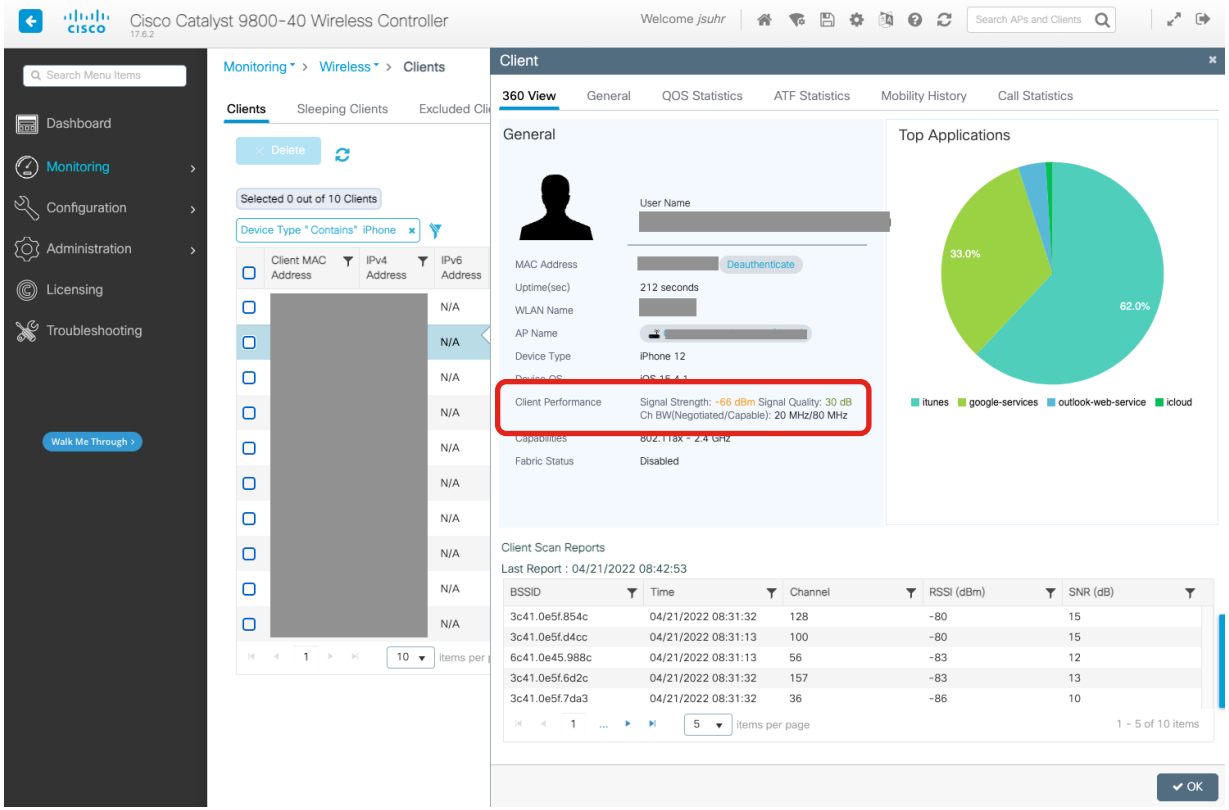
*Bonus points: Client <-> Client – harder to influence

How Clients Hear AP's – C9800 UI



Client Scan Report shows how this client hears all AP's within range

How AP's Hear Clients – C9800 UI



Client Performance readings *show how the currently associated AP hears this client*

How AP's Hear Clients: Catalyst AP

For a table of all clients on an AP, at AP CLI:

Telnet/SSH to AP and use "show dot11 clients" for immediate client RSSI readings of ALL clients associated to the specified radio

```
ap#show dot11 clients
AP Mode - Local
Client MAC      Slot ID WLAN ID AID     WLAN Name RSSI Maxrate  WGB
FC:F8:AE:60:98:34       1       3   1 AbrahamLinksys  -47 MCS82SS  No
00:24:D7:7E:48:D8       1       3   2 AbrahamLinksys  -54    M23  No
78:F8:82:EF:2E:A0       1       3   3 AbrahamLinksys  -37 MCS82SS  No
84:38:35:42:E1:F0       1       3   4 AbrahamLinksys  -71 MCS82SS  No
```

How AP's Hear Clients: Catalyst AP

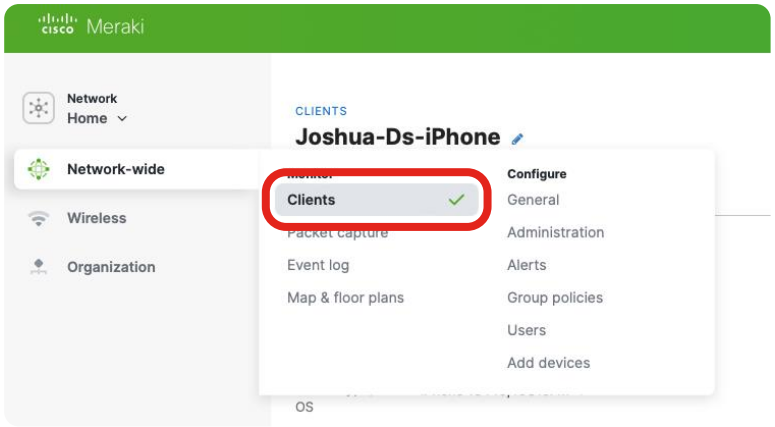
For a detail on a single client, at AP CLI:

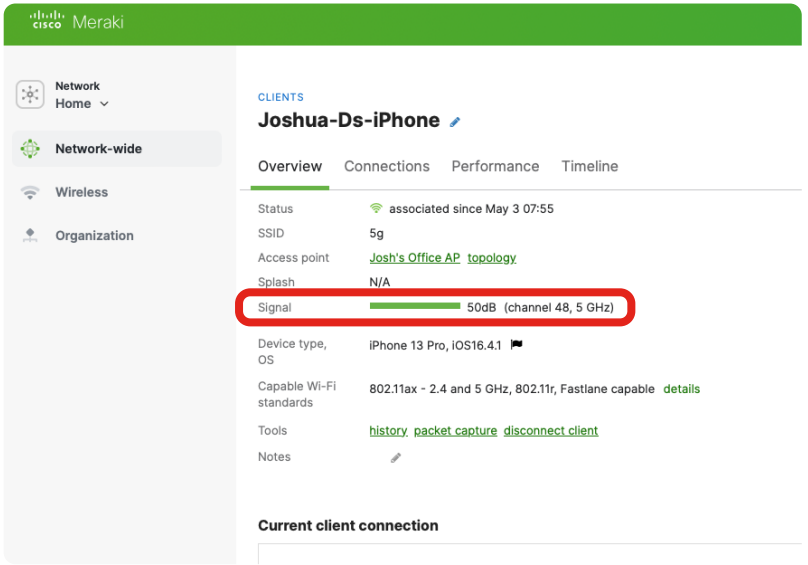
Telnet/SSH to AP and use "show controller d <0|1> client <mac-addr>" for immediate client RSSI readings of a single client

```
10#sho controller d 1 client FC:F8:AE:60:98:34
<clip>
Additional info for client FC:F8:AE:60:98:34
RSSI: -47
<clip>
Statistics for client FC:F8:AE:60:98:34
mac                 <clip> stats_ago expiration
FC:F8:AE:60:98:34   <clip>  0.700000         0
```

How long ago were these stats updated (in sec)?

How AP's Hear Clients: Meraki AP





It All Starts with Layer 1: RF Design

Antenna Selection:

Decide which antenna is right for the job.

Consider:

- Density of clients to be served
- Available mounting assets
  - Within 65'/20m of furthest client (or 200'/60m with C-ANT9104)

Antenna Placement:

Where will this antenna provide the best throughput and most reliable service?

Consider:

- Line of sight
- Isolation from ambient RF
- Angle of incidence to client devices

Antenna Selection

		Beamwidth	Use Case
	Dual-Band “Narrow” 8x8 Patch Antenna AP: 9130AXE Antenna: C-ANT9103	2.4/5GHz 75/70° Az 70/70° Elev	Augmentation and short-distance HD coverage (15’/5m – 30’/10m to clients)
	Dual-Band “Wide” Patch Antenna AP: 3802E/P, 9120AXE/P, 9130AXE Antenna: AIR-ANT2566P4W-R	2.4/5GHz 105/125° Az 70/60° Elev	Augmentation and short-distance HD coverage (< 30’ / 10m to clients)
	Dual-Band “Narrow” Patch Antenna AP: 3802E/P, 9120AXE/P, 9130AXE Antenna: AIR-ANT2566D4M-N	2.4/5GHz 65/65° Az 65/65° Elev	Augmentation and short-distance HD coverage (15’/5m – 30’/10m to clients)
	Dual-Band High Density Antenna C-ANT9104 (Antenna + Integrated AP)	70/70° 2.4GHz 80/25° 5GHz (Wide) 25/25° 5GHz (Narrow)	Primary overhead coverage (i.e. seating areas; > 30’/10m, <200’/60m to clients)

Meraki AP & Antenna Selection: Directional

MR86

Part No.	Type	5GHz Beam (Az)	5GHz Beam (Elev.)
MA-ANT-25	Patch	75 deg	84 deg
MA-ANT-27	Sector	65 deg	18 deg
AIR-ANT2513P4M-N	Array	31 deg	27 deg

*(*Coming Soon: 9166D1)*

Cisco Catalyst C-ANT9104 – Stadium Antenna + Integrated AP

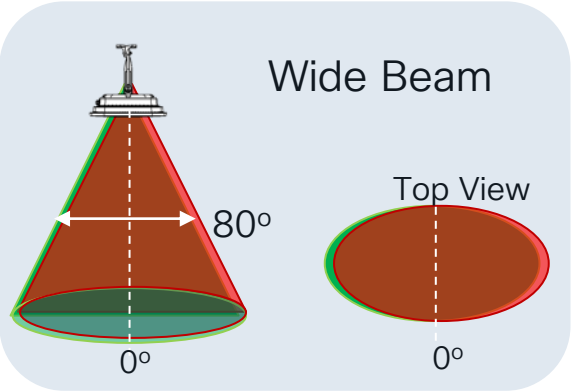
- The C-ANT9104 antenna is designed specifically to solve challenges encountered in stadium/Large Public Venue/High Client Density environments.
- Dual 5 GHz on two individual 5 GHz 4x4 Arrays
- Configurable electronic beam steering as well as Narrow and Wide modes of the antenna
- Catalyst C9800 release 17.6.1 adds configuration support for these new controls

Three generations of High-Density WiFi Stadium Antennas

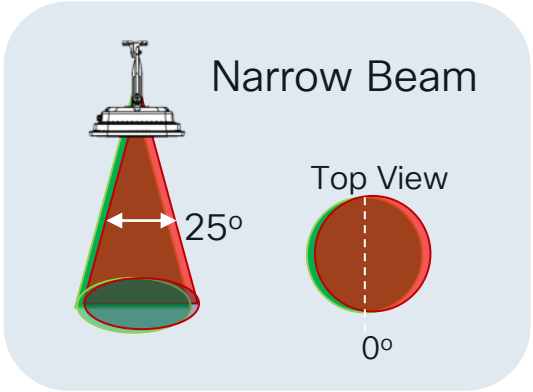
C-ANT9104: Key Things to Know

Antenna Design Improvements	Cover Clients from Longer Distances (up to 200’ line-of-sight)
Integrated Unit, Outdoor-Rated	AP + Antenna all-in-one, no enclosures required, outdoor-rated
Deployment Flexibility	Beam Switching & Beam Steering; switch between narrow/wide, meet needs of multiple different coverage types
Important Notes	Band-Locked Slots & Tx Power Implications Tight RF patterns, minimal sidelobes, RF Isolation = no RRM

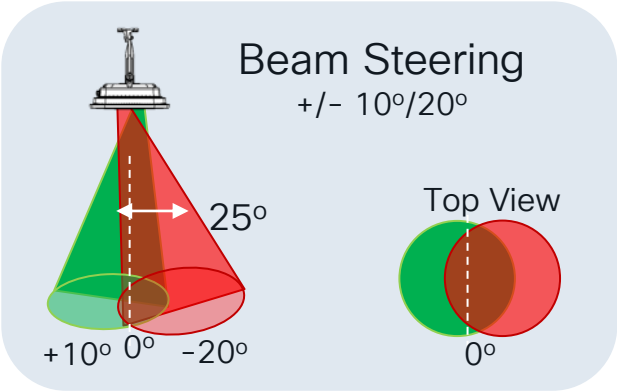
C-ANT9104: Software-Configurable Beams



Wide sector beamwidth
Dual 4x4 5GHz (80ºx25º)
2.4 GHz (75ºx85º)
8 dBi gain



Narrow sector beamwidth
Dual 4x4, 5 GHz (25ºx25º)
10 dBi gain



Software defined beam steering
Each 5GHz 4x4 can steer
+/- 10º,20º off center

5GHz Software Defined Beamwidth and Direction

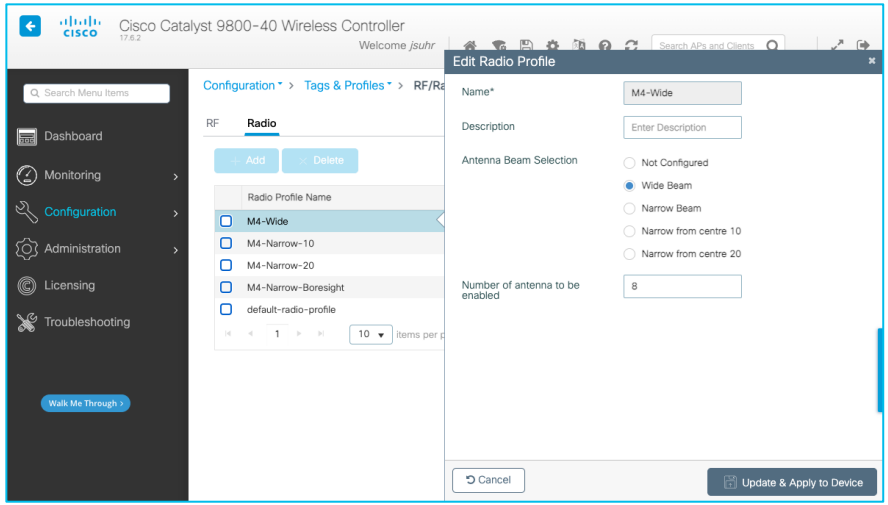
C-ANT9104: Deployment Checklist

- ✓ Physical Install:
  - ✓ All-In-One – no enclosures needed
  - ✓ Portrait vs landscape
  - ✓ Physical orientation of higher-power slot
- ✓ Channel & power planning
- ✓ Determine initial beam configuration (surveys / prediction)
- ✓ Define Radio Profiles & RF Tags
- ✓ Less (or no) RX-SOP optimization needed
- ✓ Validate & optimize

C-ANT9104 Power Table Summary

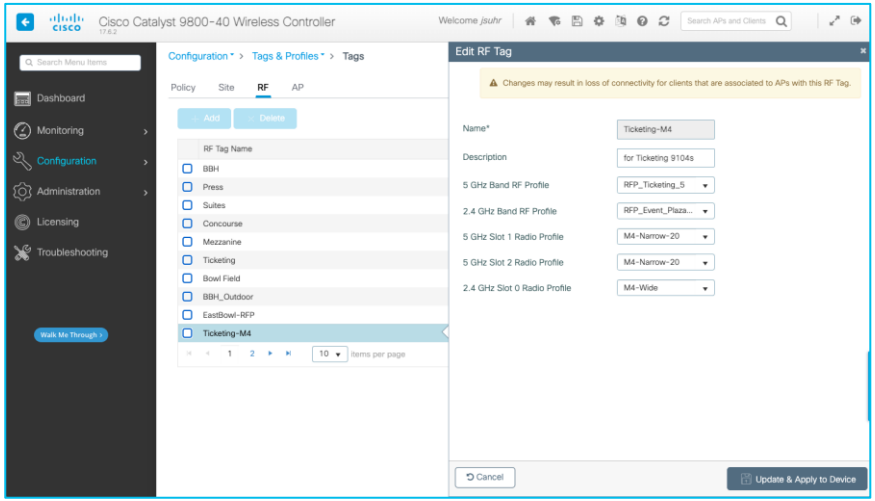
[Slot 1]	[Slot 2]
UNII-2e / 12 channels: 17dBm	UNII-1 / 4 channels: 21dBm
UNII-3 / 5 channels: 23dBm	UNII-2 / 4 channels : 17dBm

C-ANT9104: Configuration (GUI)



Create **Radio Profiles**, one for each beam configuration you plan to use

**Note: "Number of antenna to be enabled" can be set to 8*



Create new or edit existing **RF Tags** and assign the Radio Profiles to each slot as desired

**Note: 2.4GHz Slot 0 is always "Wide"*

C-ANT9104: Configuration (CLI)

1 Define RF Profile(s):

```
ap dot11 5ghz rf-profile MP1-5
 high-density rx-sop threshold custom -85
 channel chan-width 20
 rate RATE_12M supported
 rate RATE_18M mandatory
 rate RATE_24M supported
 rate RATE_6M disable
 rate RATE_9M disable
 no shutdown
```

2 Define Radio Profile(s):

```
wireless profile radio M4-Wide
 antenna beam-selection wide
 antenna count 8
wireless profile radio M4-Narrow-10
 antenna beam-selection narrow tilt 10
 antenna count 8
wireless profile radio M4-Narrow-20
 antenna beam-selection narrow tilt 20
 antenna count 8
wireless profile radio M4-Narrow-Boresight
 antenna beam-selection narrow
 antenna count 8
```

3 Build RF tags and assign Radio Profile(s):

```
wireless tag rf MP1-rf-tag
 5ghz-rf-policy MP1-5
 dot11 24ghz slot0 radio-profile default-radio-profile
 dot11 5ghz slot1 radio-profile M4-Narrow-10
 dot11 5ghz slot2 radio-profile M4-Narrow-10
```

4 Apply tags to AP(s):

```
ap filter name "M4 Portrait Narrow 10"
ap name-regex MP1
tag policy policy-tag-1
tag rf MP1-rf-tag
tag site site-tag-1
ap filter priority 50 filter-name "M4 Portrait Narrow 10"
```

OR

```
ap f4bd.9ed1.4700
 policy-tag policy-tag-1
 rf-tag MP1-rf-tag
 site-tag site-tag-1
```

9166D1 Wi-Fi 6 Access Point

NEW

Cisco® Catalyst® 9166D1-x

Directional, Tri-Radio with 12 Spatial Streams!

Orderability in FY ’24 Q1

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Penta-Radio Architecture

1. 2.4 GHz Client Radio: 4x4:4SS
2. 5 GHz Client Radio: 4x4:4SS
3. 6 GHz Client Radio 4x4:4SS (XOR to 5GHz)
4. Dedicated tri-band auxiliary radio
5. 2.4 GHz IoT Radio

Directional antenna architecture

- 2.4+5 GHz: 6 dBi gain (70x70 deg), 6 GHz: 8 dBi (60x60)
- Same X,Y as CW9166I – and only 0.1cm taller!
- Wide support for pan/tilt combinations

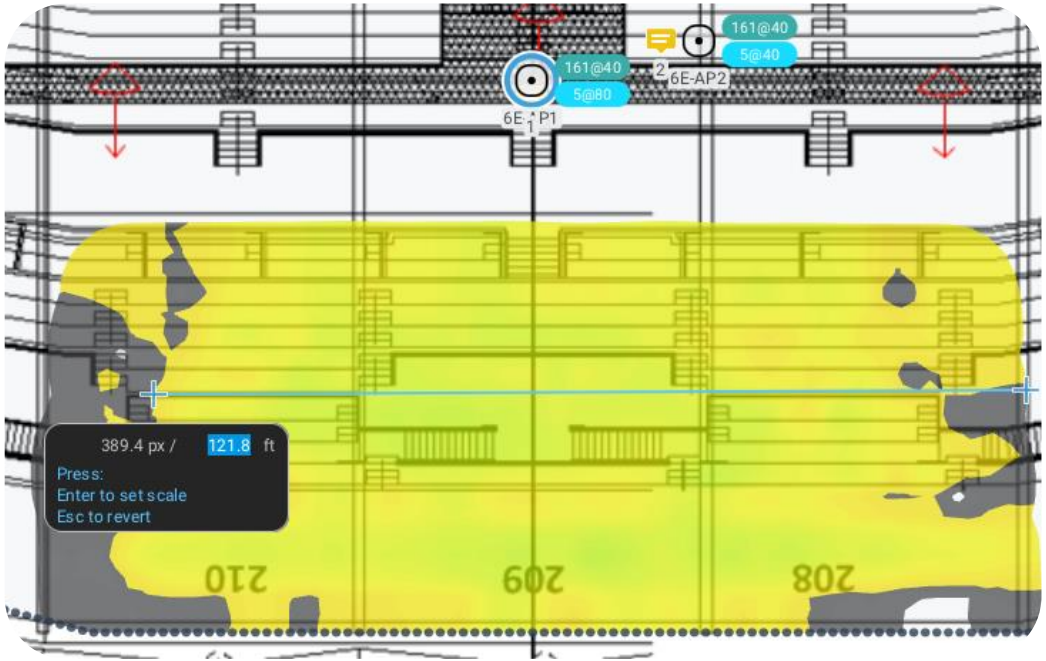
Internet of Things Capabilities

- Built-In Environmental Sensors
- Application Hosting Technology
- USB port with 4.5 W power output

5 Multigigabit (mGig) PoE Port

- Optional DC Power

9166D 6GHz Cell Size @ 55’ Height



- 121’ cell width @ -63dBm
- 5GHz beam is slightly wider than 6GHz beam
- At >30’/10m mount height, consider “overlay” with 9104 for 5GHz

Industry's Best And Broadest Wi-fi 6E And Wi-Fi 6 Portfolio

6E

9162

9164

9166

9136

6

9105I/W

9115

9120

9130

9124

Assess environmental RF coverage using the Catalyst 9136I's site survey mode

Puts AP in standalone mode and enables it to broadcast 2.4-, 5-, and 6-GHz SSIDs and have clients join via internal DHCP.

Supports WebUI access for easy configuration and viewing of various RF metrics for RF coverage and planning.

Supports configuration of channel number, channel width, Tx power, SSID, and data rates.

Cisco outdoor AP portfolios

1572 › 1542 › 1562 › 9124 ›

1570 Series (Wave 1)

- 802.11ac Wave 1
- 4x4:3 80 MHz; 1.3 Gbps
- External antenna model (EAC)
- Cable modem model (IC/EC)
- SFP
- GPS
- PoE-Out 802.3at (ext. ant. only)
- Flexible antenna ports
- Cisco CleanAir® and ClientLink
- Centralized, Cisco FlexConnect®, and mesh

1540 Series (Wave 2)

- 802.11ac Wave 2, MU-MIMO
- 2x2:2, 80 MHz, 867 Mbps
- Ultra low profile
- Internal antenna only
- PoE (802.3af) power
- Centralized, FlexConnect, mesh, and Mobility Express

1560 Series (Wave 2)

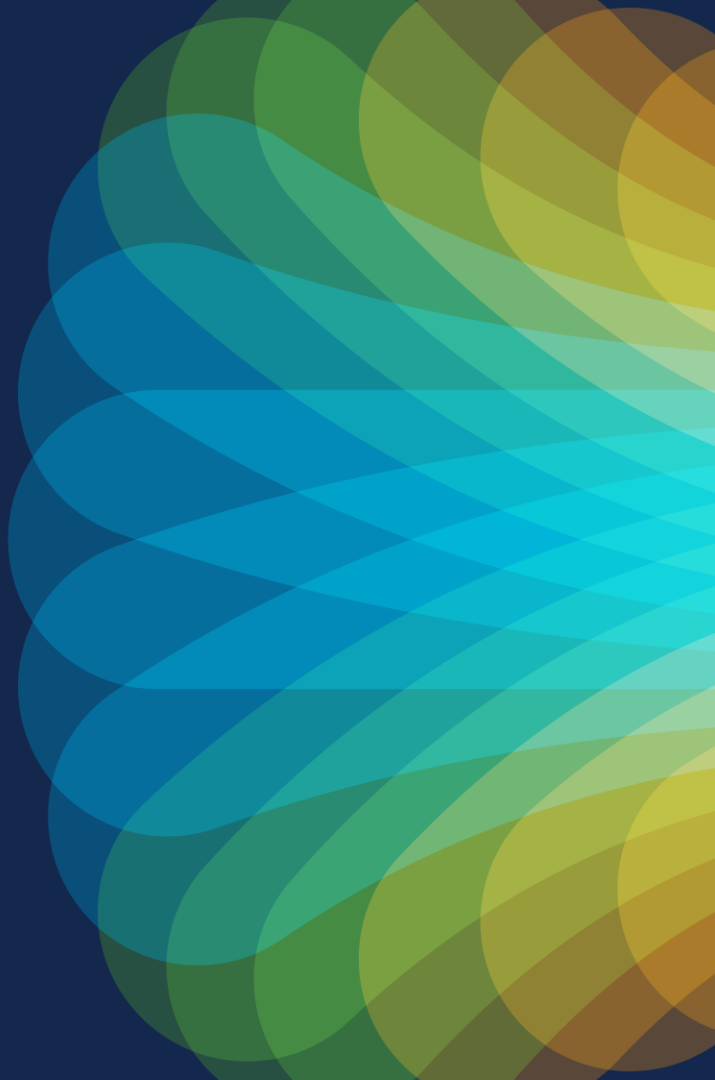
- 802.11ac Wave 2, MU-MIMO
- 3x3:3, 80 MHz, 1.3 Gbps (I)
- 2x2:2, 80 MHz, 867 Mbps (E/D)
- Internal or external antenna model
- Internal directional antenna model (D)
- SFP
- Flexible antenna ports
- Cisco CleanAir and ClientLink
- Centralized, FlexConnect, mesh, and Mobility Express

9124 Series* (Wi-Fi 6)

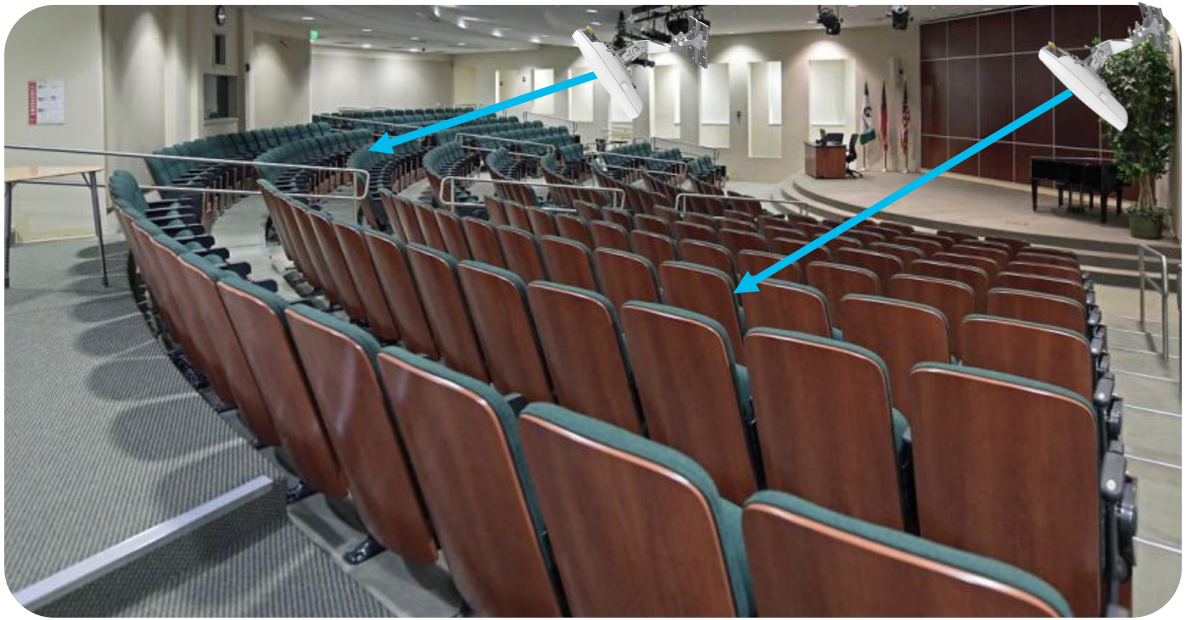
- 802.11AX, MU-MIMO, OFDMA
- 4x4 + 4x4:4
- Cisco RF ASIC for next-gen Cisco CleanAir
- IoT ready
- 1x 2.5G mGig
- SFP
- PoE-In 802.3af/at/bt
- DC power input (24 to 56 VDC)
- 1 Gbe PoE-Out
- 30 dBm Transmit Power(Same as 1572 and higher than 1562)
- Centralized, FlexConnect, Flex+Bridge**, Mesh**, and EWC**

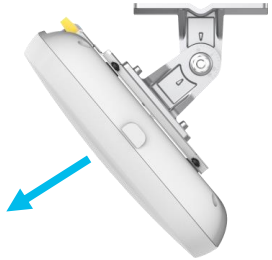
* C9124AXE-x unavailable until Summer calendar year 2021.
Catalyst 9124AXI-x and 9124AXD-x initially available in US and Canada only. Worldwide availability set for Summer calendar year 2021.
** Available second half 2021

Antenna Placement



Classrooms & Auditoriums



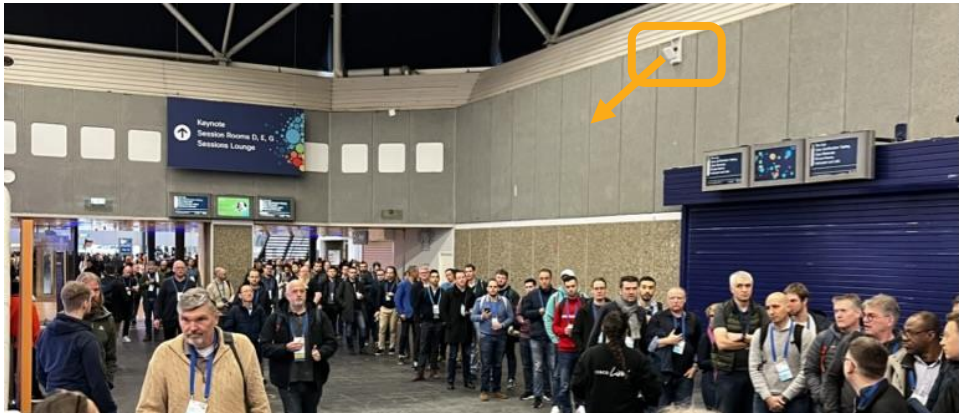


Directional antennas: more coverage cells in the same physical area, better control of the RF environment

Directional antennas strongly preferred over omnis

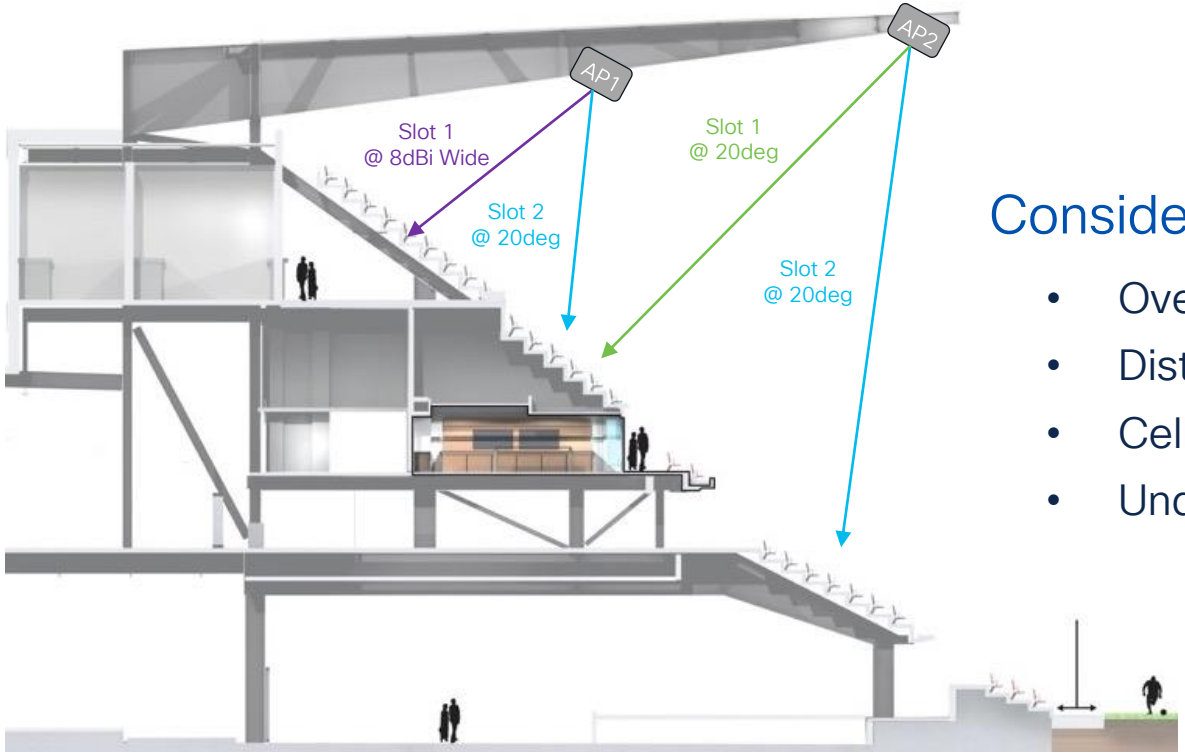
Conference Halls, Airports

High Density Open Areas – Conference Halls, Classrooms



- Omnis not preferred for open areas where high capacity is needed
- Create smaller cells with directional antennas mounted above, aimed directly downward
- Understand RRM implications of this type of design

Stadiums & Large Public Venues

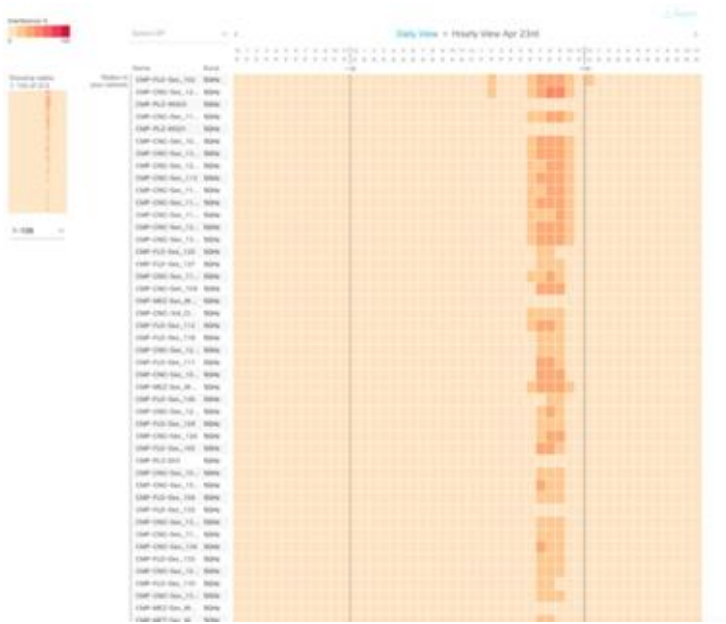


Consider:

- Overhead / Line-of-Sight
- Distance to Clients
- Cell Size & Overlap
- Under seat as backup option

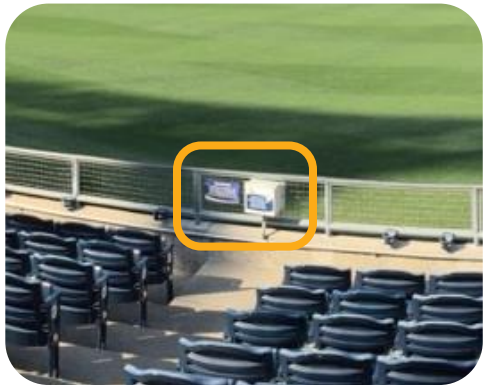
Performance Comparison

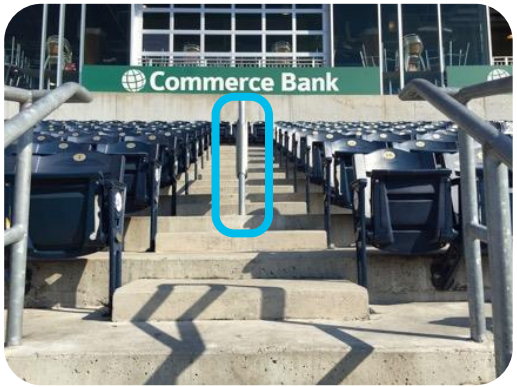
Under seat/Omni



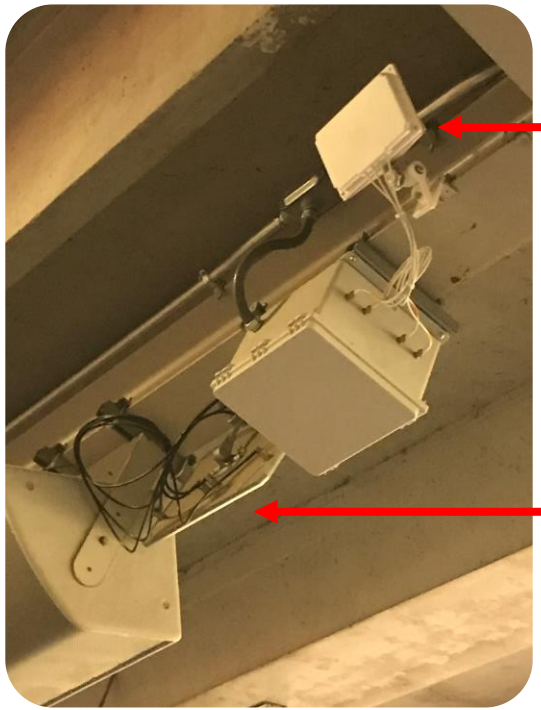
Overhead/Directional

Creative AP/Antenna Mount Examples





Multiple Coverage Areas with 1 AP



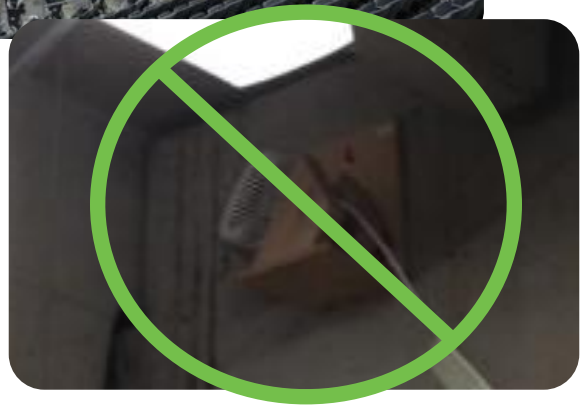
“Wide” Patch Antenna

“Narrow” High-Gain Antenna

Antenna Placement: What Not To Do

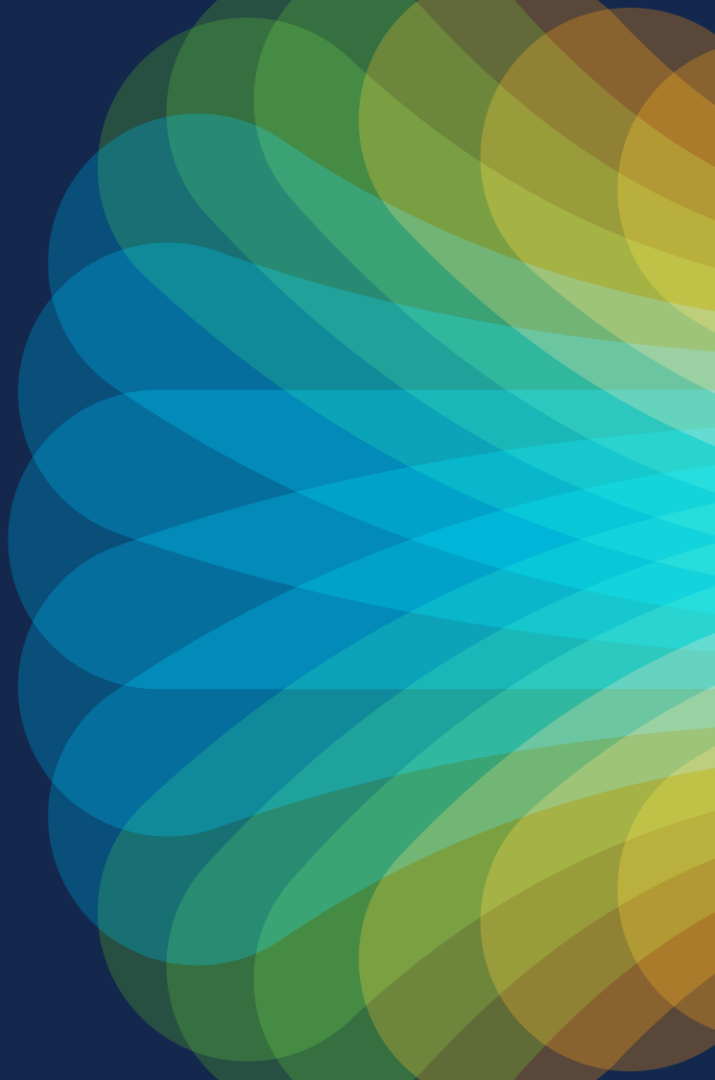
Challenging Areas

Avoid long-distance shots with poor angle of incidence / line of sight to each client



Avoid obstructions in front of your antennas

Wi-Fi 6E Deployment Considerations



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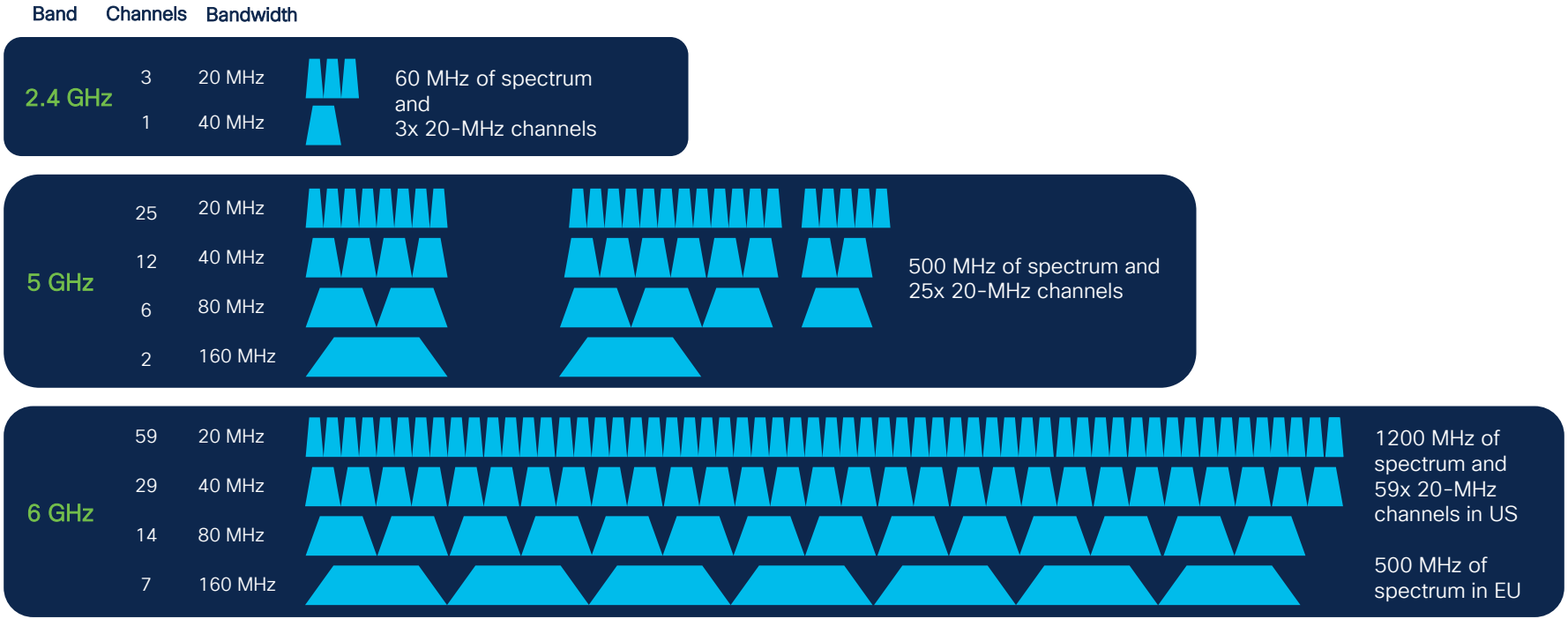
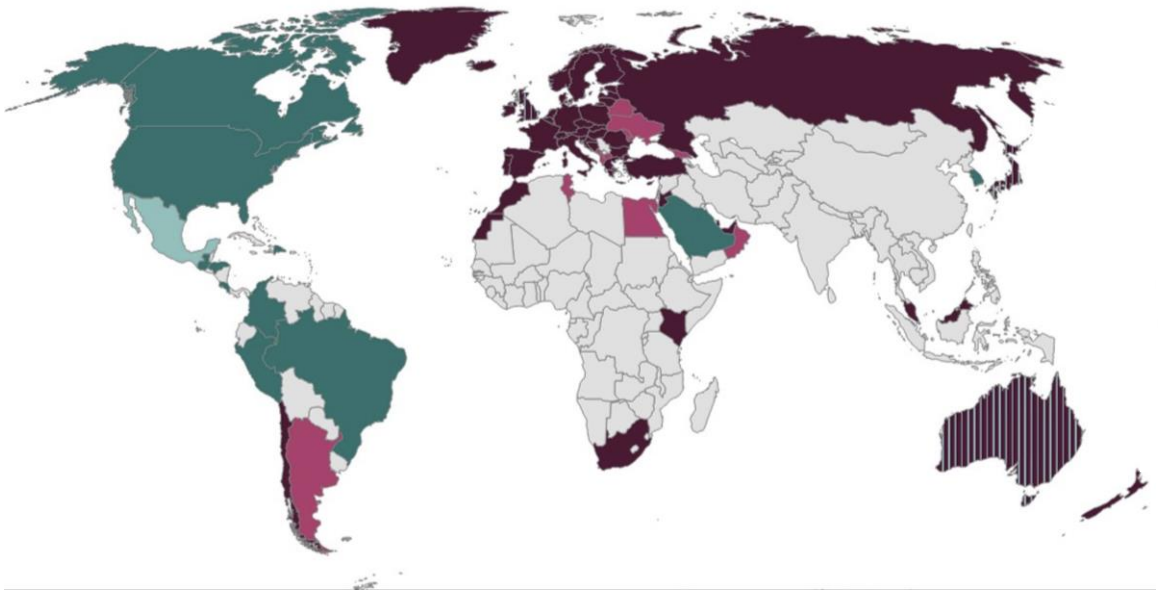
6 GHz is the biggest Wi-Fi spectrum expansion ever



6GHz Availability – A Global View



500MHz
Adopted 5925-6425 MHz

500MHz
Considering 5925-6425 MHz

1200MHz
Adopted 5925-7125 MHz

1200MHz
Considering 5925-7125 MHz

Adopted 5925-6425 MHz, 500MHz
Considering 6425-7125 MHz 1200MHz

https://www.wi-fi.org/countries-enabling-wi-fi-in-6-ghz-wi-fi-6e

Deploying and migrating to Wi-Fi 6E
Key Considerations

6GHz SSID Discovery

- Active Scanning is less practical – too many channels
- Reduced Neighbor Report announces 6GHz capable networks for passive detection
- Different device types discover 6GHz networks differently – testing is important

Examples:
- Google Pixel 6: https://www.jiribrejcha.net/2022/11/google-pixel-6-wi-fi-6e-scanning-and-6-ghz-ssid-discovery/
- iPad Pro: https://www.jiribrejcha.net/2022/11/ipad-pro-wi-fi-6e-scanning-and-6-ghz-ssid-discovery/

Security Requirements

- WPA3 is required for Wi-Fi 6E networks
- OpenRoaming can make the transition easier

6E Deep Dive:

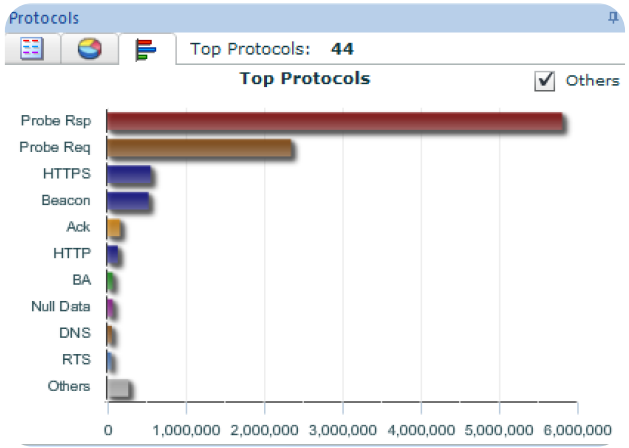
Wi-Fi 6E Glossary
RNR: Reduced Neighbor Report
FILS: Fast Initial Link Setup
PSC: Primary Scanning Channel

Maximize your Spectrum

- Limit SSIDs (reduce management traffic)
- Integrate existing networks
- Optimize PHY Rates
- Monitor Noise Floor & use power adjustments
- Remove barriers to entry

Maximizing the Spectrum

Avoiding Excessive Management Traffic

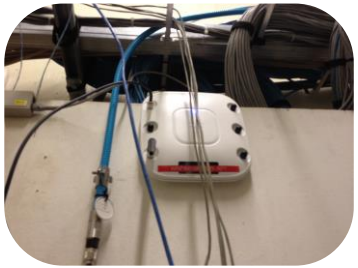


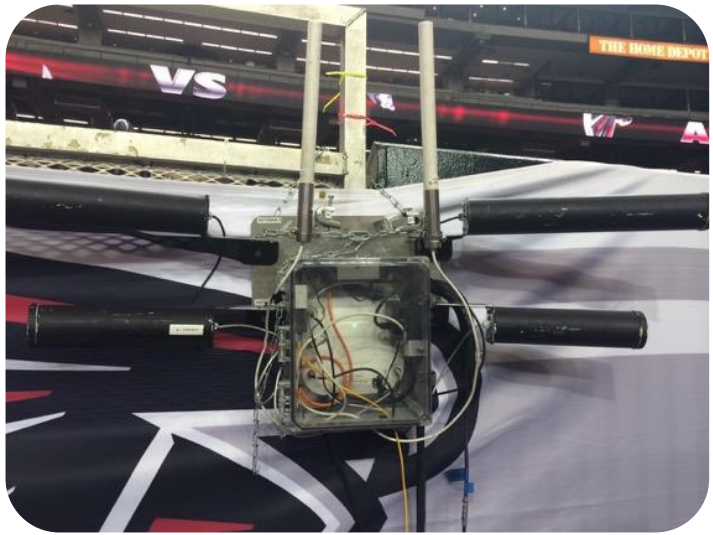
- Always aim for 1 SSID
  - Especially in high density areas
- More SSID's = Worse Performance
- Why?
  - Each SSID requires a separate beacon
  - Each SSID will beacon at the minimum mandatory data rate
  - Radios will respond to null probe requests for each broadcast SSID
  - Exponential amounts of airtime wasted!

Maximizing the Spectrum

Integrate Existing WLANs

- Common to see various existing WiFi deployments in venues
- Efficient HD WLANs are deployed holistically – one infrastructure
- Benefits?
  - Configuration consistency
  - Airtime efficiency
  - Legacy management traffic that once chewed up 30-40% of airtime typically drops to < 1% of airtime



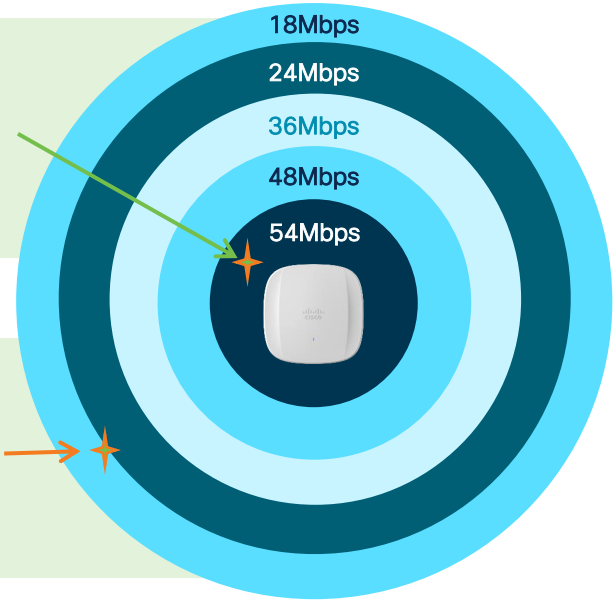


Maximizing the Spectrum

PHY Rate Tuning: Why PHY Rates Matter

Client near AP:
Higher PHY Rate
More Efficient
(high signal-to-noise ratio)

Client far from AP:
Lower PHY Rate
Less Efficient
(lower signal-to-noise ratio)

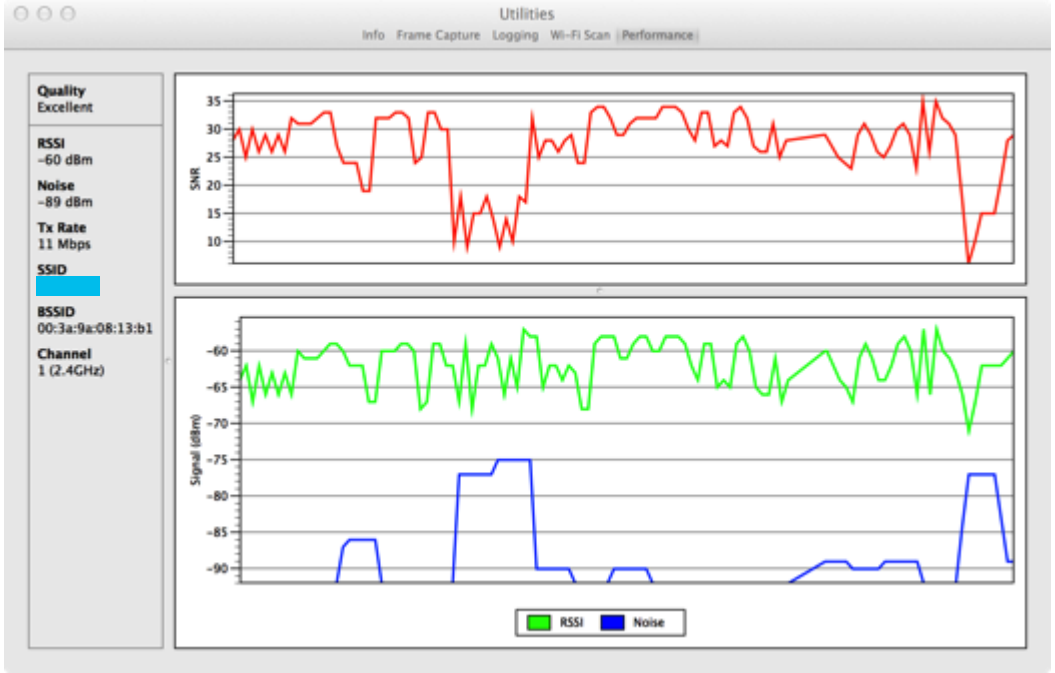


- Tune your Minimum Mandatory and Supported data rates to optimize airtime
- Higher rates require higher SNR – don't be too aggressive
- Leave 1 or 2 rates below your Minimum Mandatory rate as "supported" to provide a "soft landing" and allow some SNR flexibility
- Generally, no need to adjust MCS rates (client compatibility)
- Common starting points (5ghz): 18mbps Minimum Mandatory, 12mbps Supported, <12 disabled, >18 Supported

Maximizing the Spectrum

RSSI vs. SNR

- Check your noise floor in each band during peak usage
  - Packet captures with a NIC that you trust (MacBook Pro, etc.)
  - Fluke AirCheck
  - Spectrum Expert
  - Metageek Chanalyzer for Clean Air



Maximizing the Spectrum

Ease-of-Use & Client Induced Interference

- Ask yourself - how difficult is it to get on your WiFi network?
- Ease-of-use directly impacts airtime efficiency
- Low take rate = lots of probe request noise (1mb, max power, all channels)
  - Results in Client Induced Interference
- A device on the network is far less damaging than a device off the network!
- Make captive portals easy, implement OpenRoaming, etc.

Agenda

- Designing RF for High Client Densities
- HD Wi-Fi Configuration Tips
- HD Wi-Fi Engineering Toolkit

Josh Learns Things The Hard Way

...or, everybody has a plan until you're 40 years old and changing your first diaper

1) I was **overconfident**
2) I didn't **read the manual**!

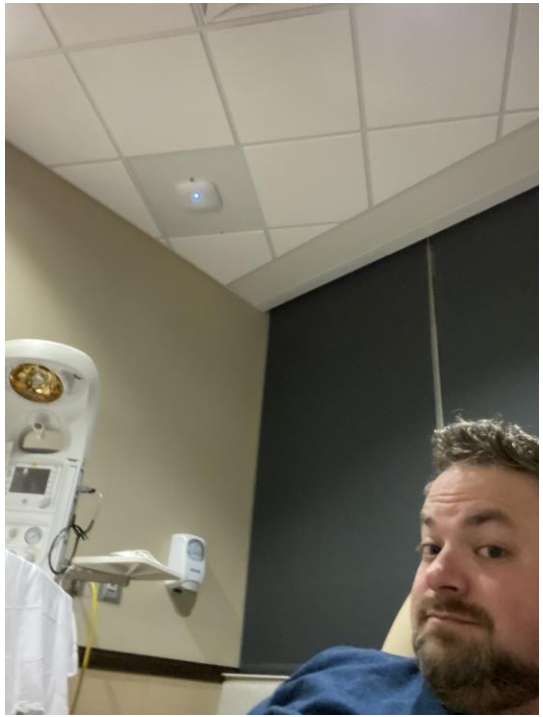
Fast forward to 6 years later...

Surprise!

This time, I decided to read the “manual(s)”…

Surprise!

The big day...



The big day...

The big day...

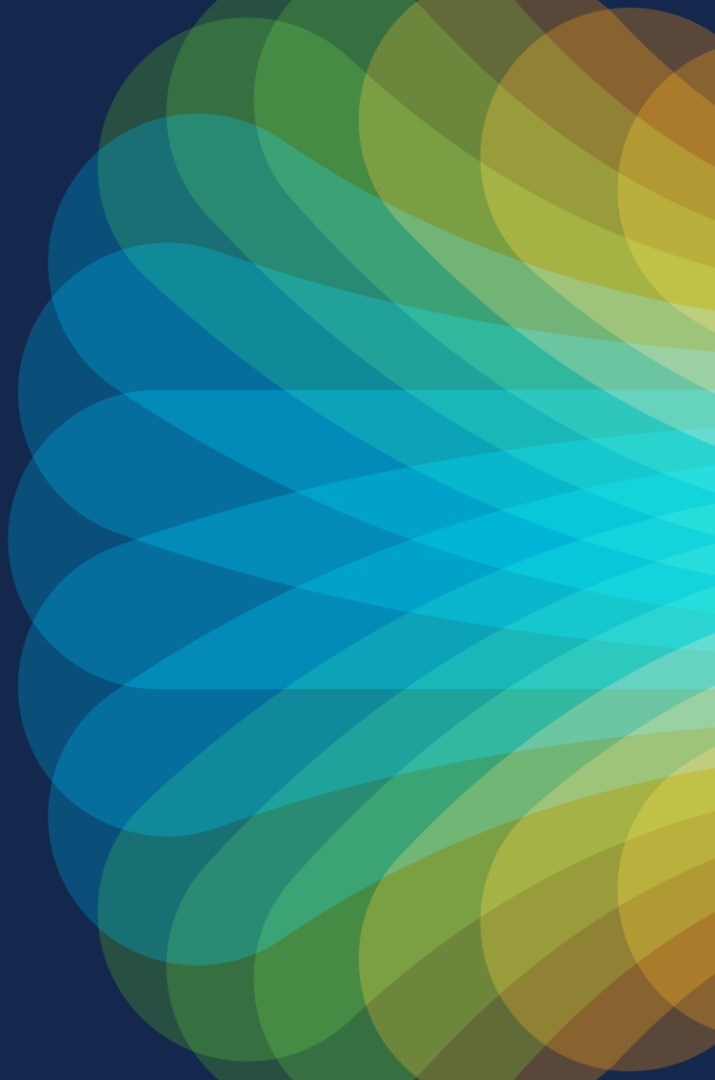
The books were great, but...

Total panic!

There is no better teacher than real life experience ☺

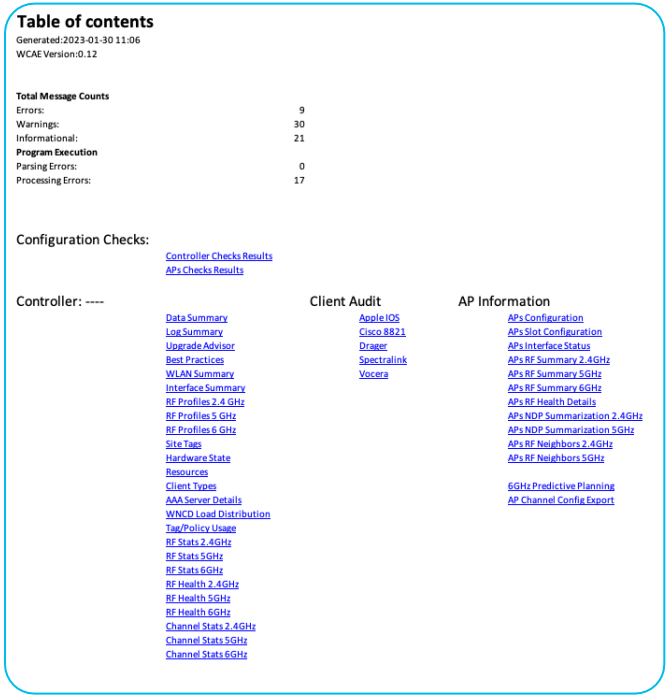
Now for some of our hard-learned experiences…

The Basics: RF Profiles, TPC, DCA



First – a handy (free!) tool: WCAE

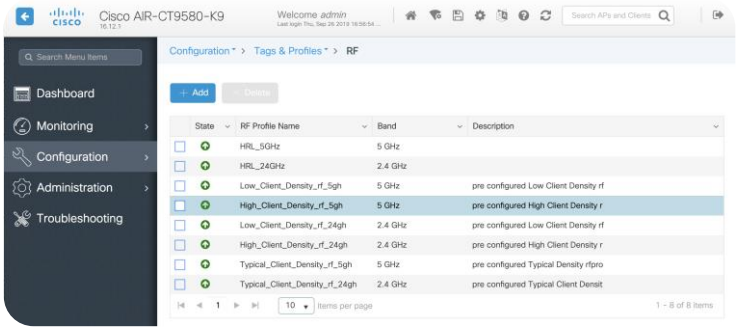
- **Wireless Config Analyzer Express** (WCAE) is an extremely valuable tool when validating and optimizing a Cisco Wi-Fi deployment
- Feed your WLC config output to WCAE and it will help you:
  - Find and troubleshoot problems quickly
  - Identify top areas for RF optimization
  - Check configs against best practices
  - RRM overview with the RF Summary

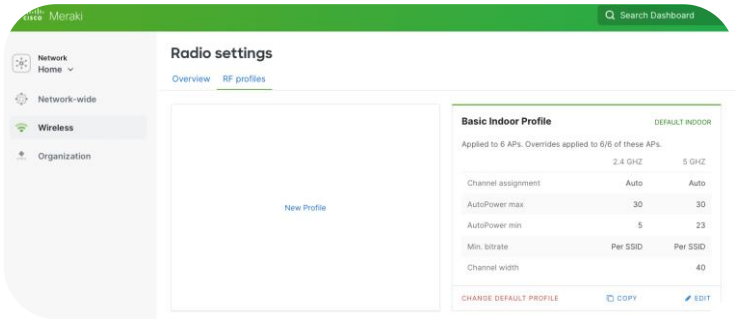


Download: https://developer.cisco.com/docs/wireless-troubleshooting-tools/

More info: Cisco Live US 2022 – BRKEWN-3006

High Density WLAN Features & Configurations

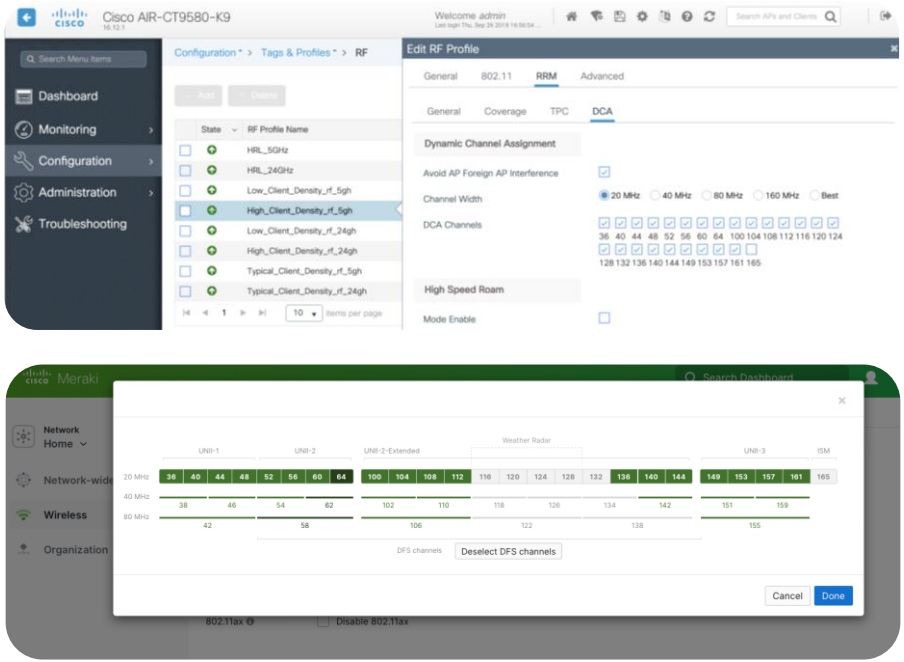




- WiFi deployments **are not "one-size-fits-all"**
- **Use RF Profiles** on both Catalyst and Meraki deployments for granular RF control
  - **Configure network-wide channel parameters:** remove channels as needed, set channel widths
  - **Configure transmit power min/max:** ensure balance, avoid "client magnets"
  - **Configure RX-SOP thresholds** to selectively reduce radio sensitivity where needed
- On C9800, **plan Site Tags** to balance APs across processes

Channel Planning with RF Profiles

- Plan channels with Dynamic Channel Allocation (Catalyst) or AutoChannel (Meraki) via RF Profile
- If needed – **eliminate unusable channels** for business-critical areas (DFS, etc)
- Reserve channels for use by other systems



Catalyst Tip: Identifying Potentially Unhealthy Channels

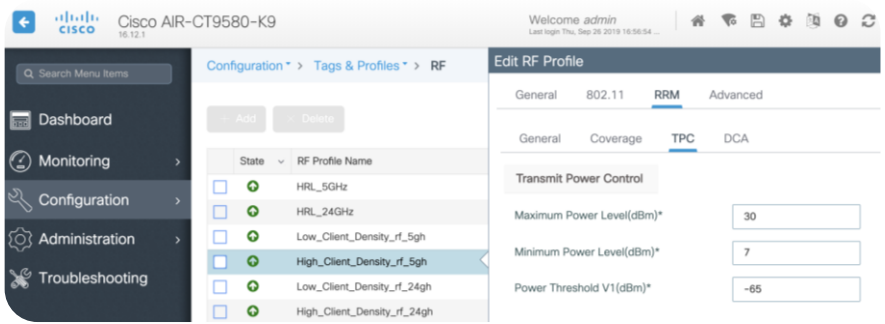
WCAE – 'APs RF Summary' tab – "High Channel Changes" column

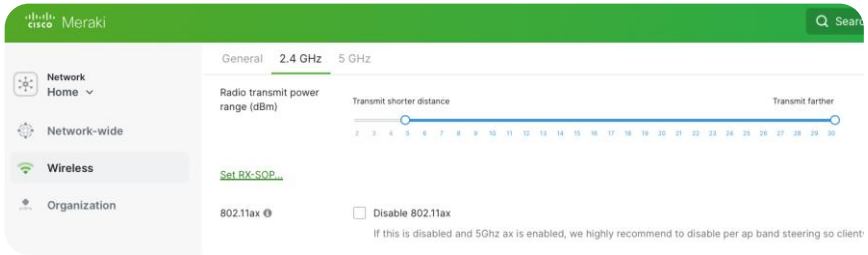
C	D	G	H	I	J	K	L	M	N	O	V
Model	Mode	Chann	TX Pow	TX Power dB	Total Clients	RX SOP	CH Util%	CH TX Util%	CH RX Util%	Channel Changes	High Channel Chang
C9130AXI-B	Client Serving	108	3	9	18	medium(-78)	50	3		18	Yes
C9130AXI-B	Client Serving	140	2	12	8	medium(-78)	73	50		20	Yes
C9130AXI-B	Client Serving	52	2	11	17	medium(-78)	46	5		20	Yes
C9130AXI-B	Client Serving	64	2	11	4	medium(-78)	11	0		25	Yes
C9130AXI-B	Client Serving	100	3	9	12	medium(-78)	49	2		30	Yes
C9130AXI-B	Client Serving	44	5	9	7	medium(-78)	47	8		23	Yes
C9130AXI-B	Client Serving	100	3	9	13	medium(-78)	38	7		19	Yes
C9130AXI-B	Client Serving	56	2	11	22	medium(-78)	46	17		28	Yes
C9130AXI-B	Client Serving	132	3	9	14	medium(-78)	37	8		32	Yes
C9130AXI-B	Client Serving	52	2	11	15	medium(-78)	45	1		18	Yes
C9130AXI-B	Client Serving	56	2	11	23	medium(-78)	42	7	1	25	Yes
C9130AXI-B	Client Serving	116	3	9	9	medium(-78)	24	3		22	Yes
C9130AXE-B	Client Serving	52	2	15	0	medium(-78)	2	0		19	Yes
C9130AXE-B	Client Serving	36	2	19	0	medium(-78)	1	0		20	Yes
C9130AXE-B	Client Serving	56	2	15	0	medium(-78)	1	0		30	Yes
C9130AXE-B	Client Serving	149	2	20	0	medium(-78)	2	0		22	Yes
C9130AXE-B	Client Serving	124	2	15	88	medium(-78)	78	19	1	70	Yes
C9130AXE-B	Client Serving	48	2	20	0	medium(-78)	2	0		66	Yes
C9130AXE-B	Client Serving	36	2	19	0	medium(-78)	2	0		19	Yes
C9130AXE-B	Client Serving	44	2	20	0	medium(-78)	2	0		21	Yes
C9130AXE-B	Client Serving	108	2	15	0	medium(-78)	1	0		25	Yes
C9130AXE-B	Client Serving	149	2	20	0	medium(-78)	1	0	0	21	Yes

"High Channel Change: Yes" triggered for radios with more than 4 channel changes per day

Balancing Transmit Power with RF Profiles

- **TPC** (Catalyst) and **AutoPower** (Meraki)
- **Ensures AP-to-AP consistency** (no “client magnets”) and 2.4GHz to 5GHz balance (5GHz hotter, 2.4GHz cooler)
- **TPC/AutoPower Min** – lower power limit specified for a given radio. TPC/AutoPower will never adjust power below this level.
- **TPC/AutoPower Max** – upper power limit specified for a given radio. TPC/AutoPower will never adjust power above this level.





Identifying Possible Power Imbalance

WCAE – 'APs RF Summary' tab – "TX Power dBm" and "Total Clients" columns

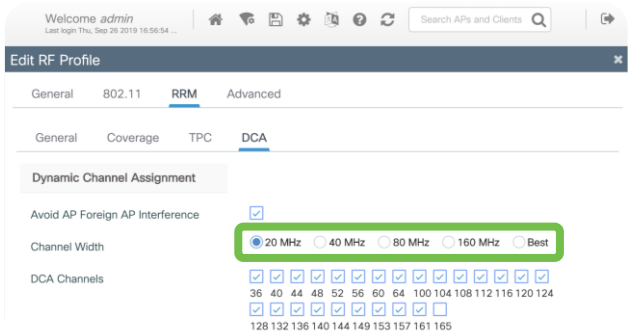
Name	Slot	Band	Channel	TX Power	TX Power dBm	Total Clients
AP1	1	5	100	1	17	21
AP1	2	5	48	1	23	70

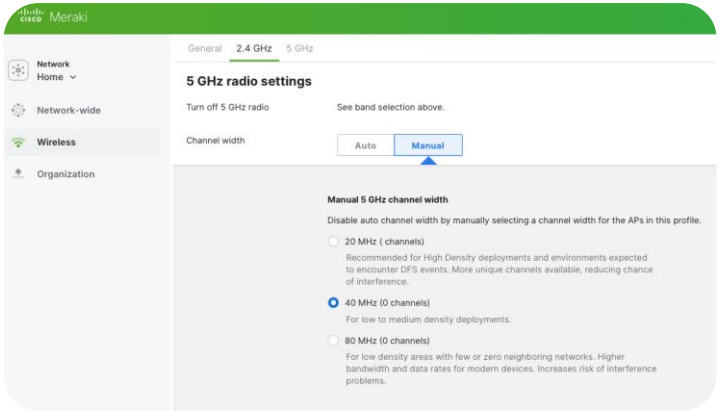
6dB power difference = client imbalance

Refer to AP power tables to determine max TX power per UNII band

Use "show controller" on a sample AP for all details

Selecting Channel Width with RF Profiles





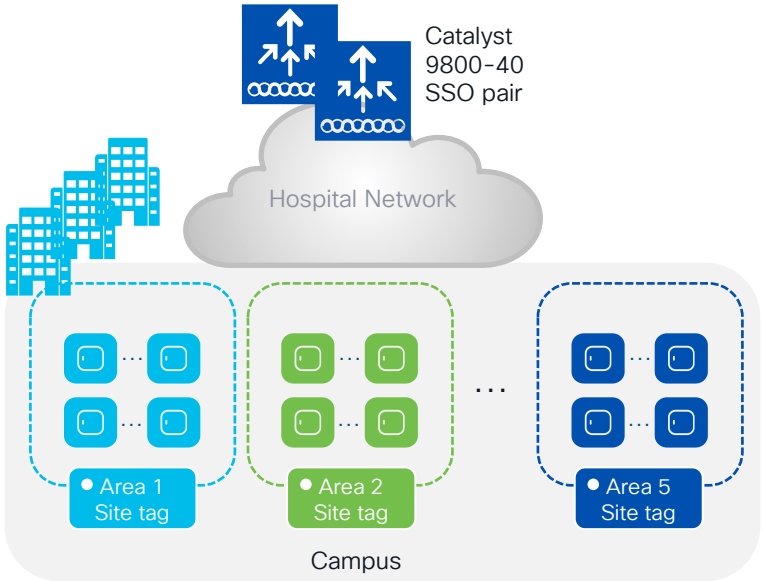
5GHz

- In general, **20MHz channels** provide the most channel reuse (capacity) for high density environments
- **Wider channels may be used selectively** in more isolated areas – smaller classrooms, lobbies, conference rooms, etc.

6GHz

- Heavily dependent on regulatory domain
- Note! Higher channel width results in higher max Tx power for data frames (but not beacons – remember when surveying!)

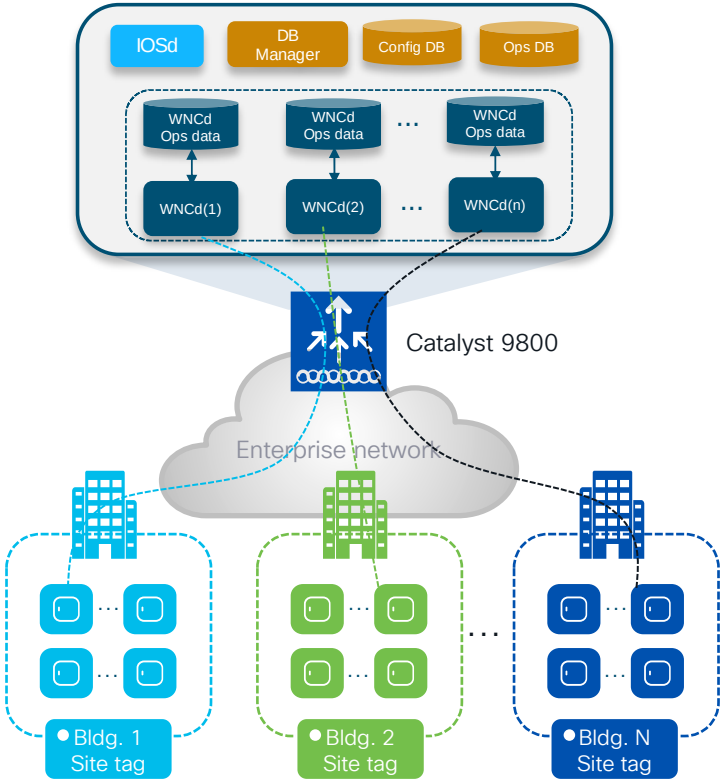
C9800 Site Tag Design in High Density



- Custom Site Tags deterministically distribute APs across C9800 processes, aka “WNCd’s”
- Always use Custom Site Tags – not Default – to ensure load is balanced in a predictable way
- 500 APs per Site Tag is the rule of thumb, BUT…
- Platform limits on AP count per Site Tag will differ from “ideal limits” in High Density / High Roam frequency environments
- Recommended AP count per Site Tag will vary based on the environment
  - Consider roaming patterns and minimize roaming between Site Tags

Refer to the C9800 Best Practices guide for the latest guidance

Site Tags – Design considerations



Important facts:

- Distributing APs (and clients) across custom Site Tags (and thus WNCd's) gives better scale and performance
- In large public venues, avoid having more Site Tags than # of WNCd's
- The number of WNCd varies from platform to platform:

Platform	# of WNCD instances
EWC (on AP or C9k switch)	1
C9800-L	1
C9800-CL (small)	1
C9800-CL (medium)	3
C9800-40	5
C9800-CL (large)	7
C9800-80	8

Refer to the C9800 Best Practices guide for the latest guidance

The following command shows the # of WNCDs processes:

```
9800#sh processes platform | inc wncd
```

Site Tag Limitations

Platform	Maximum number of APs per site tag*
C9800-80, C9800-CL (medium and large)	1600
C9800-40	800
Any other C9800 platform	Equal to the maximum number of APs supported

Platform	Recommended number of site tags
C9800-80	8 or a multiple (16, 24, ...)
C9800-CL (large)	7 or a multiple (14, 21,..)
C9800-40	5 or a multiple (10, 15, ...)
C9800-CL (medium)	3 or a multiple (6, 9, ...)

Always refer to the C9800 Best Practices guide for the latest guidance

Helpful Site Tag Monitoring Commands

show wireless stats ap loadbalance summary
- Shows summary of APs assigned to each WNCd

```
[redacted]#show wireless stats ap loadbalance summary
DTLS drop - 380

WNCD            APs Discovered  APs Joined      APs Timedout
-------------------------------------------------------------
0               179             179             8715
```

show wireless loadbalance tag affinity wncd <wncd-number>
- Shows which site tags are assigned to each WNCd

```
[redacted]#show wireless loadbalance tag affinity wncd 0
Tag                             Tag type                    No of AP's Joined
-------------------------------------------------------------------------------
[redacted]                      SITE TAG                    177
[redacted]                      SITE TAG                    1
```

Other 9800 Tips: L2/L3

On 9800's - **Don't assign an IP Address to SVI's** without good reason!
(Can quickly overwhelm upstream L3 hops)

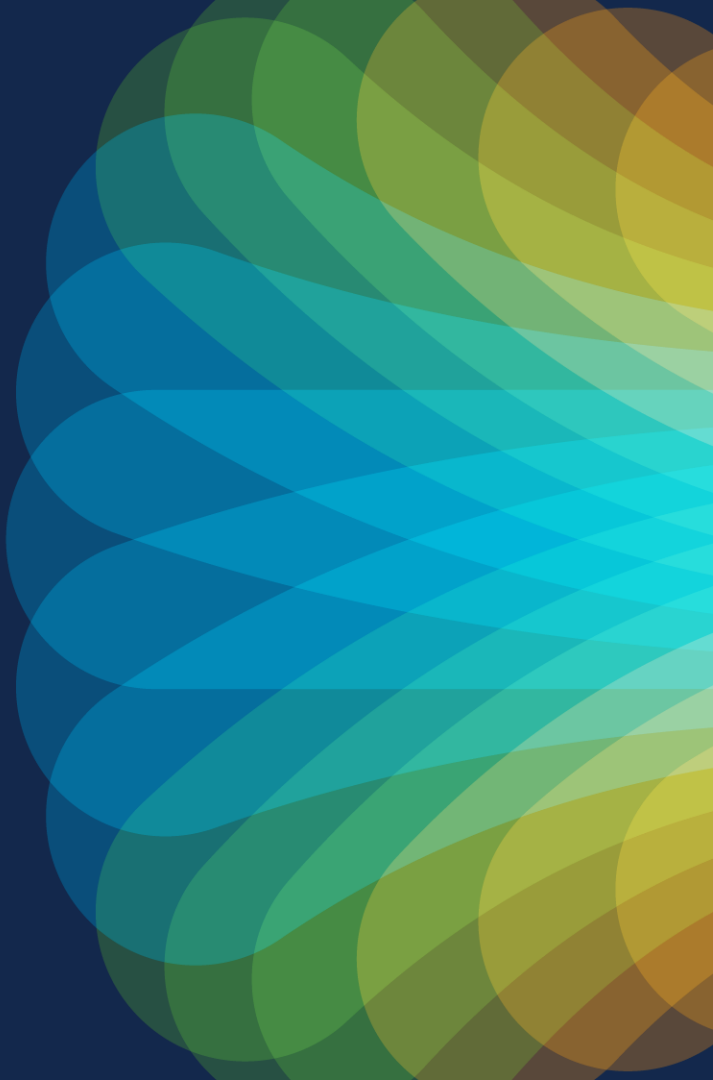
Primary reasons you may need an SVI:

- mDNS
- DHCP Relay (uncommon in High Density)

If you need an SVI - plan Layer 3 scale upstream accordingly!

https://www.cisco.com/c/en/us/products/collateral/wireless/catalyst-9800-series-wireless-controllers/guide-c07-743627.html

The (Not So) Secret High Density Weapon: RX-SOP



cisco Live!

Receive Sensitivity Threshold (RX-SOP)

What if…

I put AP's wherever I needed them…
I used all the right antennas…
I surveyed and optimized and surveyed and optimized again…

…but my Channel Utilization is still really high, with almost no "real" traffic?

Vendor	Signal	Noise	SNR	Channel	Channel Utilization	Clients
Cisco Sys…	-85 dBm	-96 dBm	11 dB	48	90%	
Cisco Sys…	-70 dBm	-96 dBm	26 dB	153	89%	
Cisco Sys…	-74 dBm	-96 dBm	22 dB	153	89%	7
Cisco Sys…	-74 dBm	-96 dBm	22 dB	153	89%	
Cisco Sys…	-74 dBm	-96 dBm	22 dB	153	89%	
Cisco Sys…	-90 dBm	-96 dBm	6 dB	144	87%	
Cisco Sys…	-78 dBm	-96 dBm	18 dB	157	86%	2
Cisco Sys…	-64 dBm	-96 dBm	32 dB	1	84%	
Cisco Sys…	-70 dBm	-96 dBm	26 dB	153	82%	
Cisco Sys…	-76 dBm	-96 dBm	20 dB	153	80%	
Cisco Sys…	-86 dBm	-96 dBm	10 dB	161	80%	
Cisco Sys…	-80 dBm	-96 dBm	16 dB	153	80%	
Cisco Sys…	-64 dBm	-96 dBm	32 dB	44	79%	3
Cisco Sys…	-62 dBm	-96 dBm	34 dB	44	79%	
Cisco Sys…	-64 dBm	-96 dBm	32 dB	44	79%	2
Cisco Sys…	-80 dBm	-96 dBm	16 dB	153	78%	
Cisco Sys…	-74 dBm	-96 dBm	22 dB	153	77%	
Cisco Sys…	-70 dBm	-96 dBm	26 dB	153	76%	
Cisco Sys…	-80 dBm	-96 dBm	16 dB	153	76%	
Cisco Sys…	-80 dBm	-96 dBm	16 dB	153	76%	
Cisco Sys…	-80 dBm	-96 dBm	16 dB	153	76%	
Cisco Sys…	-70 dBm	-96 dBm	26 dB	153	76%	
Cisco Sys…	-80 dBm	-96 dBm	16 dB	153	75%	
Cisco Sys…	-78 dBm	-96 dBm	18 dB	153	75%	
Cisco Sys…	-78 dBm	-96 dBm	18 dB	153	74%	2

Receive Sensitivity Threshold (RX-SOP)

What does it do?

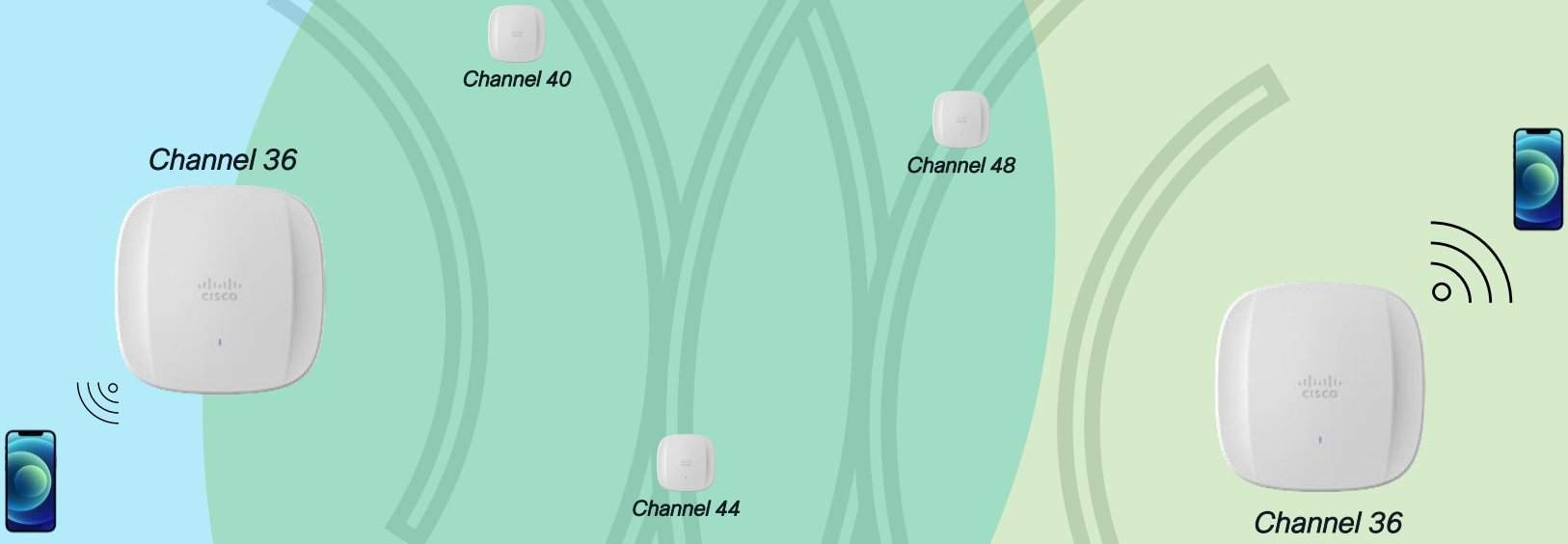
Reduces “receive” sensitivity of the AP to a pre-determined power level

> Example: ignore everything coming into the radio at lower than -80dBm, because those devices are unlikely to be in our cell

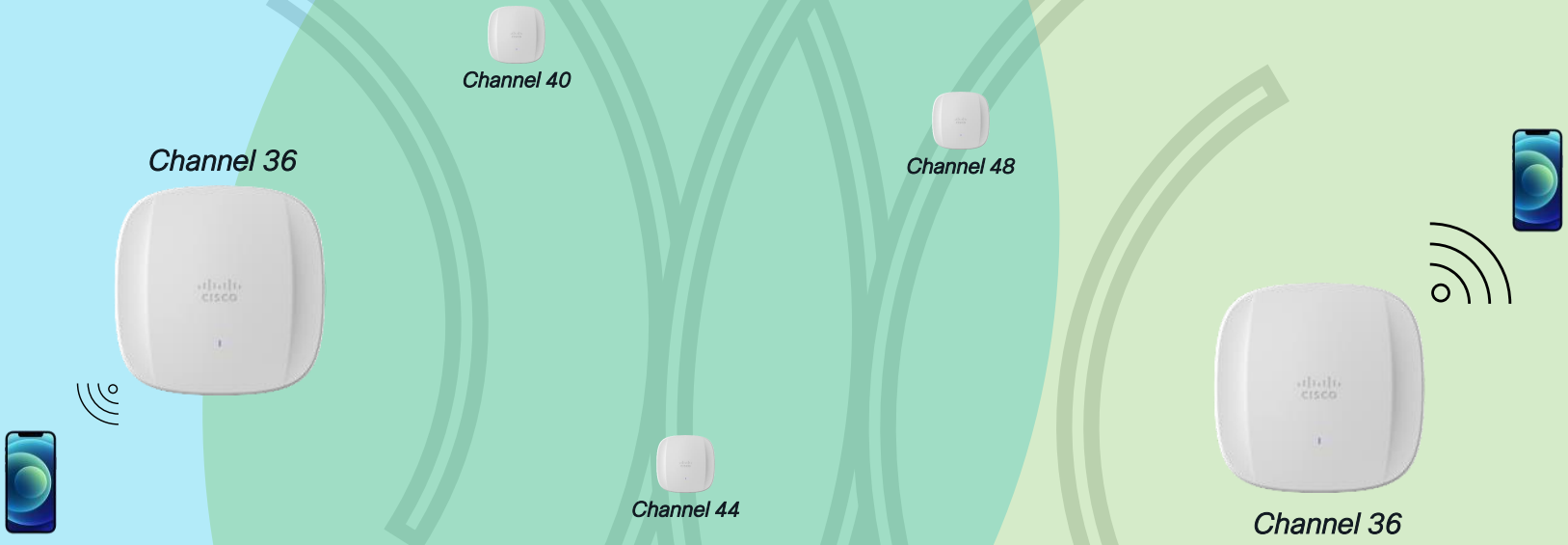
Why is it helpful?

Allows us to transmit more often to clients in our intended cell

- *802.11 is a “polite” protocol*



- *802.11 is a “polite” protocol*
- *I must listen before I start to talk - I will not talk until it’s “quiet” on my channel*



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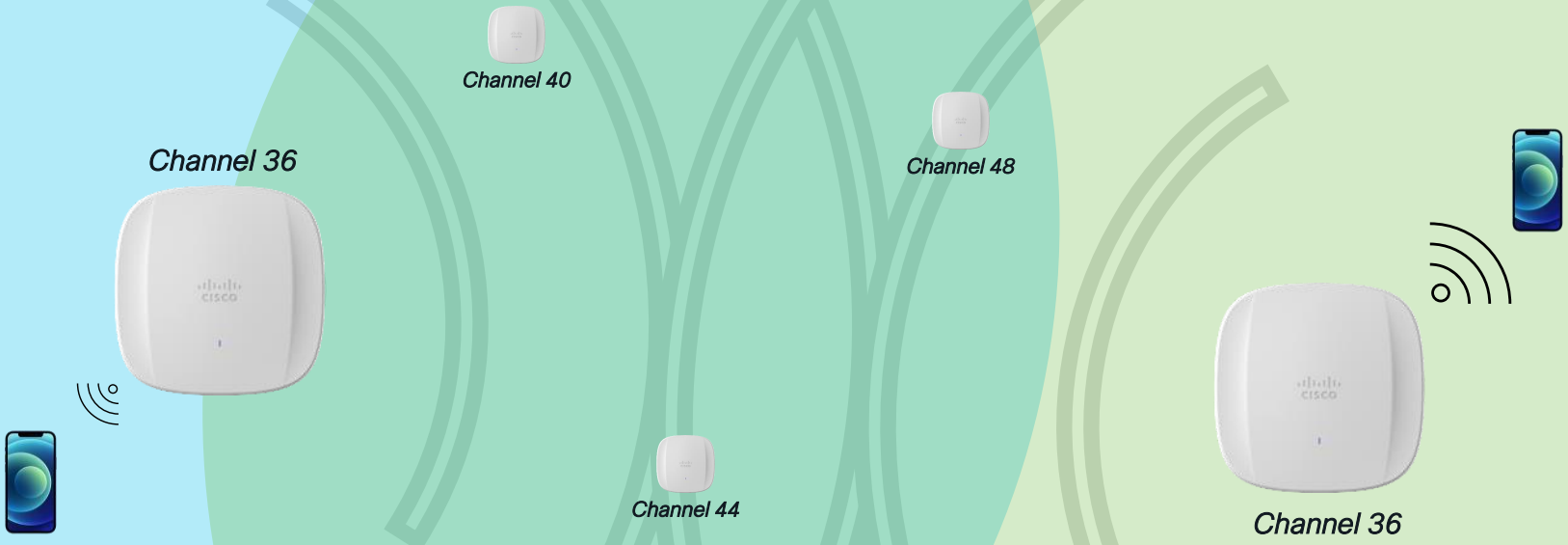
- *In dense deployments, you <u>will</u> have co-channel AP’s in range of each other*



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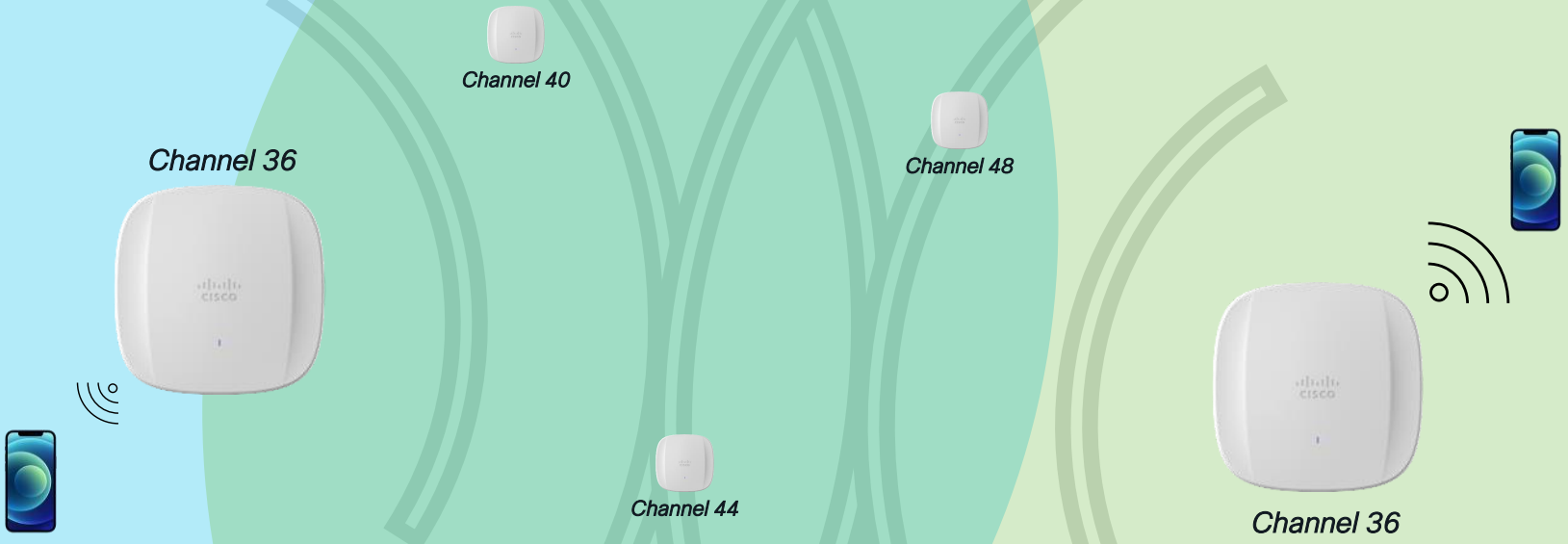
- *I must listen before I start to talk - I will not talk until it’s “quiet” on my channel*
- *In dense deployments, you <u>will</u> have co-channel AP’s in range of each other*
- *RX-SOP optimization helps us tune out the <u>most distant</u> co-channel transmissions*



Receive Sensitivity Threshold (RX-SOP)

- Be careful and make small adjustments
  - Generally, start in the -80's

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- **Be careful and make small adjustments**
  - Generally, start in the -80's
- Remember – adjusting the RX-SOP threshold **doesn't impact the actual RF energy on the channel**, but it does impact APs' sensitivity to it
  - High Channel Utilization still affects all clients

Receive Sensitivity Threshold (RX-SOP)

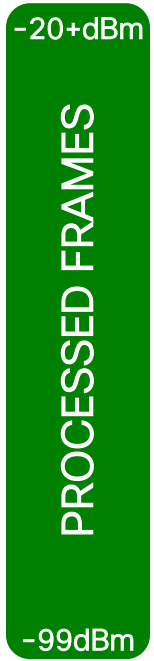
- **Be careful and make small adjustments**
  - Generally, start in the -80's
- Remember – adjusting the RX-SOP threshold **doesn't impact the actual RF energy on the channel**, but it does impact APs' sensitivity to it
  - High Channel Utilization still affects all clients
- **WiFi6, WiFi6E, and/or use of C9104 may reduce the need for RX-SOP** in some environments; continue to monitor your Channel Utilization and adjust as needed

Receive Sensitivity Threshold (RX-SOP)

Without Custom RX-SOP Threshold

(Default / “Auto” Radio Sensitivity)

Radio processes everything that it can hear – any frame with enough SNR



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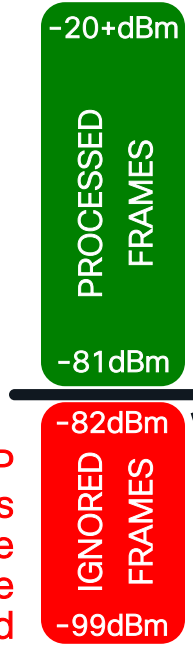
With Custom RX-SOP Threshold



The AP radio processes *only* the frames heard above the threshold

Frames where SOP (start of packet) is heard below the threshold are ignored

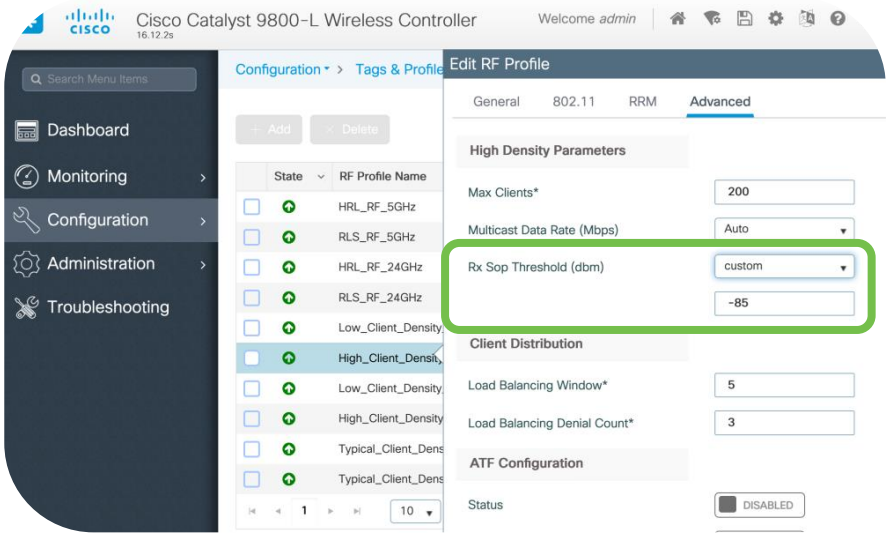
-82dBm RX-SOP Threshold

Ignored frames are now considered “Noise” and I can talk over them

HOW TO: Optimize RX-SOP Thresholds

1. Choose client devices and representative areas to test
2. Create a temporary SSID on one AP in the test area so your client doesn't roam
   (see hidden slides for tips on AireOS / 9800)
3. Monitor the AP's view of test clients throughout the cell
   (from WLC UI, WLC CLI, or AP CLI)
4. Pad the worst reading by another 15dB or more = initial RX-SOP threshold

Example: Worst AP-observed RSSI value is -72; initial RXSOP threshold with 15dB cushion = -87 (or higher)



HOW TO: Optimize RX-SOP Thresholds (9800)

1. Pick the client device(s) you want to test
2. Pick the representative area(s) you want to test
3. Create a new temporary WLAN and Policy Tag
4. Assign the Policy Tag to the test AP
5. Join your client device(s) to the new SSID and monitor how the AP hears your client(s) (from AP CLI – “show controller d 1 client <mac-addr>”)
6. Test for “worst case scenario” – bodies between device and AP, furthest corner of the cell, etc. Continually check RSSI from AP side.
7. Take your “worst” RSSI value, add a 10-15dB cushion, and use that as your initial RXSOP threshold for that cell type (set in RF Tag)

Example: Worst RSSI value is -72; initial RXSOP with 15dB cushion = -87

Review: How AP's Hear Clients

For a detail on a single client, at AP CLI:

Telnet/SSH to AP and use "show controller d <0|1> client <mac-addr>" for immediate client RSSI readings of a single client

```
10#sho controller d 1 client FC:F8:AE:60:98:34
<clip>
Additional info for client FC:F8:AE:60:98:34
RSSI: -47
<clip>
Statistics for client FC:F8:AE:60:98:34
mac                 <clip> stats_ago expiration
FC:F8:AE:60:98:34   <clip>  0.700000         0
```

How long ago were these stats updated (in sec)?

HOW TO: Optimize RX-SOP Thresholds (AireOS)

1. Pick the **client device**(s) you want to test
2. Pick the **representative area(s)** you want to test
3. **Create a new temporary SSID and a new AP Group**
4. **Add the AP's you want to test** to the new AP group
5. **Join your client device(s) to the new SSID** and monitor how the AP hears your client(s) (from AP CLI – "show controller d 1 client <mac-addr>")
6. **Test for "worst case scenario"** – bodies between device and AP, furthest corner of the cell, etc. Continually check RSSI from AP side.
7. Take your "worst" RSSI value, add a 10-15dB cushion, and use that as your **initial RXSOP threshold** for that cell type

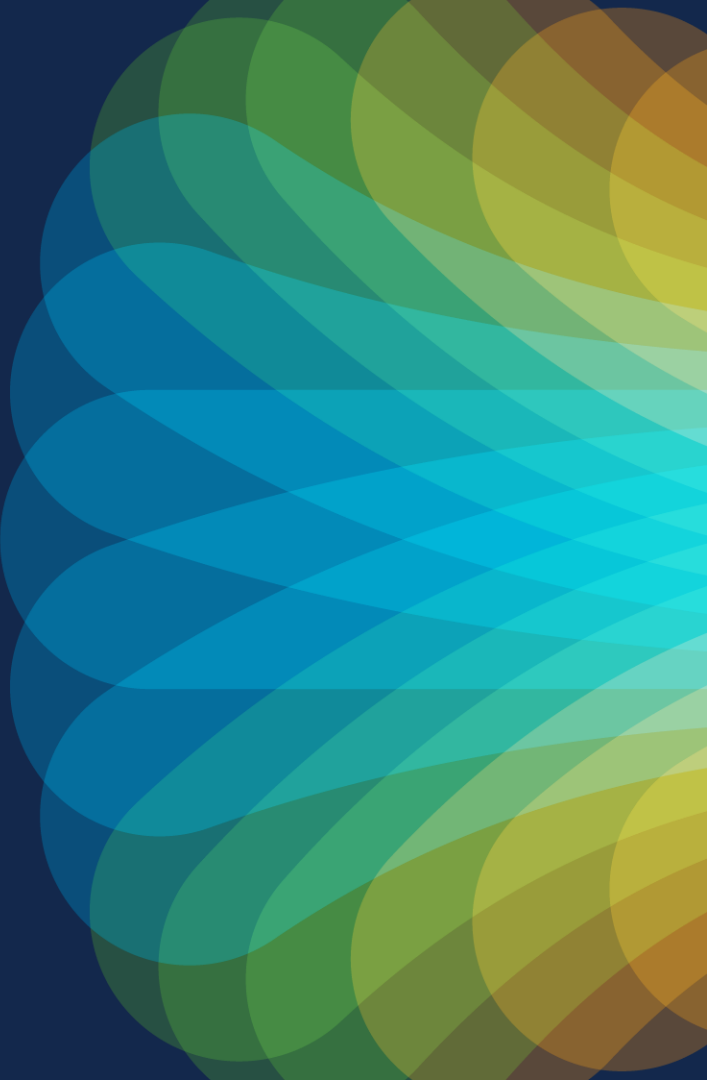
Example: Worst RSSI value is -72; initial RXSOP with 15dB cushion = -87

HOW TO: Optimize RX-SOP Thresholds

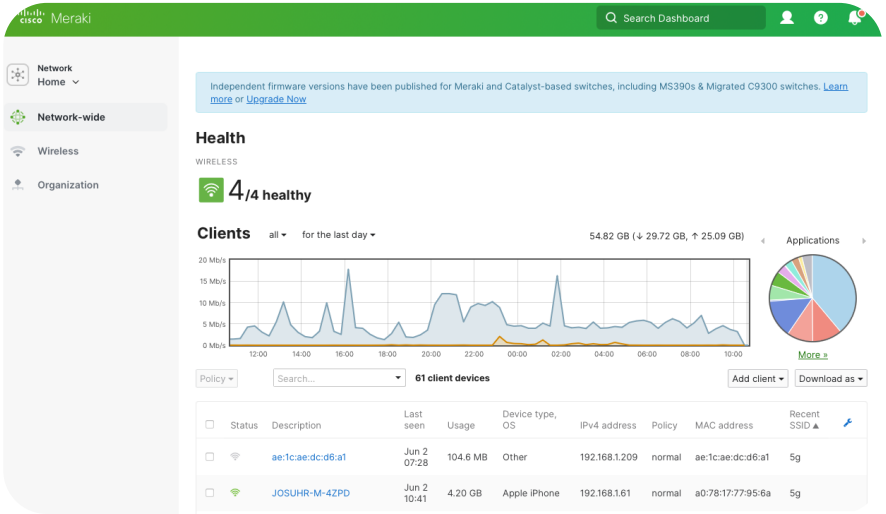
A key takeaway:

Be **conservative** and make **small adjustments**!

Cloud-Managed High Density



Cloud-Managed High Density



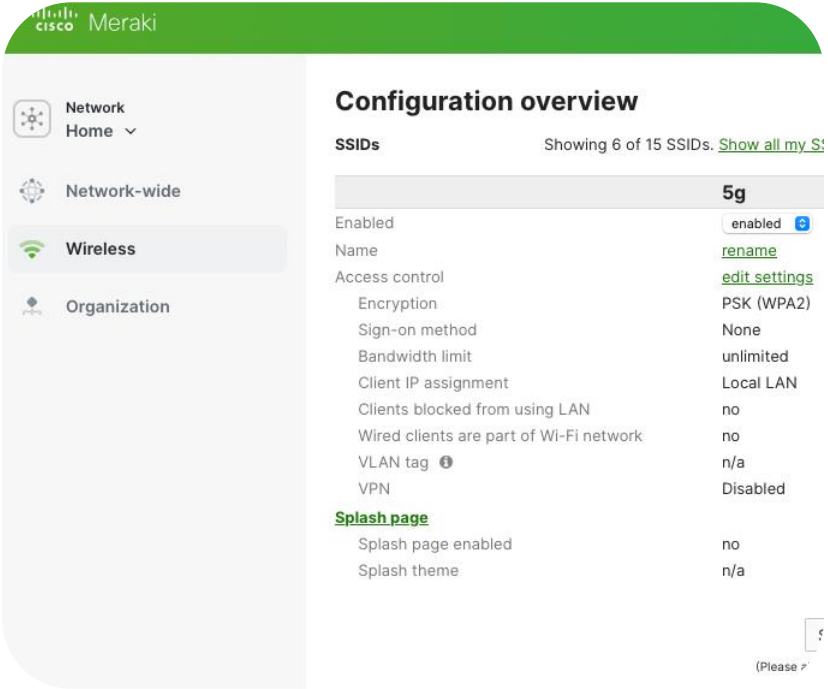
Can be ideal for:

- Classrooms
- Theaters & Auditoriums
- Hotspots

Be aware of:

- Switched Network Capacity (L2 / L3)
- Roaming Domains & Expected Roaming Experience

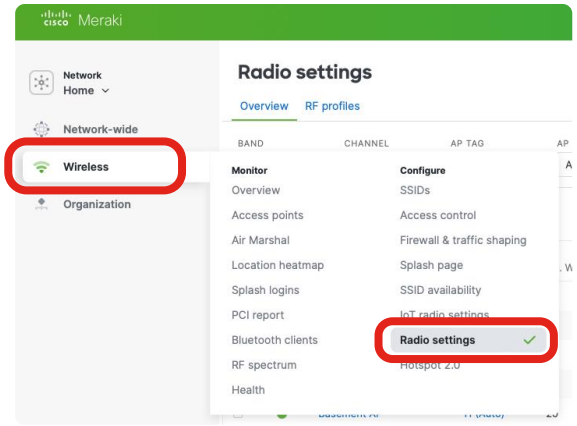
Cloud-Managed High Density

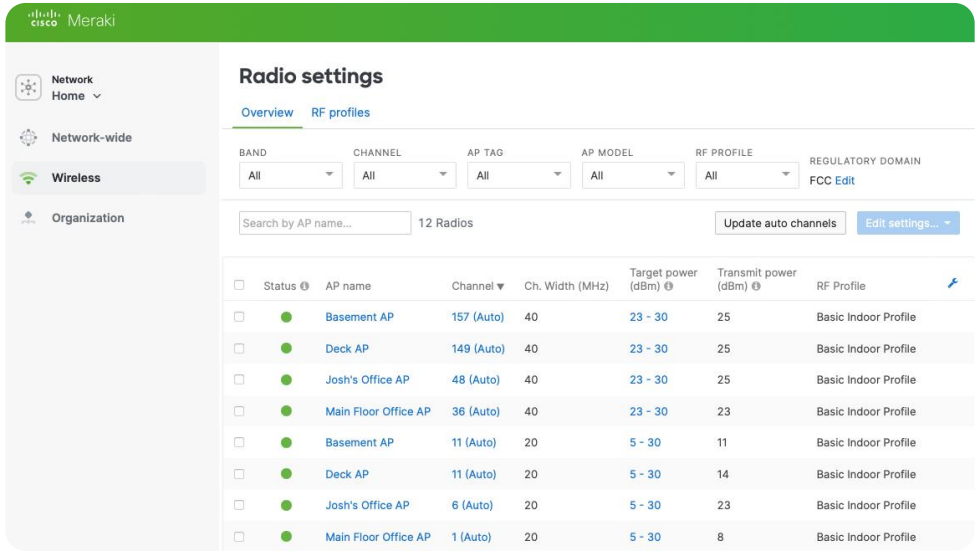


Similarly to “traditional” Catalyst networks:

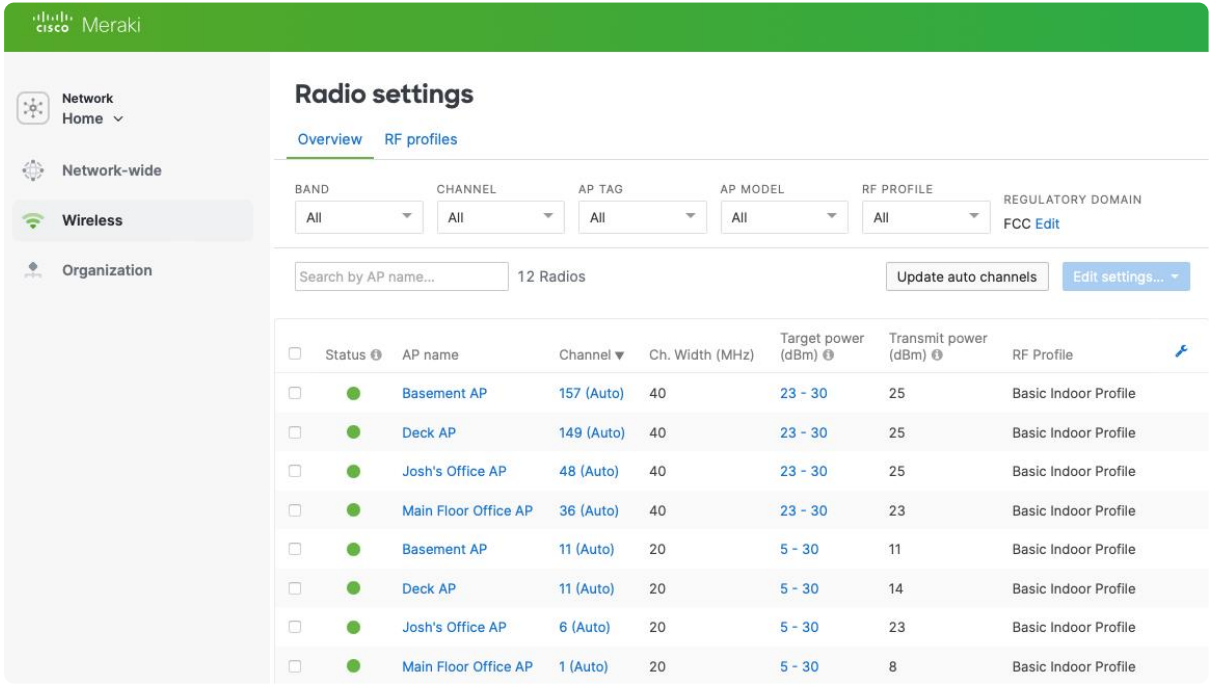
- Manage AP Tx power appropriately
- Tune PHY rates
- Limit SSID count per AP as much as possible
- Optimize channels
- Leverage RX-SOP (carefully, when needed)

RF Optimization: Radio Settings Overview



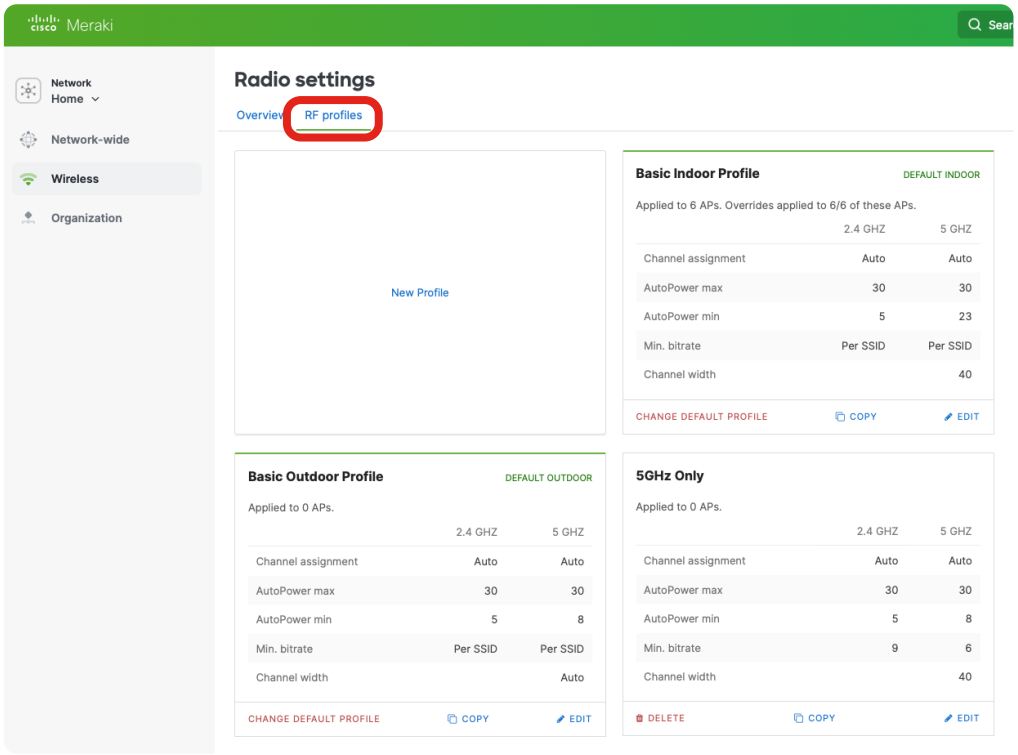


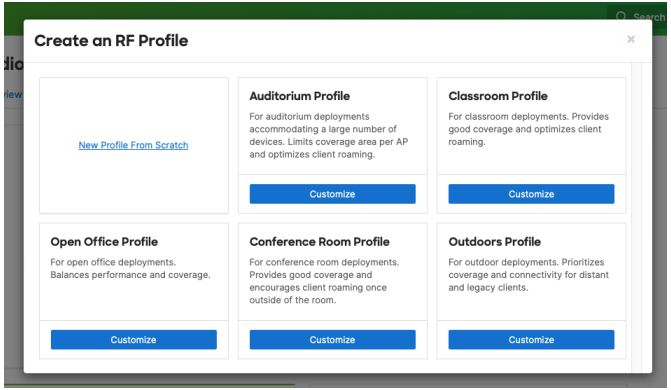
RF Optimization: Radio Settings Overview



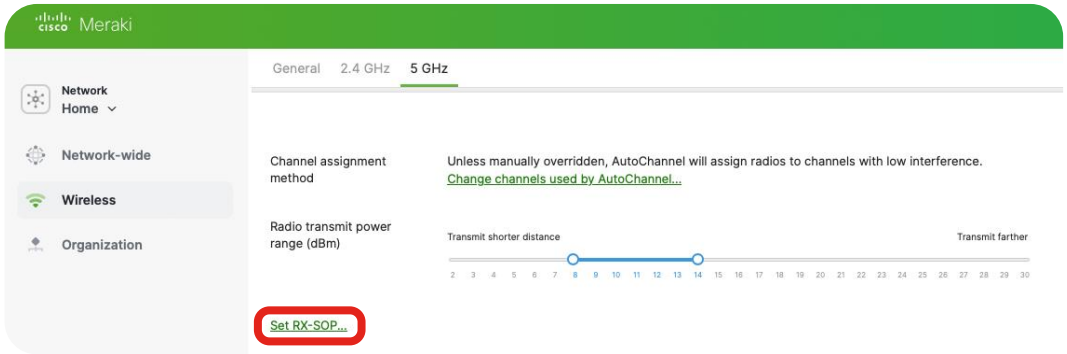
- Sortable / Filterable table for radio settings per AP
- Channel
- Width
- Min/Max Power
- Current Power
- RF Profile

RF Optimization: RF Profiles

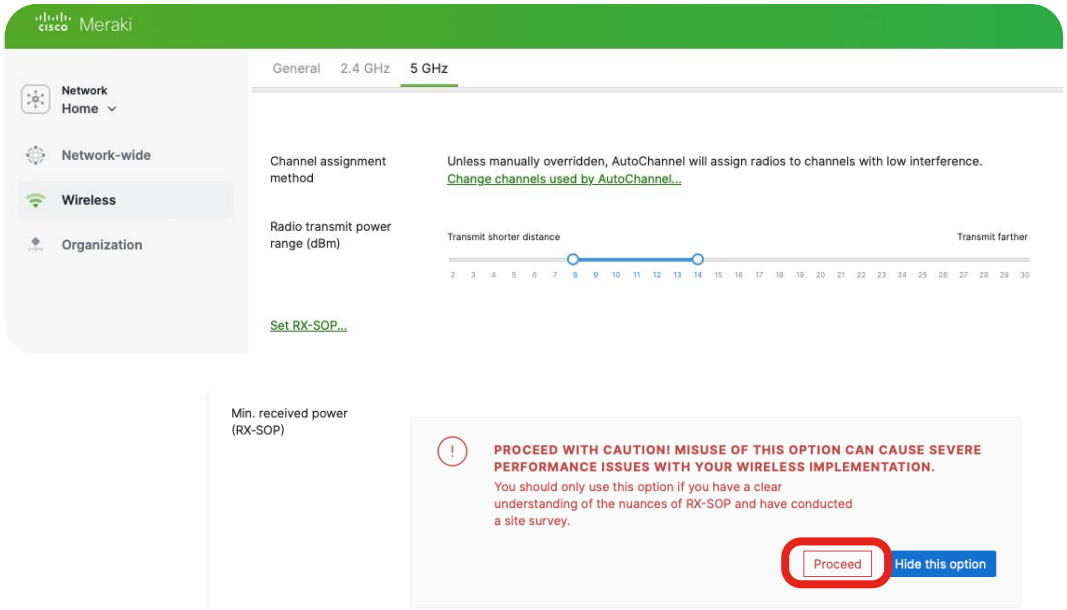




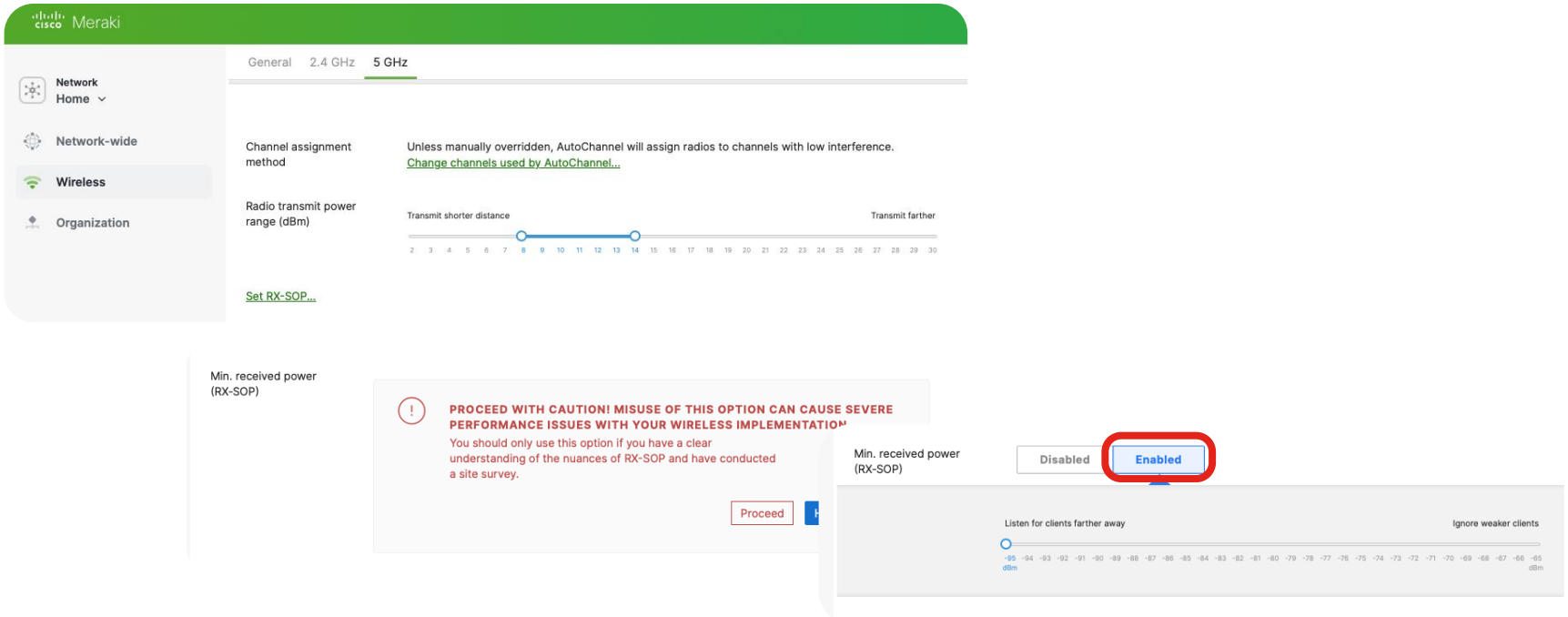
RF Optimization: RX SOP



RF Optimization: RX SOP

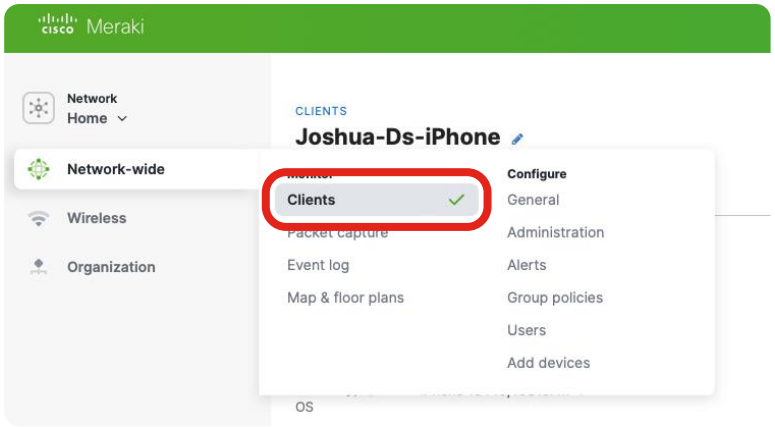


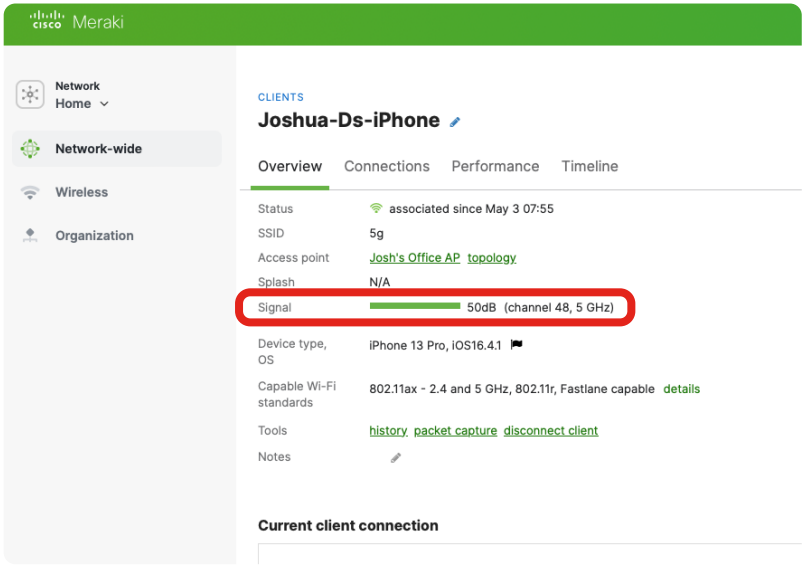
RF Optimization: RX SOP



RF Optimization: RX SOP

Monitoring Client RSSI @ AP for RXSOP Testing

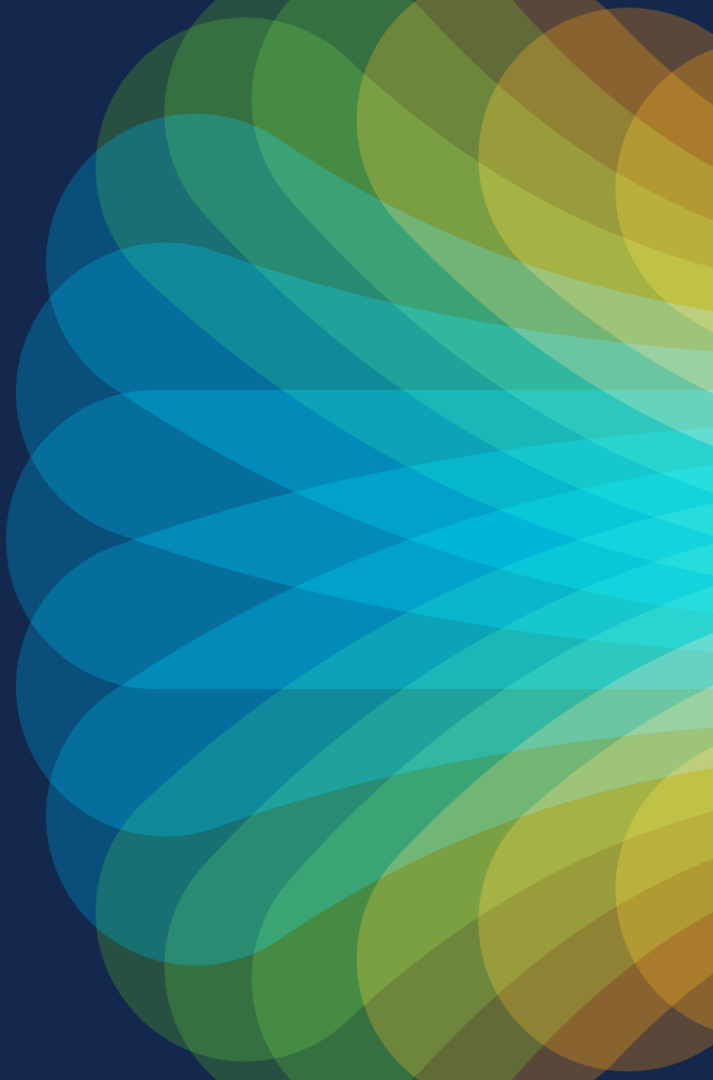




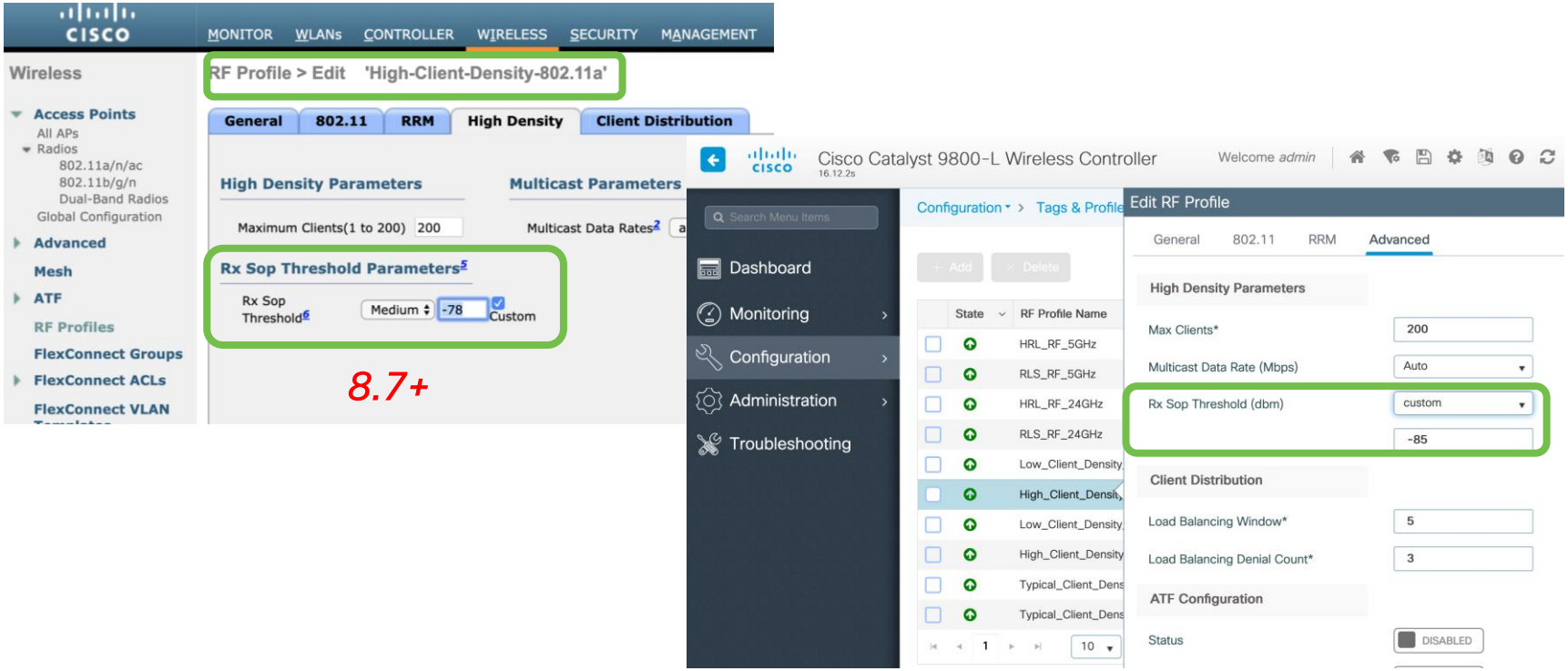
Wired Network Considerations

- Roaming domains: Meraki roaming basics
  - Roaming is either concentrator-based or distributed
  - Most viable in large HD networks means ‘hard’ roams across subnets
- Switched network capacity (throughput & L2 / MAC handling)

Common High Density Mistakes



Tuning RX-SOP Thresholds: GUI



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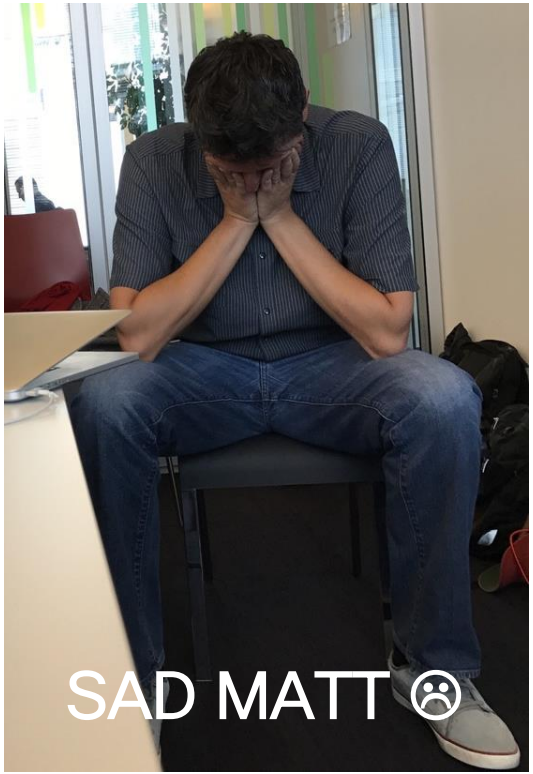

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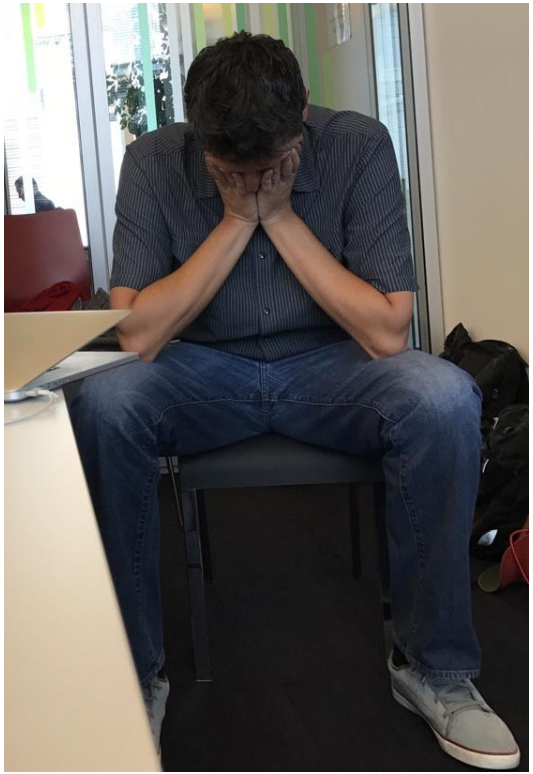


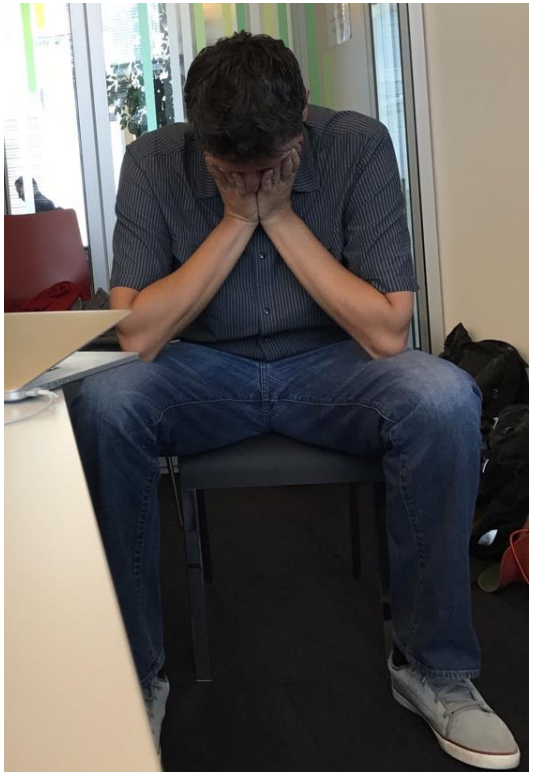
- AP-to-AP transmit power imbalance (causes “Magnet” / overloaded AP’s)

5GHz TX Power: 7dB
2 clients

5GHz TX Power: 17dB
50 clients

Note: This also applies to the dual-5GHz C9104!

Common High Density Optimization Mistakes

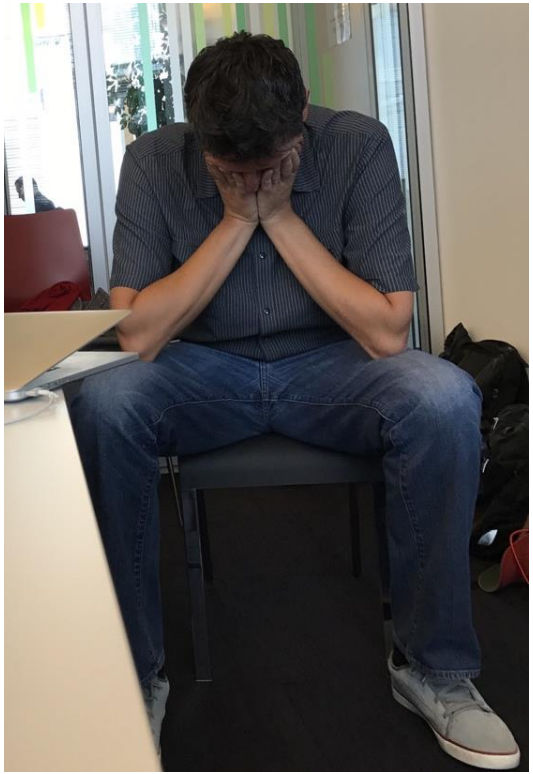


- AP-to-AP transmit power imbalance (causes “Magnet” / overloaded AP’s)
- 2.4GHz to 5GHz transmit power imbalance (draws dual-band clients to 2.4GHz)

2.4GHz: 13dB
20 dual-band clients

5GHz: 7dB
0 dual-band clients

Common High Density Optimization Mistakes



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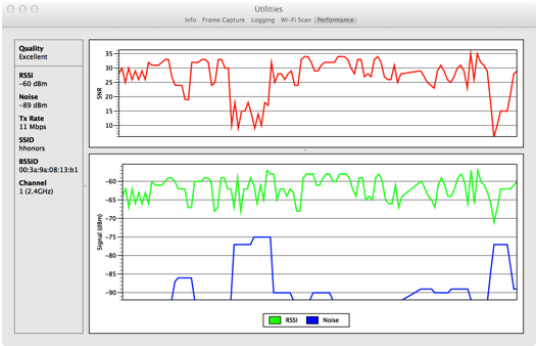
- 2.4GHz to 5GHz transmit power imbalance (draws dual-band clients to 2.4GHz)
- Transmit power too low to overcome noise floor



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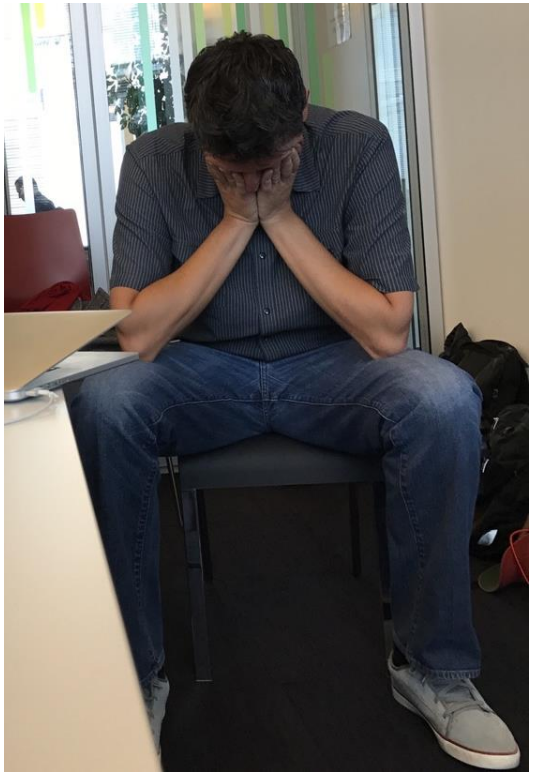

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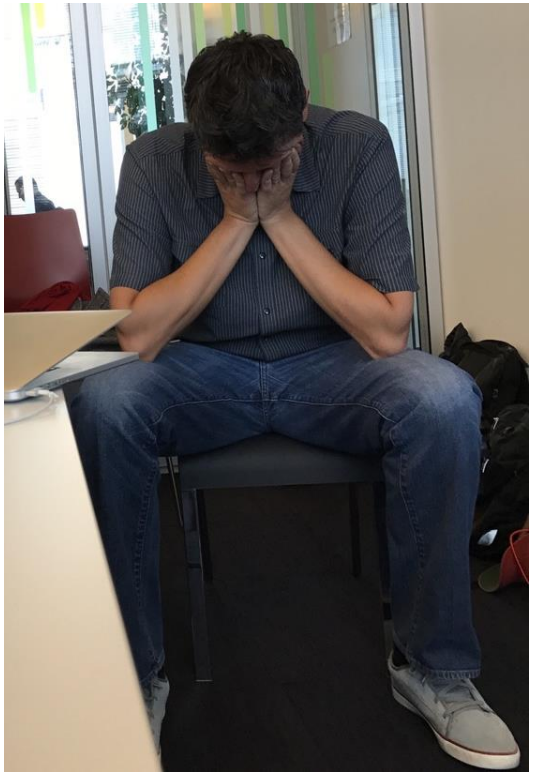
Common High Density Optimization Mistakes



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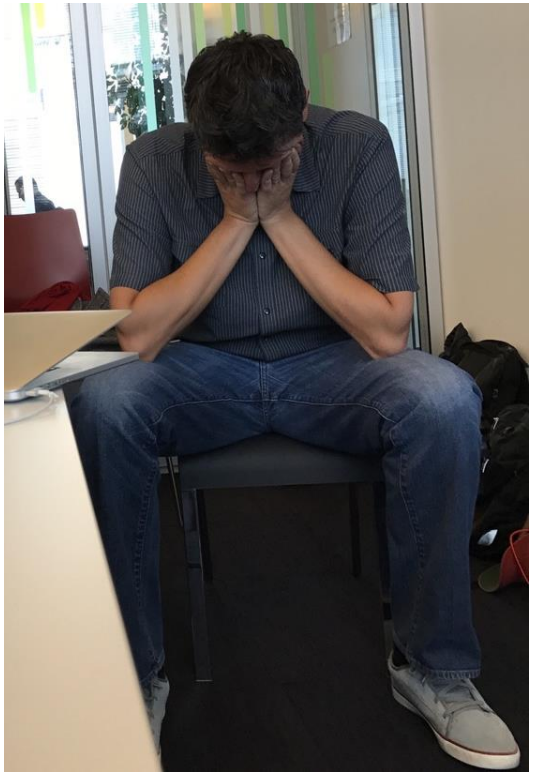
Common High Density Optimization Mistakes



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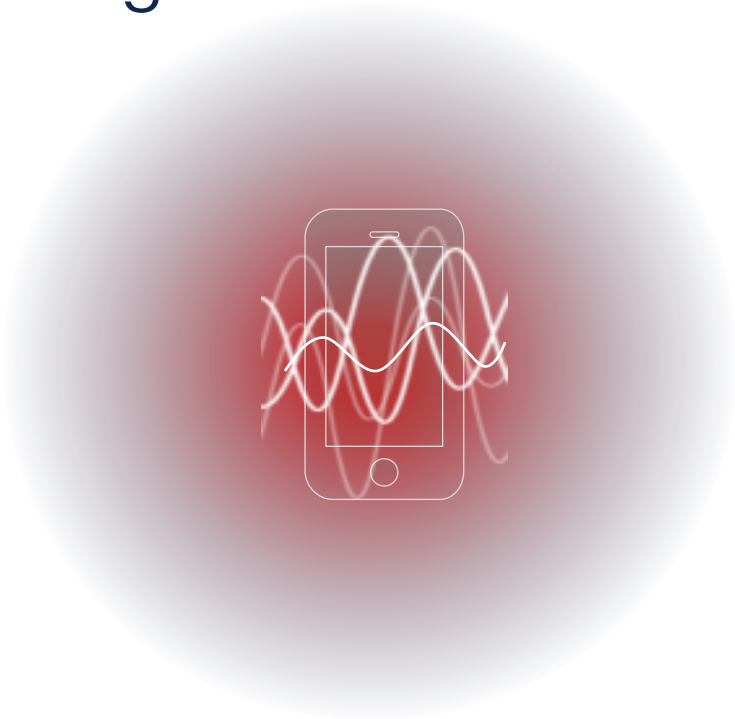
- Too many SSID’s enabled (not using AP Groups to control where SSID’s are enabled)
- Unusable channels (especially 5GHz)

Common High Density Optimization Mistakes

- AP-to-AP transmit power imbalance (causes “Magnet” / overloaded AP’s) **TPC**
- 2.4GHz to 5GHz transmit power imbalance (draws dual-band clients to 2.4GHz) **TPC**
- Transmit power too low to overcome noise floor **TPC**
- Channel Utilization too high **Env. Cleanup / RXSOP**
- Minimum mandatory PHY rate improperly tuned (too high or too low) **PHY Rate tuning**
- Too many SSID’s enabled (not using AP Groups to control where SSID’s are enabled) **Policy Tags**
- Unusable channels (especially 5GHz) **DCA**

Smartphone Roaming Challenges

- As a rule, smartphones pick the loudest AP, then stick to that AP as long as possible
- Many phones won't go looking for a "better" AP unless things are REALLY bad (low RSSI/SNR)
- We attack this problem with workarounds (Optimized Roaming feature) and standards-based features (11k, 11v, adaptive 11r)
- Standards-based methods are best!!



Rogue APs

- DSL/cable modems
  - Are often auto-configured on “least loaded” channel on 2.4ghz
- MiFi's, Eye-Fi’s, and hotspot-enabled smartphones
- Low PHY rates, max power
- Often on overlapping channels due to least-congested channel selection
- Causes exponential load on the air due to probe requests/responses and beacons

Looks like it belongs… but it doesn’t

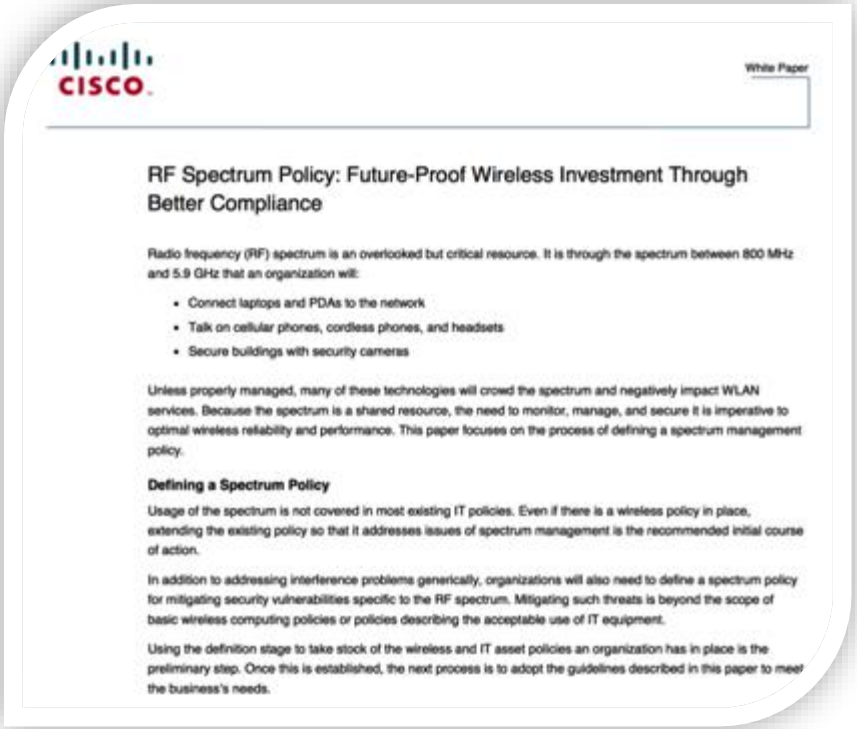
Non-WiFi Interferers

- Video cameras, wireless audio (Coachcomm, Zaxcom), lighting, pyro, and cryo systems, etc.
- Ever look at a Fluke meter and see zero AP's where you'd expect to see dozens? Non-WiFi Interferers often drown out 802.11 altogether.
- Mitigation: remove them altogether or change frequency if possible

What can we do?

- Develop and Enforce an RF Policy

- Employ an effective RF policy
- Identify:
  - what's permitted in your environment
  - what is not permitted in your environment
  - whom to contact for further information



White Paper

RF Spectrum Policy: Future-Proof Wireless Investment Through Better Compliance

Radio frequency (RF) spectrum is an overlooked but critical resource. It is through the spectrum between 800 MHz and 5.9 GHz that an organization will:

- Connect laptops and PDAs to the network
- Talk on cellular phones, cordless phones, and headsets
- Secure buildings with security cameras

Unless properly managed, many of these technologies will crowd the spectrum and negatively impact WLAN services. Because the spectrum is a shared resource, the need to monitor, manage, and secure it is imperative to optimal wireless reliability and performance. This paper focuses on the process of defining a spectrum management policy.

Defining a Spectrum Policy

Usage of the spectrum is not covered in most existing IT policies. Even if there is a wireless policy in place, extending the existing policy so that it addresses issues of spectrum management is the recommended initial course of action.

In addition to addressing interference problems generically, organizations will also need to define a spectrum policy for mitigating security vulnerabilities specific to the RF spectrum. Mitigating such threats is beyond the scope of basic wireless computing policies or policies describing the acceptable use of IT equipment.

Using the definition stage to take stock of the wireless and IT asset policies an organization has in place is the preliminary step. Once this is established, the next process is to adopt the guidelines described in this paper to meet the business's needs.

Agenda

- Designing RF for High Client Densities
- HD Wi-Fi Configuration Tips
- HD Wi-Fi Engineering Toolkit

Our Favorite Tools

Cisco Wireless Troubleshooting & Analysis Tools (Free)

- Wi-Fi Hawk
- WCAE
- WLAN Poller

Intuitibits Tools (Mac)

- WiFi Explorer
- AirTool
- WiFi Signal

Tethabyte WinFi (Windows)

- WinFi

Packet Capture & Analysis Tools

- Metageek Tonic
- Wireshark
- *(Article)* Analyzing Wireless Packet Captures

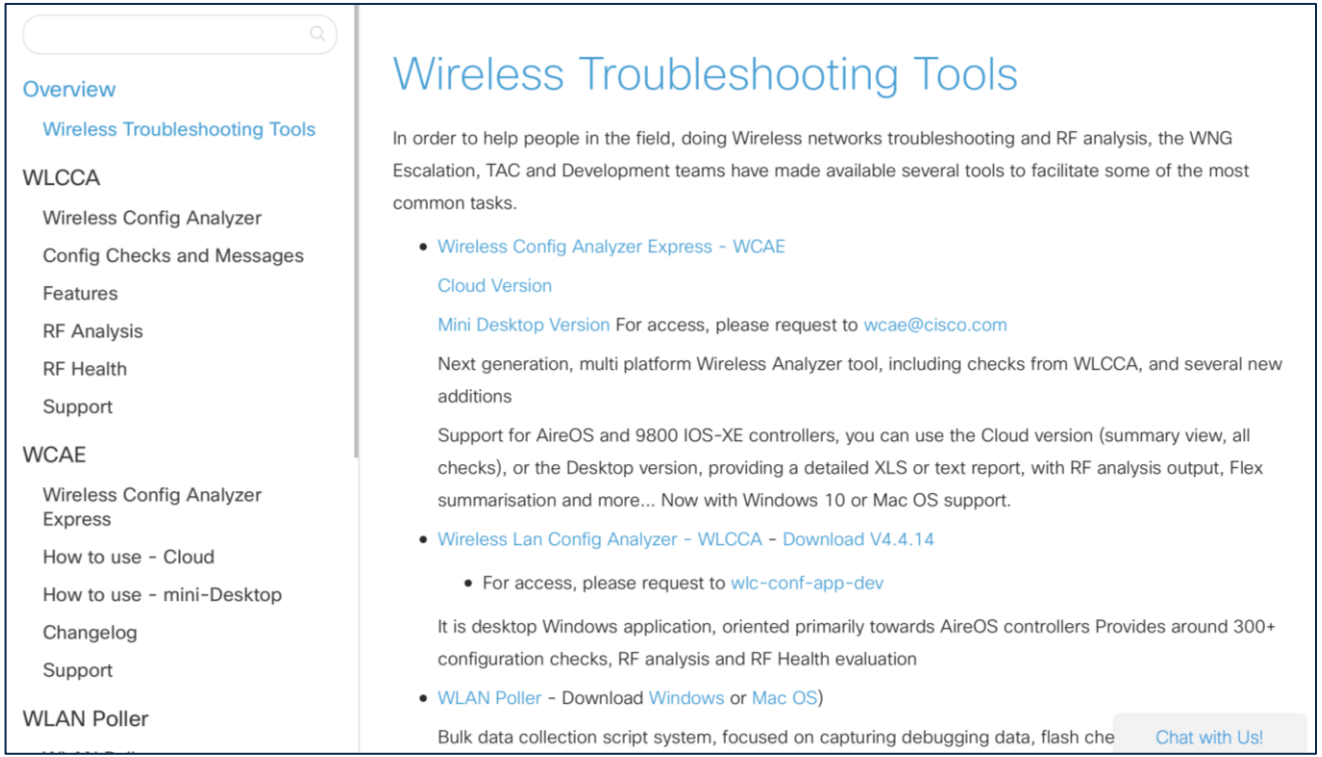
Site Survey Tools

- Ekahau Pro & Sidekick

NetOps, AIOps, DevOps Tools

- Cisco DNA Center Assurance

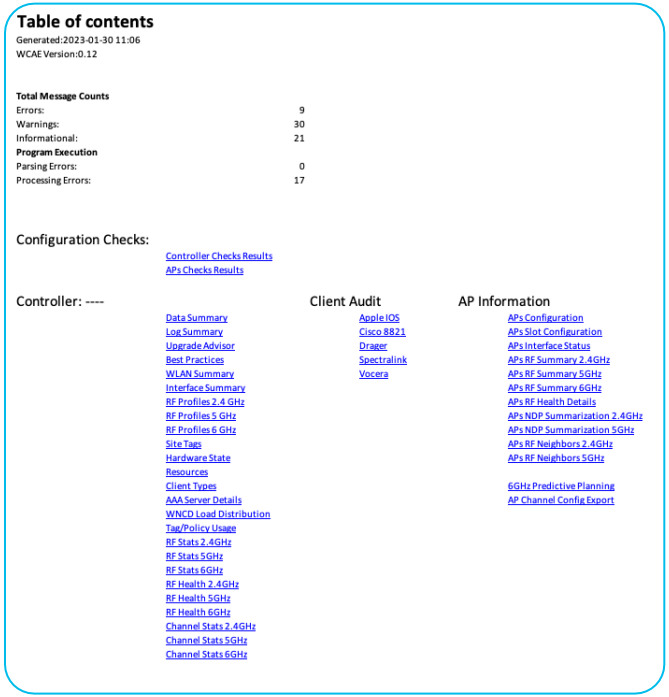
Wireless Troubleshooting Tools



Download: https://developer.cisco.com/docs/wireless-troubleshooting-tools/

Wireless Troubleshooting Tools

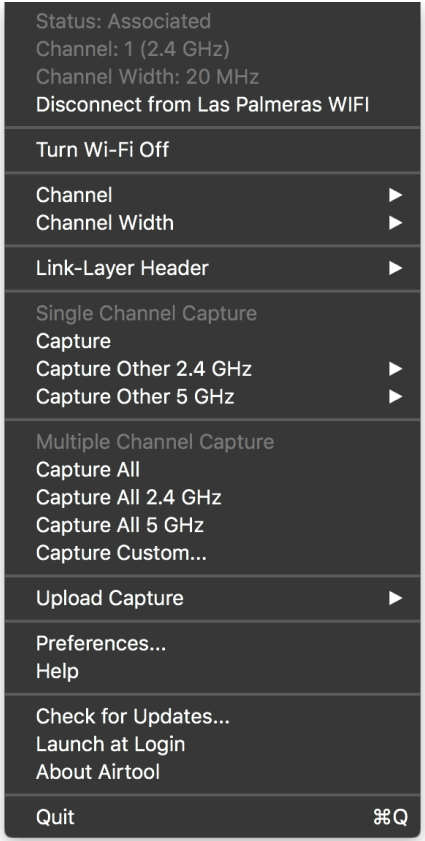
- Wireless Config Analyzer Express (WCAE) is an extremely valuable tool when validating and optimizing a Cisco Wi-Fi deployment
- WCAE helps us determine:
  - Configuration consistency across multiple WLC's
  - RF Problem Finder – determine likely "problem" RF areas
  - AP Neighbors – how do AP's hear each other? Too well, not well enough?
  - Additional views of CleanAir data
  - RRM overview with the RF Summary



Download: https://developer.cisco.com/docs/wireless-troubleshooting-tools/

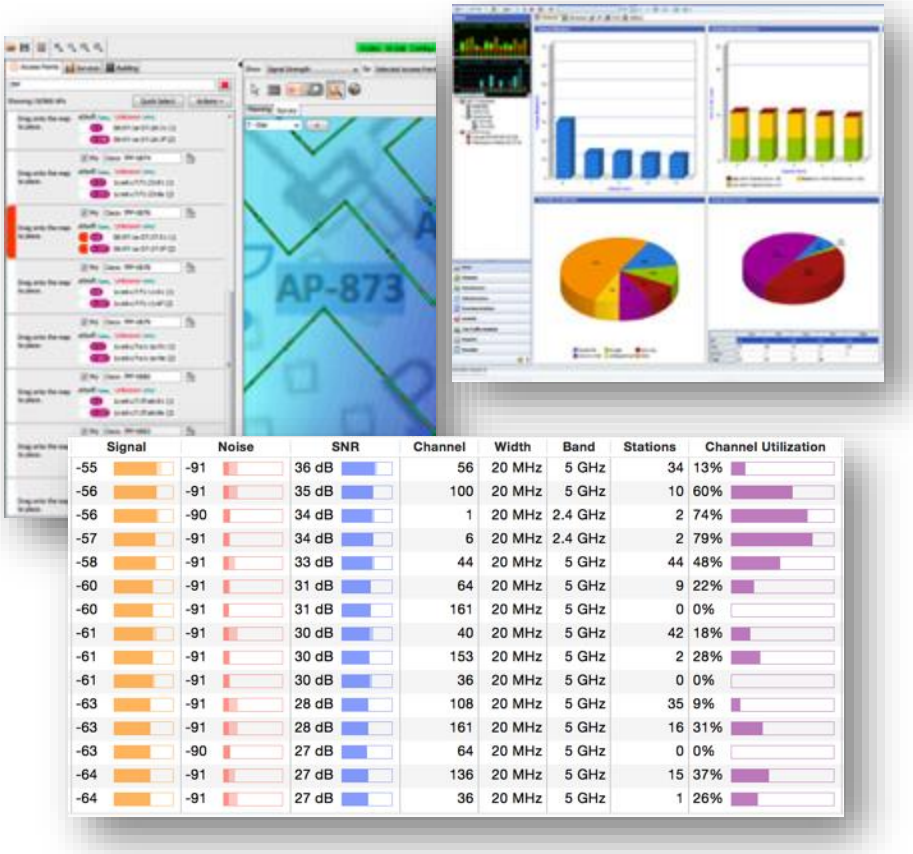
Packet Captures

- OmniPeek/Wireshark
  - For packet captures of the WLAN, including beacons and other management traffic
  - Helpful for troubleshooting of problems at the source
- AirTool
  - Free app for Mac – simplifies packet capture process
  - https://www.adriangranados.com/apps/airtool



Site Surveys

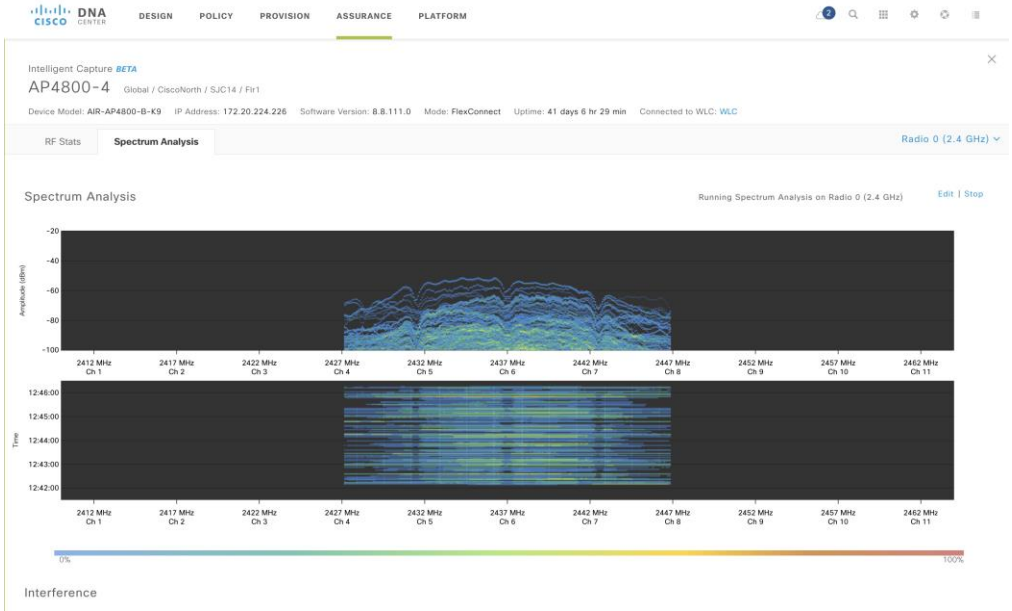
- Ekahau Site Survey Pro
  - Design & Verify
  - Determine differences in coverage that occur as a result of tuning changes



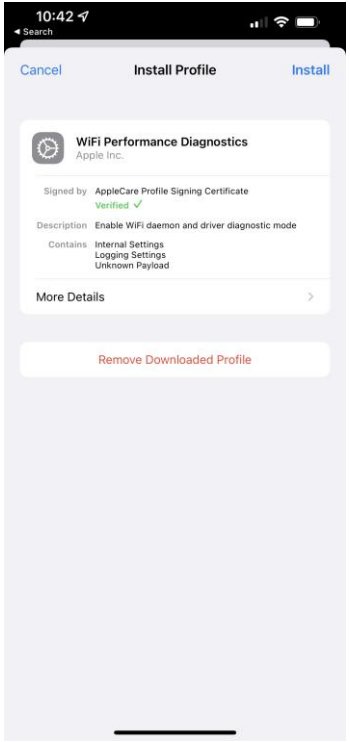
Spectrum Analysis

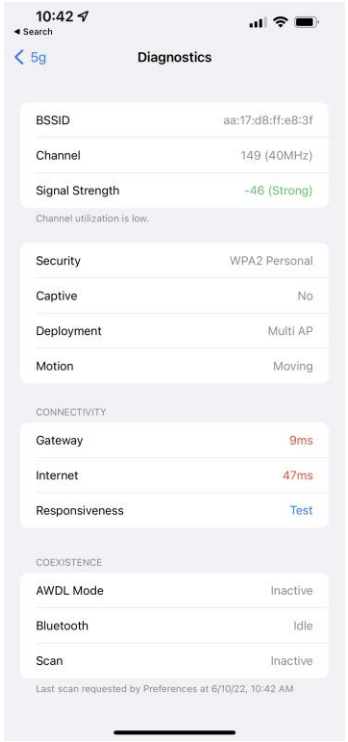
Cisco DNA Center Intelligent Capture

- Layer 1
- Provides a view of real energy on a channel
- Identify interferers of all types
- Critical part of the “big picture”



iOS Wi-Fi Diagnostics with iOS





Diagnostics Profile for installation on iOS devices extends on-device WiFi diagnostics capabilities

More Info:

https://tidbits.com/2022/04/22/use-apples-networkquality-tool-to-test-internet-responsiveness/

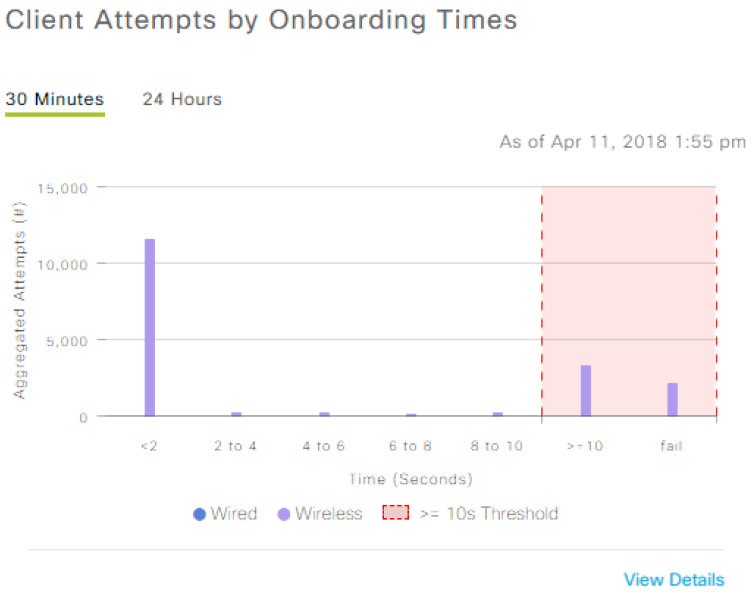
Profile Download:

https://developer.apple.com/services-account/download?path=/iOS/iOS_Logs/MegaWifiProfile.mobileconfig

Note: Profile auto-expires after 7 days and must be re-installed when needed

Cisco DNA Center Assurance

Broad applicability to High Density deployments



- iOS Analytics
- Detailed client onboarding analysis
- Aironet Active Sensor support
- Intelligent Capture
- Network Time Travel

...and much more!

https://clnv.s3.amazonaws.com/2018/usa/pdf/BRKEWN-2034.pdf

Key Takeaways

- Design the RF environment with appropriate antennas and sensible physical placements
- Employ HD-focused WLC feature configurations such as RF Profiles for more flexible and robust designs
- Understand the key outside factors that may impact a live HD WLAN, including enemies of performance
- Get comfortable with Wi-Fi analysis and optimization tools to make informed, data-driven decisions

Fill out your session surveys!

Attendees who fill out a minimum of four session surveys and the overall event survey will get **Cisco Live-branded socks** (while supplies last)!

Attendees will also earn 100 points in the **Cisco Live Challenge** for every survey completed.

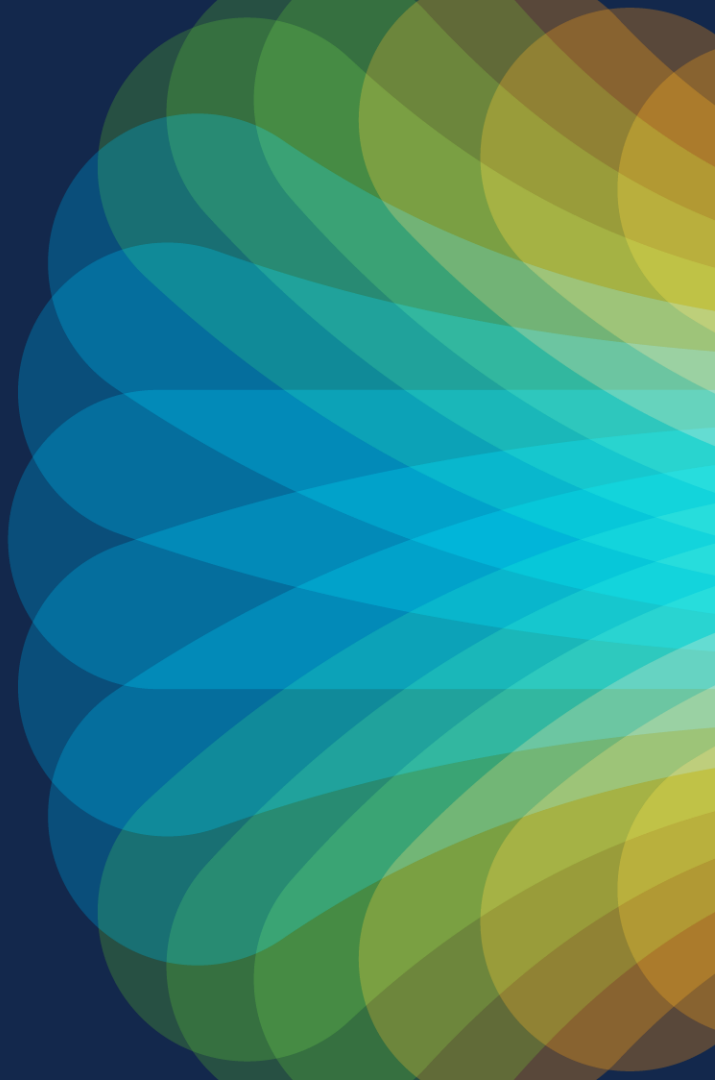
These points help you get on the leaderboard and increase your chances of winning daily and grand prizes

Continue your education

- Visit the Cisco Showcase for related demos
- Book your one-on-one Meet the Engineer meeting
- Attend the interactive education with DevNet, Capture the Flag, and Walk-in Labs
- Visit the On-Demand Library for more sessions at www.CiscoLive.com/on-demand

The bridge to possible

Thank you



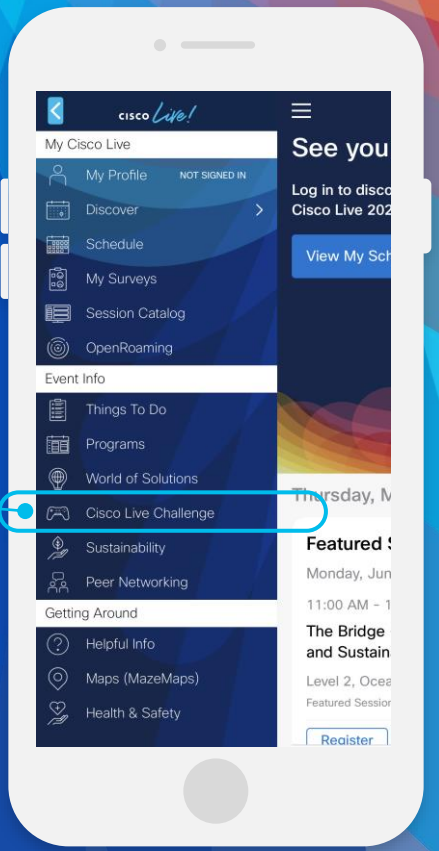
Cisco Live
Challenge

Gamify your Cisco Live experience!

Get points for attending this session!

How:

1. Open the Cisco Events App.
2. Click on 'Cisco Live Challenge' in the side menu.
3. Click on View Your Badges at the top.
4. Click the + at the bottom of the screen and scan the QR code:

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Let's go
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