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# High Density Wi-Fi Design, Deployment, and Optimization

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BRKEWN-2087

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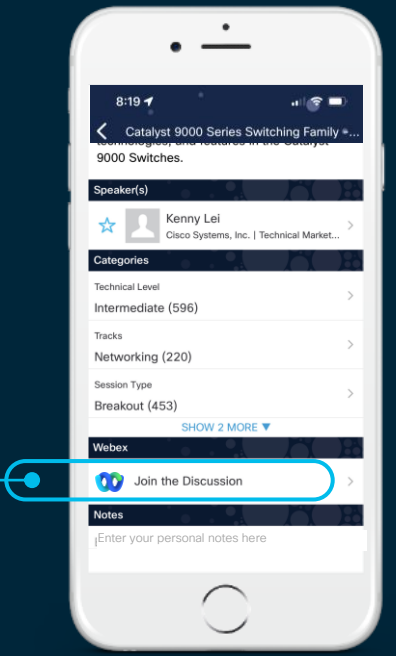


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# Josh Suhr

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
- 6GHz / Wi-Fi 6E – more spectrum!!!
- Smarter clients (11k/11v/11r)
- More devices per user
- Auto authentication & OpenRoaming

# Agenda

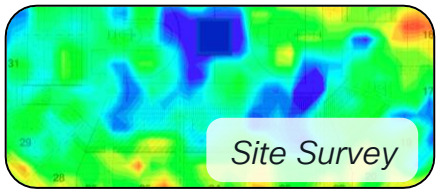
- **Designing RF for High Client Densities**
- HD Wi-Fi Configuration Tips
- HD Wi-Fi Engineering Toolkit

# 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 |

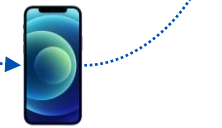
*WCAE*

## 1 AP to Client




## 3 AP to AP

## 2 Client to AP

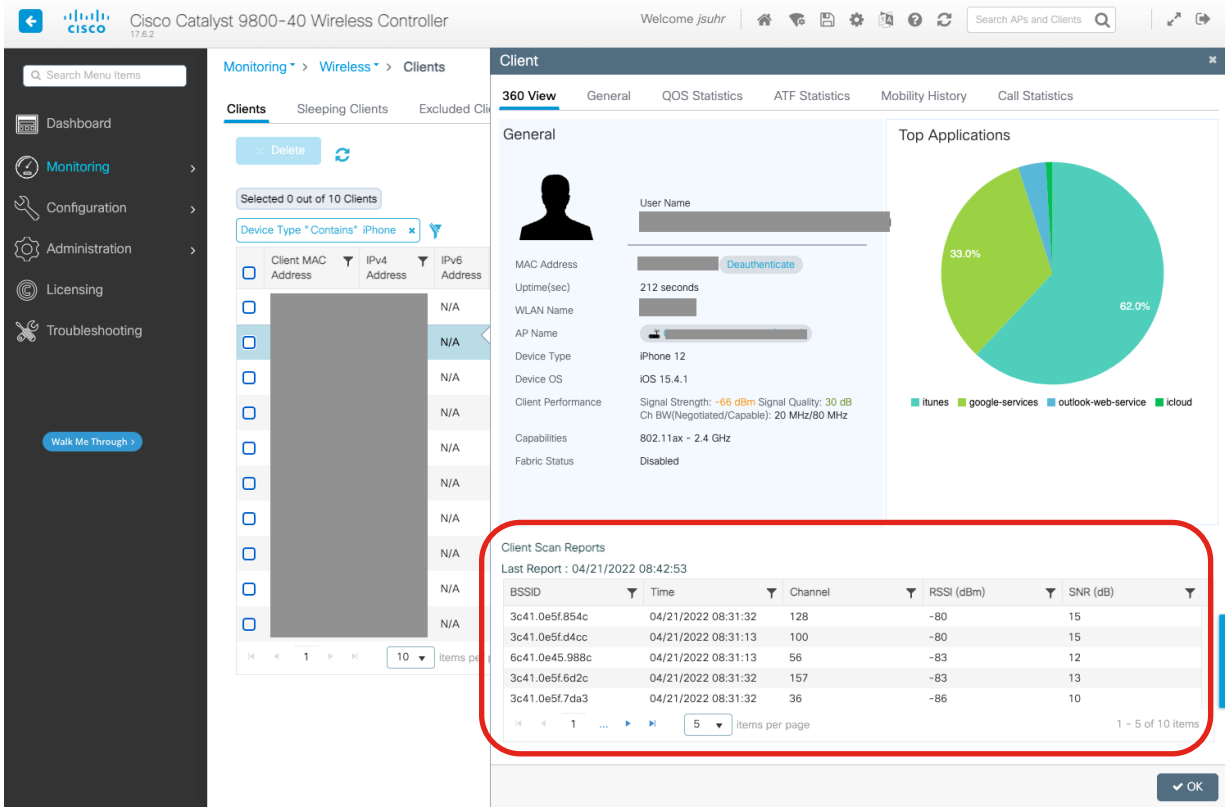


| | |
|---|---|
| Device Type | iPhone 12 |
| Device OS | iOS 15.4.1 |
| Client Performance | Signal Strength: -66 dBm Signal Quality: 30 dB<br>Ch BW(Negotiated/Capable): 20 MHz/80 MHz |
| Capabilities | 802.11ax - 2.4 GHz |
| Fabric Status | Disabled |

*WLC UI / CLI*

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

# How Clients Hear AP's – UI




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

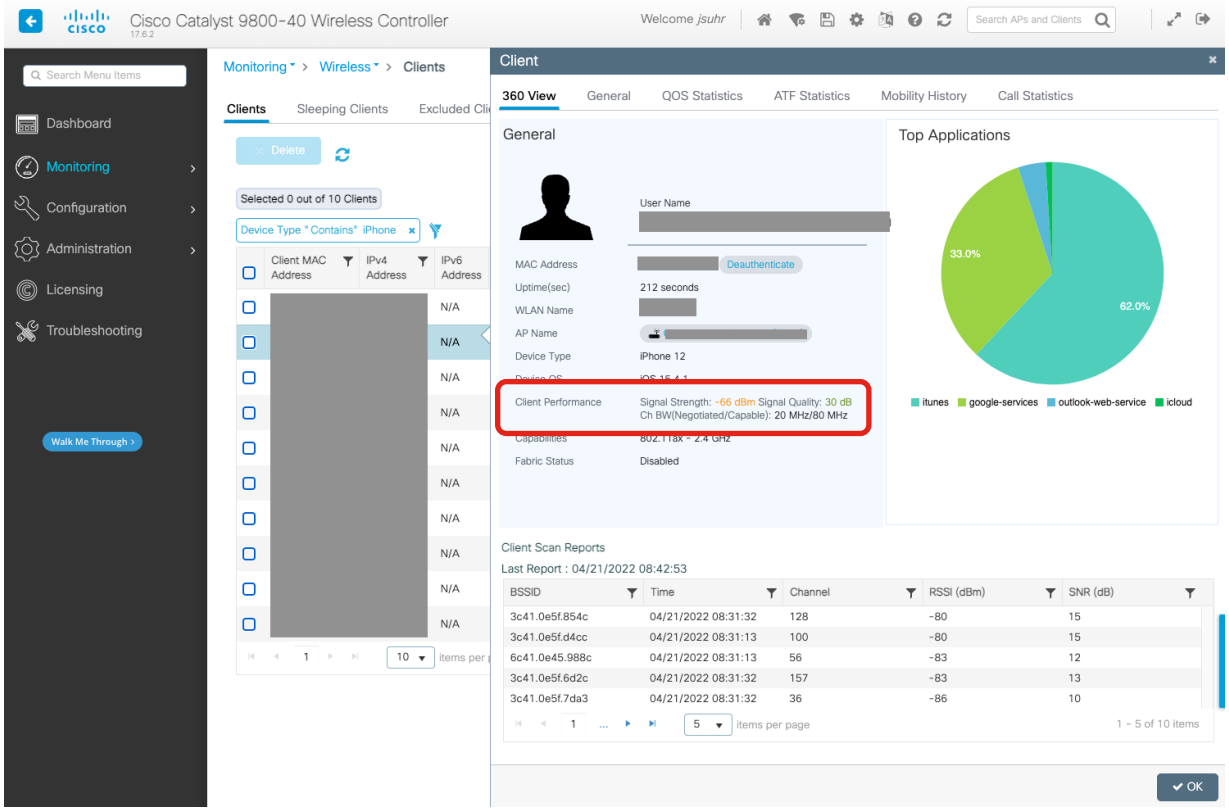
# Aironet Active Sensors

## Cisco Aironet Active sensors...

- are hardware devices (dedicated **1800S** sensor or supported models of Cisco AP)
- connect to your WiFi network and run a series of tests as a client device
- send test results back to Cisco DNA Center for further analysis

See how the sensor sees AP's:
*CLI: show dot11 sensor scan list*

# How AP's Hear Clients – UI




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

# How AP's Hear Clients

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

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)?

# 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

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

# Cisco Catalyst C-ANT9104 – Stadium Antenna + Integrated AP

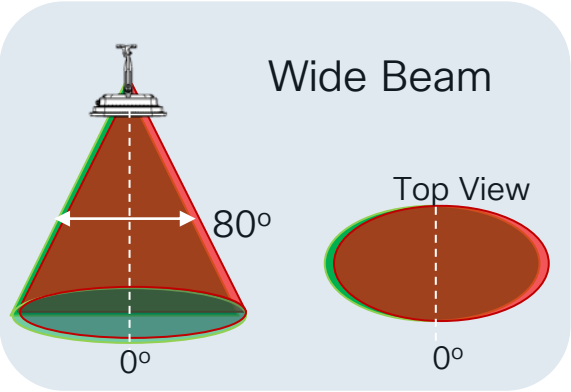
- The C-ANT9104 antenna is designed specifically to solve challenges encountered in stadium/Large Public Venue/High Client Density environments.
- Dual 5 GHz on two individual 5 GHz 4x4 Arrays
- Configurable electronic beam steering as well as Narrow and Wide modes of the antenna
- Catalyst C9800 release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


Three generations of High-Density WiFi Stadium Antennas

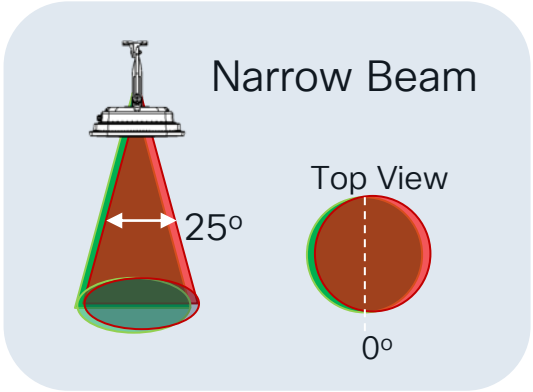
# C-ANT9104: Key Things to Know

| | |
|---|---|
| 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<br>Tight RF patterns, minimal sidelobes, RF Isolation = no RRM |

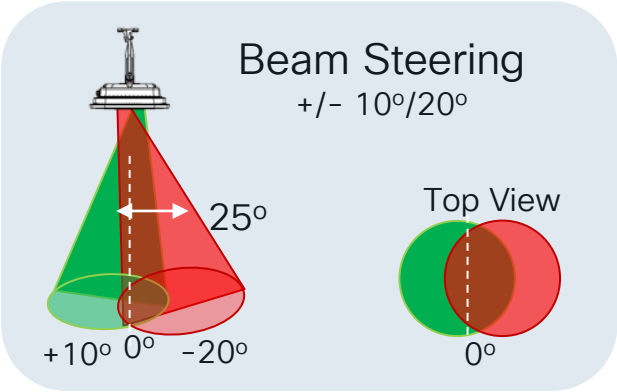
# C-ANT9104: Software-Configurable Beams




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 |

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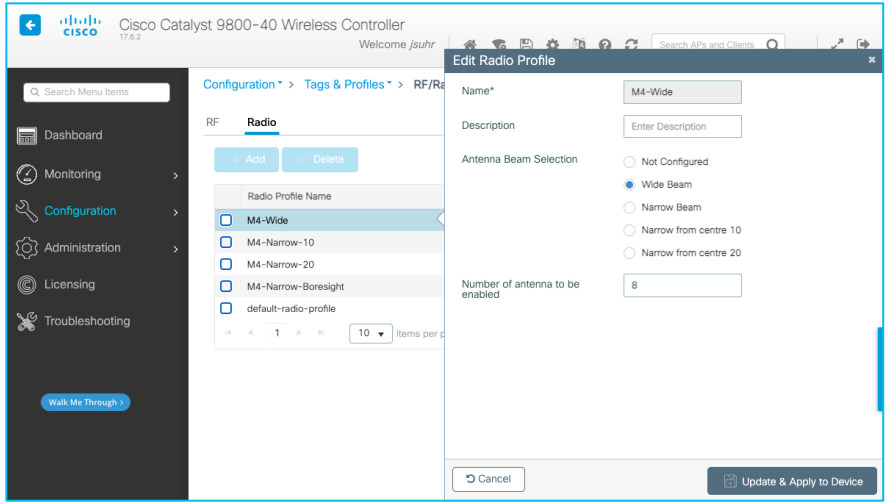
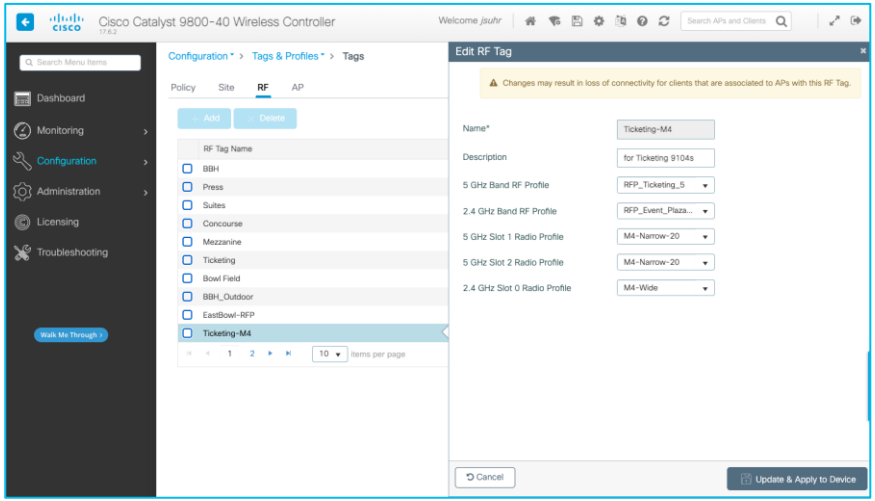
# C-ANT9104: Configuration (GUI)




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"*

(Hidden Slide)

# 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
```

# AP Selection

# Cisco Catalyst 9100 Series Access Points

Ideal for small to medium-sized deployments › Mission critical › Best in Class

New smaller design

## 9105AX

- 2x2 + 2x2
- MU-MIMO, OFDMA
- Spectrum intelligence
- IoT ready
- 1x 2.5 mGig (WP)
- TWT

## 9115AX

- 4x4 + 4x4 | 8x8 + 4x4
- MU-MIMO, OFDMA
- Spectrum intelligence
- 1 x 2.5 mGig | 1 x 5 mGig
- TWT

Powered by Cisco RF ASIC

## 9120AX

- 4x4 + 4x4
- Cisco RF ASIC for Next Gen CleanAir
- Dual 5GHz, Next Gen HDX
- IoT ready
- 1 x 2.5 mGig
- TWT

Powered by Cisco RF ASIC

## 9130AX

- 8x8 + 4x4; 4x4 + 4x4 + 4x4
- Tri-radio: Dual 5GHz + 2.4GHz
- Cisco RF ASIC for Next gen CleanAir
- Full iCap with data packets
- Dual 5GHz, Next Gen HDX
- IoT ready
- Smart Antennas supporting up to 8x8
- 1 x 5 mGig
- First 8x8 AP with external antennas
- TWT

Bluetooth 5 | USB | Integrated or External Antenna | Cisco DNA Assurance with iCAP

# Catalyst 9136 Series access point

## Best-in-class Wi-Fi 6E technology starting from Cisco IOS® XE 17.7.1

NEW

### Catalyst® 9136 Series

Concurrent tri-radio with 16 spatial streams


**Hexa-radio architecture**

- 2.4-GHz serving radio (slot 0): 4x4, 4SS
- 5-GHz serving radio (slots 1 and 2): 8x8, 8SS
- Dual 5-GHz serving radio (slot 1 or 2*): 4x4, 4SS
- 6-GHz serving radio (slot 3): 4x4, 4SS
- Dedicated AI/ML-driven scanning radio
- 2.4-GHz IoT radio

**Dual PoE for power redundancy**

- 2x 5 Multigigabit (mGig) PoE ports
- 802.3 link aggregation > up to 5 Gbps uplink

**Internet of Things (IoT) capabilities**

- Built-in environmental sensors
- Application hosting technology
- USB port with 9W power output

| Analytics with Cisco DNA Center 2.3.2 | Extending Cisco's intent-based network | Location and IoT with Cisco DNA Spaces |
|---|---|---|

* The slot 2 radio in 4x4 will be supported in a future software release.

# 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

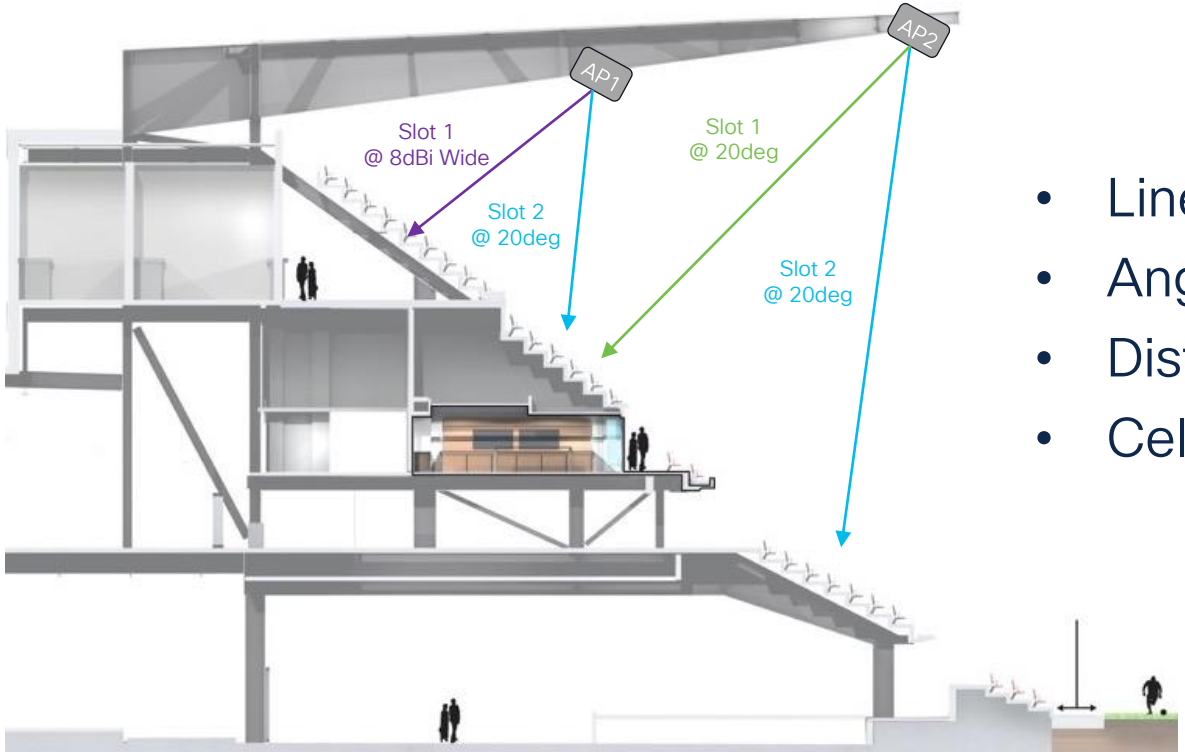

## 9124 Series* (Wi-Fi 6)

- 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

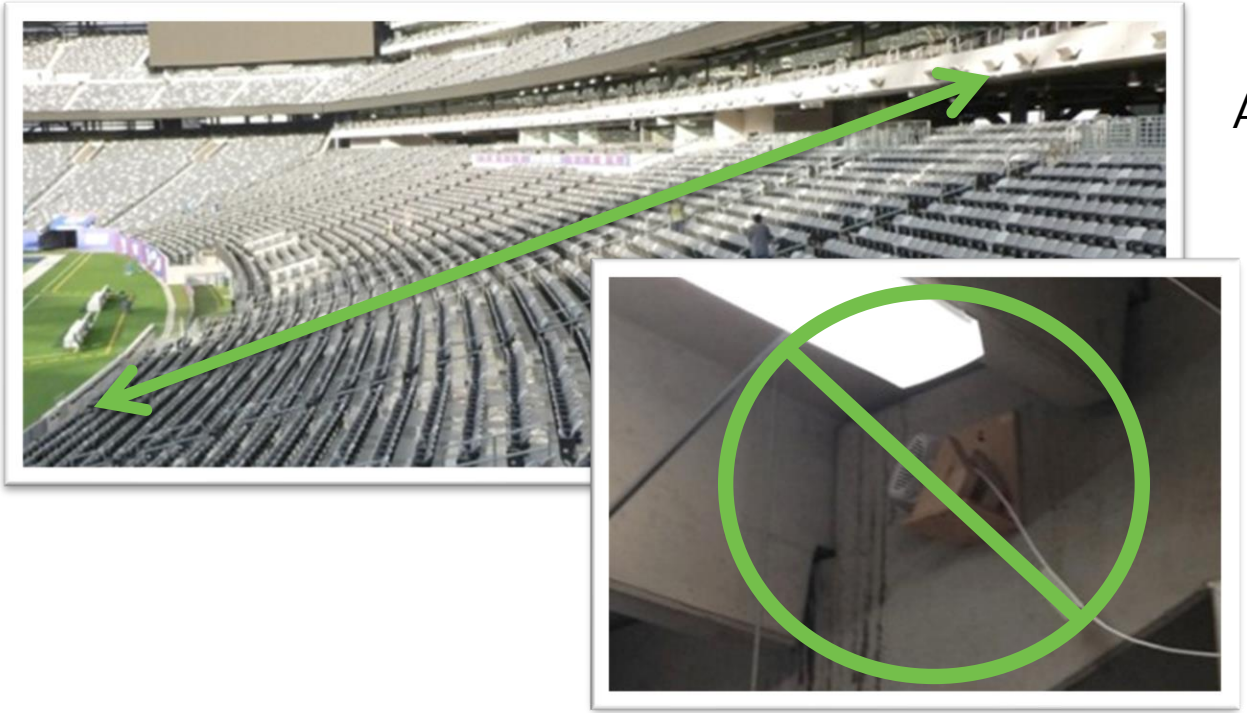
# AP Placement Tips




- Line-of-Sight
- Angle of Incidence
- Distance to Clients
- Cell Size & Overlap

# Antenna Placement: What Not To Do

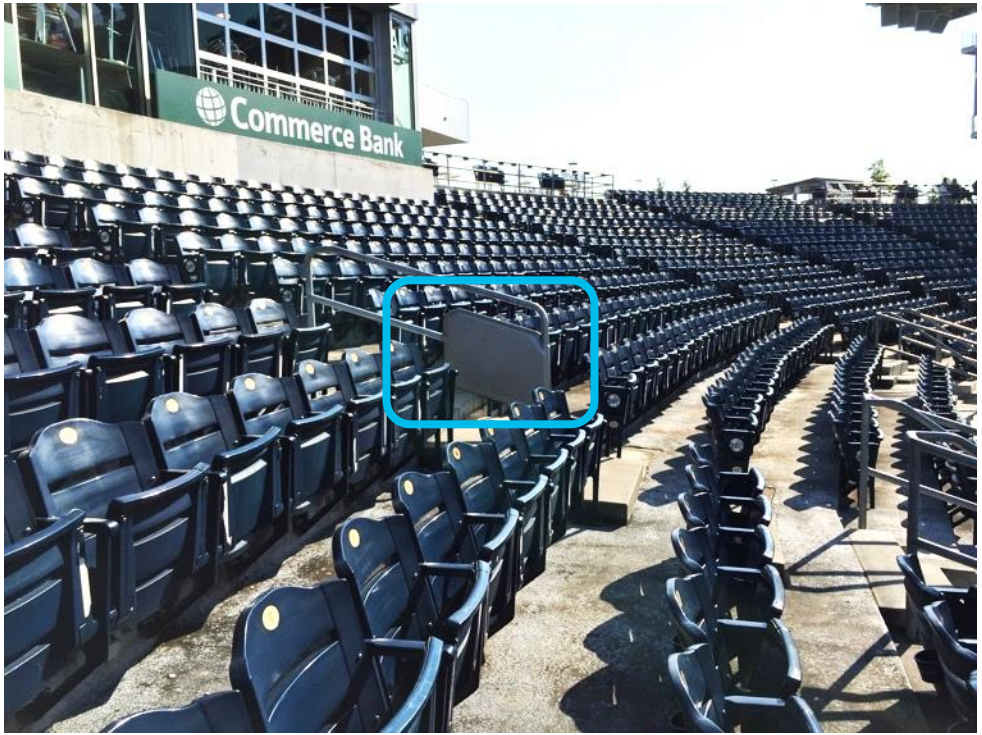
- Seating Area Coverage: Challenging Areas

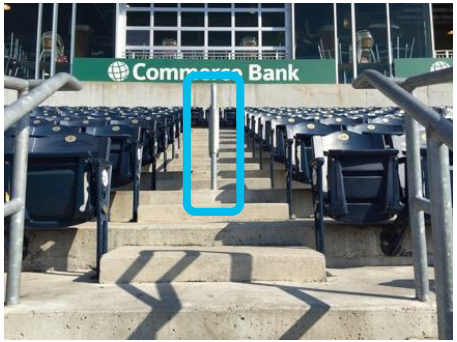


Avoid long shots like this

**Avoid** obstructions in front of your antennas

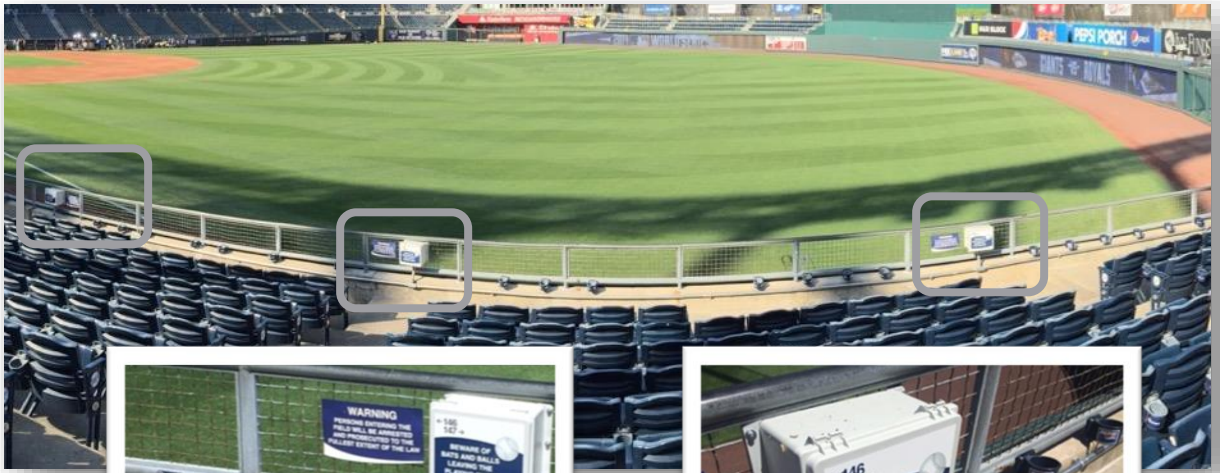
# Creative AP/Antenna Mount Examples

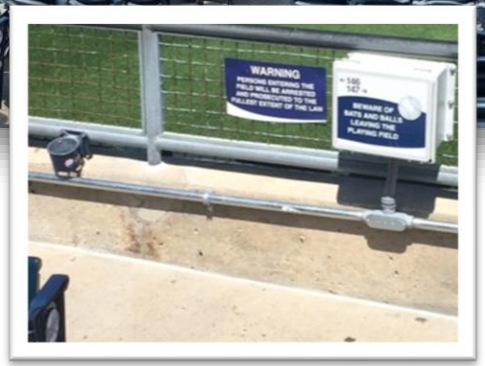


# Creative AP/Antenna Mount Examples

- Seating Area Coverage: Challenging Areas







- Creative options may be required for low seating rows
  - Handrails
  - Front walls (aimed away from playing surface)
- Ensure compliance with minimum distances to bodies – >20cm
- Stick to directional antennas

# Antenna Placement

- High Density Open Areas – Conference Halls, Classrooms

- Omnis are not ideal 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

# Increase Coverage and Capacity

- Dual 5GHz -Micro/Macro Cell

## Increase Capacity and Coverage from a Single Access Point Location

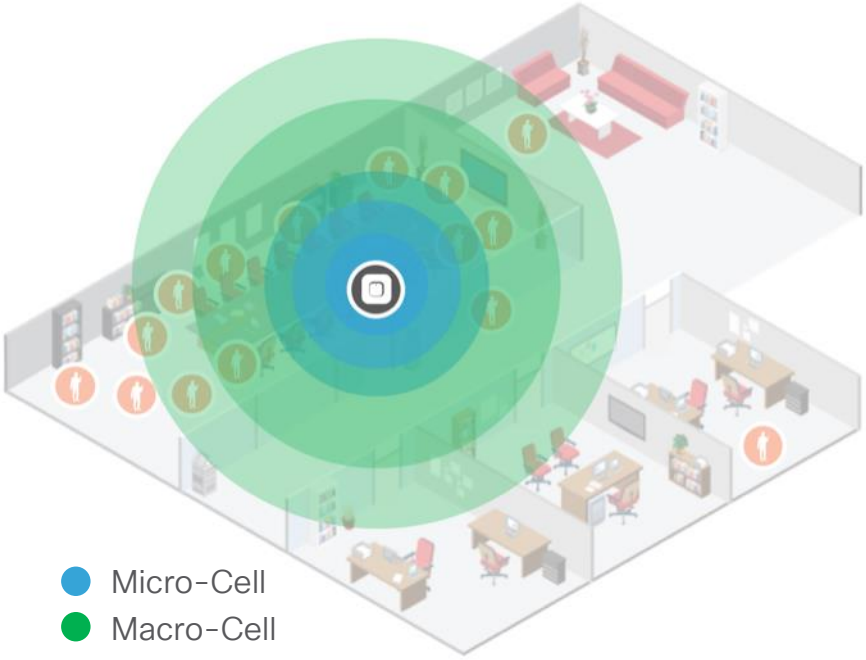
**One AP for Different Coverage Areas:**

Provide High Density Service for a Small Coverage Area

- Conference room, classroom, patient room, operating room

Simultaneously Cover Wider Areas Such as Hallways and Lobbies

3802i/4800/9120i/9130i




Better User Experience in Locations with Varying Density Needs

# Maximizes Coverage in Two Distinct Areas

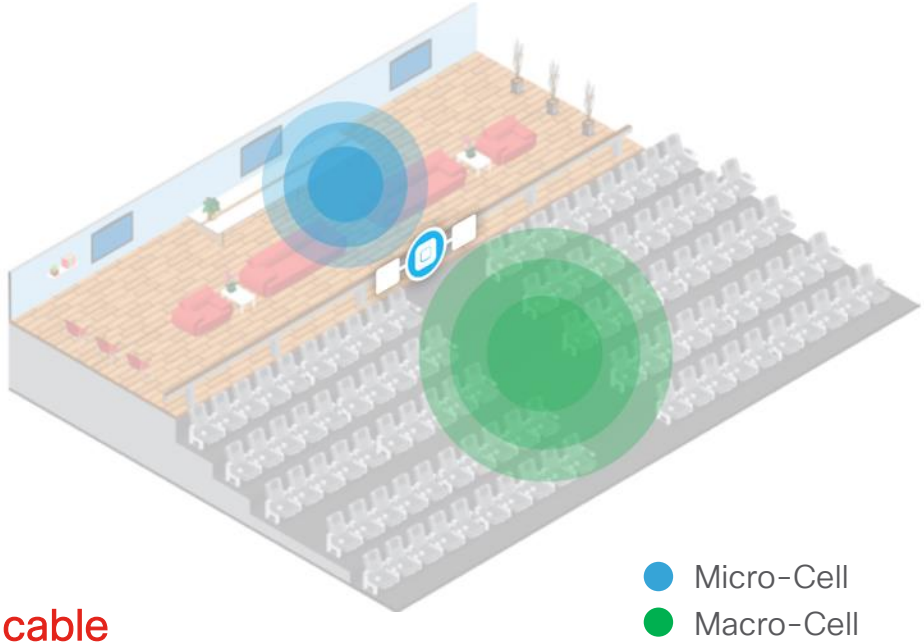
- Dual 5GHz-Macro/Macro Cell

Deliver Coverage in Two Distinct Areas with a Single Access Point Using External Antennas

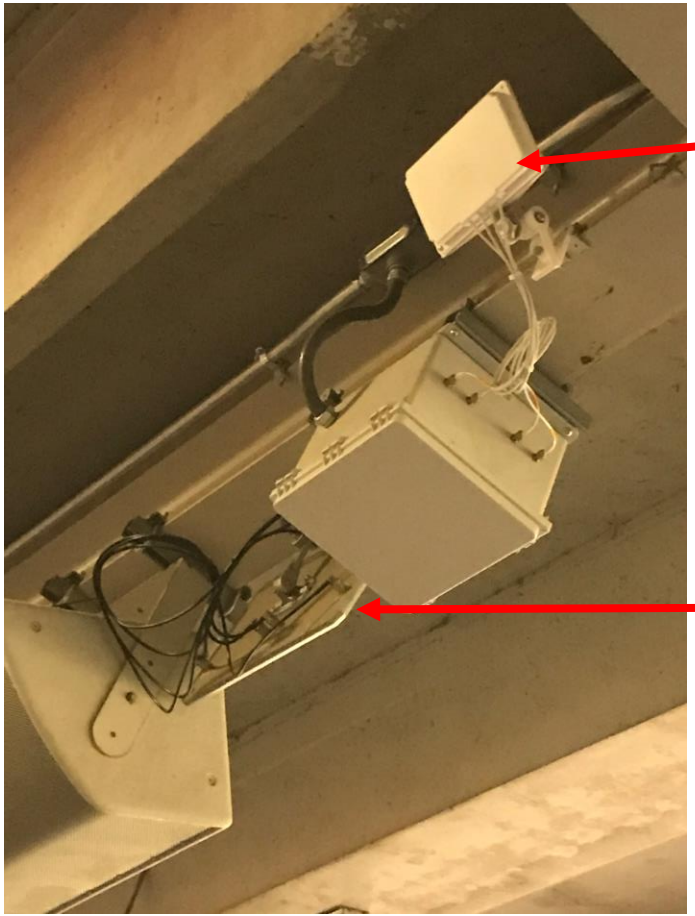
Better User Experience in Locations with Consistent Density Needs

Ideal for Warehouses: Optimize Costs with One Dual Radio Access Point That Covers Different Sections of a Large Space

3802e/p, 9120e/p or 9130 with breakout cable




Optimize Network Cost with Fewer Access Points



“Wide” Patch Antenna

Stadium Antenna

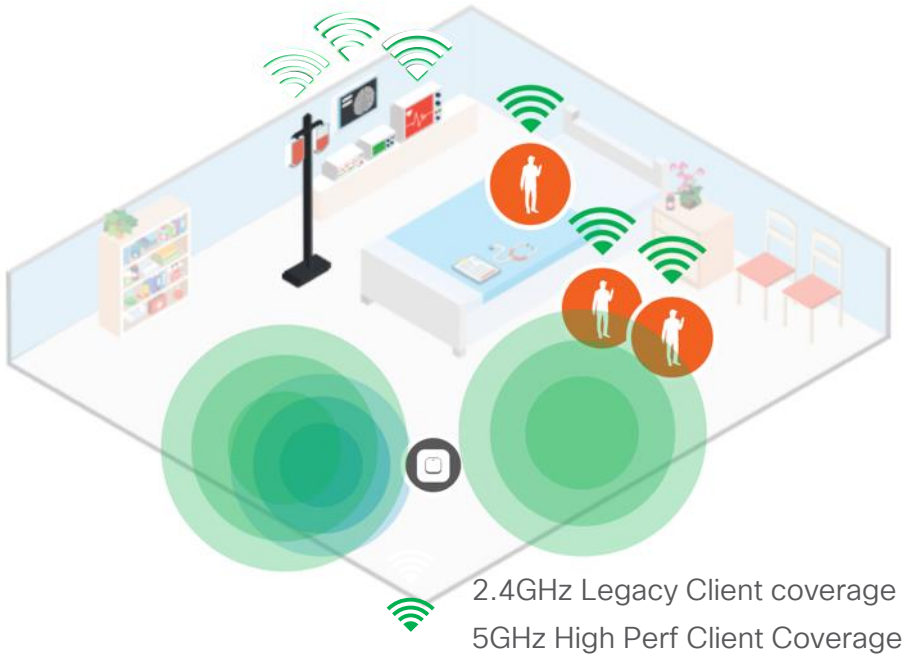
# Segment Legacy Devices in your Network

- Improve User Experience with Flexible Radio Assignment

Improve User Experience by Separating Performance Degrading Legacy Clients

Dedicate Specific 2.4Ghz Radios for Legacy Traffic Such as 11b While High Performing Clients Connect via 5Ghz Radio

Ideal for Healthcare, Warehouses and Retail Networks Where a Broad Mix of Modern and Legacy Devices Exists




Provide a Better User Experience While Extending the Life of Legacy Clients

# Flexible Radio Assignment

- A Better Mobile User Experience for High-Density Networks

- **Automatically detects** when a large number of devices are connected to a network
- **Adds capacity** by changing the access points from 2.4/5GHz to Dual 5GHz
- **Monitors the network** for security threats and RF interference that may affect performance
- **Schedule** more capacity through time of day templates
- For detailed info on FRA (and other advanced RRM topics) – see Jim Florwick's Cisco Live session BRKEWN-3010: https://www.ciscolive.com/c/dam/r/ciscolive/us/docs/2019/pdf/BRKEWN-3010.pdf

Supported on Cisco Aironet 2800/3800/4800/91XX Series Access Points

# Agenda

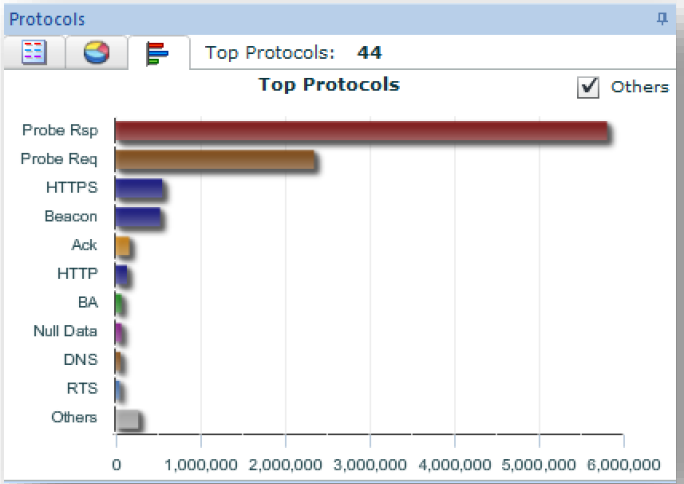
- Designing RF for High Client Densities
- **HD Wi-Fi Configuration Tips**
- HD Wi-Fi Engineering Toolkit

# Maximize your Spectrum

- Limit SSIDs (reduce management traffic)
- Filter unnecessary traffic OTA (IPv6, mcast)
- Integrate existing networks
- Optimize PHY Rates
- Monitor Noise Floor & use power adjustments
- Remove barriers to entry

# Maximizing the Spectrum

- Avoiding Excessive Management Traffic

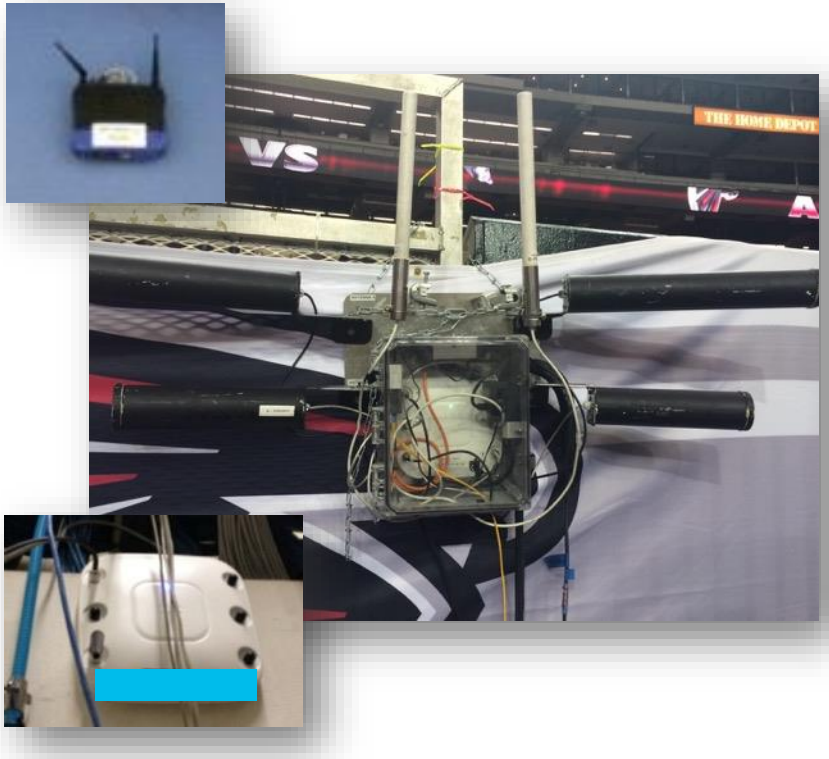



- Always aim for 1 SSID
  - **Especially** in high density areas
- More SSID's = Worse Performance
- Why?
  - Each SSID requires a separate beacon
  - Each SSID will beacon at the minimum mandatory data rate
  - Each broadcast SSID will respond to null probe requests
  - Exponential amounts of airtime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

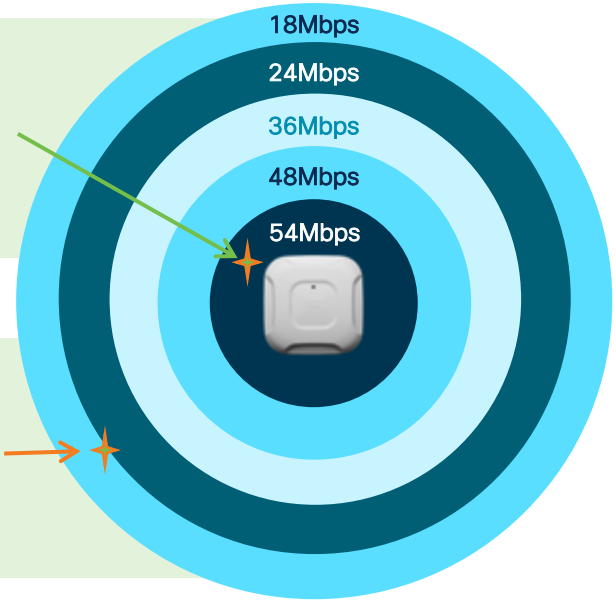


# Maximizing the Spectrum

- 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)

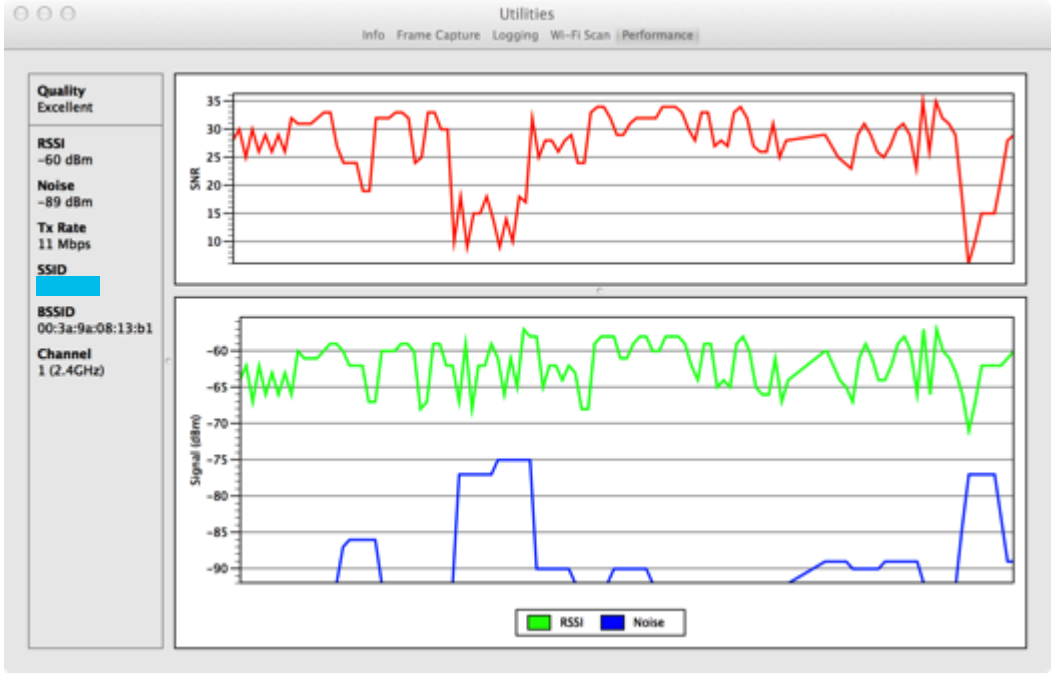



- How fast can we talk?
  - Signal (RSSI) and Noise are key factors
- As client moves further from AP or as noise worsens, client rate-shifts downward
- Lower rate, more airtime consumed
- Position AP's and antennas to allow elimination of low rates (i.e., <18mbps)
- Eliminate 802.11b rates
- Accommodate "Soft Landing"

# Maximizing the Spectrum

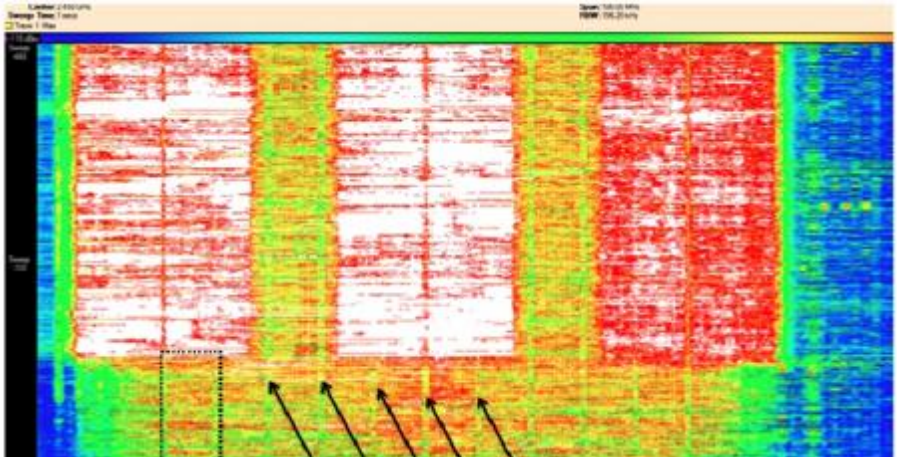
- RSSI vs. SNR

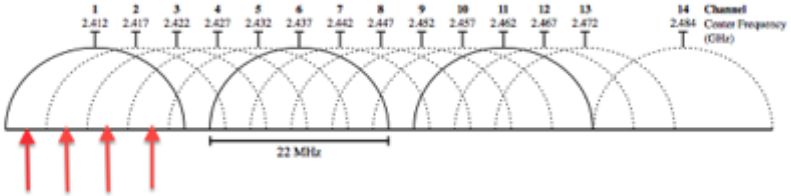
- Check your noise floor in each band during peak usage
  - Packet captures with a NIC that you trust (MacBook Pro, etc.)
  - Fluke AirCheck
  - Spectrum Expert
  - Metageek Chanalyzer for Clean Air



# Maximizing the Spectrum

- Client Induced Interference (Cont'd)






- Client-induced interference: especially damaging on 2.4GHz but also impacts 5GHz via ACI (Adjacent Channel Interference)
- Probe requests sent on *all* channels
  - Many frames on overlapping channels, driving noise floor to be higher/worse
- Getting these devices on your network can help
  - Probe frequency diminishes significantly on an associated device

# 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!
- Device classification guide:
  - http://www.cisco.com/c/en/us/td/docs/wireless/controller/technotes/8-0/device_classification_guide.html

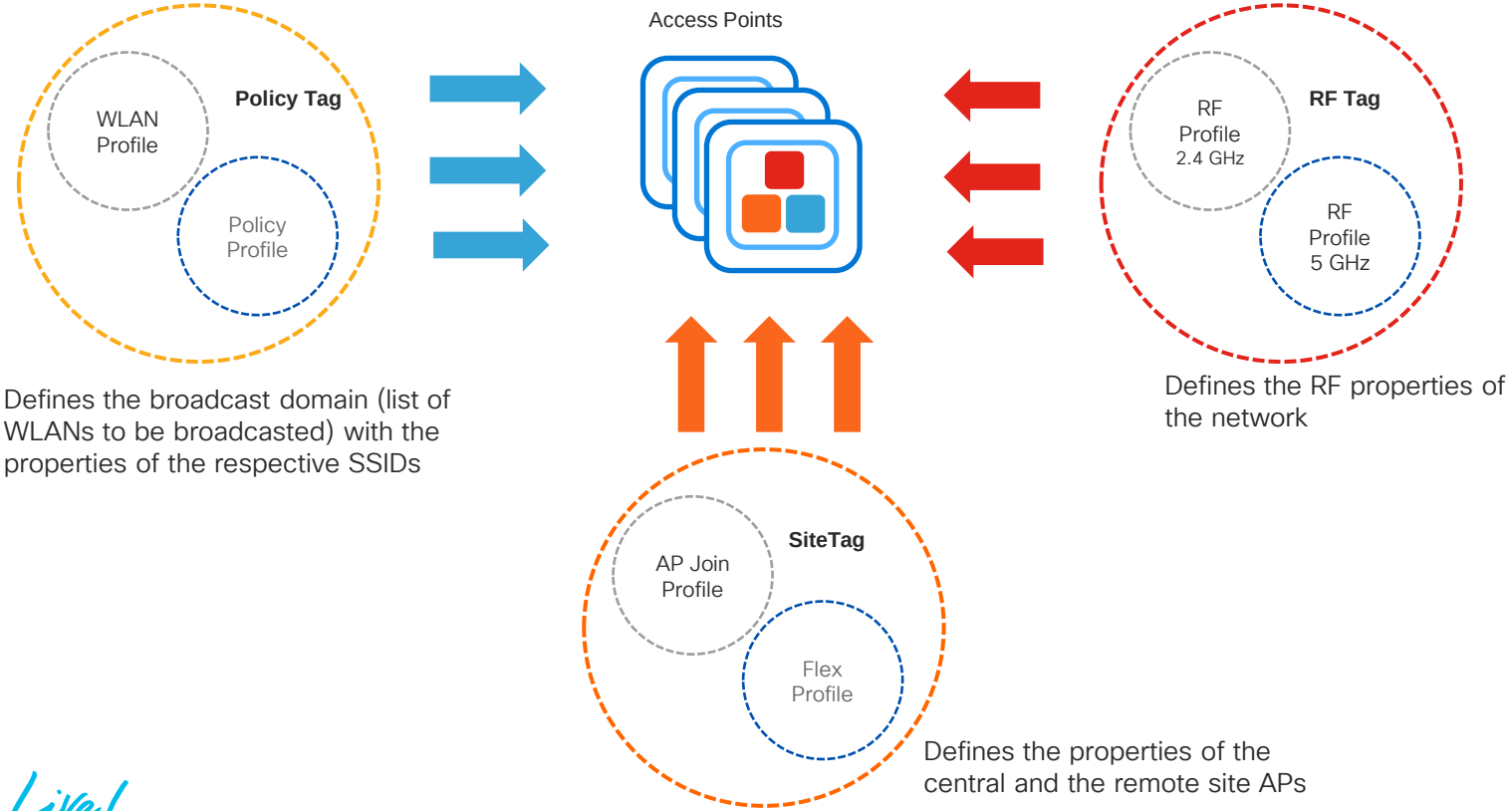
# The Basics: RF Profiles, TPC, DCA

cisco Live!

# High Density WLAN Features & Configurations


- WiFi deployments **are not "one-size-fits-all"**
- **Use RF Profiles** for granular RF control
  - **Dynamic Channel Allocation** (DCA) per RF Profile
  - **Transmit Power Control** (TPC) minimum & maximum per RF Profile
  - **RX-SOP** to selectively reduce sensitivity
  - **Channel Width** – 20MHz still preferred for Very High Density areas
- On C9800, **plan Site Tags** to balance APs across processes

# Cisco Catalyst 9800 Config Model

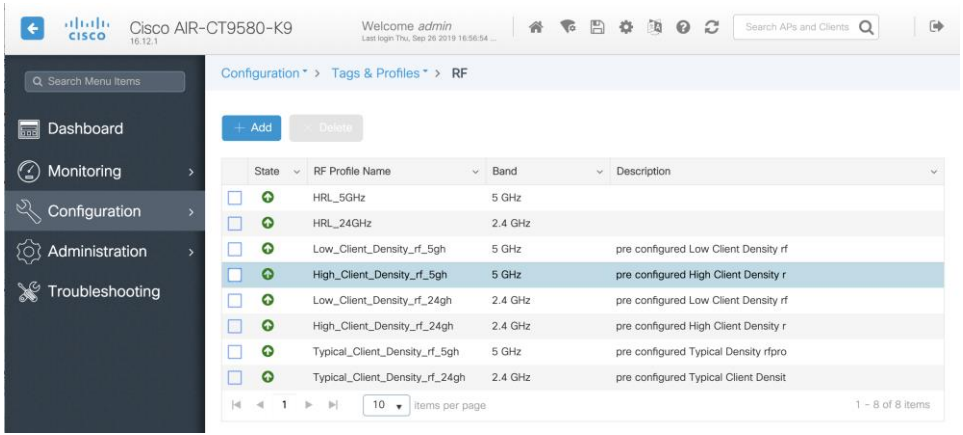



Defines the broadcast domain (list of WLANs to be broadcasted) with the properties of the respective SSIDs

Defines the RF properties of the network

Defines the properties of the central and the remote site APs

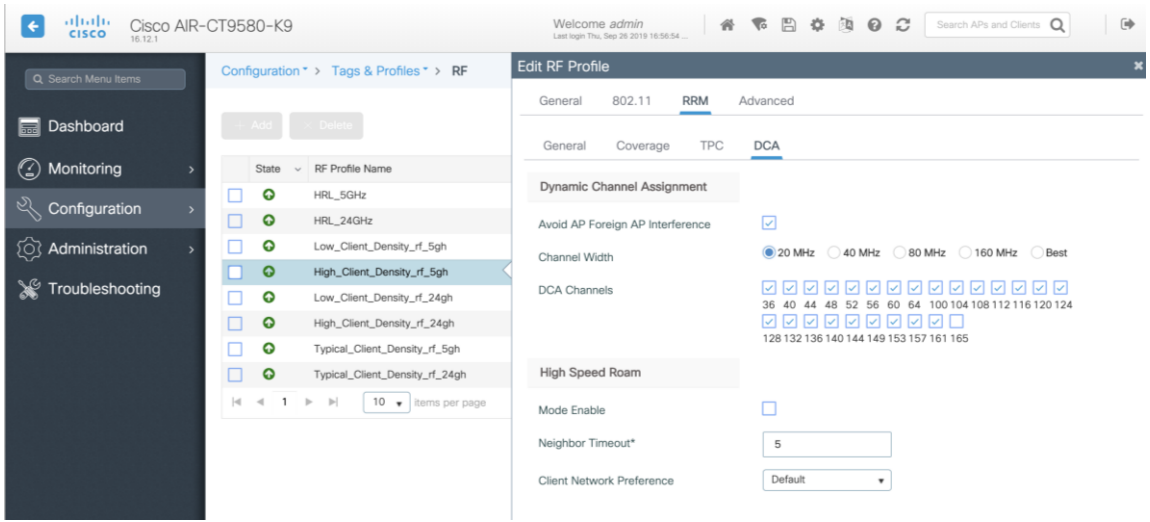
# RF Profiles for High Density Optimization




- RF Profiles provide granular control of RF parameters – especially useful in High Density WiFi
- Many HD WiFi optimizations are configured via RF Profiles

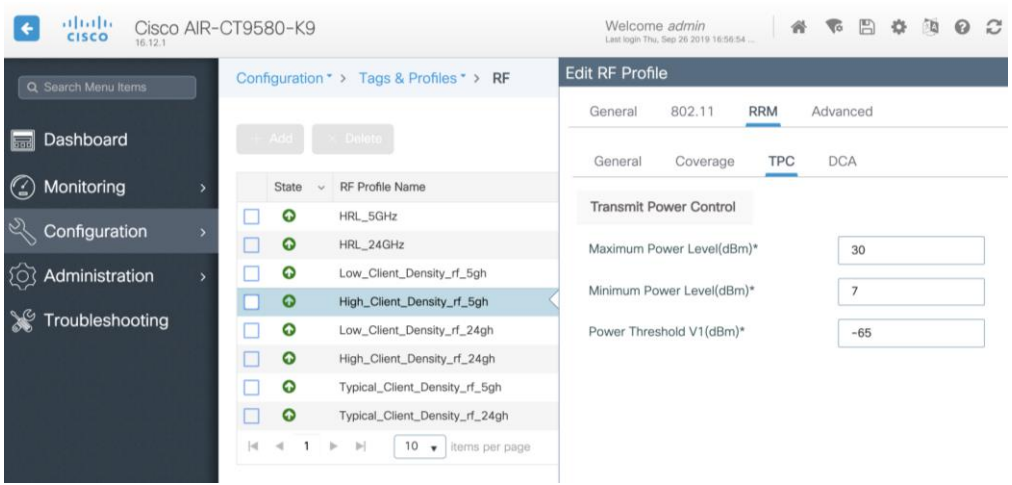
# Channel Planning with RF Profiles

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

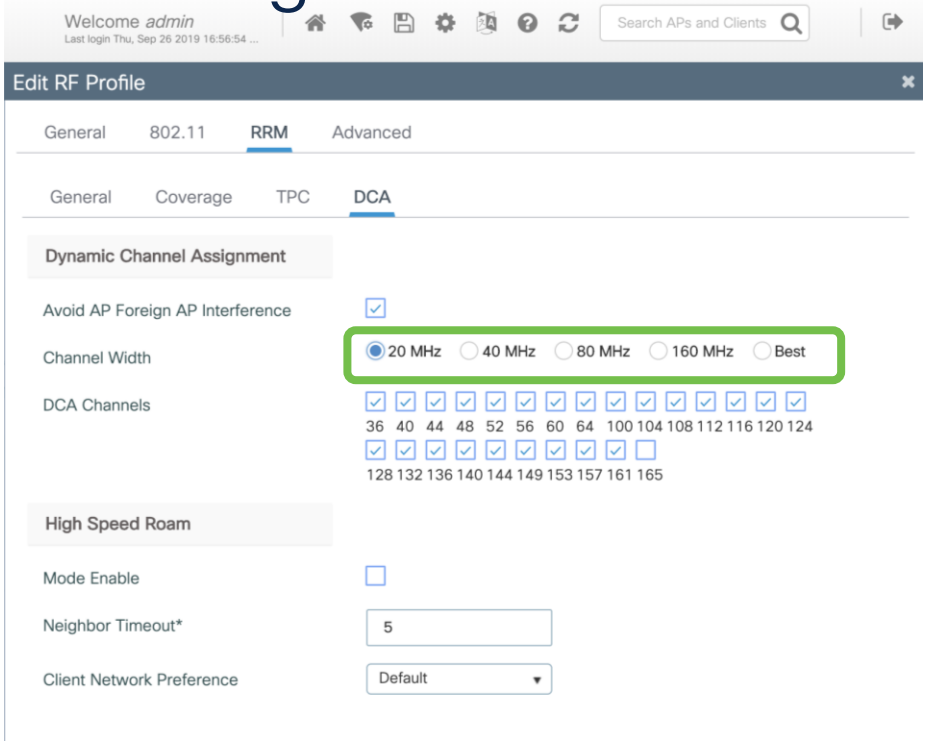


# Balancing Transmit Power with RF Profiles

- **Ensures AP-to-AP consistency** (no "client magnets") and 2.4GHz to 5GHz balance (5GHz hotter, 2.4GHz cooler)
- **TPC Min/Max:** set **actual limits on dBm levels** to avoid ambiguity of the relative "Power Levels"
- **TPC Min** – lower power limit specified for a given radio. RRM will never adjust power below this level.
- **TPC Max** – upper power limit specified for a given radio. RRM will never adjust power above this level.



# Selecting Channel Width with RF Profiles

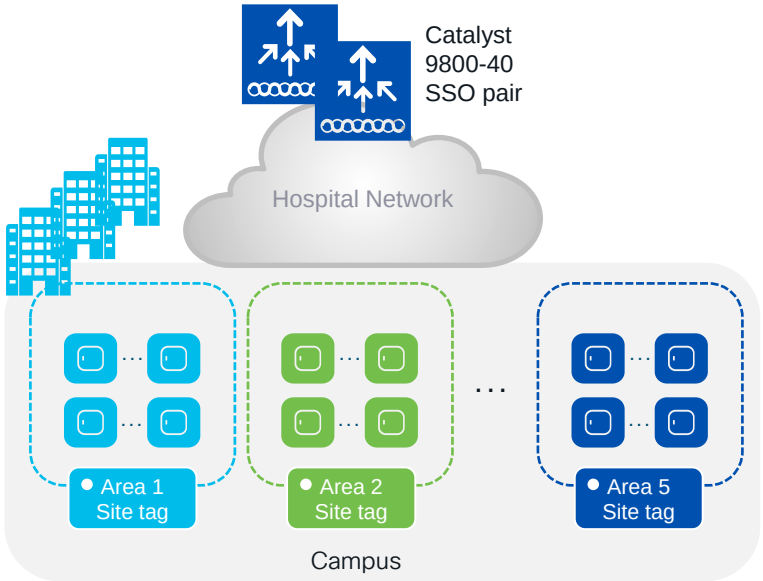



- In general, 20MHz channels provide the most channel reuse (capacity) for high density environments
- Wider channels may be used selectively in more isolated areas – smaller classrooms, lobbies, conference rooms, etc.

# RF Profiles for High Density Optimization (9800)

| | | | |
|---|---|---|---|
| RF Tag | Classroom-Tag | Theater-Tag | Office-Tag |
| RF Profile | Classrm-24g<br>Classrm-5g<br>*RXSOP, DCA, TPC customized for classrooms* | Theater-24g<br>Theater-5g<br>*RXSOP, DCA, TPC customized for theaters* | Office-24g<br>Office-5g<br>*RXSOP, DCA, TPC customized for offices* |

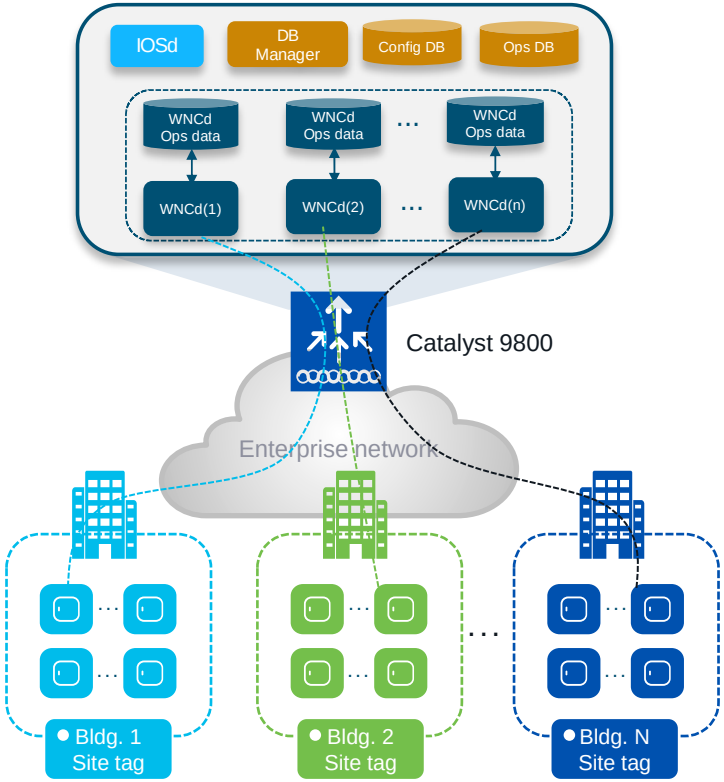
# C9800 Site Tag Design in High Density




- 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
- 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 |

The following command shows the # of WNCDs processes:

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

Refer to the C9800 Best Practices guide for the latest guidance

# 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

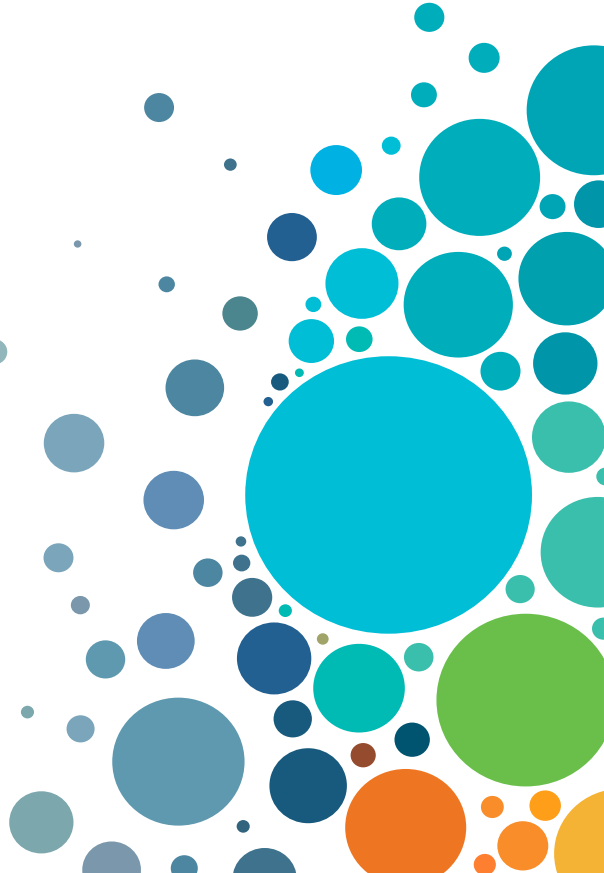
```
[redacted]#show wireless stats ap loadbalance summary
DTLS drop - 380

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
```

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



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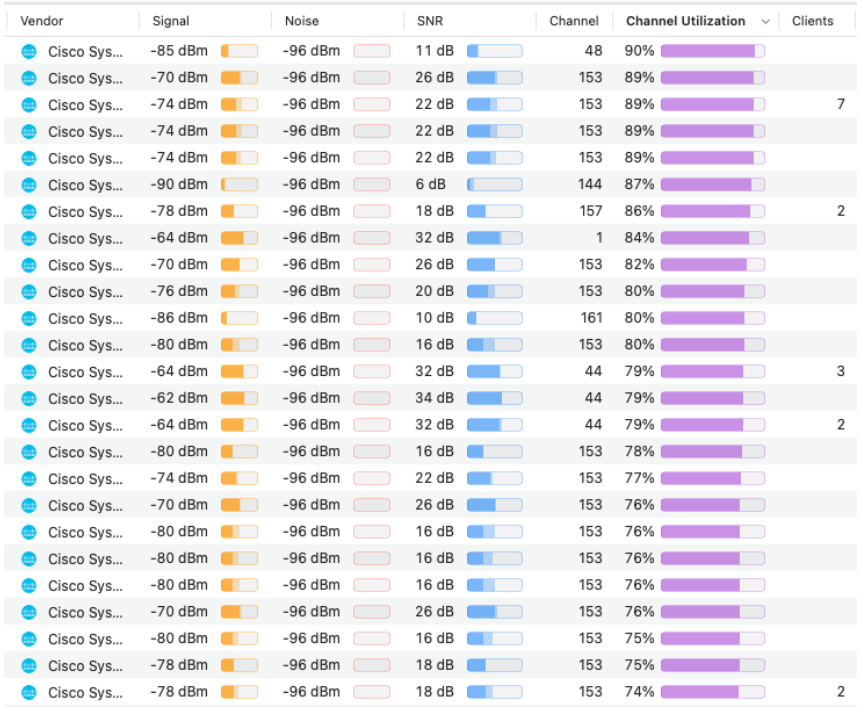
# Receive Sensitivity Threshold (RX-SOP)

"I have a well-designed network, but my Channel Utilization is always high anyway, even with low client counts. I've done as much as I can do per Best Practices. What do I do next?"



| 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

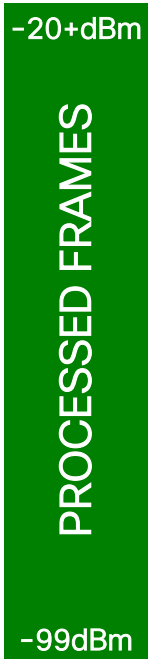
# Receive Sensitivity Threshold (RX-SOP)

- 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
- **Antenna placement** matters!
- **WiFi6 adoption may reduce the need** for RX-SOP in some environments; monitor your Channel Utilization as client adoption increases

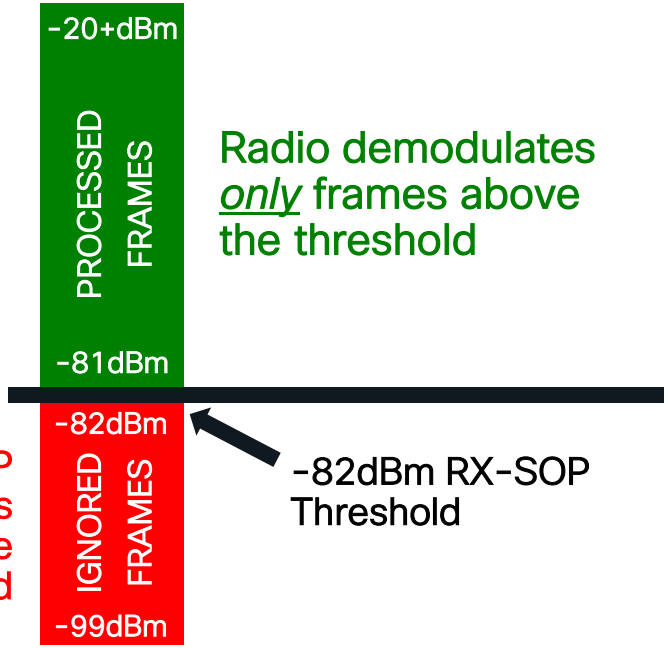
# Receive Sensitivity Threshold (RX-SOP)

Without Custom RX-SOP Threshold
(Default Radio Sensitivity)

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




With Custom RX-SOP Threshold



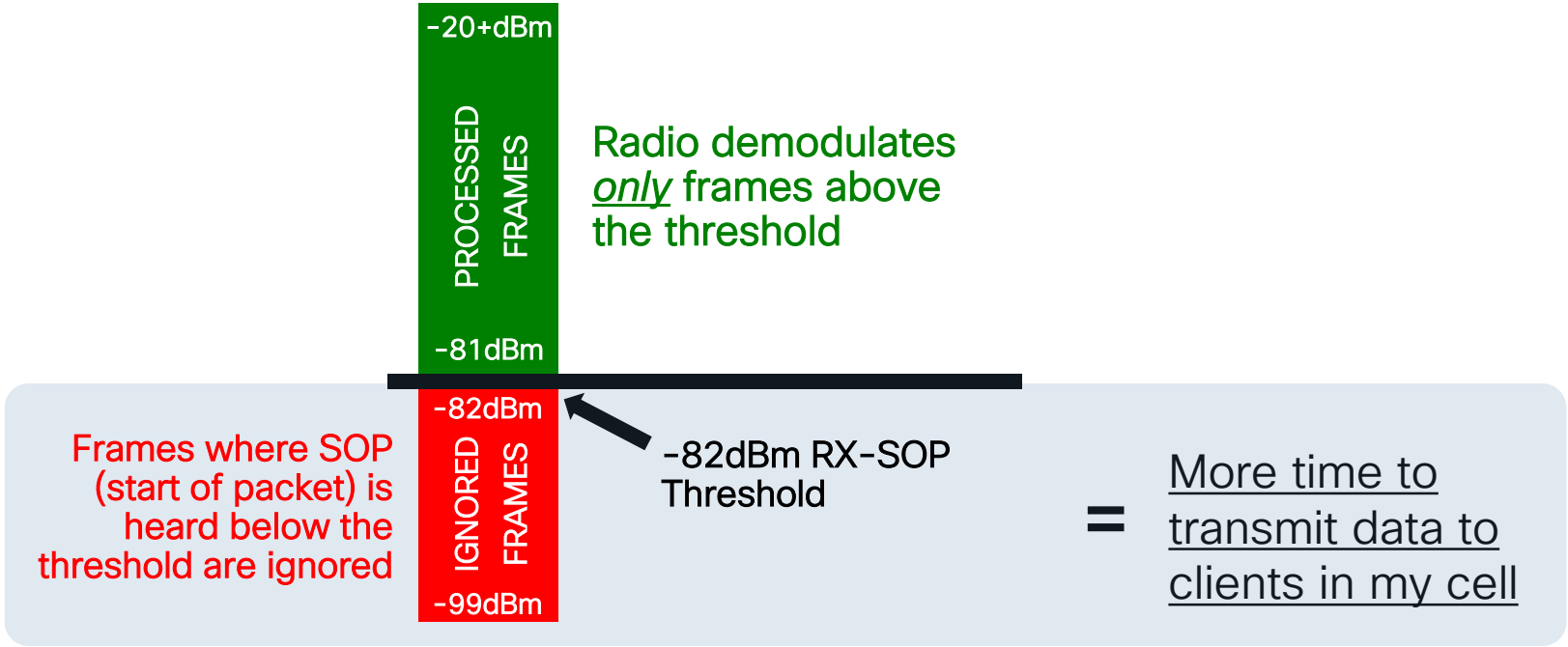

Radio demodulates *only* frames above the threshold

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

-82dBm RX-SOP Threshold

# Receive Sensitivity Threshold (RX-SOP)

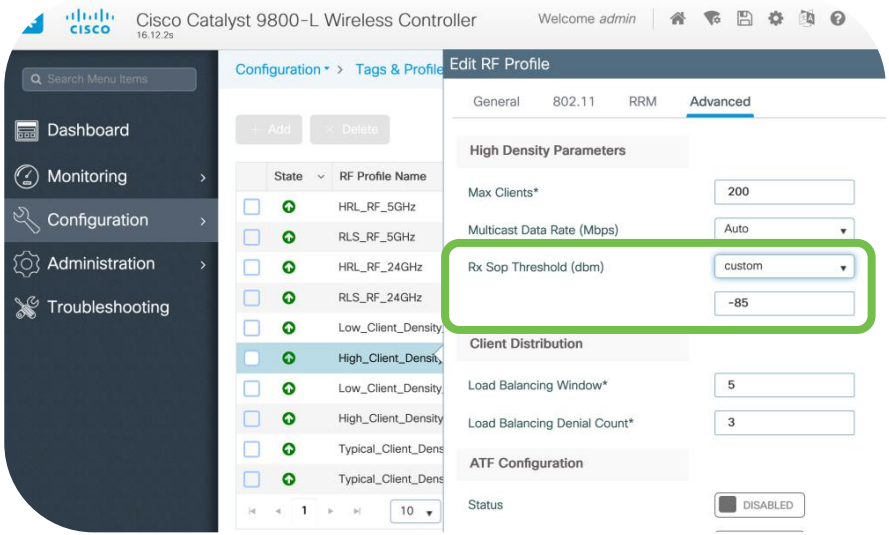
With Custom RX-SOP Threshold



# 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 threshold

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



# 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

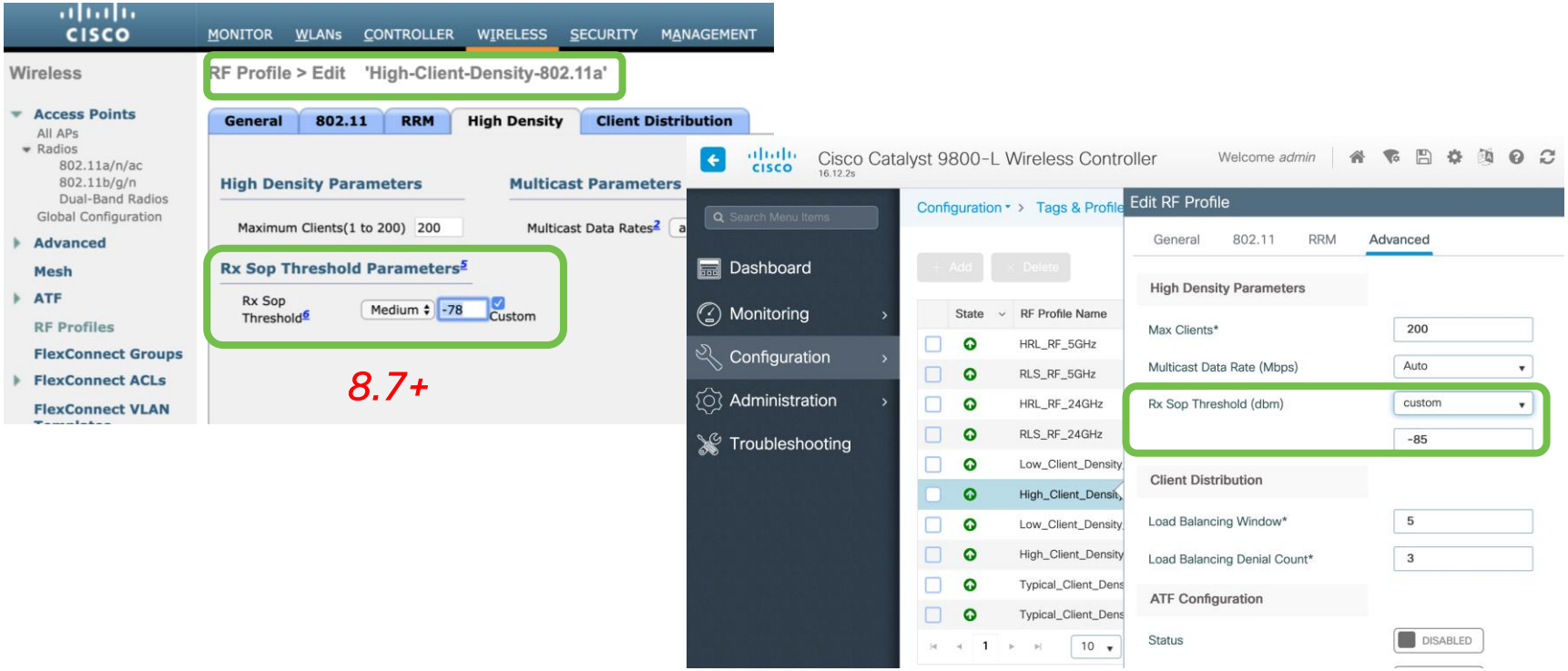
*Example: Worst RSSI value is -72; initial RXSOP with 15dB cushion = -87*

# HOW TO: Optimize RX-SOP Thresholds

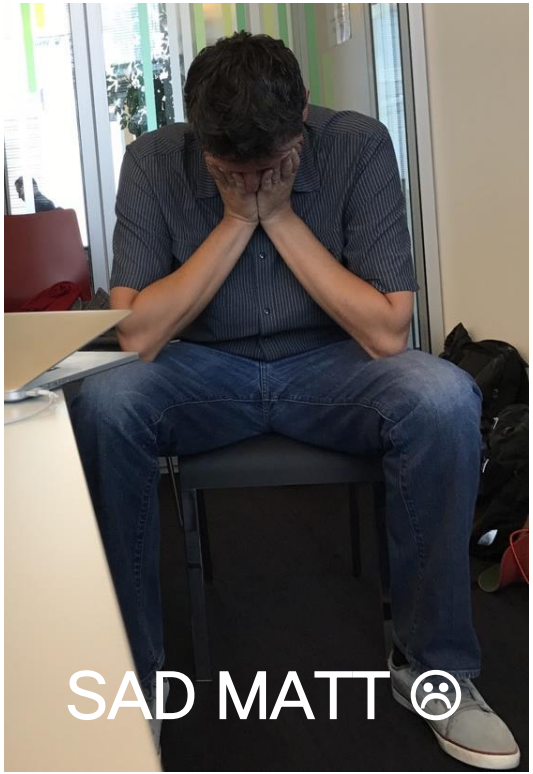
The last rule……

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

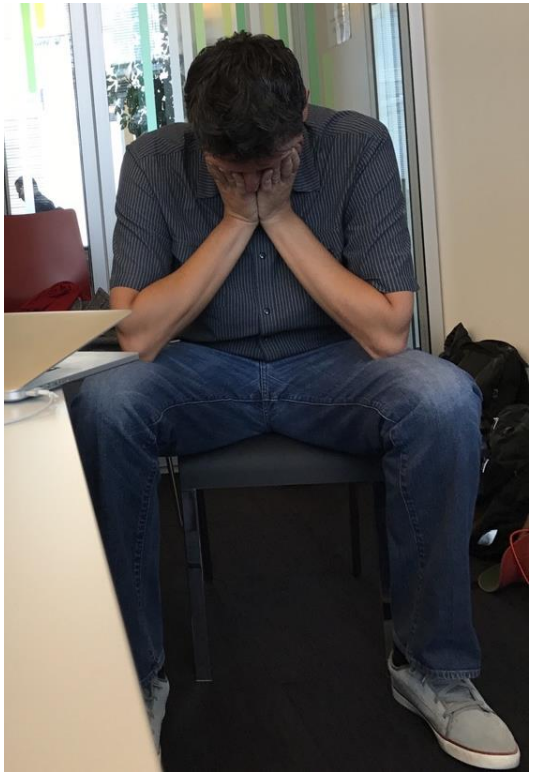
# Tuning RX-SOP Thresholds: GUI



# Common High Density Optimization Mistakes



# Common High Density Optimization Mistakes

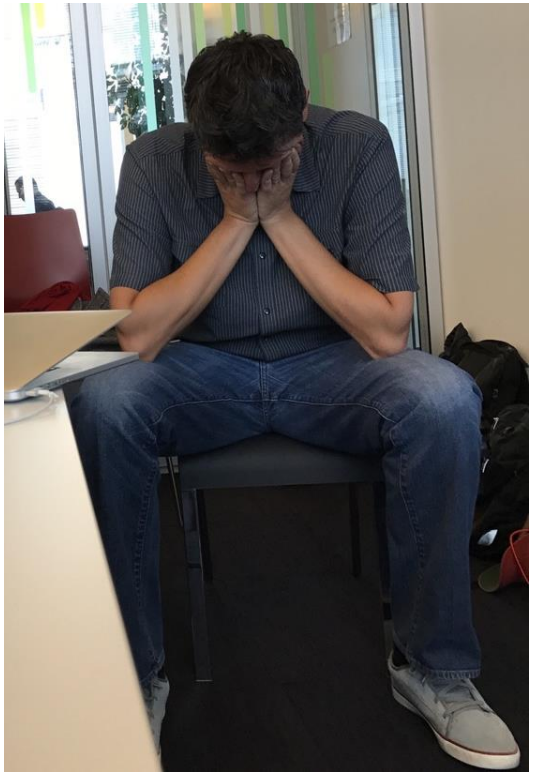


- AP-to-AP transmit power imbalance (causes “Magnet” / overloaded AP’s)


5GHz TX Power: 7dB
2 clients


5GHz TX Power: 17dB
50 clients

# 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: 10dB
20 dual-band clients

5GHz: 7dB
0 dual-band clients

# Case Study – Poor HD Optimization

Open Secure

| BSSID | Beacon Airtime | Vendor | SNR | Device Name | Signal | Noise | Channel | Channel Width | Band | Channel Utilization |
|---|---|---|---|---|---|---|---|---|---|---|
| <Multiple values> | 5.612 ms | | 38 dB | | -47 | -85 | 1, 6, 11, 48, 112, 124 | 20, 40, 80 MHz | 2.4, 5 GHz | 85% |
| **<Multiple values>** | **4.804 ms** | | **40 dB** | | **-47** | **-87** | **1, 6, 11, 48, 112** | **20, 40, 80 MHz** | **2.4, 5 GHz** | **83%** |
| **38:FF:36:9D:63:A8** | **0.204 ms** | | **40 dB** | | **-47** | **-87** | **6** | **20 MHz** | **2.4 GHz** | **83%** |
| 38:FF:36:9D:7E:58 | 0.204 ms | | 33 dB | | -61 | -94 | 6 | 20 MHz | 2.4 GHz | 74% |
| 38:FF:36:9D:85:F8 | 0.196 ms | | 24 dB | | -63 | -87 | 1 | 20 MHz | 2.4 GHz | 76% |
| 34:8F:27:84:8B:D8 | 0.204 ms | | 23 dB | | -64 | -87 | 11 | 20 MHz | 2.4 GHz | 76% |
| 38:FF:36:9D:82:C8 | 0.204 ms | | 23 dB | | -64 | -87 | 11 | 20 MHz | 2.4 GHz | 69% |
| **38:FF:36:9D:63:AC** | **0.104 ms** | | **20 dB** | | **-67** | **-87** | **48** | **40 MHz** | **5 GHz** | **39%** |
| 38:FF:36:9D:7F:D8 | 0.204 ms | | 19 dB | | -68 | -87 | 6 | 20 MHz | 2.4 GHz | 82% |
| 38:FF:36:9D:7E:28 | 0.204 ms | | 16 dB | | -69 | -85 | 6 | 20 MHz | 2.4 GHz | 79% |
| 38:FF:36:9C:6A:D8 | 0.204 ms | | 18 dB | | -69 | -87 | 1 | 20 MHz | 2.4 GHz | 77% |
| 38:FF:36:9D:84:F8 | 0.204 ms | | 12 dB | | -73 | -85 | 6 | 20 MHz | 2.4 GHz | 82% |
| 38:FF:36:9D:7F:F8 | 0.204 ms | | 12 dB | | -75 | -87 | 11 | 20 MHz | 2.4 GHz | 78% |
| 38:FF:36:9C:76:9C | 0.104 ms | | 11 dB | | -76 | -87 | 48 | 40 MHz | 5 GHz | 37% |
| 38:FF:36:9D:7E:5C | 0.104 ms | | 11 dB | | -76 | -87 | 48 | 40 MHz | 5 GHz | 31% |
| 38:FF:36:9D:82:CC | 0.108 ms | | 10 dB | | -77 | -87 | 112 | 40 MHz | 5 GHz | 43% |
| 38:FF:36:9C:65:88 | 0.204 ms | | 16 dB | | -78 | -94 | 11 | 20 MHz | 2.4 GHz | 77% |
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- Same SSID, same AP – 2.4GHz overpowers 5GHz

http://www.adriangranados.com/apps/wifi-explorer

# Case Study – Poor HD Optimization

Open Secure

| BSSID | Beacon Airtime | Vendor | SNR | Device Name | Signal | Noise | Channel | Channel Width | Band | Channel Utilization |
|---|---|---|---|---|---|---|---|---|---|---|
| <Multiple values> | 5.612 ms | | 38 dB | | -47 | -85 | 1, 6, 11, 48, 112, 124 | 20, 40, 80 MHz | 2.4, 5 GHz | 85% |
| **<Multiple values>** | **4.804 ms** | | **40 dB** | | **-47** | **-87** | **1, 6, 11, 48, 112** | **20, 40, 80 MHz** | **2.4, 5 GHz** | **83%** |
| **38:FF:36:9D:63:A8** | **0.204 ms** | | **40 dB** | | **-47** | **-87** | **6** | **20 MHz** | **2.4 GHz** | **83%** |
| 38:FF:36:9D:7E:58 | 0.204 ms | | 33 dB | | -61 | -94 | 6 | 20 MHz | 2.4 GHz | 74% |
| 38:FF:36:9D:85:F8 | 0.196 ms | | 24 dB | | -63 | -87 | 1 | 20 MHz | 2.4 GHz | 76% |
| 34:8F:27:84:8B:D8 | 0.204 ms | | 23 dB | | -64 | -87 | 11 | 20 MHz | 2.4 GHz | 76% |
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| **38:FF:36:9D:63:AC** | **0.104 ms** | | **20 dB** | | **-67** | **-87** | **48** | **40 MHz** | **5 GHz** | **39%** |
| 38:FF:36:9D:7F:D8 | 0.204 ms | | 19 dB | | -68 | -87 | 6 | 20 MHz | 2.4 GHz | 82% |
| 38:FF:36:9D:7E:28 | 0.204 ms | | 16 dB | | -69 | -85 | 6 | 20 MHz | 2.4 GHz | 79% |
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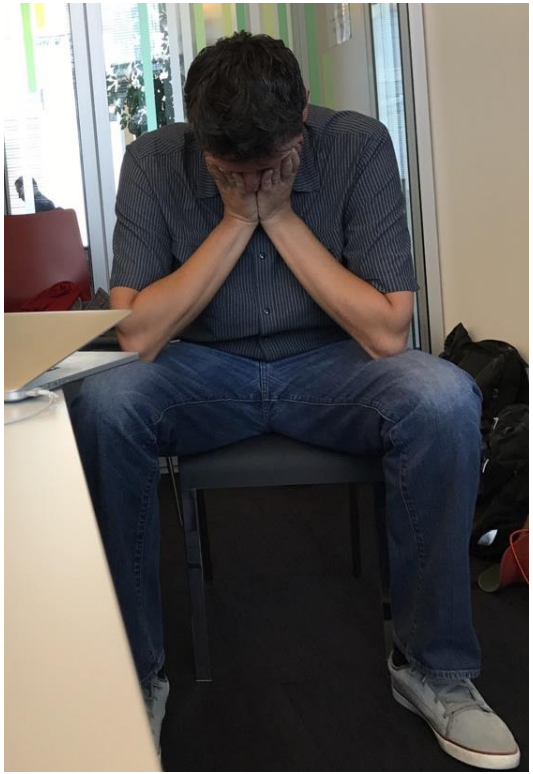
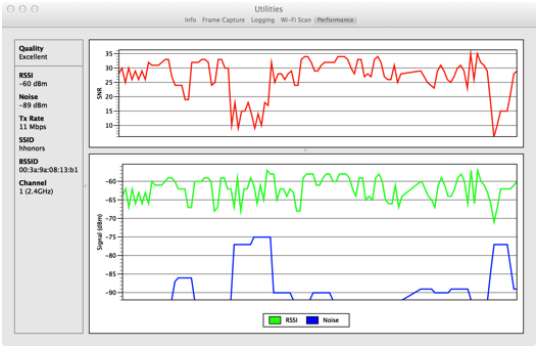
- Same SSID, same AP – 2.4GHz overpowers 5GHz
- 2.4GHz is in very bad shape (high CU, low throughput)
- **I can't get on 5GHz because 2.4 is too hot!**

http://www.adriangranados.com/apps/wifi-explorer

# 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)
- Transmit power too low to overcome noise floor



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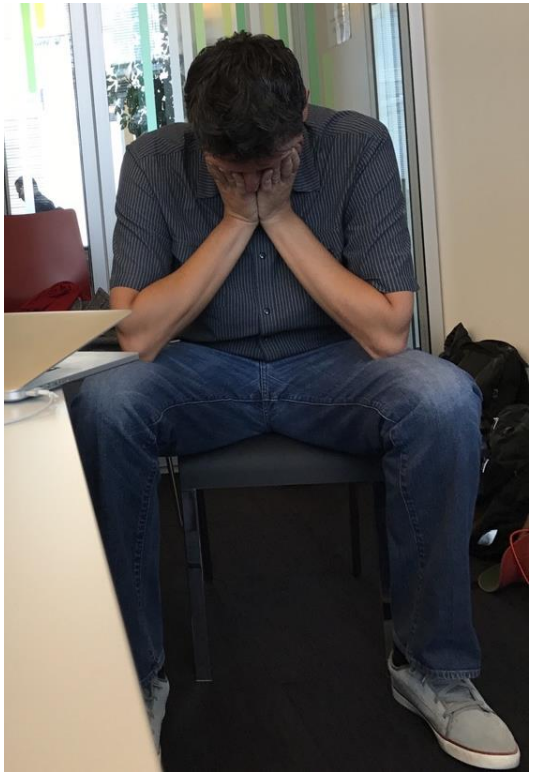

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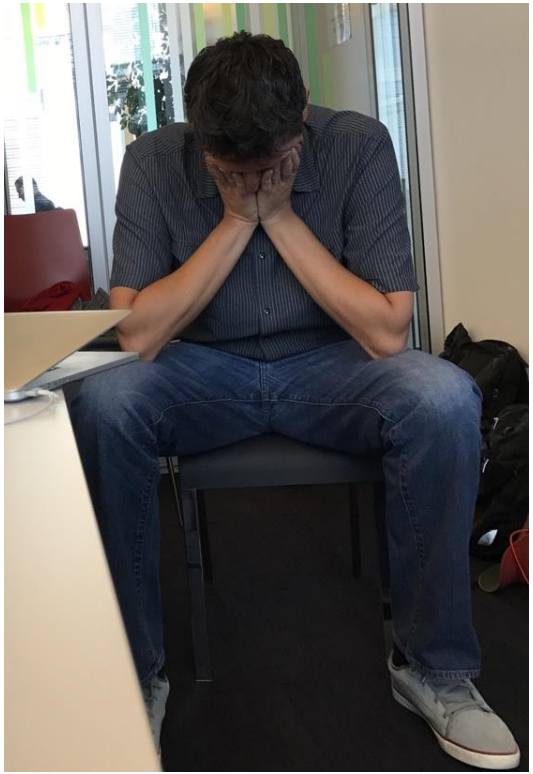

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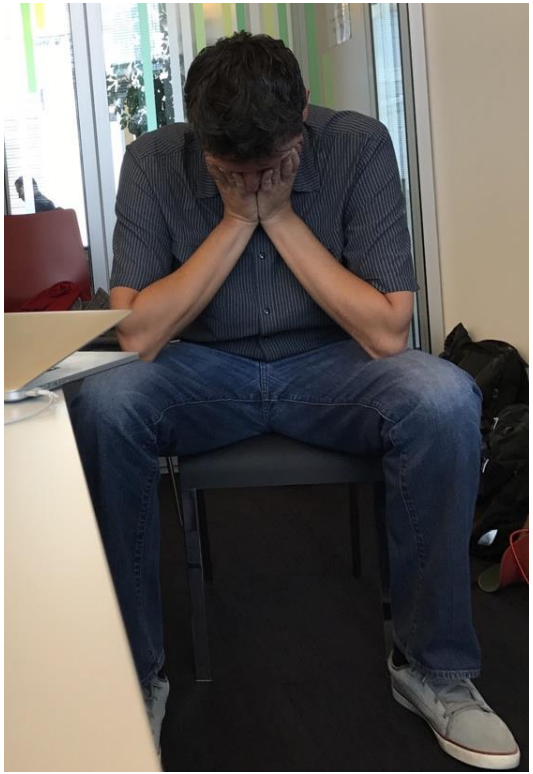

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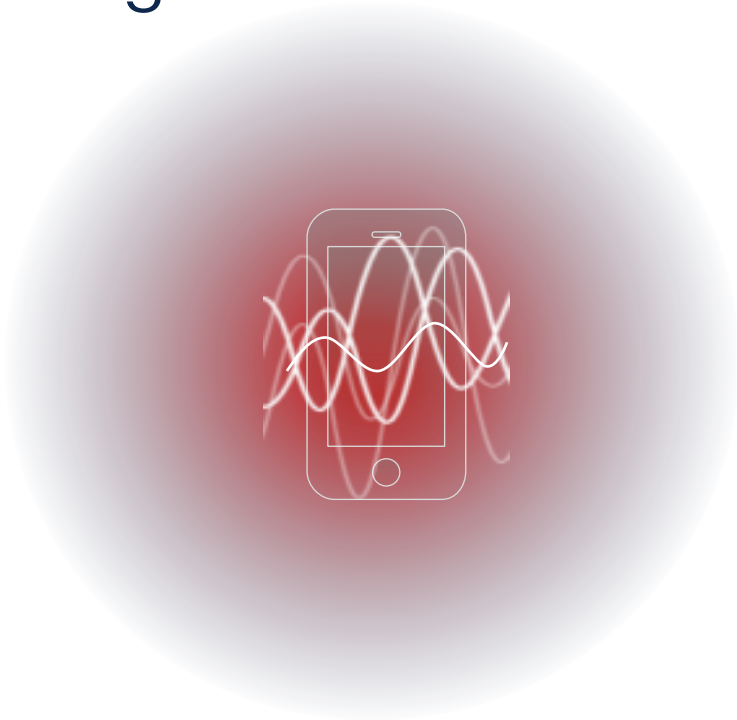
- Too many SSID’s enabled (not using AP Groups to control where SSID’s are enabled)

# 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

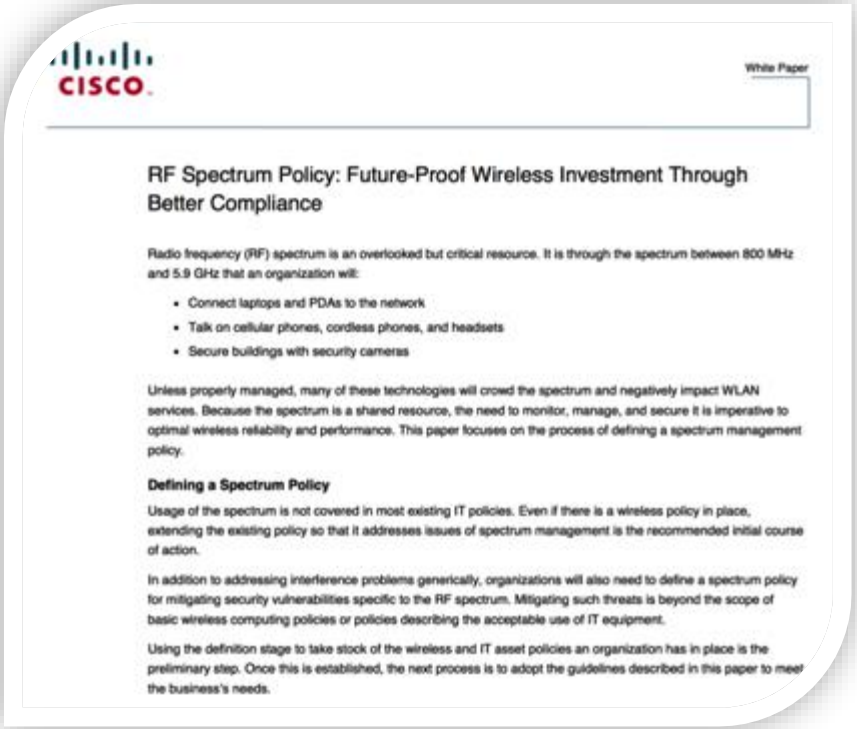
# Non-WiFi Interferers


- 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

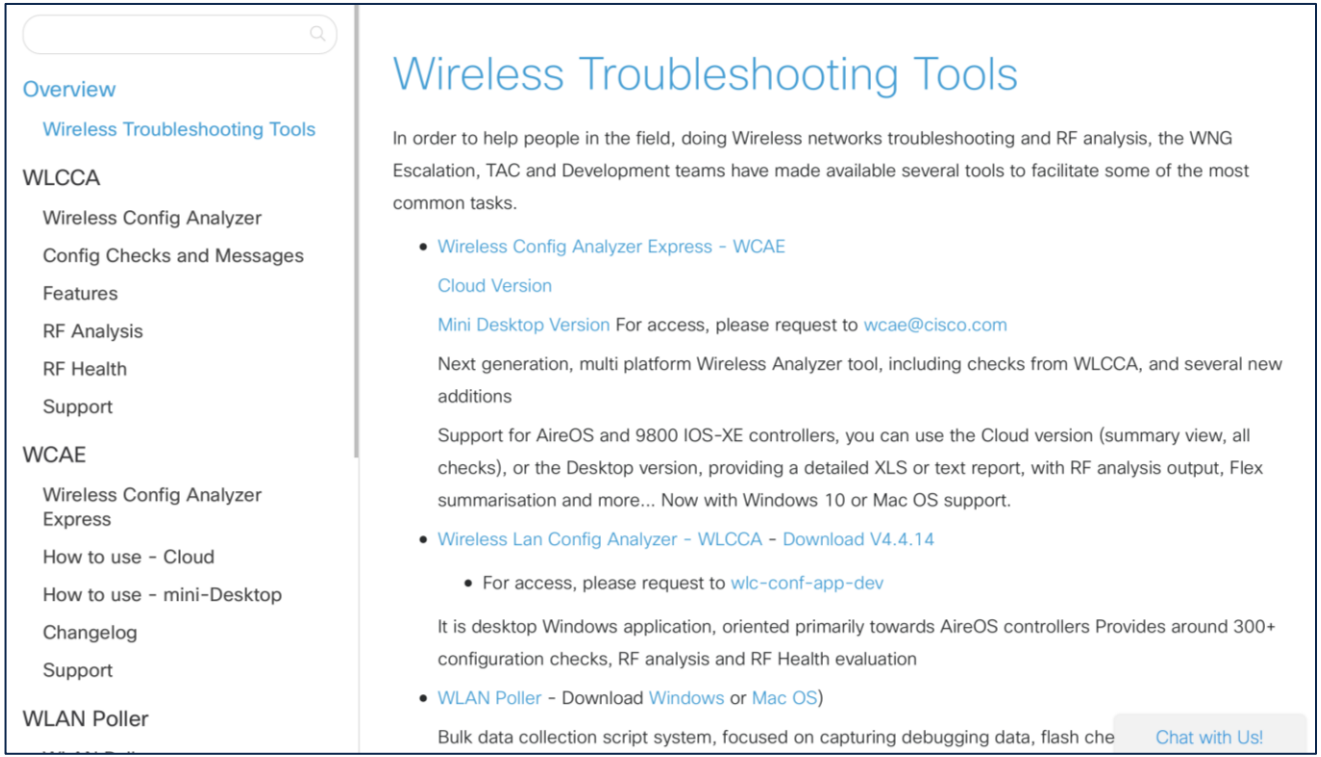
## Site Survey Tools

- Ekahau Pro & Sidekick

## NetOps, AIOps, DevOps Tools

- Cisco DNA Center Assurance

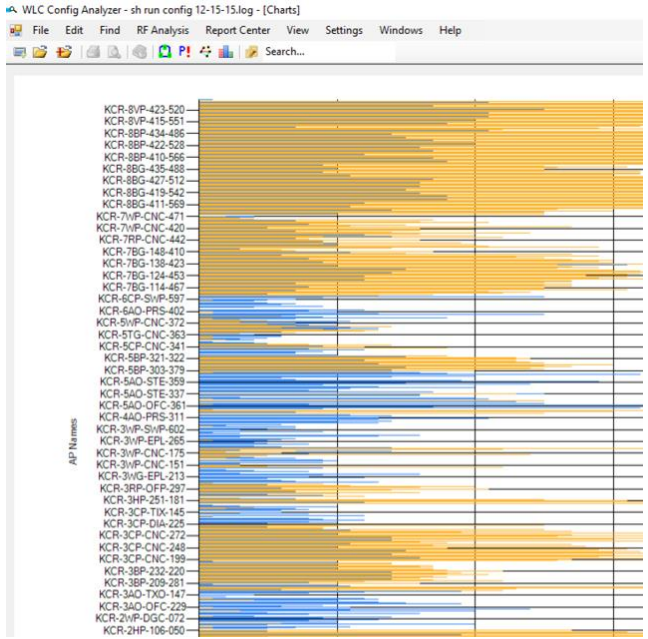
# Wireless Troubleshooting Tools




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

# Wireless Troubleshooting Tools

- The WLC Config Analyzer (WLCCA) is an extremely valuable tool when validating and optimizing a Cisco Wi-Fi deployment
- WLCCA 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

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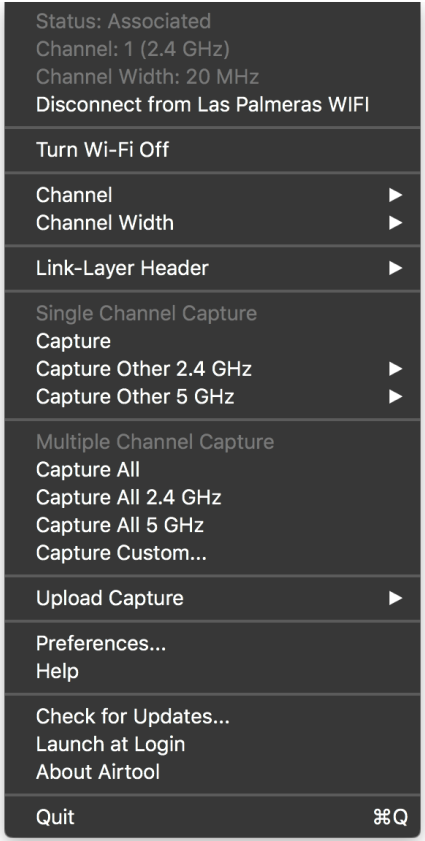
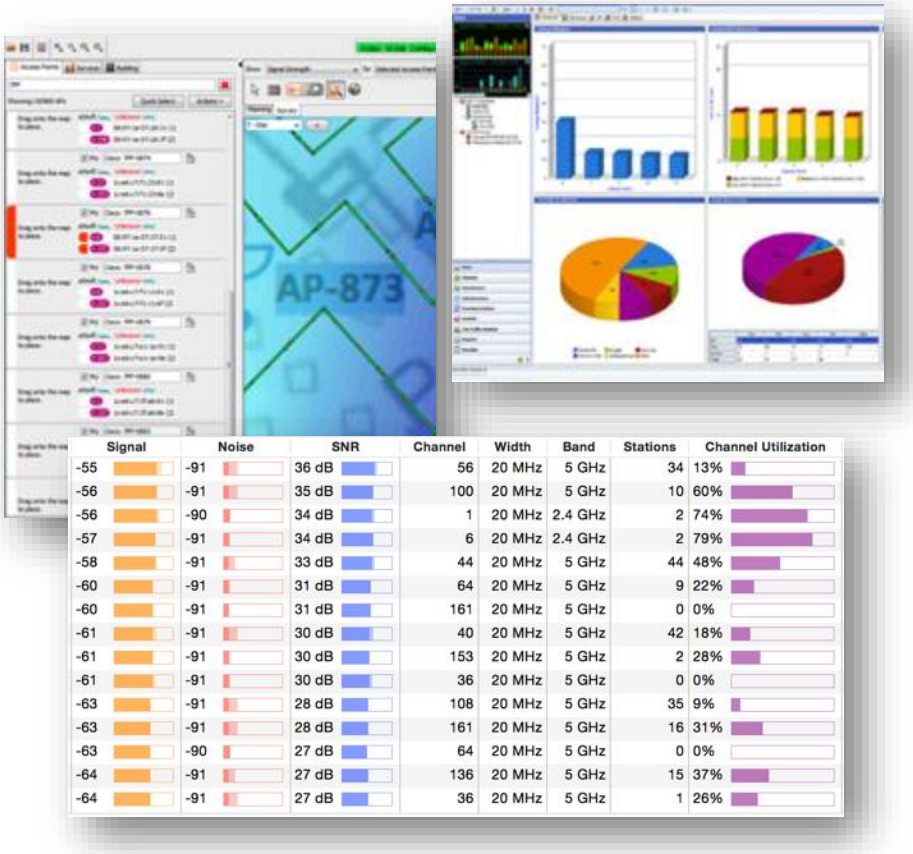
# Packet Captures

- 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



# Ekahau Sidekick

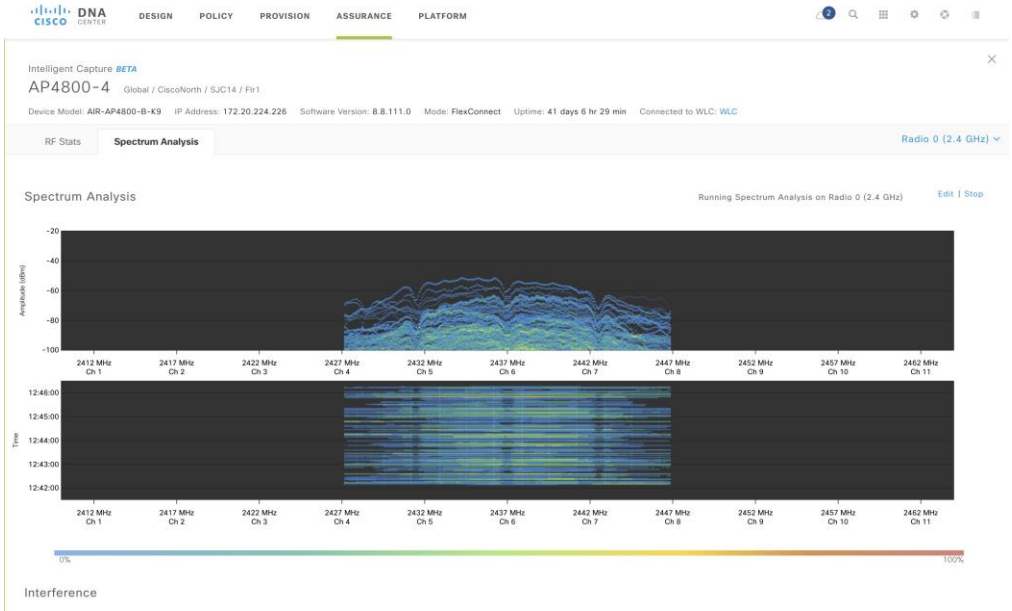

- Multi-Radio Survey Device, Spectrum Analyzer, and Realtime Troubleshooting Tool
- No more USB dongles that you may or may not inadvertently break off (not that we've ever done that…)

https://www.ekahau.com/products/sidekick/overview/

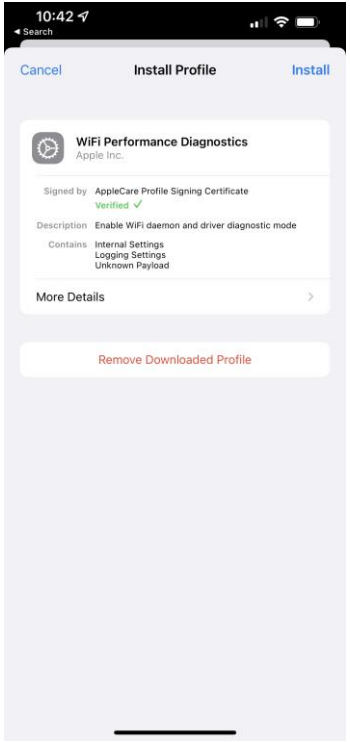
# Spectrum Analysis

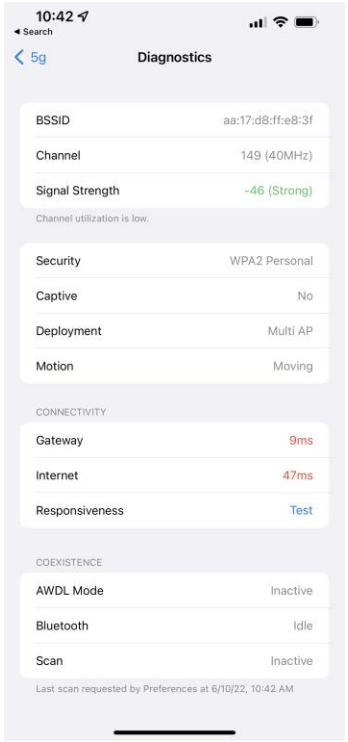
Cisco DNA Center Intelligent Capture

- 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/

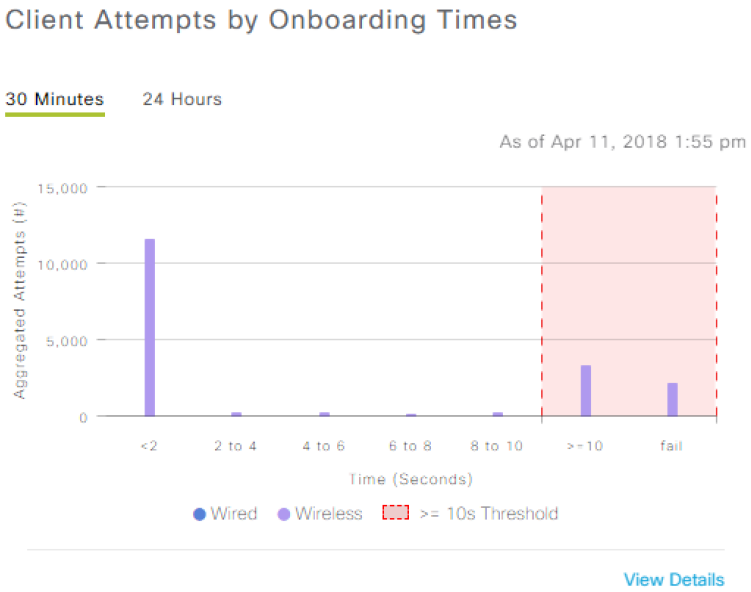
## Profile Download:

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**

# Technical Session Surveys

- Attendees who fill out a minimum of four session surveys and the overall event survey will get Cisco Live branded socks!
- Attendees will also earn 100 points in the Cisco Live Game for every survey completed.
- These points help you get on the leaderboard and increase your chances of winning daily and grand prizes.

# Cisco Learning and Certifications

From technology training and team development to Cisco certifications and learning plans, let us help you empower your business and career. www.cisco.com/go/certs

**Pay for Learning with Cisco Learning Credits**

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Network simulation platform for design, testing, and troubleshooting

**Cisco Learning Network**
Resource community portal for certifications and learning

## Train

**Cisco Training Bootcamps**
Intensive team & individual automation and technology training programs

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Authorized training partners supporting Cisco technology and career certifications

**Cisco Instructor-led and Virtual Instructor-led training**
Accelerated curriculum of product, technology, and certification courses

## Certify

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Recertification training options for Cisco certified individuals

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# 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

cisco Live!


# Thank you


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ALL IN