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# Wi-Fi Roaming Revealed

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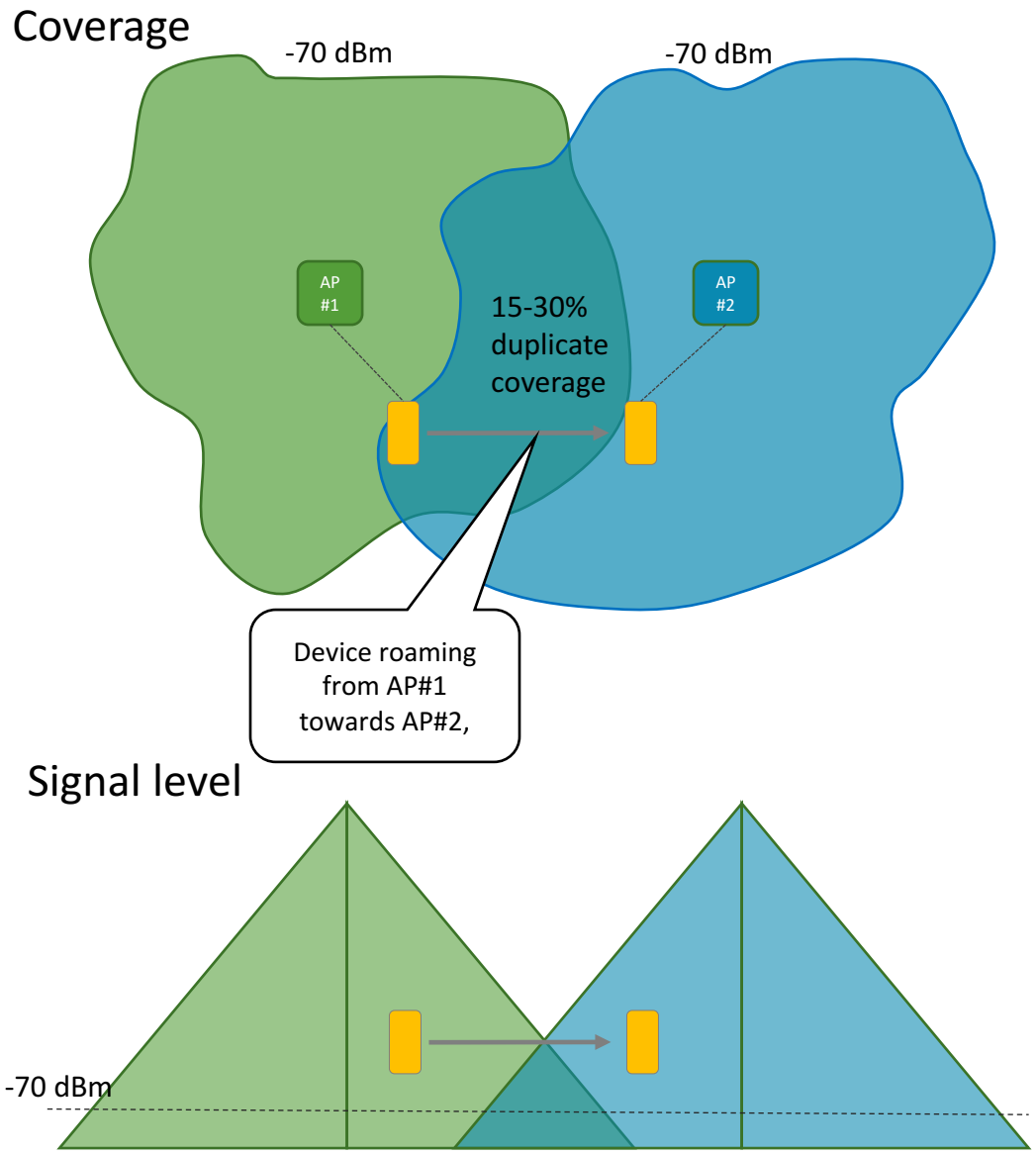
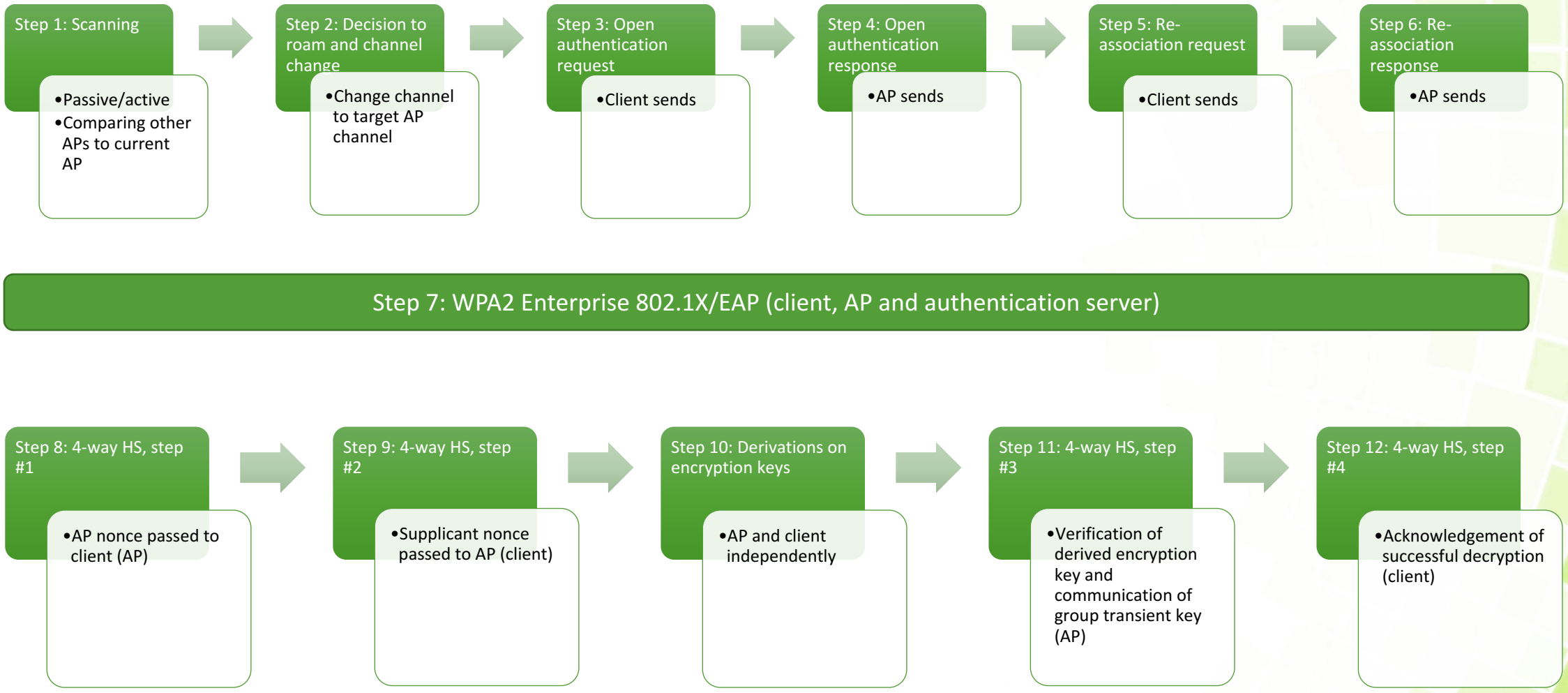
@VPonwireless

# Wi-Fi Roaming




- Enables Mobility
- Layer 2 / Layer 3 roaming
- Wi-Fi terminals make the decision
- Large variance in Wi-Fi drivers/devices
- Various techniques used at the network side
- Roaming gap from 10ms to >1000ms depending on encryption and authentication
- Acceptable gap depends on the application
  - Voice requires < 100-150ms delay
- Enterprises should use only WPA2-Enterprise level security with Radius server

# Layer 2 roaming phases




http://www.networkcomputing.com/wireless-infrastructure/wifi-fast-roaming-simplified/1993108957

# Client operation during roaming

- Makes always the final roaming decision
- Vendor proprietary, mostly confidential
- Pre-emptive discovery / Roam time discovery
- Active scanning threshold around -65 - -70 dBm
- Roaming threshold around -70 - -75 dBm
- Hysteresis, 5-12 dB better signal needed, prevents ping-pong
- Client's roaming decision factors
  - Signal strength (RSSI)
  - SNR
  - Missed beacons
  - Frame retries
  - Data rates
  - Bit error rate/CRC

Coleman, D, et. al. CWSP Study guide
7signal Mysteries of Wi-Fi roaming revealed

# AP-to-AP operation during roaming

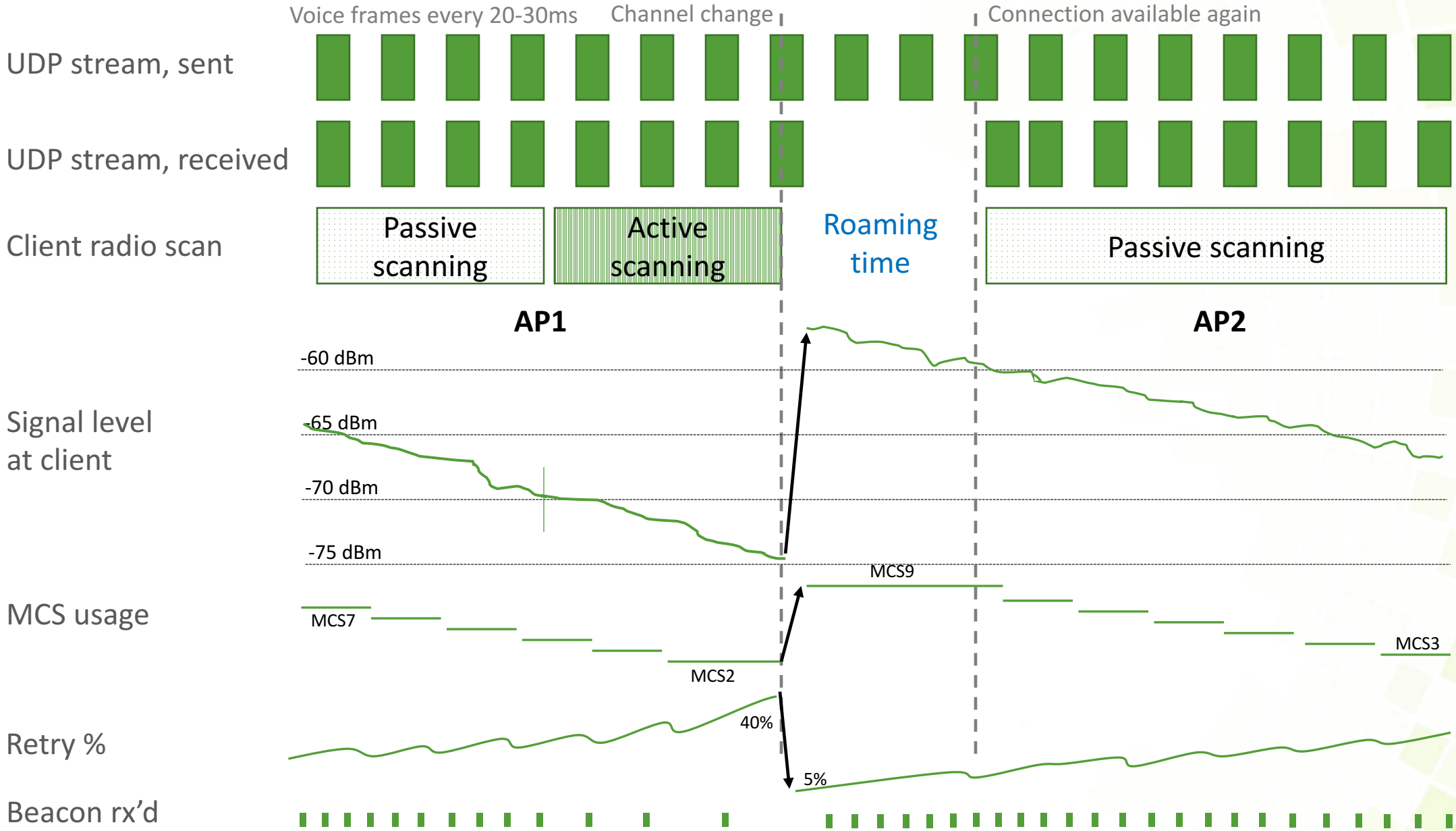
1. Re-association request to target AP + ACK
   - Includes original AP MAC
2. Target AP communicates with original AP over the 802.3 Ethernet
   - Notify original AP about roaming client
   - Request buffered data from original AP
   - Communications through controller or at the edge between cooperative APs
3. Target AP receives buffered data
   - Old AP send buffered data which was stored while client was not reachable
4. Target AP sends re-association response to client + ACK
5. Buffered data is forwarded to client
6. If process fails, client attempts to resume communications to original AP

- AP to AP operation during roaming is not standardized. Implementations vary.
- APs need to be in the same VLAN to be able exchange information

Coleman, D, et.al. CWSP Study guide

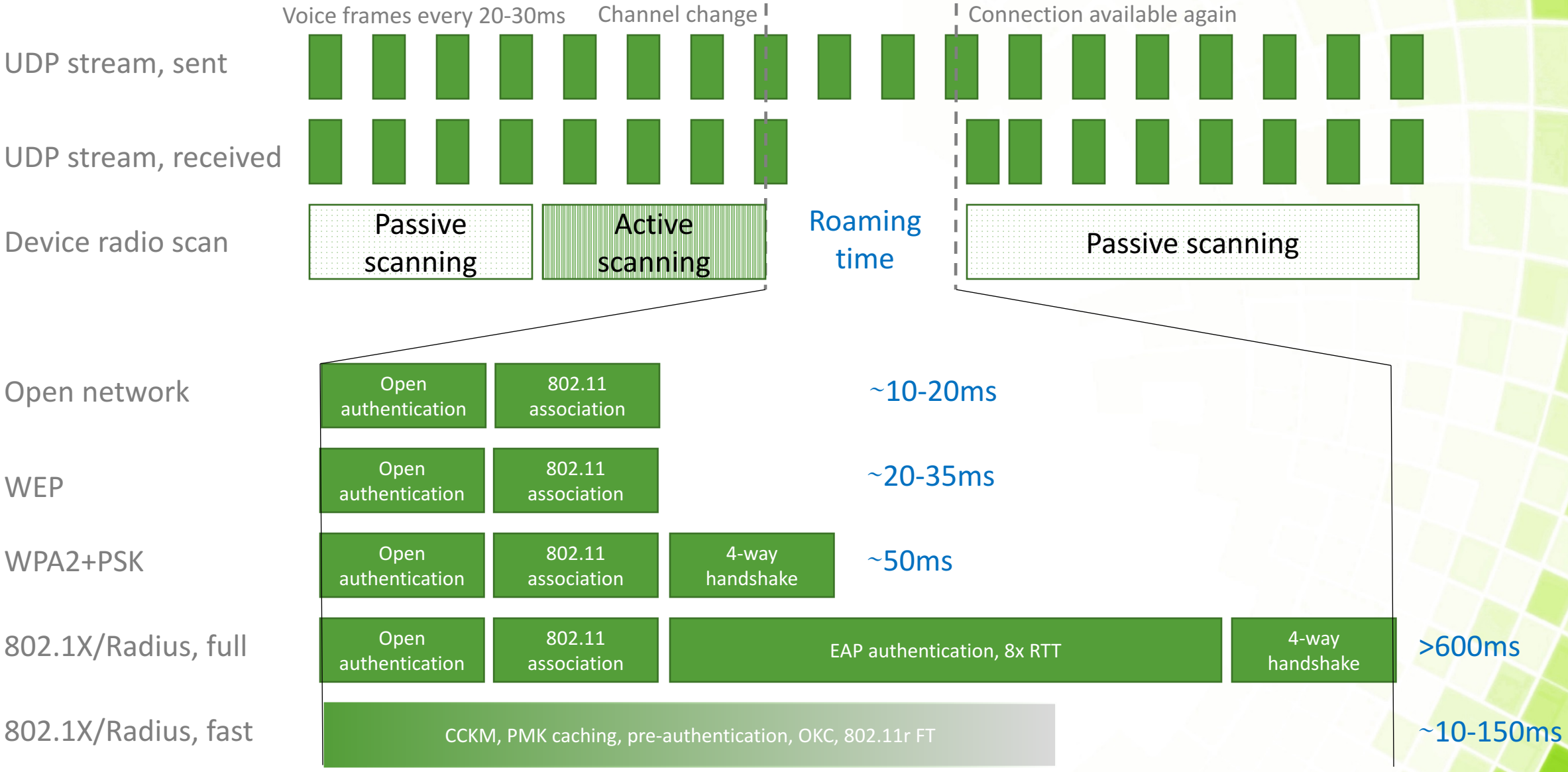
# Roaming during voice call (UDP flow)

ILLUSTRATION, NOT IN SCALE



# Roaming and authentication delay

ILLUSTRATION, NOT IN SCALE




http://www.revolutionwifi.net/revolutionwifi/2012/02/wi-fi-roaming-analysis-part-2-roaming.html
7signal Mysteries of Wi-Fi roaming revealed

# Cisco Compatible Extensions (CCX)

## The early roaming aid for supporting devices

### Cisco Centralized Key Management (CCKM)

- Early form of Fast Roaming technology for LEAP
- Allows roaming without accessing Radius server during the process
- Roam times < 50ms

### CCX message S36 Radio Measurement request

- From AP to client, both supporting CCX
- Measurement include Channel load, Noise histogram, Beacon, Frame

### CCX message S51 RF Parameters

- From AP to client, both supporting CCX
- Roaming thresholds
- Minimum RSSI needed, AP Tx Power, Start scanning threshold, Hysteresis, Allowed Transition time

http://expertwireless2be.blogspot.com/2011/10/why-wireless-80211-roaming-is-nightmare.html
http://www.revolutionwifi.net/revolutionwifi/2012/02/wi-fi-roaming-analysis-part-2-roaming.html

# Standards improving roaming

### 802.11r (2008)

- **Fast secure roaming with Radius/EAP**
  - A roaming standard
  - No need to authenticate with Radius during roaming
  - Fast, standardized process

### 802.11v (2011)

- **Wireless Network Management (WNM)**
  - *BSS transition management* the main feature related to roaming
  - Network recommends and assists in roaming decisions

### 802.11k (2008)

- **Radio resource management**
  - *Neighbor reports* the main feature related to roaming
  - Scan only channels which are used by nearby APs

### 802.11e (2005)

- **MAC enhancements QoS**
- Admission control
- QBSS metrics relate to roaming
  - Channel utilization
  - Station count
  - Available capacity

### 802.11i (2004)

- **MAC security enhancements**
  - Authentication and key management. Robust Network Security (RSN), 802.1X/PSK
- PMK caching/Sticky Key Caching" SKC
  - Pre-authentication

### 802.11u (2011)

- **InterWorking with External Networks**
  - Hotspot 2.0
  - Finds roaming partner Wi-Fi network automatically and securely connects
  - Seamless as mobile roaming

### 802.21 (2008)

- **Media Independent handovers**
  - Roam between Wi-Fi and cellular

### 802.11ai (2016)

- **Fast initial link setup**
  - Makes initial connection setup faster for Radius authentication
  - Improvements to active and passive scanning
  - Addresses probing storms

http://www.cisco.com/c/en/us/td/docs/wireless/controller/8-1/Enterprise-Mobility-8-1-Design-Guide/Enterprise_Mobility_8-1_Deployment_Guide/Chapter-11.pdf
802.11v/k/r standards

# Fast Secure Roaming alternatives (Radius/EAP) before 802.11r

## PMK caching/ Fast Secure Roam Back (.11i)

- "Sticky Key Caching" SKC
- Pairwise Master Key (PMK) is cached
- If client roams back, fast authentication is available
- 802.1X/EAP can be skipped
- 4-way HS is needed
- Does not help roaming forward
- 40-60ms

## Pre-authentication (.11i)

- PMKs pre-created over the existing AP before roaming
- Requires all clients create different keys with all APs
- High load to Radius
- Does not scale well
- 4-way HS is needed
- 40-60ms

## Opportunistic PMK Caching (OKC)

- Vendor driven, non-standardized
- Enhancement for Pre-Authentication
- Original PMK shared with roaming target APs
- If fails, full 802.1X/EAP is used
- Supported quite widely in APs.
- Client side support more variable
- < 100ms

http://www.revolutionwifi.net/revolutionwifi/2012/02/wi-fi-roaming-analysis-part-2-roaming.html

# 802.11r Fast BSS Transition, FT

**Fast Secure Transition. A standardized method**

- Works with both pre-shared key (PSK) and 802.1X
- Initial handshake with the new AP is done before the client roams to the target AP. Pairwise Transient Key (PTK) is calculated in advance
- No need to re-authenticate at the time of roaming
- Benefits especially voice calls and video streams

**Two phases**

- 802.11r initial Mobility Domain association
  - Initial association is not faster than full EAP
  - Prepares the network and client for FT
- 802.11r re-association
  - Fast roaming, uses pre-stored keys
  - Open authentication, re-association and 4-way HS combined
  - Target is <50ms handoff delay

- **Two versions**
  - Without resource request
  - With resource request
- **Two methods**
  - Over the Air
  - Over the DS

**Support**

- APs support broadly, feature may be on by default
- Many legacy clients may not connect to a 802.11r network. Clients may struggle recognizing .11r beacons and probe responses
- Need to ensure compatibility before turning on.
- Vendor workarounds for compatibility, like Cisco Adaptive 802.11r

https://documentation.meraki.com/MR/WiFi_Basics_and_Best_Practices/Roaming_Technologies
http://blogs.cisco.com/wireless/what-is-802-11r-why-is-this-important

# 802.11k Radio Resource Management/
## Neighbor Report

### Improves roaming with measurement data

- Not only roaming related standard
- Neighbor report commonly used at this time
- When supported, advertised in beacon IE element
- Many further roaming improvements
  - Measurement pilots between beacons for passive better scanning, traffic counters indicating quality, device location

### Benefits

- Faster roaming
- Better roaming decisions
- Battery usage (less probing)
- Lower channel utilization (less probing)

### 802.11k measurements

- Neighbor Report
- Beacon (client measures and reports)
- Frame (AP counters)
- Channel Load
- Noise Histogram
- STA Statistics (STA counters)
- Location
- Configuration Information
- Link Measurement
- Transmit Stream/Category Measurement

### Operation

- Client requests neighbor report with Action Frame
- AP responds with Action Frame including neighbor APs in the same SSID with channel numbers
- Client can scan only most relevant channels
- Neighbor list generated on demand
- Single (current) or dual band list
- Example: Cisco lists 6 best APs in the same floor/band

http://blogs.cisco.com/wireless/why-the-802-11k-and-neighbor-report-are-important
https://documentation.meraki.com/MR/WiFi_Basics_and_Best_Practices/Roaming_Technologies

# 802.11v Wireless Network Management (WNM)/
## BSS Transition Management

**Network offering guidance for roaming decision**

- Not only roaming related standard
- Enables clients to exchange information for the purpose of improving performance of the wireless network
- Enables client RF parameters management based on network conditions
- In addition for example Location information, multi-BSSID capability, WNM sleep mode

**Benefits**

- Network can guide clients roaming
- Network can force client to roam
- Client can ask advice for better AP
- Better roaming decisions

**802.11v functionalities**

- BSS transition management
- xxBSS Max idle period management
- Channel usage
- Collocated interference reporting
- Diagnostic reporting
- Directed multicast service (DMS)
- Event reporting
- Flexible multicast service (FMS)
- Location services
- Multicast diagnostic reporting
- Multiple BSSID capability
- Proxy ARP
- QoS traffic capability
- SSID list
- Triggered STA statistics
- TIM broadcast
- Timing measurement
- Traffic filtering service
- U-APSD Coexistence
- WNM-Notification
- WNM-Sleep mode

**Operation**

- ***Solicited request*** - Client asks for better AP
- ***Unsolicited Load Balancing request*** - AP suggests client roam due to load
- ***Unsolicited Optimized Roaming request*** - AP suggests client roam due to low RSSI or data rate
- ***802.11v BSS Transition Management Request*** - AP suggest client to roam or forces to roam with disassociation-imminent

802.11v-2011 standard

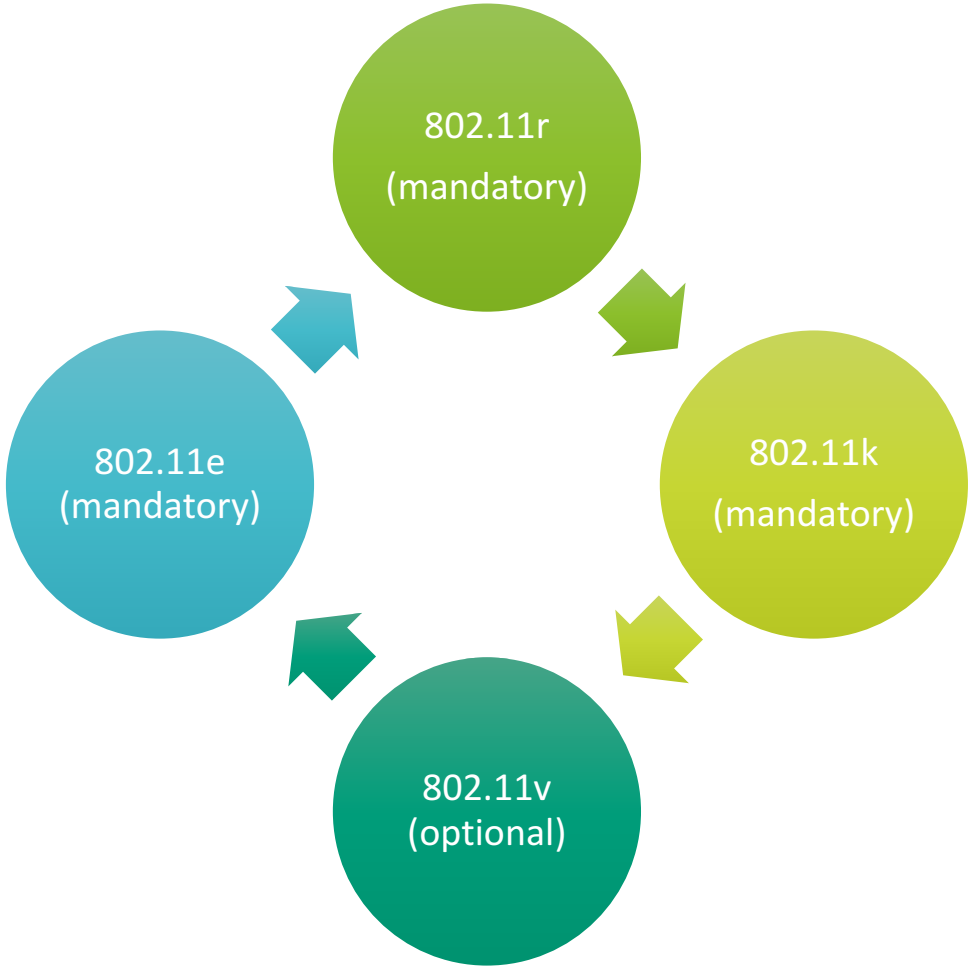
https://blogs.cisco.com/wireless/enhancing-hdx-optimized-roaming-extended-with-11v-bss-transition-management

# Cisco adaptive 802.11r

- A proprietary functionality
- Developed by Cisco and Apple together. Available in Cisco and Meraki Wi-Fi
- Offers Fast Transition without the need to enable 802.11r on the configured Cisco wireless network
- With adaptive .11r, infrastructure will perform .11r authentication without advertising in beacons
- FT negotiation is in association request
- 802.11r remains disabled, while adaptive 802.11r is enabled
- Helps to avoid negatively impacting clients which do not co-operate with 802.11r
- iOS 10 includes support for adaptive 802.11r on Cisco wireless networks
- Requires Cisco WLC SW 8.3 or later and specific AP models

https://support.apple.com/en-us/HT202628
https://documentation.meraki.com/MR/WiFi_Basics_and_Best_Practices/Roaming_Technologies
https://www.cisco.com/c/dam/en/us/td/docs/wireless/controller/technotes/83/Optimizing_WiFi_Connectivity_and_Prioritizing_Business_Apps.pdf

# Wi-Fi CERTIFIED Voice-Enterprise




- Wi-Fi Alliance certification for voice over Wi-Fi
  - 411 phones
  - 33 APs
    - Only certain APs have this, not necessarily all new APs
- Performance
  - Pre-defined test cases
  - Latency (incl. BSS FT): One-way delay <50 ms
  - Jitter: <50 ms
  - Packet loss: <1%
  - Consecutive lost packets: No more than three

http://www.wi-fi.org/download.php?file=/sites/default/files/private/wp_20120507_Voice_Enterprise_FINAL_0.pdf

# Layer 3 roaming

- Wi-Fi roaming operates only in layer 2, between APs under the same subnet.
- Client moving between controllers would cause change if IP address and termination of ongoing connections, like calls.
- Layer 3 roaming capability is provided by Wi-Fi vendors.
  - RFC 3344 defined Mobile IP standard
  - Uses tunneling and IP header capsulation between controllers
  - Allows packets traverse between two layer 3 domains
  - Maintains ongoing connections

# Factors impacting roaming

# Passive scan / Active scan

## Passive scan

- Passively capture beacons at all channels. Typical beacon interval is 102ms.
- To capture at least one beacon, would need to stay at least 102ms/channel
  - Voice traffic packet interval 20-30ms
  - Voice is interrupted if > 50ms break, cannot stay 102ms of channel during voice traffic
- Client may not be on channel when beacon is out
- Beacon may not be captured due to interference
- Device consumes more battery if radio is on continuously. Power save mode applied.
- **=> Passive scanning is very inefficient and use is minimized**

## Active scan

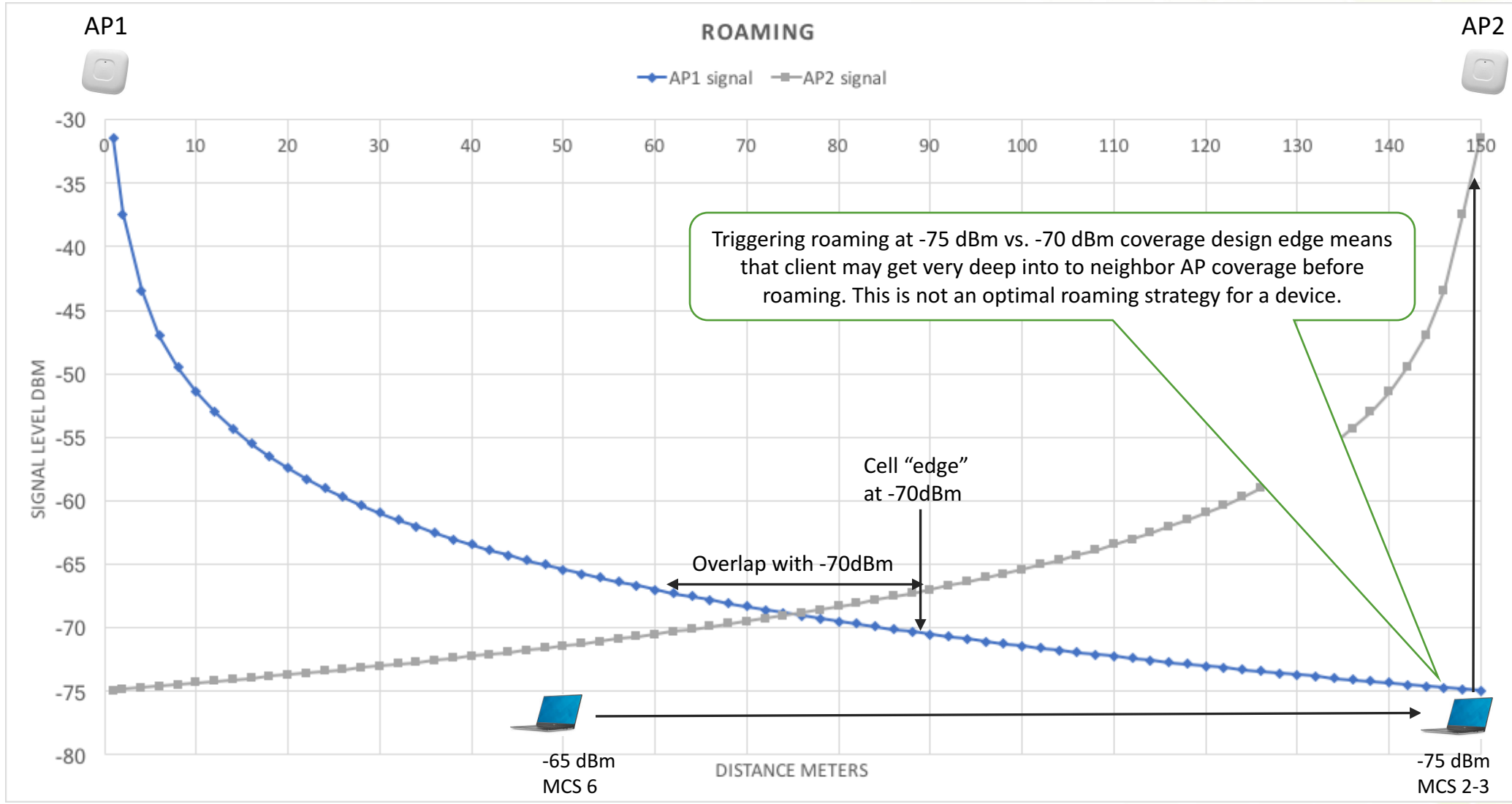
- Send probe requests at all channels
- Getting response to probe request takes 10-20ms
- Can probe again immediately after channel change
- Probe response may not be captured due to interference or congestion
- All APs which receive probe request will respond with probe response. Active scans, especially probe responses, consume significant amount of airtime in HD environments
- Active scans require probe request transmissions, which consume battery
- From information capturing point of view, active scans are 5-10x mode efficient than passive scans
- **=> Active scans are favored, but their use is also minimized as much as possible**

# BSSID selection and brute force steering methods

- **Initial BSSID selection**
  - Initial selections usually based on signal level only
  - If 2.4 GHz is stronger, many clients will prefer it. Keep 5 GHz 6-7dB stronger at terminal.
- **Band steering**
  - Delay or deny probe responses at 2.4 GHz until certain number of attempts
  - Forces terminals scan 5 GHz more times
- **Load balancing**
  - After client count at AP reaches certain level (like 20) and other APs have light load, busy APs may stop responding to probing. This steers clients to other APs.
  - This may be achieved by having AP respond to open authentication attempt with status code 17 (AP busy) up to certain times before allowing a persistent clients authenticate.
- **“Smart roaming”, brute force**
  - AP may disconnect client if too low signal level

# Roaming based on low AP signal level

## RF propagation loss in not linear, 6 dB doubles distance in open space




Free space loss model used

# Roaming on DFS channels

## No immediate probing allowed

- Client cannot probe on DFS channel before at least one beacon is first received properly
- Need to always start with passive scan and if lucky, catch a beacon and get permission to probe

## Impacts

- APs in DFS channels are much more difficult to discover quickly and thus roaming is more difficult
- In case of positive DFS event, AP disassociates clients within 1s channel closing time. If disassociation is missed or roam fails, client needs to start a new association and authentication.
- Roaming to AP does not work during 60s Channel Availability Check period. May cause lacking coverage

| Region | Band | Non-DFS 20 MHz | DFS 20 MHz |
|---|---|---|---|
| US | 5 GHz | 9 | 15 |
| EUR | 5 GHz | 4 | 15 |

https://www.cwnp.com/dynamic-frequency-selection/ http://community.arubanetworks.com/t5/tkb/articleprintpage/tkb-id/tkb%40tkb/article-id/136

https://badfi.com/blog/2016/2/15/yet-another-reason-avoid-using-hidden-ssids

# Hidden SSIDs

## Hidden SSIDs in non-DFS channels

- Client cannot use beacon capture rate to determine quality of existing channel
- Passive scan of other channels does not add any value
- Need active scanning on current channel as well

## Hidden SSIDs in DFS channels

- Client cannot use beacon to determine quality of existing channel, need active scan
- Any AP beacon on target channel allows start of active scan, even hidden SSID is ok
- => Roaming may be negatively impacted

**Note:**

802.11k neighbor lists improve roaming on hidden SSIDs by limiting scans to right channels only. 802.11v allows Wi-Fi network to steer clients.

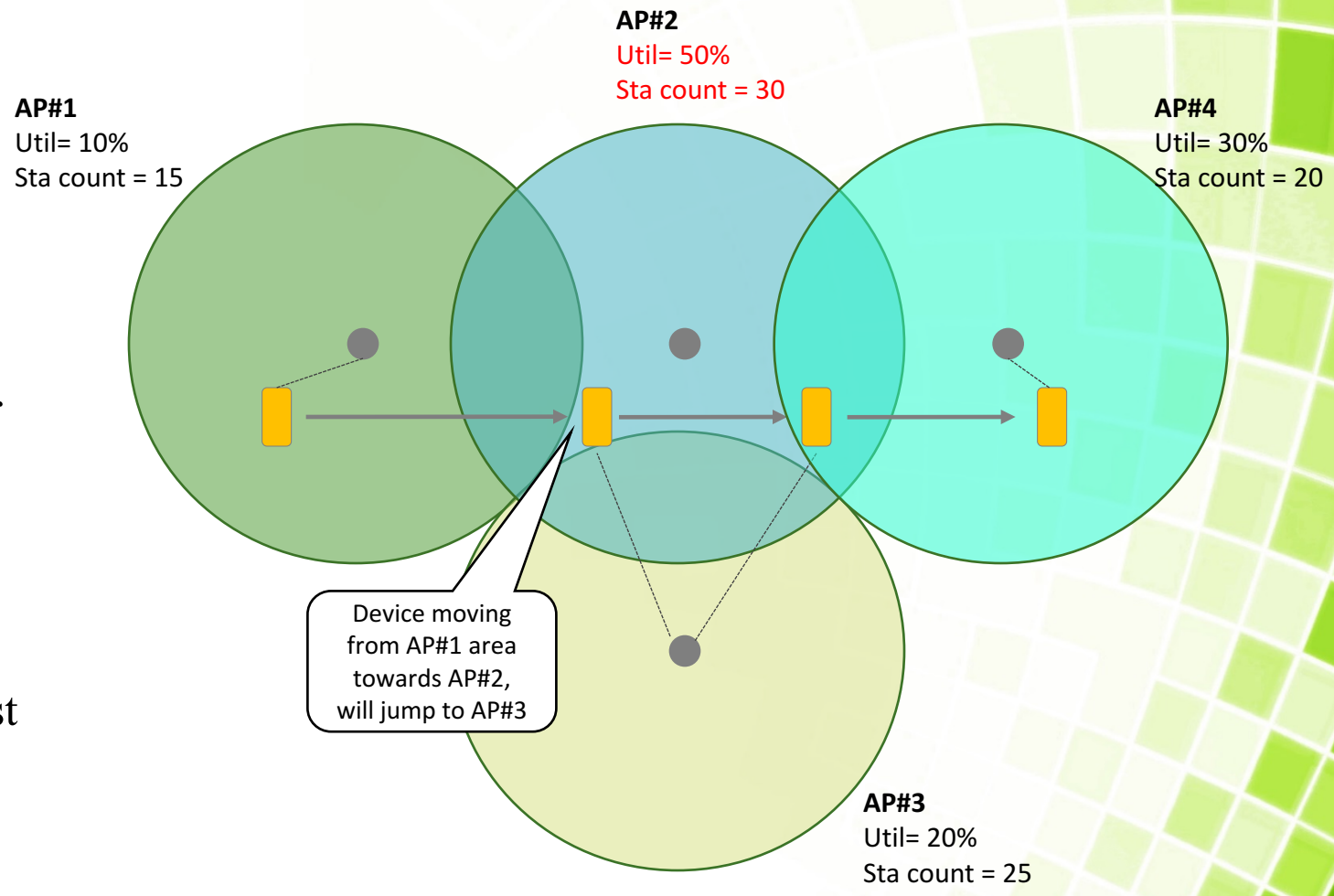
http://community.arubanetworks.com/t5/tkb/articleprintpage/tkb-id/tkb%40tkb/article-id/136
https://badfi.com/blog/2016/2/15/yet-another-reason-avoid-using-hidden-ssids

# Turning off low data rates

- Turning off lower data rates is often used to help roaming
  - Recommendation is often to use 12M or 24M as the lowest rate
- Clients listen to beacons in the current channel
- If client starts to miss beacons, it starts to actively probe
- Disabling lowest rates can be used to encourage clients roam sooner
  - Beacons using higher data rates cannot be decoded at large distance even though their signal level may still be above roaming threshold
- Disabling too many rates will make connection unreliable
  - All management and control traffic often use the lowest allowed rate
- Usually devices have no issues with this, but Wi-Fi driver implementations vary

# 802.11e QBSS metrics

- QoS enhancements for Wi-Fi
- QBSS metrics
  - Channel utilization
  - Station count
  - Available capacity
- Certain terminals use QBSS metrics for roaming decision
  - Apple iOS 10 forward
  - No knowledge of others
- Significant impact on roaming patterns
  - Client may avoid roaming to AP with best SNR/signal level
  - Roaming patterns become more load dependent
- Enabling/disabling impacts roaming
  - => Observe impacts when turning on



# RF automation's impact

- RF automation generally does not consider roaming success
  - Automation uses neighbor signal levels, interference and utilization
  - Automation does attempt to maintain certain cell overlap
- Varies AP power levels
  - Sometimes automation drives power levels to min/max
- Varies channels
  - Channels vary between DFS and non-DFS channels
  - Max power levels vary between channels
- Varying channels and power levels adds variance roaming patterns

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# Clients

# MacOS roaming

- **Signal level**
  - Monitor and maintain connection until the RSSI crosses the -75 dBm
  - After RSSI -75dBm, macOS scans for roam candidates
  - Roams when BSSID RSSI is >=12 dB than current BSSID
- **Other selection criteria**
  - **Band:** Always defaults to the 5 GHz when 5 GHz RSSI is -68 dBm or better.
  - **SSID:** If multiple 5 GHz SSIDs meet -68 dBm level, preference 802.11ac -> 802.11n -> 802.11a.
  - **Channel width:** Order of preference: 80 MHz channel –> 40 MHz channel –> 20 MHz
  - **802.11v/k:** No support
  - **PMK caching:** Supported
  - **OKC:** Supported
  - **802.11r (FT):** No support, but interoperates with APs having 802.11r on

https://support.apple.com/en-us/HT206207

# iOS roaming

- **Signal level**
  - **Starts probing** at RSSI of – 70dBm
  - Roam if **using Wi-Fi** connection actively and there is **8 dB better** AP
  - Roam if **not using the Wi-Fi** connection actively and there is **12 dB better** AP
- **PMK caching: Supported widely**
  - Supported by all iOS devices with iOS 5.1 and later
- **OKC:** Not supported
- **802.11k/r: Supported widely**
  - iPhone 4s and later, iPad Pro, iPad Air and later, iPad mini and later, iPad (3rd generation) and later, iPod touch (5th generation) and later
- **802.11v: Supported widely**
  - iPhone 5c, iPhone 5s, and later, iPad Pro, iPad Air and later, iPad mini 2 and later, iPod touch (6th generation)
- **Adaptive 802.11r: supported by new devices**
  - iPhone 6s and later, iPhone SE, iPad Pro and later
- **802.11e/QBSS**
  - iOS 10 and later use QBSS metrics (load, utilization) to determine best AP
- **Blacklisting**
  - If network denies iOS client 5 times, iOS blacklists SSID. Need to reboot device and disable radio to override.

https://support.apple.com/en-us/HT206207 https://support.apple.com/en-us/HT203068

# Android roaming

- Many manufacturers and different variants
- "Vanilla" Android AP selection logic
  - Uses absolute **SNR value as main factor**
  - If the SNR value difference between the two "best" radios is **at least 7dB**, the decision is done based on **SNR alone**
  - If difference between best BSSIDs < 7dB, select one with highest max data rates. If rates are similar, uses SNR
  - If SNR not available, uses Quality metric
  - If difference in Quality is small, prefer 5 GHz
- 802.11r/k: Vendor specific
- 802.11v: Vendor specific
  - Many devices support
    - Galaxy S6, Galaxy S7, Galaxy S7 Edge, Moto E (2nd Gen), Moto X (2nd gen), Moto X (3rd gen) Moto Z Force, Nexus 6, Nexus 9, One Plus One, One Plus Two, Amazon Fire Phone

| Phone | 11r | 11k | 11v | Probing frequency | Roaming behavior |
|---|---|---|---|---|---|
| Samsung S4 / Android 4.2.2 /4.4.2 | Yes | Yes | No | 285s | AP signal is < 25 dB |
| Samsung S5 / Android 4.4.2 | Yes | Yes | No | 300s | |
| Samsung S6 / Android 5.0.2 | Yes | Yes | No | 300s | AP signal is < 25 dB |
| Samsung S7 Edge / Android 6.0.1 | Yes | Yes | Yes | | |
| HTC One (M8) | No | No | No | Never | AP signal is < 25 dB |

https://www.ekahau.com/blog/2017/05/30/wi-fi-capacity-planning-importance-balancing-2-4ghz-5ghz/
http://www.cisco.com/c/en/us/td/docs/wireless/controller/technotes/80/device_classification_guide.html
http://clients.mikealbano.com/ http://www.arubanetworks.com/assets/support/Interoperability_Test_Results_Samsung-S7Edge.pdf

# Windows 10 roaming

- **OKC:** Supported
- **802.11r/k/v:** Generally supported
  - However, variance between devices
- **802.11r**
  - Radius supported
  - Pre-Shared Key (PSK) is not supported

Intel Wi-Fi cards and Windows 10

| Product | 802.11k | 802.11v | 802.11r |
|---|---|---|---|
| Intel® Tri-Band Wireless-AC 18260 | Yes | Yes | Yes |
| Intel® Tri-Band Wireless-AC 17265 | Yes | Yes | Yes |
| Intel® Dual Band Wireless-AC 8260 | Yes | Yes | Yes |
| Intel® Dual Band Wireless-AC 3165 | Yes | Yes | Yes |
| Intel® Dual Band Wireless-AC 7265 | Yes | Yes | Yes |
| Intel® Dual Band Wireless-N 7265 | Yes | Yes | Yes |
| Intel® Wireless-N 7265 | Yes | Yes | Yes |
| Intel® Dual Band Wireless-AC 3160 | No | No | No |
| Intel® Dual Band Wireless-AC 7260 | No | No | No |
| Intel® Dual Band Wireless-N 7260 | No | No | No |
| Intel® Wireless-N 7260 | No | No | No |

https://www.intel.com/content/www/us/en/support/network-and-i-o/wireless-networking/000021562.html

https://docs.microsoft.com/en-us/windows-hardware/drivers/network/fast-roaming-with-802-11k--802-11v--and-802-11r

# Intel roaming controls

- **Roaming aggressiveness**
  - **Lowest**
    - Your wireless client won't roam. Only significant link quality degradation causes it to roam to another access point.
  - **Medium-Low/Medium-High**
    - Allow roaming.
  - **Medium**
    - Balanced setting between not roaming and performance.
  - **Highest**
    - Your Wi-Fi client continuously tracks the link quality. If any degradation occurs, it tries to find and roam to a better access point.
- **Preferred band**
  - No Preference
  - Prefer 2.4 GHz band
  - Prefer 5.2 GHz band

http://www.intel.com/content/www/us/en/support/network-and-i-o/wireless-networking/000005585.html

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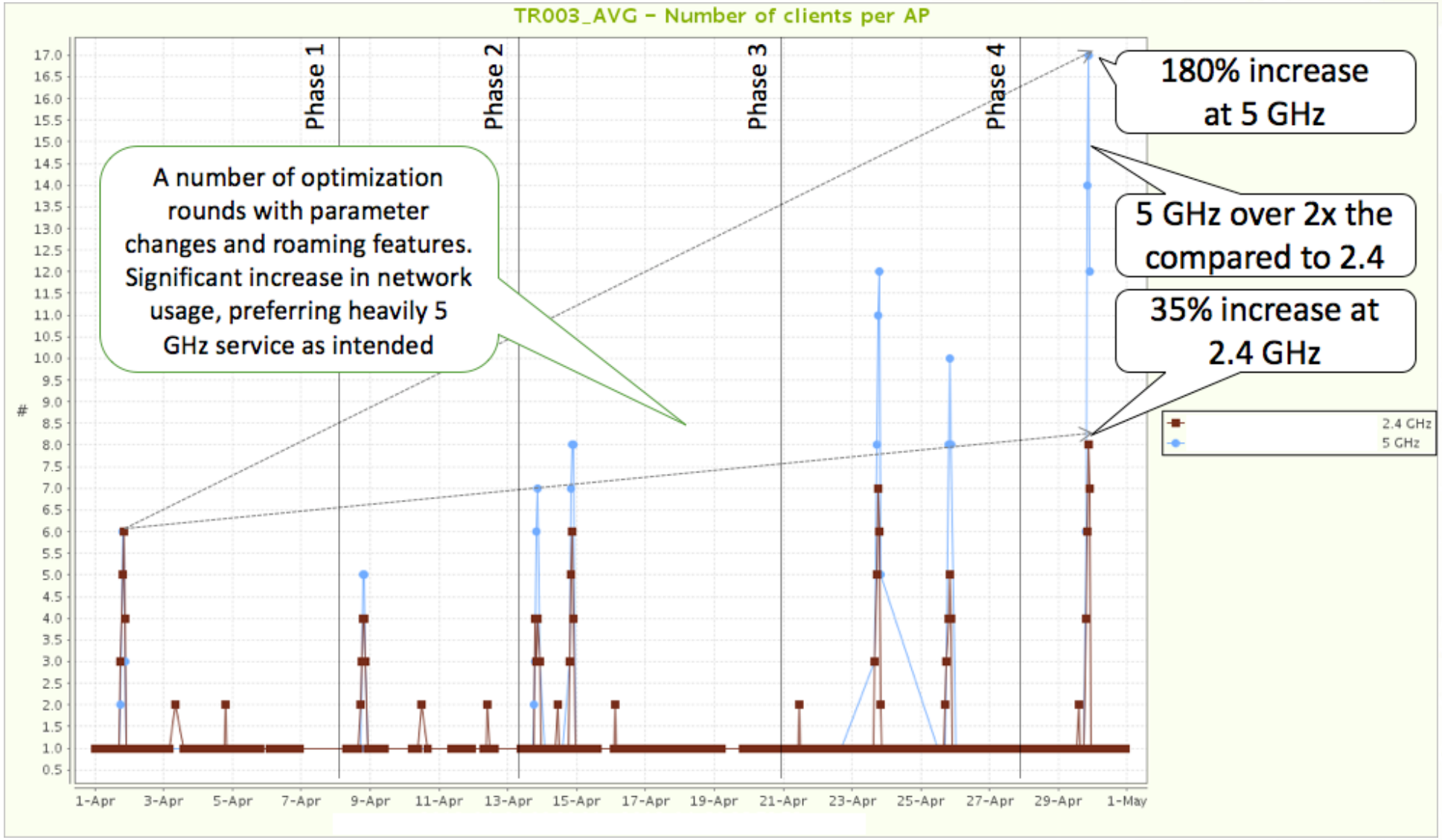
# Understanding and Optimizing Roaming

# Arena

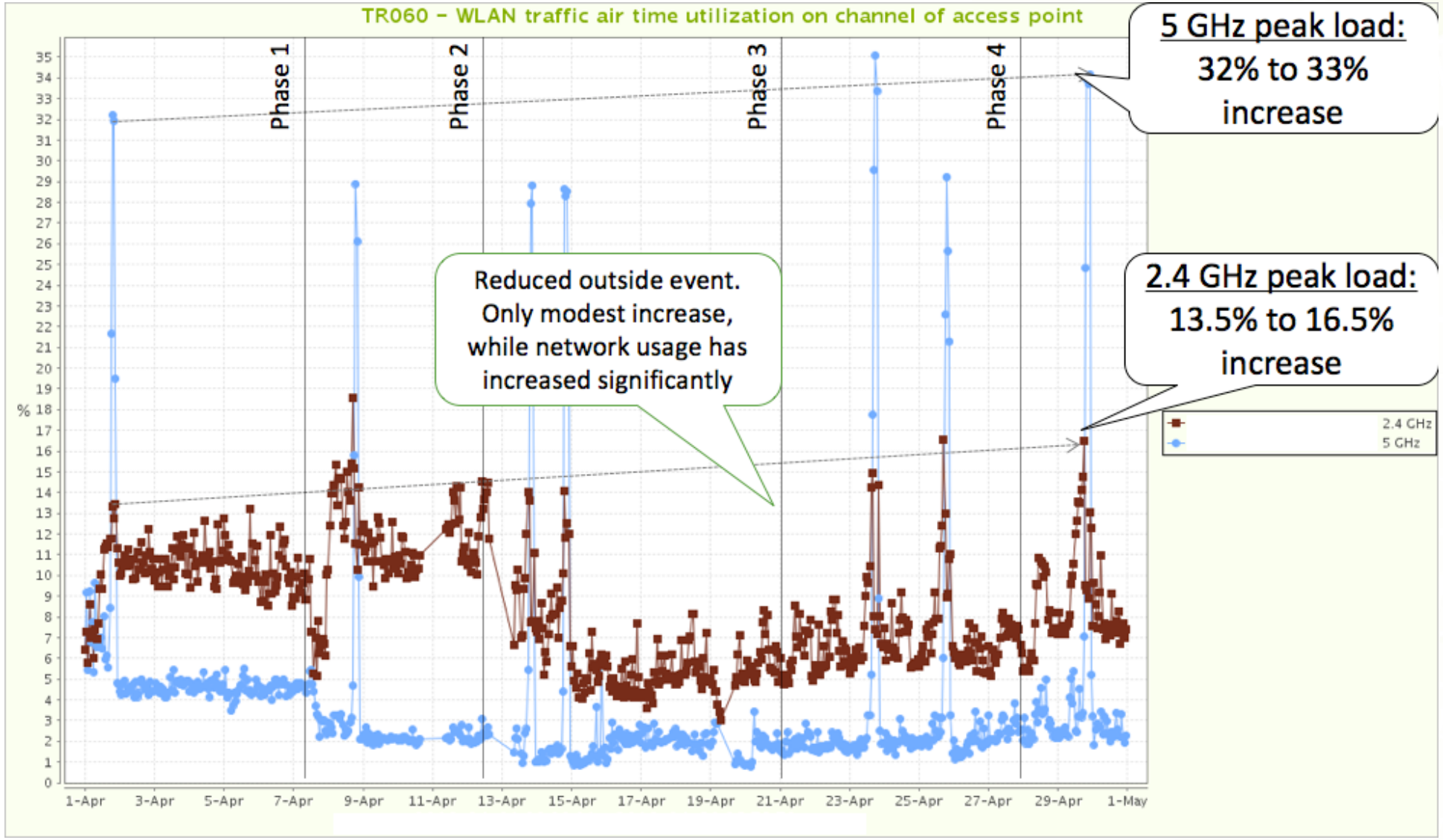
Optimization, example of guiding clients to use 5 GHz band and optimal AP

7signal Sapphire

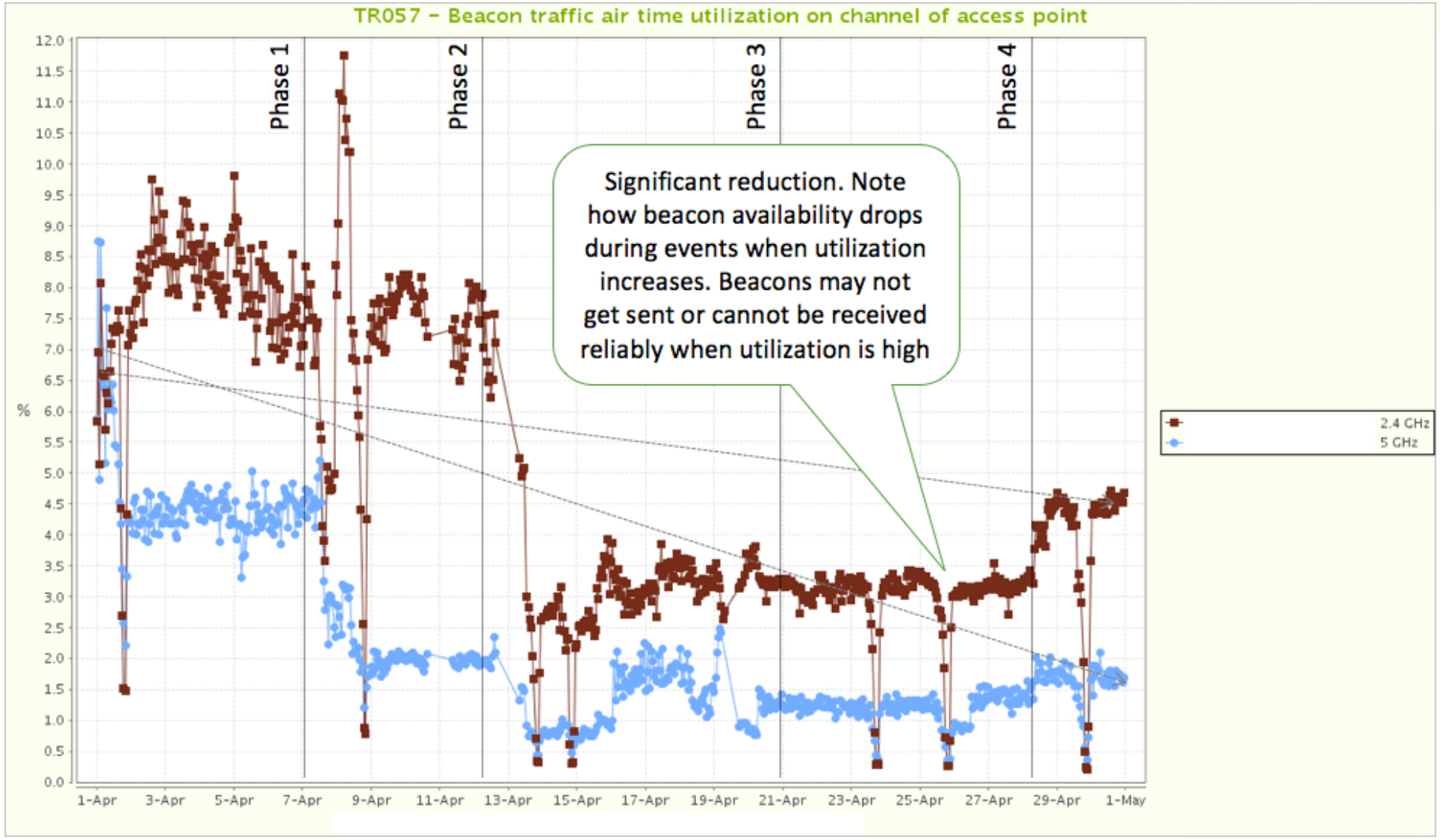
# Number of active clients/AP for 2.4 and 5 GHz bands



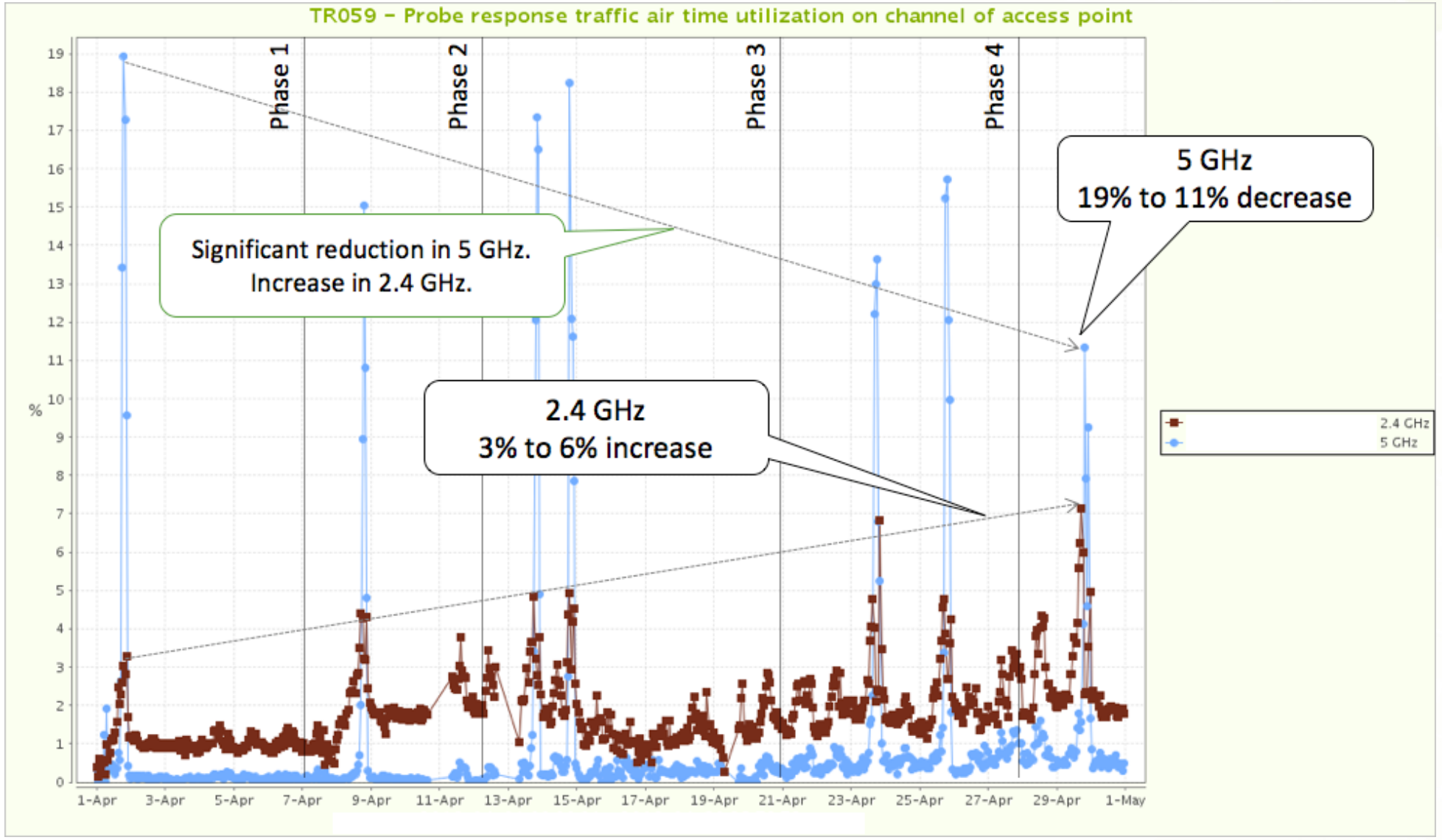
# Air utilization



# Beacon air utilization



# Probe response air utilization



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# Hospital

Troubleshooting VoIP roaming

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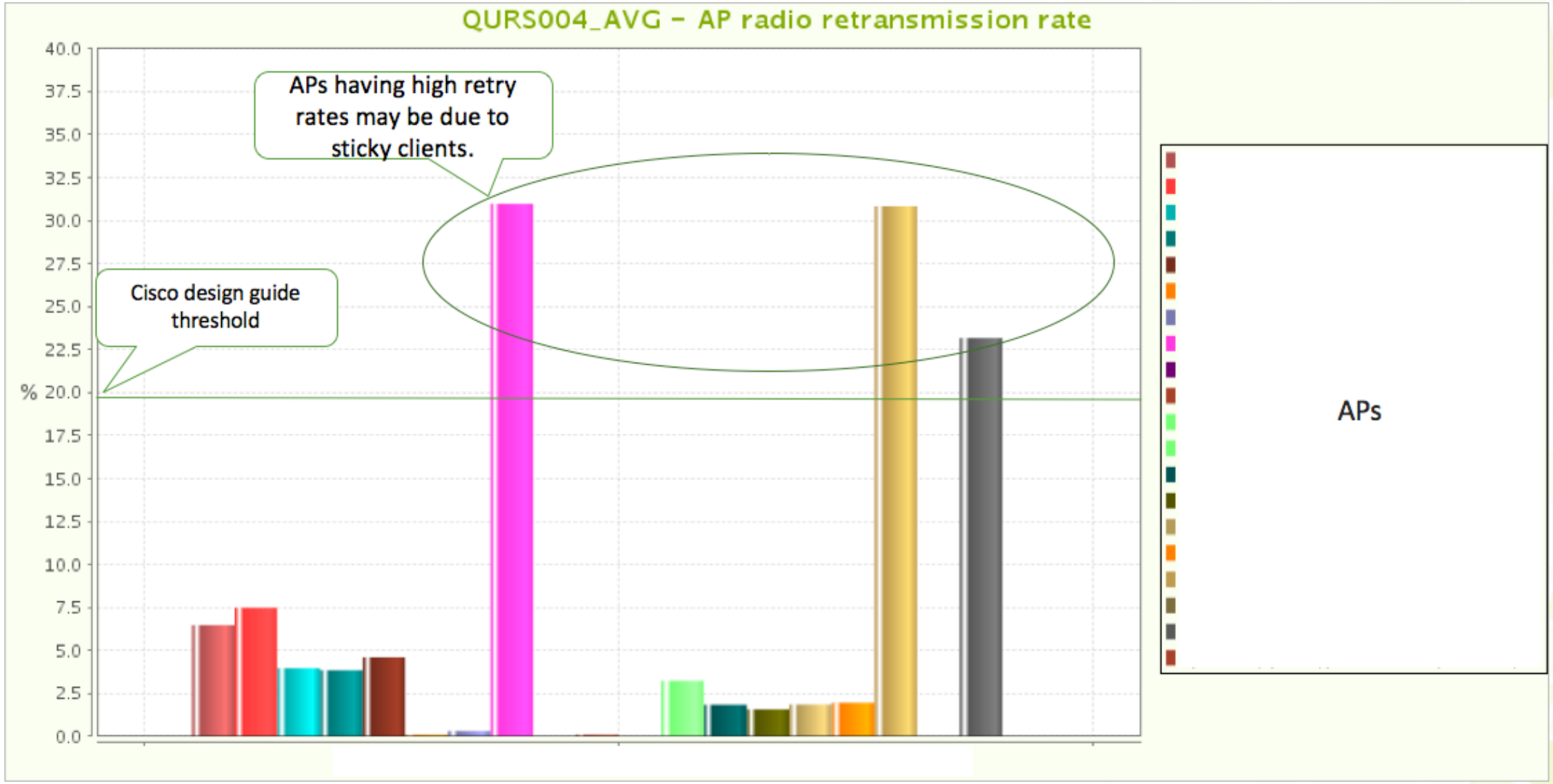
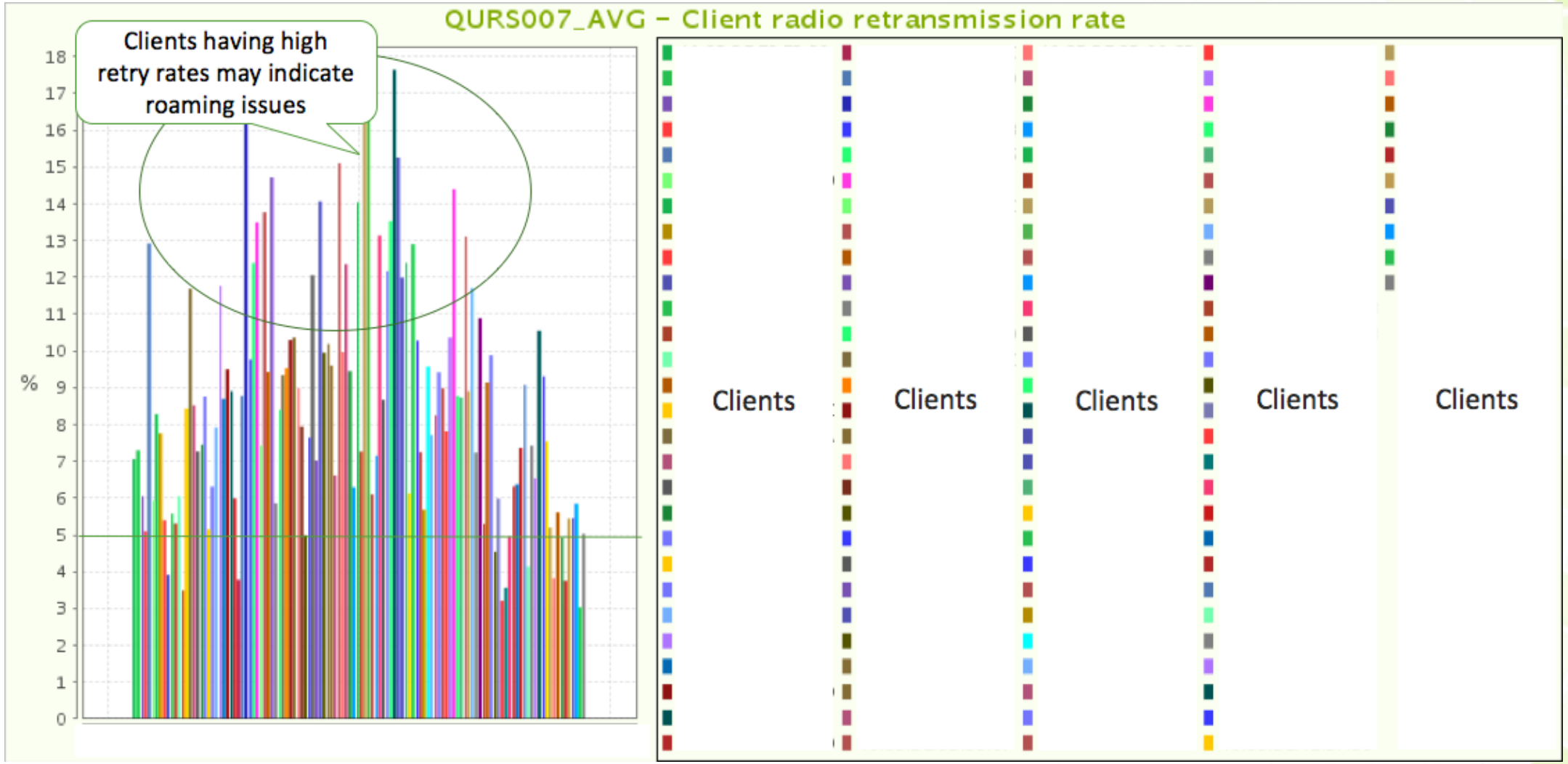
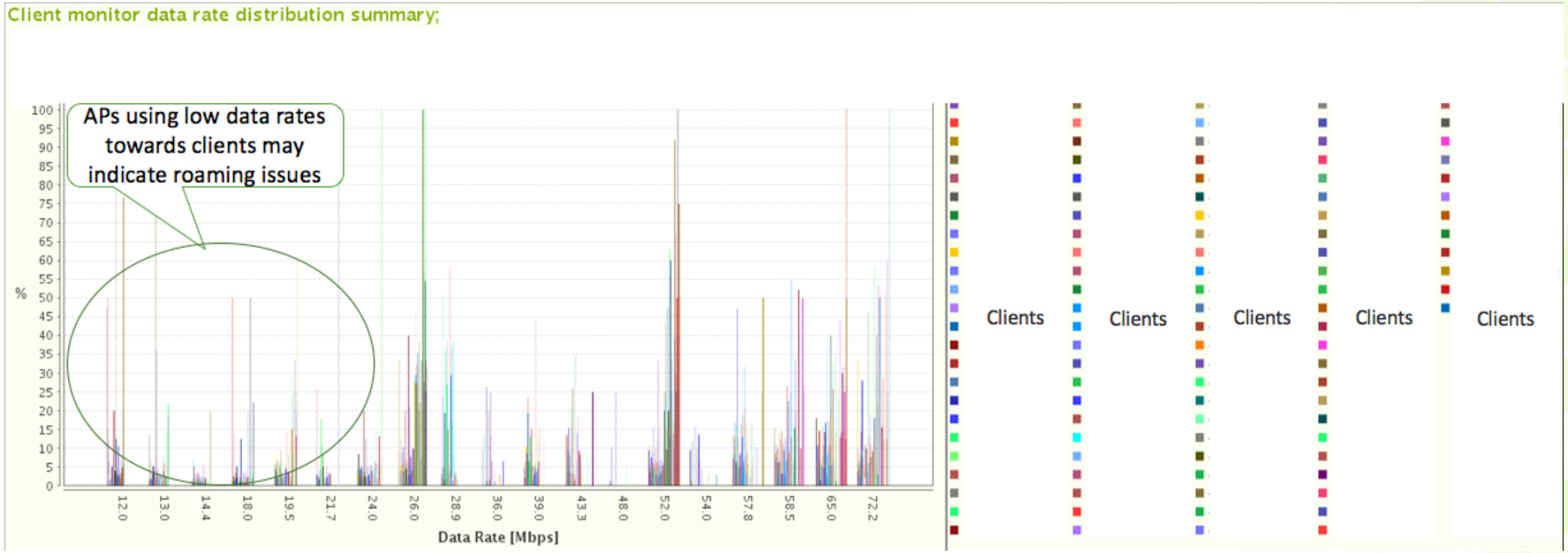
# AP retransmissions



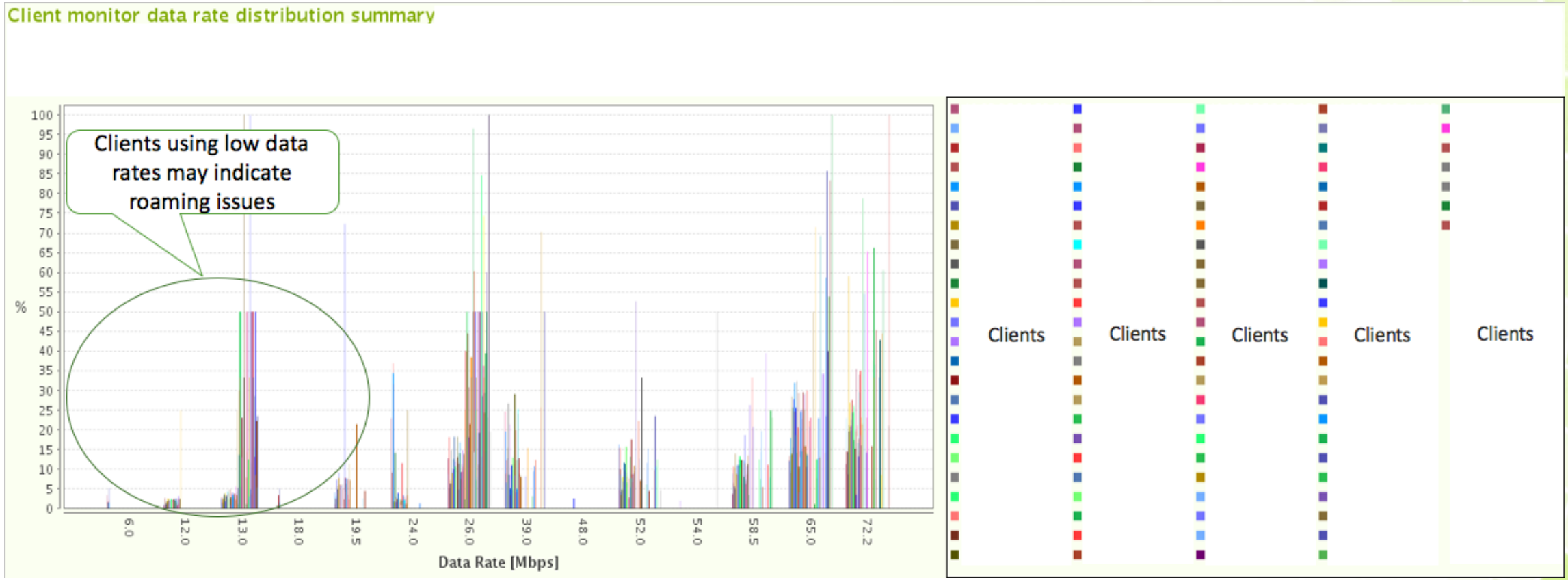
# Clients retransmissions



# Client data rates, downlink



# Client data rates, uplink



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# Enterprise

End user terminal experience, roaming analysis

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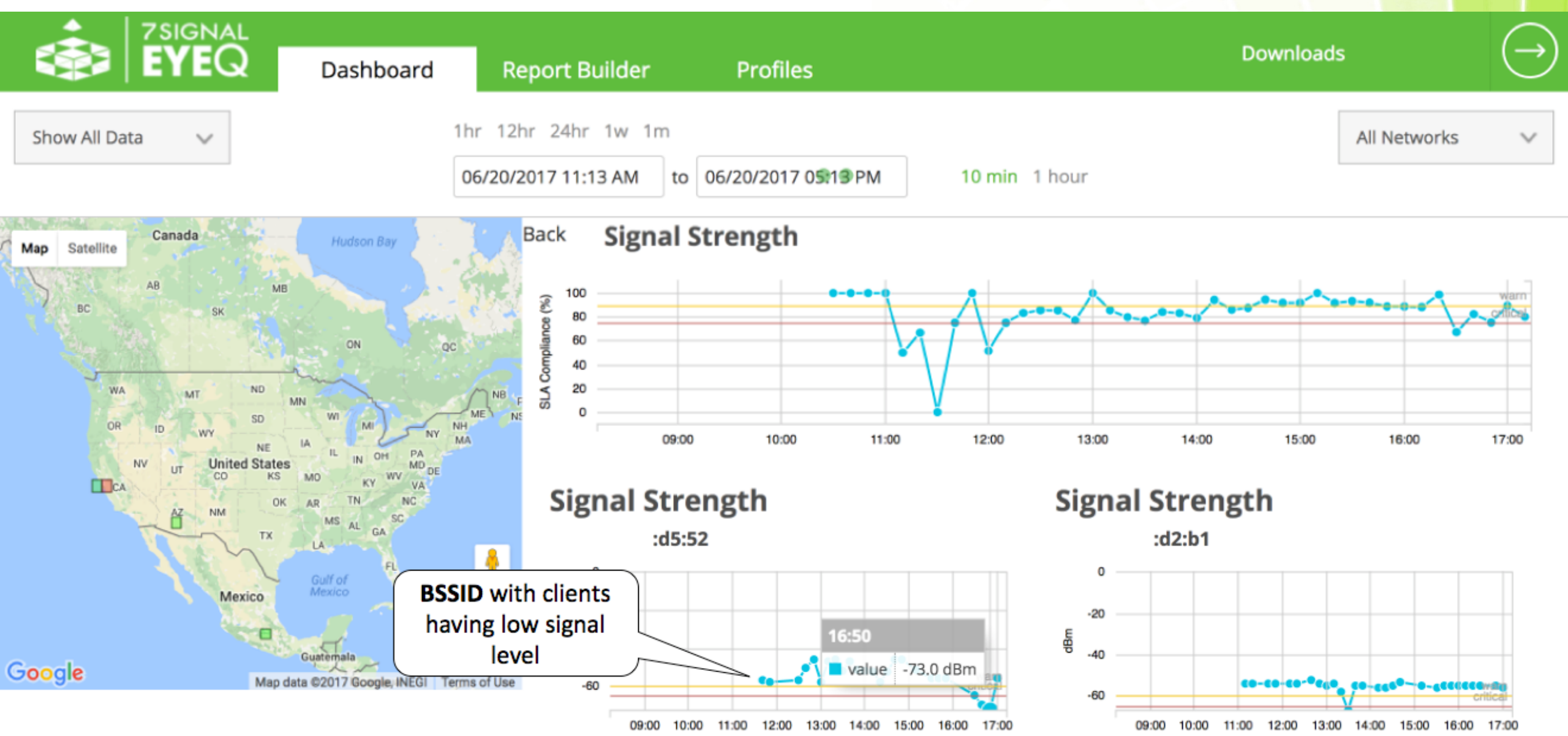
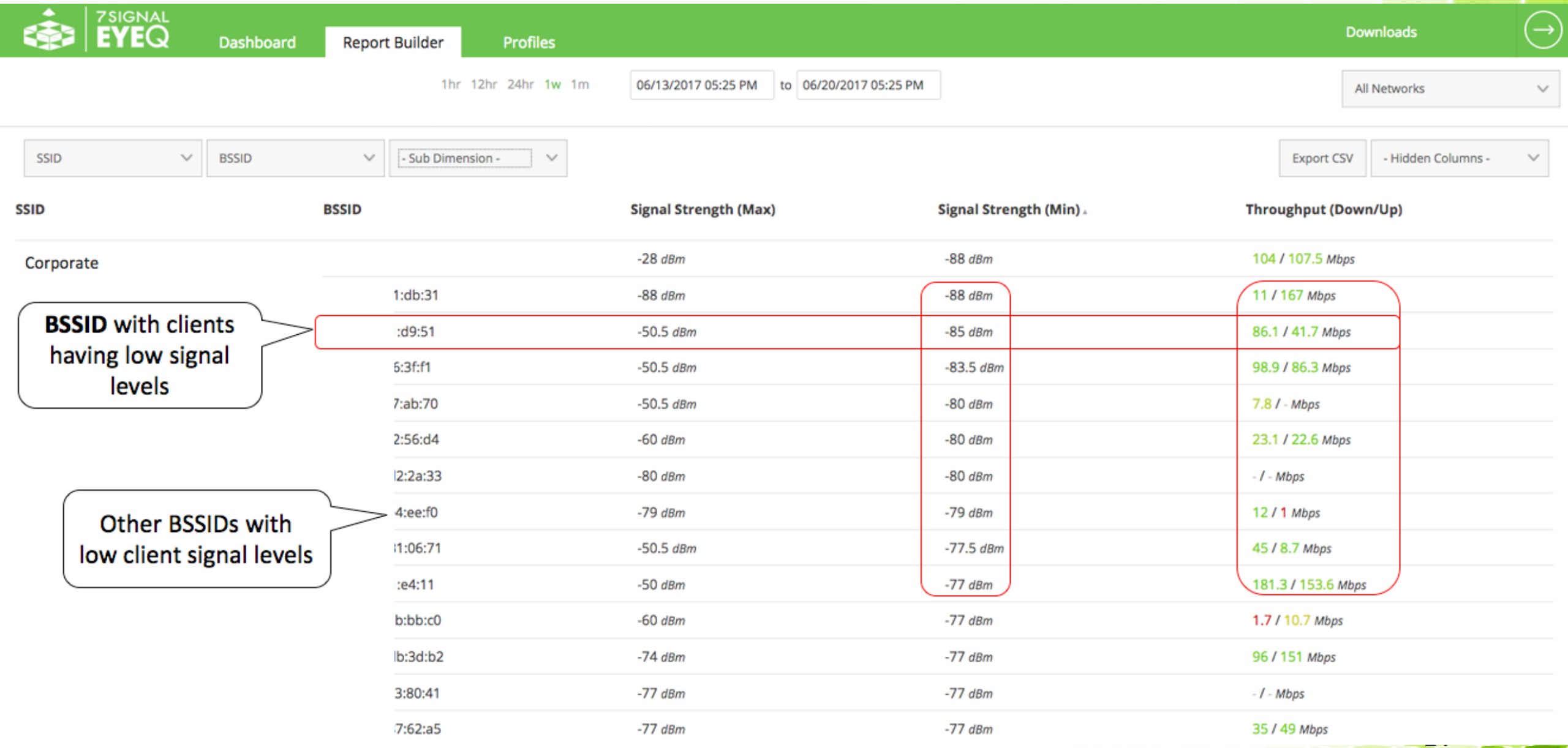
# Client RSSI over time

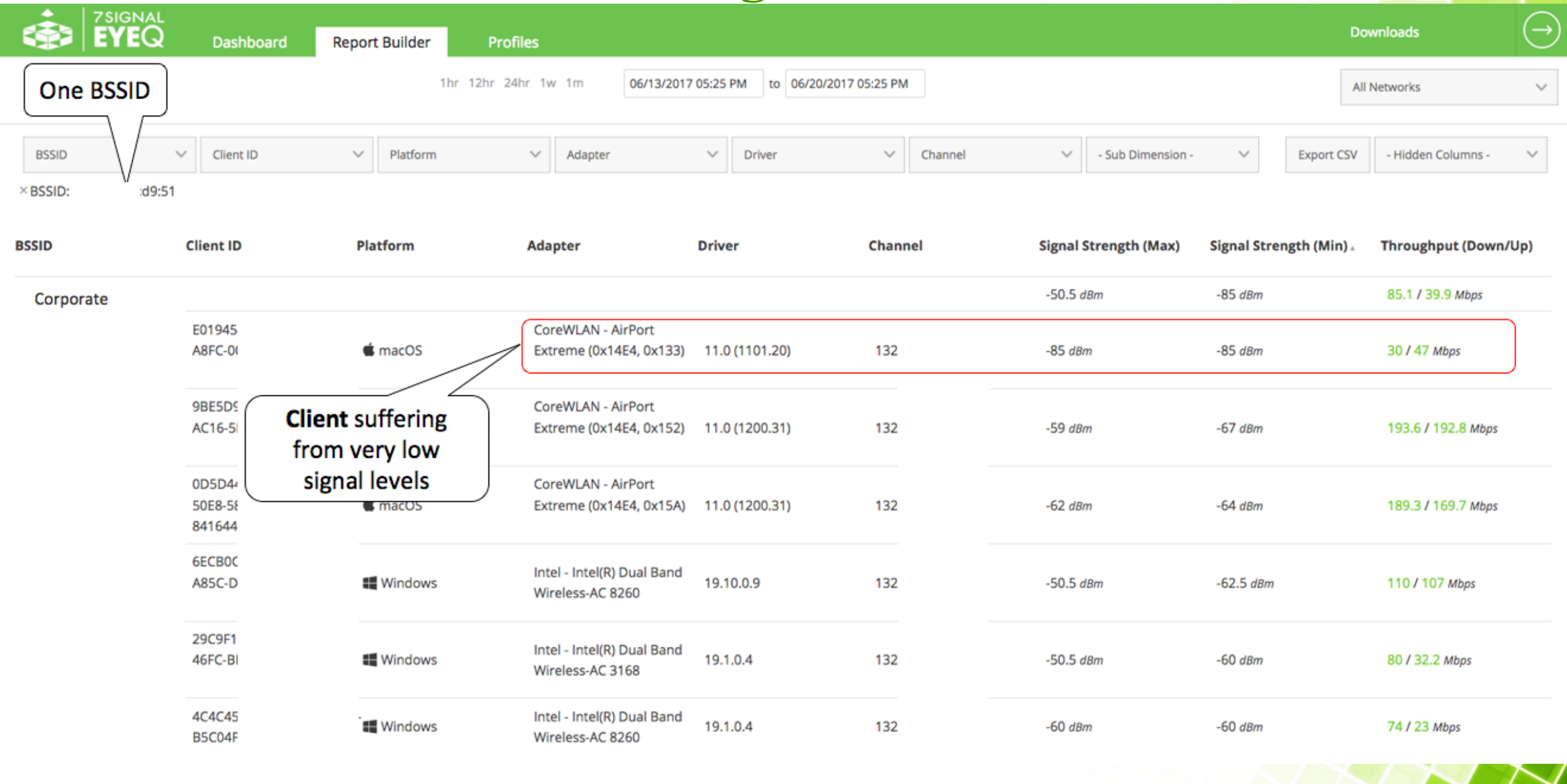


# Stats: BSSIDs with low client signal levels




| SSID | BSSID | Signal Strength (Max) | Signal Strength (Min) | Throughput (Down/Up) |
|---|---|---|---|---|
| Corporate | | -28 dBm | -88 dBm | 104 / 107.5 Mbps |
| | 1:db:31 | -88 dBm | -88 dBm | 11 / 167 Mbps |
| | :d9:51 | -50.5 dBm | -85 dBm | 86.1 / 41.7 Mbps |
| | 5:3f:f1 | -50.5 dBm | -83.5 dBm | 98.9 / 86.3 Mbps |
| | 7:ab:70 | -50.5 dBm | -80 dBm | 7.8 / - Mbps |
| | 2:56:d4 | -60 dBm | -80 dBm | 23.1 / 22.6 Mbps |
| | 2:2a:33 | -80 dBm | -80 dBm | - / - Mbps |
| | 4:ee:f0 | -79 dBm | -79 dBm | 12 / 1 Mbps |
| | 1:06:71 | -50.5 dBm | -77.5 dBm | 45 / 8.7 Mbps |
| | :e4:11 | -50 dBm | -77 dBm | 181.3 / 153.6 Mbps |
| | b:bb:c0 | -60 dBm | -77 dBm | 1.7 / 10.7 Mbps |
| | b:3d:b2 | -74 dBm | -77 dBm | 96 / 151 Mbps |
| | 3:80:41 | -77 dBm | -77 dBm | - / - Mbps |
| | 7:62:a5 | -77 dBm | -77 dBm | 35 / 49 Mbps |

# Drill in: Client with low signal level in one AP




| BSSID | Client ID | Platform | Adapter | Driver | Channel | Signal Strength (Max) | Signal Strength (Min) | Throughput (Down/Up) |
|---|---|---|---|---|---|---|---|---|
| Corporate | | | | | | -50.5 *dBm* | -85 *dBm* | 85.1 / 39.9 *Mbps* |
| | E01945 A8FC-0( | macOS | CoreWLAN - AirPort Extreme (0x14E4, 0x133) | 11.0 (1101.20) | 132 | -85 *dBm* | -85 *dBm* | 30 / 47 *Mbps* |
| | 9BE5D9 AC16-5( | | CoreWLAN - AirPort Extreme (0x14E4, 0x152) | 11.0 (1200.31) | 132 | -59 *dBm* | -67 *dBm* | 193.6 / 192.8 *Mbps* |
| | 0D5D4( 50E8-5( 841644 | macOS | CoreWLAN - AirPort Extreme (0x14E4, 0x15A) | 11.0 (1200.31) | 132 | -62 *dBm* | -64 *dBm* | 189.3 / 169.7 *Mbps* |
| | 6ECB0( A85C-D | Windows | Intel - Intel(R) Dual Band Wireless-AC 8260 | 19.10.0.9 | 132 | -50.5 *dBm* | -62.5 *dBm* | 110 / 107 *Mbps* |
| | 29C9F1 46FC-B( | Windows | Intel - Intel(R) Dual Band Wireless-AC 3168 | 19.1.0.4 | 132 | -50.5 *dBm* | -60 *dBm* | 80 / 32.2 *Mbps* |
| | 4C4C45 B5C04F | Windows | Intel - Intel(R) Dual Band Wireless-AC 8260 | 19.1.0.4 | 132 | -60 *dBm* | -60 *dBm* | 74 / 23 *Mbps* |

# Best practices

- **Optimize RF coverage and utilization**
  - Target at 15-30% overlap with -70dBm coverage at both bands
  - 5 GHz AP power level setting must be >6 dB higher than 2.4 GHz
  - Keep link balanced, do not make DL direction much stronger than UL
  - Limit allowed AP power control range within a few dBs
  - Use 12M or 24M as the lowest rate
- **Use secure roaming**
  - Use 802.1X/EAP authentication with Fast Transition techniques when possible
  - Use secure methods which are supported by clients
  - Use devices which support 802.11r
  - Do not turn 802.11r on without testing actual clients first
  - It may not be a good idea to enable 802.11r in Guest/BYOD network at this time
- **Enable 802.11k/v.** These give network and terminal vendors better ways of handling roaming
- **Enable 802.11e QBSS**, but remember AP load/utilization metrics do impact iOS 10 roaming
- **Do not hide SSIDs.** If you do for some reason, remember to use 802.11k/v and avoid DFS channels
- **Use Wi-Fi vendor's roaming features**, but understand how they change network and client operation

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# Thank You

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This presentation: http://go.7signal.com/CWNP

Roaming Whitepaper: http://go.7signal.com/download-wifi-roaming-whitepaper