aruba
a Hewlett Packard Enterprise company

Mobile Device Roaming Behaviors

Shawn Adams
Principal Network Engineer

12 February 2018

aruba
a Hewlett Packard Enterprise company

Agenda

– What are the factors that affect roaming performance?

– Design recommendations to provide the best roaming experience

– Aruba Customer Engineering (ACE) - Roaming Behavior Test Results

– Aruba Engineering Resolution Team (ERT) – Roaming Behavior Test Results

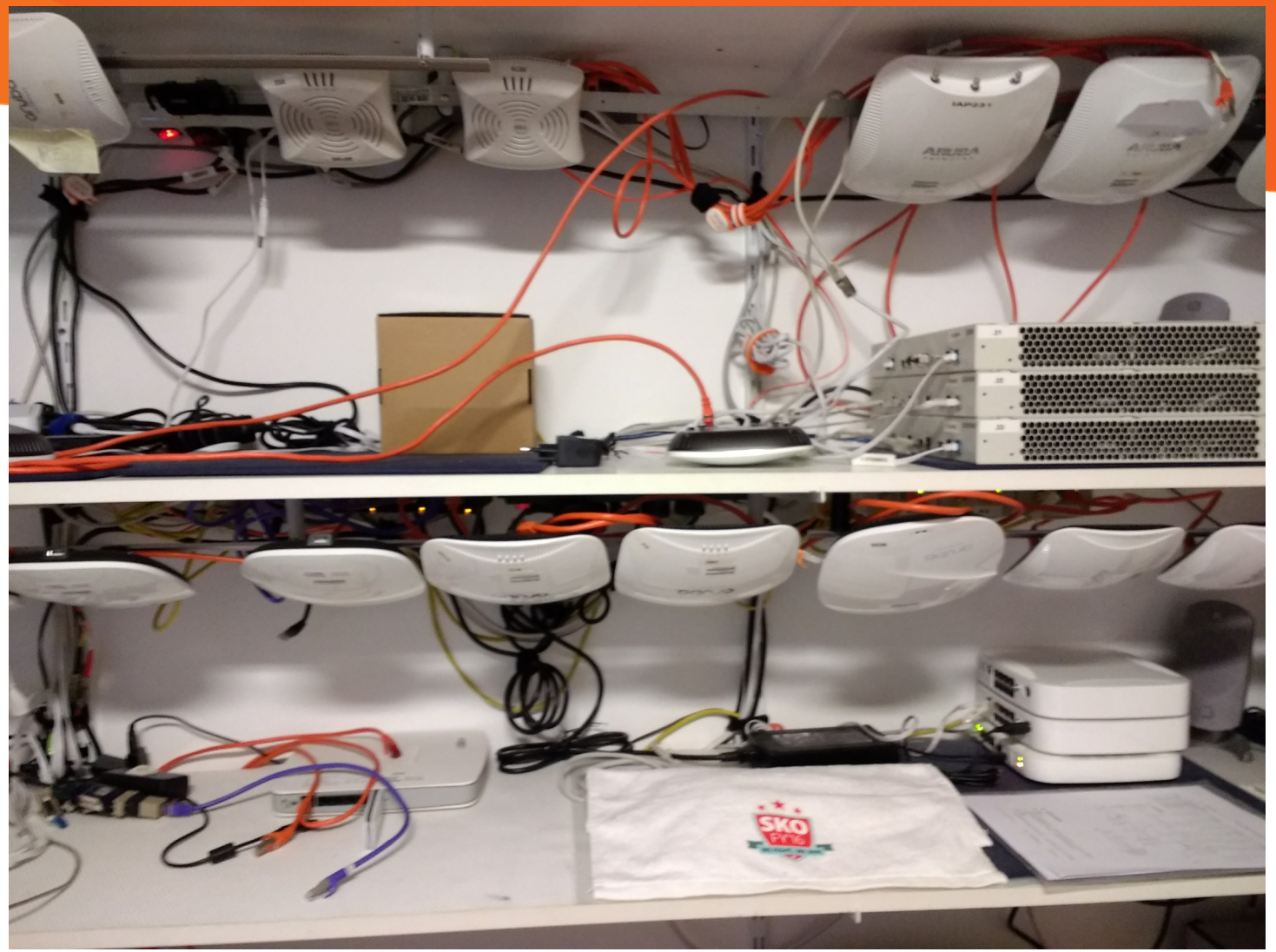
– Device monitoring and troubleshooting best practices

Lab - Tools and Preparation

- **“If it’s wireless, how come there are**
- **so many wires ?”**

- **We are replacing a low-variable cable**
- **with -**

- **air, people, obstacles and variables.**
- **no cat (Einstein)**



aruba
a Hewlett Packard Enterprise company

What affects roaming performance?

Roaming Defined

– 802.11 STA moves from one BSSID within the ESSID to another BSSID

– Can be measured - time between last data frame of BSSID_1 and the 1st data

– frame from BSSID_2

– Authentication adds delay - 10-600ms (worst-case - full RADIUS exchange)

– DHCP may play a role

– Network Learning L2 and L3 may play a role

– VOIP will suffer if any roam produces frame loss or delay > 150ms

– There is no way to guarantee that at least one frame will be seriously delayed/lost between

– BSSID_1 and BSSID_2 - if using ICMP to measure, the simple test is maximum 1 frame lost

Roaming Goals & Objectives

– Provide Best Possible Roaming experience

– Latency One-way Delay <50ms

– Round Trip Delay < 100 ms between STA and STA

– Jitter < 50ms (some documents state < 10ms)

– Packet Loss < 1% (5% can be tolerable in some networks)

– Consecutive lost packets < 3

– Provide clean RF field for STA to roam

– Primary and secondary coverage

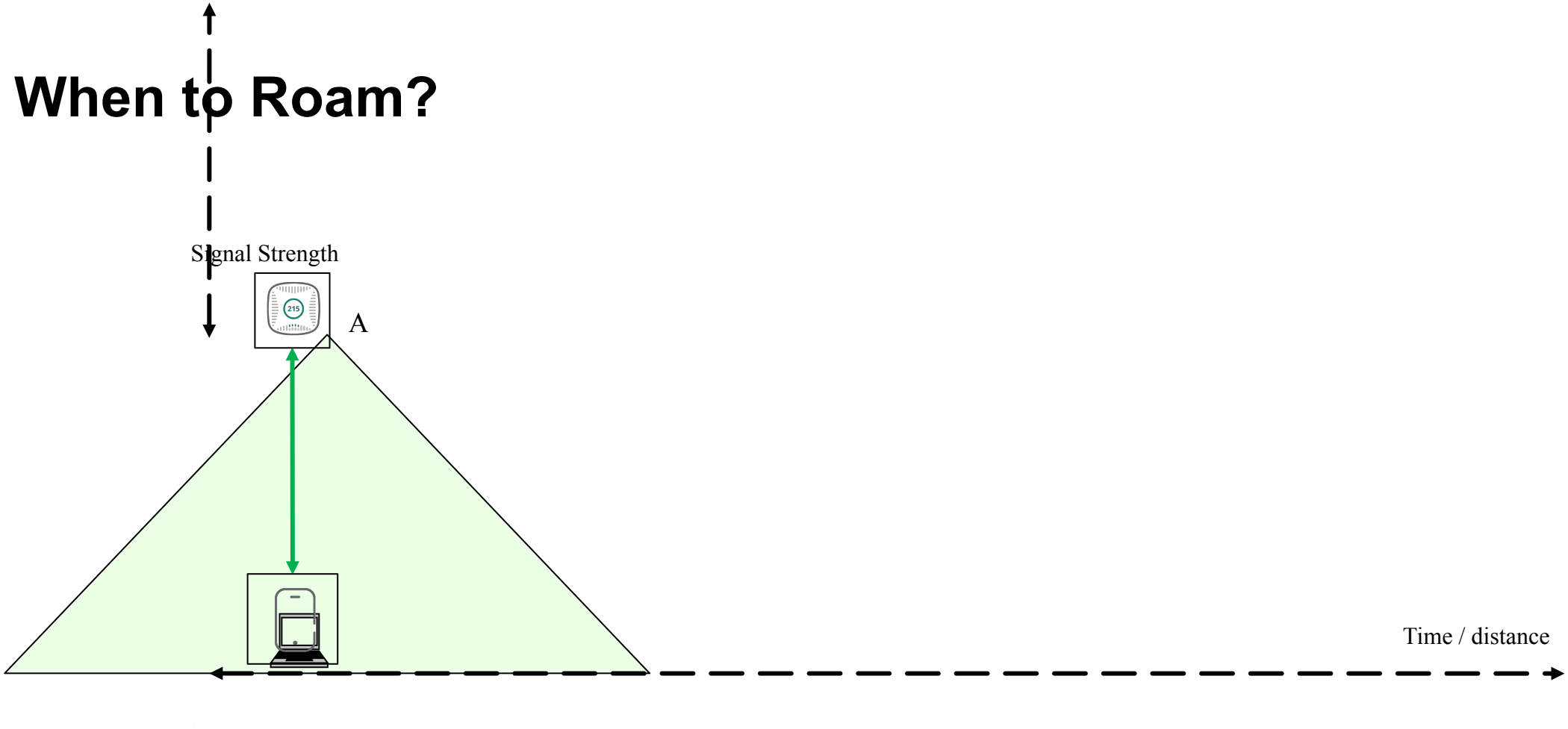
– Note: While one ICMP echo request per second sounds good, VOIP frames can come

– every 20-30ms - test with more than 1 frame/second

When to Roam?

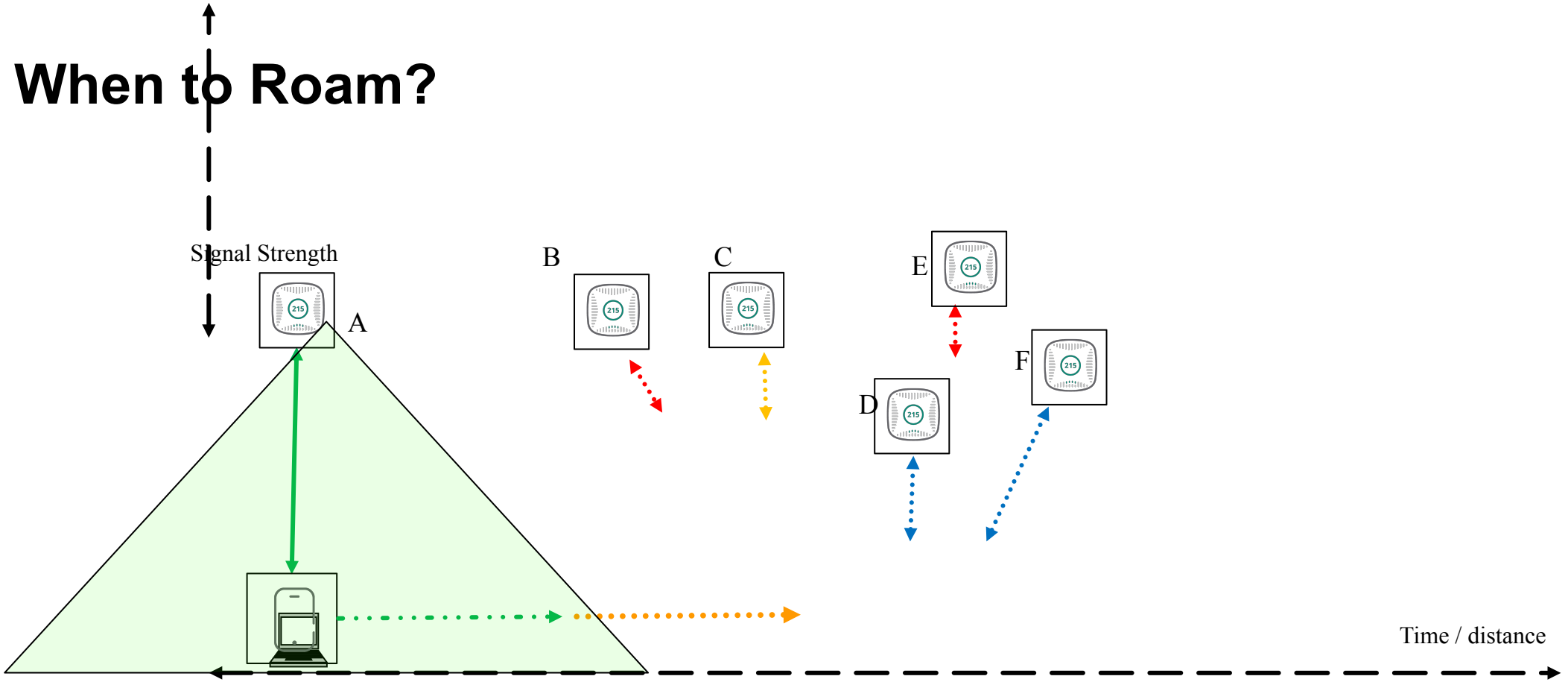
- What is the desired mobile device roaming behavior?
- The STA is solely responsible for the ultimate roaming decision
- No standard clearly identifies or mandates roaming behavior
- Based on all, some, or none of the following:
  - Current AP signal strength
  - Passive Probe listening methods
  - Active Probe Request methods
  - Channel noise, interference, utilization levels, Retries, Data Rates, Bit Error Rate
  - Signal strength of neighboring AP
  - Other unknown conditions decided upon by the client driver

When to Roam?



SNR=35, RSSI= -55dBm, Retry Rate <1%,Drop Rate < 1%

When to Roam?

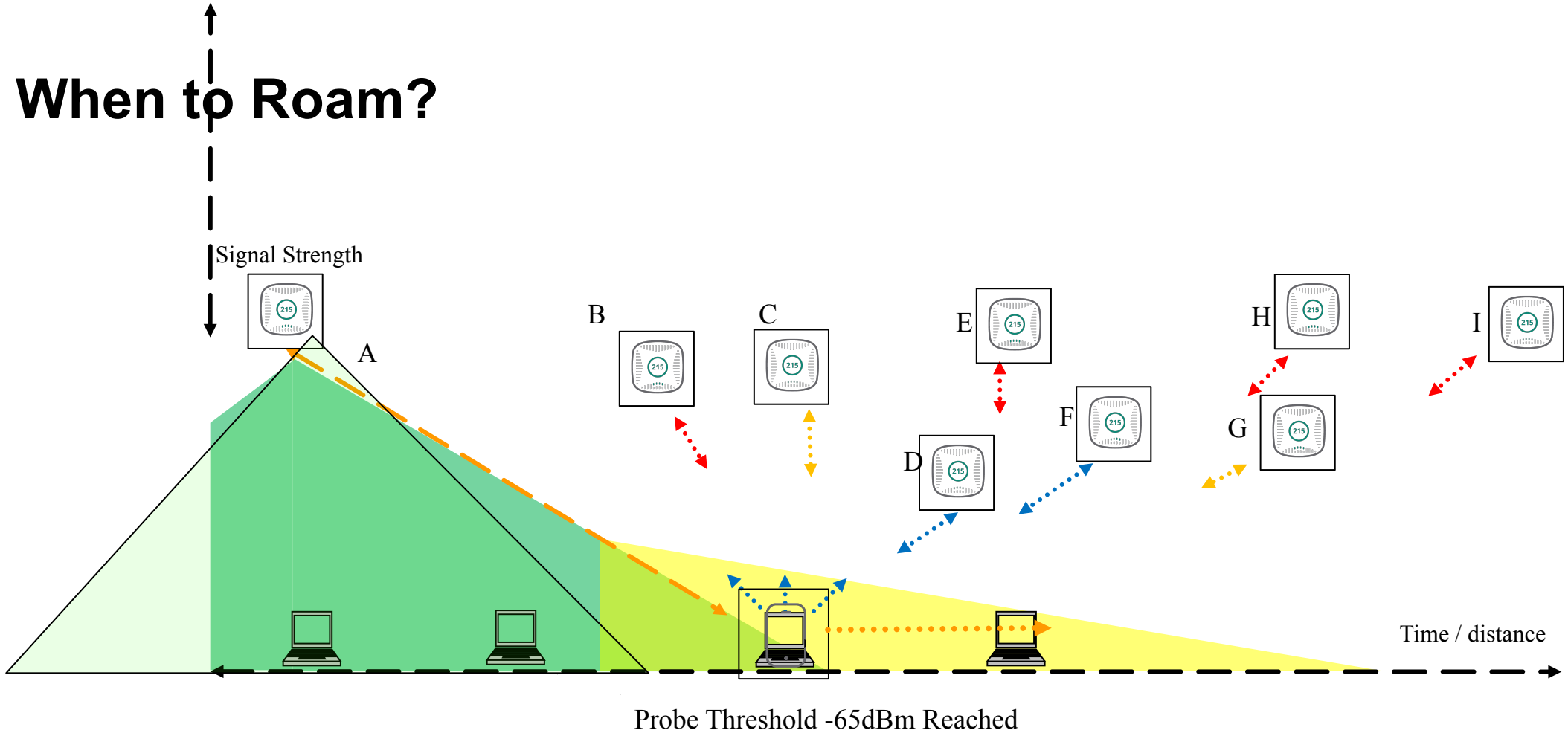


SNR=25, RSSI= -60dBm, Retry Rate <5%,Drop Rate < 3%

SNR lower, retries increase, drops increase, Data Rates drop
applications begin to suffers degredation
At what signal level does the client start probing ?

Probe-threshold and criteria critical - not yet met - passive probing ?

When to Roam?



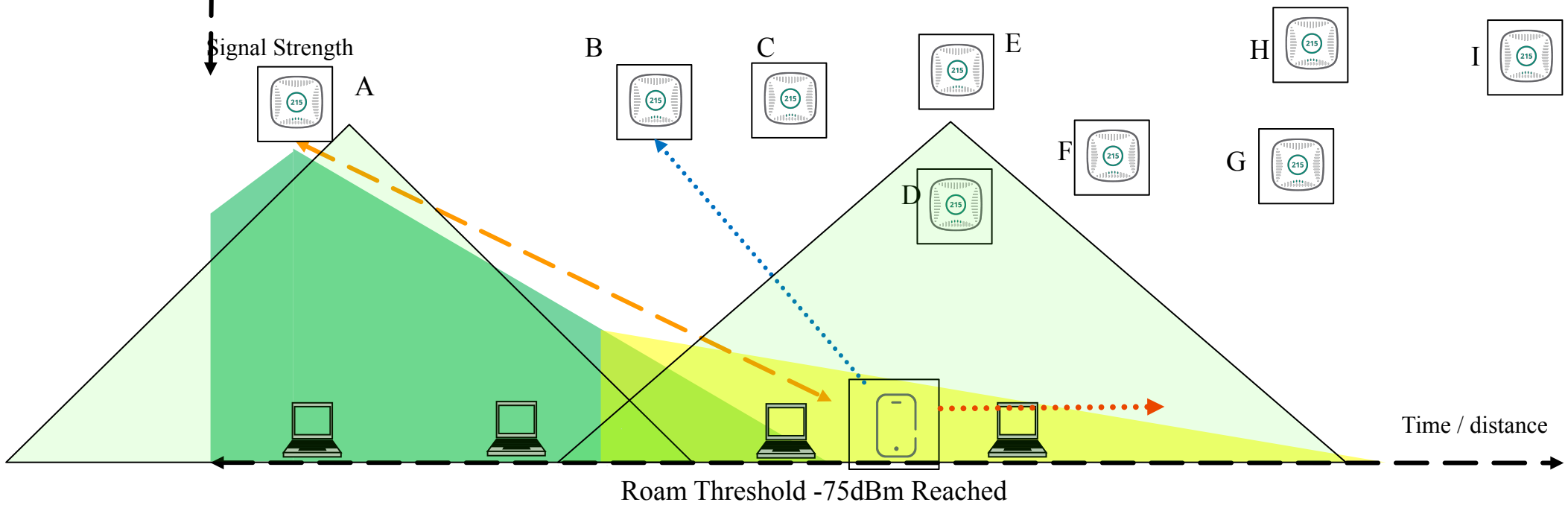
SNR=25, RSSI= -65dBm, Retry Rate <7%,Drop Rate < 5%

Client sends bcast probe-req, subsequent unicast probe-req - all hearing APs answer
Several possible problems – too many AP s– not enough delta
Scan time ? Beacons missed within this time ? Busy Air - probe responses missed ?

Too many probe resp.
corrupted probe resp.
table too small
not all APs probed

Probe-threshold and criteria critical met - bcast probe, then unicast

When to Roam?



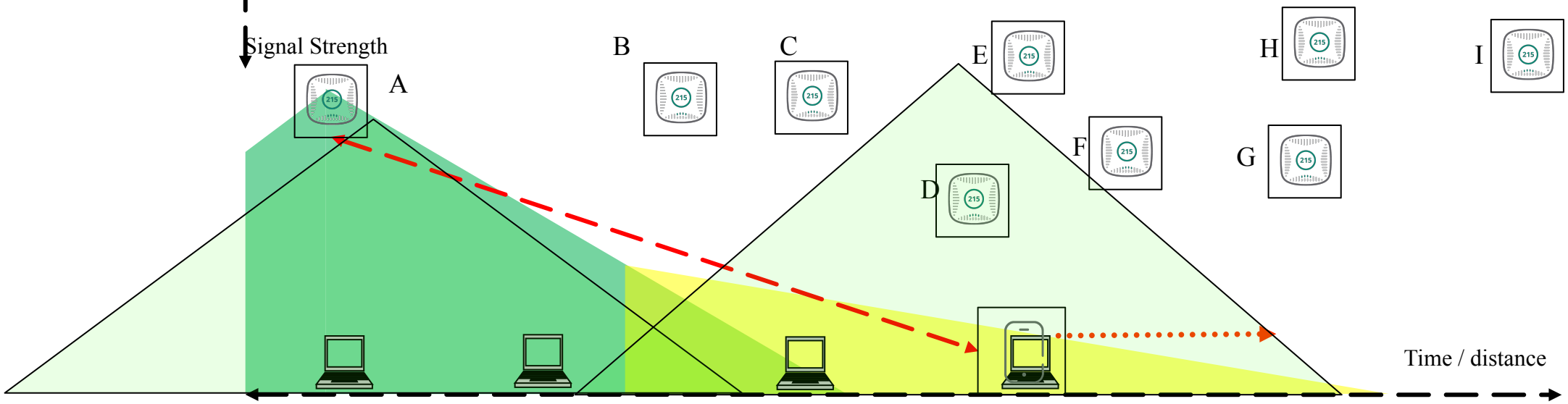
SNR=20, RSSI= -70dBm, Retry Rate <10%,Drop Rate < 5%

Client Decides on a new BSSID, sends auth. req, subsequent associate req.
Several possible problems – too many AP s– not enough delta
Scan time ? Beacons missed within this time ? Busy Air - probe responses missed ?

Old Data used
no roam-threshold reached
AP signal delta

What if the client has a roam-threshold of -75dBm ?

When to Roam?

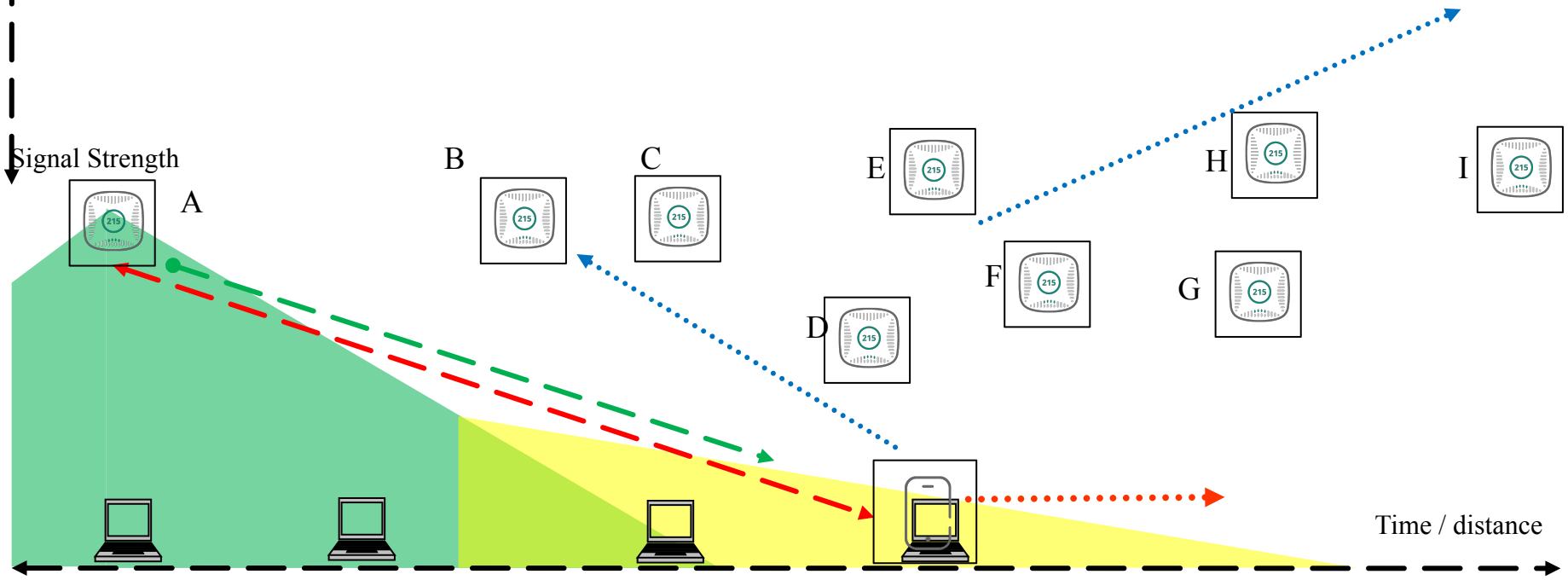


SNR=15, RSSI= -75dBm, Retry Rate <15%,Drop Rate < 10%

But what if the client doesn't send probe requests or authentication requests until -75dBm ?
Applications are already likely suffering degredation

Client finally roams - too late - application is already suffering degredation

When to Roam?

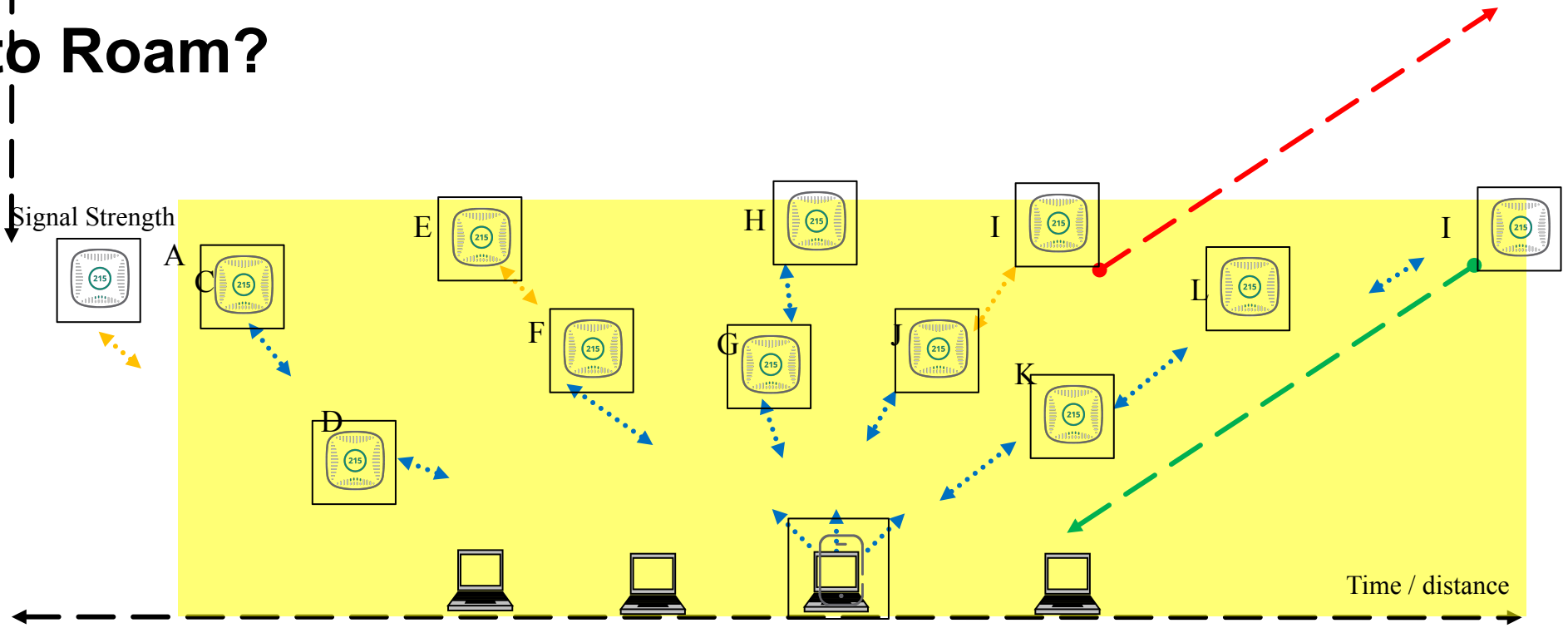


If the client happens to probe again, it obtains a new more accurate table, but what if the STA hits the roam threshold and uses old data ?

If the client does probe, if many APs are heard at the same signal level, the STA might choose the AP based on delta - not necessarily the best signal AP

Client picks far away AP versus the proper one since the received signal strengths of the probe response were within -10dB of each other. The down stream connection (green line) is okay but the upstream from the client (red line) is garbage leading to down-rating, retransmissions, errors and having negative impact on other clients
on the same AP or same channel.

When to Roam?



Device reaches an error threshold and starts looks for another AP to go to by probing and once again may go to a far away AP

Roaming Factors

– Probing Threshold - the earlier this happens, the better the roaming results

– Roaming Threshold - the earlier this happens, the better the roaming results

– Delta (hysteresis) - Received signal difference between better APs

– Scan time - Client needs sufficient time to find best APs

– Scan Interval - regular passive scans ? on demand ?

– Potential AP table space/sorting

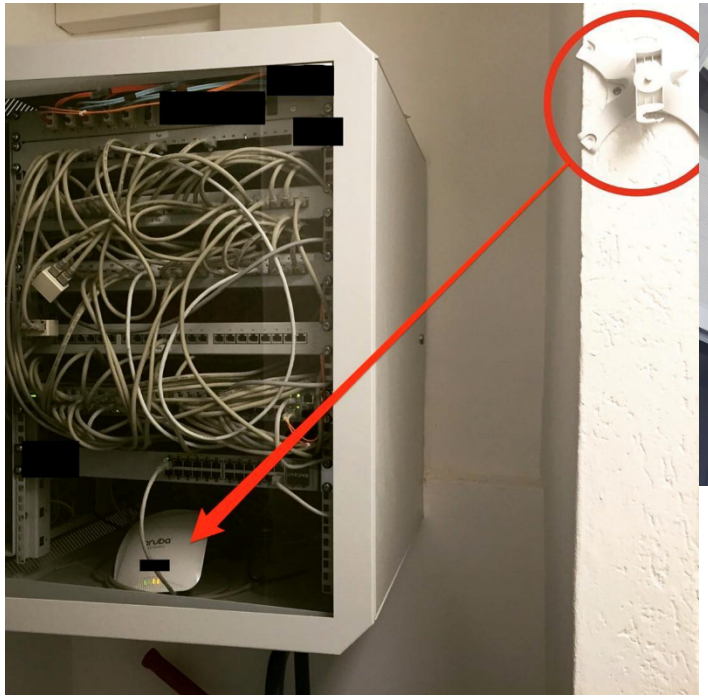
– Hidden SSID

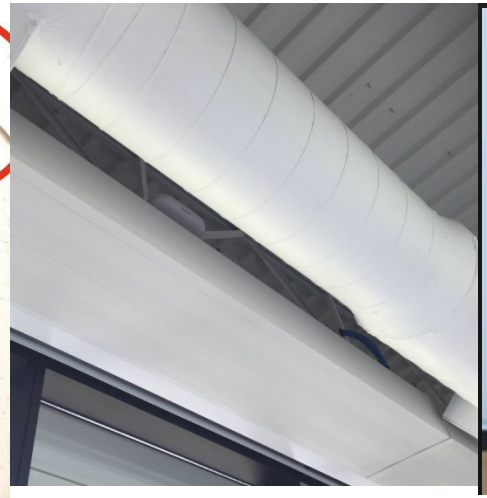
– DFS Channels - Must hear before active probing on DFS channel

– Number of Channels - takes longer to probe all possible APs

What are the factors that affect device roaming performance?

– Suboptimal AP design and deployment





aruba
a Hewlett Packard
Enterprise company

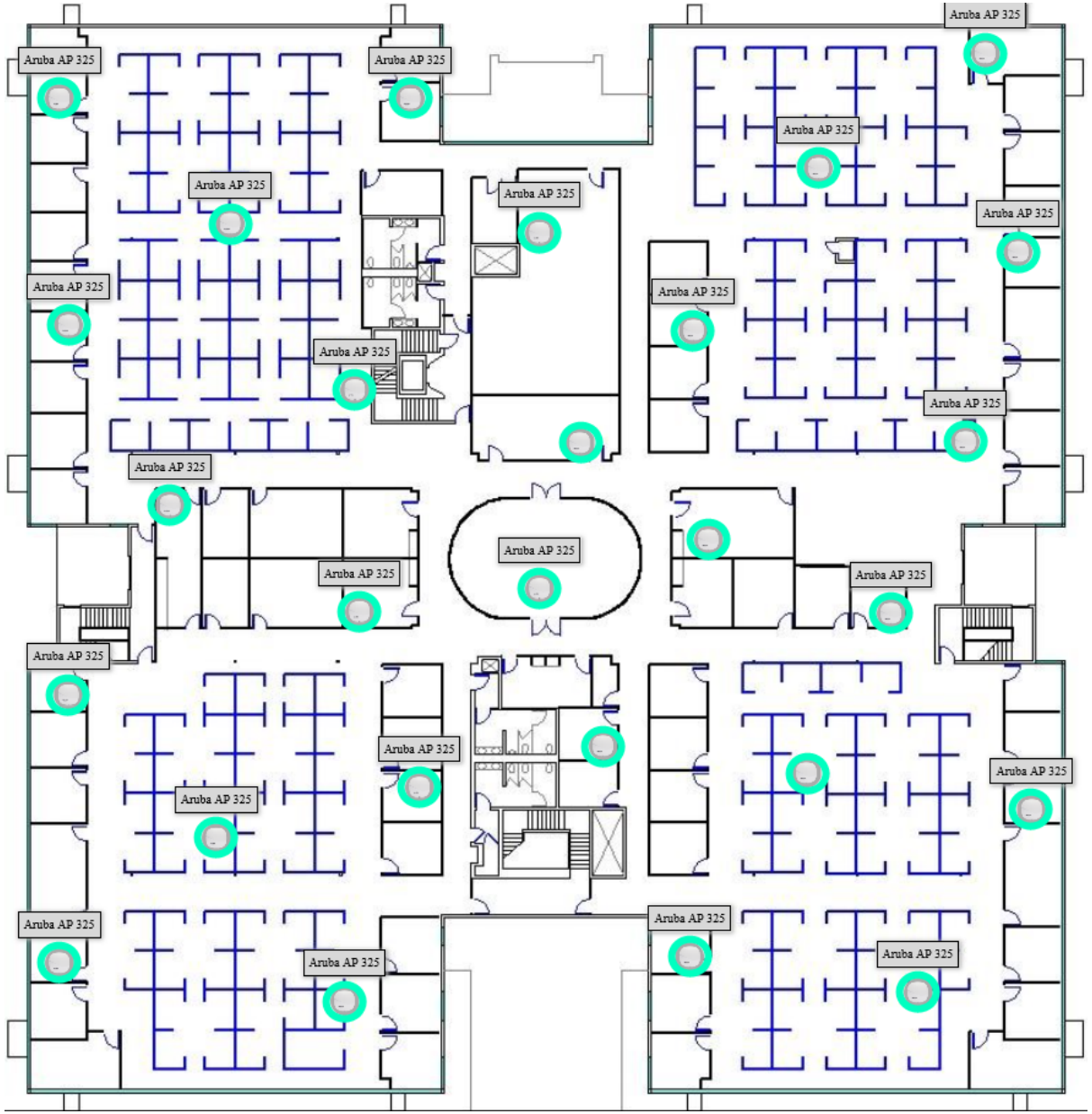
What are the factors that affect device roaming performance?

- Incorrect Controller/AP configuration
- AP transmit power is too high
- All 802.11 data rates enabled
- Protocols or features enabled that many devices don't support
- Too Many strong signals – client never hits roaming threshold
- Sub-optimal AP mounting
  - vertical stacking in multi-floor building
  - Antenna orientation
  - Poor placement choice - obstacles
- Old wireless NIC drivers
- Non-default wireless NIC configuration (i.e. roaming aggressiveness / power-save)
- Non-default OS configuration (i.e. power save mode)

Design Recommendations

Design Recommendations for Good Mobile Roaming Experience

- The following is an example site having proper AP design and placement
- This all wireless enterprise office space (combination of walled offices and cubicles) has AP-325's placed in honeycomb/staggered pattern about 15m apart.
- The expected high peak device association count in this office space was about 75 devices per AP.
- Some offices and conference rooms had an AP directly placed inside.



Design Recommendations for Good Mobile Roaming Experience

AP density

How many AP's does it take to cover typical areas without taking user density into account ?

The higher the downtilt AP is mounted (305, 315, 335) the larger the cone of coverage. If mounting a true omni (no downtilt) don't mount too high

Note: These are very raw estimates based on perfect LOS, the presence of no obstacles, and perfect uniform mounting of Aps. Actual site

Surveys and customary planning methods must be used for proper and accurate planning and results.

Warehouse (terminal applications and no VoIP)

1 AP every 750 – 1000 sq m (7500 - 10,000 sq ft) with 50% overlap so an AP every 27 – 30 m (85 – 100 ft)

Retail (open floors, eg. Grocery Store)

1 AP every 500 – 750 sq m (5000 - 7500 sq ft) with 50% overlap so an AP every 22 – 25 m (70 - 85 ft)

Open Office Space (open floor/cubes with offices around periphery)

AP every 250 – 360 sq m (2500 - 3600 sq ft) with 50% overlap so an AP every 15 – 20 m (50 - 60 ft)

Closed Office Space

Requires active site survey, depends on construction materials

Design Recommendations for Good Mobile Roaming Experience

Have consistent transmit power across all AP - Primary and secondary coverage

Reduce number of Channels used

Configure the maximum transmit power of all AP 2.4GHz radios to be at least 6 dB less than all 5GHz radios' minimum transmit power.

Consider Spectrum/Monitor Mode if AP density allows in 2.4Ghz band

Confine Mission Critical SSIDS to 5Ghz

Delete the lower 802.11 data rates on all your SSIDs

802.11 beacon rate to match your SSID’s lowest configured 802.11 data rate

Design Recommendations for Good Mobile Roaming Experience

- Keep wireless device drivers and OS up-to-date

- Keep Client Match enabled
  - Client Match is not intended to be a fast roaming tool but over time it tries to persuade devices to move to better APs based on signal strength, client capacity, and RF band support (sticky, load balance, band steering trigger)
  - It may be beneficial to reduce the restriction time out so that stubborn devices are allowed to reconnect to the AP of their choice
  - In High Density AP environments it is usually best to increase the load balancing threshold to 50+ on 5GHz radios

Design Tips to Provide the Best Mobile Roaming Experience

– Enable 802.11r if all clients support

– Ensure OKC is enabled and client support

– Ensure PMKID Validate is enabled

– Enable 802.11k if no clients experience problems

– Design for the weakest STA

– primary and secondary coverage (15-30% overlap -70dBm coverage)

– 5Ghz AP power > 6dB higher than 2.4Ghz

– Limit AP power allowed range to 3dB

– 12M or 24M as lowest basic rate

– Confine mission critical SSIDs to 5Ghz (guaranteed client behavior)

BYOD ? - not easy to accommodate all possible clients

Design Tips to Provide the Best Mobile Device Experience

- Take an in-depth look at the following extremely helpful sites to help you pick the best physical AP deployment method, AP density, channel allocation, channel width, Adaptive Radio Management options, and SSID/VAP configuration parameter values:
  - ”RF and Roaming Optimization for Aruba 802.11ac Networks” Solutions guide
    - http://community.arubanetworks.com/t5/Validated-Reference-Design/RF-and-Roaming-Optimization-for-Aruba-802-11ac-Networks/ta-p/227716
  - “Very High Density 802.11ac Networks” Validated Reference Design guide.
    - http://community.arubanetworks.com/t5/Validated-Reference-Design/Very-High-Density-802-11ac-Networks-Validated-Reference-Design/ta-p/230891
  - Aruba Solution Exchange for “RF Optimization and Deployment Models”
    - https://ase.arubanetworks.com/solutions/id/75

Roaming Behavior Test
Aruba Customer Engineering

The Test Goal and Plan

Compare device roaming experience between 3 different Controller configurations

– Allocate *“common”* devices with different models and operating systems

– Install a common application on the devices to use during the roaming tests

– Have a dedicated lab with as close as possible minimal fluctuating RF/WiFi environment

– Maintain some constant variables in each of the 3 configuration deployment tests

– Run multiple trials of each test

– Have a script to gather data from Controller/APs and a few clients during each test

– Have all APs in the test send all 802.11 frames they see to a host saving the data in aggregate

– Choose and record criteria for comparing roaming performance

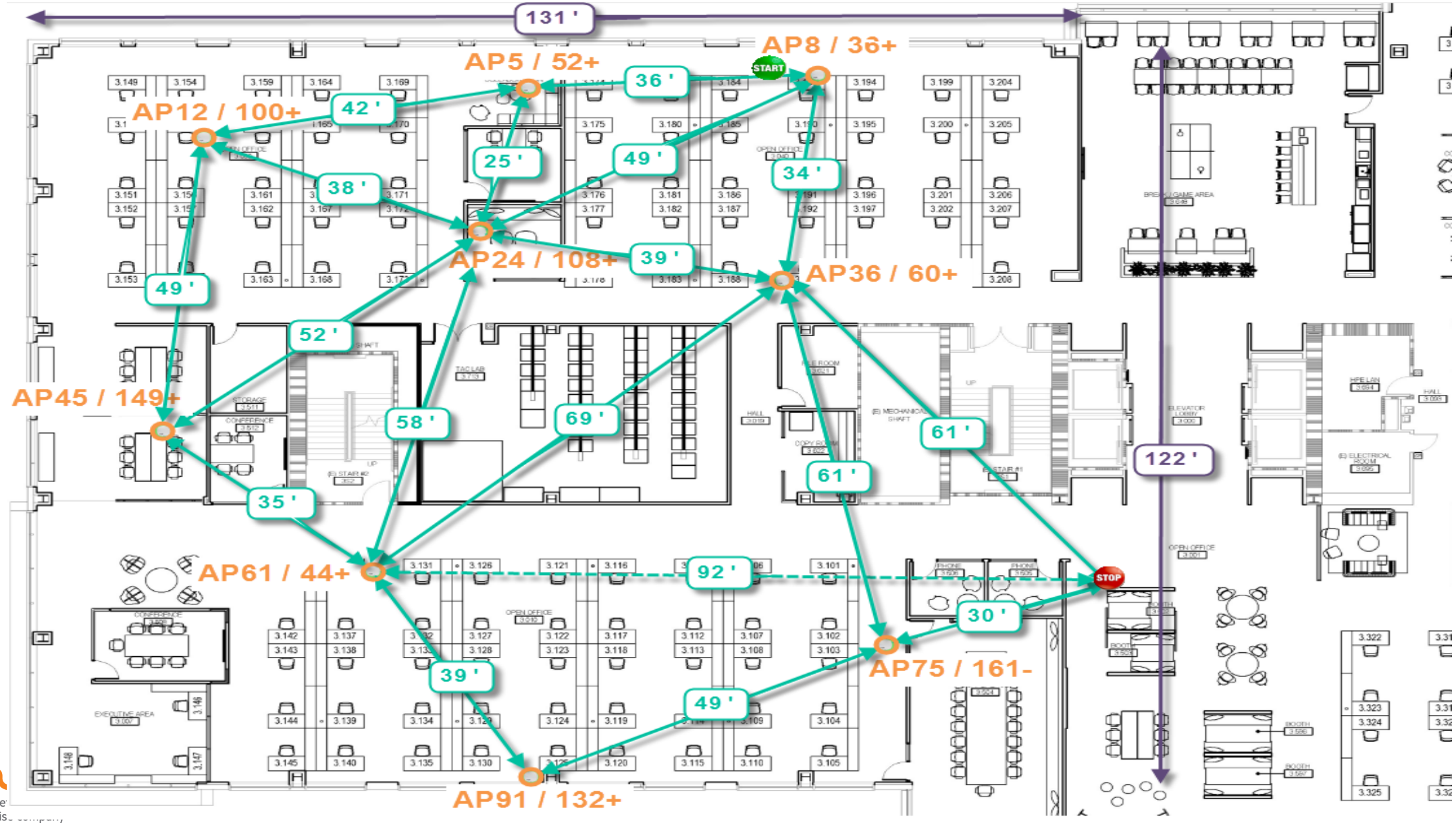
Roaming Lab Information

- WLAN
  - Aruba Controller 7210-US
  - 9 AP-335s
  - ArubaOS 6.5.1.3 build 58402
  - SSID configured for 802.1X WPA2-AES EAP-PEAP authentication
- Wired/PoE
  - Aruba MAS S3500
- Authentication
  - Clearpass 6.6.3
  - Windows Server 2012 Active Directory
- IP Address Allocation
  - Windows Server 2012 DHCP server
- Common Application Installed
  - Skype For Business

The AP Deployment Layout Used in Test

- AP placements were limited to the open ceiling cable drops available
- There was not an even distance between the APs due to contractor implementation
  - Our cable/AP contractors arbitrarily placed different model of APs throughout our 5000 sq. meter space
- A planned roaming path was selected between the APs to make use of walls and open space
- The building chosen for the test was newly built and designed for employee collaboration
  - High ceilings with no ceiling tile
  - There are several conference rooms but not employee has their own walled office
  - All employees are in low height cubicles

The Distances Between the AP-335s Under Test



The Roaming Path for Each Test

Beyond AP75's Area (stopping point) Roaming Path View

aruba
a Hewlett Packard Enterprise company

Constant Variable in the Roaming Experiment

- The following items did not change during each of the 3 roaming test comparisons
  - Kept the same pace of walk (roughly 1 step per second) throughout the building
  - Walked the same path from AP8 to past AP75
  - Used the same devices and locations on the roaming carts
  - The same APs, Controller, SSID, Authentication Server, and DHCP server were used
  - Each of the APs were configured with specific 802.11 channels
  - The Skype For Business group voice call was always started before each roam

Best Practice Controller Configuration

```
!
rf arm-profile "X4_2.4GHz_arm"
   max-tx-power 3
   min-tx-power 3
   cm-report-interval 10
   cm-band-g-max-signal 10
   cm-steer-timeout 3
   cm-lb-client-thresh 50
!
rf arm-profile "X4_5GHz_arm"
   no 80MHz-support
   max-tx-power 12
   min-tx-power 12
   cm-report-interval 10
   cm-band-g-max-signal 10
   cm-steer-timeout 3
   cm-lb-client-thresh 50
!
```

```
!
wlan ssid-profile "160MHz_WiFi-ssid_prof"
   essid "160MHz_WiFi"
   opmode wpa2-aes
   a-basic-rates 24
   a-tx-rates 24 36 48 54
   g-basic-rates 24
   g-tx-rates 24 36 48 54
   local-probe-req-thresh 10
   mcast-rate-opt
   ht-ssid-profile "160MHz_WiFi-htssid_prof"
   g-beacon-rate 24
   a-beacon-rate 24
```

```
!
wlan virtual-ap "160MHz_WiFi-vap_prof"
   aaa-profile "160MHz_WiFi-aaa_prof"
   ssid-profile "160MHz_WiFi-ssid_prof"
   vlan 2
   forward-mode decrypt-tunnel
   dynamic-mcast-optimization
   dynamic-mcast-optimization-thresh 100
   broadcast-filter all
!
```

Active AP Table

Name	Group	IP Address	11g Clients	11g Ch/EIRP/MaxEIRP	11a Clients	11a Ch/EIRP/MaxEIRP	AP Type
AP335_SLR01HPETAC3609p75	Sanya_APs	10.163.180.24	0	AP:HT:6/5.5/23.5	0	AP:VHT:161-/12/22.5	335
AP335_SLR01HPETAC3605p45	Sanya_APs	10.163.180.25	0	AP:HT:11/5.5/23.5	0	AP:VHT:149+/12/22.5	335
AP335_SLR01HPETAC3604p36	Sanya_APs	10.163.180.23	1	AP:HT:1/5.5/23.5	3	AP:VHT:64-/12/22.5	335
AP335_SLR01HPETAC3407p61	Sanya_APs	10.163.180.27	0	AP:HT:1/5.5/23.5	0	AP:VHT:44+/12/22.5	335
AP335_SLR01HPETAC3602p12	Sanya_APs	10.163.180.16	0	AP:HT:1/5.5/23.5	0	AP:VHT:100+/12/22.5	335
AP335_SLR01HPETAC3603p24	Sanya_APs	10.163.180.28	0	AP:HT:11/5.5/23.5	0	AP:VHT:108+/12/22.5	335
AP335_SLR01HPETAC3611p91	Sanya_APs	10.163.180.32	0	AP:HT:6/5.5/23.5	0	AP:VHT:132+/12/22.5	335
AP335_SLR01HPETAC3601p8	Sanya_APs	10.163.180.22	0	AP:HT:11/5.5/23.5	8	AP:VHT:36+/12/22.5	335
AP335_SLR01HPETAC3401p5	Sanya_APs	10.163.180.38	0	AP:HT:6/5.5/23.5	5	AP:VHT:52+/12/22.5	335

BP + 11krv Controller Configuration

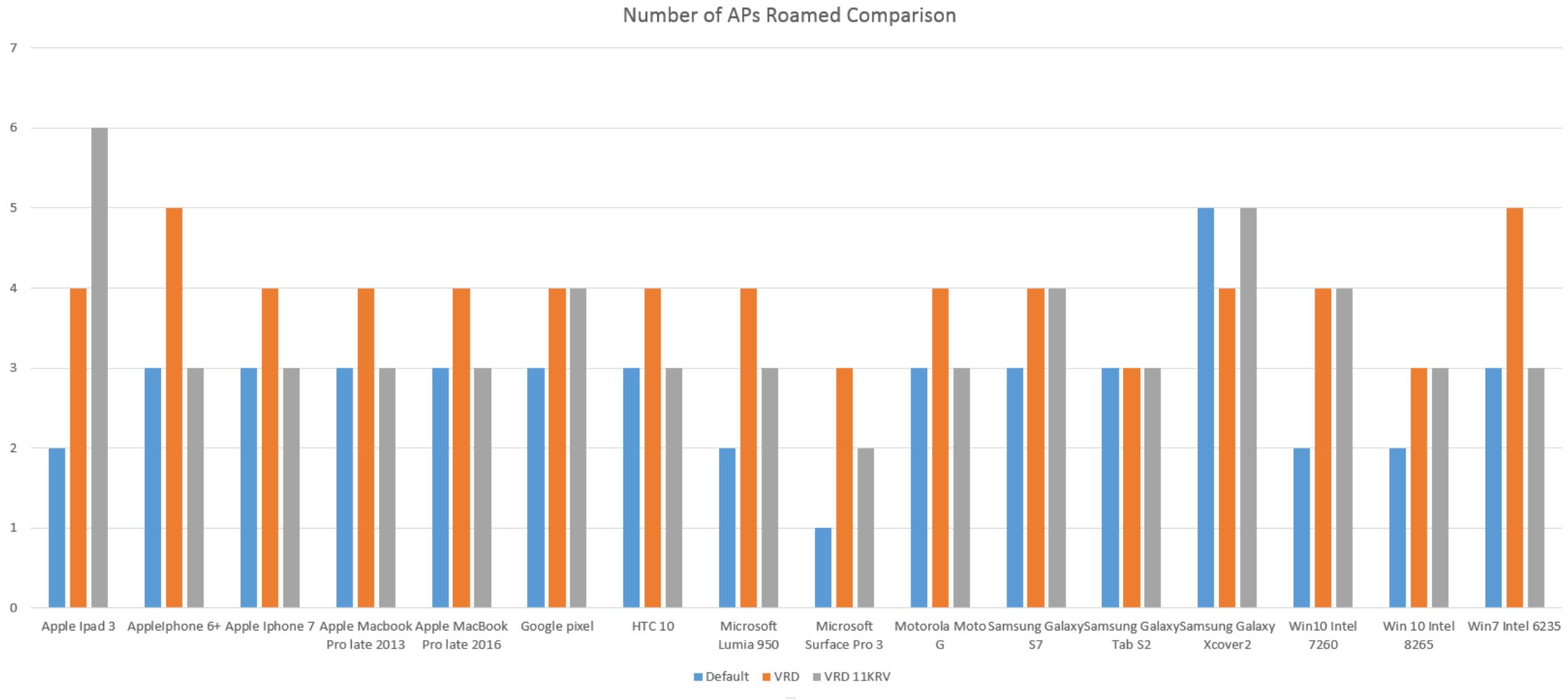
– 802.11k, 802.11r, and 802.11v was enabled in addition to best practice configuration

```
!
wlan handover-trigger-profile "handover_enabled"
   handover-trigger
   handover-threshold 65
!
wlan rrm-ie-profile "11k"
   no quiet-ie
!
wlan dot11r-profile "11r"
   dot11r
!

!
wlan dot11k-profile "11k"
   dot11k-enable
   bcn-measurement-mode active-all-ch
   bcn-req-chan-11a 0
   bcn-req-chan-11bg 0
   bcn-req-time 30
   handover-trigger-profile "handover_enabled"
   rrm-ie-profile "11k"
!
```

```
!
wlan ssid-profile "160MHz_WiFi-ssid_prof"
   essid "160MHz_WiFi"
   opmode wpa2-aes
   a-basic-rates 24
   a-tx-rates 24 36 48 54
   g-basic-rates 24
   g-tx-rates 24 36 48 54
   local-probe-req-thresh 10
   mcast-rate-opt
   ht-ssid-profile "160MHz_WiFi-htssid_prof"
   g-beacon-rate 24
   a-beacon-rate 24
   dot11r-profile "11r"
!
```

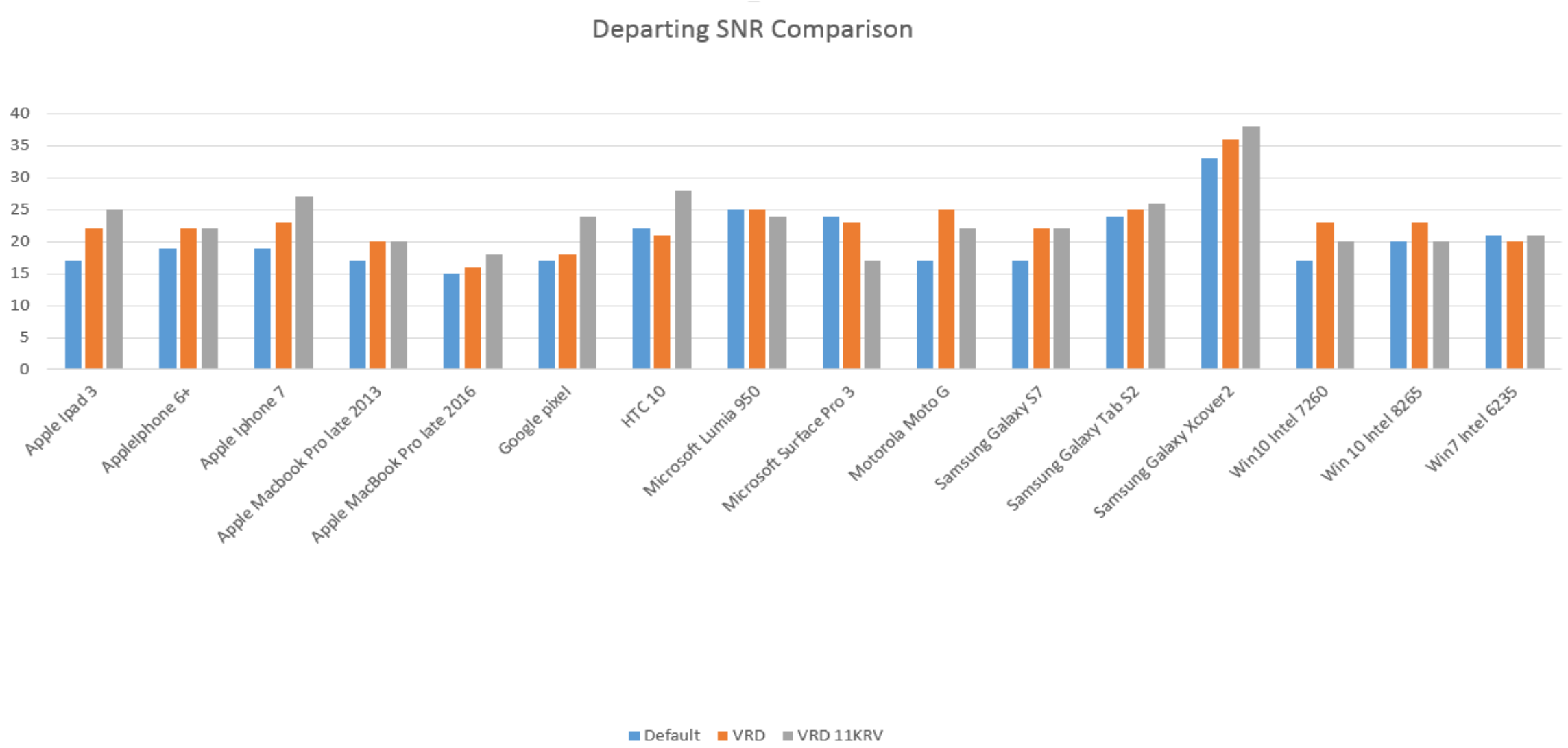
```
!
wlan virtual-ap "160MHz_WiFi-vap_prof"
   aaa-profile "160MHz_WiFi-aaa_prof"
   dot11k-profile "11k"
   ssid-profile "160MHz_WiFi-ssid_prof"
   vlan 2
   forward-mode decrypt-tunnel
   dynamic-mcast-optimization
   dynamic-mcast-optimization-thresh 100
   broadcast-filter all
!
```

Number of APs Roamed Comparison



More is better - presuming the STA always has a close AP

Departing SNR Comparison



aruba
a Hewlett Packard Enterprise company

Departing SNR is one of the most critical characteristics

Departing SNR Comparison

# of AP with Default config
# of AP with Best Practice Config
# of AP with Best Practice Config +11krv

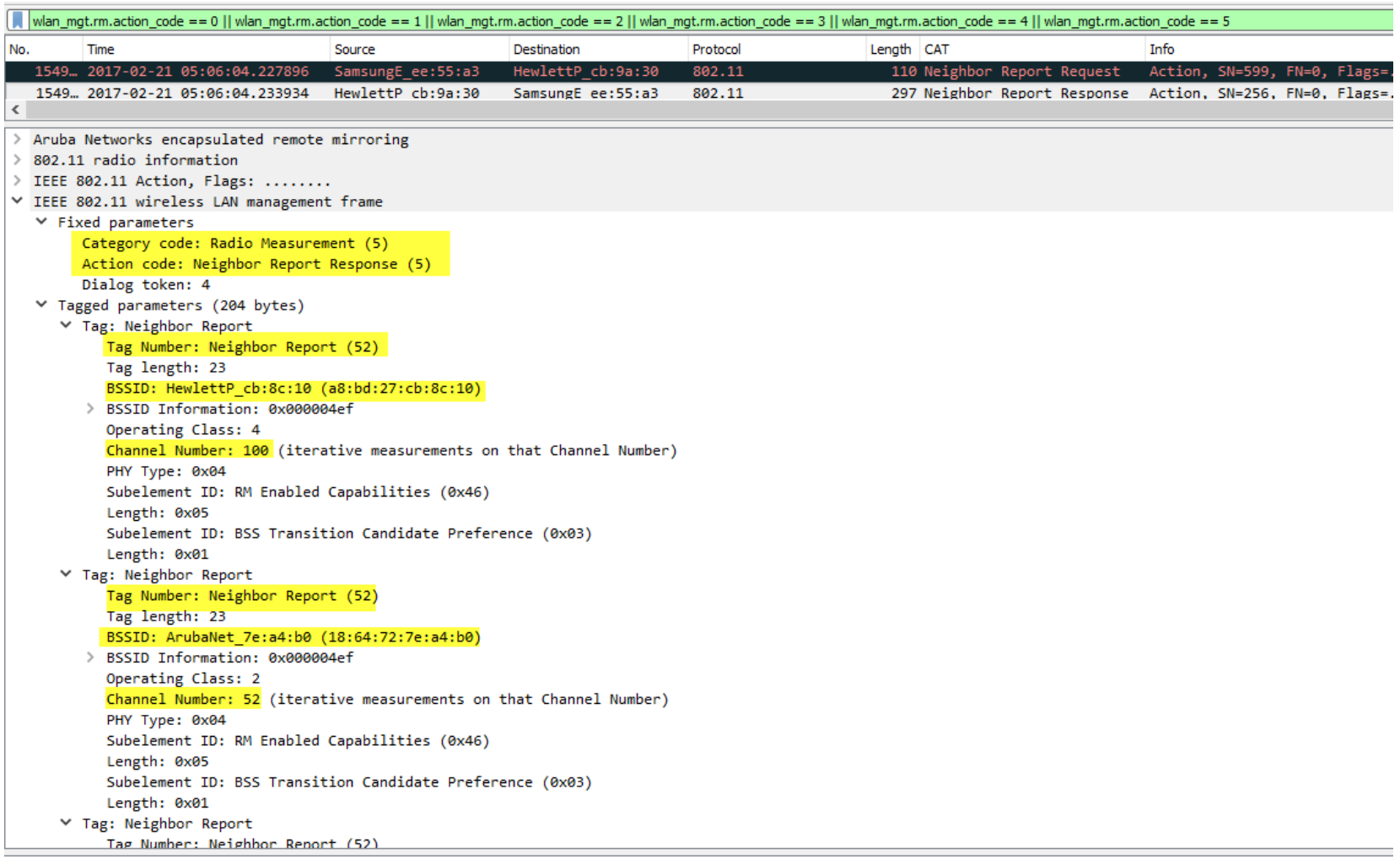
aruba
a Hewlett Packard Enterprise company

Takeaways from the Roaming Experiment

- VRD configuration offered slight improvement for most devices
- Mobile devices often did not connect to the closest AP
- Mobile devices often held its association until it was much farther away from its AP (~30m +)
  - This behavior also showed device's wireless signal strength became very low causing sub-optimal application performance
  - The 802.11 data rates seemed to deteriorate in parallel to the signal strength dropping in value.
- Mobile devices mostly connected to their APs at a very good SNR
  - Mobile devices mostly departed their associated AP at a good SNR
- Roaming experience improved slightly for clients supporting 802.11K and 802.11V
- Enabling 802.11R improved roaming latency for supporting devices

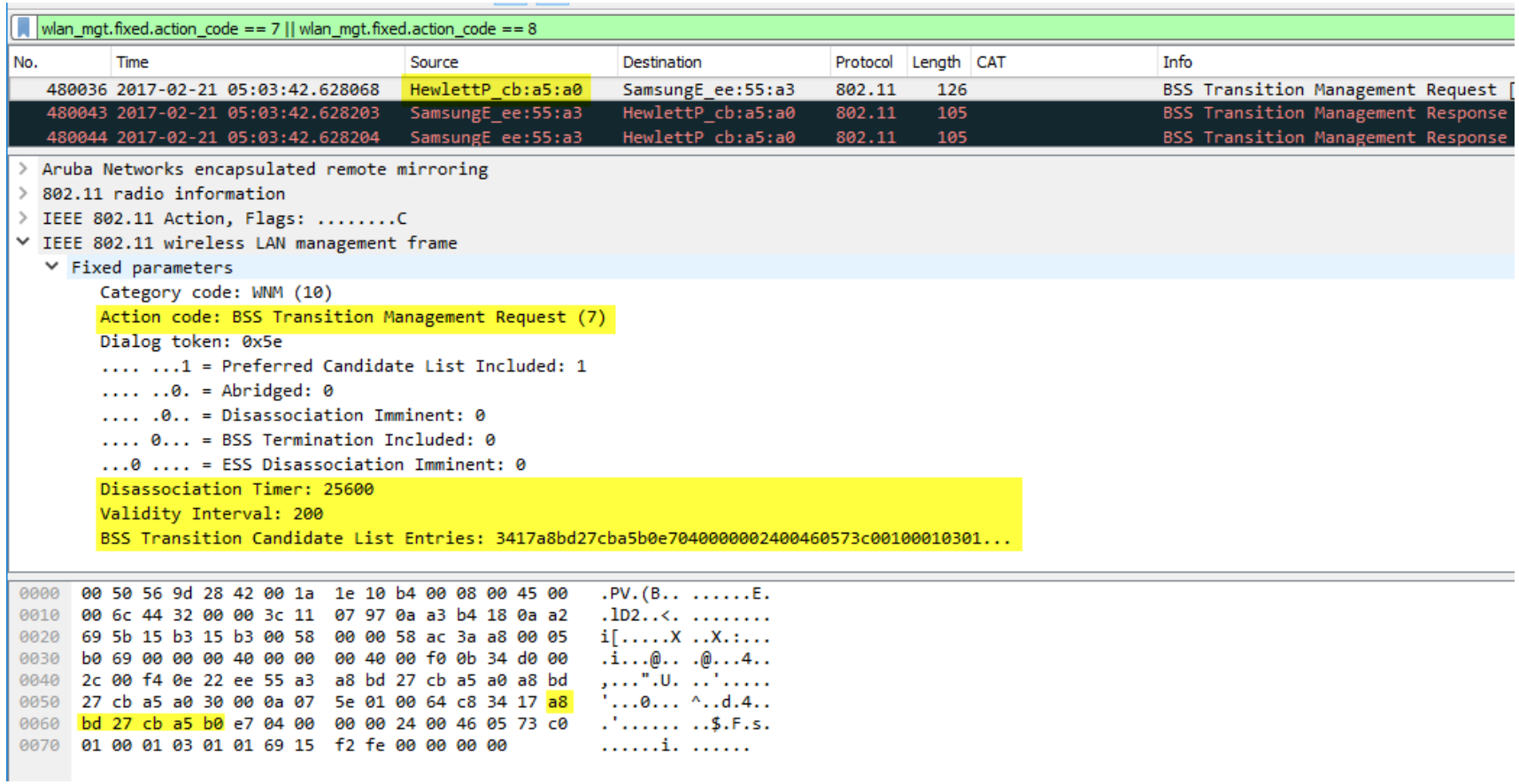
Why did enabling 802.11K improve roaming for several devices?

- Not all devices support 802.11K
- A Neighbor Report Response is one of the reports the Aruba APs sends to wireless devices when 802.11K is enabled.
- Neighbor Report may contain up to 8 radios/BSSIDs of the AP's neighbors
- Some devices that support 802.11K will use this 802.11K Neighbor Report Response list of BSSIDs as its roaming candidates in preference to what it learned in off channel scanning.



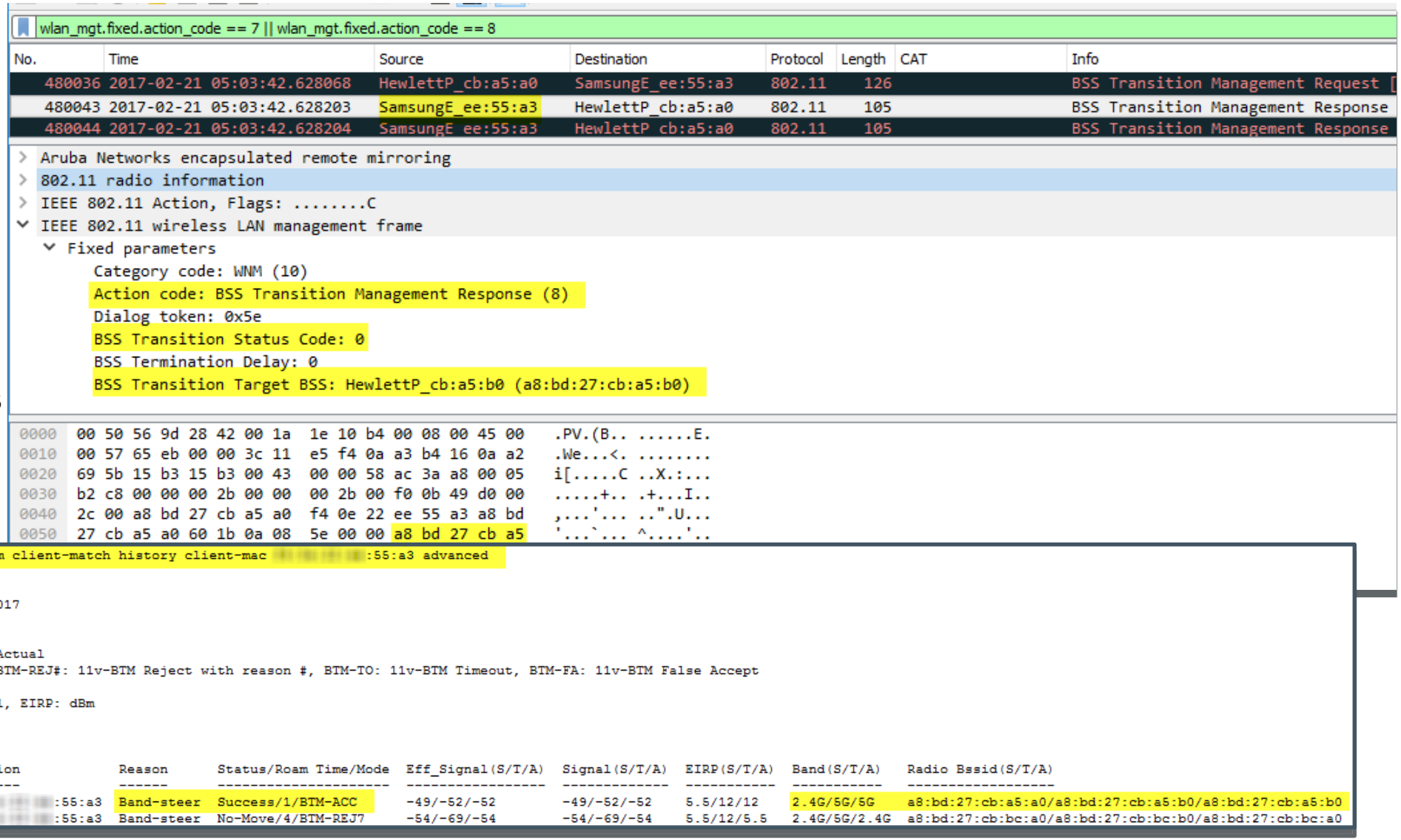
How did 802.11V improve roaming for devices that supported it?

- Client Match feature monitors devices for several minutes after they associate to a BSSID.
- If Client Match determines there is a better AP for the device due to Sticky, Band Steer, or Load Balancing trigger then it will send an 802.11 deauthentication frame to move it unless it supports 802.11V.
- If the device supports 802.11V then Client Match will try to steer the device to the better AP via BSS Transition Management Request frame as shown in the sniffer trace to the right.



How did 802.11V improve roaming for devices that supported it?

- Most devices that truly support 802.11V BSS Transition Management will accept the request if it approves the suggested BSSID in the candidate list.
- The sniffer trace and CLI output of Client Match history to the right shows 802.11V was used successfully to bandsteer an Android device.



wlan_mgt.fixed.action_code == 7 || wlan_mgt.fixed.action_code == 8

No.	Time	Source	Destination	Protocol	Length	CAT	Info
480036	2017-02-21 05:03:42.628068	HewlettP_cb:a5:a0	SamsungE_ee:55:a3	802.11	126		BSS Transition Management Request [
480043	2017-02-21 05:03:42.628203	SamsungE_ee:55:a3	HewlettP_cb:a5:a0	802.11	105		BSS Transition Management Response
480044	2017-02-21 05:03:42.628204	SamsungE_ee:55:a3	HewlettP_cb:a5:a0	802.11	105		BSS Transition Management Response

```
> Aruba Networks encapsulated remote mirroring
> 802.11 radio information
> IEEE 802.11 Action, Flags: ........C
v IEEE 802.11 wireless LAN management frame
  v Fixed parameters
      Category code: WNM (10)
      Action code: BSS Transition Management Response (8)
      Dialog token: 0x5e
      BSS Transition Status Code: 0
      BSS Termination Delay: 0
      BSS Transition Target BSS: HewlettP_cb:a5:b0 (a8:bd:27:cb:a5:b0)
```

```
0000  00 50 56 9d 28 42 00 1a  1e 10 b4 00 08 00 45 00   .PV.(B.. ......E.
0010  00 57 65 eb 00 00 3c 11  e5 f4 0a a3 b4 16 0a a2   .We...<. ........
0020  69 5b 15 b3 15 b3 00 43  00 00 58 ac 3a a8 00 05   i[.....C ..X.:...
0030  b2 c8 00 00 00 2b 00 00  00 2b 00 f0 0b 49 d0 00   .....+.. .+...I..
0040  2c 00 a8 bd 27 cb a5 a0  f4 0e 22 ee 55 a3 a8 bd   ,...'... ..".U...
0050  27 cb a5 a0 60 1b 0a 08  5e 00 00 a8 bd 27 cb a5   '...`... ^....'..
```

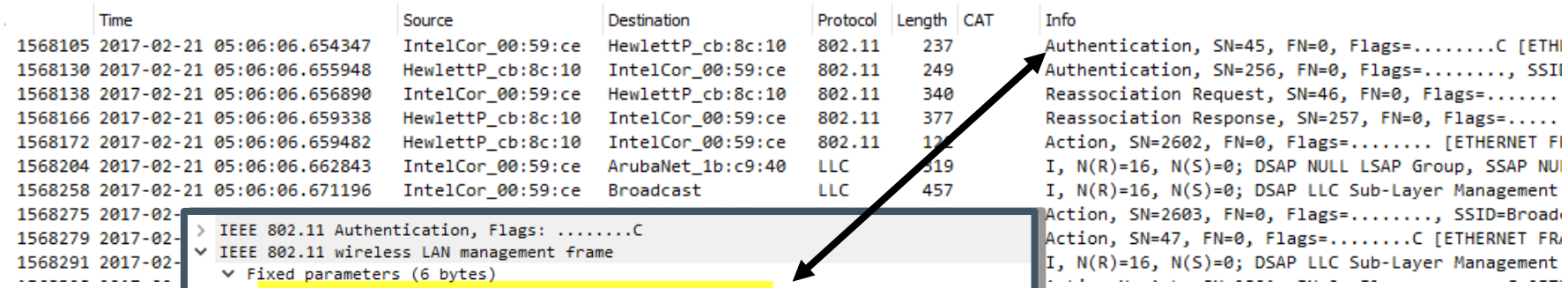
```
///// Command: show ap arm client-match history client-mac [redacted]:55:a3 advanced
///// Section: Stdout

Tue Feb 21 06:04:44.922 2017


S: Source, T: Target, A: Actual
BTM-ACC: 11v BTM Accept, BTM-REJ#: 11v-BTM Reject with reason #, BTM-TO: 11v-BTM Timeout, BTM-FA: 11v-BTM False Accept
Unit of Roam Time: second
Unit of Eff_Signal, Signal, EIRP: dBm

ARM Client match History
-------------------------
```

Time of Change	Station	Reason	Status/Roam Time/Mode	Eff_Signal(S/T/A)	Signal(S/T/A)	EIRP(S/T/A)	Band(S/T/A)	Radio Bssid(S/T/A)
2017-02-21 06:03:37	[redacted]:55:a3	Band-steer	Success/1/BTM-ACC	-49/-52/-52	-49/-52/-52	5.5/12/12	2.4G/5G/5G	a8:bd:27:cb:a5:a0/a8:bd:27:cb:a5:b0/a8:bd:27:cb:a5:b0
2017-02-21 05:48:39	[redacted]:55:a3	Band-steer	No-Move/4/BTM-REJ7	-54/-69/-54	-54/-69/-54	5.5/12/5.5	2.4G/5G/2.4G	a8:bd:27:cb:bc:a0/a8:bd:27:cb:bc:b0/a8:bd:27:cb:bc:a0

aruba
a Hewlett Packard Enterprise company

How did 802.11R improve roaming for devices that supported it?

- In analyzing sniffer traces of a roaming device (Win 10 / Intel 8265) that supports 802.11r the following authentication times were noted.
- It took **209 ms** when timing 802.11 Auth to first data packet after a full 802.1X/EAP-PEAP authentication with 802.11R disabled.
- It took **40 ms** when timing 802.11 Auth to first data packet after Opportunistic Key Caching (OKC) with 802.11R disabled.
- It took **17 ms** when timing 802.11 Auth to first data packet with 802.11R enabled as shown to the right.



	Time	Source	Destination	Protocol	Length	CAT	Info
1568105	2017-02-21 05:06:06.654347	IntelCor_00:59:ce	HewlettP_cb:8c:10	802.11	237		Authentication, SN=45, FN=0, Flags=........C [ETHI
1568130	2017-02-21 05:06:06.655948	HewlettP_cb:8c:10	IntelCor_00:59:ce	802.11	249		Authentication, SN=256, FN=0, Flags=........, SSII
1568138	2017-02-21 05:06:06.656890	IntelCor_00:59:ce	HewlettP_cb:8c:10	802.11	340		Reassociation Request, SN=46, FN=0, Flags=.....
1568166	2017-02-21 05:06:06.659338	HewlettP_cb:8c:10	IntelCor_00:59:ce	802.11	377		Reassociation Response, SN=257, FN=0, Flags=.....
1568172	2017-02-21 05:06:06.659482	HewlettP_cb:8c:10	IntelCor_00:59:ce	802.11	121		Action, SN=2602, FN=0, Flags=........ [ETHERNET FI
1568204	2017-02-21 05:06:06.662843	IntelCor_00:59:ce	ArubaNet_1b:c9:40	LLC	319		I, N(R)=16, N(S)=0; DSAP NULL LSAP Group, SSAP NUI
1568258	2017-02-21 05:06:06.671196	IntelCor_00:59:ce	Broadcast	LLC	457		I, N(R)=16, N(S)=0; DSAP LLC Sub-Layer Management
1568275	2017-02-						Action, SN=2603, FN=0, Flags=........, SSID=Broad
1568279	2017-02-						Action, SN=47, FN=0, Flags=........C [ETHERNET FR
1568291	2017-02-						I, N(R)=16, N(S)=0; DSAP LLC Sub-Layer Management

```
> IEEE 802.11 Authentication, Flags: ........C
v IEEE 802.11 wireless LAN management frame
  v Fixed parameters (6 bytes)
      Authentication Algorithm: Fast BSS Transition (2)
      Authentication SEQ: 0x0001
      Status code: Successful (0x0000)
  v Tagged parameters (137 bytes)
    v Tag: RSN Information
        Tag Number: RSN Information (48)
        Tag length: 38
        RSN Version: 1
      > Group Cipher Suite: 00-0f-ac (Ieee8021) AES (CCM)
        Pairwise Cipher Suite Count: 1
      > Pairwise Cipher Suite List 00-0f-ac (Ieee8021) AES (CCM)
        Auth Key Management (AKM) Suite Count: 1
      > Auth Key Management (AKM) List 00-0f-ac (Ieee8021) FT over IEEE 802.1X
      > RSN Capabilities: 0x003c
        PMKID Count: 1
      > PMKID List
    v Tag: Mobility Domain
        Tag Number: Mobility Domain (54)
        Tag length: 3
        Mobility Domain Identifier: 0x0001
        FT Capability and Policy: 0x00
        .... ...0 = Fast BSS Transition over DS: 0x0
        .... ..0. = Resource Request Protocol Capability: 0x0
    v Tag: Fast BSS Transition
        Tag Number: Fast BSS Transition (55)
        Tag length: 90
        MIC Control: 0x0000
        0000 0000 .... .... = Element Count: 0
        MIC: 00000000000000000000000000000000
        ANonce: 0000000000000000000000000000000000000000000000000...
        SNonce: 8d78450ac2f3a23a66fb3141acbbd945e4da69e506cbd10d...
        Subelement ID: PMK-R0 key holder identifier (R0KH-ID) (3)
        Length: 6
        PMK-R0 key holder identifier (R0KH-ID):
```

aruba
a Hewlett Packard Enterprise company

Roaming Behavior Test
Engineering Resolution Team

The Test Goal and Plan

Create a small-scale simulation of real-life roaming environments

– Focus on practical question – roaming is “fair”, but not acceptable.

– Allocate 3 android devices – good performance, poor performance, and industrial.

– Install a common application on the devices to use during the roaming tests.

– AP mounting and space based on real-life requirements.

– Based on Aruba VRD configuration.

– Eliminate as many variables as possible.

– Run multiple trials of each test.

– Apply Customer success criteria.

Written Acceptance Tests are Essential !

Roaming Lab Information

- WLAN
  - Aruba Controller 7010-RW
  - 3 AP-215
  - ArubaOS 6.4.4.12
  - SSID configured for 802.1X TLS authentication
- Authentication
  - Clearpass 6.5
- IP Address Allocation
  - Linux – ISC DHCP 4.2.6
- Common Application Installed
  - Asterisk SIP
  - Aruba Utilities

The AP Deployment Layout Used in Test

- AP placements were limited to the open ceiling cable drops available
- There was not uniform distance between the APs due to contractor implementation
  - AP placement was limited to the offices on the basis of customer aesthetic requirements

- A planned roaming path was selected between the APs to make use of walls and open space

- The building chosen for the test was newly built designed with a groovy collaborative working space
  - Standard 2.5m ceilings
  - 3 offices, connecting to a larger meeting area

The Testing

The 3 devices chosen were categorized based on observed roaming performance

- Device #1 Older Android device 5.0.1, which exhibited consistently poor behavior in multiple environments
- Device #2 Modern Android device, 6.0.1 which exhibited consistently better roaming, but not acceptable
- Device #3 Industrial Android device, 5.0.1 which exhibited consistently better roaming, but not acceptable

Roaming was always along the same path, AP_1, AP_2, AP_3, and the reverse.

Controller UCC data, Android Utilities, and scripts were used to measure

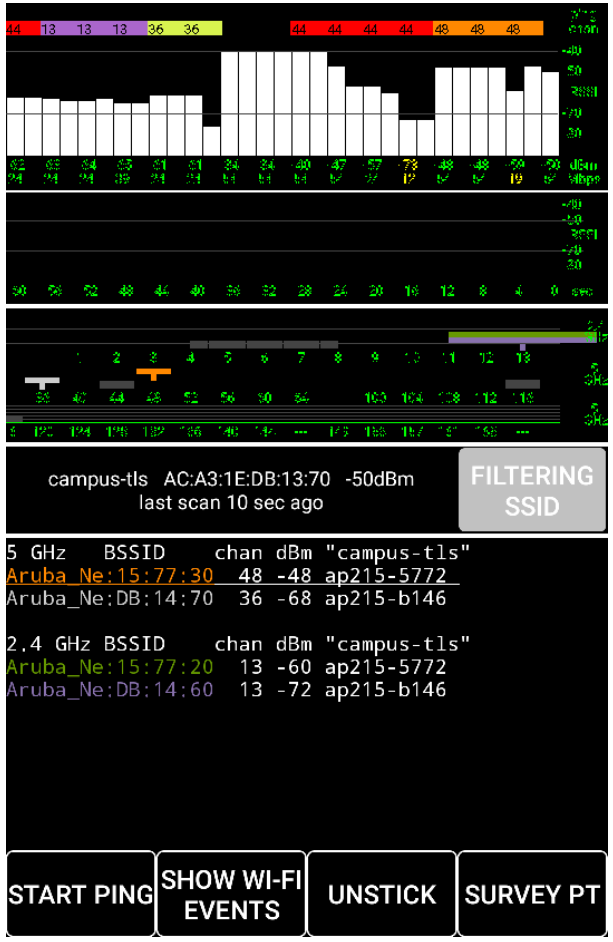
Interference, noise and AP channel stability were monitored during the testing to ensure no variance

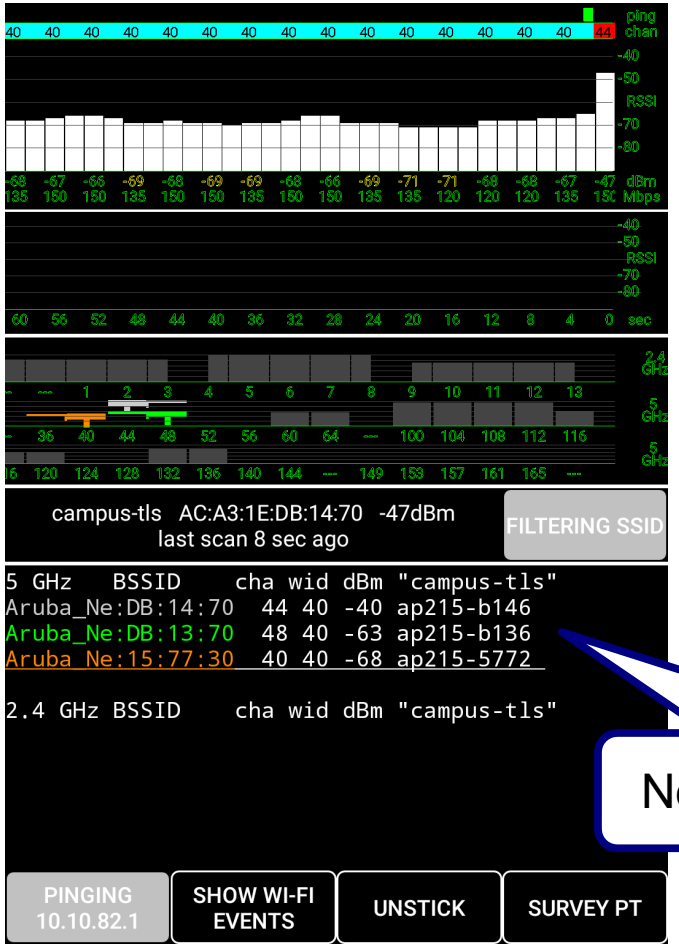
DHCP traffic was monitored at the DHCP server

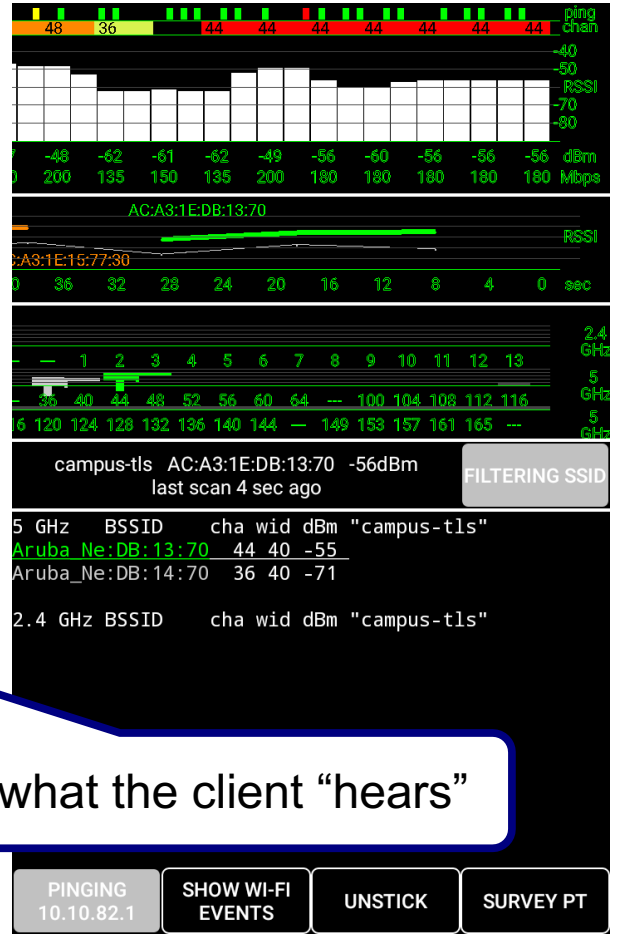
An SIP call to the conference service was placed prior to the start of roaming – music audio stream toward the client

Use VOIP and ICMP - 5-8 frames per second as a baseline test

Comparing 3 Android Clients







Note what the client “hears”

Key data points are the scroll view – departure signal and the scanned SSIDs

Observations

Jan 22, 2017 7:03:07 PM WIFI_EVENT RSSI_CHANGED_-68

Jan 22, 2017 7:03:11 PM New Wi-Fi Reading
Connected__true RSSI__-75 dBm Link__45 Mbps AP name__
BSSID__AC:A3:1E:DB:14:70 SSID__campus-tls IPaddr__10.10.82.161 GwyIPAddr__10.10.82.1 Upstream Iperf 0.0Mbps Dnstream Iperf 0.0Mbps Scanned by SSID _campus-tls_
AC:A3:1E:15:77:30 48 40 MHz cf 5220 MHz -49 dBm
AC:A3:1E:DB:14:70 36 40 MHz cf 5200 MHz -75 dBm Scanned by SSID _campus-tls_

Jan 22, 2017 7:03:11 PM Scan Results Filtered__true filterSsid__campus-tls a band 212 b band 63

Jan 22, 2017 7:03:11 PM WIFI_EVENT SCAN_RESULTS_true

Jan 22, 2017 7:03:13 PM WIFI_EVENT supplicant.STATE_CHANGE_ASSOCIATED

Jan 22, 2017 7:03:13 PM WIFI_EVENT STATE_CHANGE_[type: WIFI[], state: CONNECTED/CONNECTED, reason: (unspecified), extra: "campus-tls", roaming: false, failover: false, isAvailable: true]

Jan 22, 2017 7:03:13 PM WIFI_EVENT STATE_CHANGE_SSID: campus-tls, **BSSID: ac:a3:1e:15:77:30, MAC: 02:00:00:00:00:00, Supplicant state: ASSOCIATED, RSSI: -75**, Link speed: 45Mbps, Frequency: 5180MHz, Net ID: 1, Metered hint: false, score: 55

Jan 22, 2017 7:03:13 PM WIFI_EVENT STATE_CHANGE_{InterfaceName: wlan0 LinkAddresses: [fe80::210:40ff:fea4:7a52/64,10.10.82.161/24,] Routes: [fe80::/64 -> ::/0 wlan0,10.10.82.0/24 -> 0.0.0.0 wlan0,0.0.0.0/0 -> 10.10.82.1 wlan0,] DnsAddresses: [192.168.17.52,192.168.17.31,] Domains: lab.no-ip.org MTU: 0 TcpBufferSizes: 524288,1048576,2097152,2[illegible]8,1048576}

Jan 22, 2017 7:03:13 PM WIFI_EVENT STATE_CHANGE_ac:a3:1e:15:77:30

Jan 22, 2017 7:03:14 PM WIFI_EVENT supplicant.STATE_CHANGE_FOUR_WAY_HANDSHAKE

Jan 22, 2017 7:03:14 PM WIFI_EVENT supplicant.STATE_C[illegible]

Jan 22, 2017 7:03:14 PM WIFI_EVENT supplicant.STATE_C[illegible]

Jan 22, 2017 7:03:16 PM WIFI_EVENT RSSI_CHANGED_-47

Noted that when the departing signal was < -74 , tests failed

Feb 14, 2018 08:49:25 New Wi-Fi Reading
Connected__true RSSI__-66 dBm Link__135 Mbps AP name__
BSSID__AC:A3:1E:DB:14:70 SSID__campus-tls IPaddr__10.10.82.178 GwyIPAddr__10.10.82.1
Upstream Iperf 0.0Mbps Dnstream Iperf 0.0Mbps

Feb 14, 2018 08:49:26 WIFI_EVENT RSSI_CHANGED_-63

Feb 14, 2018 08:49:29 WIFI_EVENT RSSI_CHANGED_-63 <----------Actual received Signal

Feb 14, 2018 08:49:31 New Wi-Fi Reading
Connected__true RSSI__-63 dBm Link__150 Mbps AP name__
BSSID__AC:A3:1E:DB:14:70 SSID__campus-tls IPaddr__10.10.82.178 GwyIPAddr__10.10.82.1
Upstream Iperf 0.0Mbps Dnstream Iperf 0.0Mbps
Scanned by SSID _campus-tls_
chan 44 40 MHz wide, cf 5230 MHz -50 dBm
chan 36 40 MHz wide, cf 5190 MHz -63 dBm
Scanned by SSID _campus-tls_

Feb 14, 2018 08:49:31 Scan Results Filtered__true filterSsid__campus-tls a band 237 b band 63
Feb 14, 2018 08:49:31 WIFI_EVENT SCAN_RESULTS_true
Feb 14, 2018 08:49:32 WIFI_EVENT RSSI_CHANGED_-64
Feb 14, 2018 08:49:33 WIFI_EVENT supplicant.STATE_CHANGE_ASSOCIATING
Feb 14, 2018 08:49:33 WIFI_EVENT supplicant.STATE_CHANGE_ASSOCIATED
Feb 14, 2018 08:49:33 WIFI_EVENT RSSI_CHANGED_-49

Feb 14, 2018 08:49:33 WIFI_EVENT STATE_CHANGE_[type: WIFI[], state: CONNECTED/CONNECTED, reason: (unspecified), extra: "campus-tls", failover: false, available: true, roaming: false, metered: false]

Feb 14, 2018 08:49:33 WIFI_EVENT STATE_CHANGE_SSID: campus-tls, BSSID: ac:a3:1e:db:13:70, MAC: 02:00:00:00:00:00, Supplicant state: **ASSOCIATED, RSSI: -49**, Link speed: 150Mbps, Frequency: 5220MHz, Net ID: 6, Metered hint: false, **score: 60**

Feb 14, 2018 08:49:33 WIFI_EVENT STATE_CHANGE_{InterfaceName: wlan0 LinkAddresses: [fe80::8a79:7eff:fe5f:4a21/64,10.10.82.178/24,] Routes: [fe80::/64 -> :: wlan0,10.10.82.0/24 -> 0.0.0.0 wlan0,0.0.0.0/0 -> 10.10.82.1 wlan0,] DnsAddresses: [192.168.17.52,192.168.17.31,] Domains: lab.no-ip.org MTU: 0 TcpBufferSizes: 131072,262144,3145728,4096,221184,3145728}

Feb 14, 2018 08:49:33 WIFI_EVENT STATE_CHANGE_ac:a3:1e:db:13:70

Feb 14, 2018 08:49:34 WIFI_EVENT supplicant.STATE_CHANGE_FOUR_WAY_HANDSHAKE

Feb 14, 2018 08:49:34 WIFI_EVENT supplicant.STATE_CHANGE_GROUP_HANDSHAKE

Feb 14, 2018 08:49:34 WIFI_EVENT supplicant.STATE_CHANGE_COMPLETED

Feb 14, 2018 08:49:35 WIFI_EVENT RSSI_CHANGED_-50

Detailed View of Wireless Device's 802.11 Connection Status-CLI

(MC-LOCAL-1) #show ap debug client-table ap-name f0:5c:19:c0:bf:ba

Client Table

MAC	ESSID	BSSID	Assoc_State	HT_State	AID	PS_State	UAPSD	Tx_Pkts	Rx_Pkts	PS_Qlen	Tx_Retries	Tx_Rate	Rx_Rate	Last_ACK_SNR	Last_Rx_SNR	TX_Chains	Tx_Timestamp	Rx_Timestamp	MFP Status (C,R)	Idle time	Client health (C/R)
a4:84:31:fb:e3:66	k-tele	f0:5c:19:8b:fb:b1	Associated	WQSs	0x1	Power-save	(0,0,0,0,N/A,0)	2152	14478	0	290	72	72	33	34	3[0x7]	Wed Mar 1 11:14:35 2017	Wed Mar 1 11:14:36 2017	(0,0)	1	86/85

Client Table

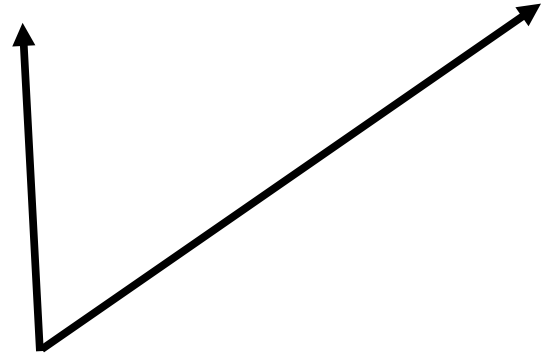
MAC	ESSID	BSSID	Assoc_State	HT_State	AID	PS_State	UAPSD	Tx_Pkts	Rx_Pkts	PS_Qlen	Tx_Retries	Tx_Rate	Rx_Rate	Last_ACK_SNR	Last_Rx_SNR	TX_Chains	Tx_Timestamp	Rx_Timestamp	MFP Status (C,R)	Idle time	Client health (C/R)
a4:84:31:fb:e3:66	k-tele	f0:5c:19:8b:fb:b1	Associated	WQSs	0x1	Power-save	(0,0,0,0,N/A,0)	2152	14478	0	290	72	72	33	34	3[0x7]	Wed Mar 1 11:14:35 2017	Wed Mar 1 11:14:36 2017	(0,0)	1	86/85
a4:84:31:fb:e3:66	k-tele	f0:5c:19:8b:fb:b1	Associated	WQSs	0x1	Awake	(0,0,0,0,N/A,0)	2154	14490	0	290	72	43	19	22	3[0x7]	Wed Mar 1 11:14:37 2017	Wed Mar 1 11:14:37 2017	(0,0)	0	86/85
a4:84:31:fb:e3:66	k-tele	f0:5c:19:8b:fb:b1	Associated	WQSs	0x1	Power-save	(0,0,0,0,N/A,0)	2155	14498	0	290	72	72	17	19	3[0x7]	Wed Mar 1 11:14:38 2017	Wed Mar 1 11:14:39 2017	(0,0)	1	86/85
a4:84:31:fb:e3:66	k-tele	f0:5c:19:8b:fb:b1	Associated	WQSs	0x1	Power-save	(0,0,0,0,N/A,0)	2156	14513	0	291	72	6	7	6	3[0x7]	Wed Mar 1 11:14:40 2017	Wed Mar 1 11:14:40 2017	(0,0)	0	86/85

aruba
a Hewlett Packard Enterprise company

If there is one command you should memorize - this is it

Detailed View of Wireless Device's 802.11 Connection Status-CLI

```
(Aruba7210_Sanya) #show ap debug client-table ap-name AP335_SLR01HPETAC3602p12

Client Table
------------
MAC               ESSID       BSSID             Assoc_State  HT_State  AID  PS_State    UAPSD           Tx_Pkts  Rx_Pkts  PS_Qlen  Tx_Retries  Tx_Rate  Rx_Rate  Last_ACK_SNR  Last_Rx_SNR  TX_Chains
---               -----       -----             -----------  --------  ---  --------    -----           -------  -------  -------  ----------  -------  -------  ------------  -----------  ---------
66:08:97:89:23:88  160MHz_WiFi  a8:bd:27:cb:8c:10  Associated   AWvSsE    0x1  Power-save  (0,0,0,0,N/A,0)  255366   136368   0        37          243      400      41            38           4[0xf]

Num of associated clients: 1
UAPSD:(VO,VI,BK,BE,Max SP,Q Len)
HT  Flags: A - LDPC Coding; W - 40MHz; S - Short GI 40; s - Short GI 20
          D - Delayed BA; G - Greenfield; R - Dynamic SM PS
          Q - Static SM PS; N - A-MPDU disabled; B - TX STBC
          b - RX STBC; M - Max A-MSDU; I - HT40 Intolerant; t turbo-rates (256-QAM)
VHT Flags: C - 160MHz/80+80MHz; c - 80MHz;  V - Short GI 160; v - Short GI 80
                  E - Beamformee; e - Beamformer
HT_State shows client's original capabilities (not operational capabilities)
```



This is an excellent command to analyze the client's health on its currently associated AP.

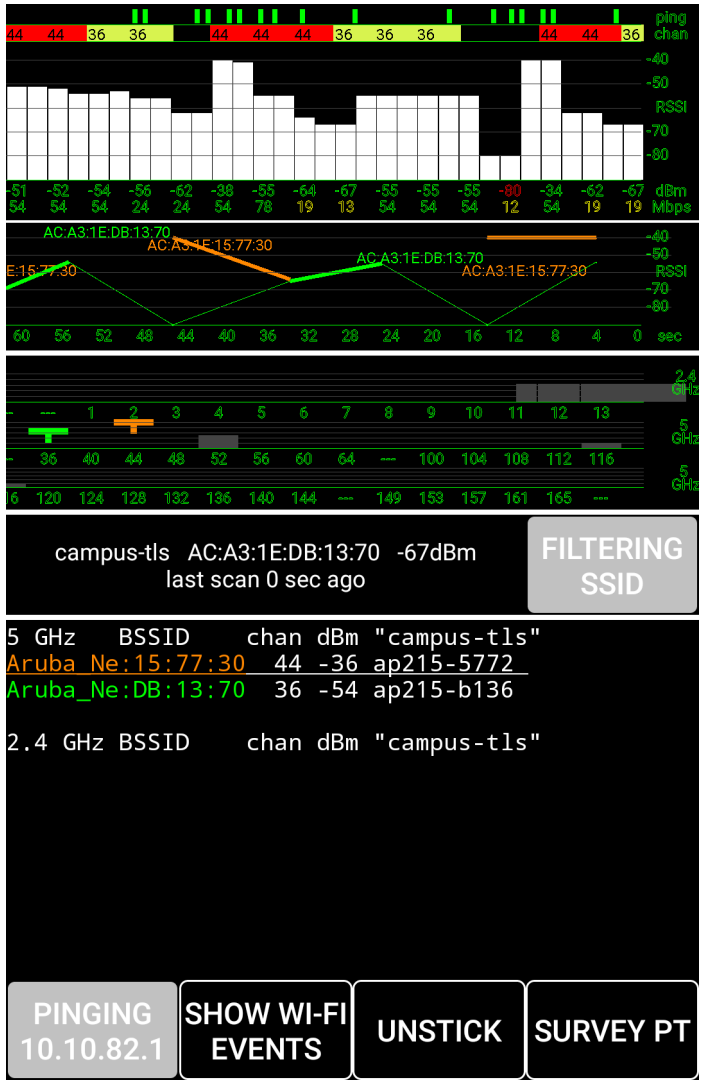
In a properly designed RF environment with best practice configuration:

1. Most wireless devices should be associated at least at a Rx SNR of 30 or better
2. Most wireless devices should have less than 20% 802.11 retries (Tx_Retries/Tx_Pkts).

aruba
a Hewlett Packard Enterprise company

Ensure Client-match, Interference, Channel Changes do not impact during roaming

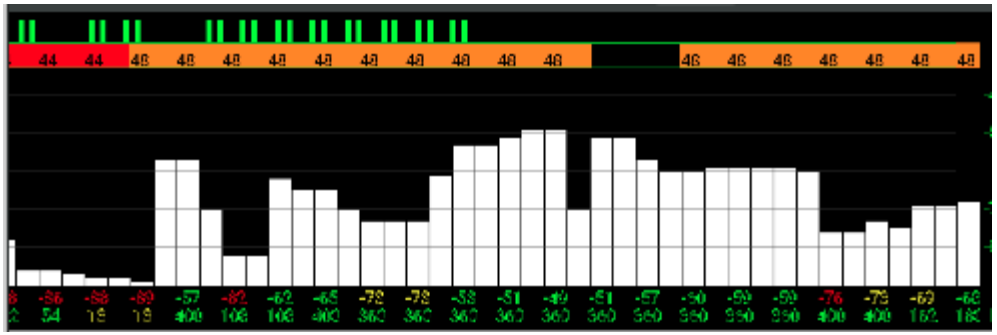
Observations



This is a sample of one of the better tests for Device #2.

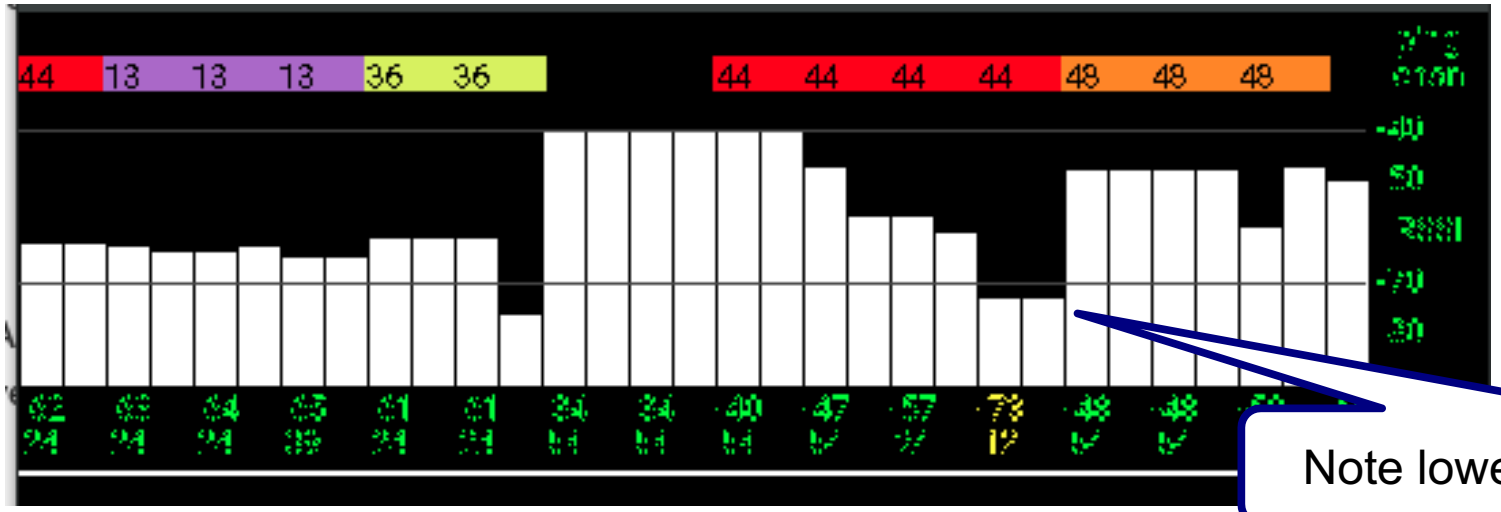
The correlation is low departure SNR, poor performance:

Retries
drops
VOIP interruptions
Application interruptions
Complete 802.11 disconnect



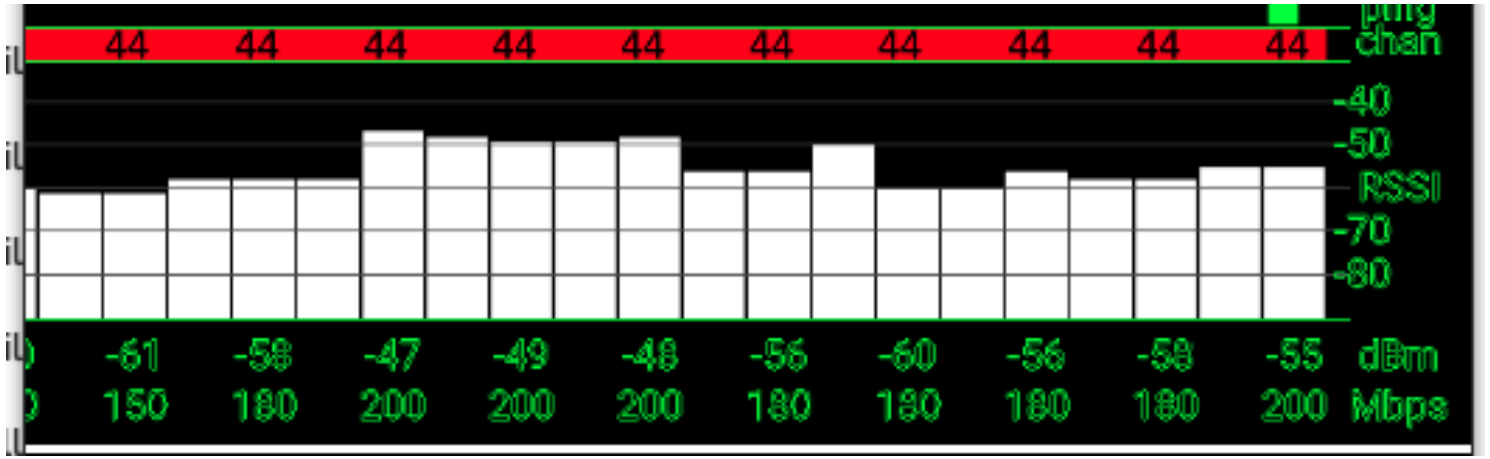
aruba
a Hewlett Packard Enterprise company

Results



Consumer-grade android
Roam-threshold -75dBm

Note lowest departing Signal level



Industrial-grade android
Roam-threshold -65dBm

aruba
a Hewlett Packard Enterprise company

Conclusions

Within the given configuration

Older Android 5.0.1 failed 4 out of 5 tests in at least one datapoint

– This most closely simulated field problems

Modern Android 6.0.1

– Default roam threshold - failed 1 out of 5 tests in at least one datapoint

– Roam threshold at -65dBm, passed all 5 tests (wl roam_trigger -65)

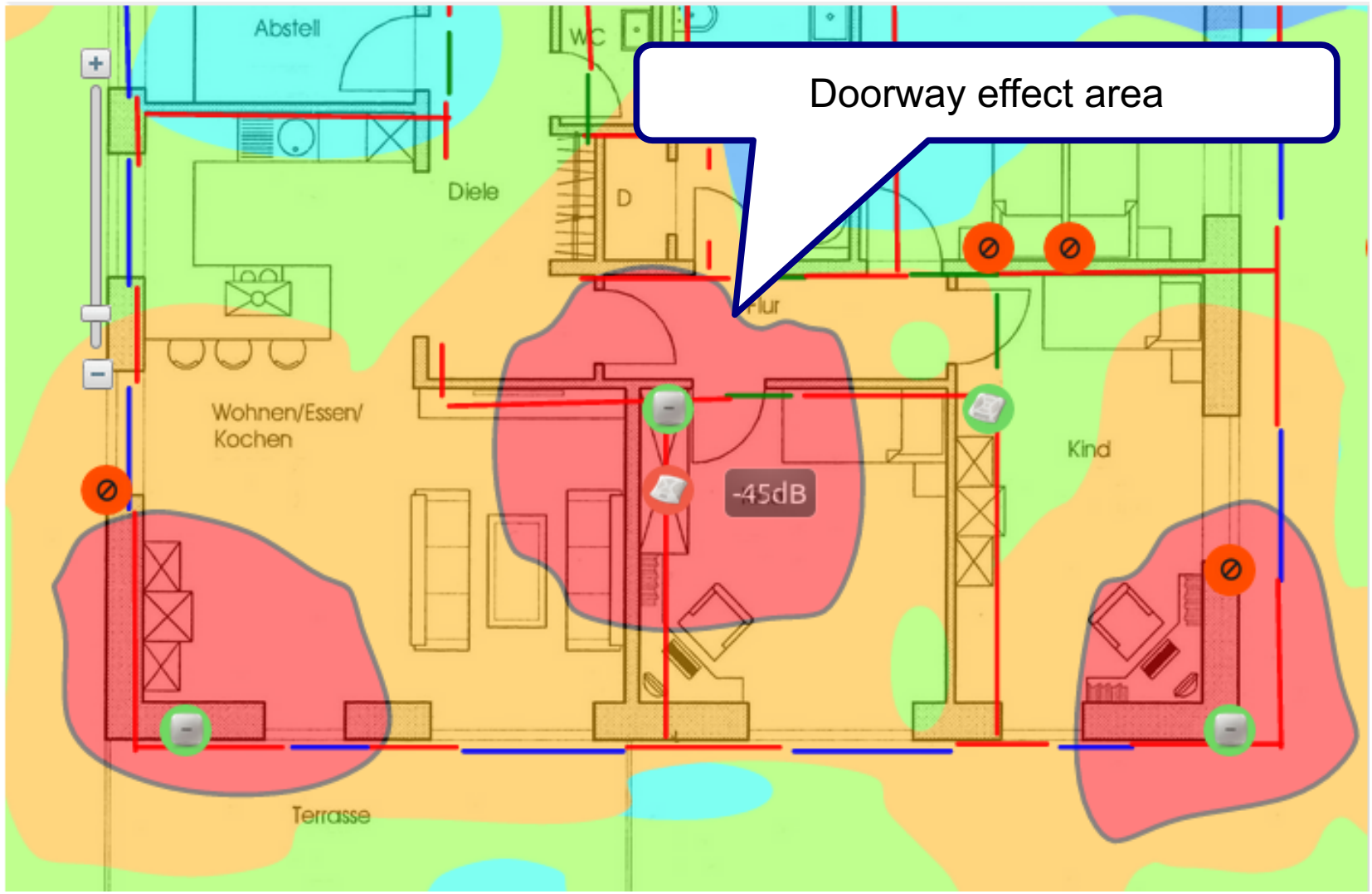
– Mirrors similar results achieved with one Smartphone manufacturer when roam threshold set to -65dBm

Industrial Android

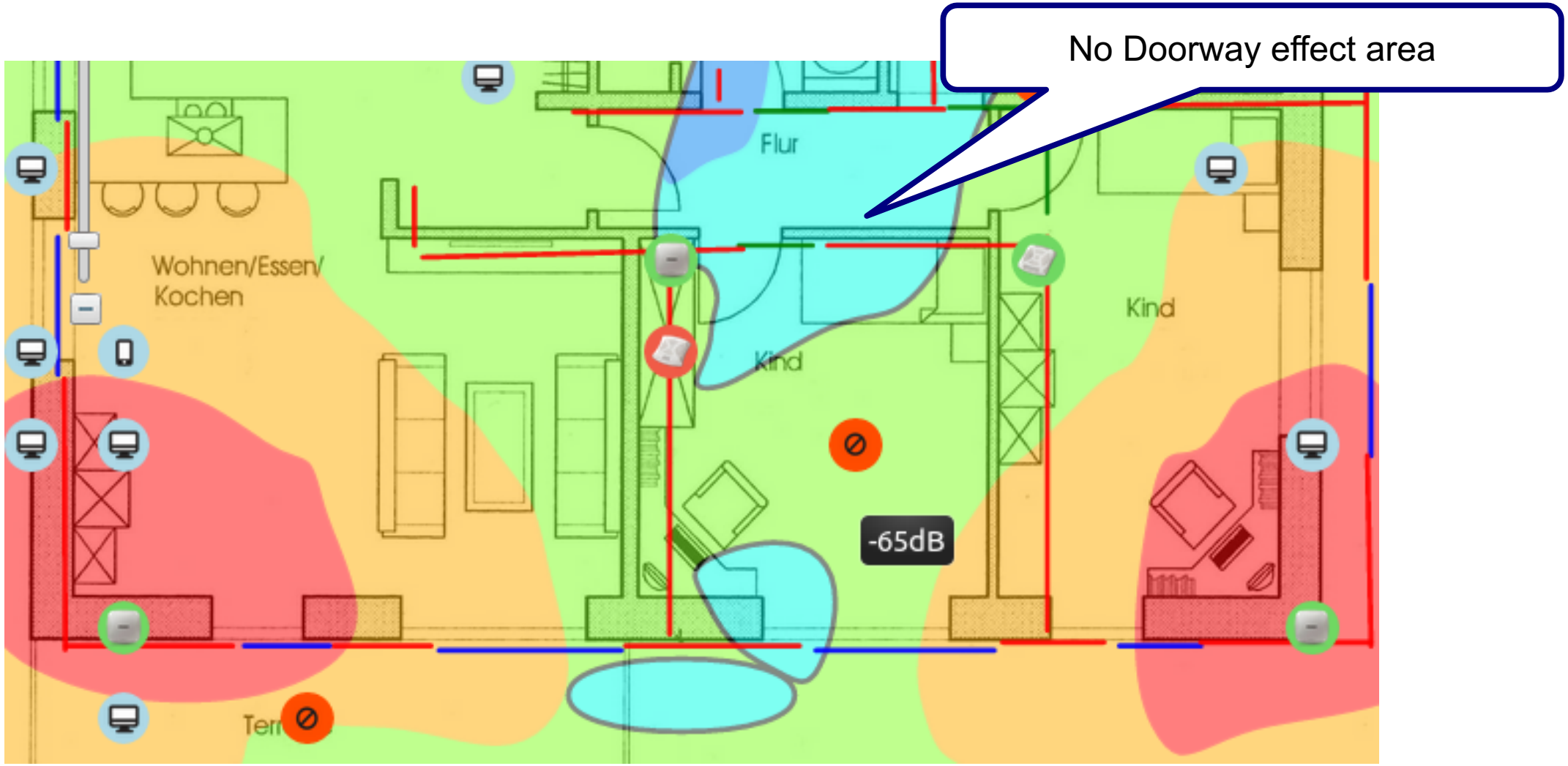
– Default parameters failed 1 out of 5 tests in at least one datapoint

– With configurable roam threshold at -65dBm, passed all 5 tests

Results – Heatmap 3APs



Results – Heat Map 2 APs

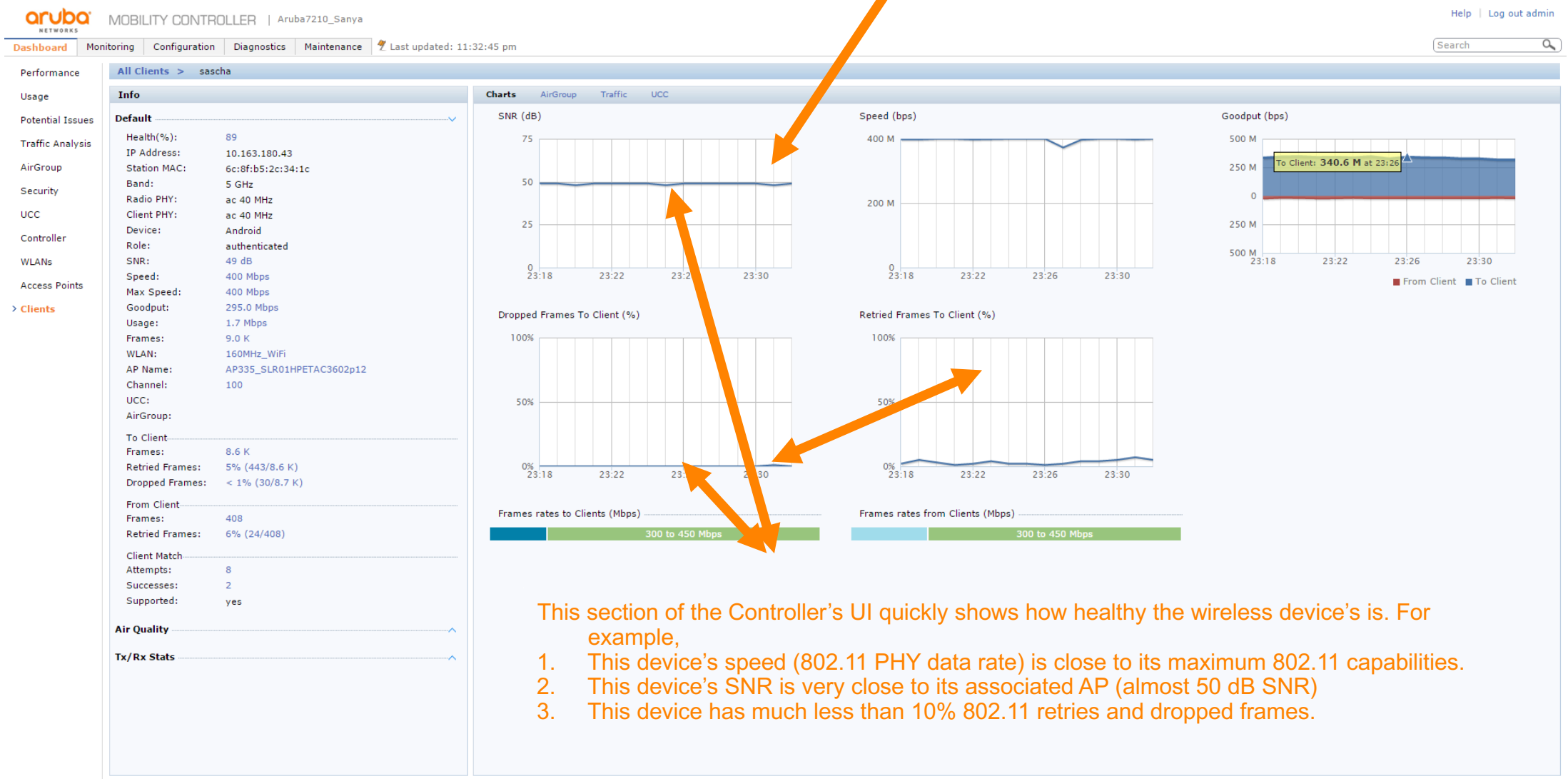


Takeaways from the Testing

- Roaming experience reasonably good with Aruba VRD configuration
  - Mobile devices often did not connect to the closest AP
  - Mobile devices often held its association until it was much farther away from its AP
    - This behavior also showed device's wireless signal strength became very low causing suboptimal application performance
    - The 802.11 data rates seemed to deteriorate in parallel to the signal strength dropping in value.
- Roaming experience Improved when devices used roaming threshold of -65dBm (scan -60dBm)
  - Mobile devices mostly connected to their APs at a very good SNR
  - Mobile devices mostly departed their associated AP at a good SNR
  - Application testing showed significant improvement for all devices using -65dBm roam threshold
  - Although a small difference – this is the difference between "pretty good" and "it works"
- Roaming experience seemed to improve when enabling 802.11K in addition to best practice configuration
- Enabling 802.11R improved roaming latency for supporting devices

Device Monitoring and Troubleshooting Best Practices

Detailed View of Wireless Device's 802.11 Connection Status-UI



This section of the Controller's UI quickly shows how healthy the wireless device's is. For example,

1. This device's speed (802.11 PHY data rate) is close to its maximum 802.11 capabilities.
2. This device's SNR is very close to its associated AP (almost 50 dB SNR)
3. This device has much less than 10% 802.11 retries and dropped frames.

Airwave, Dashboard may provide historical data

Don’t forget the fundamental troubleshooting steps

– Collect detailed information about a reported issue

– Begin with categorizing STA stationary behavior

– Is it isolated to an individual or group of users?

– Certain STA types ?

– Is it isolated to a geographical area?

– certain building or certain area of the floor ?

– Is the problem reproducible ?

– Is it isolated to an application or SSID?

– Is it isolated to a time of day?

– Did any change in the network, configuration, or on the devices?

Gather helpful data before reporting to Aruba/HPE Support

- Minimal data that should be gathered to help report a problem for quick resolution
  - Answers to the previous slides questions
  - Controller tech-support (tar logs tech-support)
  - AP tech-support (Example AP - before/After diffs are helpful)
  - user tech-support (basic client info)
- Augmenting or focused data
  - Controller syslogs
  - Airwave RF and Client health report for the specified problem report
  - AP remote packet capture if it is a reproducible connectivity problem

Log files show events, not the frames between events

Gather helpful data before reporting to Aruba/HPE Support

– Always examine the connection from the perspective of the client and the AP/controller
– Begin categorization with the client in a stationary position
– Controlled roaming tests examining both sides of the connection

Controller Side Data

Show user-table verbose
Show ap association client-mac <client mac>
Show ap debug client-table ap-name <apname> | inc <client mac>
Show ap debug client-stats <client mac>
Show auth
Show ap client trail <client mac>
Show ap virtual-beacon-report client-mac <client mac>
show ap remote debug mgmt

IAP Data – not all data available at the VC – SSH to the IAP where the client is connected

Show client debug
Show ap association
Show ap debug client-table
Show ap client trail
Show ap debug auth
show ap remote debug mgmt

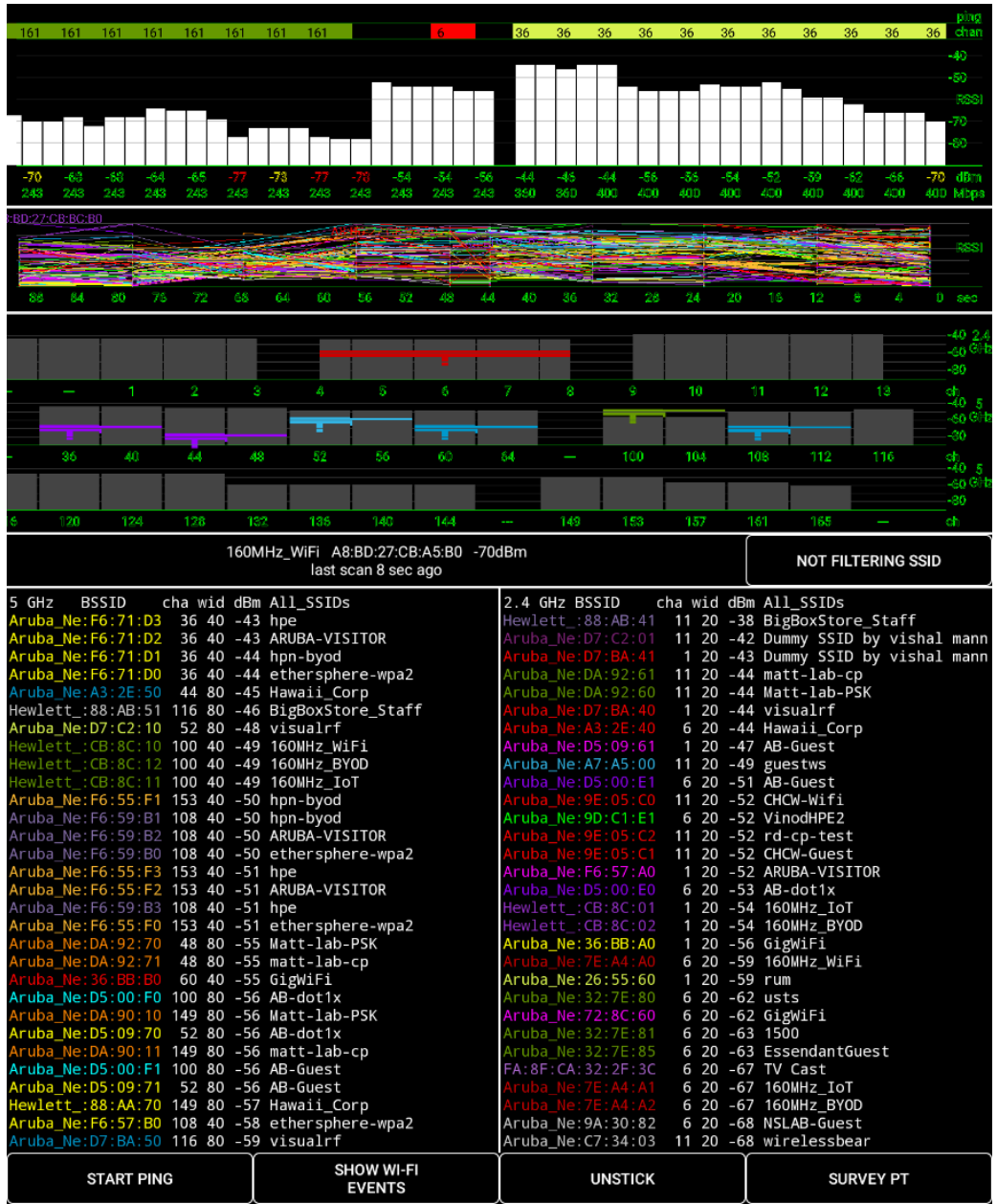
aruba
a Hewlett Packard Enterprise company

RF problem ? auth problem ? Network problem (DHCP?) or a true roaming problem ?

Great Android Tool – Aruba Utilities

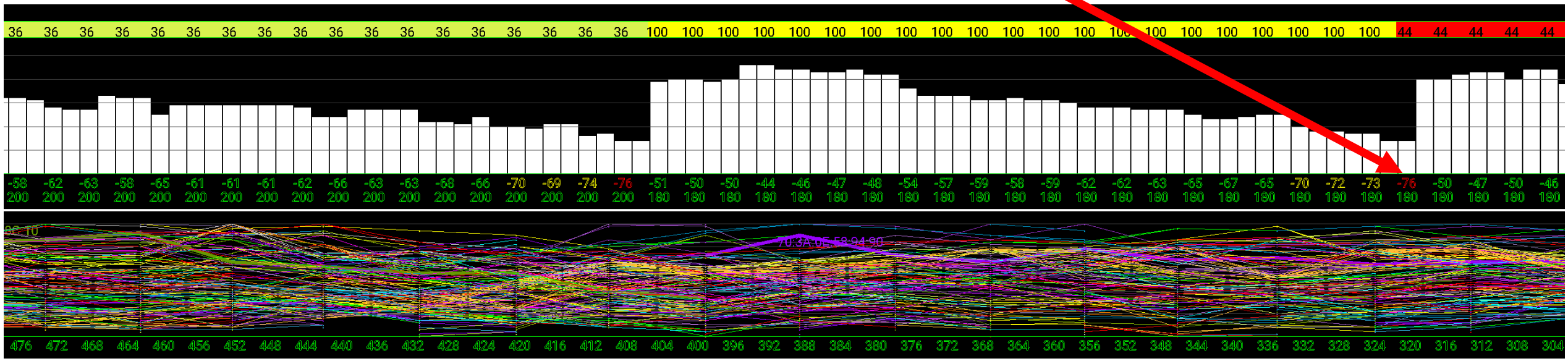
Aruba Utilities is a great app that can be downloaded from the Android “Play Store”. It has many functions like Wi-Fi Monitor, SSH to Controller CLI, Airwave VisualRF display/survey, Airwave AMC client, iBeacons, iPerf, Ping, DNS, mDNS, and ALE diagnostics.

Most engineers use the Wi-Fi Monitor quite often when verifying coverage and roaming behavior.



Great Android Tool – Aruba Utilities

After doing a roaming test on an Android device you can view the Aruba Utilities “Handover Scroll View File” (in “Email-Logs” attachments) to see at what signal strength the device chose to roam to a closer BSSID.



Summary

- What are the factors that affect roaming performance?
  - AP mounting, antenna orientation, spacing, stacking
  - Power, TX , Beacon Rates, Client drivers

- Design Recommendations for good mobile roaming experience
  - Proper mounting, proper utilization f 5Ghz band
  - Adjust Power levels, TX , and beacon rates

- Aruba ACE/ERT – Roaming Behavior Test Results
  - Improvements using VRD Configuration

- Device monitoring and troubleshooting best practices
  - Client-side data, Android Utilities
  - AirRecorder, CLI Data

Reference Material

- Aruba OKC Implementation
- https://arubapedia.arubanetworks.com/arubapedia/images/1/1b/Aruba_OKC_implementation.pdf

- Aruba OS CLI Reference Guide
- https://support.arubanetworks.com/Documentation/tabid/77/DMXModule/512/Command/Core_Download/Default.aspx?EntryId=25952

- Aruba VRD - “Optimizing Aruba WLANs for Roaming Devices” Document version v3.3
- http://www.arubanetworks.com/assets/vrd/DG_Roaming.pdf

- Aruba VRD - “RF and Roaming Optimization for Aruba 802.11ac Networks”
- https://community.arubanetworks.com/t5/Validated-Reference-Design/RF-and-Roaming-Optimization-for-Aruba-802-11ac-Networks/ta-p/227716
- Aruba TAC Case Opening Guideline
- https://support.arubanetworks.com/Portals/0/uploads/614/Aruba_Networks_TAC_Case_Guideline.pdf

Works In Progress

To be continued...

Works in Progress

There are a number of efforts underway to establish standards to allow improved client roaming. Much focus is in the area of Carrier offload – 3G/4G to and from Wi-Fi.

If and when some or any of these standards are ratified, they may or may not find adoption in released product.

Until then – we need to continue to provide a good RF neighborhood for clients to make their Roaming decisions.

Wi-Fi Alliance Mobile Multimedia

Originally intended (sort-of) as an enterprise-voice successor
Now aims to provide a performance test for inter-AP roaming

Dynamic test of changing AP signals to trigger a roaming event

-Expected certification March 2018 ???

Works in Progress

Wi-Fi Alliance MBO (Multiband Operations)

Aims to improve performance by assisting clients to move to the best band, channel and AP

Client tells AP about its preferences – capabilities
Channels it likes (or not)
APs it likes (or not)
Bands it likes (or not)

AP tells client about its capabilities and neighbours
Bands
Channels

AP can steer client to desired band or AP or to another (cellular) network
BSS transition management frame

Expected certification 2017 ???

Works in Progress

Wi-Fi Alliance OCE (Optimized Connectivity Experience)

Aims to improve performance in dense networks with fast-moving clients

FILS (Fast Initial Link Setup) from 802.11ai
Multi-function frames for discovery and association with security
Advertised frequently (20 msec) by APs
Allows cross-subnet roaming

Reduce probe requests, responses
Increase minimum rates (5.5 MHz @ 2.4 GHz)
Probing becomes unnecessary, as FILS advertisements are broadcast
Reduced (compact) neighbour reports

Expected certification May 2018 ???
Recent developments in Linux Arena

http://www.wi-fi.org/who-we-are/current-work-areas

aruba

a Hewlett Packard Enterprise company

Thank You !

aruba

a Hewlett Packard Enterprise company