Report on
High density tests and comparative study conducted on Ubiquiti UAP-AC-HD access points

Submitted to
Ubiquiti

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Contents

1 Analysis summary

Alethea conducted high density tests with **Both Bands (2.4GHz and 5GHz) Enabled** on a pre Release version of Ubiquiti AP, model UniFi AP-AC-HD, firmware version 3.7.37.6065, on 18th, 19th and 20th January of 2017 in Bangalore. Performance of this particular Access Point was compared with Access Points from Ruckus [R710:R710_104.0.0.0.1347], Aruba [IAP-325-US:6.4.4.0-4.2.3] and Meraki [MR52:up-to-date]. Clients used in the tests were configured with 2x2 MIMO WiFi cards. 70% of the clients were 802.11a/b/g/n/ac capable and 30% were 802.11a/b/g/n capable.

We also conducted high density tests with **5GHz only Enabled** on a released version of Ubiquiti AP, model UniFi AP-AC-HD, firmware version 3.7.44.6176, on 15th and 16th March, 2017 in Bangalore. Performance of this particular Access Point was compared with APs from Ruckus [R710:R710_104.0.0.0.1347], Aruba [IAP-325-US:6.5.1.0-4.3.1.1] and Meraki [MR52:up-to-date]. Clients used in the tests were configured with 2x2 MIMO WiFi cards. 75% of the clients were 802.11a/b/g/n/ac capable and 25% were 802.11a/b/g/n capable.

Two types of performance metrics were measured.

1. DL TCP throughput
2. Video Experience rating (5 - Excellent, 4 - Good, 3 - Satisfactory, 2 - Not Good, 1 - Poor, 0 - Fail).

Both tests were run on all APs with both 2.4GHz and 5GHz bands enabled and with 5GHz only enabled at the respective test sessions. Measurements were taken with 40 clients, 70 clients and 100 clients.

High level summary of the results are as below

1.1 Throughput Tests

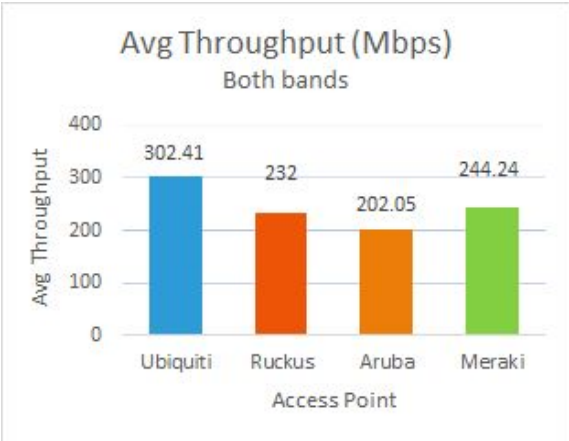
Downlink throughput tests with 2.4GHz and 5GHz enabled

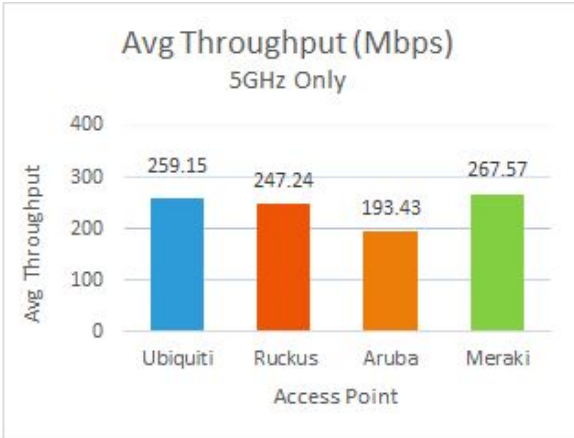
Performance goal	Aggregate TCP throughput should be above 250 Mbps at each client load level			
AP	Performance (DL TCP Throughput in Mbps) measured			Verdict on performance goal
	with 40 clients	with 70 clients	with 100 clients	
Ubiquiti	Aggregate= 282.72 Std Deviation = 2.12	Aggregate= 275.18 Std Deviation = 1.29	Aggregate= 349.32* Std Deviation = 3.81	40:pass 70:pass 100:pass
Ruckus	Aggregate= 251.01 Std Deviation = 6.28	Aggregate= 231.24 Std Deviation = 1.53	Aggregate= 213.76 Std Deviation = 0.83	40:pass 70:fail 100:fail
Aruba	Aggregate= 233.94 Std Deviation = 0.9	Aggregate= 198.65 Std Deviation = 2.84	Aggregate= 173.57 Std Deviation = 0.71	40:fail 70:fail 100:fail
Meraki	Aggregate= 280.33 Std Deviation = 7.01	Aggregate= 265.61 Std Deviation = 1.13	Aggregate= 233.15 Std Deviation = 4.87	40: pass 70:pass 100:fail

*In Ubiquiti, when all 11ac clients go to 5GHz and all 11n clients go to 2.4GHz, the throughput is recorded around 350Mbps. It falls to around 270 Mbps when clients are mixed up

Downlink throughput tests with 5GHz (only) enabled

Performance goal	Aggregate TCP throughput should be above 200 Mbps at each client load level			
AP	Performance (DL TCP Throughput in Mbps) measured			Verdict on performance goal
	with 40 clients	with 70 clients	with 100 clients	
Ubiquiti	Aggregate= 249.54 Std Deviation = 0.29	Aggregate= 262.50 Std Deviation = 2.80	Aggregate= 265.40 Std Deviation = 3.66	40:Pass 70:Pass 100:Pass
Ruckus	Aggregate= 292.75 Std Deviation = 2.20	Aggregate= 239.59 Std Deviation = 0.90	Aggregate= 209.39 Std Deviation = 0.91	40:Pass 70:Pass 100:Pass
Aruba	Aggregate= 222.35 Std Deviation = 1.88	Aggregate= 180.74 Std Deviation = 1.14	Aggregate= 177.21 Std Deviation = 1.22	40:Pass 70:Fail 100:Fail
Meraki	Aggregate= 232.04 Std Deviation = 5.86	Aggregate= 287.74 Std Deviation = 5.49	Aggregate= 282.95 Std Deviation = 3.80	40:Pass 70:Pass 100:Pass





1.2 Video Tests

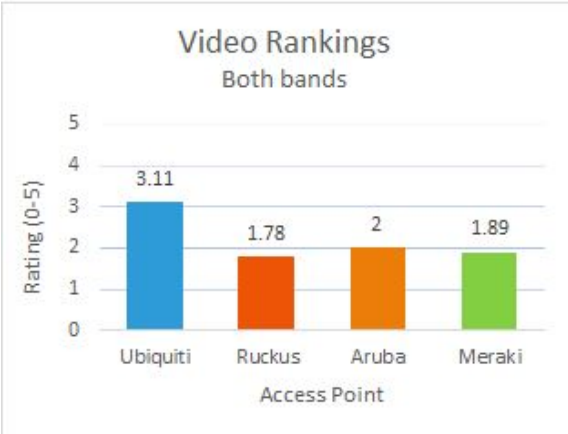
Video streaming tests with both 2.4GHz and 5GHz enabled

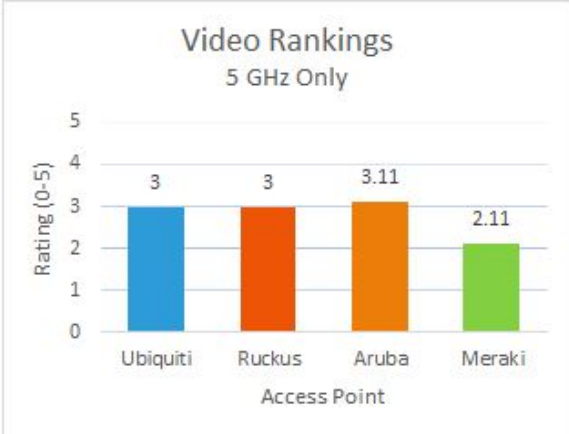
Performance goal	Cumulative Rating should be 3 and above			
AP	Performance (Video Streaming) measured			Verdict on performance goal
	with 40 clients	with 70 clients	with 100 clients	
Ubiquiti	Video Rating =4.67	Video Rating = 2	Video Rating = 2.67	40:pass 70:fail 100:fail **Average: 3.11**
Ruckus	Video Rating=3.67	Video Rating=1	Video Rating=0.67	40:pass

				70:fail 100:fail **Average: 1.78**
Aruba	Video Rating=3.67	Video Rating=1.33	Video Rating =1	40:pass 70:fail 100:fail **Average: 2.00**
Meraki	Video Rating =3	Video Rating =2.33	Video Rating =0.33	40:pass 70:fail 100:fail **Average: 1.89**

Video streaming tests with only 5GHz enabled

Performance goal	Cumulative Rating should be 3 and above			
AP	Performance (Video Streaming) measured			Verdict on performance goal
	with 40 clients	with 70 clients	with 100 clients	
Ubiquiti	Video Rating = 4.33	Video Rating =3	Video Rating =1.67	40:Pass 70:Pass 100:Fail **Average: 3**
Ruckus	Video Rating =3.33	Video Rating =3	Video Rating =2.67	40:Pass 70:Pass 100:Fail **Average:3**
Aruba	Video Rating =5	Video Rating =3	Video Rating =1.33	40:Pass 70:Pass 100:Fail **Average: 3.11**
Meraki	Video Rating =3.67	Video Rating =1.67	Video Rating =1	40:Pass 70:Fail 100:Fail **Average:2.11**





1.3 Ranking

Comparison of performance by 4 APs when both bands enabled

AP	Position in the tests	
	TCP DL both bands	Video both bands
Ubiquiti	1	1
Aruba	4	2
Meraki	2	3
Ruckus	3	4

Comparison of performance by 4 APs when only 5GHz band enabled

AP	Position in the tests	
	TCP DL 5GHz	Video 5GHz
Ubiquiti	2	2
Aruba	4	1
Meraki	1*	4
Ruckus	3	2

Ubiquiti ranked 1 for the below tests:

- **TCP DL Both bands**
- **Video streaming Both bands**

*Ubiquiti and Meraki had similar cumulative throughput for TCP DL test when 5GHz alone is enabled. However, with Meraki Access Point, quite a few clients had nil to very low throughput while the remaining clients had very high DL rates.

Ubiquiti, Aruba and Ruckus performed equally well and reached satisfactory performance goal in video streaming test at 5GHz only band

2 Introduction

At the point of testing in January, Ubiquiti was yet to release the product Unifi-AP-AC-HD. This is an 802.11ac Wave 2 4x4 MU-MIMO Access Point that is expected to be able to handle 100+ clients simultaneously with throughput good enough to serve HD video streams. The company wanted an independent third party to evaluate the Access Point from the point of view of HD video experience.

Alethea offers testing and benchmarking services for scale and load testing of wireless networks, involving multiple real clients.

Alethea uses a standard test procedure for such requirements. Formal tests were conducted with all Access points. This report shares all the details from the tests including expectations, results, findings, analysis, insights and rankings.

3 Test purpose

Purpose is to evaluate user experience of 4 access points, Ubiquiti UniFi-AP-AC-HD, Aruba IAP 325 US, Ruckus R710 & Meraki MR52 and benchmark their performance by running throughput tests and video rating tests with both bands enabled and 5GHz only enabled configurations.

Purpose of the Video Test is to measure the HD video performance. Performance is manually (subjectively) measured on a scale of 5 to 0 - 5 being Excellent and 0 being Fail. Expected performance goal is to get the rating of 3 or above at each resolution and load combination.

Purpose of Throughput Tests is to measure the throughput and standard deviation. Performance goal is to achieve aggregate TCP Throughput of 250 Mbps in Both bands configuration and Throughput of 200 Mbps in 5GHz only band.

4 Test methodology

a) Throughput Tests

Iperf was used to measure Downlink Throughput. Each of the clients runs an iperf server and the Linux server behind the Access Point runs iperf clients for all the iperf servers. This starts simultaneous data traffic with all the clients. Test is run for 3 minutes and reading is taken for throughput achieved.

With this reading, we can measure the total throughput and also the distribution of throughput across various clients. This can be measured using standard deviation. Lower the Standard deviation, fairer the distribution. Higher the Standard Deviation, less fair is the distribution.

b) Video Tests

For each video, experience is rated from 5 to 0 - 5 being Excellent and 0 being Fail. Overall score is arrived at each load level, by taking average of all the videos.

For access point to be able to say it supports HD, we need to check multiple type of videos. HD Video quality depends on the bit rate. Higher the bitrate, higher the quality. There is no specific bit rate that suggests video can be HD. HD bitrate depends on nature or content of the video. A Slow moving animation video may offer a good viewer experience at 1000 Kbps bit rate but a live sports video involving lot of fast movement may not provide good viewing experience even at 5000 Kbps bit rate .

Operators watched for the following types of artifacts:

1. Buffering
2. Stuttering
3. Lost frames
4. Smudges & pixelation

Failure scenarios

- If any one instance of buffering lasted more than 20 seconds, the client was adjudged a fail immediately
- If the video failed to finish (with all the additional delays) within 30 seconds of the first client to finish
- If the total number of artifacts were 6 or more in number

Based on study, Alethea uses video test vectors at bit rates starting from 100 kbps to 10000 kbps. Based on dry runs at both bands configuration, we chose a set of 5 video levels that are relevant for HD Videos & the loads under consideration. 1000 kbps, 2000 kbps, 3000 kbps, 4000 kbps, 5000 kbps.

- Video_Level_1 - mp4, 1080p, 1000 kbps, Slow moving animation
- Video_Level_2 - mp4, 1080p, 2000 kbps, Hollywood movie
- Video_Level_3 - mp4, 1080p, 3000 kbps, Football match
- Video_Level_4 - mp4, 1080p, 4000 kbps, Fast moving Animation
- Video_Level_5 - mp4, 1080p, 5000 kbps, Gaming Level

For Both Bands

- Client Level 40, we expected video Levels 3, 4, 5 to work with performance rating of 3 or above
- Client Level 70, we expected video Levels 2, 3, 4 to work with performance rating of 3 or above.
- Client Level 100, we expected video Levels 1, 2, 3 to work with performance rating of 3 or above.

For 5 GHz only

Based on dry runs, we chose a set of 6 video levels that are relevant for HD Videos & the loads under consideration. 1000 kbps, 1500 kbps, 2000 kbps, 3000 kbps, 4000 kbps, 5000 kbps.

- Video_Level_1 - mp4, 1080p, 1000 kbps, Slow moving speech video
- Video_Level_2 - mp4, 1080p, 1500 kbps, Slow Animation
- Video_Level_3 - mp4, 1080p, 2000 kbps, Hollywood movie
- Video_Level_4 - mp4, 1080p, 3000 kbps, Fast Moving Animation
- Video_Level_5 - mp4, 1080p, 4000 kbps, Gaming Level Animation
- Video_Level_6 - mp4, 1080p, 5000 kbps, Fast moving Sports

Below are the video levels used:

- Client Load 40, we expected video Levels 4, 5, 6 to work with performance rating of 3 or above
- Client Load 70, we expected video Levels 2, 3, 4 to work with performance rating of 3 or above.
- Client Load 100, we expected video Levels 1, 2, 3 to work with performance rating of 3 or above.

At each client load, a video is marked pass or fail depending on interruptions, buffering, frame drops, smudges etc. Then based on pass percentage across clients, ratings are given

5 - Excellent, (80%+)
4 - Good (70-80%)
3 - Average (60-70%)
2 - Not Good (50-60%)
1 - Poor (30-50%)
0 - Fail (<30%)

5 Test setup

- Access Point under Test
- 100 Clients for both band configuration
    - 65 x Dell Latitude 7440 (Core I5 / I7 with 8GB RAM, 256 GB SSD, Intel 7260 dual band 2x2 11ac Wave 1 WiFi Card) running Windows
    - 5 x Dell Latitude 6430 (Core I5 with 4GB RAM, 500GB HDD, Intel 7260 dual band 2x2 11ac Wave 1 WiFi Card) running Windows
    - 30 x Dell Latitude 5430 (Core I5 with 4GB RAM, 500GB HDD, Intel 2x2 dual band 11n WiFi Card) running Windows
    - All were powered from mains all the time, power save was not turned ON
- 100 Clients for 5GHz only configuration
    - 75x Dell Latitude 7440 (Core I5 / I7 with 8GB RAM, 256 GB SSD, Intel 7260 dual band 2x2 11ac Wave 1 WiFi Card) running Windows
    - 25x Dell Latitude 5430 (Core I5 with 4GB RAM, 500GB HDD, Intel 2x2 dual band 11n WiFi Card) running Windows
    - All were powered from mains all the time, power save was not turned ON

- Behind the AP, media server hosted on an Intel i7 based box with 16GB RAM running Ubuntu Server
- Controller PC, intel i7 PC running Ubuntu
- AP, Media Server and Controller / Management PC were powered over an UPS and connected through a Gigabit Switch

6 Test results - Both bands

Tests were conducted over the period of 3 days from 18th to 20th of January 2017 for both bands configuration.

6.1 Test Sessions & Data

We ran 12 sessions for both bands configuration. 4 Sessions on each day. In each session

- 1 throughput test
- 3 Video Tests

We had 4 APs and 3 Client Load Levels (40, 70, 100) so 12 such sessions were planned.

6.2 Configuration

Access Points

- All Access Points were configured with latest released firmware we found on the internet and Ubiquiti with the pre-release firmware provided to us for both bands configuration. For Meraki, the Access Point showed that the firmware version is up to date and we did not make any changes
- Channels were chosen manually based on lowest interference. Same channels were used for all access points for fair comparison. Auto channel select was disabled to effect this
- Bandwidth 40 MHz for 2.4 GHz band, 80 MHz for 5 GHz
- Air Time Fairness set to ON, if the access point provided the option
- Power set to Maximum

Clients

- All Clients were running Windows.
- Same Clients, Same Location for testing all access points
- For both bands configuration, 70% 11ac Clients & 30% 11n Clients at any client load level
- PINGs were checked to be working on all clients before any test was run
- All Video runs used Mozilla Firefox with applicable plug-ins in place for http video streaming
- Browser cache was cleared before each Run

Commands

- Ipers Server command - iperf3 -s
- Iperf Client Command - iperf3 -c <Server IP Address> -t 180 -i 1

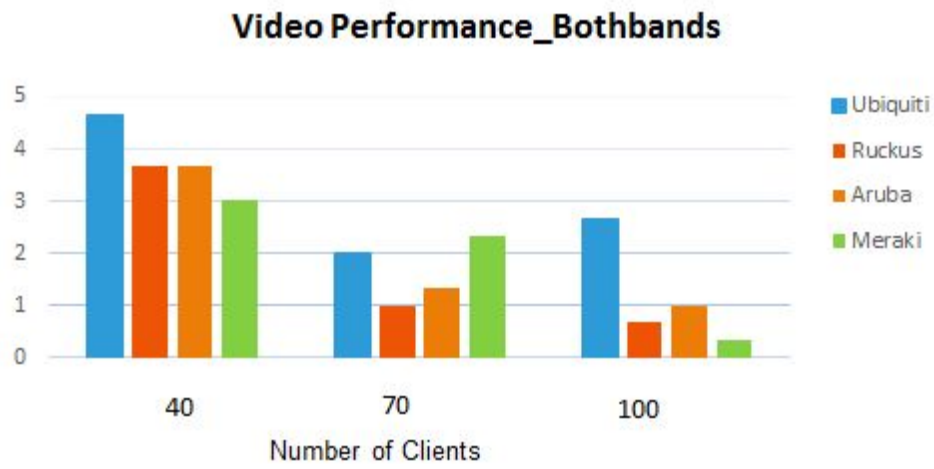
6.3 Video - Both Bands

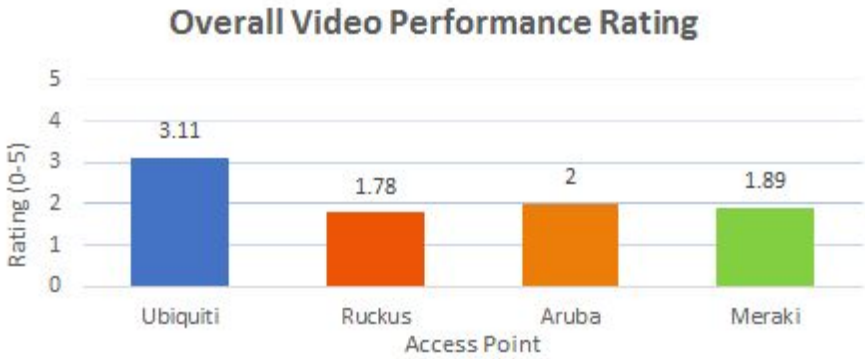
Performance of Access Points with increase in number of clients was shown below:

Number of Clients	Ubiquiti	Ruckus	Aruba	Meraki
40	4.67	3.67	3.67	3.00
70	2.00	1.00	1.33	2.33
100	2.67	0.67	1.00	0.33
Overall	3.11	1.78	2.00	1.89

Points to Note:

- Overall, Ubiquiti topped in video streaming at both bands test
- Ruckus and Meraki failed completely to handle 100 clients
- Performance decreased with increase in number clients for all access points





6.4 Throughput - Both Bands

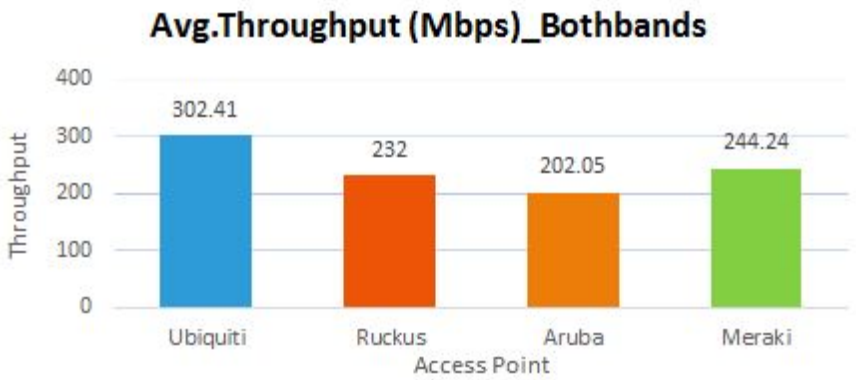
TCP DL throughput results at different client loads and corresponding standard deviation results were as below:

Throughput (Mbps)				
Number of clients	Ubiquiti	Ruckus	Aruba	Meraki
40	282.72	251.01	233.94	280.33
70	275.18	231.24	198.65	265.61
100	349.32	213.76	173.57	233.15
Average	302.41	232	202.05	244.24

Standard Deviation				
Number of clients	Ubiquiti	Ruckus	Aruba	Meraki
40	2.12	6.28	0.9	7.01
70	1.29	1.53	2.84	1.13
100	3.81	0.83	0.71	4.87
Average	2.41	2.88	1.48	4.34

Points to Note:

- Throughput of Ubiquiti was higher compared to other Access Points
- Though Aruba's throughput was the least compared to others, it managed to perform well in video streaming because of its low standard deviation



7 Test results - 5GHz only

Tests were conducted over the period of 2 days i.e. 15th and 16th of March 2017.

7.1 Test Sessions & Data

We ran 12 sessions. In each session , we ran

- 1 Throughput Test
- 3 Video Tests

We had 4 APs and 3 Client Load Levels (40, 70, 100) so 12 such sessions were planned.

7.2 Configuration

Access Points

- All Access Points were configured with latest released firmware we found on the internet and Ubiquiti with the 3.7.37.6065 firmware provided to us. For Meraki, the Access Point showed that the firmware version is up to date and we did not make any changes

- Channels were chosen manually based on lowest interference. Same channels were used for all access points for fair comparison. Auto channel select was disabled to effect this
- Bandwidth 80 MHz for 5 GHz
- Air Time Fairness set to ON, if the access point provided the option
- Power set to Maximum

Clients

- All Clients running on Windows.
- Same Clients, Same Location for testing all access points
- 75% 11ac Clients & 25% 11n Clients at any client load level
- PINGs are checked to be working on all clients before any test is run
- All Video runs used Mozilla Firefox with applicable plug-ins in place for http video streaming
- Browser cache was cleared before each Run

Commands

- Ipers Server command - iperf3 -s
- Iperf Client Command - iperf3 -c <Server IP Address> -t 180 -i 1 -w 64M

Note:
For 5Ghz only -w 64M was used which gives higher throughput. So it is fair to compare access points with each other. But we should not use these results to compare 5GHz Throughput with Both Bands Throughput

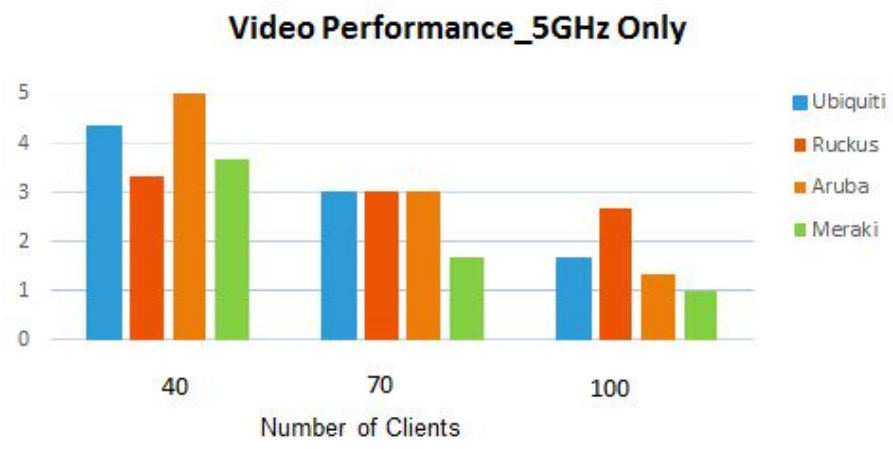
7.3 Video - 5GHz only

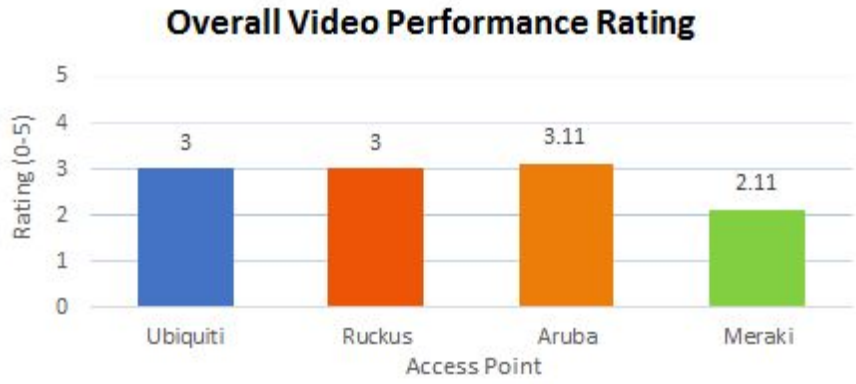
Performance of Access Points with increase in number of clients was shown below:

Number of Clients	Ubiquiti	Aruba	Meraki	Ruckus
40	4.33	5	3.67	3.33
70	3	3	1.67	3
100	1.67	1.33	1	2.67
Average	3	3.11	2.11	3

Points to Note:

- Aruba, Ubiquiti and Ruckus performed well compared Meraki
- Ubiquiti, Ruckus and Aruba access points met the performance goal





7.4 Throughput - 5GHz only

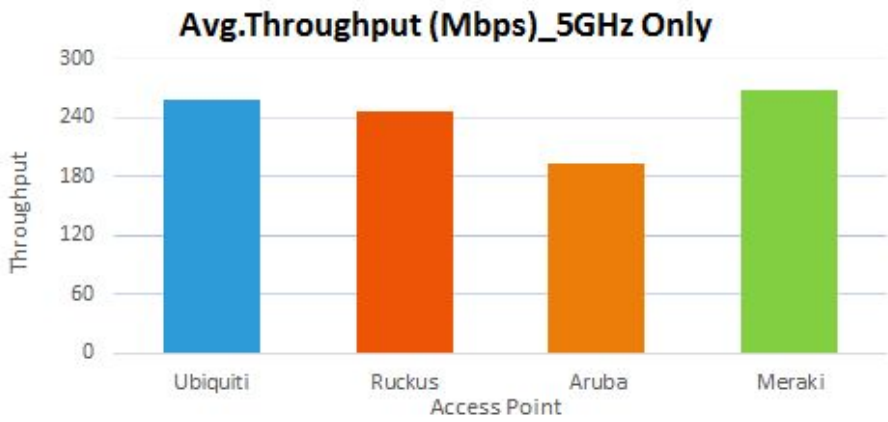
TCP DL throughput results at different client loads and corresponding standard deviation results were as below:

Throughput (Mbps)				
Number of Clients	Ubiquiti	Ruckus	Aruba	Meraki
40	249.54	292.75	222.35	232.04
70	262.5	239.59	180.74	287.74
100	265.4	209.39	177.205	282.95
Average	259.15	247.24	193.43	267.57

Standard Deviation				
Number of Clients	Ubiquiti	Ruckus	Aruba	Meraki
40	0.29	2.2	1.88	5.86
70	2.8	0.9	1.14	5.49
100	3.66	0.91	1.22	3.8
Average	2.25	1.34	1.41	5.05

Points to Note:

- Ubiquiti and Meraki performed well in the throughput tests, whereas Aruba was the least performer
- Ruckus and Aruba's standard deviation is very less compared to other access points. They can provide a relatively uniform user experience across different user loads



8 Summary of Findings

a) In **Both bands configuration**, **Ubiquiti** was best in throughput and the only one to meet the video performance goals. It did significantly better than others.

b) In **5GHz only configuration**, **Meraki** was best in throughput and Aruba was the least performer. But in video, Aruba, Ubiquiti and Ruckus could meet the video performance goals while Meraki could not perform well.

c) HD video streaming performance cannot be assessed based on raw throughput figures. It has to be tested separately

For a detailed report please go through https://goo.gl/92HHDm

Check our Youtube video at https://youtu.be/72iokPF_fzc

Full disclosure: The tests were sponsored by Ubiquiti. However Ubiquiti was not involved with definition of test cases, planning, device configuration, execution or analysis of results. All these tasks were independently undertaken by Alethea. Ubiquiti representatives were not present during the test preparation and execution, nor exerted any indirect influence on these activities