



IEEE 802.11ac Wave 2 Access Points
Comparative Performance

Cisco Aironet 1852i

Aruba AP-325

Ruckus R710



DR151120D
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1 - Executive Summary

Miercom was engaged to perform independent, hands-on, comparative testing of competitive IEEE 802.11ac Wave 2-based WiFi Access Points (APs) from Cisco Systems, Aruba Networks and Ruckus Wireless.

This report summarizes the results of the Wave 2 AP comparative testing in these areas:

- Client density: Downlink throughput as the number of clients per AP scales from 10 to 100.
- Single- vs Multi-User MIMO: Downlink throughput for MU-MIMO (Multi-User, Multiple-Input Multiple-Output), a hallmark of 802.11ac Wave 2, vs Single-User (SU-MIMO) environments.
- 1 Gbps+ Link Aggregation: Tests found that Wave 2 APs can support more than 1 Gbps of aggregate downlink throughput, tested over two 1-Gbps LAG (link aggregation) connections.

Key Findings:

Cisco APs, meet or exceed Aruba and Ruckus performance at a lower cost	The Cisco 1852i Wave 2 AP turned in the best performances in almost all tests, against the Aruba AP-325 and Ruckus R710
Throughput drops for all APs as client population approaches 100	Tests found that throughput for all the APs drops off as number of clients grows from 10 to 100. The best-performing AP in this test was the higher-end Cisco 3700, the worst was the Aruba AP-325. The others, including the low-cost Cisco 1852i, 1832i and Ruckus R710, performed comparably.
Cisco allows fewer starved clients as client population rises to 100	More WiFi clients don't get bandwidth as client density per AP rises. In this test Cisco's low-cost APs kept more clients connected at 80 to 100 clients per AP than either Aruba or Ruckus.
Cisco makes better use of Multi-User MIMO than Aruba or Ruckus	In this test Single-User MIMO clients were replaced with Multi-User MIMO clients and the difference in throughput measured. The winner: Cisco's 1852i, which nearly doubled throughput between older Single-User clients and newer Wave 2 Multi-User MIMO clients.
Only the Cisco 1852i could deliver aggregate throughput over 1 Gbps	The lower-cost Cisco 1852i AP delivered real-world, aggregate, downlink throughput over 1 Gbps, while the Ruckus R710, given the exact same environment, managed 570 Mbps and the Aruba AP-325 just 350 Mbps.

Miercom independently verified key performance differences between Cisco's low-cost Access Points and comparable, higher-priced APs from Aruba Networks and Ruckus Wireless. With performance meeting or exceeding Aruba and Ruckus, we present the **Miercom Performance Verified** certification to the Cisco 1852i WiFi Access Point.

Robert Smithers
CEO
Miercom



2 - Products Tested

Wave 2 refers to products built to the latest, formally approved IEEE 802.11 WiFi specification – the IEEE 802.11ac standard. This report contains some of the first independent, comparative performance data of leading Wave 2-based Access Points (APs).

During 2012 and 2013 a broad array of WiFi products – over 200, by some estimates – were built to the last, stable draft 802.11ac specification and delivered to market. This assortment of products is now referred to as Wave 1. The formal, final adoption of 802.11ac occurred at the end of 2013, with some additional technology enhancements that weren't included in the last draft, the basis for Wave 1 products. Products built to the final, formally adopted version of 802.11ac are referred to as Wave 2, and have been shipping since 2014.

Users can rightfully expect Wave 1 and Wave 2 products to fully interoperate. That's because the final, formal IEEE 802.11ac specification, the basis for Wave 2 products, is a proper superset of the draft specification on which Wave 1 products are based.

802.11ac is just the latest of a half-dozen WiFi standards that the IEEE 802.11 committee has issued since 1997, each more technologically advanced and performance-capable than the previous one. These bear WiFi product labels including 802.11 a, b, g, n, and now most recently, ac. The evolution of standards has featured improved distance, client density, and most important to users, per-station and per-AP throughput.

The chart below compares the salient operational characteristics of IEEE 802.11n – the last major WiFi standard adopted in 2009 – with today's 802.11ac Wave 1 and Wave 2 products.

WiFi Evolution: IEEE 802.11n ► 802.11ac Wave 1 ► 802.11ac Wave 2

Products based on	IEEE 802.11n	IEEE 802.11ac Wave 1	IEEE 802.11ac Wave 2
Standard basis	Standard adopted October 2009	Last stable draft of 802.11ac	Standard adopted December 2013
Frequency band (GHz)	2.4 & 5 (opt)	5	5
Channel width	20 & 40 MHz	20, 40 & 80 MHz	20, 40, 80, 80-80 & 160 MHz
Multiple-Input, Multiple-Output (MIMO) support	Single-User (SU-MIMO)	Single-User (SU-MIMO)	Multi-User (MU-MIMO), (2)
Number of Spatial Streams (1)	2 - 4	3	3 - 4 (opt)
Modulation (Quadrature Amplitude Modulation)	64 QAM (rate 5/6)	256 QAM (rates 3/4 and 5/6)	256 QAM (rates 3/4 and 5/6)
Theoretical capacity (PHY rate, 3 spatial streams) (3)	450 Mbps	1300 Mbps	2600 Mbps

Source: Miercom; chart is a compendium from varied published sources, including IEEE and Wikipedia.

Notes:

- (1) Spatial streams: the number of sending and receiving antennas supported, more spatial streams helps boost data rates and distance.
- (2) MU-MIMO: Multi-User, Multiple-Input, Multiple-Output, increases client density, the number of simultaneously supported clients requires beamforming support.
- (3) The above theoretical capacities are based on PHY rate and these configurations:
 - 802.11n: three spatial streams x 150 Mbps per spatial stream; 40-MHz channel, 400 ns guard interval, 64-QAM modulation at 5/6 rate.
 - Wave 1: three spatial streams x 433.3 Mbps per spatial stream; 80-MHz channel, 400 ns guard interval, 256-QAM modulation at 5/6 rate.
 - Wave 2: three spatial streams x 866.7 Mbps per spatial stream; 160-MHz channel, 400 ns guard interval, 256-QAM modulation at 5/6 rate.

The table shows the characteristics of the specifications that are built into products, and not necessarily the maximum allowed by the particular standard. For example, while the IEEE 802.11ac standard allows up to eight spatial streams to be supported by an 802.11ac-compliant device, Wave 2 products support up to three, and optionally four, downlink spatial streams.

The same is true regarding data rates. The standards specify the data rates relative to the signaling support of compliant products at the Layer-1 physical, or PHY, level. But this does not equate to the data rate that users would experience. Overhead above the physical level, such as MAC and Ethernet at Layer-2, IP at Layer 3, and UDP – and especially TCP – at Layer-4, reduce the effective, actually achievable data rates. In addition, predicted max data rates usually assume a perfect WiFi environment, devoid of interference and other electromagnetic anomalies, which is seldom the case.

To summarize, there are four notable advantages of Wave 2 – versus products based on Wave 1 and earlier WiFi standards:

- (1) Higher data rates: Up to 2.6 Gbps in the 5 GHz band
- (2) Multi-User MIMO (Multiple-Input, Multiple Output) support
- (3) 160-MHz channel width support; key to increased data rate, essentially double Wave 1
- (4) Fourth Spatial Stream: supporting four transmitting and receiving antennas, versus just three in Wave 1-based products.

Is IEEE 802.11ac the last WiFi standard? Almost certainly not, as wireless technology marches onward. Several additional 802.11 committees are already huddling to develop future WiFi standards which, by all indications, will deliver even greater data rates, densities and distances. Higher frequencies – well above the 5 GHz band of IEEE 802.11ac – are being eyed for future WiFi standards, as well as data rates up to 100 Gbps.

The first wave of Wave 2 wireless Access Points (APs) introduced into the marketplace has been oriented towards indoor deployment. Outdoor products based on the same IEEE 802.11ac Wave 2 specification are also now shipping. Still, for this testing, it was decided to compare the performance of more mature, indoor AP models from industry leaders Cisco, Aruba and Ruckus.

The specific models tested are described in more detail below.

Cisco

The Cisco Aironet 1850 (Model 1852i was tested) has been called the lowest cost and best performing 802.11ac Wave 2 AP now on the market. The results of our testing tend to support that claim. The AP, oriented to mid-sized enterprise and service provider networks, is supported by most of Cisco's Wireless Controllers – including the CT5520 we used in our testing – as well as the latest wireless module for Catalyst 6500 and 3650/3850 modular switches.

The Cisco 1850 supports 80-MHz channels, fully supports Multi-Input/Multi-Output (MIMO) operation and 4x4 MIMO with four spatial streams for Single-User MIMO. Three spatial streams are supported for the Multi-User MIMO mode of Wave 2. For backward compatibility the AP concurrently supports IEEE 802.11 a, g and n devices.



Cisco 1850

One of Cisco's higher-end Aironet 3700 Series, Model 3702i, was included in some of the tests to compare the performance of the Aironet 1852i with a higher-end AP. The 3702i, a Wave 1 AP, supports 4x4 MIMO with three spatial streams, 80-MHz channels, and PHY data rates up to 1.3 Gbps with Cisco High Density Experience (HDX). HDX is a suite of technologies which allows for enhanced performance in challenging highly dense environments. Radio support provides backward compatibility with 802.11 a, b, g and n devices.

Aruba

The Aruba Access Point tested, the AP-325, is a model of Aruba's AP-320 Series that also features integrated antennas.



Aruba AP-325
Model featuring internal
antennas

The Aruba AP-325 has radios supporting IEEE 802.11 a, b, g and n, as well as 802.11ac Wave 2. In the Wave 2 environment, the AP-325 supports 4x4 Multi-User MIMO (MU-MIMO) with three spatial streams, and four spatial streams with Single-User MIMO (SU-MIMO). The device contains eight integral down-tilt, omni-directional antennas.

Ruckus

The Ruckus ZoneFlex R710 Access Point was chosen for this comparative performance testing. Like the other APs tested, the R710 supports Single-User and Multi-User operation (SU-MIMO and MU-MIMO). Four spatial streams are supported for Single-User MIMO; three spatial streams with Wave 2's Multi-User MIMO. And as with the other APs tested, the R710 also supports all the leading predecessor WiFi specifications.

Ruckus R710
featuring internal antennas



The following table details the salient characteristics of the Wave 2 APs tested, along with their respective wireless controllers.

Table 1: Indoor, Enterprise, Wave 2 Access Points Tested

	Aruba AP-325	Ruckus R710	Cisco AP 1832i	Cisco AP 1852i	Cisco AP 3702i
Max PHY Data Rate (using 5 GHz band)	1.7 Gbps	1.7 Gbps	870 Mbps	1.7 Gbps	1.3 Gbps
Wave 2 RF Design (SU-MIMO and MU-MIMO)	4x4: 4SS SU-MIMO	4x4: 4SS SU-MIMO	3x3: 2SS SU-MIMO	4x4: 4SS SU-MIMO	4x4: 3SS SU-MIMO
	4x4: 3SS MU-MIMO	4x4: 3SS MU-MIMO	3x3: 2SS MU-MIMO	4x4: 3SS, MU-MIMO	N/A
Controller & software release tested	Aruba 7240 v6.4.4.1	Ruckus ZD3000 v9.1.12.1.0.148	Cisco CT5520 V8.1.131.0	Cisco CT5520 V8.1.131.0	Cisco CT5520 V8.1.131.0

Notes:

SS: Spatial Streams

SU-MIMO: Single-User, Multi-Input Multi-Output

MU-MIMO: Multiple-User, Multi-Input Multi-Output, unique to 802.11ac clients, where the AP can simultaneously transmit to multiple Wave 2 clients.

3x3, 4x4: A 3x3 MIMO AP comes with three antennas and radios, and is capable of transmitting and receiving via three discrete streams. A 4x4 AP has four antennas and radios and can send and receive via four streams.

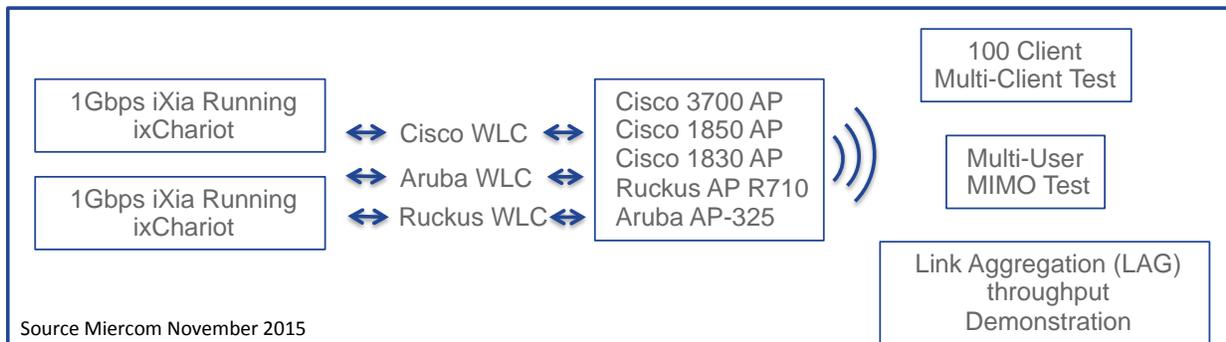
4 - Test Bed Set-up

The Wave 2 Access Points tested were all indoor models. The initial flurry of Wave 2 products has been oriented towards indoor deployment, although Wave 2 models for outdoor use are now shipping too.

The lab was specially designed for wireless product testing. Large indoor lab rooms effectively replicate large office environments. To minimize variables, all testing of the competitive APs was done in the same room, where only one AP at a time was enabled, and all APs were tested with the exact same client deployments.

The test bed configuration included two wireless Access Point ceiling mounts, to which two Gigabit Ethernet copper links were delivered. The APs were mounted below the drop ceiling and only one AP was enabled at a time for each test. The Wireless LAN Controllers (WLCs) for Cisco, Aruba and Ruckus were also acquired and appropriately deployed using vendor best practices and the latest publically available software.

Also included in the test bed were two Ixia test systems (see www.ixiacom.com), each capable of delivering a full gigabit/s of custom test traffic. We used primarily TCP traffic, and IP address pairs were used to associate the test system with each client. Both Ixia test systems could deliver a full 2 Gbps to each AP and, through the AP, to the client wireless devices (see test bed diagram below). In most tests just one test system, delivering up to 1 Gbps of test traffic, was sufficient. For our "link aggregation" test, though, both Ixia systems were connected to one AP at a time to aggregate more than 1 Gbps of throughput.



The Ixia test systems both ran IxChariot, a GUI- and script-driven application for defining and generating custom test traffic. Only one AP was actively connected, active and enabled at any time. The clients for all the tests were spread throughout the lab room, and remained in the same positions until all the APs had completed a particular test. Only the clients needed for a particular test case were WiFi-enabled and connected.

IxChariot scripts were written to execute standard throughput tests for each of the test cases. The traffic for each test was sent for 60-120 seconds depending on the test and the average throughput was calculated for multiple IxChariot runs. All of the throughput measurements included in this report are the aggregate downlink throughput that traversed the AP under test.

A preliminary run was used as a baseline for each test. That was useful because, if any throughput test result was below the baseline, that test would be re-run.

Below is a sample IxChariot screenshot of a test of the Cisco 1852i Access Point. Throughput to each of 30 Multi-User MIMO clients is being measured. This screen shot, which shows the level of throughput monitoring at the bottom, was taken while the 60-second test was running.

Group	Pair Group Name	Run Status	Timing Records Completed	95% Confidence Interval	Average (Mbps)	Minimum (Mbps)	Maximum (Mbps)	Measured Time (sec)	Relative Precision
All Pairs			485		84.039	0.332	21.220		
	Pair 1 No Group	Finished	11	-0.531 : +0.531	1.919	1.181	4.454	45.849	27.674
	Pair 2 No Group	Finished	12	-0.549 : +0.549	2.094	1.268	4.619	45.854	26.219
	Pair 3 No Group	Finished	5	-0.784 : +0.784	2.398	1.745	3.416	16.678	32.674
	Pair 4 No Group	Finished	21	-2.295 : +2.295	3.802	0.580	12.442	44.186	60.353
	Pair 5 No Group	Finished	13	-0.869 : +0.869	2.318	0.829	4.449	44.864	37.491
	Pair 6 No Group	Finished	23	-0.562 : +0.562	3.999	2.368	7.401	46.010	14.061
	Pair 7 No Group	Finished	27	-0.937 : +0.937	6.884	3.635	11.331	31.378	13.611
	Pair 8 No Group	Finished	67	-0.789 : +0.789	11.648	5.457	21.220	46.016	6.778
	Pair 9 No Group	Finished	11	-1.220 : +1.220	1.985	0.562	5.402	44.942	61.480
	Pair 10 No Group	Abandoned	29	-3.479 : +3.479	6.962	0.907	13.378	33.324	49.974
	Pair 11 No Group	Finished	56	-0.753 : +0.753	9.753	5.384	15.842	45.935	7.716
	Pair 12 No Group	Finished	15	-0.917 : +0.917	2.622	0.938	6.431	45.760	34.975
	Pair 13 No Group	Finished	15	-0.891 : +0.891	2.613	1.257	9.901	45.933	34.103
	Pair 14 No Group	Finished	35	-0.988 : +0.988	8.682	4.253	15.180	32.249	11.382
	Pair 15 No Group	Finished	28	-1.102 : +1.102	4.881	1.547	8.801	45.891	22.584
	Pair 16 No Group	Finished	10	-1.919 : +1.919	1.754	0.332	6.661	45.619	109.402
	Pair 17 No Group	Finished	50	-0.808 : +0.808	8.699	3.867	17.467	45.981	9.288
	Pair 18 No Group	Finished	27	-1.425 : +1.425	4.897	1.266	9.709	44.113	29.100

Test Cases

The test cases that were run are detailed in the following sections. In each of them aggregate downlink throughput for each AP was carefully measured and reported. The test cases are:

1. Client Density, Scaling from 10 to 100 Clients
2. Multi-User MIMO (MU-MIMO) vs Single-User (SU-MIMO)
3. Link Aggregation (LAG) for 1+ Gbps Wireless AP Throughput

5 – Client Density, Scaling from 10 to 100 Clients per AP

Test Objective

To measure how each AP performs as client load grows from 10 to 100 clients. Also noted was the number of active (working) clients that failed to transmit any data during the test.

How We Did It

A real-world assortment of 100 WiFi client devices were assembled, as detailed below:

Client device	Total Number	WiFi support, No. Spatial Streams MIMO support	Initial 10-station set-up	No. added in each 10-stn increment
MacBook Pro	10	802.11n, 3SS, SU-MIMO	1	1
iPad Air	10	802.11n, 2SS, SU-MIMO	1	1
Dell E6430 w/ Broadcom 43460	10	802.11ac, 3SS, SU-MIMO	1	1
MacBook Pro	20	802.11ac, 3SS, SU-MIMO	2	2
MacBook Air	20	802.11ac, 2SS, SU-MIMO	2	2
Dell E6430 w/ Intel 7260	30	802.11ac, 2SS, SU-MIMO	3	3

Client devices were arranged on tables throughout the room, the different types distributed evenly, as shown below.



Evenly distributed. Clients were spread on tables around the AP from 10 ft. (3m) to 45 ft. (13.7m).



A panoramic view of the test facility is shown above. The AP being tested was mounted below the drop ceiling, as indicated above.

In order to maximize throughput the APs were all set to 80-MHz channels. The client devices were all positioned from 10 to 45 feet from the AP under test. A 70/30 mix of clients operating at 5 GHz (70 percent) and 2.4 GHz band (30 percent) was maintained throughout the testing.

Downlink TCP throughput

The Ixia IxChariot test system was configured to deliver TCP traffic over GE (1-Gbps Ethernet) links to the Access Point under test, and through the AP to each active client device. Each AP supported two RJ-45/copper GE links.

Multiple tests were first run on 10 client devices, as listed in the above client table. Then, when testing that group was done, 10 more active clients were then incrementally added to each set of tests, up to the point that all 100 client devices were tested.

The IxChariot measured individual-client and aggregate downlink TCP throughput for each test. The results from three IxChariot test runs were then averaged for each client load level.

Failed clients and APs

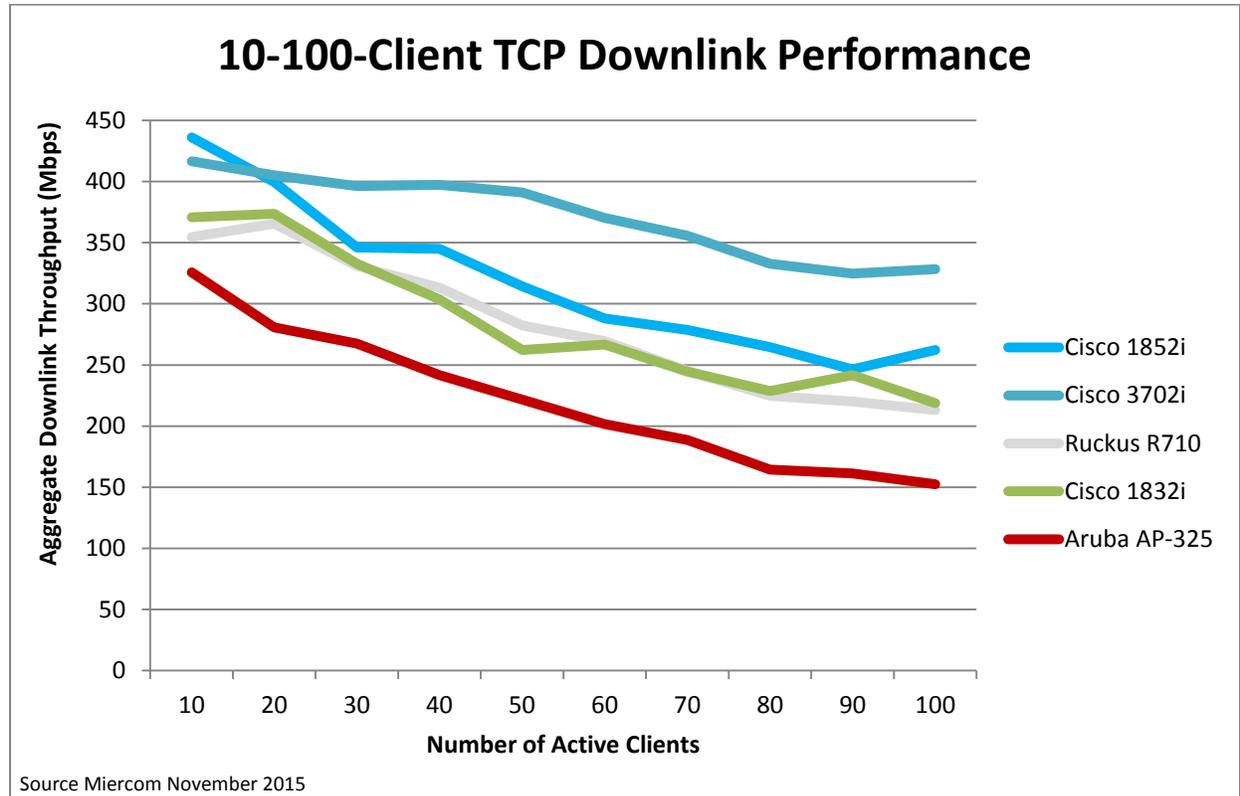
During the tests we had to deal with two types of failures that impacted results: 1) client failures and 2) AP failures.

In some test runs, one or more clients would lose network connectivity (due for example to a DHCP failure). These clients cannot then be ping'ed, during or after the test run. Such "client failure" cases would cause aggregate overall throughput to be lower than expected. In such cases the wireless connection to the absent client(s) would be re-established and the test re-run.

In other cases, one or more clients could still be ping'ed, but would fail to send any data packets through the AP during the test. Such AP failures in almost all cases are due to the APs not sharing bandwidth across all clients. These are real situations that do occur in WiFi networks, especially in high-client-density environments. The incidence of such no-bandwidth clients were recorded, where the clients did not send or receive data. (TCP, the type of traffic sent in these tests, assures that both ends of a communications session are active and able to send and receive before any data is transferred. Because of this the IxChariot test system could readily identify clients that did not send or receive data during the test.)

Results

The below graph shows the variation in aggregate downlink throughput for the APs tested, as client density increases by 10-client increments up to 100.



The Cisco 3702i was included in these tests to show the higher end of Cisco AP performance.

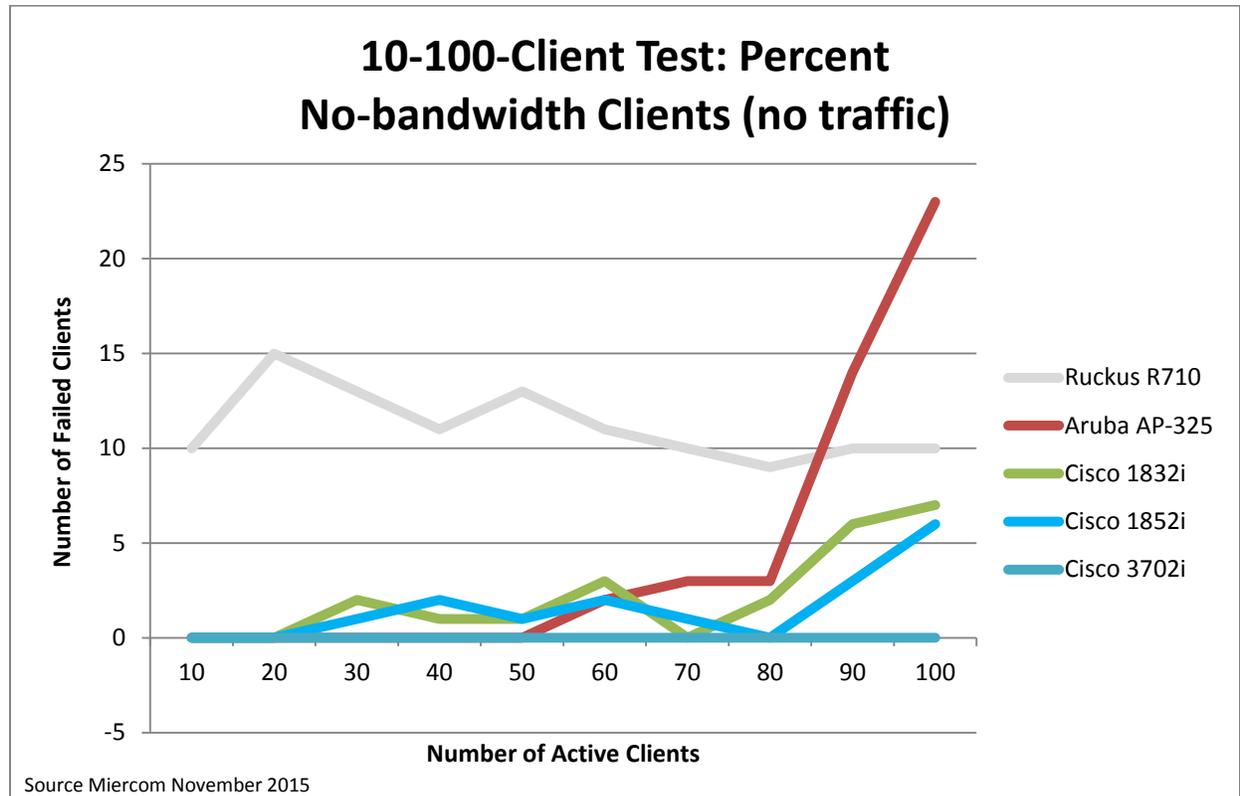
With this real-world mix of clients, frequency bands and IEEE 802.11 technologies, the results show that the Cisco 1852i AP performs better than either the Ruckus R710 or the Aruba AP-325.

As the number of clients increases, the overall average throughput decreases slightly with all the APs tested. However, the Cisco APs deliver comparable performance across the client-density spectrum, despite the lower cost of the 1852i.

Failed clients.

As noted, we recorded cases where one or more clients remained ping-able during and after the test run, but still sent or received no data during the test. We adjudicated these as "no-bandwidth" clients, where in all likelihood the AP failed to share bandwidth to all clients.

The below chart shows where one or more clients did not send or receive data during a throughput test. These are averages from multiple tests, and so are represented as the percentage of “no-bandwidth” clients, by AP, for each client-density level.



This chart shows that the three Cisco APs perform well, adequately sharing bandwidth across the clients, even as the number of clients approaches 100.

Except for the Ruckus R710, which tended to incur one or more such no-bandwidth clients in most of its test runs, this did not occur with the other APs until there were at least 30 active clients. The Aruba AP-325 performed very well in this regard, until the number of active clients exceeded 80. After 80 clients, a steep increase in number of clients’ percentage with no-bandwidth can be seen in the Aruba AP-325

We note that high-end Cisco Aironet 3702i was masterful at sharing bandwidth among even 100 concurrently active clients. We did not encounter a single case of a “no-bandwidth” client in any of the throughput tests with the 3702i AP.

6 – Multi-User MIMO (MU-MIMO) vs Single-User (SU-MIMO)

Test Objective

Multi-Input, Multi-Output capability, or MIMO, has been supported in 802.11n and Wave 1 products, but in Single-User mode only (SU-MIMO). Multi-User MIMO, however, is a new feature with Wave 2 – not supported by Wave 1 products. MU-MIMO support is required on both the AP and the client device to work. MU-MIMO works on downstream data delivery, AP to client, and allows an AP to transmit to multiple client devices simultaneously.

This test shows the throughput advantage of Multi-User MIMO over Single-User MIMO. The tests start with 10 SU-MIMO clients, which are then replaced one at a time with MU-MIMO clients. The gain in bandwidth is shown for each AP.

A second part of this test was to show how the different APs handle increasing MU-MIMO client loads. To do this we run a throughput test for each AP with 10 MU-MIMO clients, then increase it to 20 MU-MIMO clients, and finally 30.

How We Did It

The throughput gain metric for these tests is the aggregate TCP downlink throughput that ten clients can realize, running MU-MIMO versus SU-MIMO. A second part of the testing, as noted, compares the same, downlink TCP throughput for 10, 20 and 30 clients – first with their MU-MIMO turned off, and then with MU-MIMO enabled.

As before, test traffic was generated and measured by the Ixia IxChariot test system.

One-for-one MU-MIMO.

First, for each Access Point, ten Single-User MIMO clients (ten iPhone 6s, each supporting a single spatial stream) are throughput tested. Then, one SU-MIMO client is replaced with one MU-MIMO client and the throughput is measured again. This is repeated until all ten clients (ten Acer Aspire E15s) are MU-MIMO clients.

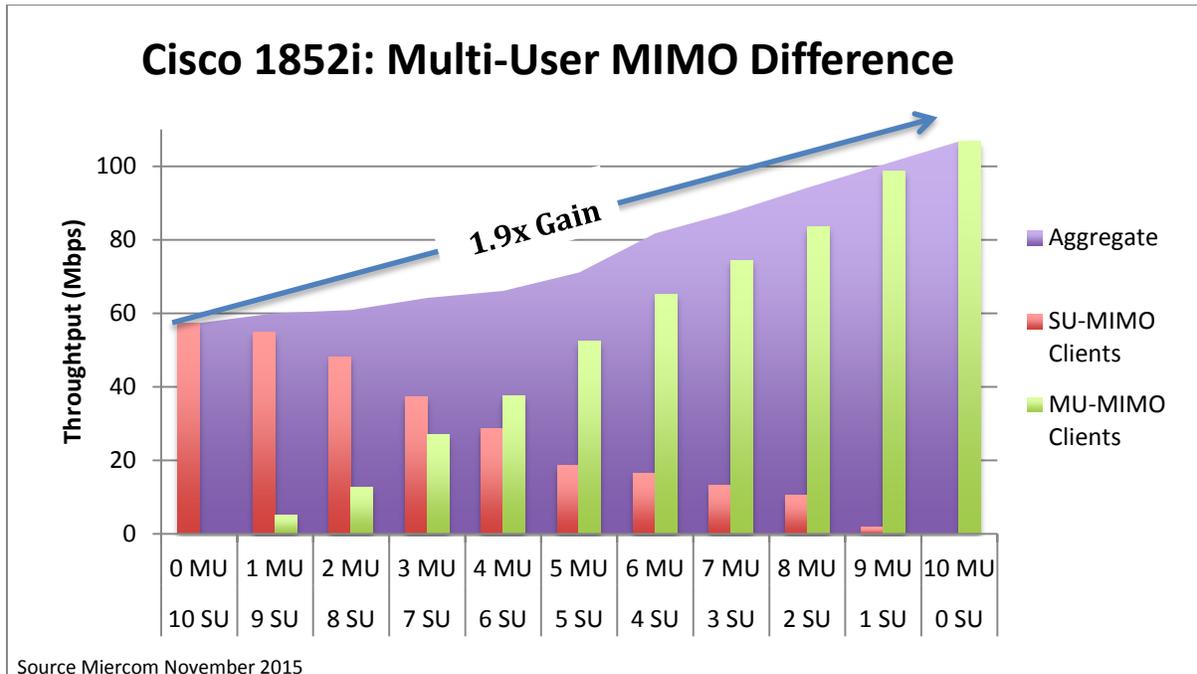
The APs were configured for 20-MHz channels. Traffic was TCP and aggregate downlink throughput was measured – the environment that would most favor MU-MIMO vs SU-MIMO operation.

Quantity	Client type	Wi-Fi Type	MU/SU MIMO
10	Acer Aspire E15 laptop	802.11ac, one Spatial Stream	MU-MIMO
10	iPhone 6 smartphone	802.11ac, one Spatial Stream	SU-MIMO

Test note: We were unable to get the Aruba AP-325 to work with the iPhone 6 SU-MIMO clients, so we substituted Acer laptops with their MU-MIMO disabled for the Aruba AP tests. Our testing has found the performance of the two clients – iPhone 6 and Acer E15, both running in SU-MIMO mode – to be comparable.

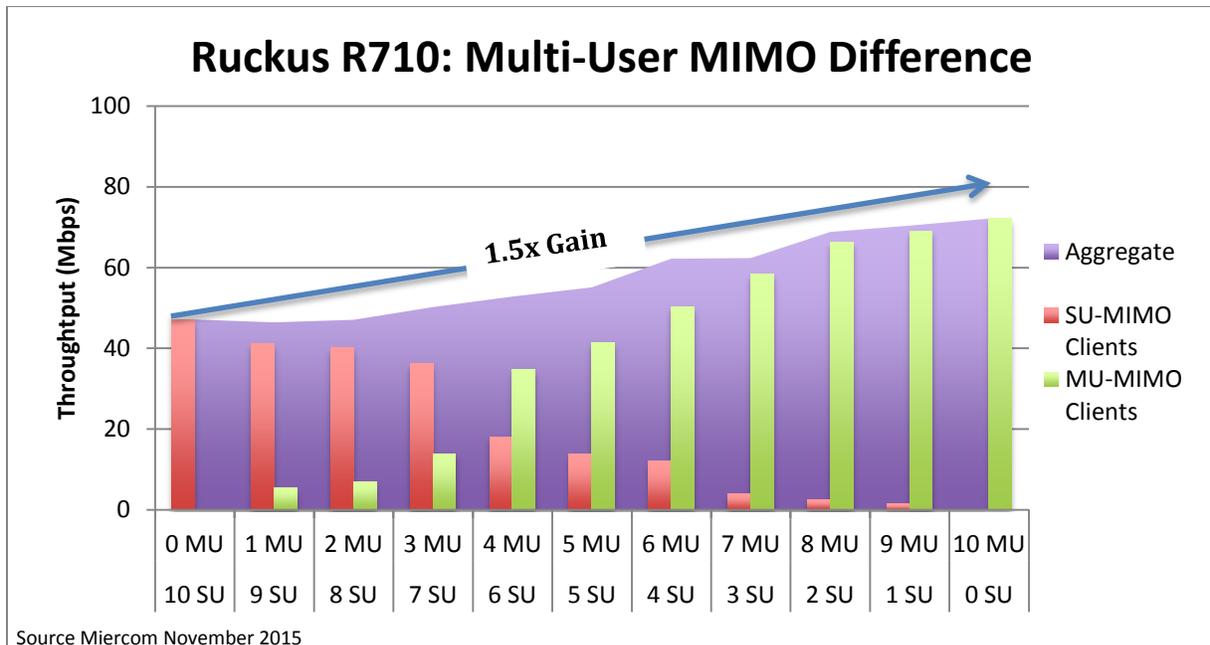
Results

The value of MU-MIMO became apparent– for most of the Access Points tested. In the first case (see graph below), the downlink throughput with the Cisco Aironet 1852i AP nearly doubled for ten clients operating in Multi-User MIMO mode, versus Single-User MIMO.

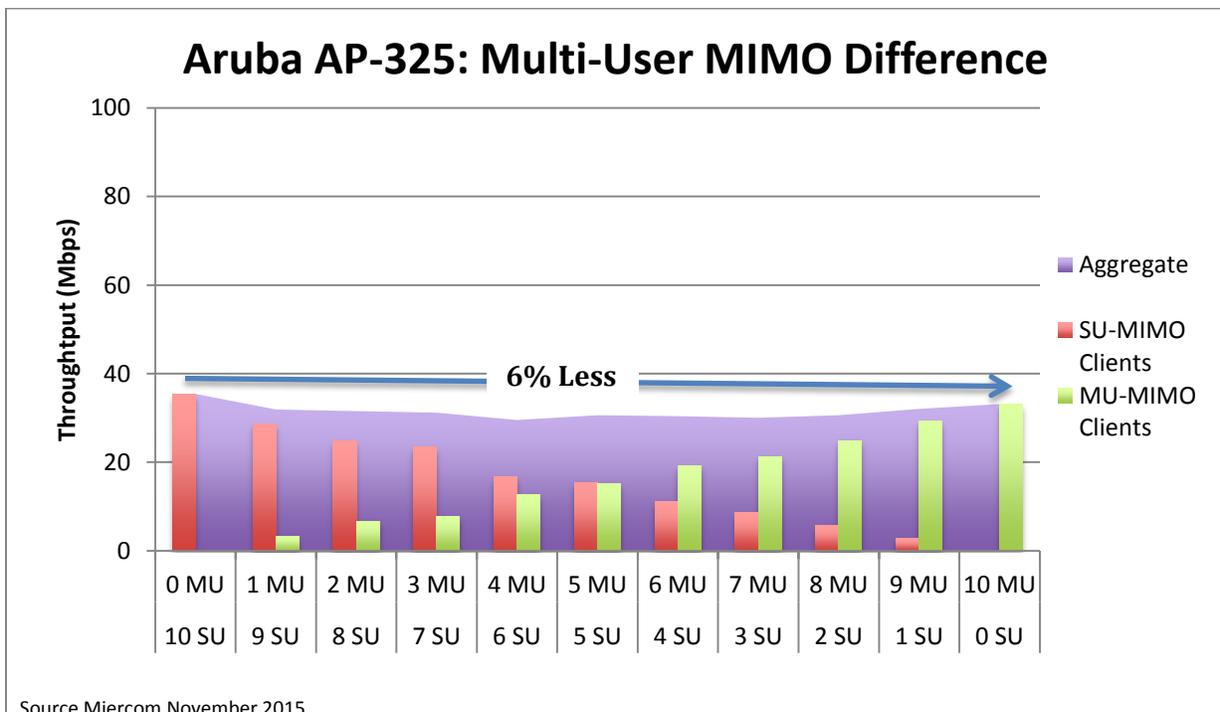


Tests found that the Cisco 1852i AP achieved an 86 percent improvement in aggregate downlink throughput for ten clients running Wave 2's Multi-User MIMO, versus Single-User MIMO.

The Ruckus R710 achieved an equivalent 53-percent gain with MU-MIMO.

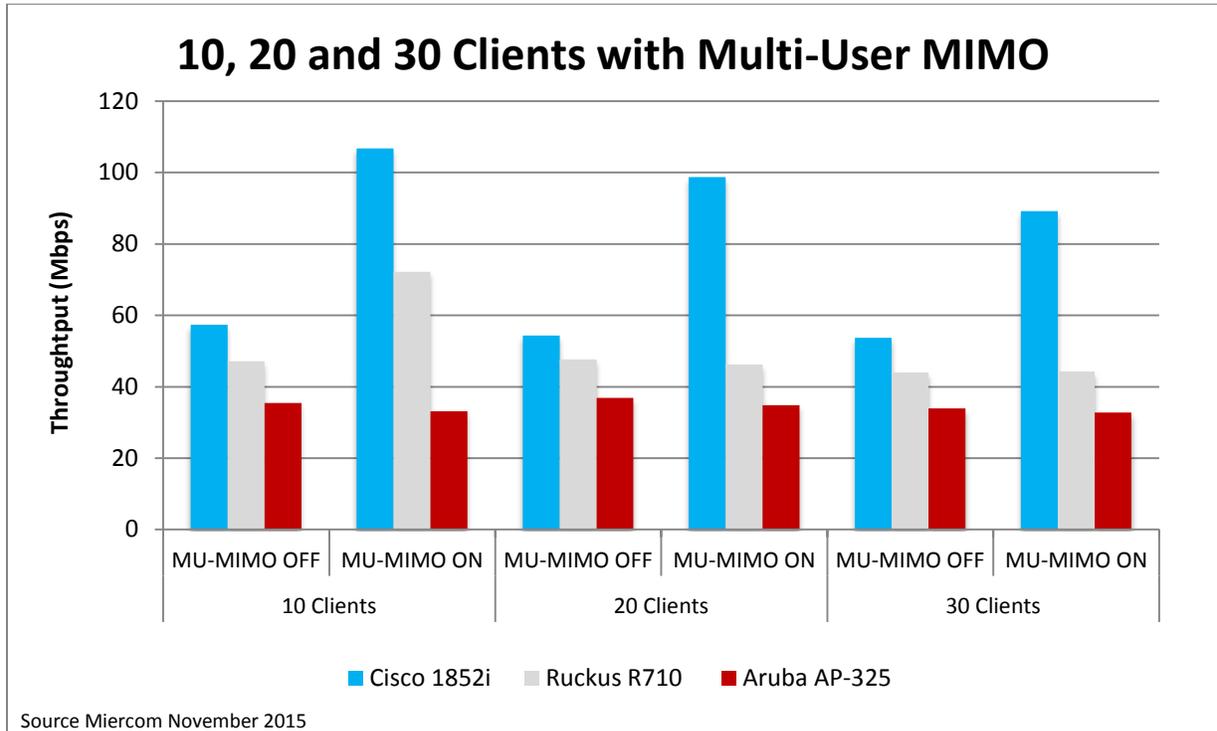


Aggregate throughput with the Aruba AP-325 saw a slight reduction with MU-MIMO (see below).



Up to 30 MU-MIMO clients.

The first part of this testing ended with ten MU-MIMO clients – Acer Aspire E15 laptops. The throughput test was then repeated for each AP with 20 and then with 30 MU-MIMO clients – all Acer Aspire E15 laptops, each operating on a single spatial stream – to see how MU-MIMO throughput performance scales with double and triple the client density.



The above graph shows the difference in AP performance – aggregate downlink TCP throughput – with the same clients: first 10, then 20 and then 30 Acer Aspire E15 laptops, each operating on a single spatial stream. Throughput was first measured with the laptops’ Multi-User MIMO support disabled. Then MU-MIMO was enabled on all clients and a second throughput test was run. The individual results of these tests are shown in the table below. All values are Mbps.

	MU-MIMO setting	Cisco 1852i	Ruckus R710	Aruba AP-325
10 Clients	Off	57.3	47.1	35.4
	On	106.7	72.1	33.1
20 Clients	Off	54.3	47.6	36.8
	On	98.7	46.2	34.8
30 Clients	Off	53.7	44.0	33.9
	On	89.2	44.2	32.7

The best MU-MIMO-based performance was delivered by Cisco's 1852i AP – achieving over 106 Mbps of aggregate downlink TCP throughput for 10 laptop clients. This dropped slightly with 20 clients to 98 Mbps, and then to 89 Mbps with 30 clients, as available bandwidth is shared among many more clients.

Ruckus' R710 AP delivered MU-MIMO throughputs of 72, 46 and 44 Mbps among the clusters of 10, 20 and 30 laptop clients, respectively. Aruba's MU-MIMO throughput remained nearly the same as its Single User-MIMO throughput, ranging from 33 to 37 Mbps, regardless of Single- or Multi-User MIMO, and regardless of 10, 20 or 30 clients.

As shown in the previous testing, the Cisco 1852i showed the greatest increase in throughput as clients stepped up from Single User to Multi-User MIMO. The Ruckus R710 was close behind.

Interestingly, all the APs showed a slight reduction in aggregate downlink throughput as the number of MU-MIMO clients increased. The exception is Aruba, which showed the same – although relatively low – aggregate downlink throughput in all test cases.

7 – Link Aggregation (LAG) for 1+ Gbps Wireless AP Throughput

Test Objective

To verify that it is possible to exceed 1 Gbps of actual throughput with an 802.11ac Wave 2-compliant Access Point under certain conditions.

How we did it

This test was run using just two clients:

- A three spatial stream (3SS) MacBook Pro, Single-User-MIMO laptop, connecting in the 2.4-GHz band, and
- A Linksys EA8500 wireless router with a wired Dell E5540 laptop, acting as a four-spatial-stream (4SS)-capable, Multi-User-MIMO client, connected via a 5-GHz channel.

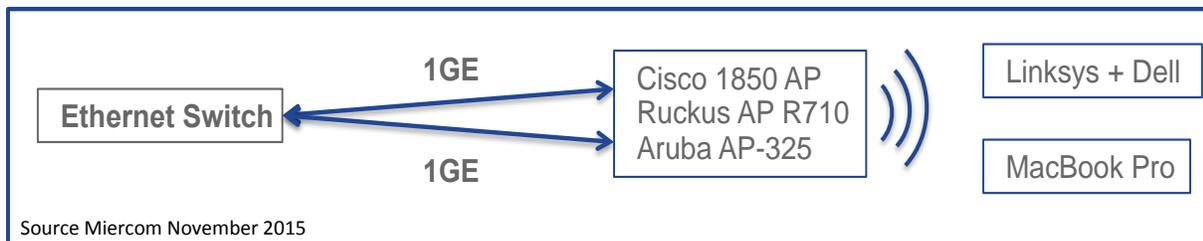
The AP channel width was set to 80 MHz to maximize throughput on the 5-GHz channel to the Dell/Linksys client.

Clients in test to achieve greater-than-1 Gbps of wireless throughput

Quantity	Client type	Wi-Fi Type	MU/SU MIMO
1	Linksys EA8500 w/ wired Dell E5540 laptop	11ac, 4 SS	MU-MIMO
1	MacBook Pro	11ac, 3 SS	SU-MIMO

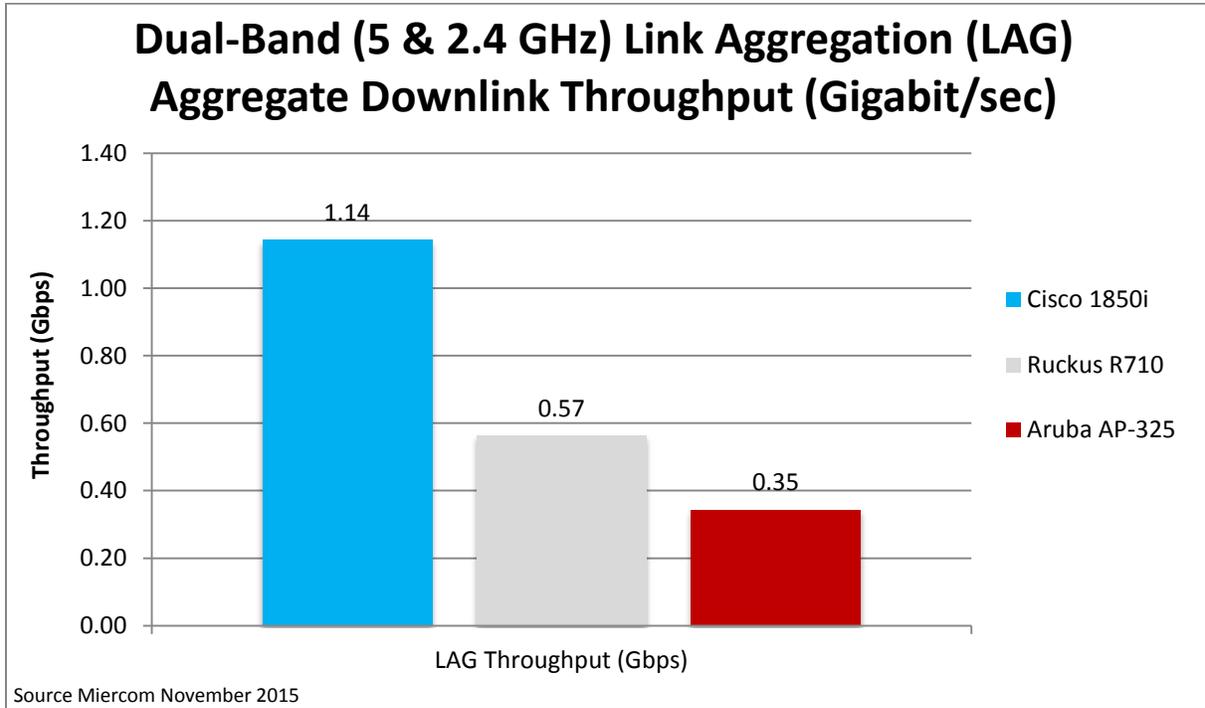
The IxChariot test system issued TCP traffic over two Gigabit Ethernet copper links to each AP, and recorded the aggregate downlink throughput.

The below diagram shows the lab set-up for the link-aggregation test. Two Gigabit Ethernet links are required in order to deliver more than 1 Gbps through the AP to clients, and the links in our testing were set-up to deliver up to 2 Gbps of load-shared data.



Results

As the below graph shows, it is possible with Cisco's 1852i Wave 2-based Access Point to achieve and exceed 1 Gbps of real, downlink TCP throughput, to suitable clients using Link Aggregation (that is, two load-sharing, copper Gigabit Ethernet links to the AP).



MU-MIMO, a unique new feature of Wave 2, it should be noted, does not increase the throughput of the AP, but rather makes more effective use of unused transmitters to send data to multiple client devices at the same time.

8 - Summary

The test results make clear that not all IEEE 802.11ac Wave 2-compliant Access Points perform the same. Certainly the Cisco 1852i AP performs in all tested respects as well as, and in all areas outperform, the popular Aruba AP-325 and Ruckus R710 APs.

The tests were devised to highlight performance differences between 802.11ac Wave 1 and Wave 2 devices, but also identified clear differences in the performance of today's market-leading Wave 2 Access Points. The tests uncovered performance differences in several areas:

Ten-to-100-client Throughput.

Tests found that the APs deliver from 325 to 425 Mbps of downlink aggregate TCP throughput with 10 mixed clients. Aggregate throughput gradually decreases as number of active clients increases. At 100 clients, aggregate throughputs from 150 to 300 Mbps are achieved, down about 30 to 40 percent from 10 clients.

No-bandwidth clients.

Tests showed that, for most APs tested, an increasing number of clients are deprived of bandwidth as client density grows. The number and distribution of clients that get no bandwidth varies appreciably from AP to AP.

MU-MIMO vs SU-MIMO.

The Wave 2 APs tested perform differently in their ability to exploit the Multi-User MIMO feature of Wave 2. For transitioning clients from Single-User to Multi-User MIMO, the biggest throughput gains were delivered by the Cisco 1852i and the Ruckus R710.

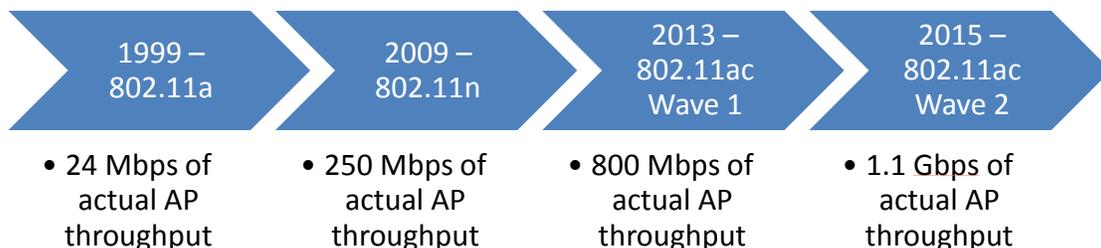
10, 20 and 30 MU-MIMO clients.

Tests found that, while aggregate throughput for Single-User MIMO clients varies little for 10, 20 or 30 clients, throughput for Multi-User-MIMO clients drops noticeably as the number of clients grows from 10 to 30 per AP.

802.11ac Throughput.

The Cisco 1852i AP was able to deliver more than a Gigabit/s of actual throughput under certain conditions. It is possible to make more effective use of unused transmitters to transmit to multiple devices at the same time.

Testing confirmed that Wave 2 products can achieve unprecedented WiFi performance. Evolution of the 802.11 specifications has dramatically improved wireless throughput.



9 - Independent Evaluation

This report was sponsored by Cisco Systems, Inc. The data was obtained completely and independently as part of Miercom's competitive analysis.

10 - About Miercom

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11 - Use of This Report

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