Draft 802.11n Interoperability Performance Test Report

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The Need for Interoperability Performance Testing

Wi-Fi started out as a low cost SOHO technology and until now the industry had no reason to focus on its performance. Today the new generation 802.11n is proliferating into CE (consumer electronics) devices, including set-top boxes, DTVs, DVRs, cameras, PDAs and phones. Performance or lack thereof is both visible and audible to the end-user.

Most households still have two separate networks – one for data and the other for video distribution. But with the throughput levels achievable by 802.11n, a single network supporting data and CE traffic is becoming feasible. The Wi-Fi Alliance CE certification is expected to focus on QoS and throughput necessary for the wireless transport of video, gaming, voice and music applications. But the current Wi-Fi Alliance 802.11n Draft 2.0 certification incorporates little performance testing and focuses on the basic interoperability of devices and their 'good neighbor' behavior towards legacy installations[1].

Independent performance testing to date has used client-AP pairs based on chipsets from the same vendor. But, with the complexity of 802.11n specification and many optional features in the emerging standard, throughput between different chipset implementations may be unpredictable.

The industry has little information on cross-vendor performance – a critical factor on which the success of the CE market penetration depends.

This test was sponsored by the 802.11n silicon vendor, Metalink, and our mission was to measure cross-vendor interoperability performance of AP-client pairs based on chipsets from Atheros, Broadcom, Marvel, Metalink and Ralink. We have made throughput measurements at 2.4 and 5 GHz for a full vendor-vendor matrix (figure 1, table 1).

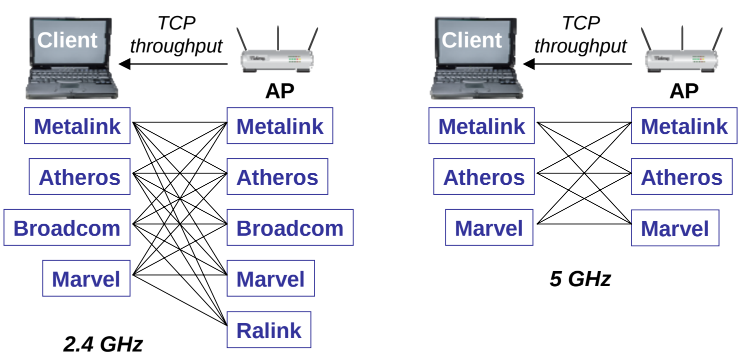


Figure 1: 802.11n test matrix
Downstream TCP throughput was measured on AP-client pairs based on silicon from different vendors. Table 1 lists the APs and clients used in the test.

Prior to the test we suspected that performance of the AP-client pairs with the same chipset would be higher than the performance of AP-client pairs with different chipsets, but the results have surprised us. In some cases cross-vendor throughput performance was better than same-vendor performance (figure 2).

[1] See the Wi-Fi Alliance white paper by this author, "Wi-Fi CERTIFIED™ 802.11n draft 2.0: Longer-Range, Faster-Throughput, Multimedia-Grade Wi-Fi® Networks", www.wi-fi.org/whitepaper_80211n_draft2_technical.php

Table 1: *AP and client devices in the test*

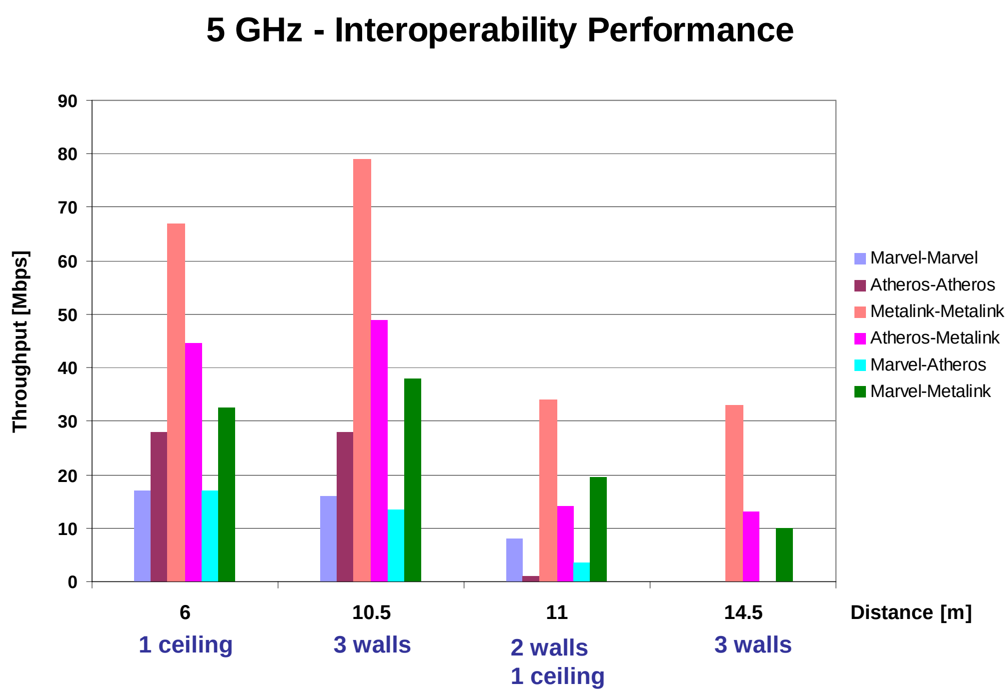
5 GHz APs	**Chipset**	**Certification**	**Frequency**
Metalink WLANPlus Firmware: 2.2.3.23	Metalink MtW8171 MAC / BB MtW8151 RFIC	Draft 2.0	2.4 / 5 GHz
Apple A1143 Firmware: 7.2.1	Atheros AR5416 MAC / BB AR5133 RFIC	Draft 2.0	5 GHz
Buffalo WZR-AMP300NH Firmware 1.48	Marvel 88W8363 MAC / BB 88W8060 RFIC	Draft 2.0	2.4 / 5 GHz

5 GHz Clients	**Chipset**	**Certification**	**Frequency**
Metalink WLANPlus Firmware: 2.2.3.23	Metalink MtW8171 MAC / BB MtW8151 RFIC	Draft 2.0	2.4 / 5 GHz
Apple – internal to laptop model #A1181 Firmware: 7.2.1	Atheros AR5416 MAC / BB AR5133 RFIC		5 GHz
Buffalo WLI - CB - AMG300N cardbus x2 Firmware 3.0.1.13	Marvel 88W8363 MAC / BB 88W8060 RFIC	Draft 2.0	2.4 / 5 GHz

2.4 GHz APs	**Chipset**	**Certification**	**Frequency**
D-Link 655 Firmware: 1.1	Atheros AR5416 MAC / BB AR5133 RFIC	Draft 2.0	2.4 GHz
Belkin N1 Wireless Router V3000 Firmware: 3.10.12	Ralink RT2860 MAC / BB RT2820 RFIC	Draft 2.0	2.4 GHz
Buffalo WZR-AMP300NH Firmware 1.48	Marvel 88W8363 MAC / BB 88W8060 RFIC	Draft 2.0	2.4 / 5 GHz
Linksys WPC300N Firmware: 1.51.2	Broadcom BCM4321 MC / BB BCM2055 RFIC	Draft 2.0	2.4 GHz
Metalink WLANPlus Firmware: 2.2.3.23	Metalink MtW8171 MAC / BB MtW8151 RFIC	Draft 2.0	2.4 / 5 GHz

2.4 GHz Client	**Chipset**	**Certification**	**Frequency**
Metalink WLANPlus Firmware: 2.2.3.23	Metalink MtW8171 MAC / BB MtW8151 RFIC	Draft 2.0	2.4 / 5 GHz
Linksys 300 Cardbus Firmware: 4.150.31.0	Broadcom BCM4321 MC / BB BCM2055 RFIC	Draft 2.0	2.4 GHz
Buffalo WLI - CB - AMG300N cardbus x2 Firmware 3.0.1.13	Marvel 88W8363 MAC / BB 88W8060 RFIC	Draft 2.0	2.4 / 5 GHz
D-link 652 Cardbus Firmware: 6.0.3.107	Atheros AR5416 MAC / BB AR5133 RFIC	Draft 2.0	2.4 GHz

The level of throughput we have measured is impressive, particularly since the residential house used for the test presented a challenging environment. The walls of the house are constructed of stone, concrete and iron rods and the ceiling is made of concrete. These materials limit the range of RF propagation to a greater extent than the wooden homes typically found in the United States.



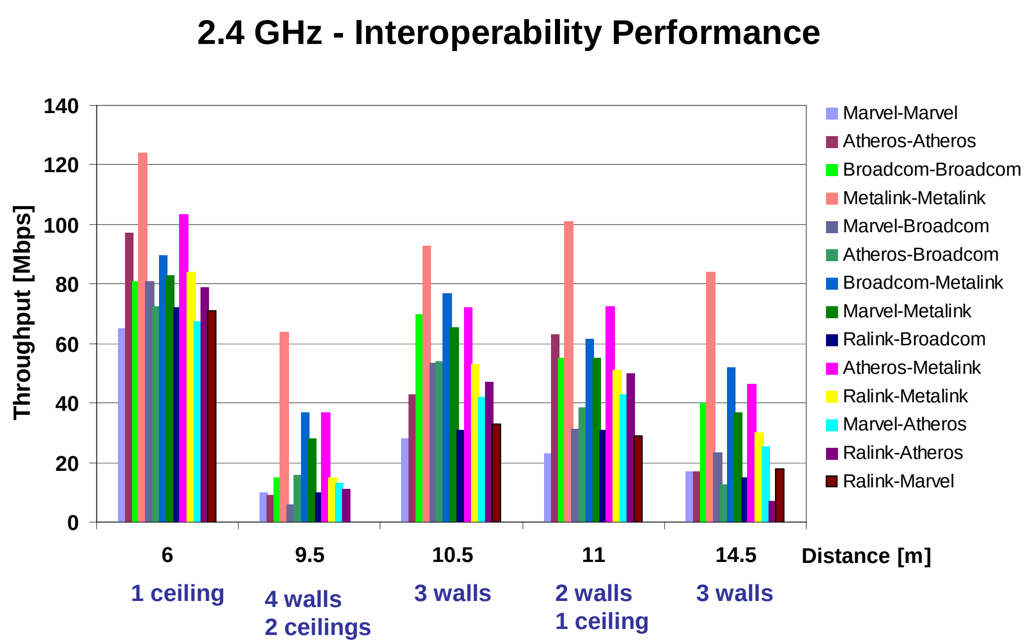


Figure 3: Interoperability performance test results *Top: 5 GHz, Bottom: 2.4 GHz; Vendor1-Vendor2 throughput is an average of Vendor1 AP to Vendor2 client and Vendor2 AP to Vendor1 client measurements. The AP-client pairs involving the Ralink-based AP are actual measurements and not averages since we didn't have a Ralink-based client to form a complementary pair.*

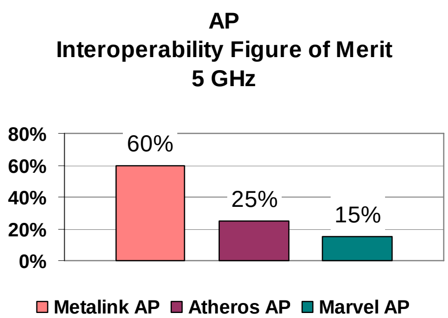
Interoperability Figure of Merit

In an interoperability performance test the winner is not the device that works best with its own chipset, but rather the device that works best with other chipsets.

To quantify the interoperability performance of devices in the test, we computed the Interoperability Figure of Merit, IFM, for each device.

IFM for an AP is the percentage of throughput for the AP-client pairs involving that AP with respect to total throughput for the test matrix. Similarly, IFM for a client is the percentage of throughput transported by the AP-client pairs involving that client with respect to total throughput in the test matrix. See Appendix B for an example of an IFM calculation.

Metalink had the highest AP and client IFM scores in both the 5 GHz and the 2.4 GHz test matrices (figures 4, 5).



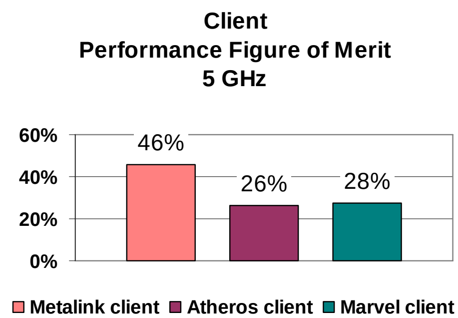
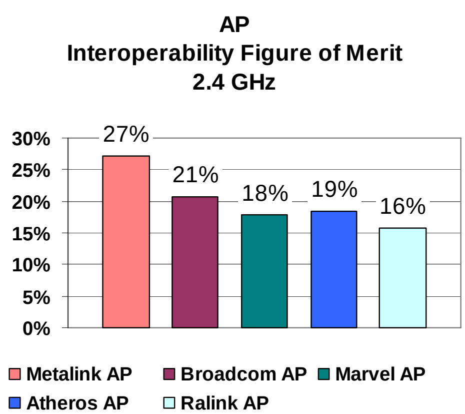


Figure 4: Interoperability Figure of Merit at 5 GHz *The AP with the highest IFM – Metalink – was responsible for 60% of the total throughput in the 5 GHz matrix. The client with the highest IFM – also Metalink – was responsible for 46% of the total throughput in the 5 GHz matrix.*



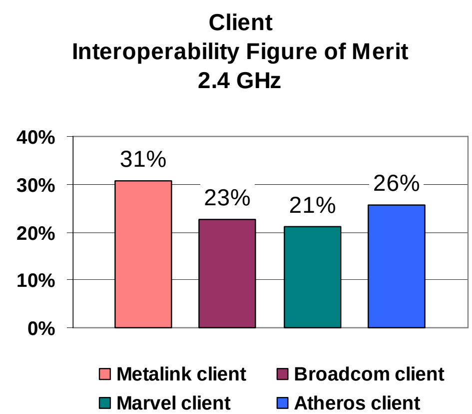


Figure 5: Interoperability Figure of Merit at 2.4GHz *Metalink was the interoperability performance leader at 2.4 GHz with its AP and client. The Metalink AP transported 27% of the total throughput in the 2.4 GHz matrix. The Metalink client transported 31% of the total throughput in the 2.4 GHz matrix. The percentages for the APs are lower than for the clients because we had more APs than clients in the 2.4 GHz matrix and each client was involved in more pairs than each AP.*

Test Results

Figures 6 to 13 show throughput for each vendor in the test with its own partner and with partners based on other chipsets. All throughput numbers were measured in the downstream direction – sending TCP traffic from the AP to the client using IxChariot (see Appendix C for details on the test setup and methodology).

The throughput numbers for each pair are averages of Vendor1 client to Vendor2 AP and Vendor1 AP to Vendor2 client. For example, the throughput for the Atheros-Broadcom pair is an average of the Atheros-based AP paired with the Broadcom-based client and the Broadcom-based AP paired with the Atheros-based client. The actual throughput measurements are tabulated in Appendix A. Since we didn't have a Ralink-based client and thus no complementary AP-client pair to average, the pairs involving the Ralink-based AP are shown as measured.

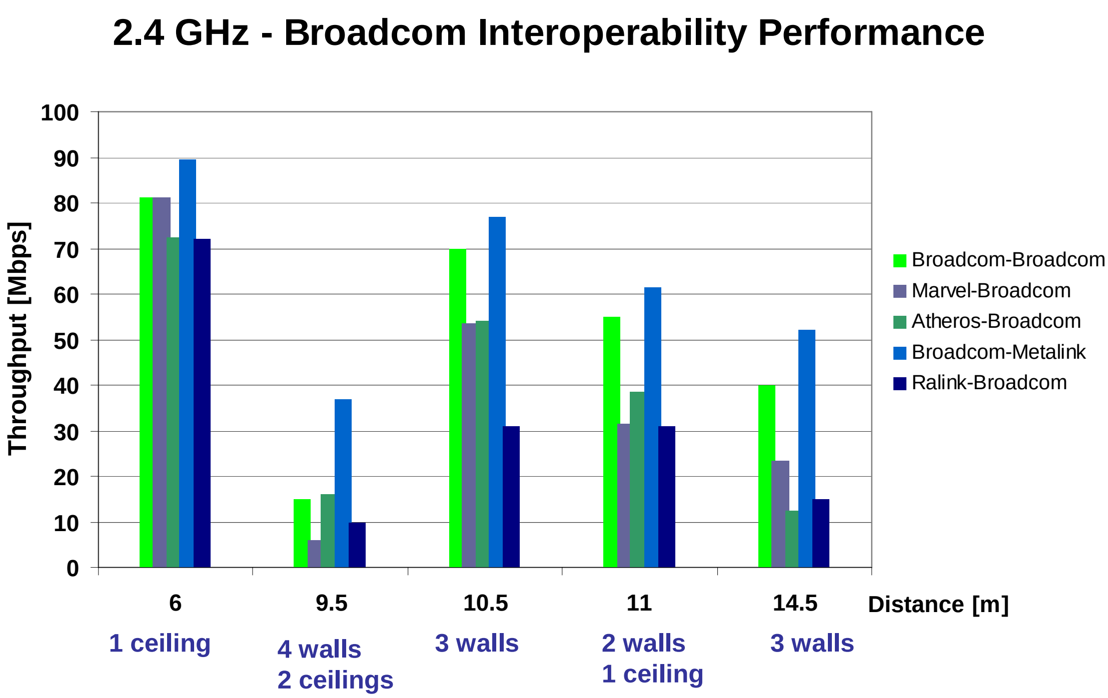


Figure 6: Broadcom interoperability performance at 2.4 GHz *The Broadcom chipset, exhibited the highest throughput when paired with Metalink, exceeding the performance with its own chipset.*

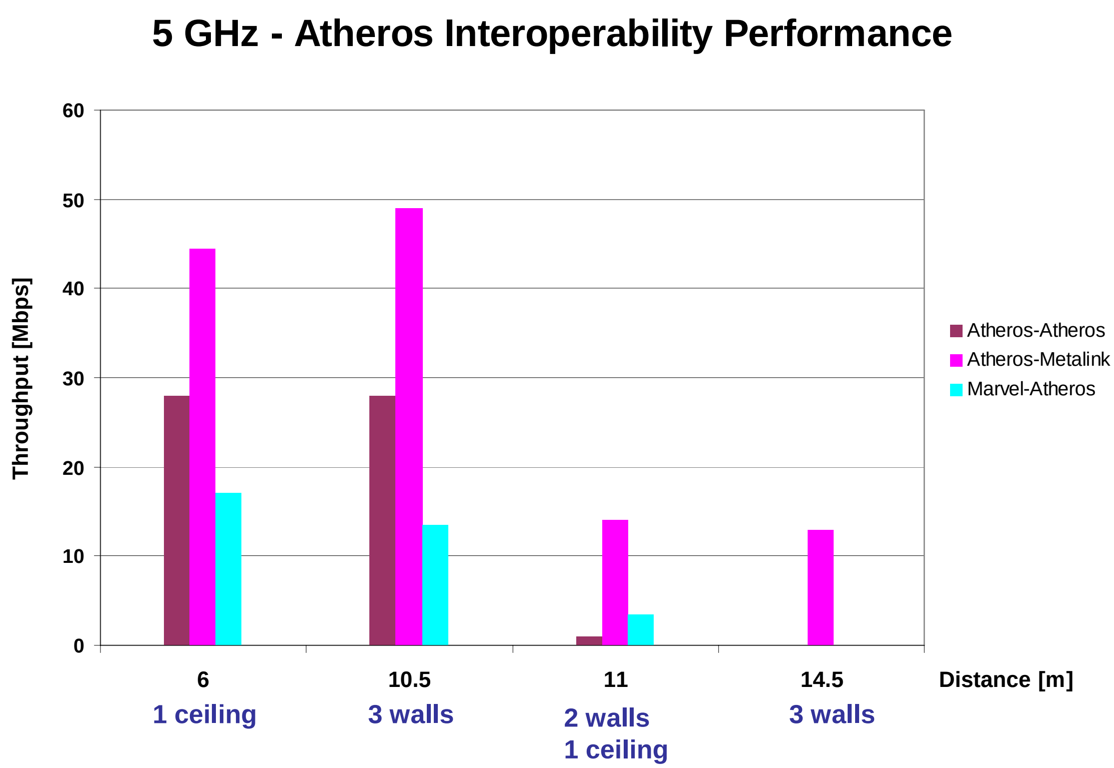


Figure 7: Atheros interoperability performance at 5 GHz *Atheros at 5 GHz exhibited the highest throughput when paired with Metalink, especially at the more challenging test points.*

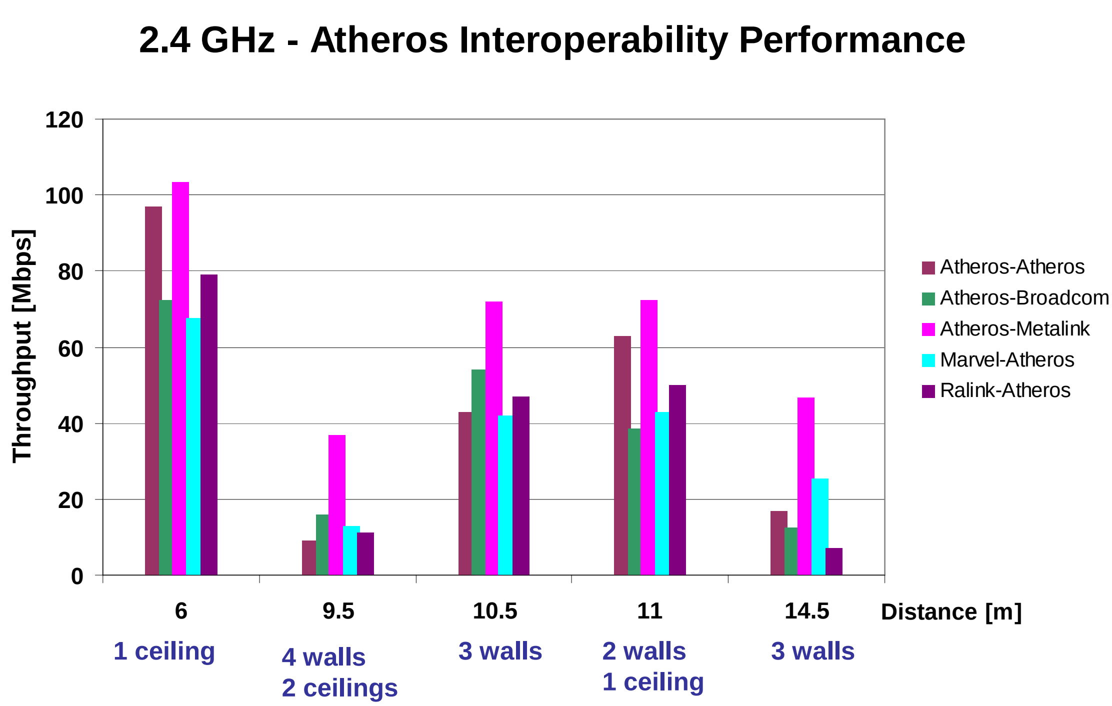


Figure 8: Atheros interoperability performance at 2.4 GHz *Atheros at 2.4 GHz exhibited the highest throughput when paired with Metalink, exceeding the performance with its own chipset.*

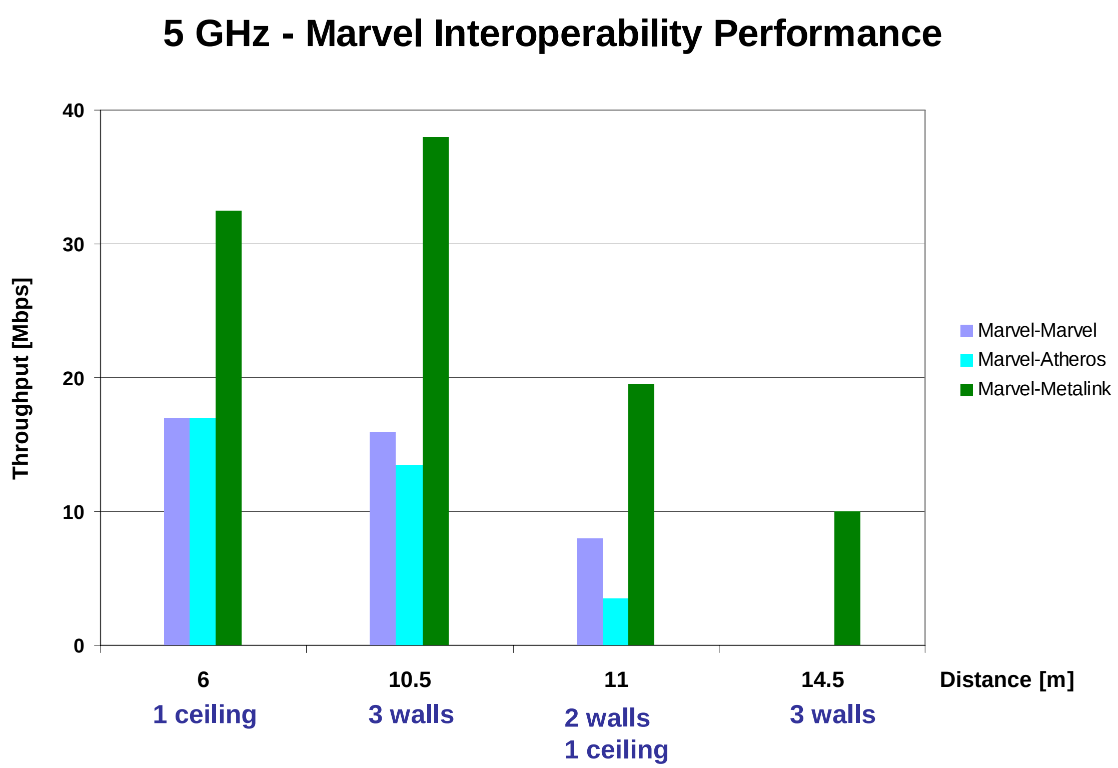


Figure 9: Marvel interoperability performance at 5 GHz *Marvel at 5 GHz exhibited the highest throughput when paired with Metalink, exceeding the performance with its own chipset.*

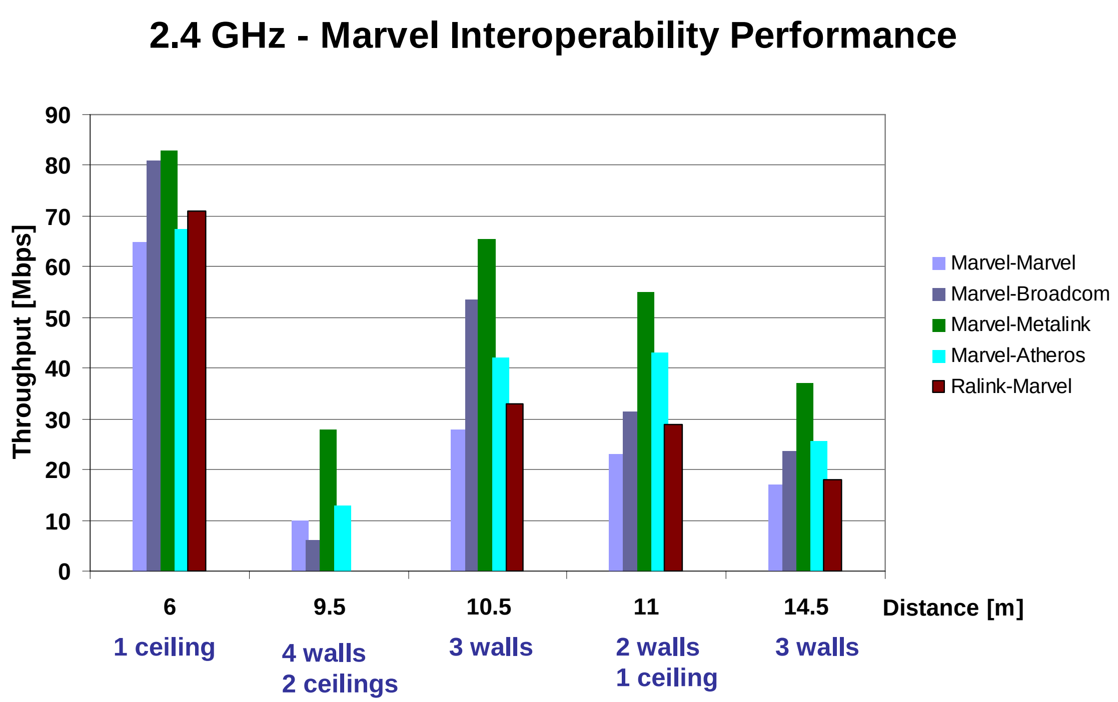


Figure 10: Marvel interoperability performance at 2.4 GHz *Marvel at 2.4 GHz exhibited the highest throughput when paired with Metalink, exceeding the performance with its own chipset.*

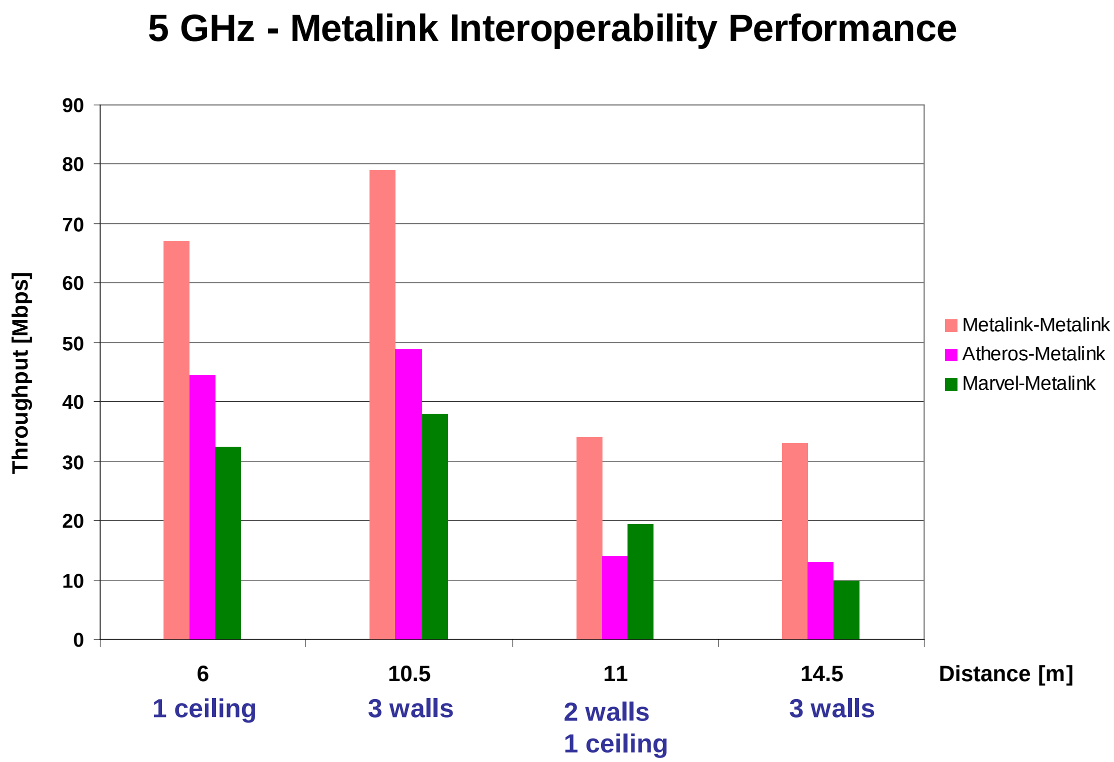


Figure 11: Metalink interoperability performance at 5 GHz *Metalink at 5 GHz worked best when paired with its own chipset.*

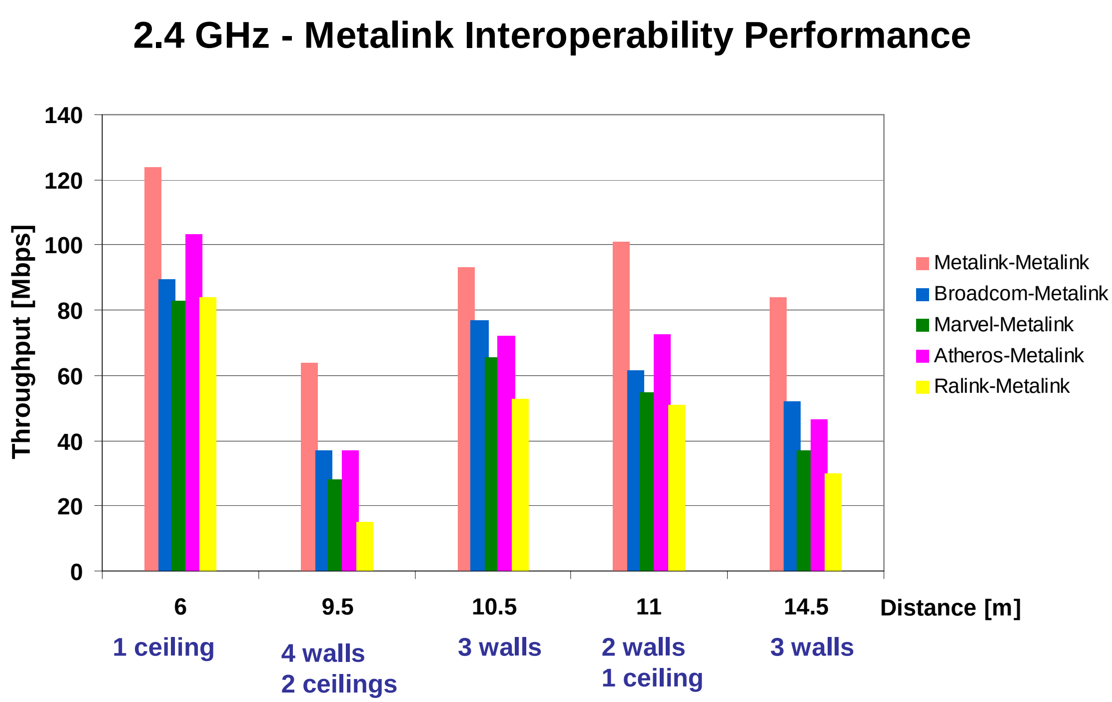


Figure 12: Metalink interoperability performance at 2.4 GHz *Metalink at 2.4 GHz worked best when paired with its own chipset.*

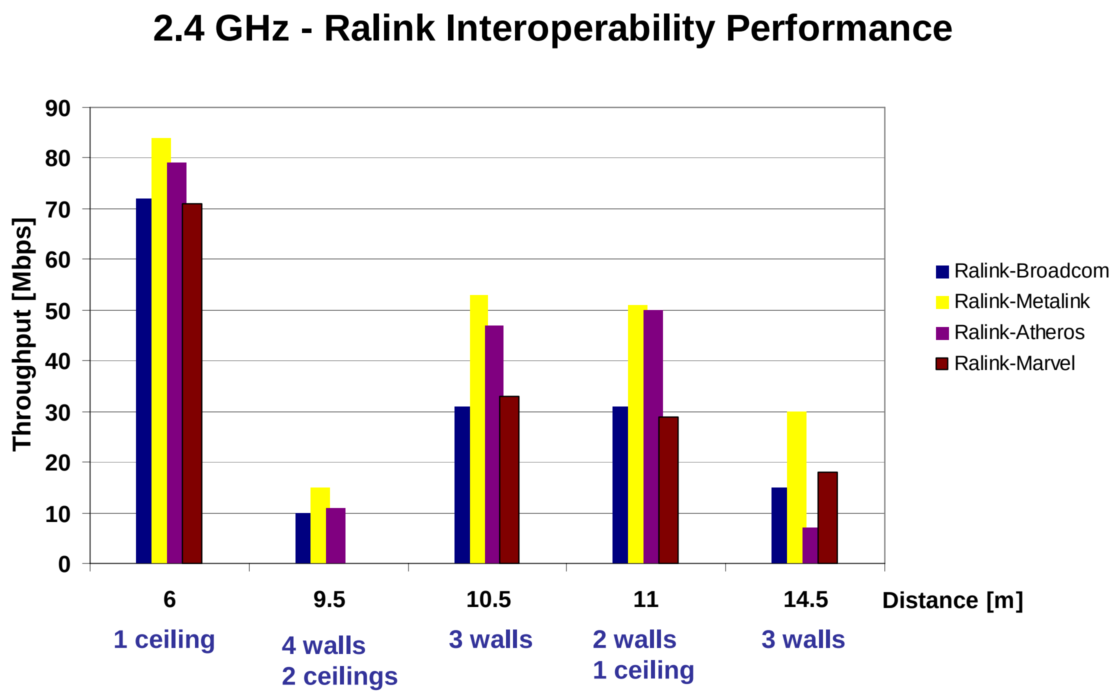


Figure 13: Ralink interoperability performance at 2.4 GHz *Ralink worked better with Metalink than with its own chipset.*

Analysis of Results

Vendors tend to focus on short range throughput when promoting their 802.11n chipsets. But 100+ Mbps at a short range, where technologies such as UWB can deliver 500+ Mbps of TCP throughput (see our recent EE Times UWB test), is of limited advantage to Wi-Fi. The real win for Wi-Fi is full-house wireless coverage supporting HD video streaming. For this reason our test included far away points reachable through multiple stone/concrete walls and ceilings (see Appendix C for the details on the test setup and methodology).

The throughput of most AP-client pairs in the test was impressive and demonstrates that the industry has come a long way since its last generation 802.11a/g with maximum throughput of about 20 Mbps. Devices from different vendors interoperated surprisingly well, reaching the throughput of over 100 Mbps even under non-line-of-sight conditions.

As expected, the 5 GHz pairs had lower throughput vs. range performance than the 2.4 GHz pairs. For example, at our most distant point, 14.5 meters through 3 walls, with the Metalink-Metalink pair we measured 80+ Mbps at 2.4 GHz vs. 30+ Mbps at 5 GHz.

5 GHz operation has been challenging for some Wi-Fi vendors and most of the existing legacy installations still operate in the 2.4 GHz band. But this is about to change since video distribution will require 40 MHz channels that are only practical at 5 GHz. Today, the Wi-Fi Alliance certification disallows 40 MHz channels in the 2.4 GHz band and requires CE devices to support 5 GHz.

Metalink has achieved the highest interoperability score of all the chipsets (figures 4, 5) and had the highest overall throughput when paired with its own chipset (figure 3).

Metalink attributes this exceptional performance to their unique MIMO decoder design and careful attention to the RF issues, particularly at 5 GHz.

To optimize interoperability performance Metalink has implemented a Maximum Likelihood (ML) algorithm in its MIMO decoder. ML is a statistical algorithm for assigning the MIMO constellation points to particular constellations when these points are located in uncertain regions. The ML detector scans all the possible transmit words (64^2, in case of 64 QAM on two spatial streams) and probabilistically determines the word that was most likely sent. Metalink claims that its ML detector offers up to 5 dB of improvement with respect to traditional detectors, which serves to almost double the range of their device over competing solutions.

Metalink also uses the LDPC (Low Density Parity Check) FEC (Forward Error Correction) scheme, which can add another 3dB of SNR (Signal to Noise Ratio) gain to their receiver.

While both ML and LDPC are computationally intensive and thus expensive to implement, Metalink has developed patented technology that lets them implement both of these powerful features economically in their chipset.

While ML helps with interoperability performance, LDPC only helps when paired with another LDPC device. Thus, Metalink's ML implementation may be responsible for their superior interoperability performance while LDPC is responsible for their overall maximum throughput performance when paired with their own device.

Video Streaming Considerations

HD video distribution in the home is the most throughput-hungry application requiring approximately 20 Mbps for an MPEG-2 1080p HD stream and about 8 Mbps for an MPEG-2 SD (Standard Definition) stream (table 2). The new MPEG-4/H.264 compression standard roughly doubles the throughput efficiency of video streaming, but most content today is still stored and distributed using MPEG-2.

Table 2: *Throughput requirements for common video formats and resolutions*

Format		**Average throughput required for high quality video**	
		480i60	**1080p30**
Broadcast Cable TV	MPEG-2	8 Mbps	20 Mbps
Windows Media Video DivX XviD QuickTime	MPEG-4 Part 10/H.264	5 Mbps	12 Mbps

Since 40 MHz channels are not recommended in the 2.4 GHz band, 5 GHz is better suited for video transport and the 5 GHz band also has more available channels.

At 5 GHz, the top performing AP-client pair, Metalink-Metalink, has demonstrated 60+ Mbps of throughput in most of the house and 30+ Mbps at far away corners of the house. Thus, Metalink would be able to comfortably transport 3 HD streams through most of the house and at least 1 HD stream to the far corners of the house. Atheros-Atheros, Atheros-Metalink and Marvel-Metalink pairs maintained throughput of 20+ Mbps through most of the house and thus can carry at least 1 HD stream through most of the house, but would be relegated to SD streaming, requiring 8 Mbps, to the far corners of the house.

Summary

We tested interoperability performance of the new 802.11n products based on chipsets from Atheros, Broadcom, Marvel, Metalink and Ralink. Our goal was to discover whether AP-client pairs based on chips from different vendors would have similar performance as AP-client pairs based on the same chipset.

We discovered that the Wi-Fi industry is in good shape as far as interoperability performance of draft 2.0 802.11n is concerned. Many of the AP-client pairs can transport HD video throughout a typical house and the top performer, Metalink, can transport up to 3 through most of the house.

Metalink's AP and client got the highest on the IFM (Interoperability Figure of Merit) ratings in both the 2.4 and the 5 GHz bands. Metalink was also the winner in the overall throughput performance when paired with its own device.

Appendix A: Tabulated Test Data

Table A-1: 2.4 GHz Test Data

AP	Client	2.4 GHz Average TCP Throughput, Mbps					Total Mbps
		6 m	9.5 m	10.5 m	11 m	14.5 m	
Marvel	Broadcom	78	6	47	26	24	181
Atheros	Broadcom	57	2	28	20	15	122
Metalink	Broadcom	88	41	71	61	42	303
Marvel	Metalink	79	22	67	58	41	267
Metalink	Metalink	124	64	93	101	84	466
Metalink	Marvel	87	34	64	52	33	270
Ralink	Broadcom	72	10	31	31	15	159
Broadcom	Broadcom	81	15	70	55	40	261
Marvel	Marvel	65	10	28	23	17	143
Atheros	Metalink	100	29	59	74	50	312
Ralink	Metalink	84	15	53	51	30	233
Broadcom	Metalink	91	33	83	62	62	331
Metalink	Atheros	107	45	85	71	43	351
Marvel	Atheros	78	21	58	55	27	239
Atheros	Atheros	97	9	43	63	17	229
Ralink	Atheros	79	11	47	50	7	194
Broadcom	Atheros	88	30	80	57	10	265
Broadcom	Marvel	84	6	60	37	23	210
Ralink	Marvel	71	0	33	29	18	151
Atheros	Marvel	57	5	26	31	24	143
Total Mbps transported during the test by all pairs, 2.4 GHz							**4830**

Table A-2: 5 GHz Test Data

AP	Client	5 GHz Average TCP Throughput, Mbps				Total Mbps
		6 m	10.5 m	11 m	14.5 m	
Atheros	Atheros	28	28	1	0	57
Atheros	Marvel	25	21	5	0	51
Atheros	Metalink	34	47	9	8	98
Marvel	Metalink	27	26	7	6	66
Metalink	Metalink	67	79	34	33	213
Metalink	Marvel	38	50	32	14	134
Metalink	Atheros	55	51	19	18	143
Marvel	Atheros	9	6	2	0	17
Marvel	Marvel	17	16	8	0	41
Total Mbps transported during the test by all pairs, 5 GHz						**820**

Appendix B: Interoperability Figure of Merit (IFM) Calculation

Example of IFM calculation:

The IFM of the Atheros-based AP at 5 GHz can be calculated from Table A-2, which lists the average TCP throughput measured by IxChariot for each pair at each test point. The top three rows of Table A-2 show the measurements performed with the Atheros-based AP. If we add the sums for these three rows, shown in the last column, we get 471 Mbps (57+51+98=206). We divide 206 by the total number of Mbps in the entire 5 GHz matrix, shown in the bottom row and get 30% (206/820=0.25). This gives us the Atheros-based AP IFM of 25%.

This IFM figure is directly related to how well the Atheros-based AP interoperated with the clients in the test matrix as compared to other APs.

Appendix C: Test Setup and Methodology

The test was done in a residential house with the walls constructed out of stone, concrete and iron rods and the ceiling made of concrete. These materials create a more challenging environment for Wi-Fi signaling than wooden homes typically found in the US.

We used IxChariot to send downstream TCP traffic – from the AP to the client. We tested one AP-client pair at a time and covered the whole matrix of AP-client configurations in the 2.4 and the 5 GHz bands (figure 1, table 1).

The AP was left in place while the client was moved to the designated points in the house (figure C-1).

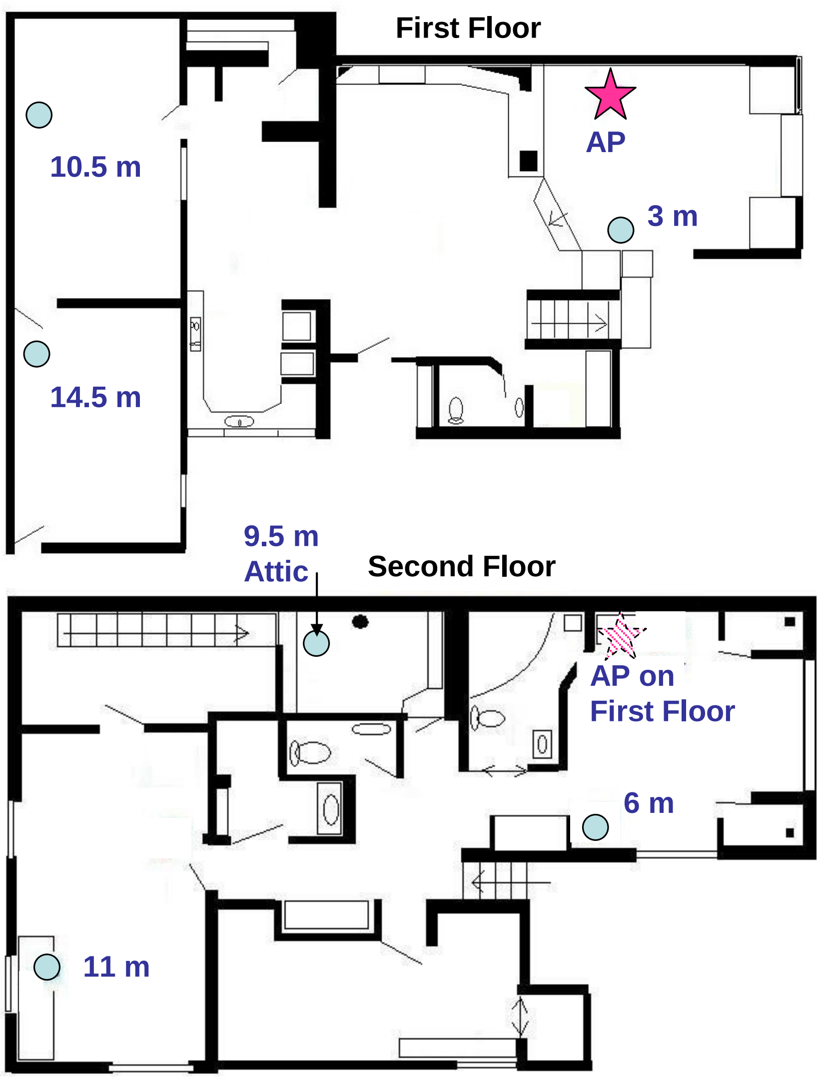


Figure C-1: Floor plan of the house *The AP was located on the first floor while the client was moved to the designated points. The 9.5 meter point was actually located in the attic above the second floor. The house is built of stone and concrete materials, creating a challenging environment for RF propagation.*

We used the Ixia very_high_throughput script with the buffer size of 65535 and TCP traffic.

At each test point, the measurement was performed 4 times with the client rotated 0º, 90º, 180º and 270º. At each orientation we ran the Ixia script for one minute. The average throughput values reported by the IxChariot for each client orientation were averaged to get a single throughput number that we entered into tables A-1 and A-2.

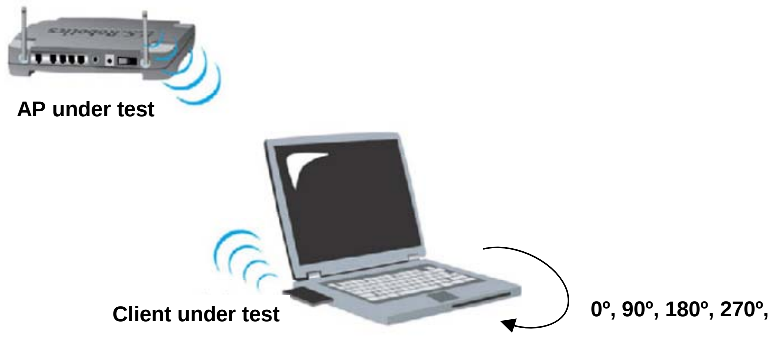


Figure C-2: *The client was rotated 4 times at each test point and throughput measured for one minute in each orientation. These 4 measurements were then averaged to get a single throughput number.*

IxChariot endpoints were configured on separate PCs with gigabit Ethernet ports and connected to the Ethernet ports of the AP/routers and clients under test. Two endpoints were used at the AP/routers to make sure that the throughput wouldn't be limited by the 10/100 Base-T ports on some APs under test. The laptops with the clients under test were operating in bridge mode forwarding the test traffic to the endpoint at the gigabit Ethernet port. The Metalink client had 10/100 Base-T ports and we connected two endpoints to these ports to make sure that the measured throughput wouldn't be limited by the Ethernet interface.

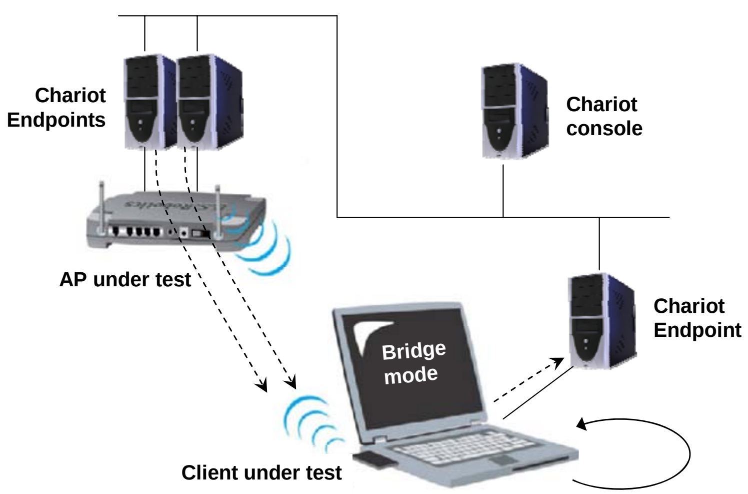


Figure C-3: IxChariot endpoint configuration *Two endpoints were used at the Ethernet ports of the AP/routers under test to make sure that offered test load exceeded 100 Mbps and filled the 802.11n pipe. The Metalink client platform had 10/100 Ethernet ports and we connected two PCs as receiving endpoints on these ports.*