Competitive Test of Draft 802.11n Products

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Introduction

802.11n is the new generation WLAN technology promising significant improvement in throughput and useful range over legacy 802.11a,b,g equipment. In the home, 802.11n is expected to provide triple play coverage including video distribution through a typical house to multiple TV sets. In the enterprise/office environment, 802.11n is expected to support mission-critical applications with throughput, QoS and security rivaling 100Base-T.

The IEEE 802.11n standardization process is stable as the draft 2.0[1] has only minor changes from draft 1.0. The standard is scheduled to be ratified in 2H08 and compliance to the standard is expected to be achievable via software upgrade of existing silicon. The WLAN industry has embraced the 2.0 draft with the Wi-Fi Alliance beginning draft 2.0 product certification by mid-2007.

Draft 802.11n chipsets and equipment now available off-the-shelf show significant improvement over legacy 802.11a,b,g technology in terms of throughput and range (figure 1).

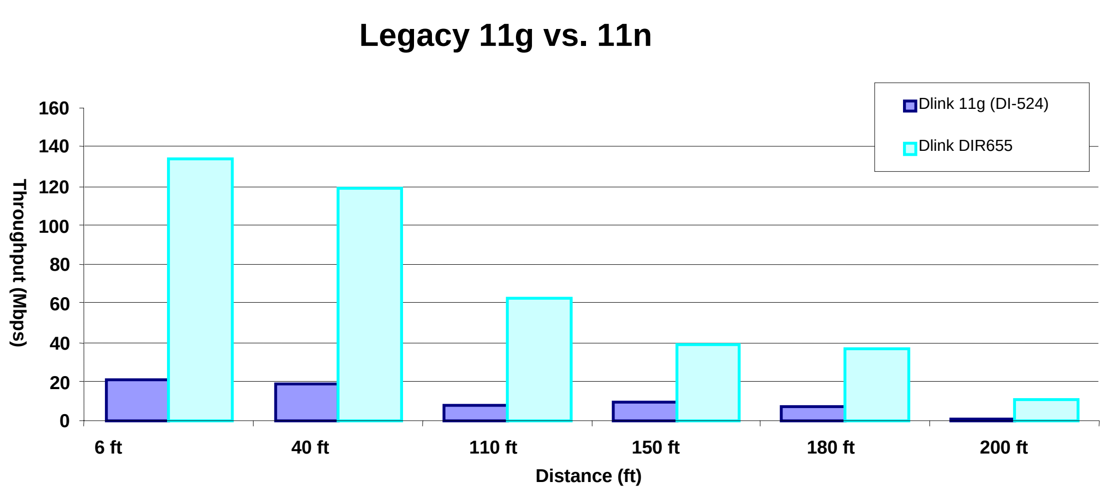

Figure 1: *Representative throughput vs. range plots showing draft 802.11n's throughput improvement over legacy 802.11g technology*

This test focused on verifying the throughput and video performance vs. range of draft 802.11n equipment. The tests were performed in both office and home environments.

[1] An overview of the draft can be found in the following article: "Testing IEEE 802.11n", Test & Measurement World, April 2007, http://www.tmworld.com/article/CA6428547.html

The equipment was enabled with the most current software available from the vendors at the time of the tests. The eight AP/client pairs tested are listed in Table 1.

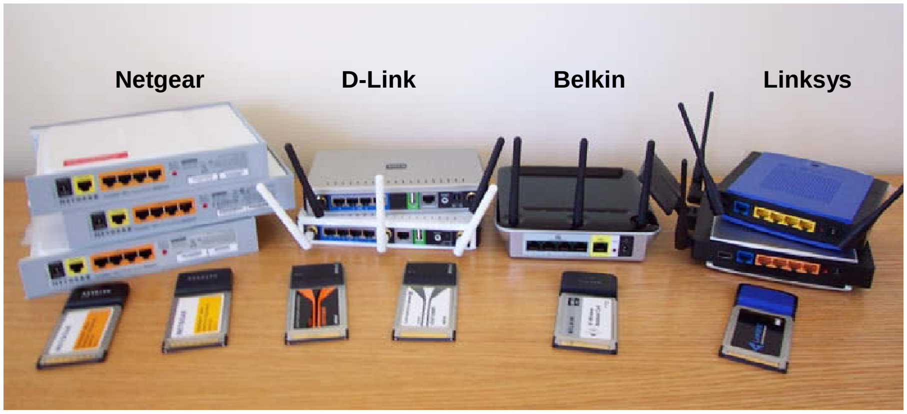

Figure 2: *Equipment tested*

Table 1: *Equipment tested*

AP/client pair	LAN Ethernet	Software version Serial number	Chipset
Belkin: F5D8231-4 with F5D8011	10/100Base-T	AP firmware v1.01.17 boot 2.02; 24apr06 AP S/N 150621R8100325 NIC driver 6.0.1.4 6jul06 NIC S/N 150620C8100042	Atheros, 3x3
D-Link: DIR-655 with DWA-652	1000Base-T	AP firmware v1.03 AP S/N F35F169000819 NIC driver v6.0.1.36 31jul06 NIC S/N F35H171001150	Atheros, 3x3
D-Link: DIR-625 with DWA-642	10/100Base-T	AP firmware v1.09 AP S/N F33O272009757 NIC driver v 6.0.1.75 28aug06 NIC S/N F34416C002941	Atheros, 2x2
Linksys: WRT350N with WPC300N	1000Base-T	AP firmware 1.03.2 22nov06 AP S/N CNQ01G113443 NIC driver v4.100.15.5 12oct06 NIC S/N CNSO1F613132	Broadcom, 2x3[2]
Linksys: WRT150N with WPC300N	10/100Base-T	AP firmware 1.00.5 AP S/N CQ601G117786 NIC driver v4.100.15.5 12oct06 NIC S/N CNSO1F613132	Broadcom, 2x2
Netgear: WNR854T with WN511T	1000Base-T	AP firmware v1.4.07NA AP S/N 1JF164KF002A6 NIC driver v2.1.4.3 4oct06 NIC S/N 1JE165K405BBD	Marvel, 2x3
Netgear: WNR834M with WN511T	10/100Base-T	AP firmware v1.4.07NA AP S/N 1K5165KG01C27 NIC driver 2.1.4.3 4oct06 NIC S/N 1JE165K405BBD	Marvel, 2x2
Netgear: WNR834B with WN511B	10/100Base-T	AP firmware v1.0.3.8NA AP S/N 1GF265A303933 NIC driver v4.100.27.0 30nov06 S/N LGE1657K01388	Broadcom, 2x3[2]

[2] The 3rd antenna in this case provides diversity; the chip only has 2 transmitters and 2 receivers. In contrast, the Atheros 3x3 device incorporates 3 transmitters and 3 receivers.

Objectives

The main objectives of the test were as follows:

- Measure and compare the throughput of the AP/client pairs in the home and office environments
- Measure and compare video prioritization performance of the AP/routers
- Measure throughput performance of the Gigabit Ethernet AP/routers between the WAN and the LAN ports.
- Analyze the competitive performance of the products from different vendors
- Analyze differences in performance among the 2x2, 2x3 and 3x3 MIMO configurations

Throughput Test Set-up

Test configuration (figure 3) consisted of 3 Chariot endpoints passing bi-directional traffic between the wireless client under test and the AP under test. Since the 802.11n specification is capable of topping the 100 Mbps TCP/IP throughput rates of the Fast Ethernet port, two wired endpoints on the Ethernet ports of the AP are necessary to generate enough traffic to saturate the available bandwidth on the WLAN. Three of the AP/routers in the test featured 1000Base-T ports and the rest had 10/100 Base-T ports (table 1).

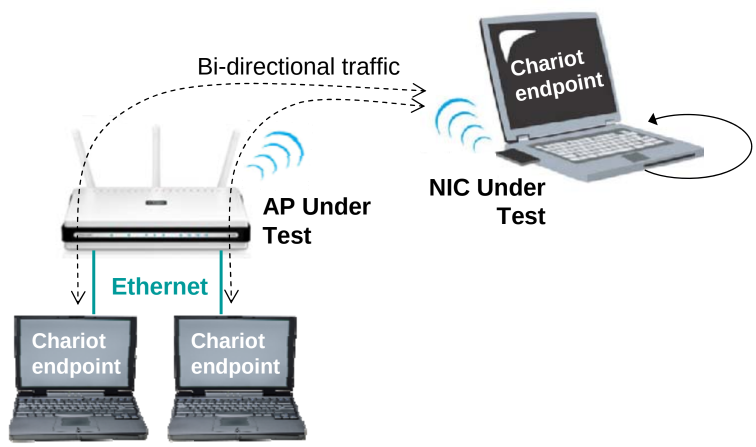

Figure 3: *Throughput test setup – bidirectional traffic was sent among the three Chariot endpoints. The two stations on the Ethernet ports generated sufficient combined traffic to saturate the available wireless bandwidth.*

To account for throughput variation due to antenna orientation, the measurements were performed at 4 client-to-AP orientations: 0º, 90º, 180º and 270º. These 4 measurements were averaged to obtain a single throughput number for each test location.

The AP and the client were placed on plastic carts or on wooden fixtures approximately level with one another. The AP stayed in one place and the client PC was carried to the designated test locations.

Throughput Test Traffic

For the throughput test the Chariot script, throughput_largebuffer.scr with traffic payload size of 65,535 bytes was used. The script ran for 60 seconds or longer. In many cases multiple script runs were recorded and averaged to improve the reliability of the data.

Test Environments

Office testing was performed at 5 locations in an unoccupied office building (figure 4) at increasing distances and through increasing number of walls. The AP under test was kept in one place while the client PC under test was rolled around on a cart.

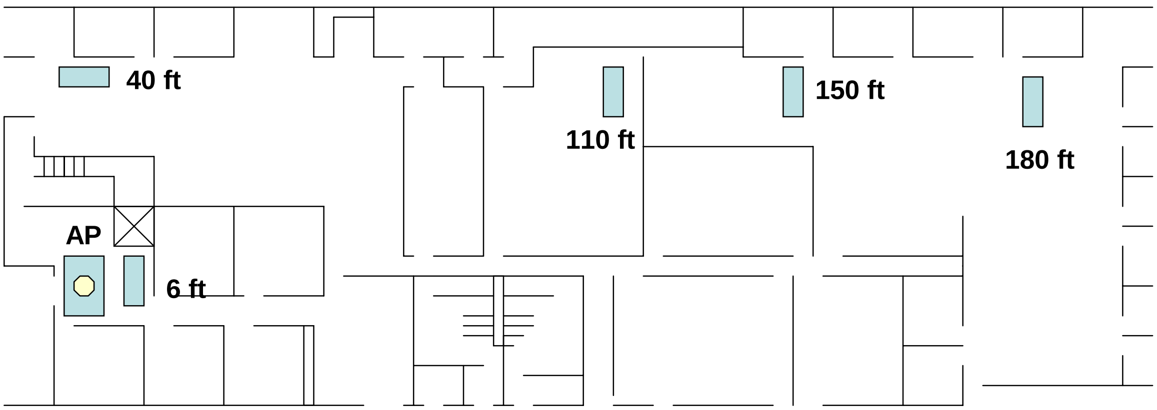

Figure 4: *Office layout showing 5 test locations with progressively increasing range and number of walls between the AP/router and the client*

The home setting (figures 5-7) included 4 locations inside the house and 3 locations outside the house in the woods. The house used for the test represented a challenging fully-furnished environment with the RF signal propagating through inside and outside walls and across floors to its destination. The outdoor environment in the woods also presented some obstructions in the form of trees and a slight downward slope with respect to the AP location.

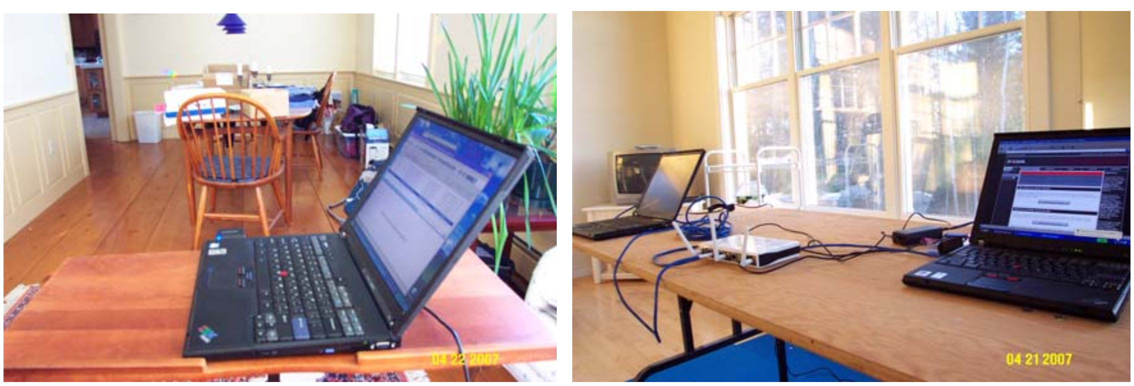

Figure 5: *Home test setting – client under test (left) in the dining room 80 ft away from the AP (right) in the exercise room. The AP signal also went through the window into the woods where the outdoor test locations were set up.*

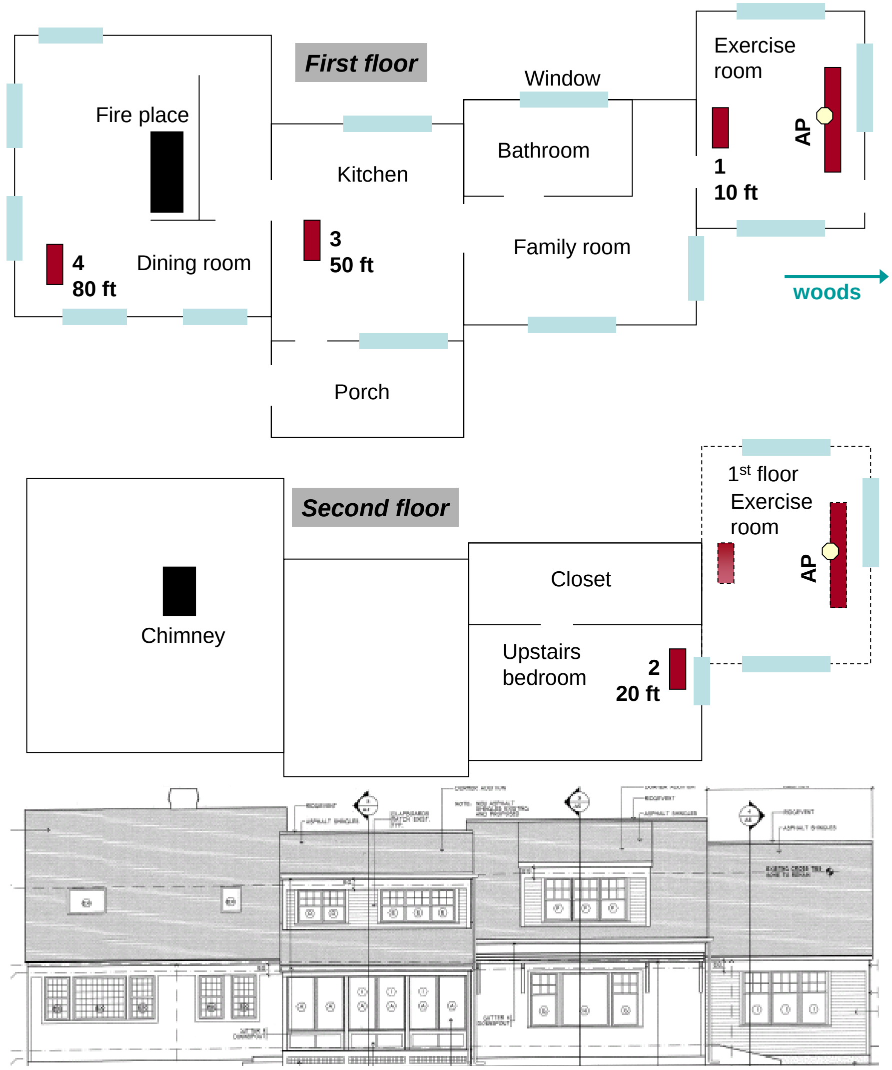

Figure 6: *House layout and test locations on first and second floors*

The AP under test was kept in the exercise room (figure 6) while the client under test was carried around the house and to the outdoor locations in the woods. Similarly to the office test, the measurements were performed at 4 angles: 0º, 90º, 180º and 270º.

In both the home and the office environments, the equipment was placed on plastic carts or wooden fixtures so as not to disturb the antenna field.

Figure 7: *Home setting – outdoors locations. The AP was located behind the window in the exercise room (left) with outdoor locations in the woods (right) slightly downhill from the house. Plastic supports were used with a wooden top to hold the client PC.*

Throughput Test Results

All of the draft 802.11n products exhibited impressive throughput and range performance. At close range, the results were comparable for the home and office environments – at almost 140 Mbps. This level of throughput is clearly competitive with 100Base-T and a major improvement over the legacy 802.11 a,b,g technology (figure 1).

Throughput vs. distance in the office environment (figure 8) was higher than in the home (figure 9). This may be because the sparse office furniture was creating fewer obstructions than the furniture and fixtures in the home.

The Atheros-based devices exhibited the longest range and were providing throughput above 30 Mbps even at 180 ft of operating range and through 7 walls. This level of throughput is more than adequate for an HDTV video stream (table 2) and represents a true breakthrough in the new generation MIMO WLAN technology.

In the home setting, the close range performance was similar to the office environment – approaching 140 Mbps. However, due to a higher number of obstructions such as furniture, bathroom and kitchen fixtures, the throughput of all products dropped off more significantly as a function of distance. Nevertheless, the best-performing products still held up the impressive throughput of around 40 Mbps even at 80 ft and through 4 walls – a significant range for the home and with bandwidth to spare for multiple video streams (table 2).

The measurement data is organized to show all the office graphs together and all the home graphs together (figures 8-9). To help compare the competitive performance of the tested products, the plots are also grouped by MIMO configuration: 3x3, 2x3 and 2x2 (figures 10-13).

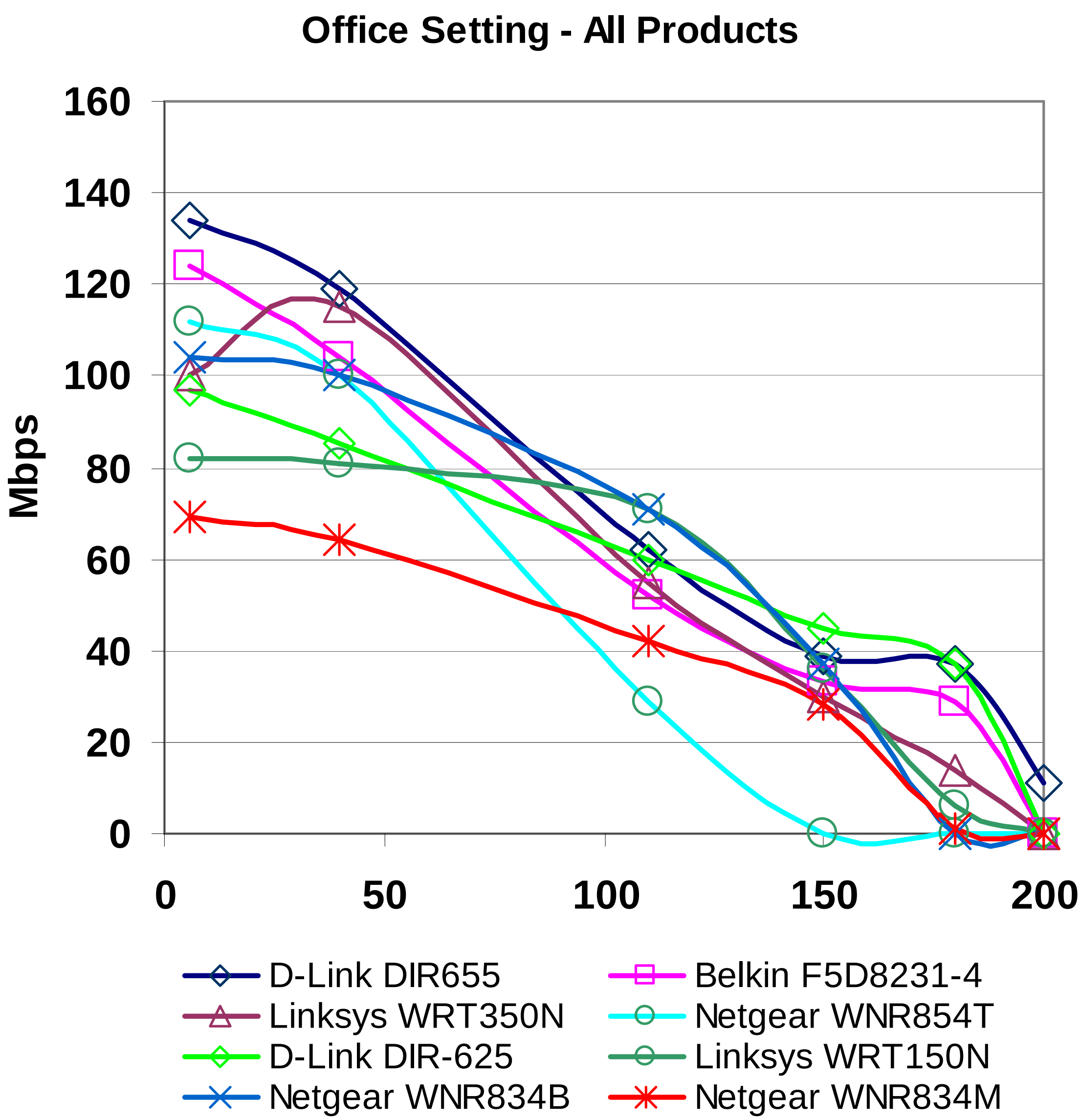

Figure 8: *Throughput vs. range performance in the office environment – nearly 140 Mbps at close range and 80 Mbps at 100 ft with DIR 655 generally in the lead*

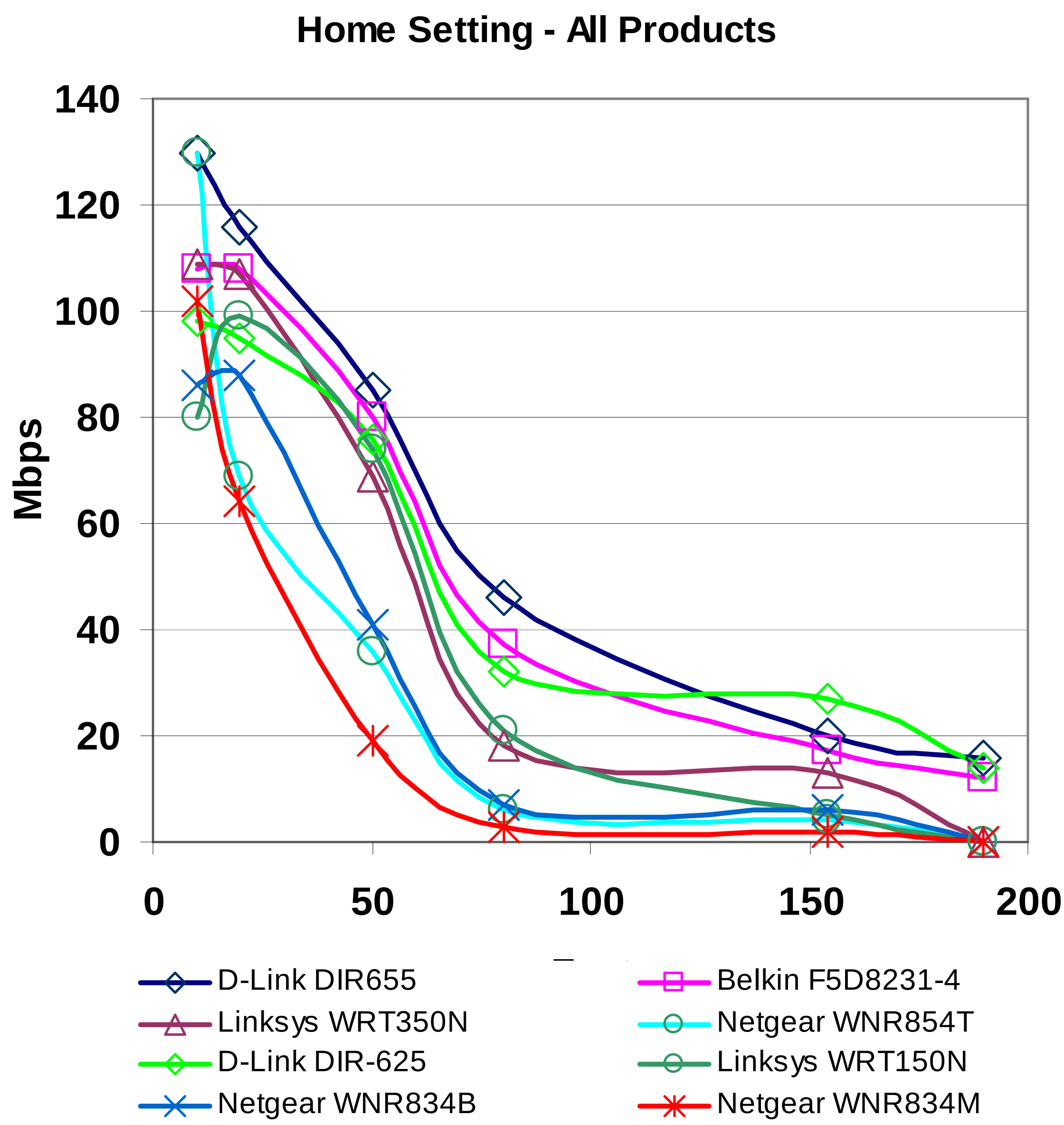

Figure 9: *Throughput vs. range in the home environment dropped off faster than in the office due to more obstructions such as furniture and household fixtures. Even so, D-Link and Belkin equipment exhibited smother roll-off with D-Link throughput of almost 40Mbps at 100ft.*

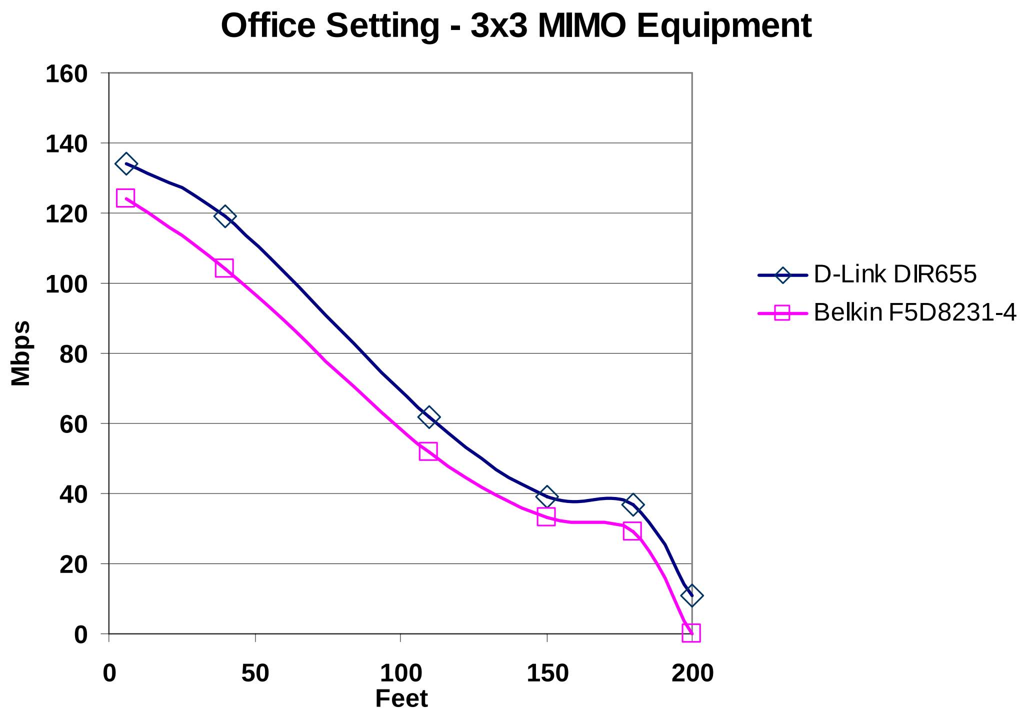

Figure 10: *Throughput vs. range for 3x3 MIMO devices in the office environment*

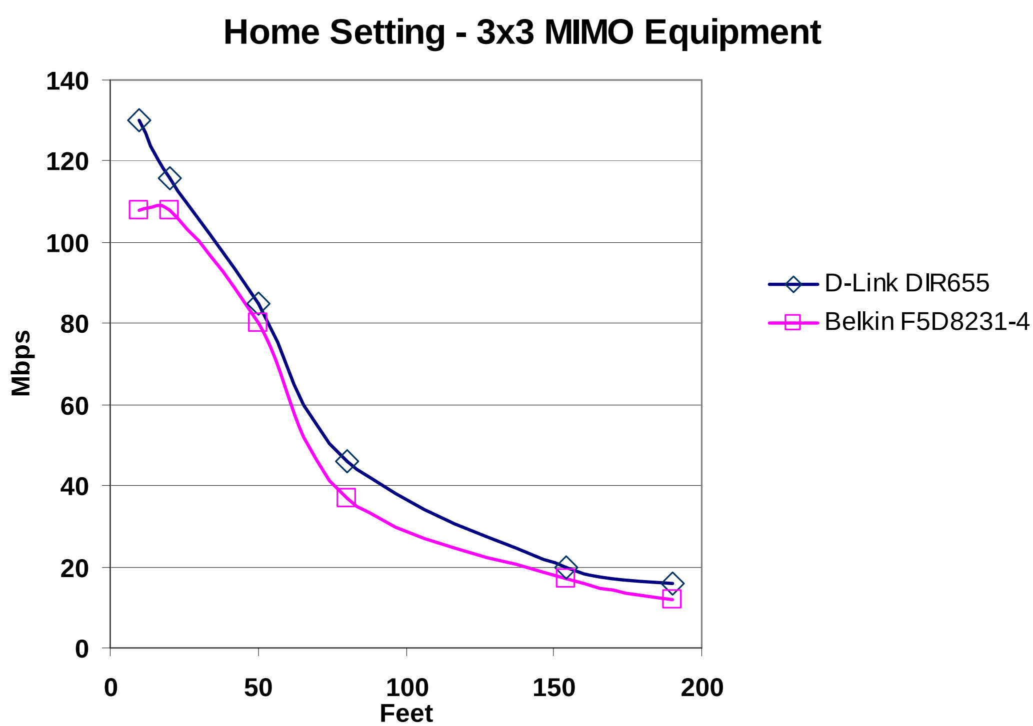

Figure 11: *Throughput vs. range for 3x3 MIMO devices in the home environment*

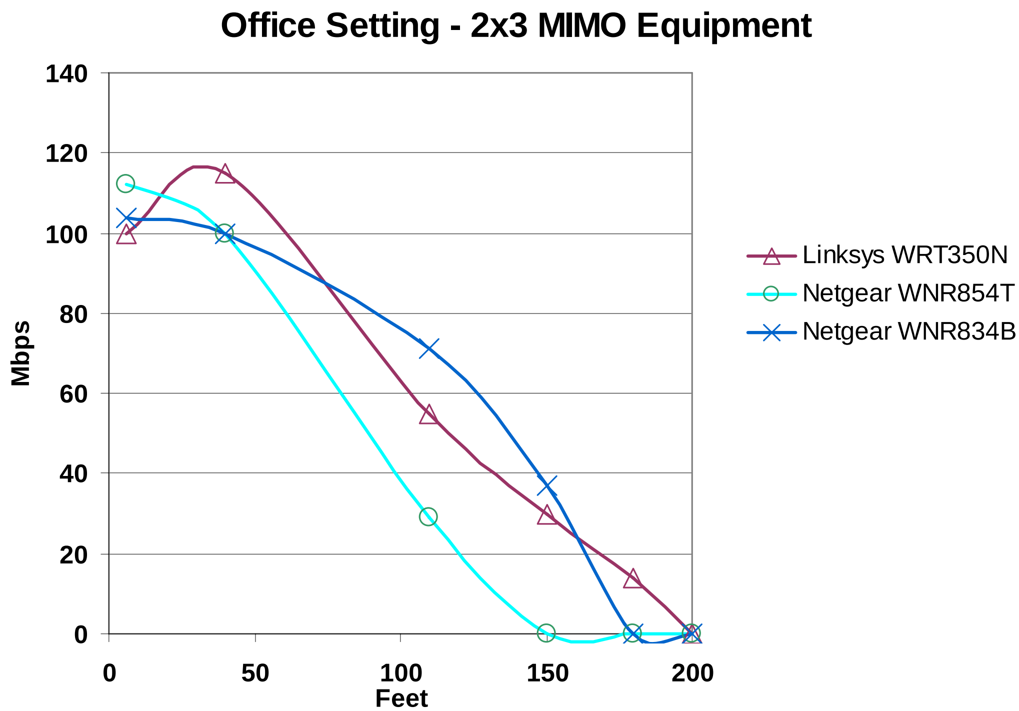

Figure 12: *Throughput vs. range for 2x3 MIMO devices in the home environment*

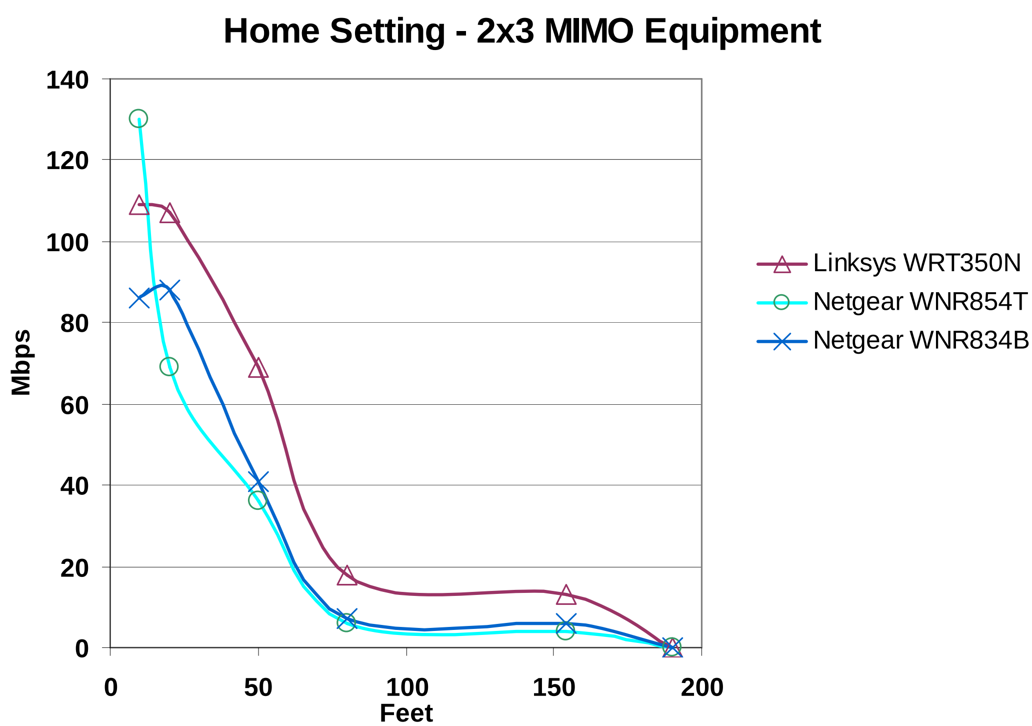

Figure 13: *Throughput vs. range for 2x3 MIMO devices in the home environment*

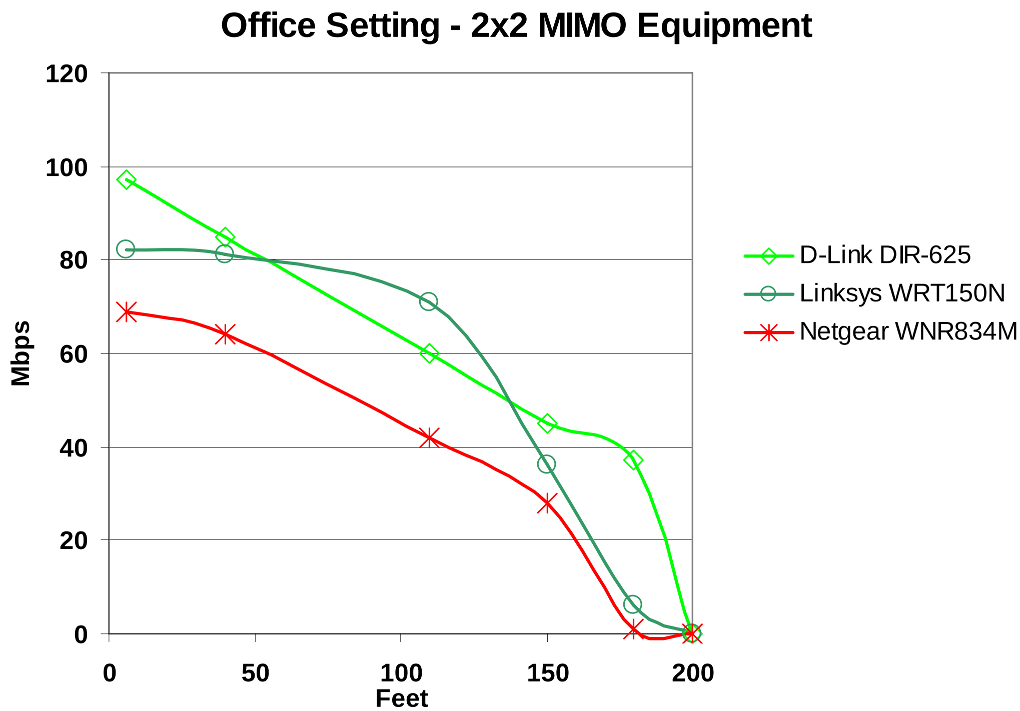

Figure 14: *Throughput vs. range for 2x2 MIMO devices in the office environment*

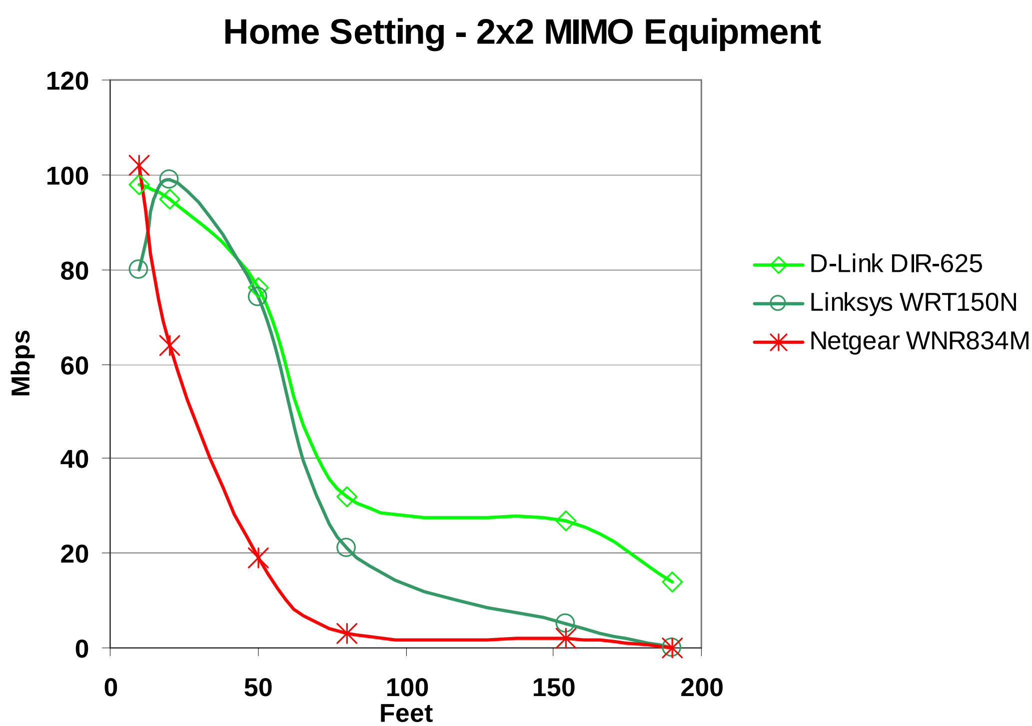

Figure 15: *Throughput vs. range for 2x2 MIMO devices in the home environment*

The measured data reveals that D-Link DIR-655 AP/router is the top performer in its 3x3 class and across the board. The DIR-655 exhibits throughput of nearly 140 Mbps at short range, holds above 60 Mbps at 100 feet and still maintains close to 40 Mbps at 180 feet in the office environment (figure 10). In the home (figure 11) DIR-655 will let you to watch high quality HDTV even at 150 ft since it maintains about 20 Mbps of throughput at that distance (table 2).

Linksys WRT-350 performs best in the 2x3 class. Its throughput peaks just below 120 Mbps in the office and gradually drops to 20 Mbps at around 170 ft (figure 12). In the home, Linksys dropped below 20 Mbps at around 60 feet, so HDTV would be limited to this range.

D-Link DIR-625 tops the 2x2 category in the home and in the office. Its acceptable HDTV range would be about 180 feet in both settings.

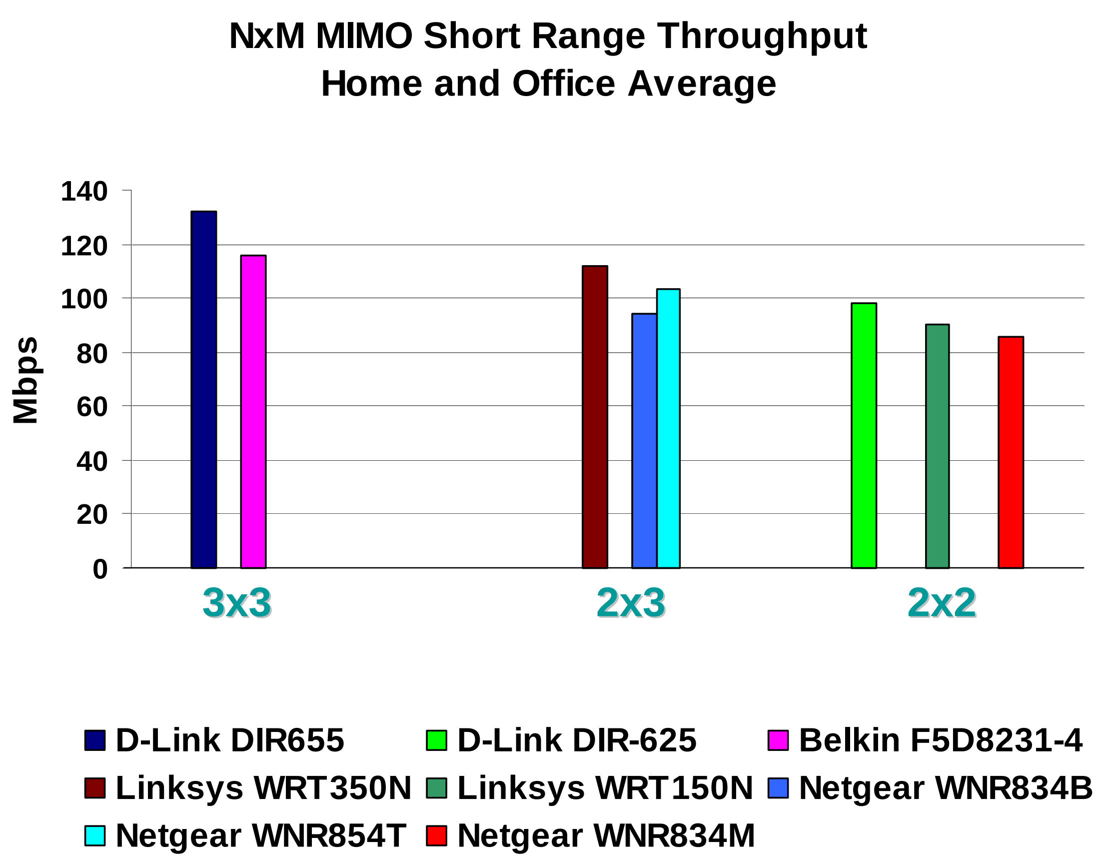

Figure 16: *Short range average throughput organized into NxM groups. The points were obtained by averaging short range measurements in the home and office settings.*

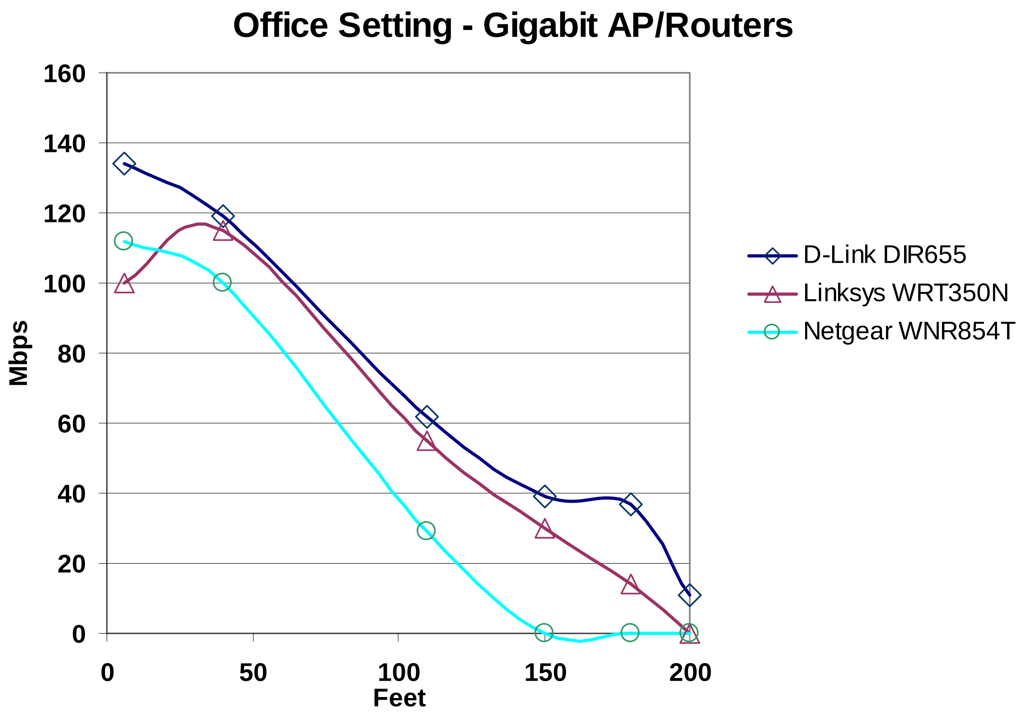

Figure 17: *Gigabit Ethernet AP/routers' performance in the office environment*

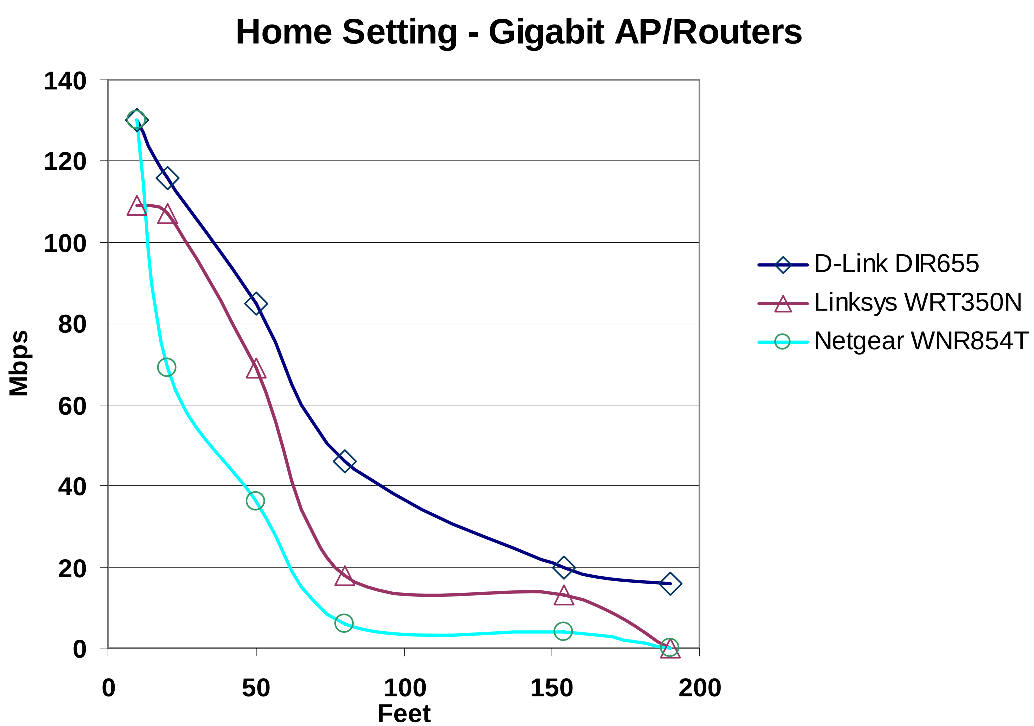

Figure 18: *Gigabit Ethernet AP/routers' performance in the home environment*

Three of the AP/routers in the test featured Gigabit Ethernet ports: D-Link DIR-655, Linksys WRT350N (figures 17-18). Among this group D-Link DIR-655 came in first.

Video Test Results

The video test was designed to demonstrate video prioritization performance of the AP/routers. We selected the three gigabit-capable routers for this test: D-Link DIR-655, Linksys WRT350N and Netgear WNR854T. These routers are high end models recommended by their manufacturers for HD video streaming and all three of them feature Gigabit Ethernet LAN ports with sufficient bandwidth to support a multimedia server sourcing multiple video streams.

The D-Link DIR-655 AP/router employs a proprietary QoS algorithm called Wireless Internet Stream Handling (WISH). WISH is implemented at the MAC layer alongside WMM[3] and helps enhance video prioritization even when WMM is not used.

Video and background traffic was sent from two PCs connected to the Ethernet side of the router under test (figure 19).

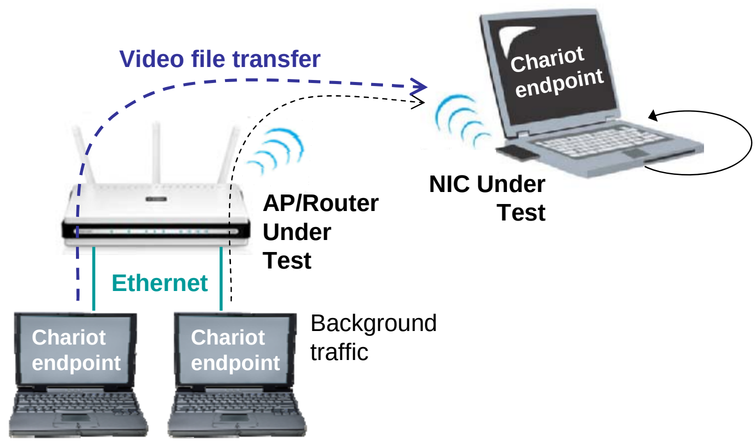

Figure 19: *Video test setup – downstream traffic sent to the client to emulate the video stream from a video server that would typically be on the wired Ethernet network. The second Chariot endpoint on the Ethernet sent downstream background traffic.*

The traffic was sent in the downstream direction to emulate a typical video transmission scenario where video may be streamed from a central server, such as Microsoft Home Server, to TV sets or set-top boxes throughout the house.

The test traffic was as follows. An http MPEG-2 video stream (137 MB file) was repeatedly sent from one of the Ethernet PCs and background traffic (throughput.scr) was

[3] WMM – Wireless Multi Media – the Wi-Fi Alliance QoS protocol that assigns different priorities to voice, video, background and best effort traffic.

sent from the other. The combined traffic from these PCs exceeded the available bandwidth on the Gigabit Ethernet side and on the WLAN side of the AP/router, requiring the router to select what traffic gets priority.

Prioritizing video traffic over background traffic is a key function of a WLAN router since video quality directly depends on the available throughput (table 2). For example, a 1080 progressive scan MPEG-2 HDTV stream that is refreshed at 30 frames per second requires 20 Mbps of throughput for good quality of video.

Table 2: *Video bandwidth requirements for common video formats and displays*

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 2	5 Mbps	12 Mbps

The throughput on the video transfer was measured and reported separately from the throughput on the background transfer to determine whether video traffic was allocated a larger percentage of the available bandwidth than background traffic.

The results reveal how effective D-Link DIR-655 is at prioritizing video traffic with respect to competing products from Linksys and Netgear (figure 20).

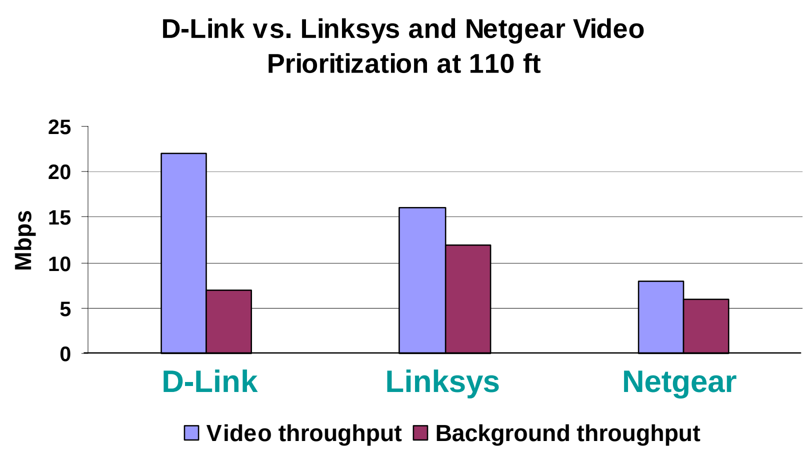

Figure 20: *Video throughput comparison of the AP/routers. The D-Link router provides sufficient throughput for an MPEG-2 HDTV stream even at 110 ft and through 5 walls. The competing Linksys and Netgear products would not support an MPEG-2 HDTV stream at this range.*

The D-Link WISH algorithm is also shown to be very effective, allocating 100% more bandwidth to video traffic than to background traffic over a variety of physical layer conditions (figure 21).

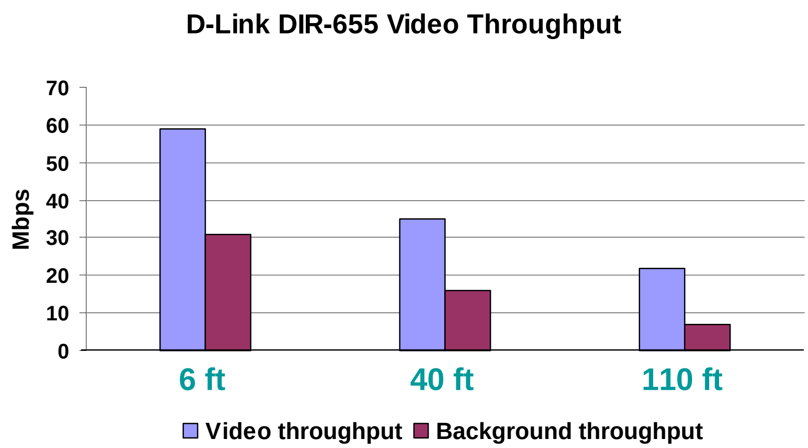

Figure 21: *Video throughput of D-Link DIR-655 AP/router as a function of range. As total available throughput decreases with distance, video traffic maintains proportionally more bandwidth than background traffic. Even at 110 ft there is still sufficient video throughput for an MPEG2 HDTV stream.*

The higher average throughput of video traffic can be seen on the time plots below (figures 22-24).

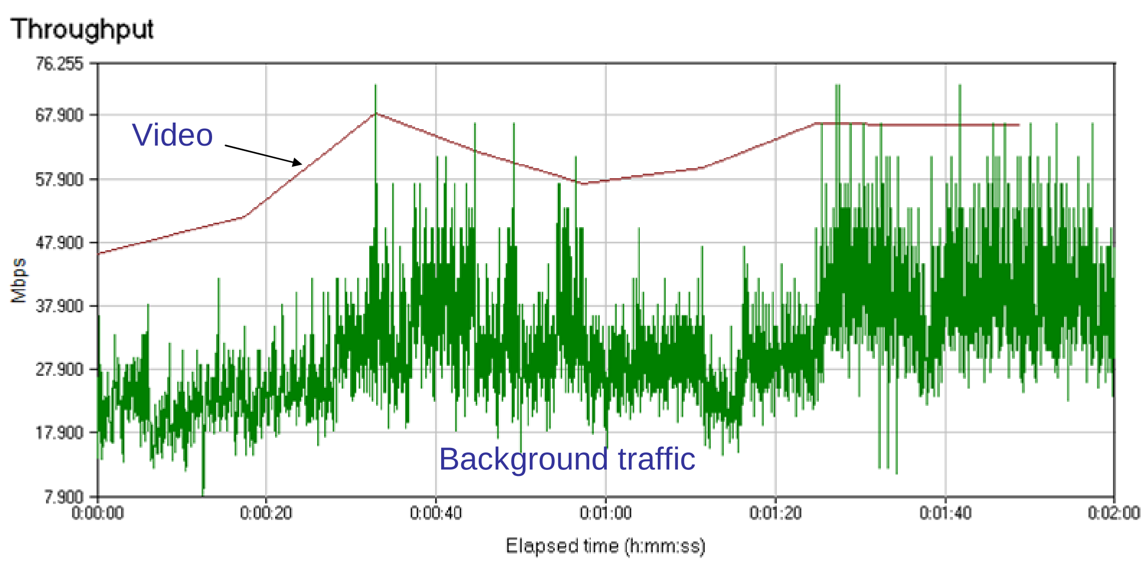

Figure 22: *D-Link DIR-655 AP/router at 6 ft*

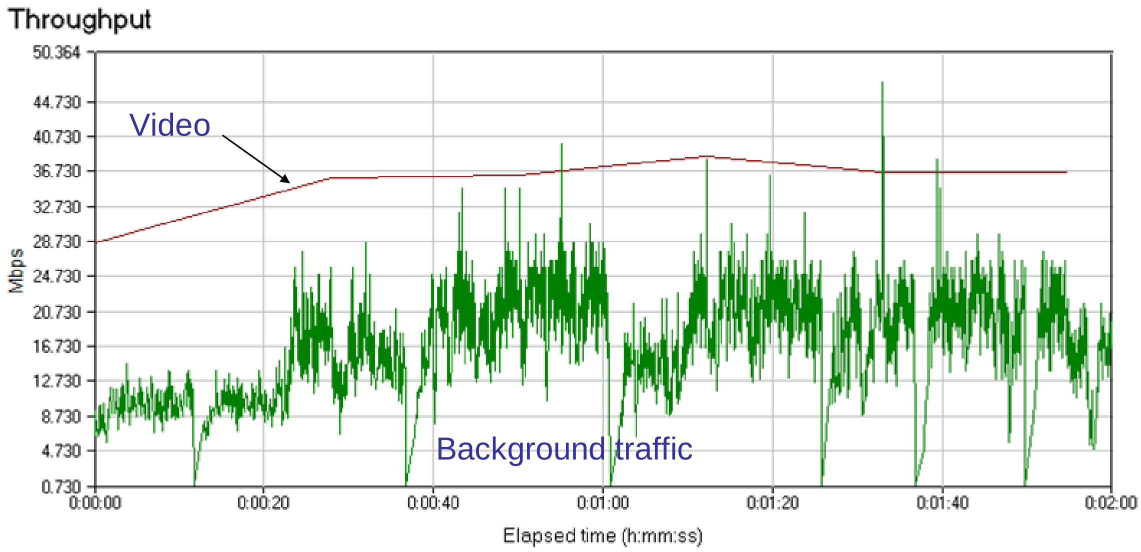

Figure 23: *D-Link DIR-655 AP/router at 40 ft*

Figure 24: *D-Link DIR-655 AP/router at 110 ft – still sufficient throughput for an MPEG-2 HDTV stream*

Linksys WRT350N and Netgear WNR854T AP/routers offer no specialized prioritization for the video traffic and as a result the video throughput deteriorates proportionally to background traffic over distance as total available throughput diminishes (figures 25-26).

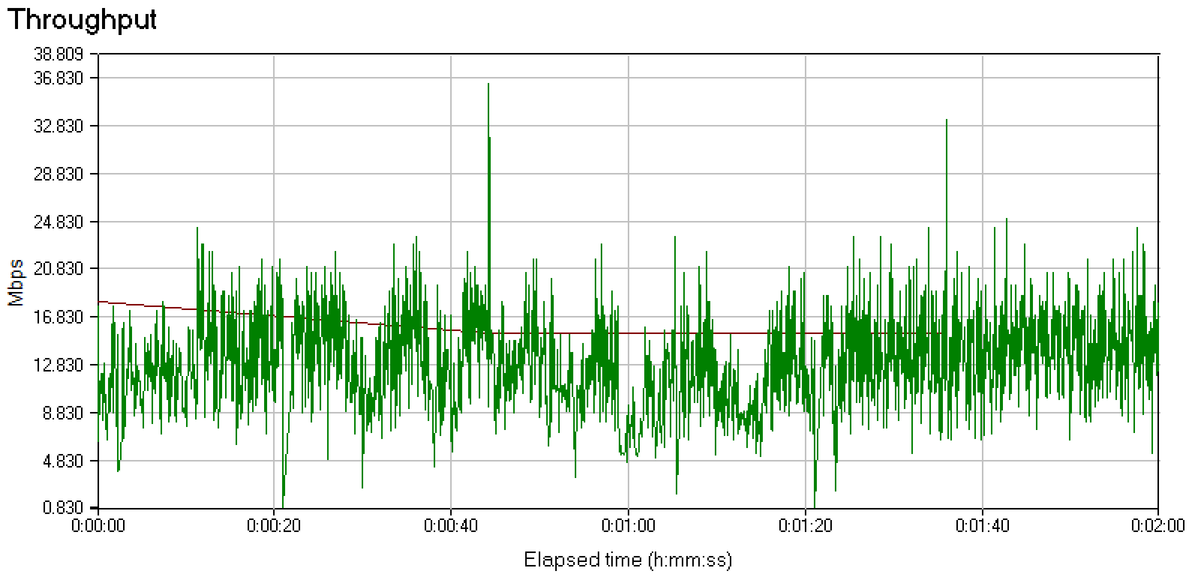

Figure 25: *Performance of the Linksys WRT350N AP/router at 110 ft – video throughput is at the same average level as the throughput of background traffic and video bandwidth is insufficient for transporting an MPEG-2 HDTV stream.*

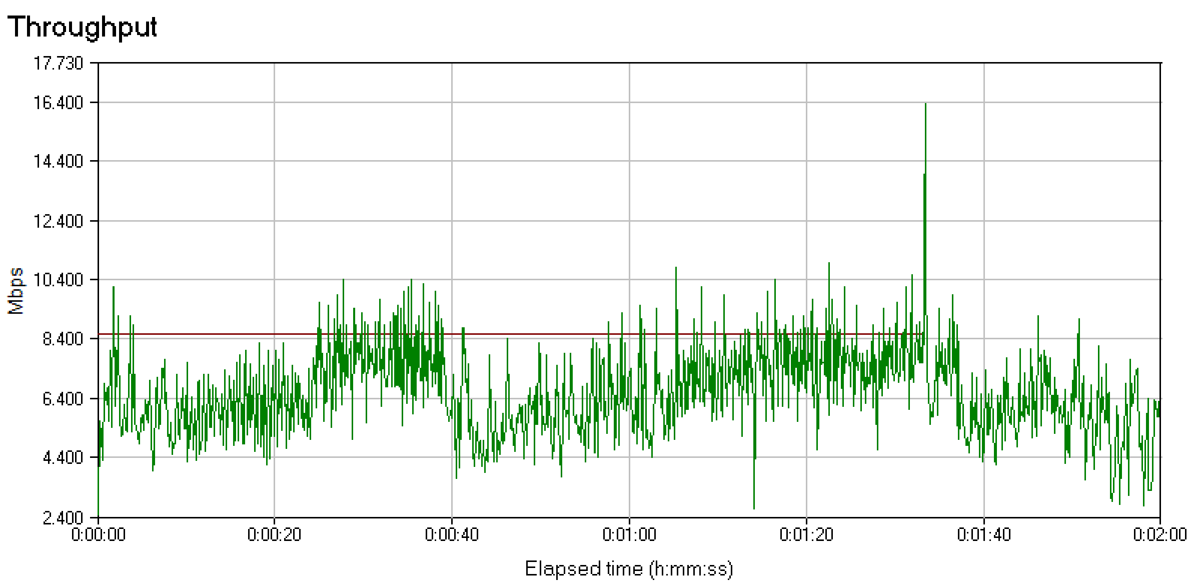

Figure 26: *Netgear WNR854T AP/router at 110 ft. Netgear does not prioritize video traffic and, thus, provides insufficient throughput for MPEG-2 HDTV at this range.*

Router test

The router test setup consisted of 2 Chariot endpoints – one connected at the LAN Gigabit Ethernet ports of the router and the other connected at the WAN Ethernet port (figure 27). The Chariot throughput.scr script was used to measure throughput between the two ports.

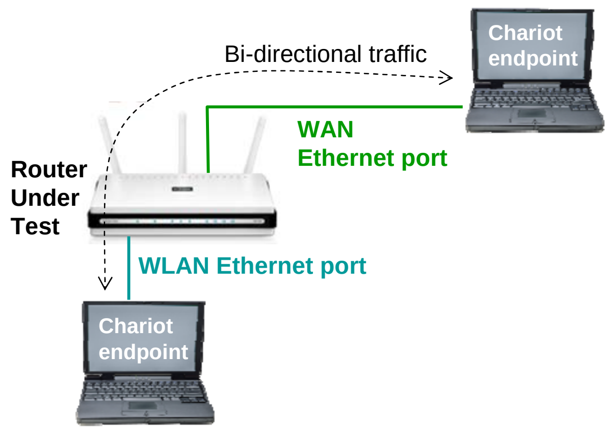

Figure 27: *Router test configuration – bidirectional traffic was sent between two PCs, one on the WLAN side of the AP/router, the other on the WAN side.*

The measurement results are summarized in table 3.

Table 3: *Throughput performance of Gigabit Ethernet AP/routers*

	Mbps
D-Link DIR-655	298
Linksys WRT-350N	200
Netgear WNR854T	102

The D-Link DIR-655 can route bi-directional TCP/IP packets at ~300 Mbps while performing Network Address Translation (NAT) and Stateful Packet Inspection (SPI). This high performance layer 3 routing is done by the Ubicom network processor integrated into the DIR-655.

Especially in Asia where deployment of fiber to the curb is becoming mainstream, 100Mbps+ throughput on the WAN is common and such high routing performance makes a big difference in the total application bandwidth available on the LAN.

Summary and Conclusions

This test, performed on draft 802.11n equipment, reveals more than 5x improvement in throughput with respect to the legacy 802.11a,b,g technology. The short range throughput was measured at nearly 140 Mbps for 3x3 devices, at around 110 Mbps for 2x3 devices and close to 100 Mbps for 2x2 devices.

Throughput measured in the office and in the home environments demonstrates that draft 802.11n equipment is competitive with the throughput of 100Base-T in a typical office or home setting.

Draft 11n equipment tested is well suited for video distribution in the home and can carry multiple video streams to WLAN-enabled displays and set-top boxes with comfortable coverage of a typical house. The WISH video prioritization algorithm implemented by the D-Link DIR-655 router further improves video quality and range by doubling the proportion of bandwidth allocated to video.

The impressive routing performance of the DIR-655 demonstrates that the Ubicom processor used in this product is number one in Gigabit-11n routing.

Among the products tested, the D-link DIR-655 with Atheros chipset came in first in its class of 3x3 MIMO and first in overall throughput, range and video performance. Linksys WRT350N was first in the 2x3 class and D-link DIR-625 was first in the 2x2 class.