



White Paper

802.11 Wireless LAN Performance

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Introduction

This white paper compares the performance of a variety of widely available 802.11 retail products (with the latest drivers as of March 21, 2003), and shows that **Atheros-based 802.11a, 802.11b, and 802.11g solutions significantly outperform the competition in both range and throughput.**

Comparisons between the IEEE 802.11a, 802.11b and draft 802.11g wireless LAN standards are a continuing source of debate as new products enter the marketplace at a rapid pace. 802.11a and 802.11g are accepted as having higher throughput compared to 802.11b because they use orthogonal frequency division multiplexing (OFDM) modulation instead of complementary code keying (CCK). The maximum achievable TCP and UDP throughputs for these three standards are listed in [Table 1-1](#).

Table 1-1. Theoretical Maximum Application-level Throughput

	Number of Non-Interfering Channels	Modulation	Maximum Link Rate	Theoretical Maximum TCP Rate	Theoretical Maximum UDP Rate
802.11b	3	CCK	11 Mbps	5.9 Mbps	7.1 Mbps
802.11g (with 802.11b)	3	OFDM/CCK	54 Mbps	14.4 Mbps	19.5 Mbps
802.11g (11g-only mode)	3	OFDM/CCK	54 Mbps	24.4 Mbps	30.5 Mbps
802.11a	19 ¹	OFDM	54 Mbps	24.4 Mbps	30.5 Mbps
802.11a Atheros Turbo Mode™	6	OFDM	108 Mbps	42.9 Mbps	54.8 Mbps

¹ 13 non-overlapping channels in the United States and up to 19 non-overlapping channels in Europe depending on local regulations.

The entries in [Table 1-1](#) are calculated using 1500 byte packets, encryption enabled, default 802.11 MAC configurations, zero packet errors, and maximum available channel bandwidth (i.e., operating at close range). Two different rates are shown for 802.11g because when 802.11b and 802.11g devices operate on the same network, every 802.11g OFDM packet needs to be preceded by an RTS-CTS or CTS packet exchange that can be recognized by the legacy 802.11b devices. This additional overhead causes the maximum 802.11g throughput

to be reduced significantly. If CTS 802.11b protection is used, 802.11g TCP throughput drops from 24.4 Mbps to 14.4 Mbps, and if RTS-CTS 802.11b protection is used instead of CTS-only, then the 802.11g maximum TCP throughput drops further to 11.8 Mbps. If there are no 802.11b devices connected, or if connections to all 802.11b devices are denied so that 802.11g devices can operate in 11g-only mode, then 802.11g throughput should match the standard throughput of 802.11a. This means that **802.11g may provide either high throughput like 802.11a or 802.11b compatibility, but not both at the same time.** 802.11a, on the other hand, offers both high throughput and high capacity. 802.11a greatly simplifies the deployment tasks for avoiding co-channel interference compared to 802.11b and 802.11g because there are up to 19 non-interfering channels in the 5 GHz frequency band compared with only 3 non-interfering channels in the 2.4 GHz band. Additionally, some 802.11a devices even support a Turbo mode that doubles the link rate to 108 Mbps.

Even though the maximum throughput, or data rate, may be attainable at relatively short distances with well-engineered WLAN products, actual performance will decrease as the distance between wireless stations is increased. A common misconception about radio performance and distance is that higher frequencies don't propagate as well as lower frequencies. As a good counter example to this misconception, however, consider visible light which is simply ultra-high frequency electromagnetic radiation that propagates perfectly well across large distances. Many factors that actually do affect radio range and performance, on the other hand, include antenna efficiency, RF component performance, and absorption through and scattering around objects. While these factors do depend upon frequency, the actual differences between operating performance at 2.4 GHz or 5 GHz are small compared to differences between radio design in areas such as signal-processing algorithms, RF component capabilities, and the amount of electrical noise generated within RF electronics. For example, an 802.11a system with high signal integrity will likely have superior range, coverage, and performance compared with an 802.11b or 802.11g design with weaker signal integrity.

Environmental variables also have an impact on range and throughput:

- Outdoor: typically a direct line of sight between the access point (AP) and the client station. Examples include outdoor campus coverage, public areas, or even large, open buildings like airport concourses or convention halls.
- Open office: no longer a direct line of sight between the AP and the client station, but typically with at most two or three obstructions (such as walls). Examples are buildings with open areas such as offices occupied by cubicles, lobbies, meeting areas or warehouses.
- Closed office or home: no direct line of sight between the AP and the station with many obstructions. Examples are buildings with regular offices or residential homes.

In these different environments the total coverage range will be significantly different. The outdoor environments will provide the longest ranges and the closed office environments will provide the shortest ranges. In general, the relative performance and throughput for different products under test should be similar across the different environments. So if Vendor #1's product is significantly better than Vendor #2's in an open office environment, it is highly likely, although not guaranteed, that Vendor #1's product will perform better in other environments as well. In this white paper, we will present measured data of 802.11a, 802.11b, and pre-802.11g WLAN products in the open office and home environments.

Test Setup and Procedure

The setup for testing 802.11a products is depicted in [Figure 1-1](#). In this setup, two generations of products were tested: products using Atheros' first-generation 802.11a chipsets (examples include the SMC® EZ Connect™¹ 802.11a and the Intel® PRO/Wireless 5000) and products using Atheros' second-generation AR5001 chipsets, which are used in all currently shipping 802.11a/b retail PC cards and embedded Mini PCI cards solutions in laptops. The performance comparison between products based on Atheros' first-generation chipset and products based on Atheros' second-generation chipset was performed using the following setup:

- 802.11a testing was conducted on channel 60 (5.300 GHz):
 - Atheros' first-generation chipset: Intel PRO/Wireless LAN 5000 AP (WSAB5000AM) was tested with an Intel PRO/Wireless LAN 5000 PC Card (WCB5000AM) as the station.
 - Atheros' second-generation chipset: NETGEAR® Dual Band AP² (WAB102) was tested with a NETGEAR Dual Band PC Card (WAB501) as the station in 802.11a mode.



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Figure 1-1. 802.11a Test Setup

1. SMC is a registered trademark of SMC Networks and EZ Connect is a trademark of SMC Networks.
2. The NETGEAR Dual BAnd AP uses Atheros' second-generation chipset for 802.11a and RFMD/Atmel chipset for 802.11b.

The test setup for 802.11b products is depicted in [Figure 1-2](#). In this setup, three station products were tested using the Cisco® AP1200 Access Point:

- 802.11b testing was conducted on channel 1 (2.412 GHz):
 - A NETGEAR Dual-Band Wireless Adapter card (based on Atheros' second-generation dual-band 802.11a/b chipset) in 802.11b mode was tested with a Cisco AP1200.
 - An Intel PRO/Wireless 2011B LAN PC Card (based on the Intersil¹ chipset) was tested with a Cisco AP1200.
 - A Pre-11g Retail PC Card #1 in 802.11b mode (based on the Broadcom² chipset) was tested with a Cisco AP1200.

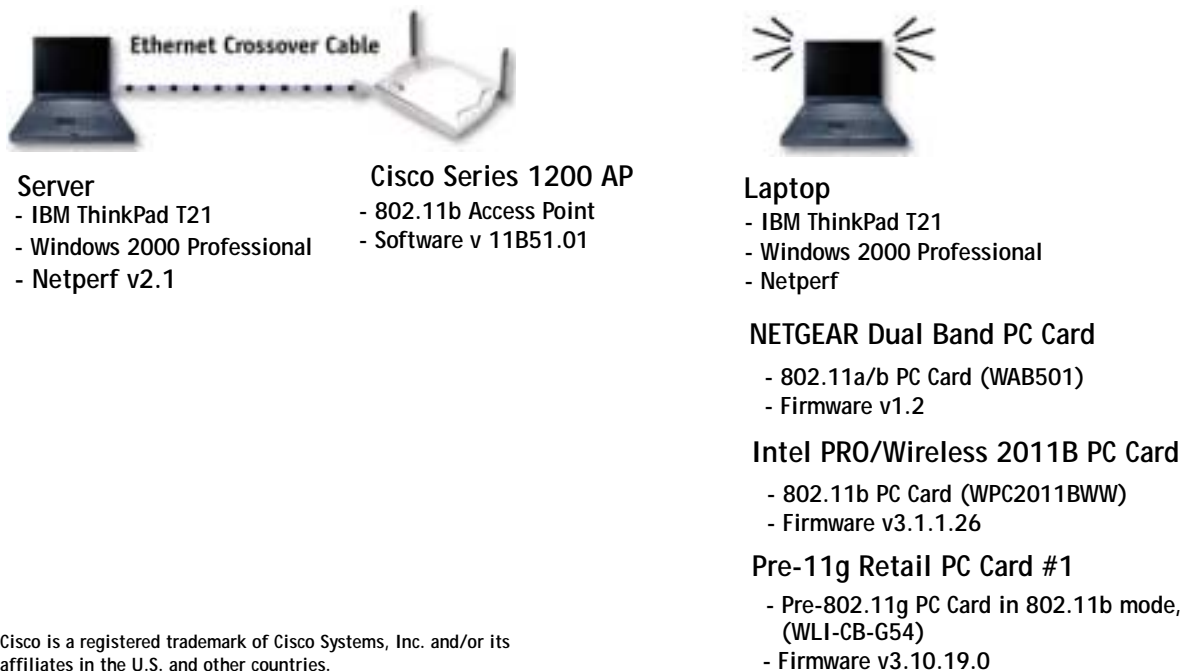


Figure 1-2. 802.11b Test Setup

Since IEEE 802.11g compliant products are not yet shipping, five commercially available products were used to assess the performance of pre-11g products: three are based on the Broadcom pre-11g WLAN chipset and two are based on the Intersil pre-11g WLAN chipset³. An Atheros pre-11g Reference Design was also included in the testing for comparison purposes. Prior to testing, each pre-11g product was upgraded to the latest

1. Intersil is a registered trademark of Intersil Americas Inc, and its subsidiaries.
2. Broadcom is a registered trademark of Broadcom Corporation and/or its subsidiaries.
3. Several of the products in this list are rolling to Atheros silicon in the near future. Performance measurements will be updated once these products are available in the retail channel.

firmware available from the vendor's web site. The test setup for these pre-11g products is depicted in [Figure 1-3](#) and listed as follows:

- Pre-11g testing was conducted on channel 6 (2.437 GHz):
 - Pre-11g Retail AP #1 was tested with a Pre-11g Retail PC Card #1
 - Pre-11g Retail AP #2 was tested with a Pre-11g Retail PC Card #2
 - Pre-11g Retail AP #3 was tested with a Pre-11g Retail PC Card #3
 - Pre-11g Retail AP #4 was tested with a Pre-11g Retail PC Card #4
 - Pre-11g Retail AP #5 was tested with a Pre-11g Retail PC Card #5
 - Pre-11g Atheros AP Reference Design was tested with a pre-11g Atheros PC Card Reference Design



Server

- IBM ThinkPad T21
- Windows 2000 Professional
- Netperf v2.1

Pre-11g Retail AP #1

- Pre-11g Access Point (WBR-G54)
- Firmware v 1.13

Pre-11g Retail AP #2

- Pre-11g Access Point (WRT-G54)
- Firmware v 1.02.1

Pre-11g Retail AP #3

- Pre-11g Access Point (AirPort Extreme)
- Firmware v5.0.1

Pre-11g Retail AP #4

- Pre-11g Access Point (DI-624)
- Firmware v 1.12

Pre-11g Retail AP #5

- Pre-11g Access Point (WG602)
- Firmware v 1.04.01

Pre-11g Atheros AP Reference Design

- Firmware v 2.3.1



Laptop

- IBM ThinkPad T21
- Windows 2000 Professional
- Netperf v2.1

Pre-11g Retail PC Card #1

- Pre-802.11g PC Card (WLI-CB-G54)
- Firmware v3.10.39.8

Pre-11g Retail PC Card #2

- Pre-802.11g PC Card (WPC54G)
- Firmware v3.10.39.7

Pre-11g Retail PC Card #3

- Pre-802.11g PC Card (AirPort Extreme)
- Firmware v3.0

Pre-11g Retail PC Card #4

- Pre-802.11g PC Card (DWL-G650)
- Firmware v1.0.5.0

Pre-11g Retail PC Card #5

- Pre-802.11g PC Card (WG511)
- Firmware v1.0.6.0

Pre-11g Atheros PC Card Reference Design

- Software v2.3.1

Figure 1-3. Pre-11g Test Setup

In all tests, only one station and one AP were transmitting over the channel. For the Pre-11g products this means that they were operating at full throughput because no 802.11b devices were present. The same AP location was used for all 802.11a, 802.11b, and pre-11g tests. Each series of tests was done consecutively, minimizing the total elapsed time so as to mitigate any impact from possible environment changes. All tests were conducted using Netperf v2.1, and each Netperf test was run 3 times. The laptop test location was displaced by a few inches between each of the 3 repetitions and then an average was taken to reduce the effects of local RF scattering and fading, thereby improving the accuracy of each measurement. Downlink TCP throughput (from the AP to the station) as a function of distance is presented as the benchmark for performance measurements because this reflects the common user experience of downloading data, such as email or web browsing, over the WLAN network. For a more detailed description of how wireless LAN performance should be measured, please refer to the *Methodology for Testing Wireless LAN Performance* white paper which can be found at <http://www.atheros.com/pt/papers.html>.

Range Performance in Open Office Environments

The first set of range tests was performed in an open office environment with its layout shown in Figure 1-4. In this environment there were both open cubes and closed-door offices. 37 locations were tested, ranging between 6 and 216 feet away from the access point. About two-thirds of the test locations were separated from the access point by a concrete structural wall, and several of the measurements were taken in closed-door offices or conference rooms.

The first test was conducted to compare the performance between the first-generation AR5000 802.11a products and the second-generation AR5001 802.11a products. The data does not smoothly decrease with distance because each test location is subject to significantly different obstructions. For example, point 166 is inside a distant conference room with several concrete walls between the test location and the AP, while point 167 is roughly the same distance away but is in a more open area.

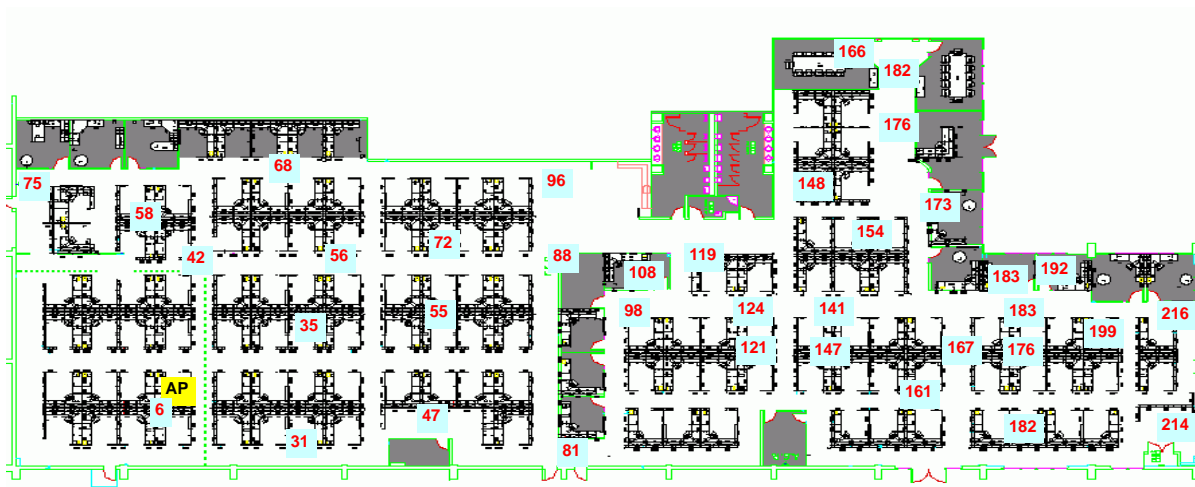


Figure 1-4. Open Office Layout as Test Environment

As shown in [Figure 1-5](#), the product based on Atheros' second generation AR5001X dual-band chipset (NETGEAR Dual-Band) significantly outperforms the product based on Atheros' first-generation AR5000 chipset (Intel PRO/Wireless 5000) in both range and throughput. This test confirms the relatively disappointing 802.11a range data displayed by some of the early products, which were introduced into the market almost two years ago. The improved performance of the second-generation AR5001 product is due to sophisticated enhancements in DSP design and analog performance based on Atheros' extensive experience with its first-generation OFDM products.

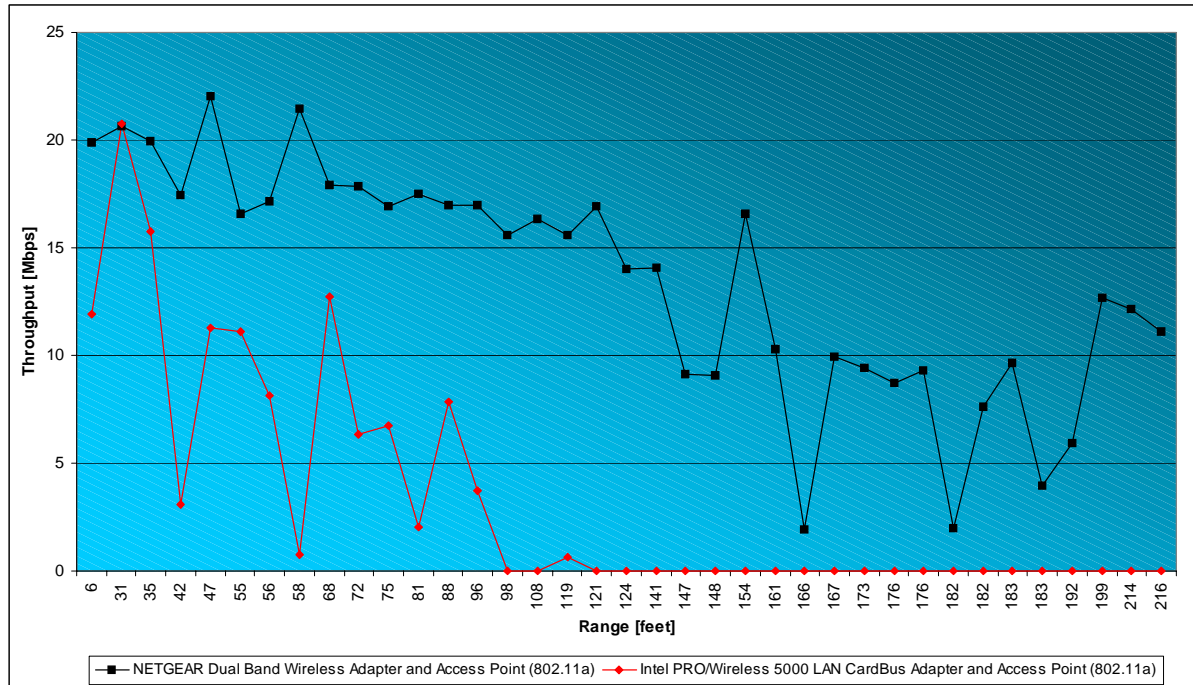


Figure 1-5. Downlink TCP/IP Performance of 802.11a Products

The second test was conducted to compare the performance between various 802.11b products on the market. As shown in Figure 1-6, the product based on Atheros' second-generation AR5001X chipset (NETGEAR Dual-Band) outperformed other 802.11b products in the test.

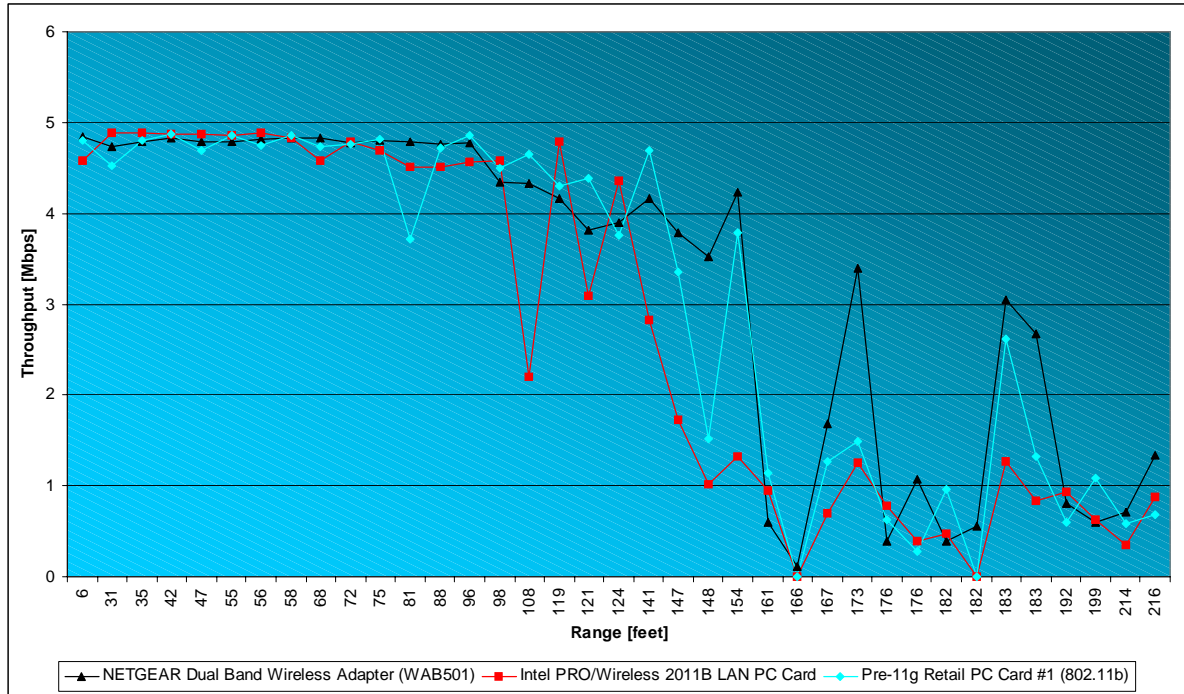


Figure 1-6. Downlink TCP/IP Performance of 802.11b Products

Combining Figure 1-5 and Figure 1-6, as shown in Figure 1-7, it is clear that the performance of second-generation 802.11a products far exceeds that of all 802.11b products, with a throughput advantage on the order of 4-5 times, even at ranges greater than 200 feet. It should also be noted that second-generation 802.11a products were able to connect at all locations in this office environment, whereas all 802.11b products failed to connect at some locations.

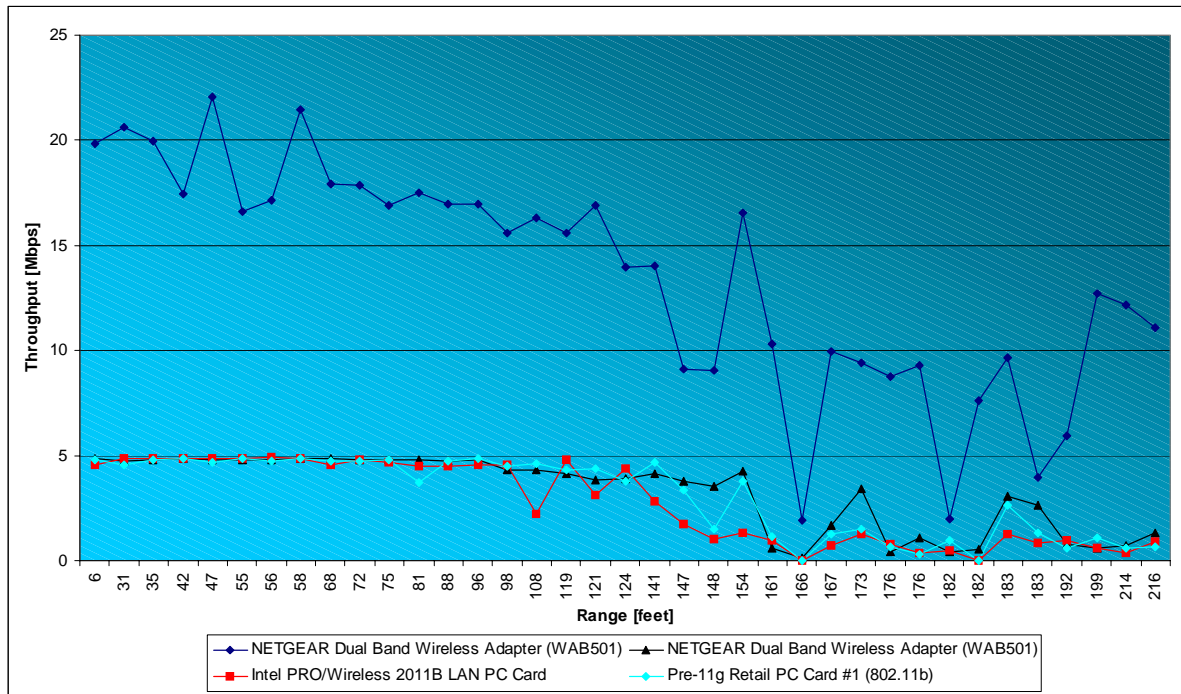


Figure 1-7. Downlink TCP/IP Performance Comparison of 802.11a and 802.11b Products

A comparison of 802.11a, 802.11b, and pre-11g products are shown in Figure 1-8. The pre-11g products were tested without any 802.11b devices in the network, so performance was not degraded by the RTS-CTS or CTS overhead noted in the Introduction. As shown in Figure 1-8, the Atheros-based 802.11a product significantly outperformed all pre-11g products even in the “pure” OFDM mode. Furthermore, Atheros-based pre-11g products significantly outperform the Broadcom and Intersil based pre-11g products in almost all test cases. Most striking is that beyond only approximately 120 feet, most of the non-Atheros pre-11g products do not deliver on the throughput advantage promised by 802.11g—they fell far short of 802.11a performance, and in most cases deliver only 50% of the throughput achieved by 802.11b, while the Atheros pre-11g product maintains the higher OFDM throughput rate.

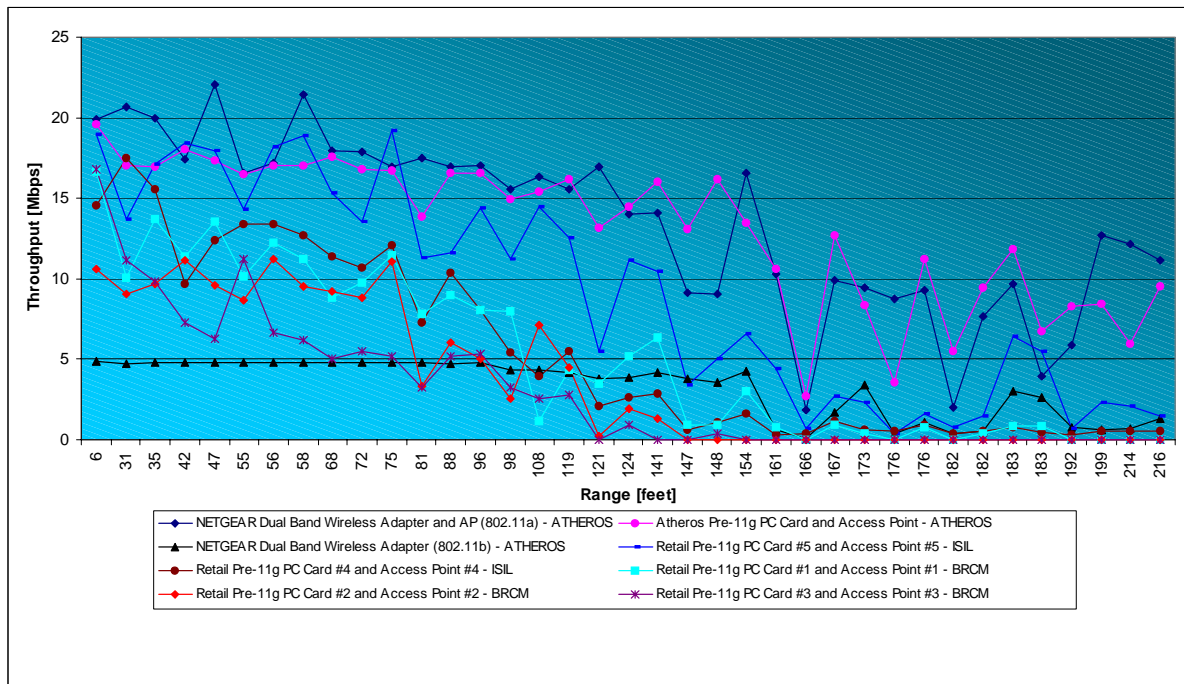


Figure 1-8. Downlink TCP/IP Performance Comparison of 802.11a, 802.11b, and Pre-11g Products

Range Performance in a Home Environment

The second set of range tests were performed in a home environment, as shown in [Figure 1-9](#), with test points located in different rooms across the house and two outside locations.

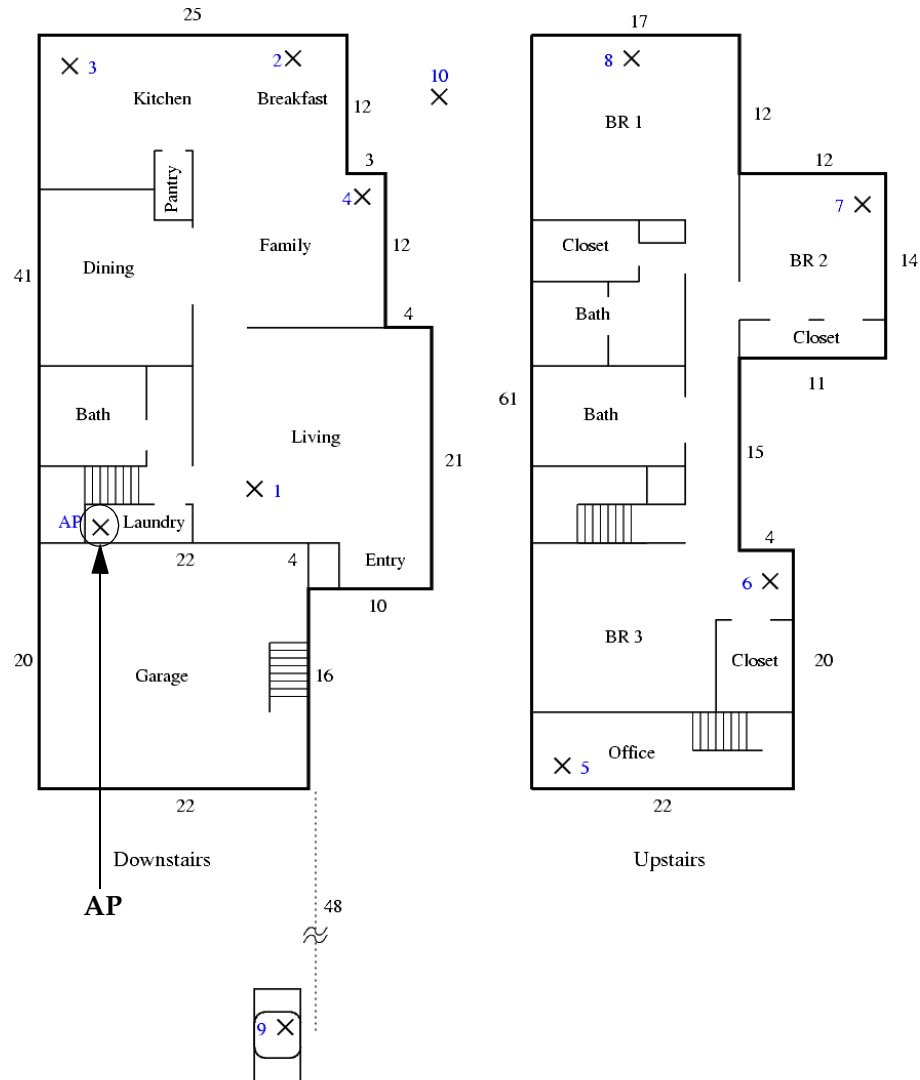


Figure 1-9. Layout of a Home Test Environment

As shown in [Figure 1-10](#), the product based on Atheros' third-generation 802.11a/g chipset significantly outperformed the pre-11g products based on Broadcom and Intersil chipsets. Notice that while three of the pre-11g products barely made a connection to the car (only 68 feet away from the house as indicated in [Figure 1-9](#)), the 802.11a product was able to reach the car with throughput of 15 Mbps and the Atheros pre-11g product maintained a 12-13 Mbps throughput rate. This certainly demonstrates the high-performance RF design and MAC/Baseband processing of the Atheros' dual-band 802.11a/g chipset. While the 802.11g standard holds the potential of delivering both range and throughput in an environment where total capacity is not a concern (i.e., no co-channel interference is present and 3 non-overlapping channels are sufficient), the non-Atheros pre-11g products fall short of delivering on this promise.

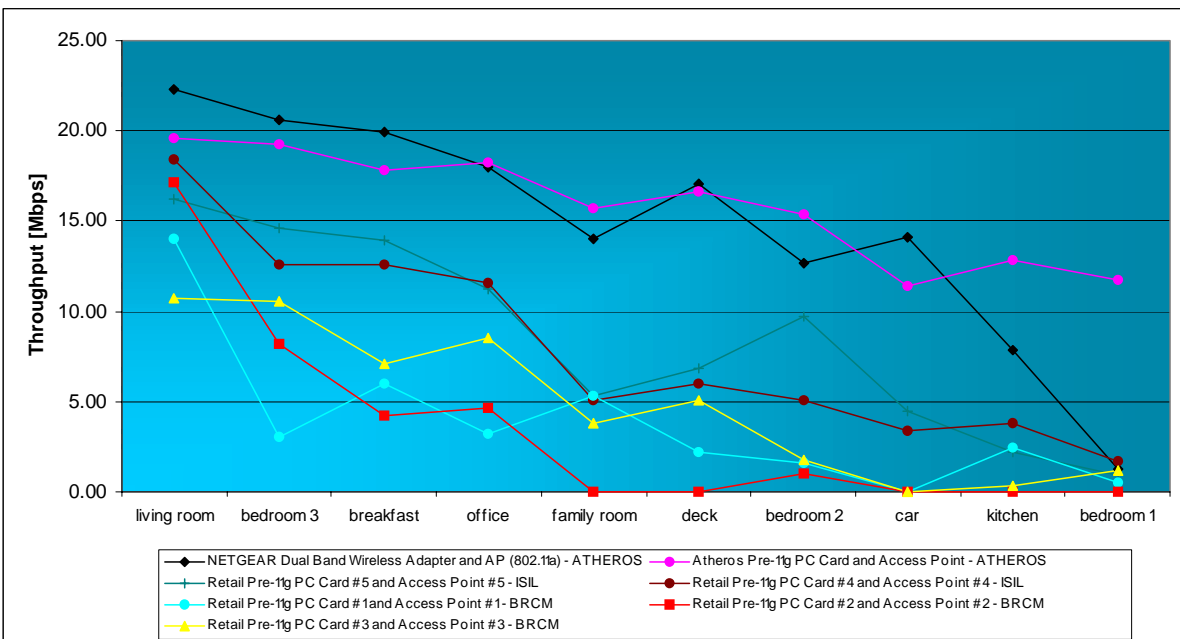


Figure 1-10. Downlink TCP/IP Performance Comparison of 802.11a, 802.11b, and Pre-11g Products

Throughput and range delivered by a wireless LAN product depends on both the standard and the quality of the chipset in the final product. Standards simply specify a minimum requirement for each product to allow interoperability. A superior product needs to exceed almost every specification of the standards, so that the maximum performance can be seen by end users. Unfortunately, the poor performance of many current pre-11g products with silicon from Broadcom and Intersil may prove detrimental to the acceptance of the 802.11g standard.

Future 802.11a/b/g Landscape

From these test results it is clear that the difference between different vendor's chipsets and product implementations far exceeds the difference in radio propagation at 2.4 GHz versus

5 GHz. More importantly, it is clear that **Atheros-based 802.11a, 802.11b, and 802.11g products outperform competitor's solutions**. 802.11g and 802.11a/g products will ultimately be a natural upgrade path from legacy 802.11b products, and although many current pre-11g products from Broadcom and Intersil fall short, the range and throughput performance delivered by Atheros solutions is compelling.

Due to the fact that 802.11g shares the same three non-interfering channels as 802.11b devices, however, 802.11g does not provide a significant increase in total capacity. Therefore, for hotspots, enterprise applications and high capacity home networks, today's widely available dual band 802.11a/b and 802.11a/g products based on Atheros chipsets are the best choice for backward compatibility, high performance and total capacity.

Ultimately, the best industry path is to combine the benefits of 802.11a and 802.11g. Dual band 802.11a/b/g cards are now available for just a few more dollars than 802.11g-only cards. This allows legacy support of 802.11b, higher throughput of 802.11g at 2.4 GHz, and a large number of clean channels and maximum throughput at 5 GHz. Compared to the three distinct channels at 2.4 GHz, dual band 802.11a/b/g cards have access to up to 16 non-overlapping channels in the United States and 22 channels in Europe, providing an aggregate link throughput of up to 1188 Mbps.

NOTE: This document may be updated periodically. Please check <http://www.atheros.com/pt/papers.html> for the latest versions of this and other Atheros white papers.

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