Comparison of Environments on 802.11 Throughput Performance

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***Abstract* – The chaotic nature of the radio frequency medium of 802.11 wireless networks makes it problematic to obtain accurate and precise repetition of performance tests and measurements. Environmental variables that deeply influence link performance must be addressed before throughput testing can be accurately measured across various devices. An RF shielded room with anechoic foam provides the most ideal environment for throughput tests compared to either an RF shielded room without foam or an "open air" laboratory. Location within the RF shielded room with anechoic foam has a negligible effect on performance, but using a rubber mat under a device can reduce reflections, producing an optimal environment for throughput testing.**

Introduction

As 802.11a/b/g wireless devices proliferate in a given environment, it becomes necessary to gauge interference with throughput testing. If the increased use of WLAN devices creates lower or sporadic throughput values, the use of an isolated environment to perform testing in the 2.4 GHz or 5 GHz range would be prudent. Wi-fi pre-certification testing, for example, requires throughput measurements to determine if a station meets the criteria of certain interoperability tests. Lower throughput due to an open-air laboratory setting may incorrectly label a device's performance. Use of an RF shielded room would provide isolation from over-lapping networks in and around the test environment.

During the design of this experiment there was concern that the RF chamber would yield lower throughput values due to increased reflections from the chamber walls. Therefore, a third environment, an RF chamber with material to absorb RF energy, was added. In this environment, five sheets of anechoic foam reduced reflections from the chamber walls. This report references the open-air laboratory setting, RF shielded room, and the RF shielded room with anechoic foam as the open-air environment, RF chamber, and anechoic chamber, respectively.

Equipment

- 8'x16'x8' RF shielded room
- 5 – 4'x4' sheets of anechoic foam
- 2 – 2'x2' sheets of anechoic foam
- Fiber-to-Ethernet converter
- Ethernet Switch
- 15' Category-5 Ethernet cord
- 2 Dell Inspiron 1150 notebook computers
- IxChariot Software server & Endpoint
- IxChariot scripts "filesendl" and "inquiryl"
- Funk Odyssey Server & Odyssey Client
- Broadcom access point (BCM94704GAP)
- Intersil access point (ISL-36356A)
- Intel 802.11a station (2100A3B Mini-PCI)
- Proxim station (8480-ABG)
- Buffalo station (WLI-CB-54A)
- Symbol station (LA-4137)
- Conexant station (ISL39000C)

Environment Analysis

In the open-air setting of the lab, the AP was located approximately 2.5 meters from the stations. It attached to the same network as the Chariot console through a router.

The RF chamber and anechoic chamber were set up as shown in the figure 1. [*Figure 1- Legend: The large open rectangles represent fold-away metal tables, the dark gray rectangles are the small 2'x2' pieces of foam that sat on the table throughout all tests, and the light gray rectangles are the large 4'x4' squares of foam that were in place during the anechoic test.*]

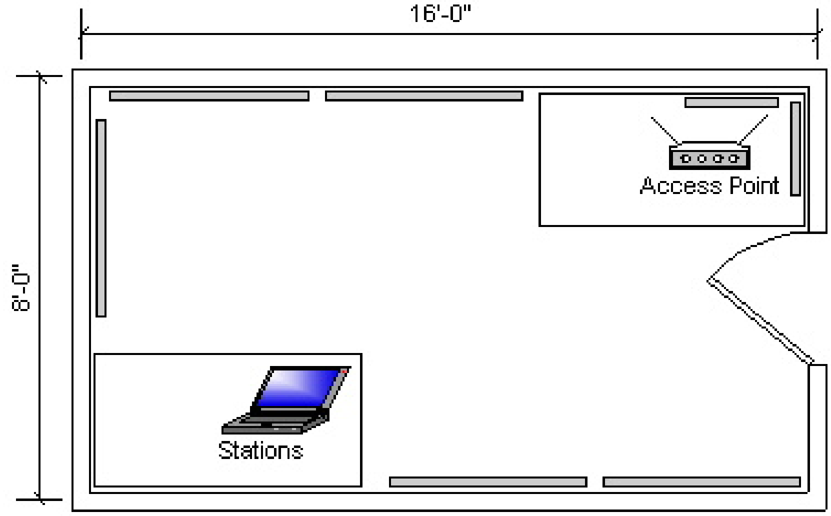

Figure 1 - RF chamber with anechoic foam. Light gray indicates foam placement during the anechoic chamber tests

A fiber optic cable ran through the chamber wall in a copper pipe to allow connection to an external network outside of the chamber while preserving an RF isolated environment. Two fiber-to-Ethernet converters on either side of the chamber wall completed the transition. The AP could then connect to the IxChariot console that was located outside the chamber.

The 2' x 2' pieces of foam were kept in the chamber during the RF chamber tests because the stations would consistently lose their connections when not enough material was present inside the chamber to absorb reflections.

Configuration Settings

The following test procedures, reflecting various configurations, measured the effect of the environment on link performance independent of fragmentation settings, authentication type, and RTS/CTS protection mechanisms. The test channels represent the upper and lower extremes of their band. Test parameter settings for 802.11a testing can be found in Table 2 and Table 3. Parameter settings for 802.11g test runs can be found in Table 4 and Table 5.

For each of the three IxChariot tests, the IxChariot server ran the scripts "filesendl" and "inquiryl". The three tests ran on each connection pair with the IxChariot configurations according to Table 1.
IxChariot configuration for the 802.11bg BG-1 test configuration used a IxChariot client on each laptop with a wireless station.

IxChariot TST 1	
STA 1	Wireless STA
STA 2	IxChariot Server
Script	filesendl

IxChariot TST 2	
STA 1	IxChariot Server
STA 2	Wireless STA
Script	filesendl

IxChariot Test TST 3	
STA 1	Wireless STA
STA 2	IxChariot Server
Script	Inquiryl

Table 1 - IxChariot configurations. Test Configuration #BG-1 uses two 802.11b stations with the IxChariot Console**.**

802.11a Configuration #A-1	
Access Point	Broadcom
RTS Threhold	Off
Fragmentation	Off
Channel	40
Security	WEP
Authentication	Open
Station	Intel
RTS Threshold	Off
Fragmentation	Off
Power Save	Active PS-Poll
Security	WEP
Authentication	Open
Operating System	MS Windows XP SP2

Table 2 – Parameters and values for configuration #A-1.

802.11a Configuration #A-2	
Access Point	Broadcom
RTS Threhold	Off
Fragmentation	Off
Channel	60
Security	WPA-PSK
Authentication	Odyssey Server
Station	Proxim
RTS Threshold	Off
Fragmentation	Off
Power Save	Active
Security	WEP
Authentication	Odyssey Client
Operating System	MS Windows XP SP2

Table 3 – Parameters and values for configuration #A-2.

802.11b/g Configuration #BG-1	
Access Point	Broadcom
RTS Threhold	Off
Fragmentation	Off
Channel	1
Security	None
Authentication	Open
Station	Buffalo & Symbol
RTS Threshold	Off & 256
Fragmentation	Off
Power Save	None
Security	None
Authentication	Open
Operating System	MS Windows XP SP2

Table 4 – Parameters and values for configuration #BG-1.

802.11b/g Configuration #G-2	
Access Point	Broadcom
RTS Threhold	Off
Fragmentation	Off
Channel	9
Security	WPA-PSK
Authentication	Microsoft IIS
Station	Conexant
RTS Threshold	256
Fragmentation	512
Power Save	Active PS-Poll
Security	WPA-PSK
Authentication	MS Client
Operating System	MS Windows XP SP2

Table 5 – Parameters and values for configuration #G-2.

Procedure

All 802.11a tests were completed inside the RF chamber, then in the open-air environment, and finally in the anechoic chamber. While randomization would have helped to further minimize time or user influences, it was not feasible to continually switch locations of all the equipment and bulky anechoic foam.

Stations and AP were approximately 2.5 meters apart inside the RF chamber at the locations shown in Figure 1. The station and AP used configuration

A-1. The sealed RF chamber provided greater than 100 dB at 2.4 GHz – 10 GHz. The IxChariot configurations TST1, TST2, and TST3 ran in a random order a total of five times each from the IxChariot server outside of the chamber. Following the completion and recording of results, test configuration A-2 followed the same procedure.

Then the stations and AP were removed from the RF chamber and positioned in the open-air environment approximately 2.5 meters apart as in the chamber. The 802.11a tests were run in the same fashion as they were executed inside the chamber and the results of the throughput testing recorded.

APs and stations were placed back in the chamber at the same locations as the initial RF chamber tests. Then the RF chamber was lined with the five sheets of anechoic foam. The stations and AP were configured and connected, and the anechoic chamber was sealed for isolation. All the tests were executed in the standard random fashion and their results were recorded.

The 802.11g tests were run in reverse order; the two configurations ran in the anechoic chamber first, followed by the open-air environment, and finally the RF chamber. The stations and AP were positioned in the chamber such that the stations were 0.5 meters apart on one table, and the AP was approximately 2.5 meters away on the other table. They were then configured for the first 802.11g test configuration BG-1, and the tests TST1, TST2, and TST3 were run in random order a total of five times apiece. For this configuration, the chariot scripts had to run on both stations, which required using two pairs on the IxChariot console. The second 802.11g configuration, G-2, ran in the anechoic chamber in the same manner as the first.

The stations and AP were then taken out of the chamber and set up in the open-air environment. The stations were positioned approximately 2.5 meters from the AP and 0.5 meters from each other for test configuration BG-1. The tests were then executed as in the anechoic chamber, except the channel was switched to channel 9 for two test runs in configuration BG-1 because of a sudden drop in throughput on the specified channel caused by other stations in the area using an over-lapping BSS.

The stations and AP were then placed in the RF chamber in the same locations as the anechoic chamber, and the tests were executed in the same fashion as in the anechoic chamber.

802.11a Test Results

The average throughputs for the 802.11a tests did not vary significantly for TST2 and TST3 between environments – all results were within a standard deviation of each other for both configurations. TST1, however, showed that the RF chamber environment yielded considerably lower throughput. The lab and the anechoic chamber were still within a standard deviation of one another for TST1. Configuration specific results are in Figure 2 and Figure 3.

The results from the three environments were averaged from both configurations and all three tests, and a percentage deviation from the average was calculated. The results are located in Table 6.
As can be seen from the tables and figures for the 802.11a test results, the RF chamber has considerably lower throughput than the other two environments, which performed the same overall.

% Above Average 802.11a Testing			
Test	Laboratory	RF Chamber	Anechoic
TST1	13.702	-30.99	17.288
TST2	1.281	0.975	-2.256
TST3	2.346	-4.639	2.293
Average	5.776	-11.552	5.775

Table 6 - Results of 11a environmental testing.

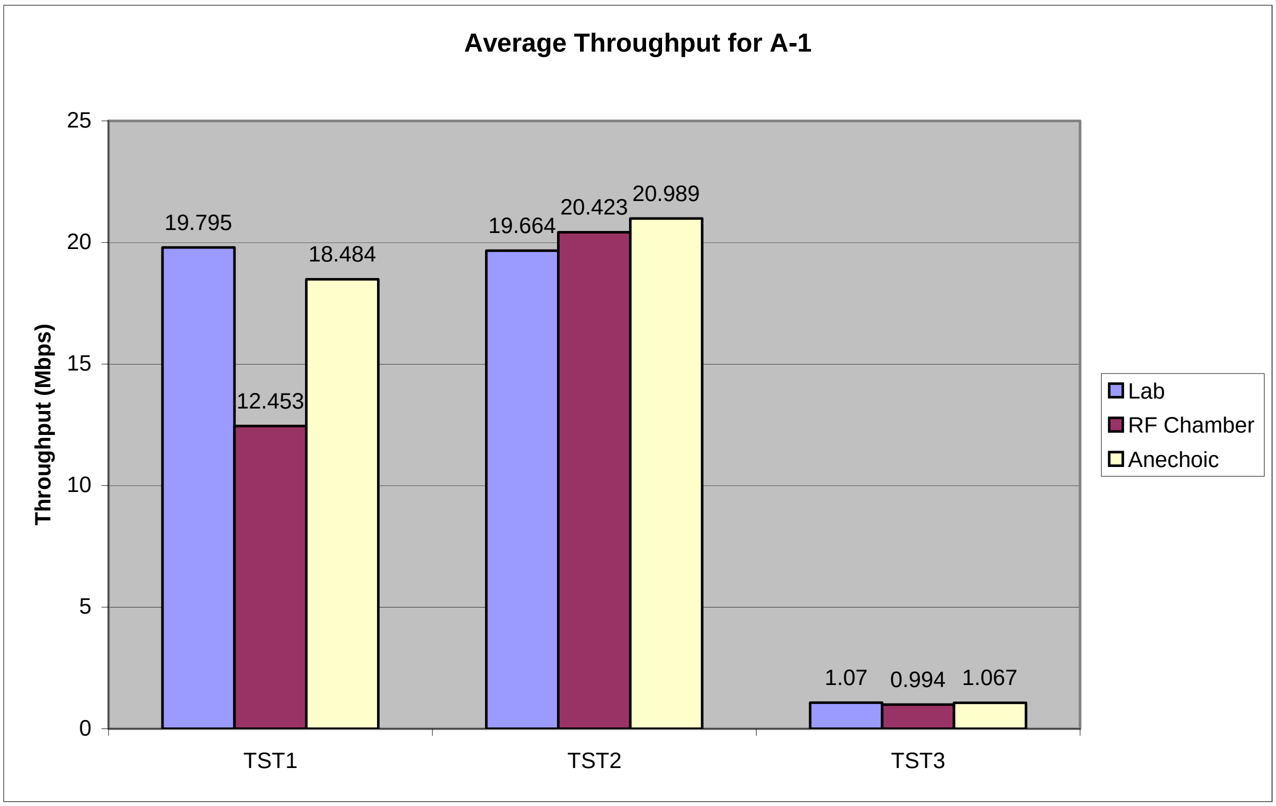

Figure 2 - Average throughput for 802.11a configuration A-1.

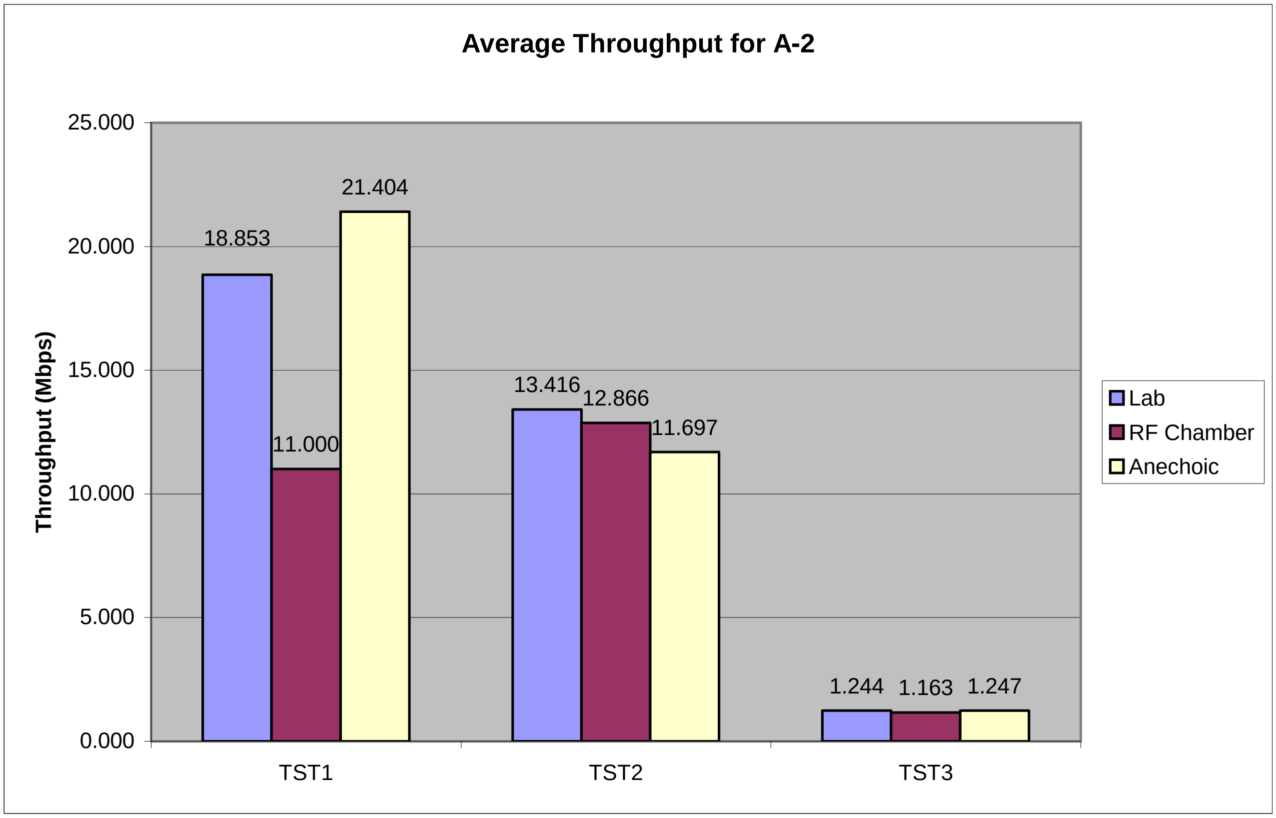

Figure 3 - Average throughput for 802.11a configuration A-2.

802.11g Test Results

The results from the 802.11g environment testing varied more than those of the 802.11a testing. The average RF chamber throughput values were lower than that of the open-air environment, and the open-air throughput was lower than that of the anechoic chamber.

Please note that for the 802.11bg BG-1 configuration, done in the open-air, the average values used to make the graph for TST1 and TST2 were taken only from the two throughput measurements done on channel 9 – they were thought to be more indicative of the open-air throughput values. However, one should note that the interference from other devices and overlapping WLAN networks caused the channel switch, and this should be taken into account when determining a suitable environment for testing devices.

The average results from each of the test configurations, including the 802.11b station in configuration BG-1, are labeled Figure 4, Figure 5, and Figure 6. It is interesting to note that test configuration G-2 using the IxChariot configuration TST3 yielded throughput values significantly lower.

The results from the three environments were averaged from both configurations and all three tests, and a percentage deviation from the average was calculated. The results are located in Table 7. The results show that the anechoic chamber is the best environment to use for testing that requires throughput measurements.

% Above Average 802.11g Testing			
Test	Laboratory	RF Chamber	Anechoic
TST1	4.034	-12.77	8.732
TST2	1.256	-11.09	9.831
TST3	-2.163	-6.849	9.012
Average	1.042	-10.23	9.192

Table 7 – Results of 11g environmental testing.

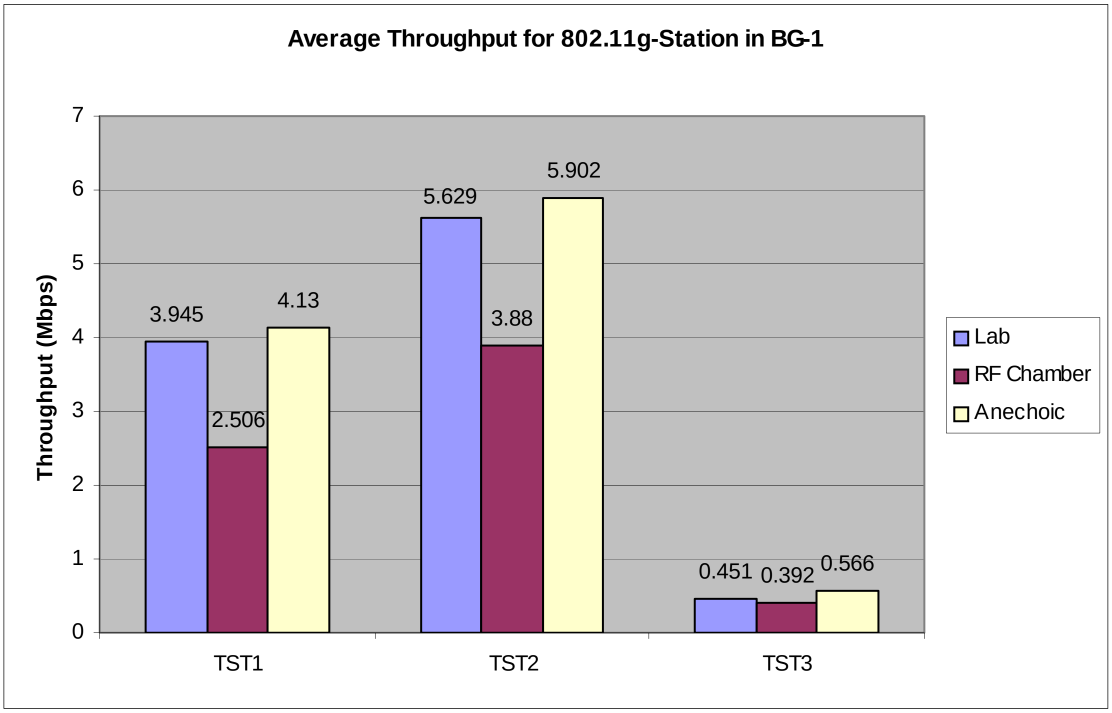

Figure 4 - Average 802.11g-station throughput for 802.11bg configuration BG-1.

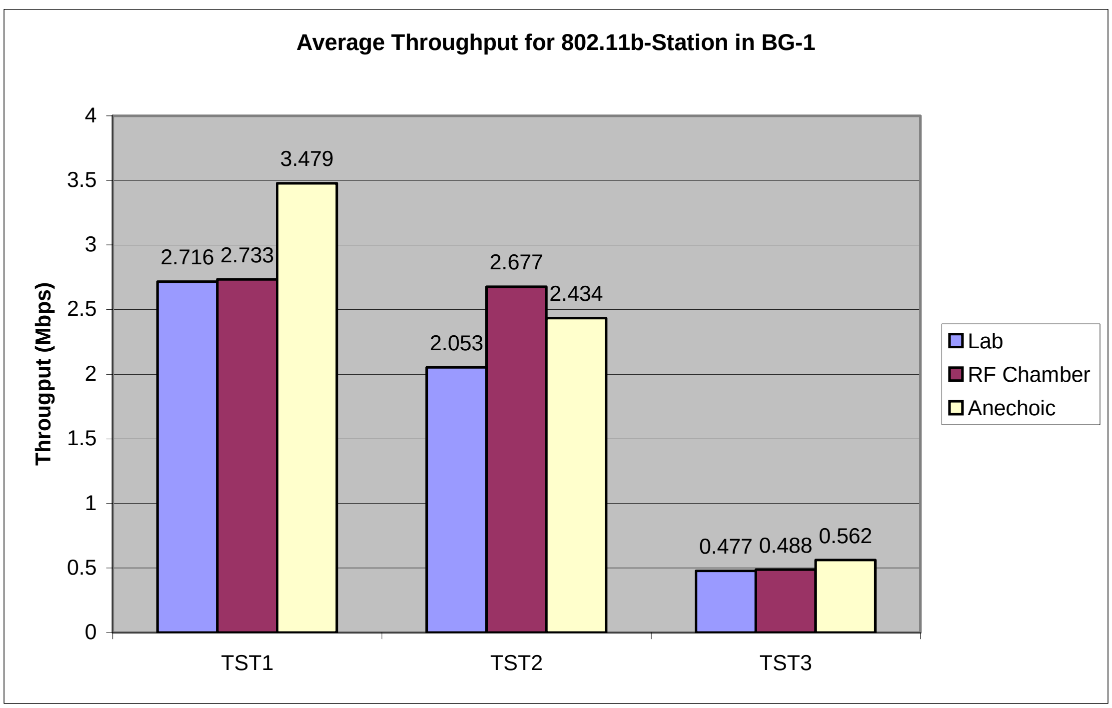

Figure 5 - Average 802.11b-station throughput for 802.11bg configuration BG-1.

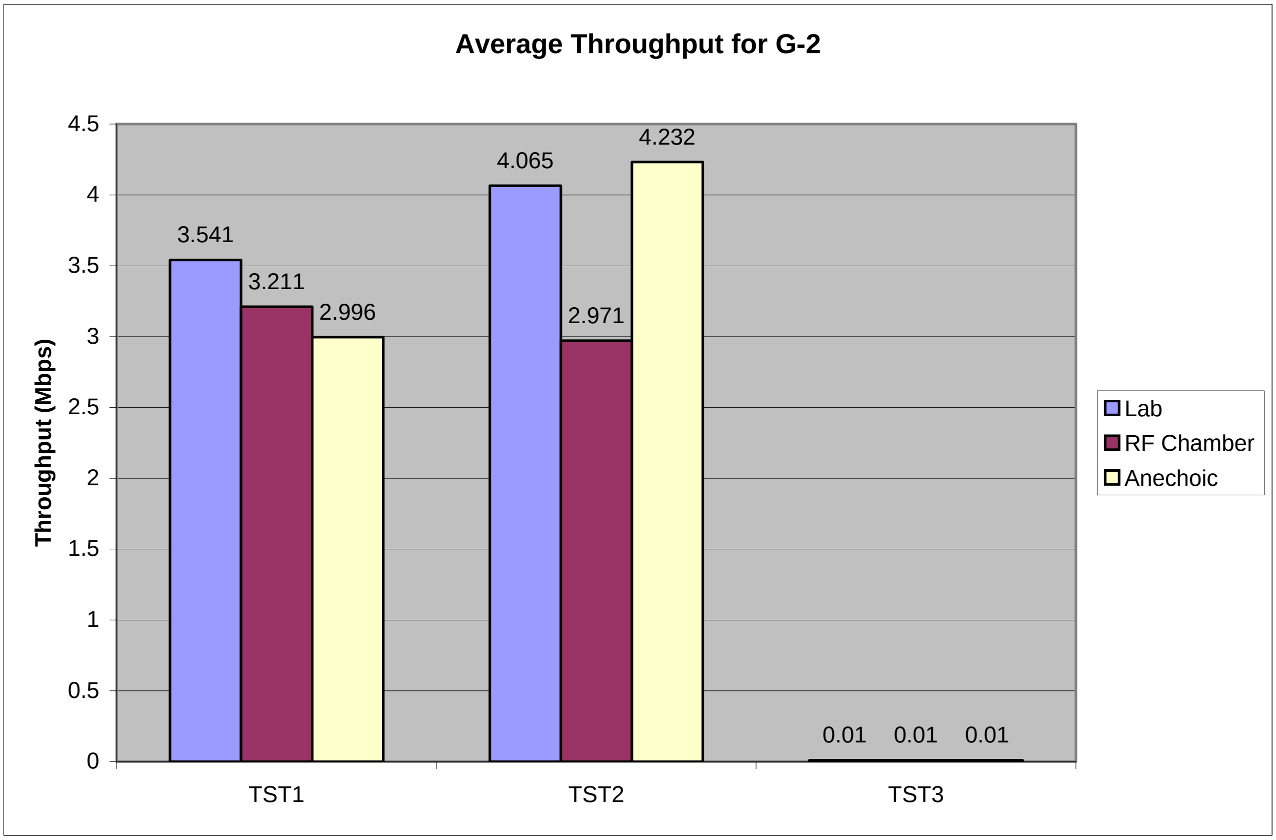

Figure 6 - Average throughput for 802.11g configuration G-2.

Placement of Radios Inside of the Anechoic Chamber

The following tests assessed possible variables related to radio and AP-station location combinations and their effects on performance results.

The AP and station locations are shown in Figure 7. For the sake of symmetry, the APs occupied one wall and the center with the stations placed along the opposite wall. Each AP location is shown in a circle, with numbers A1 – A5. The station locations are shown in boxes, with numbers ranging from S1 to S5. One station-AP arrangement is shown with asterisks – this is because the arrangement was only tested once as an afterthought, after the question was raised about whether the throughput would be better if neither station nor AP were against the wall. The technician running the test occupied the location shown for all tests, and the chariot console, connected to the DS along with the AP, sat directly in front of the technician as shown.

[*Note that the placement of the foam and the tables is different than the tests in part one. Also note that in some locations, notably A4 and A5, the AP is closer than the recommended 2 meters away from some stations (S2 and S5).*]

The AP connected to the DS in the same way it did in Part 1 (Ethernet-to-fiber converter to get to the network outside the box, then through a router to the IxChariot console). All test runs used the same hardware and configuration settings found in Table 8.

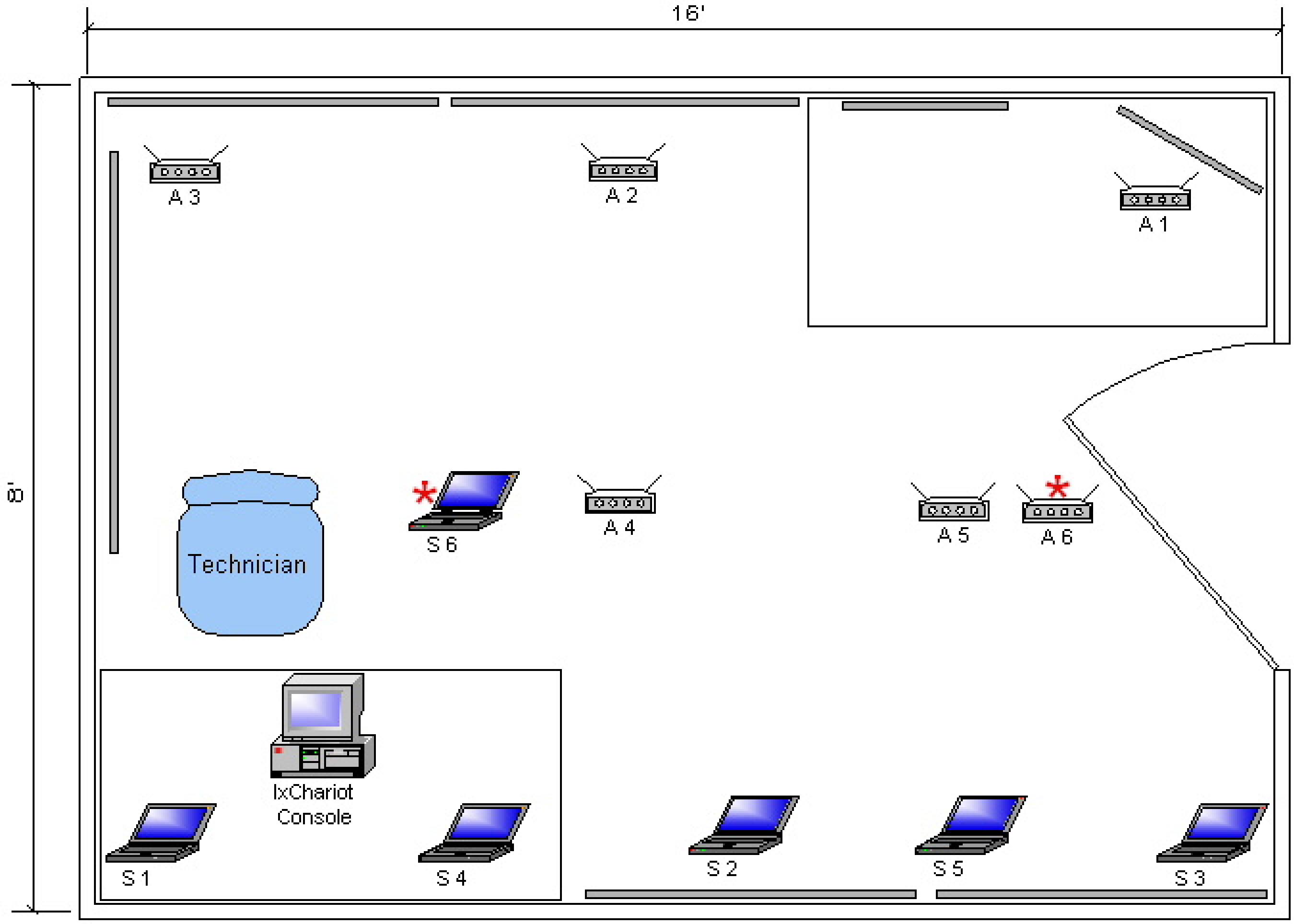

Figure 7 - AP and station locations within the chamber

Access Point Configuration		Station Configuration	
Access Point	Intersil	Station	Broadcom
RTS Threshold	Off	RTS Threshold	256
Fragmentation	Off	Fragmentation	512
Channel	6	Power Save	Off
Security	None	Security	None
Authentication	Open	Operating System	MS Windows XP SP2

Table 8 - Configuration values for optimal placement testing inside an anechoic chamber

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Procedure

The AP and stations were configured according to Table 8 and the IxChariot server ran TST1 (filesendl from the IxChariot server to the station).

The AP-station tests ran in a random order specified by assigning each testing pair a random number and running them in increasing numeric order. Before each test, the AP and station were moved to the specified location. The technician would return to the chariot console, positioned in the corner of the chamber to create control by reducing RF manipulation from movement. Each station-AP location combination was tested three times. Table 9 is an account of the randomized order in which the stations were tested.

Results

Figure 8 summarizes the average throughput values obtained for each AP/STA placement pair. The average throughput value across all of stations was 22.38 Mbps, and the standard deviation was 0.5 Mbps. The highest average throughput value was 22.805 Mbps (AP1STA3) and the lowest was 21.369 Mbps (AP3STA2).

The two lowest throughput values also had the highest standard deviations, which is more noticeable when the average throughput data is plotted to accentuate the standard deviations as in Figure 9. This is due to taking only three measurements per location – a single low throughput number results in a reduced average and a large standard deviation. AP location 3 was found to perform worse than average for four out of five station locations, which may have been caused by the technician sitting directly between the AP/STA pair. Similarly, it is also interesting to note that AP1STA3 was the AP/STA pair furthest away from the technician and had the highest throughput.

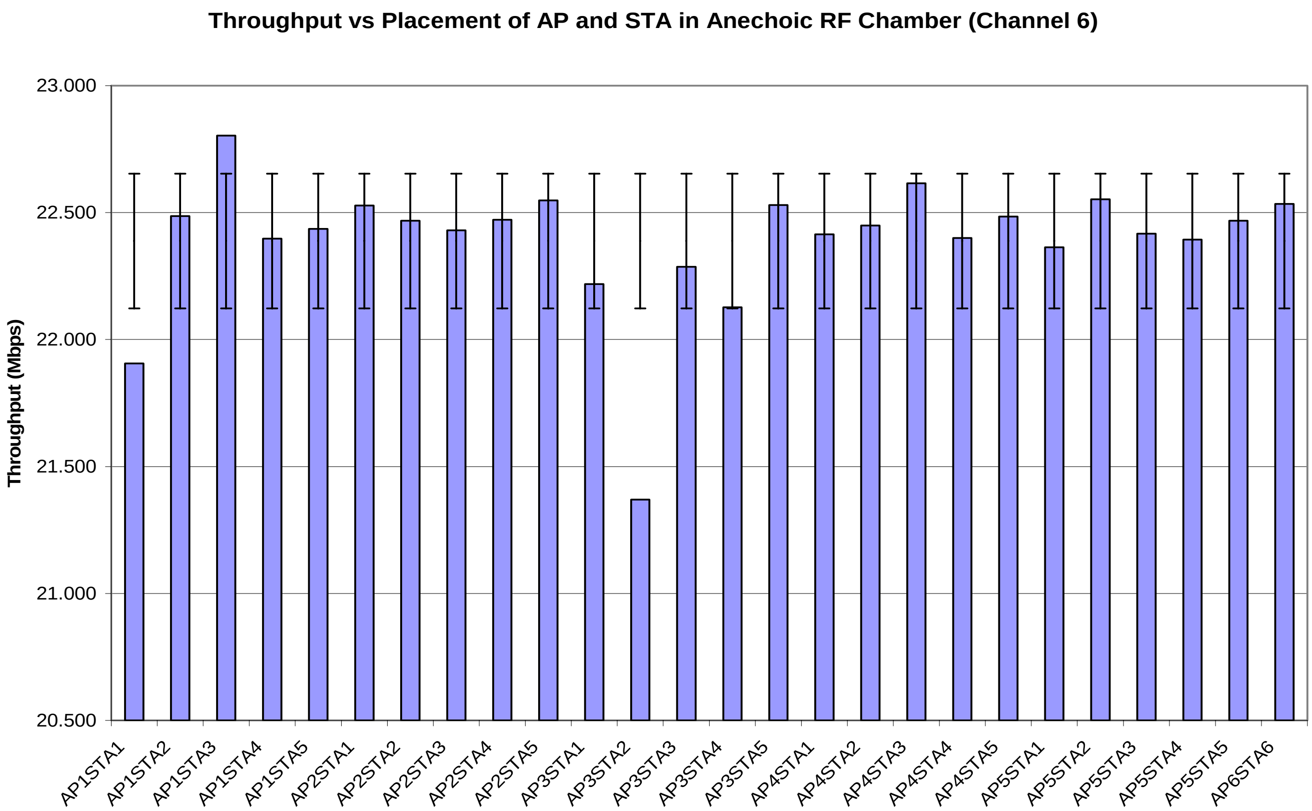

Figure 8

Run #	AP Location	Station Location	Run #	AP Location	Station Location	Run #	AP Location	Station Location	Run #	AP Location	Station Location
1	3	4	20	4	5	39	3	1	58	5	4
2	2	2	21	2	3	40	2	4	59	3	1
3	1	3	22	4	3	41	1	3	60	2	5
4	3	2	23	4	3	42	5	4	61	3	3
5	5	2	24	2	3	43	3	2	62	6	6
6	2	5	25	5	2	44	1	5	63	2	1
7	5	1	26	4	2	45	4	4	64	3	4
8	5	3	27	2	1	46	3	1	65	3	5
9	4	5	28	1	2	47	3	3	66	5	2
10	2	5	29	2	4	48	1	3	67	5	5
11	2	4	30	4	3	49	5	1	68	2	1
12	3	3	31	3	2	50	2	2	69	1	2
13	4	1	32	3	4	51	4	4	70	1	1
14	1	5	33	5	3	52	4	1	71	2	3
15	4	1	34	4	2	53	5	5	72	5	3
16	5	5	35	5	4	54	5	1	73	4	4
17	3	5	36	1	5	55	1	4	74	4	5
18	1	4	37	1	1	56	4	2	75	1	2
19	1	4	38	3	5	57	2	2	76	1	1

Table 9 - Randomization of trials to test effect of radio location on throughput performance inside of an anechoic chamber

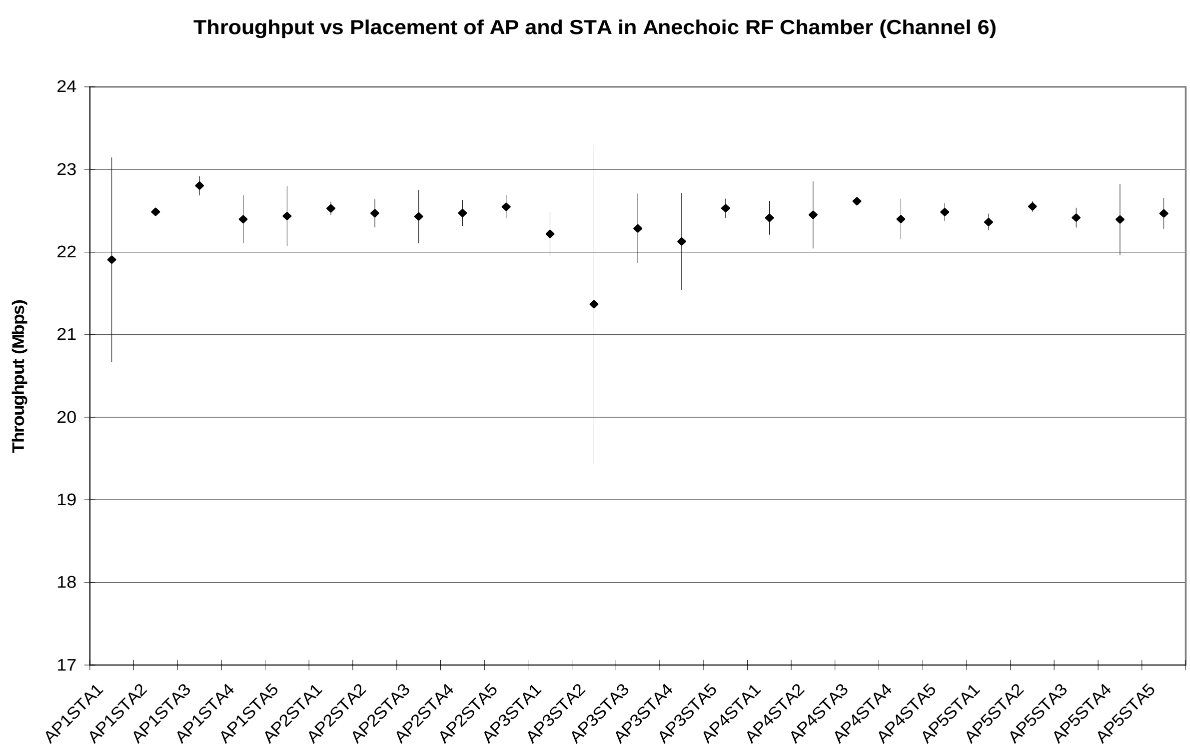

Figure 9 - Throughput vs. placement of AP and STA in anechoic chamber. The center dot is the average, while the lines show the standard deviation for that particular AP-STA combination.

Performance Effects of RF Rubber Mats

The anechoic foam placement left the floors and ceiling open to reflections. To ascertain whether these reflections had an impact on throughput, technicians used two 2' x 2' RF rubber mats to reduce the vertical reflections by placing them under the AP and station. The effects that the rubber mats have on throughput performance can be analyzed by performing identical tests with and without their presence.

Configuration

The AP and station were configured in the exact manner as the location tests. The values for test configuration can be found in Table 8 and the values for IxChariot configuration can be found in Table 1 (TST1).

Procedure

There were twenty test trials: ten trials with rubber mats and ten without, and the test order was randomized to reduce error. Between trials that required the mats to be moved, the technician would remove/replace the mats and return to the same spot specified in Figure 7. The IxChariot script "filesendl" was then run from the IxChariot server to the station (TST1).

Results

The results showed an increase in throughput with the addition of the rubber mats as illustrated in Figure 10. Furthermore, the standard deviation of the tests with the mats was found to be much lower than the standard deviation without the mats as shown in Table 10. From this we conclude that the repeatability of a higher throughput value will be higher with the mats than without them.

	Average Throughput	Standard Deviation
With Rubber Mats	22.599	0.087
Without Rubber Mats	22.457	0.226

Table 10 – Summary of average and standard deviation results

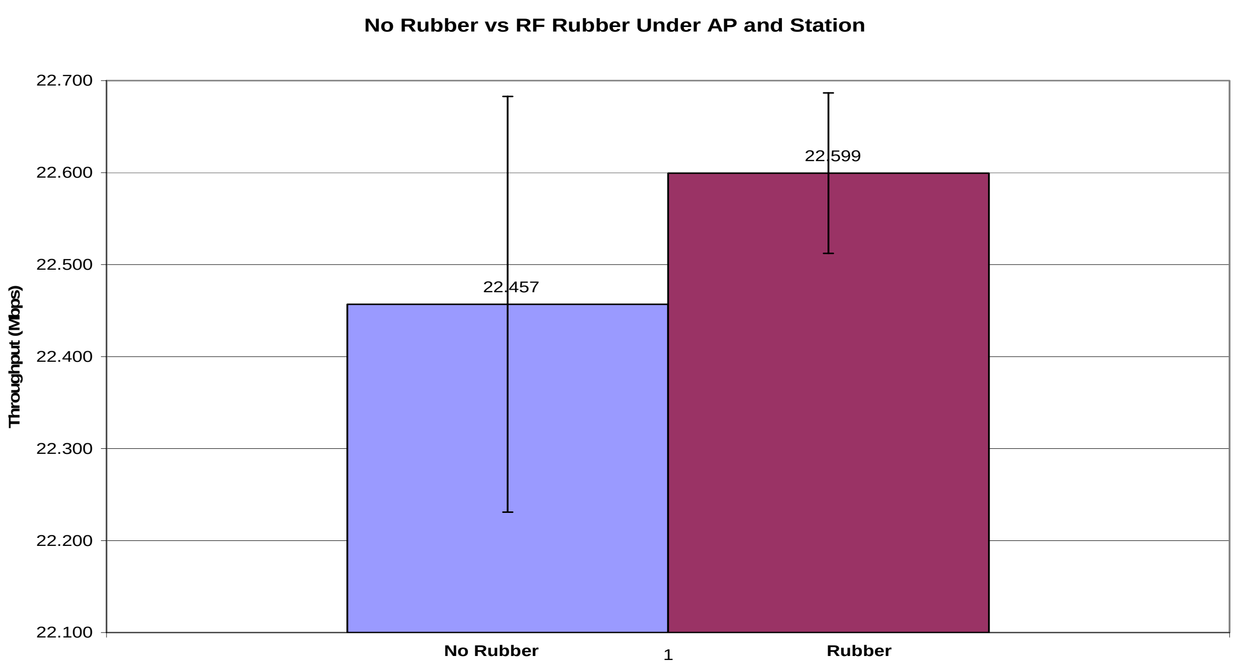

Figure 10 - Graph showing average throughput and standard deviation across ten trials

Conclusion of Environment

Table 11 shows the percent above or below the average for the individual environments. The results clearly illustrate the relative advantages and disadvantages of the different environments.

It is clear that there is a significant decrease in throughput when using the RF chamber without any anechoic foam for both bands. For the 5 GHz (802.11a) band, the open-air environment and the anechoic chamber were indistinguishable, while for the 2.4 GHz (802.11g) band, the results showed a significant increase in throughput when using the anechoic chamber versus the open-air environment. This is most likely due to interference from overpopulation of nearby devices and networks.

% Above Average for 802.11a tests		
Open-air	RF chamber	Anechoic
5.776	-11.552	5.775
% Above Average for 802.11g tests		
Lab	RF chamber	Anechoic
1.042	-10.234	9.192

Table 11 - Summary of average test results.

Conclusion of Location in Anechoic Chamber

The AP/STA combinations did not show a significant difference between locations. While some throughput values were slightly higher, and an AP location showed a small decrease in throughput for some of the station locations, there was not overwhelming evidence to suggest that the AP or Station location inside of the anechoic chamber makes a significant difference in throughput.

Conclusion of Performance Effects of RF Rubber Mats

The RF rubber beneath the station not only increased throughput, but decreased the standard deviation of the throughput as well. This means that results should be truer and more repeatable with the RF rubber in use.

Therefore, to obtain the truest throughput results, the anechoic RF chamber should be used when testing in the 2.4 GHz band. For the 5 GHz band, the testing can be done in either the anechoic chamber or in an open-air setting. When testing inside the anechoic chamber, it does not matter where in the chamber the AP and station are placed. However, the tests should be run with RF rubber mats placed under the AP and station for the best results.