

**802.11b Wireless Technology
Senior Design Project
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Abstract

802.11 wireless technology is a set of specifications based on wireless communications. While there are currently four different types of 802.11 specs, our senior design project focused on 802.11b. The initial project concentrated on making it possible for an individual to use the Internet, along with an 802.11b device, to turn on or off an AC powered device. The initial project was unsuccessful due to the lack of resources. Due to these circumstances, a new project was proposed. The new goal was to extend the range of an 802.11b Linksys router by implementing an RF amplifier and antenna. Using our final product, the range for the router was extended significantly compared with the original antenna.

Introduction

802.11 technology is based on a fairly new form of wireless communication. There are currently four different types of 802.11 specifications available: 802.11, 802.11a, 802.11b, and 802.11g. The main difference between them is the speed at which data can be transferred and the maximum range that the device can operate. 802.11 technology can be found in many devices that require wireless communications such as cell phones, Internet routers, PDA's and even automobiles just to name a few.

Our senior design project was chosen based on 802.11b. The goal of the project was to create an application that would utilize 802.11b in a way that had not been done before. We wanted to make it possible for an individual to be able to use the Internet to turn on or off an AC power device located in the home or office. In order for us to accomplish this, the use of an 802.11b device was required. Although the idea of being able to turn on or off any AC powered device in the home or office sounded interesting, unfortunately, due to several major setbacks, we were forced to alter the project designs significantly. Instead of the primary design idea, the goal of our senior design project focused on increasing the range of an 802.11b Linksys Router using an RF amplifier and a homemade directional antenna.

Original Project Design

The original project design focused on making it possible for an individual to log on to their home or office computer and turn on or off an AC powered device by clicking on the icon designated to that device. This particular design consisted of several parts: an 802.11b development board, a PC with Internet access (or Host Computer), an Internet supporting device (Laptop, PC, PDA, etc), and an AC device. Assisting us with the 802.11b development board and associated programming tasks was Atheros

Communications. Figure 1 shows the block diagram of how the design was to be carried out.

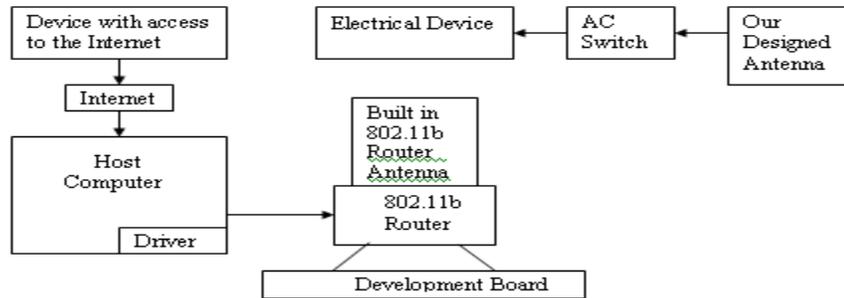


Figure 1. Block Diagram for Web-Based Control System

Using a little HTML and web page design knowledge, a server was set-up on the Host Computer. Once this was done, accessing the host computer from another PC was easily done by logging onto the website under which the host is the server. Linking the host PC and the 802.11b development board was to be done upon completion of the 802.11b development board hardware and software portion. The 802.11b development board was provided by Atheros Communications and is pictured in Figure 2.

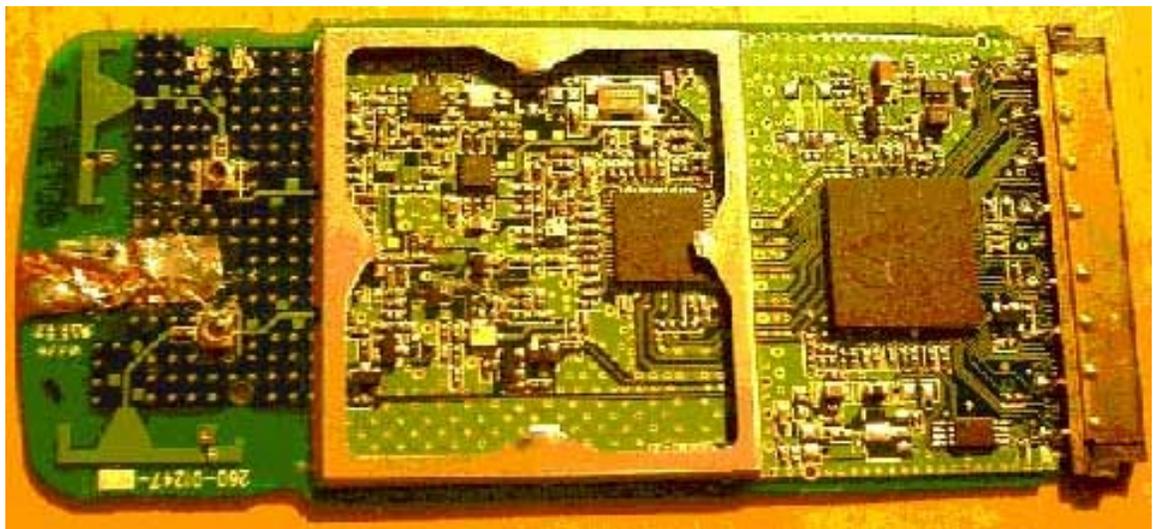


Figure 2. The 802.11b Development Board

The development board consisted of some very involved circuitry. A somewhat simplified block diagram is shown in Figure 3 below.

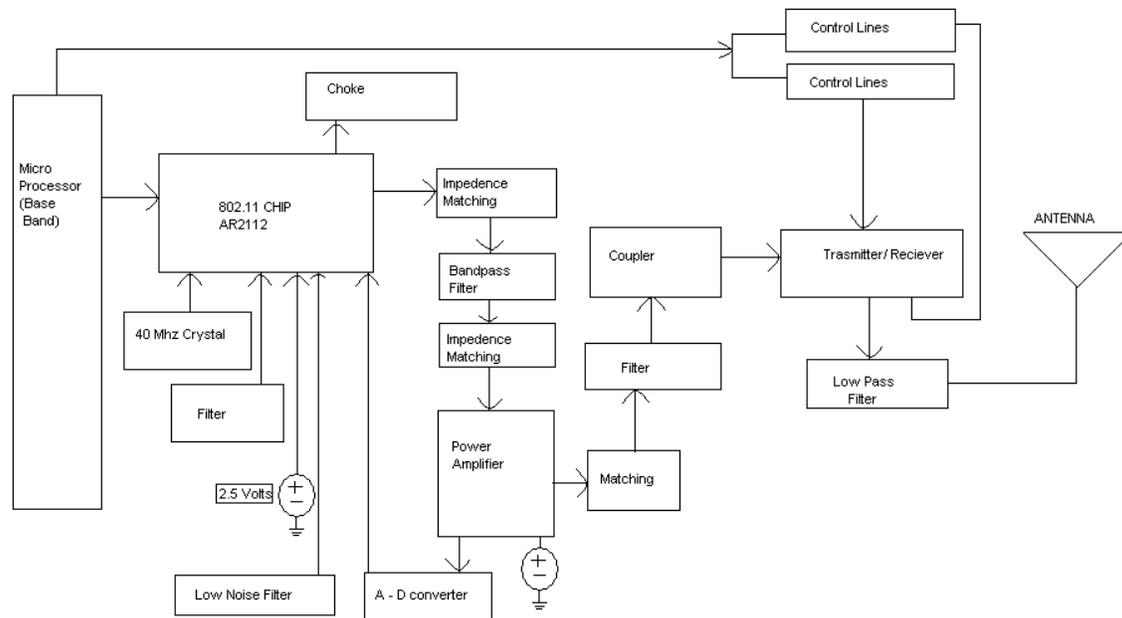


Figure 3. Block Diagram for the Atheros 802.11b Development Board

Everything shown in Figure 3 starts with what is called the Base Band Processor. There are several companies out there that manufacture their own processor such as Intel; however, Atheros also makes their own. From there, a number of operations are performed and the end result is a transmission of instructions which are sent out to the AC adapter, which tells the AC powered device to turn on or off. After a brief overview of how the circuit worked, we were aware of what we needed to do in order to fit the needs of our project. One of the most important tasks that needed to be performed was the programming aspect. A combination of the computer languages Pearl and C were needed to program the development board. We got in touch with a couple of programmers from Atheros and they informed us that we would have their full support in our project. After several e-mails back and forth, we were a few days within signing non-disclosure agreements when we were notified that, due to “an increase in workload“, Atheros would not be able to help us. At the time, they were in the process of going public and they succeeded as of February 2004. This basically left us and our project at a

halt. With no help with the programming needed to run the development board, and none of the parts or resources that we were expecting to receive, we needed to make some major changes to our design project. With only approximately three months left at the time, we needed to think of something fast.

New Project Design

We needed to think of a project that would still utilize 802.11b technology. The idea we came up with was to take an 802.11b Linksys Router, which could be purchased at any electronics retailer, and extend the transmission range of it by means of an RF amplifier and homemade directional antenna. Some of the things we wanted to keep in mind were efficiency, cost, and reliability. Figure 4 shows the block diagram for the project layout.

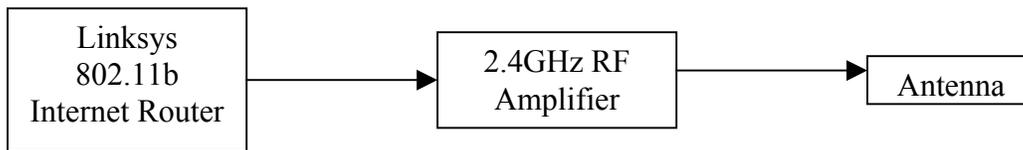


Figure 4. Block Diagram for Revised Project

The basic components to this project consist of the Linksys Router, an RF amplifier, and a directional antenna.

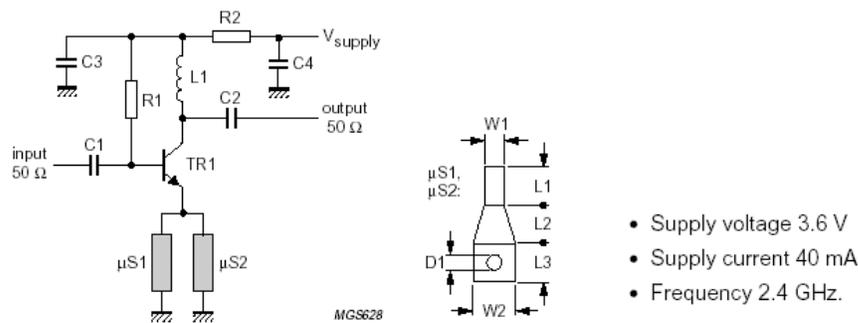
The Internet router that was used was the Linksys Wireless B Broadband Router (Model #BEFW11S4 – See Figure 5).



Figure 5. Linksys 802.11b Internet Router

We decided to use this particular device based on a couple of factors. Linksys, the manufacturers for the device, is a well-known brand name in the wireless router industry. Also, at the time, the price for it at the electronics store was not too bad of a deal. This router is capable of handling data rates of up to 11Mbps and because of the 802.11b characteristics it has a standard range of approximately 300 feet. There are two antennas located on the device, one for transmitting and the other for receiving. Our design project only deals with the transmitting antenna.

The RF amplifier we decided to use is the 2.4 GHz Low Noise Amplifier (LNA) with the BFG480W originally manufactured by Philips Semiconductors. This was, by far, the most difficult part of the project. The amplifier consists of a handful of surface mount components as well as several microstrip lines with length and width values ranging from 0.4 mm up to 1.0mm. Philips Semiconductor was kind enough to donate the transistor needed in order to construct the circuit. Also providing assistance was Harnam Singh of Atheros Communication. Figure 6 shows the schematic for the LNA as well as a few specification numbers.



SYMBOL	PARAMETER	CONDITION	VALUE	UNIT
$ S_{21} ^2$	insertion power gain		9.6	dB
VSWR _{IN}	input voltage standing wave ratio		1.6	
VSWR _{OUT}	output voltage standing wave ratio		1.6	
NF	noise figure		3.0	dB
IP3 _i	third order intercept point	$P_i = -10$ dBm; $\Delta f = 200$ kHz	17	dBm

Figure 6. Philips Semiconductors 2.4 GHz Low Noise Amplifier w/ the BFG480W

Dealing with the surface mount components without the proper tools necessary to mount them was a very frustrating experience. Although there were a few components to solder onto the FR4 copper board, it still proved to be an extremely tedious process. Even a small amount of excess solder on a connection could alter the performance of the amplifier. Keeping this in mind, we tried our best to make each connection as accurate as possible to avoid compounding errors. Figure 7 shows a photo of our RF amplifier.

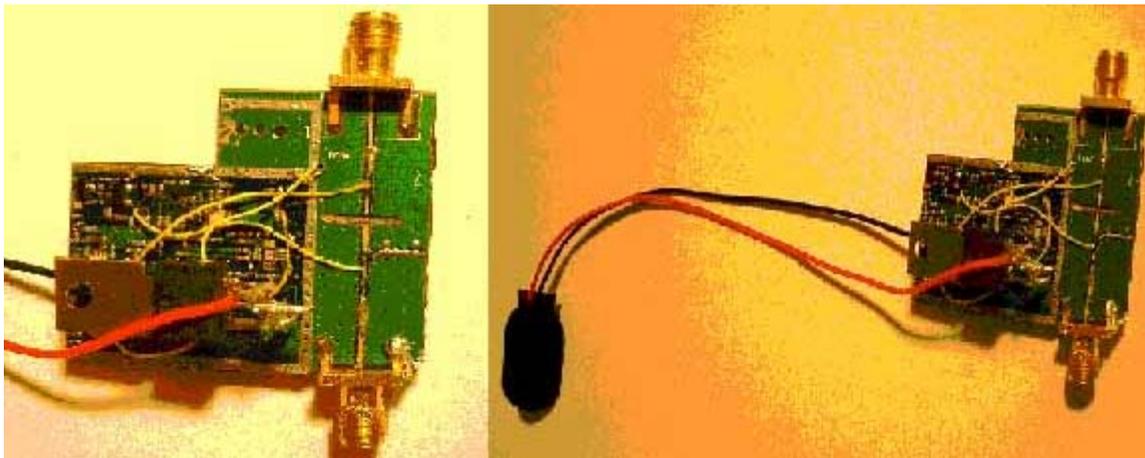


Figure 7. Photo of the 2.4 GHz RF Amplifier Circuit

For the antenna design the first step was to figure out what type of antenna to use. Of the many different types, we decided to go with the directional antenna. This type of antenna transmits a signal in a specified direction. For this design we used TNC Female Chassis Jack along with a baby formula can with a diameter of 3.375" and a length of 7.56". The placement of the TNC Female Jack was very important. A minor variation can have a significant impact on the frequency of operation. Since the 802.11b router operated at a 2.437 GHz frequency, we used this frequency for our calculations. To calculate the location for the hole placement we needed the radius for the can. Using equation 1 we determined the TE₁₁ and TM₀₁ modes.

$$f_{cmn} = \frac{P_{nm}}{(2 * \pi * a * \sqrt{\mu * \epsilon})} \quad (1)$$

where,

$p_{nm}=1.841$ (TE11) and 2.405 (TM01) $a=1.688''$; $\mu=4*\Pi \times 10^{-7}$ H/m ; $\epsilon=8.854 \times 10^{-12}$ F/m

$$\therefore f_{cTE11} = 2.049GHz$$

The purpose of these particular modes was to assure ourselves that the 2.437 GHz frequency is supported by our antenna design. Using equation 2 and a specified center frequency of 2.437 GHz, we were able to find the guide wavelength in inches.

Henceforth, we were able to determine the $\frac{1}{4}$ guide wavelength and the $\frac{3}{4}$ guide wavelength. The $\frac{1}{4}$ Guide Wavelength number told us, how far up from the bottom metal end of the can to put the center of the hole. As a result we were able to place the TNC connector at the exact location.

$$\text{Guide Wavelength in inches, } \lambda_g = \frac{c}{\sqrt{f^2 - f_{cTE11}^2}} \quad (2)$$

where,

$$c=11.811 \text{ GHz-in; } f = 2.437 \text{ GHz}$$

$$\therefore \lambda_g = 8.95''$$

Taking $\frac{1}{4}$ of λ_g gave us the $\frac{1}{4}$ guide wavelength and the distance from the bottom of the can where we mount our connector. Figure 8 shows what our tin can antenna looked like upon completion.



Figure 8. Photos of Tin Can Antenna

Theoretically, the radiation pattern for our tin can antenna should look like what is shown in Figure 9. The radiation pattern is basically a plot of where the transmission signal can be detected. Unfortunately, we did not have the equipment necessary to record such data.

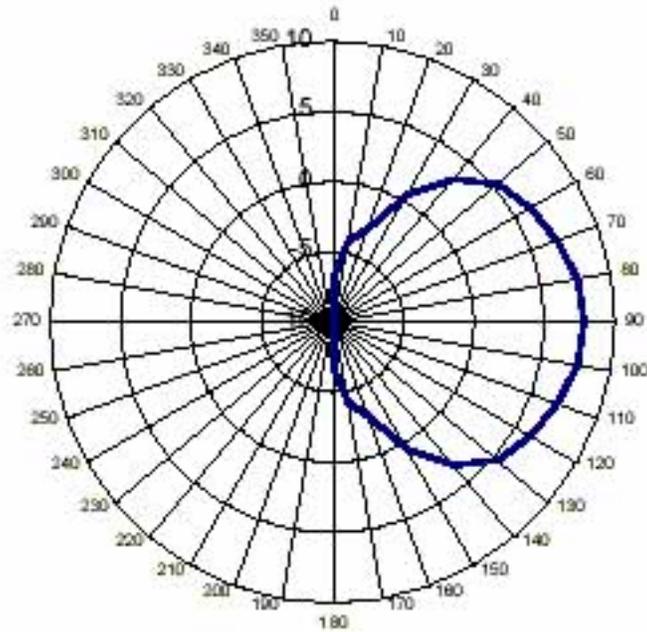


Figure 9. Theoretical Radiation Pattern for the Directional Antenna
Testing

Testing the final project was fairly straightforward. Upon inserting an 802.11b Wireless PC Card into a laptop a signal strength window appears, indicating how strong the signal is coming from the wireless router. There are essentially six different settings that the indicator can read: excellent, good, fair, poor, very poor, and no signal. The environment under which we conducted the testing was nearby campus on 7th Street, in between East San Salvador and East William Street. The router was set up using a DSL connection and placed in front of the window facing the street. From the window facing the street, we measured and marked distances in increments of 10 feet. Due to the fact that we were limited on the distance that we could test the signals (i.e. running out of room due to the house across the street), we had to make a decision on what data we were going to base the results on.

We decided that we would take each case and test the distance at which the signal strength indicator changed from fair to poor. It was very important to ensure that each

case was tested under the exact same conditions (time of day, weather, path of measuring, etc.). The first set of data was taken starting at approximately 12:15pm on a Wednesday afternoon. At this time of the day it was a very busy atmosphere, which meant signal interference. There were cars constantly driving up and down the street and people walking by every 10-15 minutes. Despite these factors, as long as we ran each experiment under the same conditions, we would still be able to get good data. We tested three different cases using: the Linksys provided antenna, the directional antenna we designed, and the RF amplifier and directional antenna combined. For each case, we conducted 20 trials. In order to ensure that our results were accurate, we repeated the testing procedures at about 2:30am. At this particular time, it was very quiet and hardly any cars or people were going by, giving us the best conditions that we could conduct testing under the circumstances.

Results

After conducting the experiments, it is evident that the transmission range for the router was increased after we replaced the original antenna with our project. Figure 10 shows a plot of our data after we conducted the experiment in the middle of the day. In the case of the Linksys antenna the average distance was determined to be 79.55 feet. With our antenna alone the average distance came out to 99.02 feet. And finally for our antenna, along with the amplifier, the average distance was 103.62 feet.

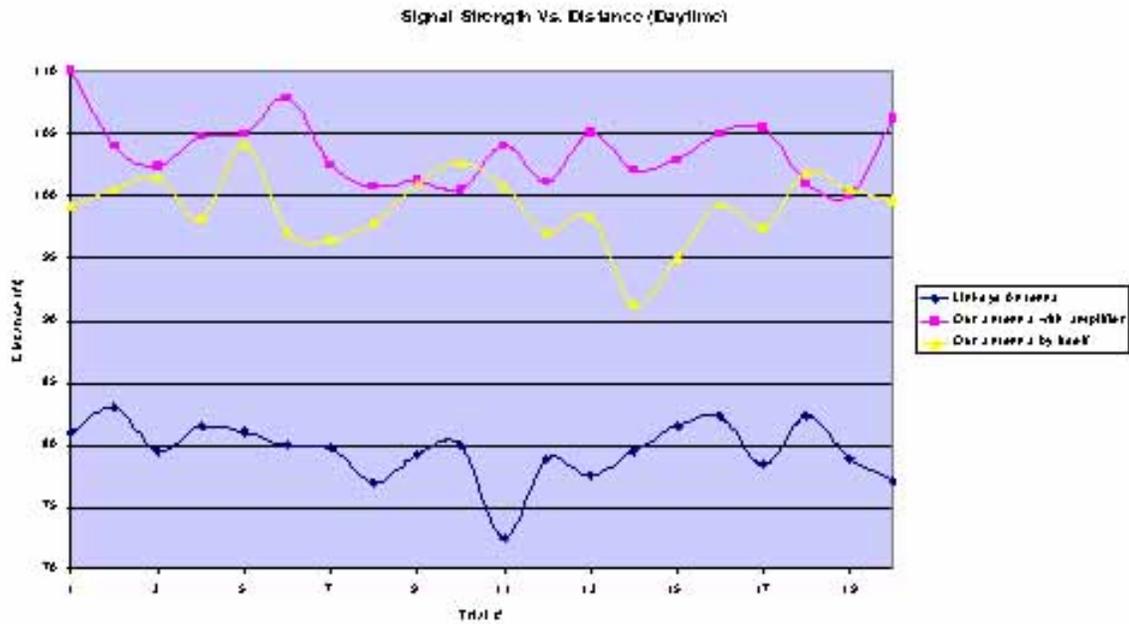


Figure 10. Plot of Signal Strength vs. Distance (Daytime Data)

Figure 11 below shows a similar plot as presented in Figure 10, but this time using the data collected after we conducted the experiment in the middle of the night/early morning. This time, with the Linksys provided antenna, the average distance came out to be 83.14 feet. Using our antenna alone, the average distance was 104.54 feet. And with our antenna, along with the amplifier, the average distance was calculated to be 109.05 feet.



Figure 11. Plot of Signal Strength vs. Distance (Nighttime Data)

There is a slight difference between the data collected during the daytime experiment and the nighttime experiment. This is most likely due to the difference in the amount of interference introduced by the environment (i.e. cars, people, nearby cell phones being used, etc.). In both cases, our antenna with or without the amplifier outperformed the Linksys provided antenna. The results for our amplifier did not come out as well as we expected it to most likely due to human error in the amp construction.

Cost Analysis

In comparison with the Linksys provided antenna, our antenna cost approximately 59% less. It is important to note, however, that Linksys would not disclose the price for the same exact original manufactured antenna. They informed us that, if a replacement were needed we would need to log onto www.antennasystems.com and order part number FO2400-10. The cost for this product is approximately \$99.00 +tax and shipping. The cost to make our project came out to approximately \$41.00. Table 1 below shows a tabulated list of all the components we used for our project.

Part	Value	Units	Quantity	Cost
Tin Can	N/A	N/A	1	Free
TNC Female Chassis Jack Reverse Polarity	N/A	N/A	1	\$5
TNC Male to TNC Male Assembly	N/A	N/A	2	\$36
BFG480W PNP Transistor	N/A	N/A	1	Free
FR4 Copper Board	N/A	N/A	1	\$10
Resistor 1	2.7	k Ω	1	\$0.02
Resistor 2	39	Ω	1	\$0.02
Capacitor 1	5.6	pF	1	\$0.14
Capacitor 2	3.3	pF	1	\$0.07
Capacitor 3	5.6	pF	1	\$0.04
Capacitor 4	1	nF	1	\$0.07
Inductor 1	150	nH	1	\$0.35
Adjustable Voltage Regulator	N/A	N/A	1	\$0.08

Table 1. List of Parts Used

Conclusion

Our original design project was to implement an 802.11b device in such a way that it could communicate with another device, using the Internet, and turn it on or off. Unfortunately, due to lack of resources, we were unsuccessful. However, for our revised project, we decided to modify the 802.11b router in such a way to extend the transmission range for it. We used an RF amplifier and directional antenna to reach our goal. Using radio frequency theory, we were able to design our own antenna using a tin can. Although we were not able to succeed in our initial project, we were still able to succeed on a very important part of this growing technology. The range was for the router using our project was significantly increased compared to the antenna provided with the router. We were able to increase it by approximately 27% in mid-day time, and 28.5% during the nighttime. In addition, we were able to reduce the costs associated with replacing the original antenna. 802.11 wireless technology will continue to be

implemented in many of the electronic wireless devices we use today and in the future. In order for it to carry on its success, it will continue to require a lot of research and experimentation.

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