
An Experimental Pilot Wireless Wide Area Network: a Project Based Learning approach in Radio Frequency Course

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Abstract: Within the Bloomsburg University Electronics Engineering Technology (EET) program the RF effects and measurements course is identified as one of the key courses necessary to provide the fundamental points of knowledge and the skills required by the graduating engineering technologist in the field of RF and wireless communication. For pedagogical reasons, a structured learning approach is pursued in developing the course through well compacted lectures that have clear objectives, supplemented by extensive laboratory sessions. Finally, a project based learning approach is utilized to bridge the gap between the knowledge gained in class room, the skills gained in the laboratory, and real-life experiences.

Development of a campus wireless wide area network was one of the projects implemented during the project based learning phase; after the student gained the fundamental technical background in RF communication, and attained commanding skills in handling state of the art RF equipment and components. The project group, formed from three students with the instructor acting as their advisor, performed a complete RF site survey to optimize the network operation, successfully developed, and tested a low cost pilot wireless wide area network. The work was done in collaboration with a local wireless communication company and the University Office of Technology/ Networking and Operation. The project was a viable tool to enhance student understanding of the complex topic of RF effects and measurements, and an excellent venue to apply knowledge gained in class to a real life practical design problem.

This paper discusses the technical issues pertaining to the development of the project and the associated educational outcome.

I. Introduction

The fast changing field of radio frequency (RF) communication technology is one of the disciplines strongly emphasized within the electronics engineering technology (EET) program. Within this discipline, the RF effects and measurements course was identified as one of the core courses to provide the fundamental points of knowledge and necessary skills required by the graduating engineering technologist. For pedagogical reasons a structured learning approach was pursued in developing the course through well compacted lectures that have clear objectives, supplemented by extensive laboratory sessions¹. The lectures introduced the concepts of electromagnetic and RF signal propagation in metallic coaxial cables and in free space, defined the parameters of RF signals and systems, and presented the principles of antenna theory. The lab experiments provided hands-on experience in using modern RF measurement equipment, allowing students to perform various RF measurements at system and component level, and handle specialized RF components. There is no specific text book that sufficiently covers all these topics at an introductory level for engineering technologists. The lectures were based on notes using three text books^{2,3,4}, which were proven to be viable resources. The course topics and the lab experiments are outlined in tables I and II.

Table I. RF effects and measurement course topics

Transmission lines and their characteristics. ^{2,3}
Electromagnetic and RF signal propagation through free space. ^{2,4}
Propagation coefficient, reflection coefficient, voltage standing wave ratio (VSWR) and their use in analysis of RF systems and devices. ^{2,3,4}
Introduction to Antennas, as the interface device between transmitters, receivers and free space. ^{2,3}

Table II. RF experiments

Signal analysis using spectrum analyzer
Network analysis using network analyzers
S parameter characterization of RF networks
Characterization of various RF components, including filters, mixers and couplers

The culmination of the course was a project based learning exercise during the last six weeks of the semester. "Projects can serve as bridges between phenomena in the classroom and real-life experiences"⁵. Working on a project as a group the students will be discussing ideas, developing systems, and analyzing data. They will learn how to effectively utilize the knowledge gained in the lectures and the tools used during the laboratory periods to measure and analyze data. The fourteen students enrolled in the course were divided into five groups and assigned projects covering various topics in RF communication such as antenna design, AM/FM transceiver construction and analysis, and wireless networking. The four hours per week of lectures and lab time, in the final six weeks of the course, were dedicated to implement and complete their assigned project. This paper presents one of the projects implemented during the project based learning phase, the "Development of a Low Cost Campus Wireless Wide Area Network". The project group was formed from three senior students, with the instructor acting as an advisor to the group. They were given the specification of the project, and from there were on their own

self learning track. The work was done in collaboration with a local communication company, “Keystone Communication”, and the University Office of Technology.

In the following sections the technical objective of the project is introduced together with the theoretical points of knowledge utilized by the students to implement the project and analyze the outcome of the experiments. The project plan is outlined taking into consideration the technical goals to be achieved and the resources needed to be procured. The stage is then set to implement the project through a number of experiments. The results of these experiments are individually analyzed, the technical and educational outcomes are discussed, and suggested future improvements are presented.

II. Objective of the Project

The objective was to develop a long range, broadband, low cost, wide area wireless network utilizing the existing university in-building 802.11b wireless system, thereby facilitating access to the university computer from any location on campus. The general design specification called for implementing a number of 802.11b based picocells, carefully positioned around the campus area. The picocells communicate to a central wireless base station (access point) linked to the university computer and each picocell act as a bridge allowing access by multiple users’ laptops (see figure 1).

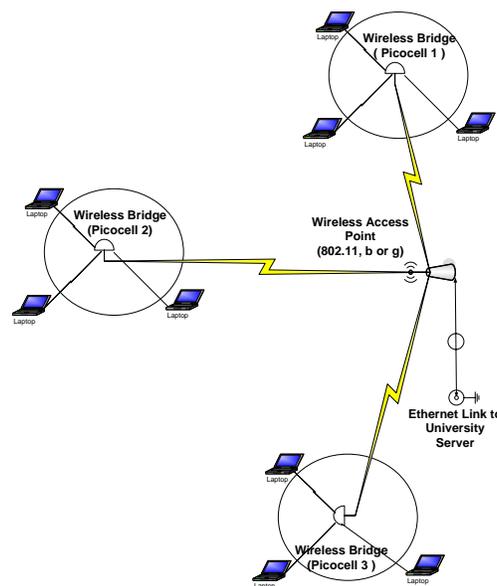


Figure 1: Proposed wide area wireless network

The proposed design has many inherent difficulties that can significantly reduce data rate leading to loss of transmitted information. As a prelude, the team was tasked with developing a pilot system to analyze and determine the technical and economical feasibility of implementing the proposed wireless network using low cost off-the-shelf components and parts. Students owned the project: they had to generate specifications, establish project plans, procure resources, monitor development costs, and write progress reports. The project team was comprised of three

students, which is a typical team size. Team spirit was fostered through collaborative learning/activities to increase efficiency and ensure timely completion. The professor acted as a facilitator; guiding the group effort, and acting as a problem solving resource.

III. Theoretical Background

Figure 2 is a typical RF wireless link block diagram; it shows how the signal strength changes as it propagate from the transmitter to the receiver. The RF signal strength at the receiver is determined by transmitter power, overall path gain, path losses, signal fading, line of sight (LOS), signal reflections, and Fresnel effects. To ensure a reliable wireless communication network, the signal strength needed to be calculated, measured and analyzed at various locations around the site. A review of the theoretical background is presented below.

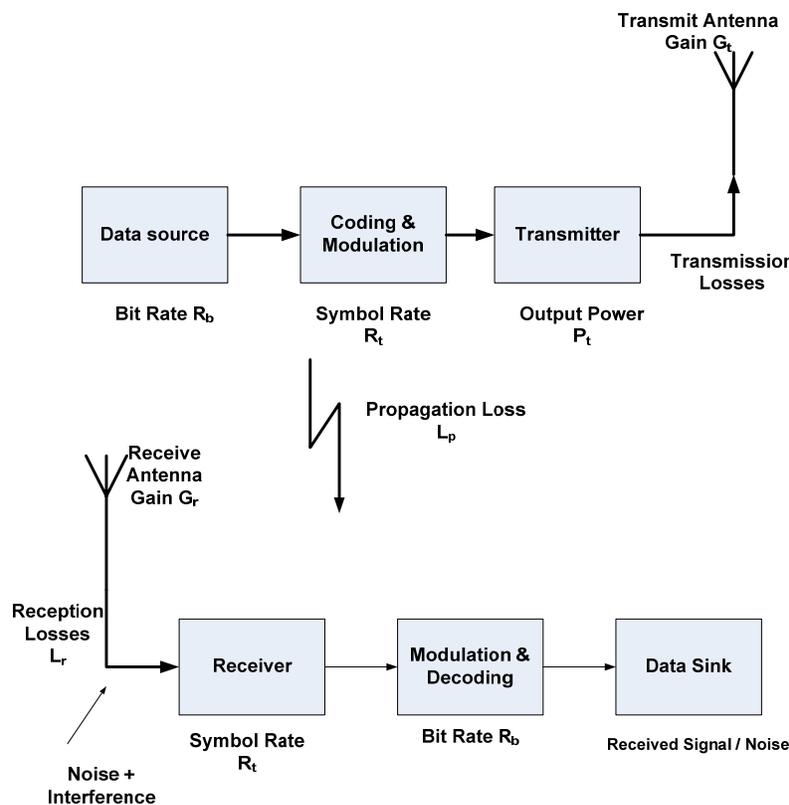


Figure 2: Block diagram of a typical wireless RF link

A. Link Budget Calculations

A link budget calculation (LBC) analyzes the theoretical signal strength at the receiver. It takes account of all the gains and losses the signal encounters as it travels from the transmitter to the receiver. This includes transmitter power, antenna gain, receiver sensitivity, RF cable path losses, free space path loss, and signal fading.

Energy radiating from a point (transmitter) to a destination (receiver) encounters losses. As the signal propagates farther from the source it fades and its strength is reduced by a factor proportional to $1/r^2$, where r is the distance from the transmitter. The total free space path loss is given by the following formula^{2, 4}:

$$\text{Path_Loss (L}_p\text{)} = 92.4 + 20 \text{Log}_{10} (f) + 20 \text{Log}_{10} (d) \tag{1}$$

Where the Path-Loss is in dB, f is the frequency in GHz and d is the distance from the transmitter in kms.

Signal strength is also reduced by another factor besides the free space loss, i.e., the fading margin. The fading margin (F_{margin}) equation⁴ takes into account the losses due to weather/climate, interference due to various transmissions, and terrain changes. It is an additional loss that is added to the free space loss in the analysis and usually important over a long transmission path.

$$F_{\text{margin}} = 30\text{Log}_{10}D + 20\text{Log}_{10} (6 \times A B f) - 10 \text{Log}_{10} (1-R) - 70 \tag{2}$$

Where: F_{margin} =Fade Margin (dB), D=Distance (kms), f=Frequency (GHz) , R=Reliability, (1-R) =Reliability Factor

A, Terrain sensitivity (Roughness Factor)	A=4 over water or very smooth terrain	A=0.25 over a very rough Mountainous terrain	A=1 over an average terrain
B, Climate Annual Availability	B=0.5 Hot/Humid	B=0.25 Average inland area	B=0.125 Very dry mountain area

The above formulae and a link budget calculator from AFAR Communication⁶, shown in figure 3 below, were used to perform the theoretical signal strength calculations. These calculations were then compared to the actual measured signal strengths at different locations away from the transmitter.

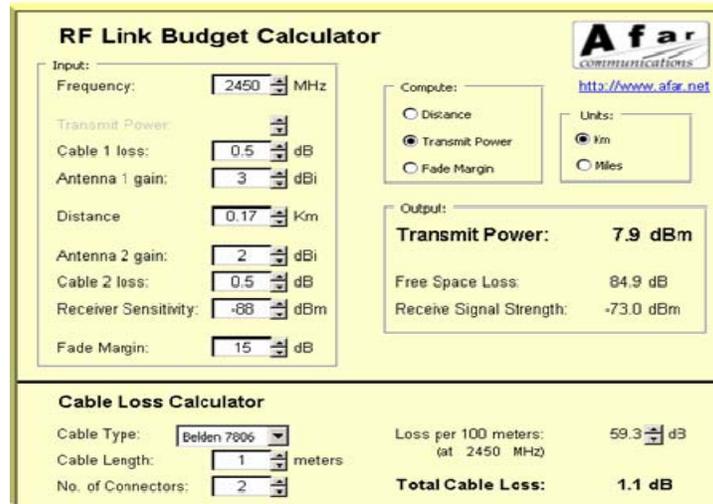


Figure 3: AFAR link budget calculator⁶

B. Line of sight (LOS) & Fresnel Zone

The signal strength is further reduced by obstruction of line of sight (LOS). LOS is a direct straight line between the transmitter antenna and the receiver antenna. The Fresnel zone is important to the integrity of the RF link. It defines an area around LOS that can cause RF interference if blocked^{3,7}. The Fresnel Zone is the theoretical ellipsoid between the two antennas that should be free from obstruction. Any obstructions in this ellipsoid can lead to RF signal interference which prevents the main signal from fully reaching the receiving antenna. Obstructions can be caused by changes in terrain, buildings, trees, etc. The Fresnel calculated value is the perpendicular value from the center of the line of sight between the transmitter and receiver. The distance r (in meters) can be calculated by using the following equation^{7,8}:

$$r = 17.32 \times \sqrt{\frac{d}{4 \times f}} \tag{3}$$

Where: d=distance (kms), f=frequency (GHz)

Figure 4 illustrates the Fresnel Zone; its values in meters are plotted versus distance “d” in kms at a frequency of 2.45 GHz, the operating frequency of the 802.11b wireless network.

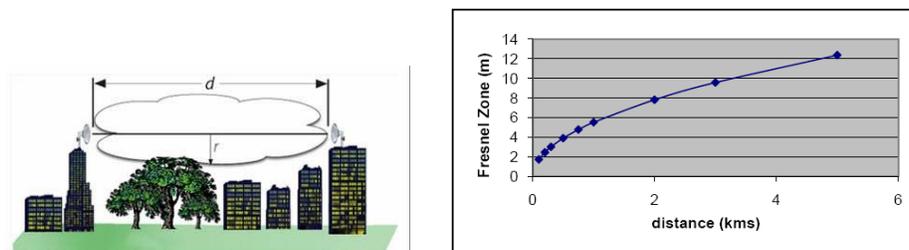


Figure 4: Fresnel Zone^{7,8} and its values vs. d, at 2.45 GHz

On average, a 20% or less obstruction of the Fresnel Zone has minimal effect on signal loss between the transmitter and antenna. Any value greater than 40% has a significant impact on the signal strength between the transmitter and receiver^{7,8}.

IV. Project Planning & Implementation

Thoughtful planning was very important for the success of the project. Project meetings were held and the project plan was discussed with the advisor. The team identified two major tasks. The first task was to determine the required equipment to set up a pilot wireless link, and the venues to procure the equipment. The second was to perform an RF signal strength survey and link budget calculations to determine the most effective and economically feasible wide area wireless pilot network configuration. The team, together with their advisor, investigated the possible resources for the project. Two sources were contacted and acknowledged their willingness to assist the team, the University Office of Technology/ Networking and Operation and Keystone Communication, a local wireless communication company. Both supplied the team with wireless devices and assisted with their industrial and technical expertise. In addition the team decided on two practical wireless books^{7,8} as references during the implementation of the project. With the technical resources secured the team decided to perform a set of experiments to implement different wireless network configurations, analyze their performance and verify their economic feasibility.

V. Experiment 1: University Supplied Equipment

The aim of the first experiment was to implement a simple wireless link using a laptop with a wireless card, and an access point link connected to the university computer. After consultation with the University Networking and Operation engineers, they required the use of their equipment so that they could securely control the wireless access link to the university computer. They provided the team with the following equipment:

Cisco Aironet Access Point, with an output of 100 mw
Omni Directional Antenna with 3 dB gain

The Cisco access point (AP) with its antenna was mounted on the roof of McCormick building, where all the university antennas are located, see figure 5. The team was provided with the AP specification, antenna specification and all the necessary information to facilitate a secure wireless connection between the laptop and the university network.

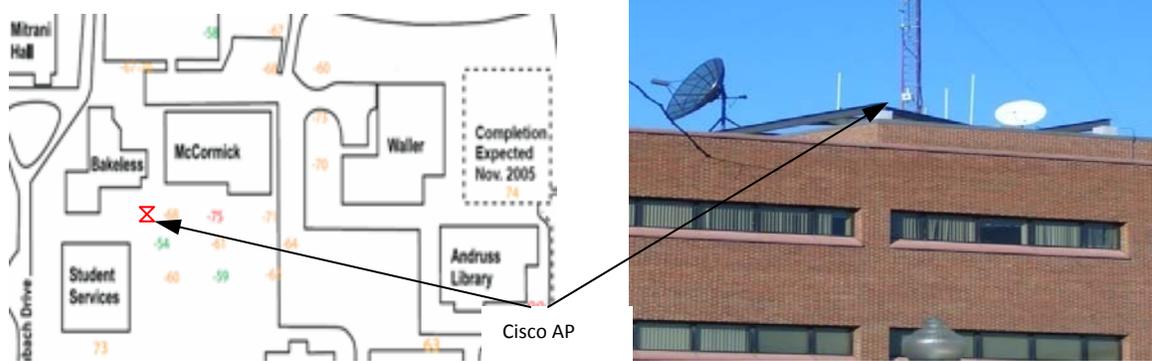


Figure 5: Cisco AP and antenna site location

A. RF Signal Strength Survey

To analyze and evaluate the operation of the pilot system, three circular rings of data centered at the access point, as well as data at a number of distant points, were recorded. The following measurements were taken at each data point:

- Latitude and longitude of each measurement location was established using a GPS device.
- The RF signal strength in dB, signal strength in percent, signal to noise ratio (SNR), and noise level at each location were measured using a laptop with Intel 802.11b PCMCIA card and wireless signal analysis software. The data are tabulated in table III.

Table III: Experiment 1 data

	Description	Location			RF Signal Measurements						
		Latitude	Longitude	Distance from McCormick	LBC value (theoretical)	dB (actual)	% error	Percent Signal Strength	Noise Level	SNR	
1	Ring1	N 41° 00.501'	W 76° 26.838'	.0238M = 126'	-52.9	-75	-29.5	65	-100	28	
2		N 41° 00.518'	W 76° 26.803'	.0367M = 194'	-56.7	-71	-20.1	68	-100	30	
3		N 41° 00.543'	W 76° 26.827'	.0298M = 157'	-54.9	-68	-19.3	69	-100	33	
4		N 41° 00.526'	W 76° 26.890'	.0396M = 209'	-57	-70	-18.6	68	-100	30	
	Ring2										
5		N 41° 00.487'	W 76° 26.854'	.0400M = 211'	-57.5	-54	6.5	76	-100	41	
6		N 41° 00.496'	W 76° 26.828'	.0324M = 171'	-55.6	-61	-8.9	73	-100	39	
7		N 41° 00.517'	W 76° 26.781'	.0559M = 295'	-60.4	-64	-5.6	71	-100	37	
8		N 41° 00.557'	W 76° 26.800'	.0571M = 302'	-60.5	-73	-17.1	66	-100	27	
9		N 41° 00.557'	W 76° 26.828'	.0441M = 233'	-58.3	-67	-13	70	-100	33	
10		N 41° 00.550'	W 76° 26.864'	.0373M = 197'	-51.9	-58	-10.5	74	-100	44	
11		N 41° 00.520'	W 76° 26.900'	.0479M = 253'	-59	-67	-11.9	70	-100	36	
	Ring3										
12		N 41° 00.477'	W 76° 26.839'	.0510M = 269'	-59.6	-60	-0.7	73	-100	39	
13		N 41° 00.485'	W 76° 26.824'	.0453M = 239'	-58.5	-59	-0.8	74	-100	42	
14		N 41° 00.500'	W 76° 26.796'	.0490M = 259'	-59.2	-63	-6	72	-100	41	
15		N 41° 00.539'	W 76° 26.788'	.0538M = 284'	-60	-70	-14.3	68	-100	30	
16		N 41° 00.566'	W 76° 26.812'	.0593M = 313'	-60.9	-60	1.5	73	-100	39	
17		N 41° 00.557'	W 76° 26.881'	.0520M = 275'	-59.7	-58	2.9	74	-100	39	
18		N 41° 00.519'	W 76° 26.909'	.0557M = 294'	-60.3	-68	-11.3	69	-100	31	

Figure 6 shows the signal strength mapping on university site map, together with the table relating signal strength to received signal data speed.



Received Signal Strength	Received Data Speed
> -60db	11 Mb/sec
> -70 dB and <-60dB	5.5 Mb/sec
< -70dB	1-2 Mb/sec

Figure 6: Cisco AP signal strength around McCormick

The measured (actual) signal strength data were compared to the calculated values using AFAR LBC and verified using theoretical calculations; a sample of which is shown below for the highlighted location in table I.

B. Sample Theoretical Calculations

Cisco AP transmitted power= $10 \text{ Log}(100\text{mw}/1\text{mw})= 20\text{dBm}$

Gains: Transmitting antenna1 gain = 3 dBi

Receiving antenna2 gain = 2 dB

Losses: Cable Losses = $0.5\text{dB}/\text{ft} \times 2\text{ft} = 1 \text{ dB}$

Free Space Loss using equation (1):

Path Loss (Lp) = $92.44 + 20 \text{ Log}_{10}(2.450) + 20 \text{ Log}_{10}(.040 * 1.609) = 76.4 \text{ dB}$

Signal strength at the receiver (dBm) = Transmitted signal power in dBm+ Gains – Losses

$20 \text{ dBm} + 3 + 2 - 76.4 - 1 = -52.4 \text{ dBm}$

The measured signal strength=-54 dBm

LBC value = -57.5 dBm

Calculated Theoretical = -52.4 dBm

In the subsequent experiments all the theoretical calculations were done using the AFAR link budget calculator.

C. Data Analysis

Measured Signal strengths less than – 70 dB caused considerable loss in received data speed. This was attributed to the path loss, height and location of the Cisco AP antenna, the output power of the AP, and Fresnel zone effects.

- Percentage error between measured signal strength and LBC values were calculated and tabulated. Locations with high percentage error were attributed to the fact that the theoretical LBC didn't include line of sight (LOS), Fresnel effects, and signal reflection. These readings were utilized as indicators to identify locations with LOS problems, and Fresnel effects, as well as possible effects of RF signal reflections.
- The height of the antenna above the ground was about 40 feet, posing additional problems. The antenna did not have enough down angle to cover the area below the antenna and around the building.
- The gain of the antenna was another significant factor. The AP output power was relatively low, only 20 dBm. Adding the antenna gain of 3 dBi to the output power gives a minimal radiated power of 23 dBm. With this radiated power, transmitting wireless signals over long distances with LOS obstruction can become a major obstacle, which was experienced when testing the coverage area.
- The Fresnel zone was interrupted, at close proximity to the building, by the edge of the roof. A blockage of more than 20% of the Fresnel zone caused a significant loss of signal from transmitter to receiver. This accounts for the lower signal strength even when the actual distance from transmitter to receiver was shorter.
- The transmitting antenna surroundings contributed significantly to the reflection of the RF signal. The university communication tower on top of McCormick building, see figure 5, reflected the transmitted signal, causing the signal strength at the rear of the building to be lower than in front of the building.

D. Concluding Remarks

- The Cisco AP supplied by the university did not perform to the team's expectations.
- The AP and transmitting antenna location, at the university antenna site, was not suitable.
- After consultation with the advisor, the team decided on a different approach, which will be explained in experiments 2 and 3.

VI. Experiment 2: Upper Campus Wireless Link

Using a high security low output AP device supplied by the university presented an obstacle to developing a viable pilot system. The team decided to avoid accessing the university computer by setting up its own wireless network. Keystone Communication, a local communication company, was willing to supply the team with a variety of Access Points, Bridges, and antennas. Table IV below shows the equipment procured by the team:

Table IV: Procured equipment

Equipment	Manufacturer/Model	Specification	RF Connector Type
Wireless Bridge	Engenius Bridge EL2611 CB3	802.11b, 200mw, 2.4-2.484 GHz	TNC F/Reverse
Access Points(AP)	Engenius Bridge EL2611 CB3	802.11b, 200mw, 2.4-2.484 GHz	TNC F/Reverse
Antennas/Bridge	RT24-14	14 dBi, Vertically Polarized, 2.4-2.484 GHz 2.4-2.484 GHz	MMCX
Antennas/AP	HGV-2409U	8.5 dBi 2.4-2.484 GHz	N Type Bulkhead
Mini PCI Laptop Wireless Network Adapter	Intel PRO/Wireless 2200 BG Network connection	Data rate 54 Mb, Sensitivity -89 dBm @ 54 Mbs	Antenna interface connector mates with connector FL-LP-066

The pilot wireless network, shown in figure 7, was set up. Two laptop computers were used, sending information between each other. One, the master computer, was hardwired to a wireless bridge, using an Ethernet CAT5 cable. The bridge, acting as a main base station, was linked wirelessly to an AP acting as a picocell. The second computer, the user laptop, communicated wirelessly through the AP and the main base station to the master computer.

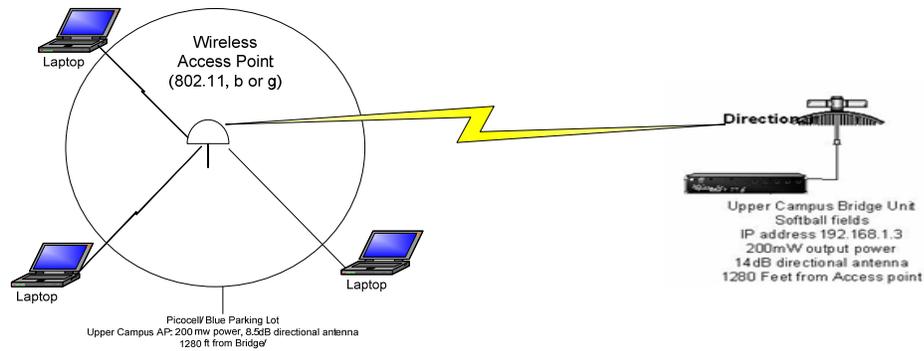


Figure 7: Wireless network set-up for experiment 2

RF signal strength measurements taken at different locations are tabulated in table V, together with theoretical values using the AFAR LBC.

Table V: RF signal strength measurements for experiment 2

	Description	Location				Signal Strength			
		Latitude	Longitude	Distance (From Picocell)	LBC value (theoretical)	dB (actual)	% error		
	Bridge	N	41°01.052'	W	76°27.047'				
1	Picocell	N	41°00.971'	W	76°27.301'	.2399M = 1267' (from bridge)	-12.4	-35	-64.6
2	Volleyball	N	41°00.889'	W	76°27.352'	0.1044M = 551'	-52.8	-54	-2.2
3	FH fields	N	41°00.895'	W	76°27.226'	0.1092M = 576'	-53.2	-77	-30.9
4	Blue Lot (back)	N	41°01.000'	W	76°27.392'	0.0859M = 453'	-51.1	-56	-8.8
5	No LOS	N	41°00.969'	W	76°27.412'	0.0966M = 510'	-52.1	-61	-14.6
6	Along Road	N	41°01.000'	W	76°27.188'	0.1038M = 548'	-52.7	-65	-18.9
7	Field Corner (stop sign)	N	41°01.001'	W	76°27.137'	0.1518M = 801'	-56	-67	-16.4
8	By bridge (max distance)	N	41°01.002'	W	76°27.055'	0.2304M = 1216'	-59.7	-73	-18.2

The signal strength data from the above table are mapped to the measurement locations on campus, see figure 8.



Figure 8: Mapping of signal strength data

A. Data Analysis

The team was encouraged with the operation of this system. The results indicated a large increase in signal strength over a longer distance, 1267 feet, between the bridge and AP. This is a considerable improvement compared to the set up of Experiment 1 using the Cisco access point. The user laptop was able to communicate with the AP over a distance greater than 500 feet, see measurements 2-6 in table III. Overall the user was able to communicate back and forth with the master computer over a distance exceeding 1700 ft. Some of the problems encountered were due to several different variables: networking laptops, obtaining a perfect 500ft. radius circle between the user laptop and the AP, and Fresnel zone interference.

- When mapping out the signal strength circles several different problems were encountered due to elevation changes between the AP and user laptop. At certain locations the lines of sight were at least 20 ft higher or lower than the AP, limiting signal strength and thereby the connectivity between the user laptop and AP.
- As with any RF signal there are always concerns with objects in the Fresnel zone. At a point near the edge of the soccer field the entire Fresnel zone was located in the soccer field. This limited the signal strength received by the laptop.

VII. Experiment 3: Upper to Lower Campus Wireless Link Analysis

With the successful results of Experiment 2, the team decided on further increasing the wireless communication link range, using a similar configuration with the same equipment. The bridge, acting as the main base station, was mounted on top of one vehicle parked on upper campus. The AP, acting as the picocell, was mounted on a second vehicle parked on lower campus. A laptop, the master computer, was attached to the Bridge via a cross-over Ethernet cable. Similar to the

previous experiment the user computer communicated wirelessly, through the picocell and the main base station, to the master computer. A radius of 500 ft from the access point was measured. Signal strength and data transfer speed measurements were recorded around the circle, using the user computer, which is connected wirelessly to the picocell (AP). The upload and download speeds were determined by transferring a 3 MB data file from one computer to the other. Measured signal strength data, together with upload and download speeds, are tabulated in table VI.

Table VI: Experiment 3 data

	Description	Measurement Location				Signal Strength		Speed	
		Latitude	Longitude	LBC value	dB (actual)	Download kb/s	Upload kb/s		
1	Access Point(AP)	N 41°00.513	W 76°26.800	-12.4	-35	550.29	490.33		
2	Point 1(Student Service)	N 41°00.457	W 76°26.860	-50.8	-59	311.12	289.43		
3	Point 2(Centennial)	N 41°00.488	W 76°26.779	-45.1	-42	434.8	389.37		
4	Point 3(Courtyard)	N 41°00.457	W 76°26.834	-49.4	-52	340.65	319.71		
5	Point 4(Bakeless)	N 41°00.481	W 76°26.856	-48.1	-45	318.42	289.62		
6	Point 5 (Bakeless-S. Street)	N 41°00.475	W 76°26.899	-52.1	-67	288.1	260.98		
7	Point 6 (Behind McCormick)	N 41°00.528	W 76°26.886	-50.1	-76	216.07	210.97		
8	Point 7(Lightstreet Rd.)	N 41°00.582	W 76°26.841	-51.2	-68	192.03	192.03		
9	point 8 (Behind Waller)	N 41°00.601	W 76°26.740	-53.6	-77	98.43	89.03		
10	Point 9(Tennis Courts)	N 41°00.587	W 76°26.671	-55.4	-73	135.65	128.84		
11	Point 10(Behind Library)	N 41°00.552	W 76°26.655	-55	-64	226.34	218.48		
12	Point 11(Black Lot)	N 41°00.485	W 76°26.694	-52.2	-60	297.43	276.75		
13	Point 12(Hartline)	N 41°00.439	W 76°26.756	-51.8	-59	289.23	259.03		

Figure 9 shows the mapping of the data points along with signal strength labeled on university lower campus layout.

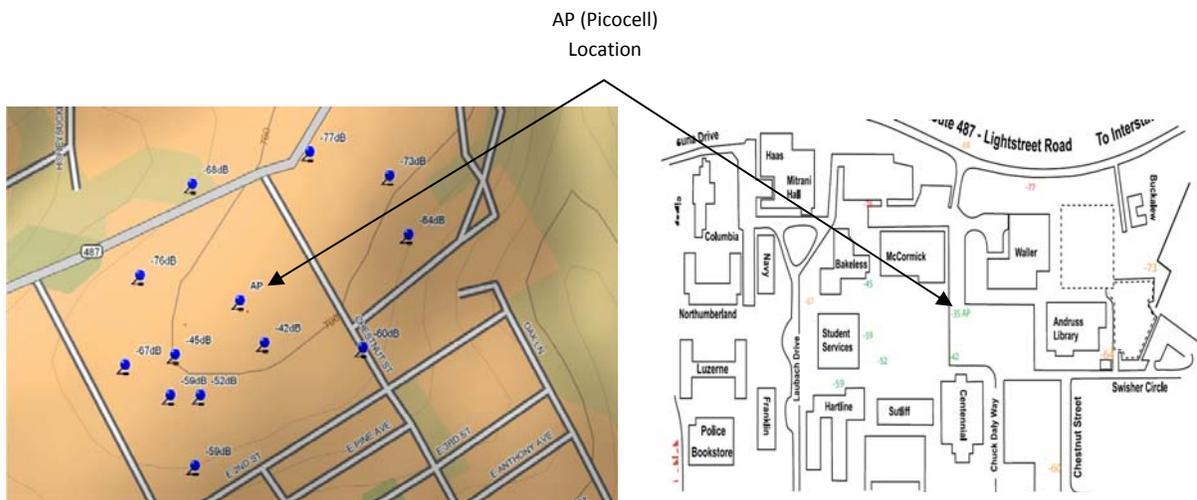


Figure 9: Data mapping for experiment 3

A. Data Analysis

The team successfully extended the 802.11 wireless links over a distance of half a mile between the upper and lower campus.

- The topography surrounding the AP in the lower campus library parking lot has scattered buildings and trees and as a result, the 500ft radius, with unobstructed LOS, was hard to obtain. The radius was held to as rigidly as possible but at some locations it was impossible to obtain the necessary distance.
- The Fresnel zone was intermittently intersected by the various buildings and landform features present on lower campus. As more objects entered the Fresnel zone between the AP and the user laptop the signal strength dissipated accordingly.
- The use of a high output power AP, with high gain antenna located at a height of 10 ft above ground allowed a better signal distribution and strength

VIII. Experiment 4: Catawissa Mountain to Upper Campus Wireless Link

Having gained the skills in setting up wireless networks, handling RF cables and devices, performing signal strength measurements, and the link budget calculations; the team endeavored to a more ambitious experiment. This experiment was performed using two Engenius Access point/ bridges, supplied by Keystone Communications, one mounted on a tower atop Catawissa Mountain. A directional antenna was used and aimed toward upper campus. The other was mounted on a car parked on upper campus. Keystone Communications allowed the team to mount the bridge on a tower on Catawissa Mountain, and a network (IP) camera was attached to the Bridge via a cross-over Ethernet cable. This acted as a base from which signals were sent to an AP, acting as a picocell, that communicated information wirelessly back and forth between the IP Camera and the user laptop at the upper campus. The user laptop accessed the IP camera at Catawissa Mountain, retrieving video and audio signals from the camera at 10 frames per second.



Figure 10: The Bridge and its installation on the tower

Prior to establishing the video link, RF signal strengths and data transfer speeds were measured at various locations around the lower and upper campuses using the user laptop and communicating to the bridge at Catawissa Mountain through the picocell. The measured data is tabulated in table VII.

Table VII: Percent RF signal strength and data rate at various locations on campus

Description	Signal Strength & Data Rate		
	Distance Mile from Tower at Catawissa	Speed Mb/sec	Percent Signal Strength
Hartline	4.88	11	41
Tri Level	4.78	5.5	19
Monty's Parking lot	5.4	11	46
Behind Nelson Field	5.6	11	36
Blue Lot	5.56	11	41
Welch Circle	5.56	11	36

Figure 11 below is a map indicating the data collection points labeled with their corresponding signal strength.

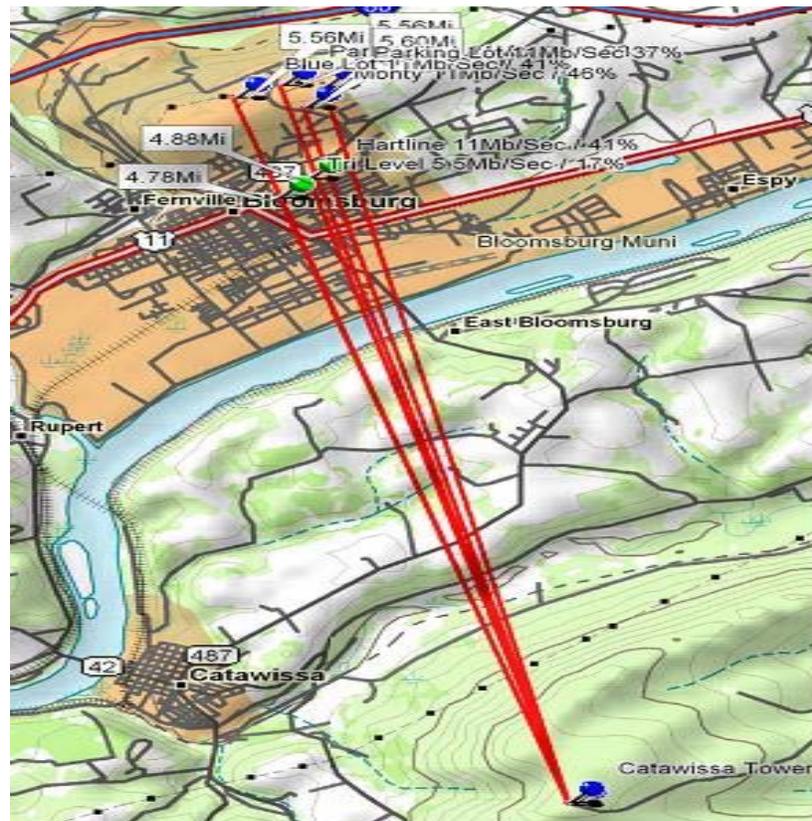


Figure 11: Mapping of RF signal measurements taken at upper campus

Problems encountered in this experiment were: distance, line of sight, tower locations, beam width, beam direction, down-angle and mounting location.

- Distance was the first obstacle that needed to be overcome, as the distance from Catawissa Mountain to Upper Campus is 5.60 Miles. Using a 200mW (23dBm) transmitter power, two directional antennas were needed to overcome the path loss present between the two points.
- LOS was obstructed by mountainous terrain and trees. This was solved by locating the antenna on top of a tower at the far side of the ridge to obtain a good line of sight to the university campus, thereby completing the wireless link from Catawissa Mt. to upper campus. When traversing long distances with low power units, large gain directional antennas are suited for the application.
- Another drawback is the limited beam width at greater distances. Proper beam aiming of the directional antenna and allowing the antenna to have a downward tilt provided enough beam width to encompass most of the campus. Sufficient signal strength was established to provide a good wireless communication link and to send streaming live video over 5.6 miles.

IX. Cost Analysis

There were many products capable of functioning in the tested scenarios. Cost analysis was performed on three sets of products, two of which were used in the experiments, and another which is available from the Motorola Canopy. The team concluded that the most economically feasible system configuration would be achieved using the set “2” equipment, see table VIII.

Table VIII: Cost analysis

Set	Equipment	Cost(\$)	Total(\$)
1	University Cisco Aironet Access	2000	2200
	Antennas(2)	200	
2	Engenius Access Point	100	300
	Engenius Bridge	100	
	Antennas (2)	100	
3	Motorola Canopy Access Point	600-	1300- 1700
	Motorola Canopy Bridge	600-	
	Antennas (2)	100	

X. Team Achievement

Technically, the team achieved valuable results which will be used to pursue future research:

- The feasibility of extending the range of the existing university wireless network to cover the whole campus and beyond was verified through received signal strength surveys and data rate analysis.
- Using AP as a wireless picocell facilitated a reliable wireless communication link between the user’s laptop, from multiple locations on the campus, and the base station. The wireless link was achieved over a distance exceeding 5 miles, using low cost off-the-shelf components.

- Establishing a wireless link over 5 miles, using low cost components, can be utilized to provide broadband wireless internet to the rural areas around the university, where no high speed internet is available.
- Long distance streamed video transmission, over 5 miles, was achieved.

XI. Assessment and Suggestions for Improvements

Qualitative assessment of the project was performed by polling the team's response to the outcome of the project and a summary of their responses are outlined below:

- The project enhanced their knowledge in RF communication
- Working on developing a wireless communication network was an excellent venue to apply knowledge gained in class to real life practical design problems
- Team work and good planning is essential for the success of any project, especially when timely implementation is required.
- The team gained valuable practical technical knowledge and experience by collaborating with local wireless companies.
- The experiments required diversified knowledge; the team suggested to have more focused project specification.
- Also, for a project of this size, it would be a good idea to divide the work into tasks assigned to more than one team; one team on networking, one team on RF surveys, and one team on antennas.
- The team would like to see this project further developed and implemented as part of the university wireless network.

XII. Conclusion

The project based learning approach proved to be a valuable technique to enhance student knowledge. It helped to bridge the gap between what the student learned in the traditional lecture/lab setting and the real life experience. In any real life environment, economic feasibility of any project is of prime importance. Integrating this into the project was indeed a viable tool that helped to enhance and expand student knowledge. The knowledge gained was otherwise unattainable during the limited 2 hour lecture/two hour lab allocated to the course. The students started the project with only basic knowledge and skills in RF communication attained through the lectures and lab experiments. They had to implement the project within a tight schedule over a period of six weeks, analyze their design, and determine its economical feasibility. The essence of success of the project implementation was good team work and well timed planning. They gained valuable industrial experience interacting with the Office of Technology staff and Keystone Communications engineers. This experience was otherwise not attainable during a traditional lectures/labs approach. Integrating a similar project, with focused specification, within the RF course in an EET program will provide the engineering technologist with the entry level practical experience needed by the industry.

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