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A Review of Setup Practices and Procedures for Creating IEEE 802.11 Wireless Community Networks

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A REVIEW OF SETUP PRACTICES AND PROCEDURES FOR CREATING IEEE 802.11 WIRELESS COMMUNITY NETWORKS

by

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GRADUATE COMMITTEE APPROVAL

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ABSTRACT

A REVIEW OF SETUP PRACTICES AND PROCEDURES FOR CREATING IEEE 802.11 WIRELESS COMMUNITY NETWORKS

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IEEE 802.11 wireless networking equipment has made it possible to bridge the last mile for new broadband internet service providers. Inexpensive wireless networking equipment and high gain antennas enable high speed internet delivery at a fraction of the cost of installing or upgrading land lines for cable or DSL services. Based on this research, a guide of general practices and procedures is proposed for designing, installing, and maintaining a reliable wireless community area network. Included tests have provided performance results for several types of wireless antennas (including wire grid parabolic dishes, Yagi and Vagi styles, and echo backfire), wireless bridges, and other factors which influence overall signal strength and throughput. Two separate configurations are recommended. The first configuration is based on high reliability, longer distances, and low error rates. The second recommendation is based on lower overall cost, ease of installation, and shorter link distances.

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

Chapter 1

1 INTRODUCTION

1.1 Background

The "last mile" is commonly known as the distance in which a reliable communications medium is unavailable between a data provider and the end user. The actual distance can be as short as a few feet or as long as several hundred miles. In most cases, the final branching to each individual user on the network is the most expensive part of a network to install. This is simply due to the sheer number of connecting feeds needed in single bus and hub-based branching networks. Digging up roads, sidewalks and yards to bury new cabling can cost thousands of dollars per line for service providers. The problem which occurs is that most service providers will not complete last mile connections if it is not profitable. As applicable to this thesis, the last mile problem will refer to any inadequacy or void in the connection medium between an internet service provider and potential end user.

Internet service providers have been using various existing mediums to bridge the last mile. Digital Subscriber Lines (DSL) utilize the twisted pair wiring used in existing telephone lines to deliver speeds from 128 Kbps to 7 Mbps. Cable ISPs such as Comcast and Roadrunner use existing coaxial cable to offer speeds up to 3 Mbps. Satellite ISPs use small roof-mounted satellite dishes similar to those used by Dish Network and DirectTV. Satellite services are able to achieve download speeds up to 500 Kbps.

Each of these has their own set of technical constraints and drawbacks:

- The upload speed of DSL is usually much slower than download speed and phone lines must meet requirements of thickness, quality, and proximity to the hub.
- Cable networks use a bus topology in which service is shared throughout an area, which results in slower overall speeds during high-usage times. Coaxial cable lines must also meet requirements of quality and proximity to the bus feed.
- Residential satellite services tend to be very expensive and slow when compared to cable and DSL alternatives. Satellite is often only used in remote locations as a last resort.

Wireless technology is not new to computer networks, but until recently has not been a widely accepted mode for network data transfer. This was possibly due to difficult setup procedures, high equipment costs, and/or non-interoperable proprietary equipment. In 1999, the IEEE approved a new wireless networking standard known as IEEE 802.11b. The new wireless network standard led to equipment that was cheaper, fully interoperable, and relatively easy to set up. Although initially quite expensive, aggressive sales, high equipment availability, and rebate programs now make the 2.4 GHz access points and client cards available for less than 60 dollars a set.

Based on Ethernet compatible data standards, the equipment can be used for anything from networking computers in older non-wired buildings to providing internet access “hot spots” for laptop users in cafes and other convenient areas. Many ISPs are expanding on that idea to bridge the last mile by extending the original 300 meter range to several miles by using specialized antennas and rooftop broadcast points.

In speaking with the owners and management of several local wireless ISPs (WISPs) attempting this point-to-multipoint fixed wireless solution, some general observations were made about their respective companies. They are mainly small local companies, usually with fewer than 10 employees, with the majority working in sales or equipment installation. Most of the companies were started by a few friends wirelessly sharing a single high speed internet connection and splitting the cost. Soon after, they realized the possibility of reselling service for a small profit and formed their own wireless ISP.

Inexperience in WISP networks during the early stages of design and development may lead to problematic and unreliable service as the subscriber pool grows. There are several factors that enter into the equation early on that are often not addressed properly by those designing the network.

Some typical problems can be illustrated by experiences at a local WISP which was plagued by problems stemming from a poor initial design. While working with this WISP, the author received numerous complaints from customers about the service. The complaints centered on slower speeds than stated, high percentages of packet loss, and broken network connections. To remedy the problems, client-side radios were replaced, antennas were upgraded to get higher gain, and base station amplifiers were implemented. These were all just patches used to remedy earlier design flaws in the network and marginal client installations that probably should not have been added due to low signal strength.

The system installers working for this particular WISP used an iPAQ handheld PocketPC running NetStumbler (which displays received signal strength) with an Orinoco wireless card to perform qualifying site surveys. A 15 dBi parabolic dish antenna was usually used to test average signal strength. Anything receiving greater than a 17 dB signal-to-noise ratio (SNR) was approved and installed. The majority of customer links installed with low signal strength had problems. As an attempt to remedy the low signal strength, amplifiers were added to the base access point units. The result of using the amplified broadcast signal was an overall boost in signal strength readings. Logically, using amplifiers on the access points also expanded the area capable of receiving the signal. The client bridges were receiving a better signal than before, and yet the number of problem spots escalated. New installations that were located further away from the access point were having many types of throughput issues.

In some cases, customers were told that poor weather was to blame for slow performance. In others, customers were told that the equipment was being updated (which it was) and that future speeds would be much better. Customer premise installations took place based on signal strength, paying little attention to line-of-sight and Fresnel zone link requirements. A multitude of problems arose, but installations continued without thought of personal fault, always blaming other sources.

Admittedly, not all problems are caused by inexperience. Weather has a known effect on wireless communications, both on the link itself and on radio equipment and connections. Noise is also an important factor which can disrupt service and must be addressed during design procedures and monitored. Problems such as these can be avoided or minimized with appropriate design procedures.

WISPs can provide a very valuable service in bridging the last mile. It is already a proven method for bridging the last mile and has been successfully implemented in many areas. Although there many issues which may effect network reliability, if general design and setup guidelines are followed and capacity is not exceeded, the resultant WISP can be profitable and provide reliable service.

1.2 Problem Statement

Delivering fast and reliable service to paying subscribers is a key factor in customer satisfaction for a long term business. Wireless ISPs face a different set of problems than their wired counterparts. The main parts of any WISP are the antennas, radios, and the connecting cables between the equipment. Each of these parts is susceptible to human error during the four phases of WISP growth. These phases are: design, network backbone setup, subscriber rollout, and expansion into new areas. Furthermore, an environmental factor which includes planning around local terrain, foliage growth, future construction, and weather conditions must be anticipated during each phase of growth. Failure to do so will result in slow and unreliable service.

Specific conditions which lead to poor performance may be caused by any of the following:

- Improper use of amplifiers
- Improper equipment placement
- Using inadequate weatherproof enclosures for equipment
- Failure to allow adequate signal strength buffer to compensate for bad weather and other unforeseeable obstacles

- Using incompatible or unmatched equipment
- Using substandard equipment for the network backbone
- Overselling the available bandwidth
- Exceeding the ratio of maximum users to bandwidth on a single radio

Any WISP network that begins with a poor design will undoubtedly suffer more and more as the subscriber base increases.

1.3 Hypothesis

The question of whether or not wireless networks can be used effectively to bridge the last mile has been successfully answered. It can, and has been done for several years now. There are many existing WISP networks in operation today. Many of them are excellent examples of reliability. Unfortunately, some of them are plagued with problems and yet continue to add users.

In an effort to enable higher quality wireless town area networks, this research focuses on:

- providing useful information for inexperienced designers and installers,
- determining equipment factors which greatest influence link reliability,
- determining the extent to which weather can influence network stability,
- and providing an in depth analysis model for achieving optimal links.

It is the intent of this research to ascertain the most advantageous setup for deploying a wireless town area network. This has been achieved through a two part process of research and test procedures. The research was used to identify "best practice" setup procedures, including location selection, initial site survey, network design layout, and basic hardware installation procedures. The testing portion was used to test and resolve questions concerning effects of weather and obstructions, antenna quality and proper usage practices, and differences in equipment features.

1.4 Justification

The last mile has caused many problems for service providers and will continue to do so. Wireless technologies have been used to bridge the gap and notably some setups work much better than others. As stated above, most wireless ISP's are learning from trial and error how to install and run a wireless network. Given that the frequency range being used most widely falls within the open-use Industrial Scientific Medical (ISM) band, there is no requirement for network designers and installers to be licensed RF technicians, but they should be educated on how the equipment works and what conditions will work best.

At the time of writing this paper, no other work has been identified that shows the actual documented effects of antennas, radios and environmental factors in combination to suggest that there is a superior method and configuration for building wireless networks. There are several books and papers containing recommended procedures for outdoor setup which include basic equations for calculating distances and required power levels. This thesis provides experimental data beyond the basic equations to map actual network speeds when using varied equipment and antennas at given distances. It also provides recommendations for proper design practices to increase the effectiveness and reliability of any wireless town area network.

1.5 Methodology

Perhaps the most important part in analyzing the effectiveness of a wireless town area network is to identify similar desirable traits shared with its wired network counterparts. Some factors which may affect choice of service for a broadband connection include price, connection speed, customer service, network reliability, and ease of use. This research will investigate the key technical areas of speed and reliability. Price and customer service aspects will not be covered here.

Several tests have been designed to determine which factors influence wireless network speed and connection reliability. The tests focused around using readily available and field-tested wireless equipment including access points, bridges, antennas, and enclosures. Measurements were made using basic 'ping' tests and a program called PingPlotter to determine up-time. Throughput will be tested using on-site peer-to-peer file transfers using an FTP server-client setting. Tests were performed in an attempt to determine best-case setup scenarios using variables such as different antenna types and gains, radio equipment, and environmental effects. Each test setup used the basic practices for designing and building high-performance reliable wireless networks as researched and outlined in chapters two and three.

1.6 Assumptions

It is important to realize that there is no such thing as a perfect wireless network. In fact, the IEEE 802.11b standard was handicapped to begin with. The FCC created the ISM band and assigned it for public use in part because of existing disruptive interference in that particular area of the radio spectrum. Microwave ovens, baby monitors, wireless phones, Bluetooth enabled devices, and a host of other devices create noise which can cause any number of problems that would be difficult to pinpoint and resolve. These high frequency radio waves are also degraded by obstructions between broadcaster and receiver and require clear line of sight. Trees, houses, buildings, mountains, and even lakes can be difficult – if not impossible – to penetrate or cross. The electromagnetic field surrounding power lines is also thought to significantly degrade performance.

The goal is not to create a flawless network. It is to create the most reliable wireless network available given the current equipment on the market, the broadcast technologies available, and the environmental conditions in the area.

1.7 Delimitations

The purpose for this testing was to arrive at a general conclusion about what equipment and design combinations provide optimal connectivity for both throughput and reliability for a WISP town area network.

The privacy and security of the system must also be considered. Wireless security consists of two parts. The first is encrypting the data to keep it secure, the second is authentication to keep unwanted users out. Since most WISPs desire to keep setup simple and reduce as many points of confusion as possible, data encryption in the form of WEP or WPA is often kept to a minimum. However, it is very important for WISPs to use some type of authentication method such as MAC address filtering or some type of authentication server to keep intruders from gaining free access to the network.

In this test case, the access connection was provided from the BYU School of Technology lab access network. It was therefore imperative that the network be kept secure. This was achieved by using both MAC address filters on the access point for authentication and WEP encryption for data security. This dual security system provided sufficient security for the research project, and no problems were encountered during the research program.

All equipment used in testing was unmodified IEEE 802.11b certified with the latest firmware version loaded. In cases where the most recent version of firmware did not interoperate with the other equipment used, the most recent compatible version was used.

As generally stated above, only hardware configurations were tested. All software settings were set to optimal levels as given in the equipment setup manuals and remained fixed throughout the testing procedures.

Only one extended network was used for testing. All general conclusions are derived from this one network and related research.

Chapter 2

2 REVIEW OF LITERATURE

2.1 Broadband Internet Access

The term “broadband internet” has many different definitions which include data rate speed requirements and types of connections. As used in this thesis, the term “broadband” will refer to any internet connection faster than 56 Kbps dial-up.

Broadband internet access is a valued service to most internet users. Many users are making the switch from dial-up modem access to much faster cable broadband, DSL and other types of service. The reasons for switching to broadband vary for each individual. For some, it may be a work requirement (e.g., work-from-home telecommuters). For others, the reason may be as simple as a gamer wanting the fastest connection available to enable lag-free online games. The need is strong and current growth is steadily rising.

2.1.1 Broadband Need

As technology advances and computer hardware accelerates, there is a need to transfer data at faster and faster speeds. At one point in time this was thought to be a need only for medium to large businesses with large amounts of information to be moved quickly from point A to point B. In today’s world, the need to move data quickly has become increasingly important to the average home computer user. As end users have demanded more from their Internet access, they have upgraded hardware and software systems to deliver rich, dynamic content – the highest performance processors, broadband modems, the fastest corporate networks and intranets (Last-Mile 2003). With massive downloadable applications, the growth of fast online gaming, file sharing at an all-time high, and voice over IP on the horizon, dial-up internet access is quickly being replaced by faster alternatives.

2.1.2 Household Broadband Growth

As of March 2004, the Nielsen//NetRatings reports that 45.97% of active Internet users enjoy some type of broadband internet connection (WebsiteOptimization 2004). USA Today reports from the Pew Internet & American Life Project showing a 60% increase in broadband household users from 30 million in March 2003, to more than 48 million in February of 2004. DSL provides approximately 42% of the home broadband market, up from 28% in 2003 (Baig 2004).

Why the move to broadband? Nearly 60% of Pew respondents made the switch because they felt dial-up was too slow, frustrating, or downloads took too long. Only 3% switched because of the affordability of broadband. Geographically, only about 10% of people living in rural areas can receive broadband connections at home. In comparison, about 30% of people who do not live in rural areas are using broadband connections (Baig 2004).

Figure 2-1 shows the increase by percentage in broadband Internet usage trends as compared to modem usage for U.S. residences.

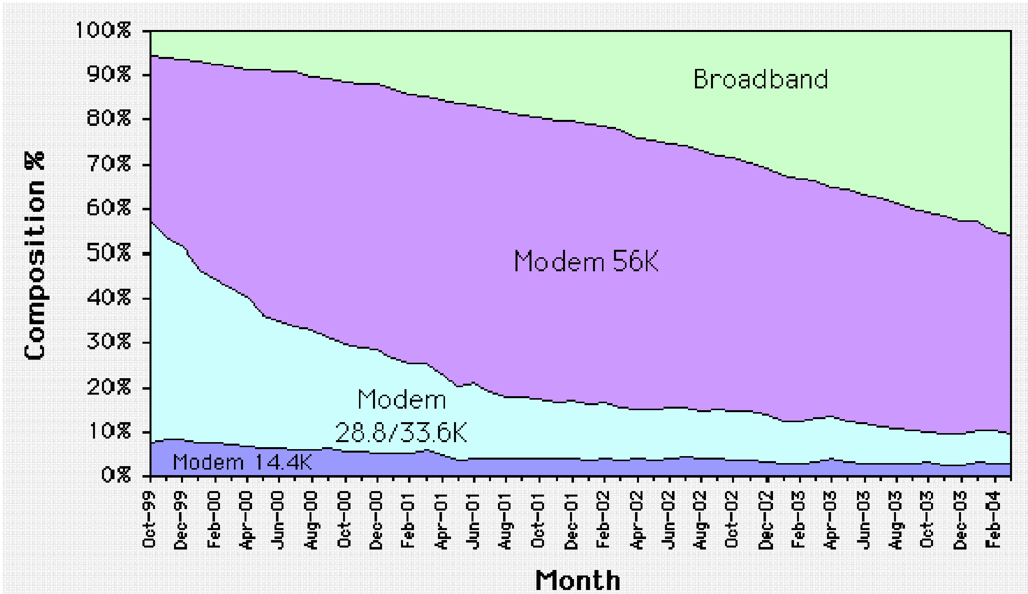


Figure 2-1 Residential broadband vs. dial-up modem trends (WebsiteOptimization 2004)

Figure 2-2 shows the measured and predicted U.S. growth for residential broadband use. Assuming the predicted future is correct, the industry should see almost 80% of all internet users getting broadband Internet access by mid 2006 (WebsiteOptimization 2004).

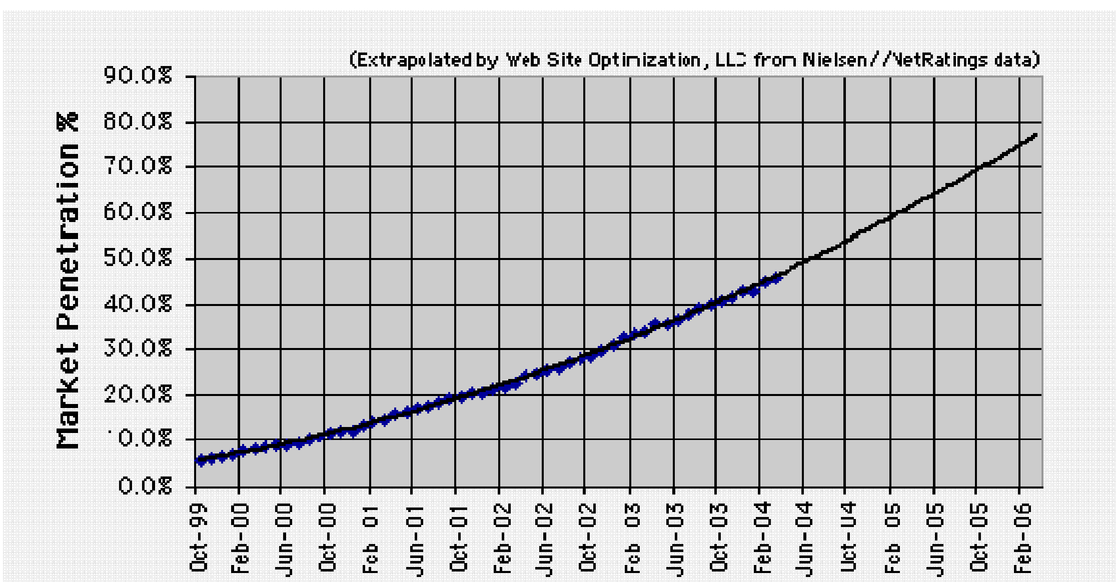


Figure 2-2 Broadband measured and predicted growth trends (WebsiteOptimization 2004)

2.1.3 Broadband Service Options

Although the numbers and graphs presented above suggest that broadband internet access will continue to increase at the rate at which it has been growing, it is likely it will not. It appears as though providers are reaching profitability/population saturation points using existing and proposed wired infrastructure. Low density areas in which customer numbers do not justify the expense of installing internet gateway equipment are unlikely to get broadband access. Users living in older areas of town where proper wiring does not exist are also unlikely to qualify without the costly expense of laying new lines.

Engineers have long been creating new ways to reduce costs by better utilizing existing phone and cable lines. DSL and cable broadband are the two main current broadband technologies. DSL uses existing phone lines to connect to a central office up to 5500 meters away (that is actual cable length, not straight-line distance). Cable television lines are used for broadband cable connections, provided the existing cables meet certain criteria. Cable connections can support a higher data bandwidth, and can provide service beyond DSL's 5500 meter limit. Cable is also an analog signal, whereas DSL is digital. This means that in certain cases the cable network is more susceptible to RF noise and interference. DSL is a dedicated circuit so that other users will not significantly affect overall speeds. Cable is a shared medium which may result in slow speeds and other latency issues during periods of high usage. DSL will usually have asynchronous download/upload speeds with higher downstream speed than up (DSLReports 2004 a).

Other broadband services available include T1/T3 lines, ISDN, Frame Relay, high earth orbit satellite, high speed fixed wireless (Local Multipoint Distribution System or LMDS), spread spectrum wireless, U-NII wireless, low earth orbit (LEO) satellite, optical-over-air, hybrid wireless/fixed line, high altitude transmitters, high speed mobile wireless (3G), Broadband over Power Line (BPL), and iBLAST. Many of these are proprietary systems and widespread adoption is slow as a result of high deployment costs, subscriber costs, wiring needs, reliability, lack of standardization, and many other obstacles (DSLReports 2004 b).

2.2 Spread Spectrum Fixed Wireless

Wireless alternatives to land lines have increased in popularity over the last few years for providing access across the last mile. Small wireless ISPs, or WISPs, have been appearing worldwide. These wireless networks range from free community shared-access networks to for-profit companies covering large areas. As initial setup costs enter into the equation, the option of using inexpensive off-the-shelf 802.11 wireless equipment is much more appealing than laying new cables to accommodate higher bandwidth. This also gives local businesses an opportunity to enter a market that has been dominated by land-line owners such as cable and telephone companies. The technology is easy to deploy and since it does not require any existing infrastructure, setup costs are comparatively quite low. The radio frequency spectrum it uses is unlicensed, so it is free of licensing fees. All this, combined with low operating overhead, make the WISP market a very appealing venture (Dornan 2003).

2.2.1 IEEE 802.11a/b/g

There are three main standards for IEEE 802.11 wireless: 802.11a, 802.11b, and 802.11g. Equipment which uses 802.11b and g use the same 2.4 GHz frequency, whereas 802.11a uses three different bands in the 5 GHz range. Table 2.1 shows a summary of the three current wireless standards.

Table 2.1 IEEE 802.11a/b/g standards (Cisco 2004 a, Cisco 2004 b, Flickenger 2002, and Gast 2002)

	IEEE 802.11a	**IEEE 802.11b**	**IEEE 802.11g**
Maximum data rate	54 Mbps	11 Mbps	54 Mbps
Supported Rates	54, 48, 36, 24 ,18, 12, 9, 6 Mbps	11, 5.5, 2, 1 Mbps	54, 48, 36, 24, 18, 12, 11, 9, 6, 5.5, 2, 1 Mbps
Spread spectrum technology	OFDM	DSSS	OFDM (and DSSS for 802.11b compatibility)
Frequency use	5.15GHz - 5.25 GHz 5.25GHz - 5.35 GHz 5.725 GHz – 5.825 GHz (UNII lower, mid and upper channels)	2.401 GHz – 2.4730 GHz (License free ISM band)	2.401 GHz – 2.4730 GHz (License free ISM band)
Number of channels	12 available 8 commonly used 12 non-overlapping	14 available 11 for use in U.S. 3 non-overlapping	14 available 11 for use in U.S. 3 non-overlapping
Channel width	20 MHz	22MHz	22MHz
Channel separation	20 MHz	5 MHz	5 MHz
Modulation Techniques	64 QAM 16 QAM QPSK BPSK	64 QAM 16 QAM CCK QPSK BPSK	CCK QPSK BPSK
Back off times Slots/milliseconds	15 slots 9 milliseconds	31 slots 20 microseconds	With ‘b’ clients: 31 slots 20 microseconds With ‘g’ only: 15 slots 9 milliseconds
QAM - Quadrature Amplitude Modulation QPSK - Quadrature Phase Shift Keying CCK - Complimentary Code Keying BPSK - Binary Phase Shift Keying			

2.2.2 Frequency Channel Spacing

An interesting element found in the 802.11b/g channel schemes is there are 11 channels, but only three available non-overlapping channels. This occurs because the channel width is greater than the channel separation, so channels overflow into higher neighboring channels. Figure 2.3 shows the 2.4 GHz channel separation for IEEE 802.11b/g systems. The only possible combination of non-overlapping channels is 1, 6, and 11, as shown (Cisco 2004 b). Therefore, adjacent access points must be placed in a physical configuration to minimize overlapping coverage areas using the same channels (see section 3.2.4).

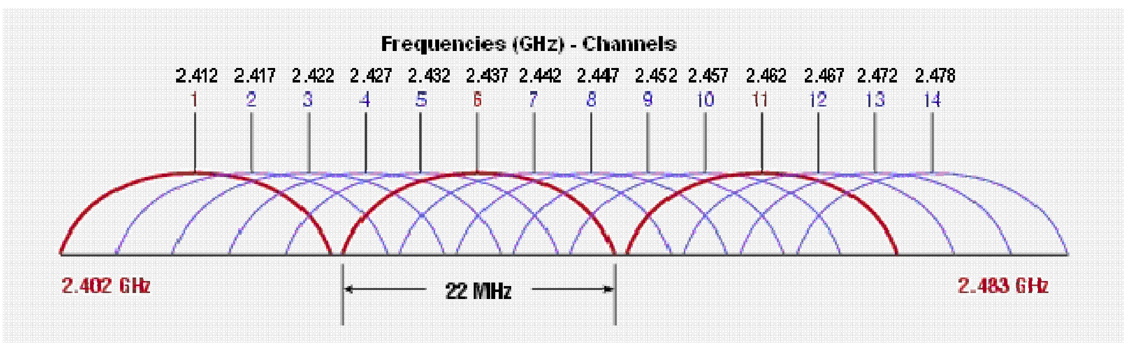


Figure 2.3 IEEE 802.11b/g channel separation (Cisco 2004 b)

In contrast, 802.11a uses a separation scheme such that there is minor overlap between channels. There is, however, a small overlap and it is advisable to keep at least one channel between neighboring access points. Figure 2.5 shows the channel breakdown for 802.11a frequencies (Cisco 2004 b).

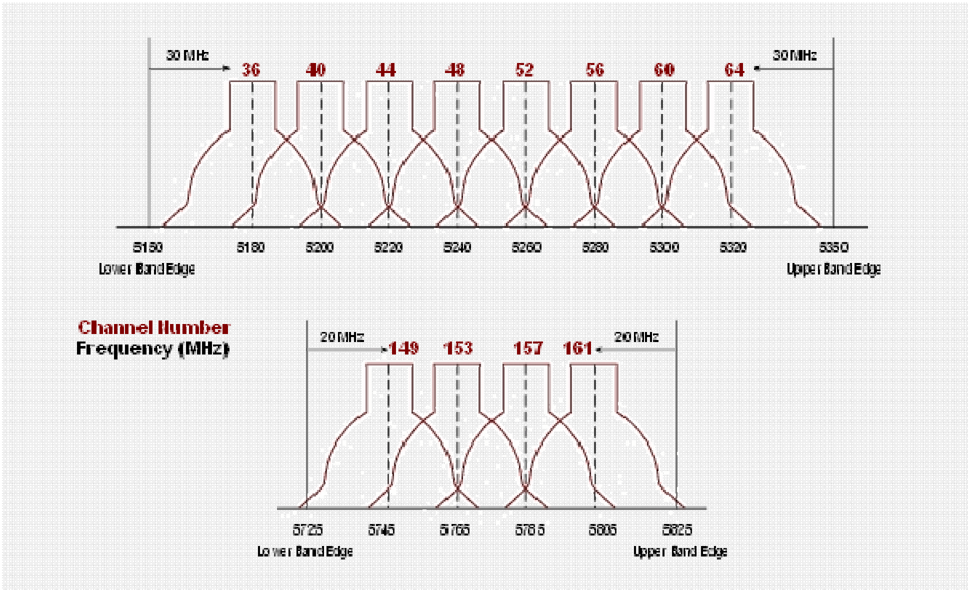


Figure 2.4 802.11a frequency layouts (Cisco 2004 b)

2.2.3 Direct Sequence Spread Spectrum

IEEE 802.11b uses Direct Sequence Spread Spectrum (DSSS) encoding. This technology spreads power over a wide frequency band which is determined by mathematical coding functions (Gast 2002, 156). The data originating at the transmitter is combined with a chipping code which divides the original data into pieces and spreads it across several frequencies. The chipping code also provides redundancy for the transmitted bits. If by chance some of the received signal is corrupted due to noise, the overall data package can usually be reconstructed, including the damaged portions (Webopedia 2002). This also adds extra overhead to transmissions, which can reduce the overall link speed.

2.2.4 Request to Send/Clear to Send (RTS/CTS)

IEEE 802.11b also uses a Request to Send/Clear to Send (RTS/CTS) client-to-access-point handshaking method. This was incorporated to prevent "the hidden node problem" which occurs when several clients hidden from each other by distance are connected to the same access point and all try to transmit simultaneously. Logically this causes the access point to receive multiple signals, each of which is unreadable due to interference from the others. The protocol requires that each client node ask permission from the connected access point before transmitting. If no reply is given, the client waits and the request is sent again. When a reply is transmitted by the access point, all clients hear it and translate to a "do not send" for all clients except the one who has permission to transmit (Cisco 2004 a, 3).

2.2.5 Orthogonal Frequency Division Multiplexing (OFDM)

Both 802.11a and 802.11g use Orthogonal Frequency Division Multiplexing (OFDM), which allows for speeds up to 54 Mbps. OFDM is a spread-spectrum technology which transfers pre-packaged data through parallel frequencies within a given channel space (Vaughan-Nichols 2004).

2.2.6 Characteristics of Wireless 802.11 Systems

One of the requirements for 802.11g is that it must be backwards compatible with 802.11b, meaning that all functions of 802.11b are also built into 802.11g equipment. When an 802.11b client connects to an 802.11g access point, the RTS/CTS protocol must be enabled as well as an increase in “back off” times. This refers to the time period in which a client will wait to resend an RTS signal in the event of a data collision. The client will not transmit for a certain amount of time which is determined by randomly choosing a slot number. Each slot contains an equal amount of time, and the client will not transmit again until the total time runs out. The total wait-time is given by multiplying the slot number by the amount of time in each slot. As seen previously in table 2.1, 802.11b has more slots and longer wait-times, making it better for access points with many simultaneous connections, but slower overall due to increased wait-time transmit overhead. 802.11a has fewer slots and lower times, making network throughput higher, but less suitable for a large number of concurrent client connections. 802.11g access points will use the higher slots/times when 802.11b clients are connected and will switch to the lower slot-time combination when connected exclusively with 802.11g clients (Cisco 2004 a, 3). Table 2.2 shows the data rates for each of the 802.11 standards. Notice the drop in speed when an 802.11b card connects to an 802.11g access point.

Table 2.2 Approximate throughput comparisons for 802.11a/b/ and g (Cisco 2004 a).

	Advertised Data Rate (Mbps)	Actual Throughput (Mbps)
IEEE 802.11b	11	6
IEEE 802.11g (with 802.11b client associated)	54	8
IEEE 802.11g (no 802.11b clients associated)	54	22
IEEE 802.11a	54	25

WISPs with existing 802.11b systems installed have little incentive to upgrade to 802.11g. When an 802.11b client associates with an 802.11g network, the entire network throughput is decreased due to the overhead that 802.11b introduces. Therefore, unless a network will be designed from the ground up, it is best to keep the two standards separate. Furthermore, when configuring an exclusive 802.11g area network, it is best to lock the radio to accept only 802.11g connections. This will also shield the beacon broadcast from being seen by 802.11b receivers. (Cisco 2004 a, 3)

As a property of physics, there is an inverse relationship between wavelength and effective traveling distance. All other things being equal, a longer wavelength (lower frequency) will travel further and pass through solid matter better than the shorter wavelengths (higher frequencies)[*] (Cisco 2004 a). This makes 802.11b and 802.11g equipment better candidates for large coverage areas due to the more robust 2.4 GHz signal. Furthermore, OFDM is a more efficient means of transmission than DSSS, such that, at a given distance, higher OFDM data rates will be supported than DSSS. This may imply that 802.11g would be the best option for WISP use, but that also depends on other variables.

One important factor to consider when using OFDM is Error Vector Magnitude, or EVM. This is an observable phenomenon that may affect output power and receive sensitivity. OFDM uses Quadrature Amplitude Modulation (QAM), a type of modulation scheme which at higher orders (64 QAM is used for maximum throughput) requires higher acuity at the receiver. This high power coming from the transmitter tends to desensitize the receiver, such that higher transmit power results in lower data rates. This phenomenon is known as Error Vector Magnitude (EVM). 802.11g equipment will automatically switch to use a lower power setting when operating in ‘g’ mode than when

[*] In this assumption the sending and receiving link have similar **gain** antennas. In an actual case with all things held equal - including actual antenna reflector **area** (not gain) the 5.4 GHz link would come out with more than 6 dB signal strength better than the 2.4 GHz signal. However, since power levels are limited by the FCC, the 2.4 GHz signal will travel further on the lower gain antennas (McLarnon 2004, 3).

in ‘b’ mode (Cisco 2004 a, 4). This characteristic of 802.11g OFDM may suggest that 802.11b DSSS would be better suited to high power/large area WISP applications. However, bear in mind that 802.11g can also use DSSS for lower data rates.

For the reasons cited, the most widely-used standard for 802.11 wireless area networks at the time of this writing is considered to be 802.11b.

2.3 Characteristics of RF and Wireless Limitations

Although using 802.11 wireless equipment appears to be an excellent solution for the last mile problem, there are several reasons why it has not replaced land line methods. Among these reasons are environmental factors that affect signal strength and quality, FCC limitations on power output levels, geographical terrain and foliage which limits usage areas, and noise created by other products sharing the microwave RF spectrum.

2.3.1 Shannon’s Law of Communication

Shannon’s law provides a theoretical maximum rate at which error free bits can be transmitted over a channel. The variables used in the equation for finding the maximum channel rate are frequency bandwidth in Hertz and the signal to noise ratio (SNR). The equation is:

$$C = W \log_2 (1 + S/N) \tag{2.1}$$

where C is equal to the channel capacity in bits per second, W is the bandwidth in Hertz, and S/N is the signal to noise ratio.

As shown in figure 2.3, the channel bandwidth for IEEE 802.11b and g radios is set to 22 MHz per channel. The implications of Shannon's law as related to 802.11b wireless networks are that to achieve the greatest throughput, the signal to noise ratio must be the highest possible within the set limits of the FCC and the IEEE 802.11 standard. All wireless radios also have a receive sensitivity which determines what data rate is possible given the signal to noise ratio. If a certain data rate is desired, then the signal to noise ratio must be above what the radio specifications say is the required SNR for that data rate. Receive sensitivity is explained in greater detail in section 2.4.7.

2.3.2 Environmental Conditions

The 2.4 GHz frequency is widely used in microwave ovens because 2.4 GHz is a frequency at which the positive and negative dipole moments in water molecules react to electromagnetic RF stimuli. The high power 2.45 GHz electromagnetic radio waves twist and rotate the molecules, creating heat through kinetic energy (Gast 2002, 154). Water molecules in any form are unfavorable to the signal propagation of 802.11b long range wireless networks because they react and distort electromagnetic RF waves in the 2.4 GHz space. To a certain extent, rain, snow, and fog all absorb RF energy and attenuate the signal degrading the signal to noise ratio and thus the throughput. In the 2.4 GHz range, torrential rain of 4 inches/hr may attenuate the signal up to 0.08 dB/mile. Thick fog can produce up to 0.03 dB/mile signal attenuation. Likewise, 5.8 GHz may face up to

0.8 dB/mile attenuation in heavy rain, and up to 0.11 dB/mile in thick fog (McLarnon 2004). This makes 2.4 GHz the better candidate frequency band for wet locations.

Although rain and snow do cause some minor signal attenuation, it is far more likely to cause problems in the equipment, on the antennas, and inside cabling connections. Raindrops hanging from an open Yagi antenna can make the elements appear longer and detune gain performance (WLANAntennas, 2004 b). Snow and ice buildup on antennas can drastically change signal effectiveness by changing the reflectivity and focal point of a parabolic dish antenna (Otero, Yalamanchili, and Braun 2004, 3). If moisture penetrates unsealed connectors, it can raise the Voltage Standing Wave Ratio (VSWR) at the transmitter and increase cable loss. This results in poor transmit and receive performance. Water inside the cables can also cause the quality to decline. This will be apparent if problems start during a rainstorm and do not clear up even after the rainwater evaporates. High humidity levels and condensation can cause oxidation on connections and eventually result in equipment malfunction.

Wind may also have an adverse effect on wireless communications. There is little direct evidence to support this claim, although it is presumed that strong wind gusts and continuous vibrations may cause gradual misalignment in antennas. Temperature variances can also affect the electronic systems used in a wireless LAN. Hot and cold temperatures can cause solder connections to crack due to unequal thermal expansion rates in electronic components, resulting in bad connections and eventually equipment failure. Temperatures above or below manufacturer specifications and tolerances can cause errors in the packet processors which would result in severe error rates and even complete link failure. Extreme temperatures can cause distortion in the output waveform during final stage amplification resulting in unreadable signals (Otero, Yalamanchili, and Braun 2004, 4). The occurrence of extreme heat causing malfunctions in equipment actually occurred during this research project and required the addition of an active ventilation system.

2.3.3 Radio Frequency and Line of Sight Radio Links

Another significant characteristic of microwave frequencies is the distinction between wave travel in free space and in normal atmosphere. A 2.4 GHz signal will travel in a semi-straight line in an area of free space, that is, an area free of any objects that would absorb, reflect, or otherwise distort radio emissions. A free space circumstance is the ideal situation and is the desired scenario for real world links. To enable useful distance coverage with a wireless link, line of sight is required. This implies that from the site of one antenna, the opposite antenna should be visible, either visually or by radio line of sight. When occluding objects are introduced into the environment, the waves will bend, bounce or be absorbed. The mechanisms of radio wave distortion due to obstructions are: refraction, diffraction, and reflection (McLarnon 2004, 1); they may also be attenuated through absorption and through simple distance attenuation (inverse-square attenuation).

Refraction occurs as a phenomenon in long range links near the earth’s surface where the waves actually bend around the curvature of the earth to attain a link beyond the visible horizon. Under normal conditions the curvature path followed by the radio waves can be plotted as a straight line path on a hypothetical earth with 4/3 radius of this earth. In other words, the radio link path curvature has a higher curvature radius (meaning straighter) than the arc curvature of the earth. This is what is referred to as line of radio sight. The result is that antennas will be pointed slightly lower toward the horizon instead of directly at an imaginary antenna at height on the horizon. Refractivity profiles can also be increased or decreased by effects from weather and are called superrefraction and subrefraction. These two conditions can either increase or decrease range dramatically (McLarnon 2004, 5). However, most commercial wireless data links typically remain short enough that refraction will not become a major issue.

Reflection and Absorbtion of electromagnetic waves are two more properties of propagation which occur when objects are located between transmitters. Examples of things that absorb microwave signals are trees, earth, and brick or plaster walls. Things that reflect signals are metal, fences, metallized mylar, pipes, screens and bodies of water (Flickenger 2002, 15). Attenuation will be observed with practically anything blocking optical line of sight. Trees are a significant obstacle as they contain water. Accordingly, wet trees are less transparent than dry trees and leafy trees are less problematic than pine trees. This fact ties in with the previous section on weather effects to the extent that even though falling rain itself does not cause major propagation problems, wet leaves and flat wet surfaces will attenuate the signal until after the water has evaporated (WLANAntennas 2004 a).

Reflection is another reason for having a clear first Fresnel zone. The two different scenarios that can occur with radio waves when reaching an object are reflection (changing the direction) or penetration (attenuating the signal until reaching airspace on the other side). Everything around the radios and along the link pathway will affect the radio link to some degree. Wave energy cannot be destroyed. It can be absorbed, diffracted, or dissipated, but a wave in free space will continue forever. The inverse-square law demonstrates how an electromagnetic wave dissipates as distance between endpoints increases. Every time the distance between them doubles, signal strength drops by 3 dB, cutting the received signal in half. This is due to the fact that as the distance increases, so does the physical two-dimensional area of the actual wave. This occurs at the rate of the inverse square of the distance increase. As the waves propagate away from the transmitting antenna in a conical pattern of radiation, the waves in the center of the cone are stronger than the waves in the “fade zones” or outer edges of the cone. These weaker waves on the outer edge continually lose phase with the stronger main signal. These faded signals can be reflected from objects and arrive at the receive antenna at the same time as the main signal. If these faded and reflected waves arrive at the receiver 180 degrees out of phase with the originals, the destructive interference can be detrimental to the link quality. Ground reflections are a type of path loss which occur in long range links. Areas of flat ground, buildings, and bodies of water can all reflect signals, causing an out-of-phase signal to be received which in most cases will degrade the desired signal to some degree. This kind of signal cancellation is called multipath distortion and is due to the fact that multiple waves from different reflected paths can arrive at the receiver and will affect the overall SNR for the link (McLarnon 2004).

This reflection angle over water is sometimes referred to as the “Pseudo Brewster Angle” (PBA) because the microwave RF effect is similar to the effect found in optical physics. The angle which is of consequence is the angle at which the waves meet the reflective surface. Above this angle the reflected wave is in phase with the direct signal. Below this angle, the reflected waves are 90 to 180 degrees out of phase with the original.

As the angle increases from zero degrees and approaches the PBA, the amount of signal cancellation is reduced. Surface conductivity, dielectric constant, and operating frequency all affect the PBA. All else being equal, an increase in frequency will result in an increase in the PBA. At 2.4 GHz the PBA over fresh water is about 6 degrees and between 17 and 20 degrees on land. The higher angle on land is due to the scattering and attenuation from foliage and other non-flat surfaces; whereas water has a higher dielectric constant and smoother surface which appears almost “mirror-like” to the electromagnetic waves.

There are ways to minimize the effects of signal cancellation due to reflection. If possible, try to set up all links over dry ground, preferably over an area covered with attenuating and scattering angles instead of roads and flat-sided smooth buildings. Antenna positioning, alternative polarization schemes, and diversity antenna setup can all help reduce effects of signal cancellation from reflection (WLANAntennas 2004 a). These methods will be discussed more in depth in section 2.4.2 where antennas and radiation patterns are covered in greater depth.

Diffraction theory indicates the need for an invisible buffer zone around the line of sight for optimal signal reception. Huygens’ Principle shows that as waves travel, the wave fronts create small wavelets which radiate beyond the initial direction of travel. This is shown in figure 2.5 and explains why radio waves can appear to curve around objects.

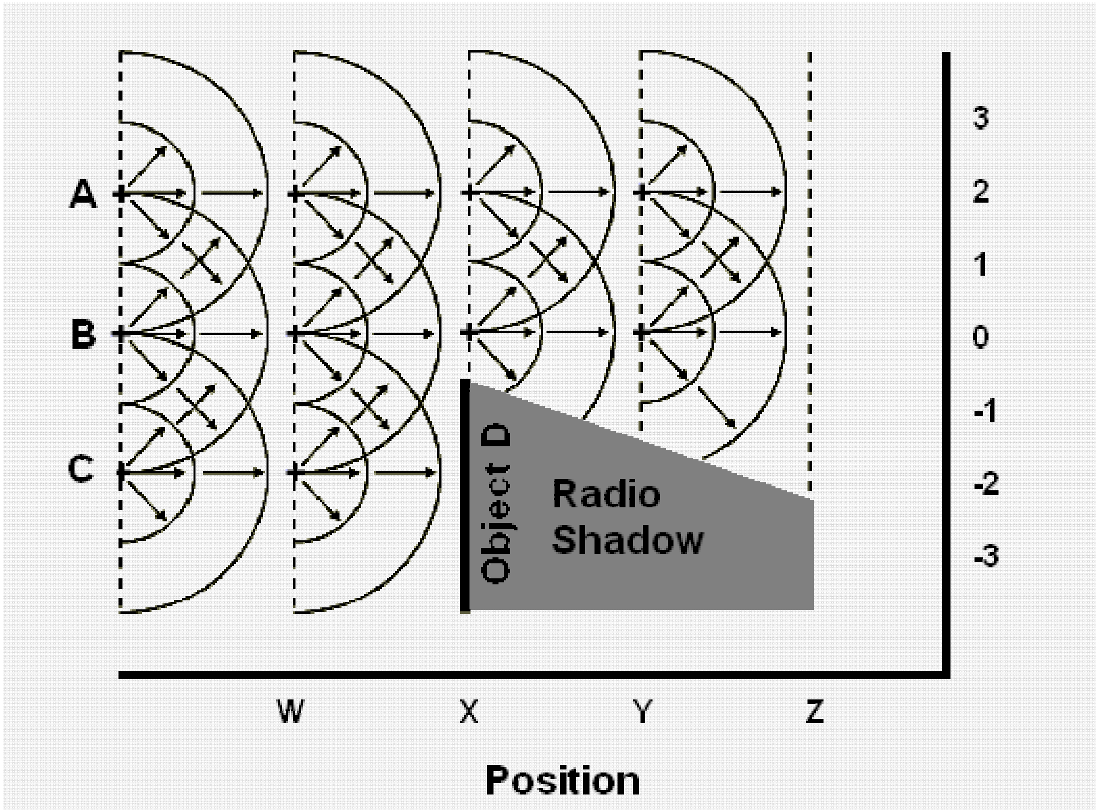


Figure 2.5 Huygens' Principle (McLarnon 2004)

As waves A, B, and C pass by the object D, wave A passes unobstructed, B is slightly obstructed, and C is completely absorbed. The interesting observation is that as B continues, energy is dispersed from the B wavelets to reconstruct what appears as a weak C passing through object D. In actuality, the combined power of adjacent waves feed off of one another to retain strength. In this example, after C is absorbed, the power of B is weakened, causing the receive power of B after the object to be much less than its power before the object. This is shown in figure 2.6 as the perceived strength relative to position (McLarnon 2004).

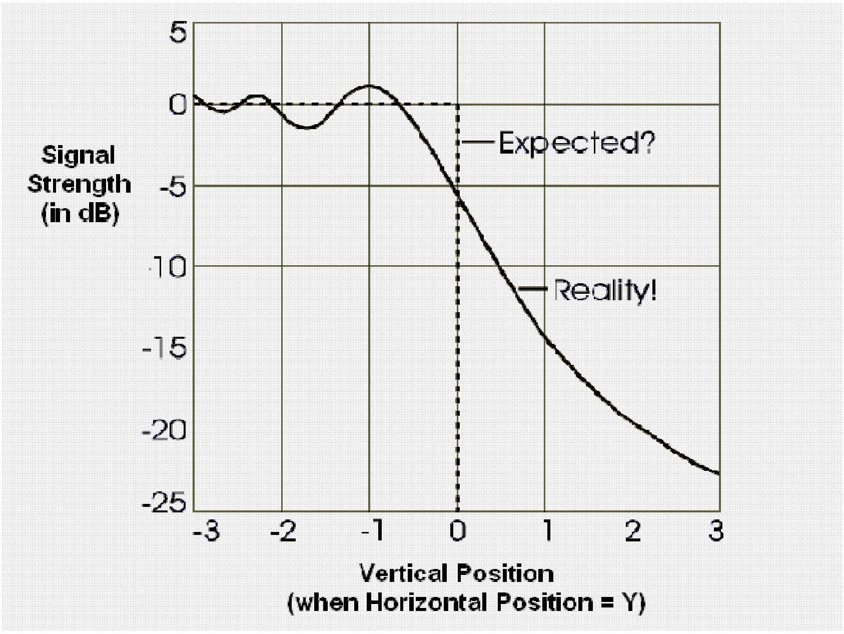


Figure 2.6 Signal Levels on the Far Side of the Shadowing Object (McLarnon 2004)

It is interesting to note that the signal strength of B, though barely obstructed, also has a lower strength because it is dispersed into the area where C was absorbed or deflected.

The area inside the invisible buffer around the line of sight is known as the Fresnel Zone. As shown in figure 2.7 it is an ellipsoid shape with either end of the radio link as its foci. First Fresnel zone clearance requires that no object protrudes into the calculated three-dimensional Fresnel zone.

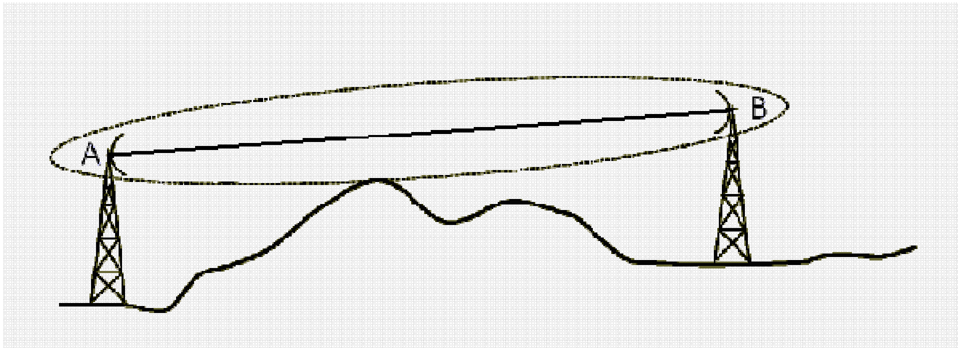


Figure 2.7 Ellipsoid shape of Fresnel zone (McLarnon 2004)

First Fresnel zone clearance is a desired level of clearance but is not absolutely necessary because it would produce the equivalent vertical position value of approximately -1.4 on the graph shown in figure 2.6. Only 60% of first Fresnel zone clearance is actually needed, giving an approximate vertical position value of .85 (McLarnon 2004). To calculate sufficient Fresnel zone allowance, the following equation can be used to calculate first Fresnel zone clearance in conjunction with measurements from figure 2.8:

$$h = 72.1 \sqrt{\frac{d1 * d2}{f(d1 + d2)}} \qquad (2.2)$$

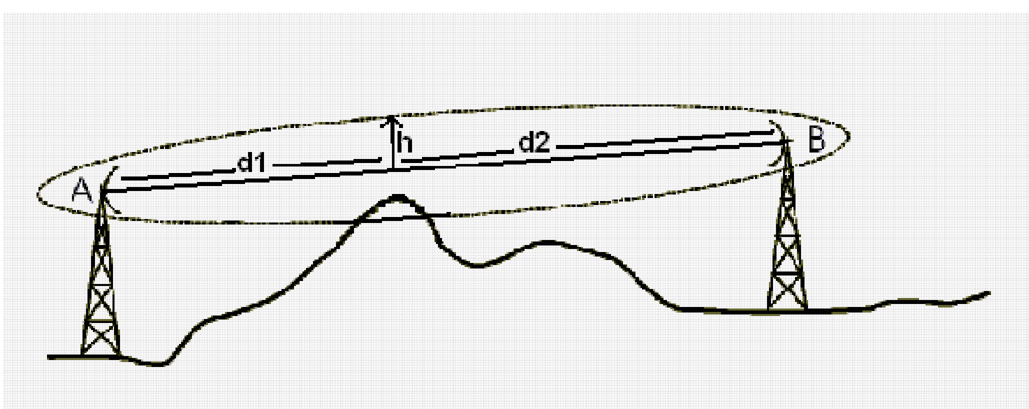


Figure 2.8 Fresnel zone measurements (McLarnon 2004)

Equation 2.2 assumes distances d1 and d2 are given in miles, f is frequency in GHz, and h is height (or radius for the circular cross section) in feet. It is important to remember that the Fresnel zone is a three dimensional space. This means not only will buildings underneath line of sight affect signal but buildings or other obstructions intruding into the zone on either side can also affect signal strength.

For example, assume that a radio link is desired from point A to point B. The total distance is 6 miles with a protruding hill 2 miles from point A. If we are using 802.11b we can assume 2.4 GHz for f. This results in height h being equal to $72.1\sqrt{\frac{2 * 4}{2.4(2 \ + 4)}}$ or 53.7 feet. This means that with the 60% allowance rule, the top of the hill could be as close as 32.2 feet from the center line of sight and still allow complete signal strength (McLarnon 2004).

2.3.4 FCC Power Regulations

Initially 802.11a/b/g wireless network equipment was meant only for small areas in homes, small offices and other limited transmission areas. The power levels that are built into most wireless equipment is just enough to reach from point A to point B with an average outdoor range of about 1200 feet and an approximate indoor range of 300 feet. These are average values given by manufacturer specification pages with access points and clients using OEM antennas and given power levels (SeattleWireless 2004).

To extend this distance to cover up to several square miles, focused antennas and higher power access points are used. Amplifiers can also be used but care must be taken to use them correctly and stay within legal power limits. Guidelines for spread spectrum gear can be found in FCC Part 15 rules and regulations.

Before continuing, it is necessary to define the three types of network structure. **Point-to-point** networks are those mainly used for getting a signal from point A to point B, and nowhere else. Point-to-point links are usually built using wireless bridges on each end of the link. This could also be accomplished using an access point with only one client, but bridges are made specifically for the task. Point-to-point links create the wireless backhaul links of the network, beaming the signal from the wired uplink site to remote access points for redistribution. **Point-to-multipoint** systems are the main distribution method of a wireless network. Access points act as the hub in a star topology, broadcasting a signal to multiple users in the surrounding area. **Ad-Hoc (**or peer-to-peer) systems are simply client adapters or multipoint bridges in a mesh configuration. No access point is required for communication. Ad-Hoc is rarely used for commercial WISPs, however several free community networks are working on a mesh topology solution to extend the reach of wireless town area networks (Flickenger 2004, 8).

The FCC limits the maximum output power for point-to-multipoint broadcasting in the 2.4 GHz ISM frequency to 36 dBm Effective Radiated Power with an isotropic antenna (EIRP). An isotropic antenna is a theoretical perfect antenna radiating equally in all directions. More realistically, it is assumed that an access point with 30 dBm Transmitter Power Output (TPO), which is equal to one watt, with a 6dBi antenna is the maximum transmit starting point. From this point every one dBi gain in the antenna must result in an equal drop of one dBm at the access point so that total dB output does not exceed 36 dB, or four watts (Flickenger 2002, 78 and Pozar 2004).

While point-to-multipoint power limitations are controlled fairly strictly, point-to-point links are allowed higher levels. This is due to the fact that antennas in a point-to-multipoint system radiate to a wide coverage area ranging from 60 to 360 degrees across the horizon. Antennas used in point-to-point applications are tightly focused and thus not as likely to interfere with other radio users (Flickenger 2002, 78). The FCC limits for point-to-point links are a bit more lenient than point-to-multipoint systems. The access point TPO only has to be reduced by 1/3 dBm per dBi increase in antenna gain. In other words, for every three dBi of antenna gain over a 6 dBi antenna, the access points' transmit power must be reduced by only one dBm (Pozar 2004, 4 and Davis and Mansfield 2002, 99). The following table 2.3 illustrates some common combinations and values.

Table 2.3 Common FCC limit radio-antenna combinations (Fab-Corp 2004)

Point to Multipoint		
Transmitter RF Power	Antenna Gain	EIRP
30 dBm / 1Watt	6 dBi	~36 dB / 3.98 Watts
27 dBm / 500 mW	9 dBi	~36 dB / 3.98 Watts
24 dBm / 250 mW	12 dBi	~36 dB / 3.98 Watts
20 dBm / 100 mW	15 dBi	~36 dB / 3.98 Watts
17 dBm / 50 mW	18 dBi	~36 dB / 3.98 Watts
14 dBm / 25 mW	21 dBi	~36 dB / 3.98 Watts
10 dBm / 10 mW	24 dBi	~36 dB / 3.98 Watts
Point-to-Point		
Transmitter RF Power	Antenna Gain	EIRP
30 dBm / 1 Watt	6 dBi	~36 dB / 3.98 Watts
29 dBm / 800 mW	9 dBi	~38 dB / 6.35 Watts
28 dBm / 630 mW	12 dBi	~40 dB / 10.14 Watts
27 dBm / 500 mW	15 dBi	~42 dB / 15.81 Watts
26 dBm / 398 mW	18 dBi	~44 dB / 25.23 Watts
25 dBm / 316 mW	21 dBi	~46 dB / 40.28 Watts
24 dBm / 250 mW	24 dBi	~48 dB / 62.79 Watts
23 dBm / 200 mW	27 dBi	~50 dB / 100.2 Watts

Although table 2.3 shows some of the common pairings for 802.11b radios and antennas, this assumes lossless cable and connectors. In reality, cables, connectors and lightning arrestors all degrade signal strength, thus allowing for slightly higher values in transmitter/antenna combinations. The total gain should still be within limits after subtracting loss values for cable etc. The following equation calculates the total EIRP value starting from the radio and moving towards the antenna. All values are either in dBi for antennas cables and connectors, or dBm for radios and amplifiers.

$$radio - jumper - arrestor - connector - cable - connector + antenna \qquad (2.2)$$

Jumpers are the short coaxial connectors between components such as the radio and lightning arrestor. Pigtails lose about 1 dB, lightning arrestors lose approximately 1.25 dB, connectors lose approximately .25 dB, and cable loss depends on cable length and type (Flickenger 2002, 76). LMR 400 is a microwave coaxial cable that has a loss of about 6.5 dB per 100 feet. LMR 195 is another popular microwave cable because of its similarity to RG-58 and can use RG-58 connectors. Loss for LMR-195 is approximately 19 dB per 100 feet (TimesMicrowave 2002). As a general rule of thumb LMR 195 may be used for runs shorter than 15 feet, otherwise use LMR 400 or better cable (lower loss) should be used depending on how much loss can be allowed. Other cable types and their loss factors can be found in the section covering cables.

Notice that the connectors on the pigtail and antenna are not included in the loss calculation. This is due to the fact that they should already be calculated for in the jumper, and any good antenna will give the overall gain measured at the connector instead of the “best-case” antenna gain measured at the receiving element.

Using equation 2.2, we can calculate the maximum transmit power for the access point shown in figure 2.9. Assume a point-to-multipoint system with a 12 dBi 360^o omnidirectional antenna.

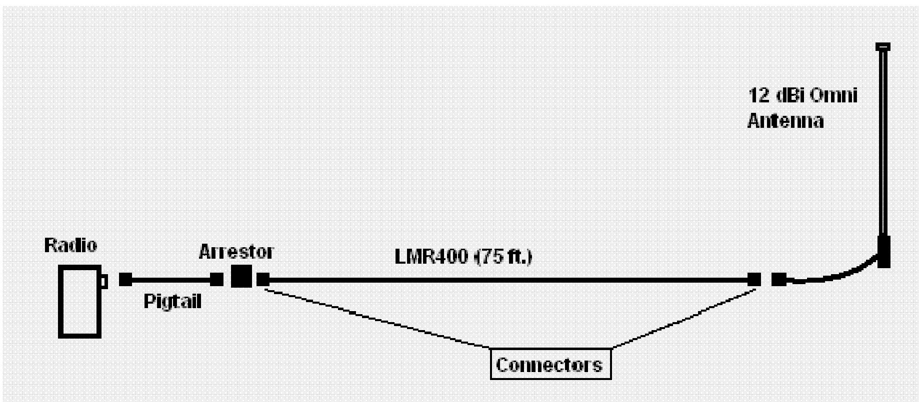


Figure 2.9 Example access point setup

$$36 - x = -1 - 1.25 - .25 - (.75 \bullet 6.5) - .25 + 12 \qquad (2.3)$$

$$x = 31.625 \text{ dB or } 1.45 \text{ watt}$$

According to the calculations, an access point with 31 dBm, or 1.45 Watts, could be used for transmitting. Most radios on the market do not come with radios above 200mW (32 to 100mW is fairly standard), however there are some radios that have output levels up to 500mW (SeattleWireless 2004). In these cases, a 1.5 Watt amplifier could be used to achieve the maximum output power. This calculation includes the extra connectors needed for the amplifier connections and thus increases the loss and allows for the 1.5 watt total power. Although technically, this is possible, it is very close to breaking the FCC limits. The FCC transmit power limit is 1 Watt, resulting in a 500mW excess on the radio end, but just short of the 24 dBm (250mW) limit at the antenna connection. One should always use a dB meter at the antenna end to verify FCC compliance.

In addition, amplifiers are generally not a good idea for point-to-multipoint links. When only one side of the link is amplified it gives the illusion at the receiving end that a solid link is possible. When connected, the non-amplified point will have difficulty sending a strong enough signal to the amplified end. Furthermore, while using the maximum power would seem like a good idea to the inexperienced operator, everyone else is also entitled to do the same. This could create a noisy area with poor overall operation; likened to an area where everyone is shouting, it can be difficult to hear well. Therefore, correct use of antennas and amplifiers will improve relations with others using the same frequency and can result in better coverage in the long run. Using several access points in smaller coverage areas with the correct antennas will perform better than an over-powered access point trying to cover a large area with an amplifier and large antenna (Flickenger 2002, 3).

2.3.5 Noise and Frequency Sharing

In addition to IEEE 802.11b/g radios, the unlicensed microwave ISM band is allocated for such Industrial, Scientific and Medical uses such as jewelry cleaners, ultrasonic humidifiers, diathermy medical equipment, and Magnetic Resonance Imaging (MRI) scans (Pozar 2004, 8). An unlicensed spectrum is often overused and the space around 2.4 GHz is no exception. Various consumer products also use the ISM spectrum and can cause noise and interference. Products such as cordless phones, Bluetooth enabled devices, baby monitors, pagers, X10 wireless spy cameras, garage door openers, new fusion lighting systems, and neighboring wireless LANs also use the 2.4 GHz band all have as much right to the frequency use as anyone else (Geier 2002, Pozar 2004, and Schramm 2002). Recalling that Shannon's law is based on frequency bandwidth (which is set for IEEE 802.11b and g) and SNR, the surrounding noise in an area can affect a wireless link greatly, and cause much lower data throughput.

The mitigating factor is that all commercial products that emit radio signals and/or interference must pass emission containment inspections and be licensed with the FCC. A label must be attached to any radio-emitting product that states:

> *This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.* [Labeling requirement in Part 15.19] (FCC 2004)
>
> Harmful interference is defined as:
>
> *Harmful interference - Interference which endangers the functioning of a radio navigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radio-communication service operating in accordance with these [International Radio] Regulations.* [Part 2.1(c)] (FCC 2004)

Interference is everywhere and can be a very big problem. However, there are a few design techniques that can be applied using directional antennas and polarity changes that can help improve signal quality in noisy areas (Pozar 2004).

2.4 Equipment Selection

There are many equipment vendors competing for business in the 802.11 long-range wireless arena. There are also many equipment classes and cost ranges for wireless network gear. Enterprise class and ISP grade equipment is going to cost as much as ten times more than everyday off-the-shelf equipment. The difference in quality is usually either very small or very large and is often worth the extra cost to test and find out. After all, the basic goal for any successful (for profit) wireless deployment is to create a positive return on investment within a given time period. Gaining and keeping paying customers is vital to success. Customers switch to broadband for speed, reliability, and an always-on connection.

A balance must be struck between equipment costs and possibility of investment return. A network made of the cheapest equipment may get the job done for a while, but will probably not last. Alternatively, if top of the line equipment is purchased at a high price to construct a fail-proof network for 50 residential users, it could be considered overkill; and is not likely to make a profit for several years. Equipment requirements that will meet customer needs include a network where little or no client maintenance is required, where all clients are capable of receiving any of the offered speeds, and links are always connected and strong.

2.4.1 Antenna Properties

Antenna selection is an important factor for a successful wireless deployment. Antennas do not actually amplify the received or transmitted signal. Antennas simply focus the emission and reception of radiated waves in a given direction. The measure of focus and directionality for an antenna is referred to as gain. Antennas have the same receive gain as transmit gain. Usually, a higher gain will result in better range (Flickenger 2002, 65). Gain is measured in a logarithmic scale of decibels (dB). A gain increase of three dB means that gain has approximately doubled because $10\log 2 \approx 3$ dB. A difference of 10 dB means that an antenna provides 10 times more signal strength than another antenna (Gast 2002, 161).

There are several types of antennas that are suited for different applications. Access points require point-to-multipoint antennas that will broadcast to a specific area similar to an angled section of a piece of pie. Coverage angles can range from 60 to 180 degrees with sector antennas up to a full 360 degrees with an omnidirectional antenna. Sector antennas will usually be available in higher gains than the omnidirectionals, as the signal can be focused on a single segment instead of the entire pie.

Client bridges and backhaul links (supply links to get internet uplink to remote access points) use the more directional point-to-point antennas which act more like a megaphone and create a conical radiation pattern. Directional antennas include Yagi, Vagi (a type of split-element Yagi), parabolic dishes, echo backfire, and patch. Patch antennas are usually not as focused as the other types of point-to-point antennas. Due to lower gain values patch antennas are not usually used for backhaul bridging (Flickenger 2002, 66).

As used in yagi/vagi and dish antennas, the driven element is the part which connects directly to the line feed. It is usually connected to the center pin of the coaxial cable. It is typically a loop or a straight element in a yagi/vagi antenna or the protruding part from the center of a parabolic dish antenna. The other parts of the antenna are used for focusing the electromagnetic signal into a desired radiation pattern. This can be a reflector such as a parabolic dish or flat metal plane, or a row of director elements which use induction to focus the signal. For Yagi antennas, a cylindrical plastic enclosure is sometimes used which protects the antenna parts from the weather (Gast 2002, 316).

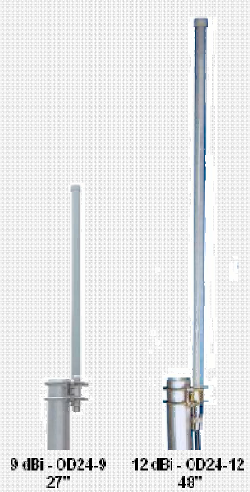
Antennas are polarized. This specifies the directionality of the electromagnetic waves as they are transmitted. In other words, it is the direction in which the individual wave peaks and troughs are emitted. Polarization is usually horizontal or vertical but other variants are sometimes used. This is determined by the orientation of the driven element. Another type of polarization is circular, in which the EM waves travel in a spiral, but this type of polarization is not often used in spread spectrum applications. The antennas on either end of the link must also have the same polarization for proper reception (Flickenger 2002, 59).

Vertical polarization is the most common and is used on almost all commercial access points with an included antenna. Using a horizontally polarized antenna scheme in an environment crowded by vertically polarized antennas can considerably decrease signal noise.

2.4.2 Antenna Types

Omnidirectional antennas are mainly used as the main access point in a point-to-multipoint system due to their 360 degree radiation pattern. The pattern is similar to a large donut shape with the antenna in the center. The worst place for reception from an omnidirectional antenna is directly above or below the antenna. When using omnidirectional antennas, the flatter the donut, the higher the gain, and the larger the radius and coverage area (Gast 2002, 316).

Since omnidirectional antennas are mounted vertically, they cannot be physically tilted downward without changing the radiation coverage area on the opposite side. Higher gain omnidirectional antennas will usually have some degree of set electrical downtilt to accommodate for mounting in tall locations. Higher mounting locations require a greater degree of downtilt. Electrical downtilt can also be used to limit cell size by mounting the antenna lower and shooting the signal into the ground instead of towards the horizon. Coverage can be calculated using triangulation and circumference calculations. There are also reliable downtilt calculators available on the web. Most omnidirectional antennas are vertically polarized, although there are several manufacturers that also provide horizontally polarized omnidirectional antennas. See figure 2-10 for an example of a vertically polarized omnidirectional antenna and figure 2-11 for an example of a horizontally polarized omnidirectional antenna.



Parameter	Min	Typ	Max	Units
Frequency Range	2400		2485	MHz
Input Return Loss (S_{11})		-14		dB
VSWR		1.5:1		
Impedance		50		OHM
Input Power			100	W
Pole Diameter (OD)	1 25		2 50	inch mm
Operating Temperature	-40		+70	Deg C

2400 - 2485 MHZ	OD24-9	OD24-12
Gain	9dBi	12dBi
Vertical Beam Width	14deg	7 deg
Electrical Downtilt	0 deg or 7 deg	3 deg
Rated Wind Velocity	125mph (56 M/sec)	125mph (56 M/sec)
Weight	1.1 Lbs (0.5Kg)	1.4 Lbs (0.6Kg)
Dimension (L +/-1.0") Diameter Approx. 0.6" (15mm)	27" (69cm)	48" (122cm)

Figure 2-10 Vertically polarized omni specifications (PacWireless Omni a 2004)

Parameter	Min	Typ	Max	Units
Frequency Range	2400		2485	MHz
Input Return Loss (S_{11})		-14		dB
VSWR		1.5:1		
Impedance		50		OHM
Input Power			100	W
Pole Diameter (OD)	2 (50)		2.5 (60)	Inch (mm)
Operating Temperature	-40		+70	Deg C

2400 - 2485 MHZ	ODH24-9		ODH24-13
Gain	9dBi		13dBi
Vertical Beam Width	20deg		7 deg
Cross Polarization Rejection	-29dB		-27dB
Downtilt	10 Deg Mech		10 Deg Mech
Wind Loading *100MPH*	25 lbf		63 lbf
140MPH	48 lbf		124 lbf
100MPH, ½" Radial Ice	34 lbf		80 lbf
Weight	6 Lbs (2.7Kg)		9 Lbs (4.8Kg)
Dimension (L +/-1.0")	27" x 4" x 1" (69 x 10 x 2.5 cm)		49" x 4" x 1" (124 x 10 x 2.5 cm)

Figure 2-11 Horizontally polarized omni specifications (PacWireless Omni b 2004)

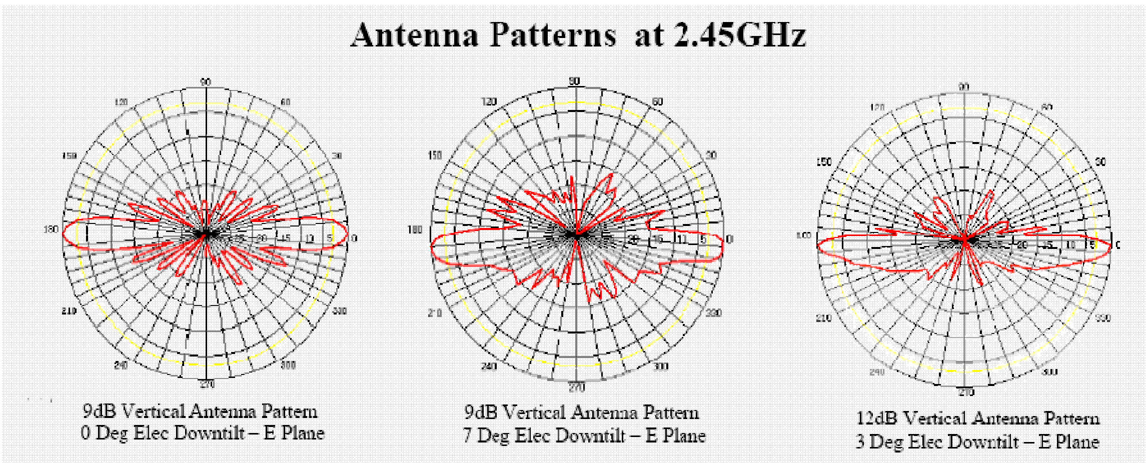


Figure 2-12 Omnidirectional antenna radiation patterns (PacWireless Omni c 2004)

The radiation plots shown in figure 2.12 are in the E plane as if looking at the antenna from the side (a cross-section of the donut) with the antenna placed in the center of the plot. Notice the electrical downtilt of the 9 dBi antennas in the first two radiation plots. The "peaks" on the left and right sides of the second antenna with a seven degree downtilt are focused seven degrees lower than horizontal. This gives a clearer idea of how downtilt works. Vertical beam width, or half-power beam width, is given by the width of the angle in which the antenna is three dB below maximum, shown in figure 2-12 as light circles. Above and below this angle, signal tends to drop rather quickly. It is also important to realize that this is not a representation of distance, but rather a logarithmic display of strength measurements (PacWireless Omni c 2004).

Omnidirectional antennas are good for areas with a limited number of clients located around the access point. They are fairly cheap (60 to 300+ dollars), have good gain values of 5 to 15 dBi, and are relatively easy to install. Access points should not become overloaded with connections or overall speed will decrease. Omnidirectional antennas also suffer in the fact that they are not directional, thus gathering all RF noise from the surrounding area. This includes multipath distortion noise from reflections coming back to the antenna from the opposite side. In large areas where there will be many clients, it is better to divide the area using sector antennas.

Sector or sectoral antennas (as seen in figure 2-13) are similar to an omnidirectional antenna and are also used frequently as the access point antenna in point-to-multipoint systems. The main difference between an omnidirectional and a sector antenna is the horizontal beam-width coverage. Radiation for sector antennas ranges from 60 to 180 degrees (Flickenger 2002, 67). Sector antennas are well suited to dense usage areas because the radiation pattern allows for customized area design. For example, given an area where the northern half of a small town is expecting high subscriber numbers (100+) and the southern half is expecting limited use, an omni would not suffice. If a mounting location can be located near the center of town, a reliable setup using three 70 degree sector antennas mounted with overlapping radiation zones to cover the north half of town and a fourth 180 degree sector could be mounted on the south side.

Parameter	Min	Typ	Max	Units
Frequency Range	2400		2485	MHz
Input Return Loss (S_{11})		-14		dB
VSWR		1.5:1		
Impedance		50		OHM
Input Power			100	W
Pole Diameter (OD)	1" (25)		2" (50)	Inch (mm)
Operating Temperature	-40		+70	Deg C

2400 - 2485 MHZ	SA24-90-9	SA24-120-9	SA24-90-17	SA24-120-16
Gain	9.5 dBi	9 dBi	17 dBi	16.4 dBi
Horizontal Beam Width	90 deg	120 deg	90 deg	120 deg
Vertical Beam Width	40 deg		7 deg	
Front to Back	25 dB		25 dB	
Mechanical Downtilt	45 deg		10 deg	
Weight	25oz (0.7kg)		9.9lb (4.5kg)	
Dimensions (LxWxH)	10" x 6.5" x 2.5" (254 x 165 x 63.5mm)		38" x 6.5" x 2.5" (965 x 165 x 63.5mm)	

Figure 2-13 Vertically polarized sector antenna (PacWireless Sector a 2004)

Sector antennas also come in vertical and horizontal polarizations, with gain values ranging from 9 to 17 dBi and prices are only slightly higher than omnis. Sector antennas are easier to tilt as well because most are equipped with an adjustable-angle mounting bracket. The drawback to using multiple sector antennas is each antenna requires a separate radio, raising total costs substantially (PacWireless Sector b 2004).

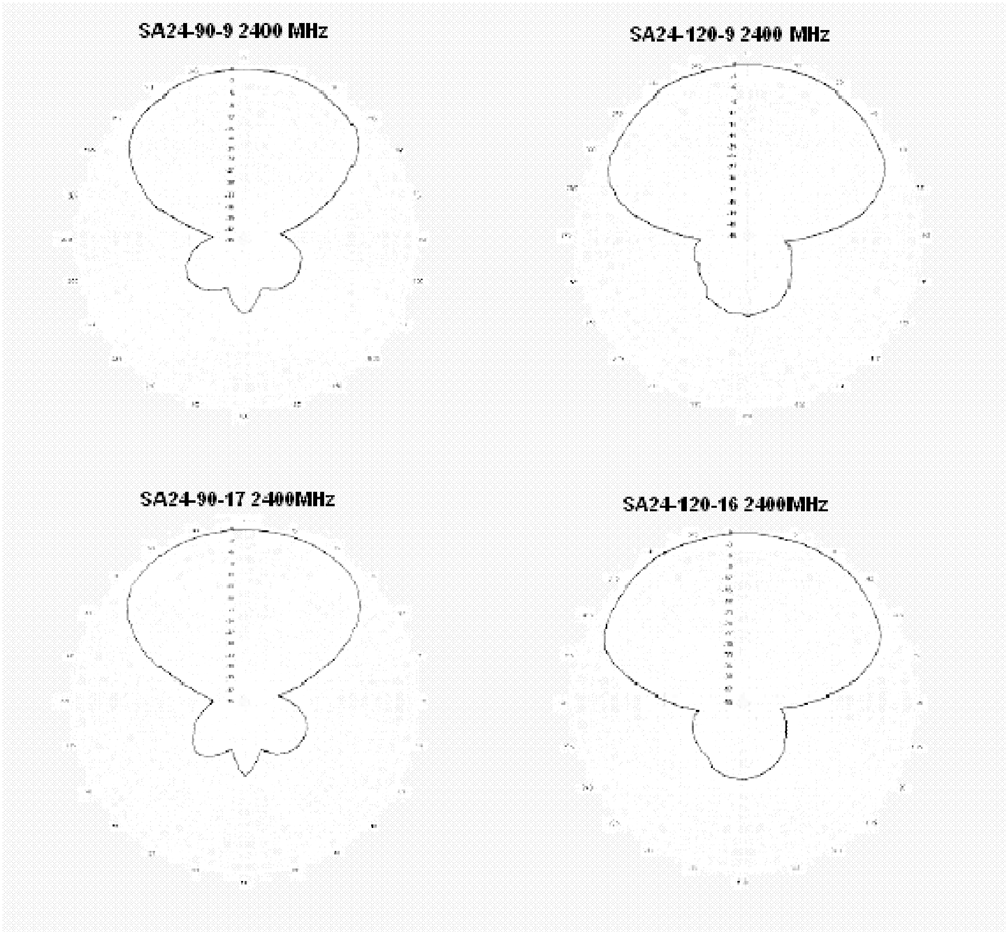


Figure 2-14 Sector antenna H-plane radiation patterns (PacWireless Sector b 2004)

Figure 2-14 shows the radiation pattern for the various types of vertically polarized sector antennas offered by Pacific Wireless. The radiation plots are oriented as if looking down on the antenna located at point zero from above.

The horizontally polarized sector antennas look physically similar to the horizontally polarized omnidirectional antenna and specifications are very similar to the vertical equivalence with the exception of lower gains (PacWireless Sector 2004).

Yagi antennas are moderately high-gain unidirectional antennas which can be used in point-to-point links or in point-to-multipoint systems as a client antenna. Yagi antennas are highly directional and gains range from 12 to 18 dBi. They look like a miniature classic television antenna with parallel metallic elements arranged perpendicular to a center rod. Most commercially made Yagis are stamped from sheet aluminum and enclosed in a cylindrical plastic enclosure as seen in figure 2-15 (Gast 2002, 317). This solves the problem addressed earlier where raindrops hanging from the elements appear to extend the perceived length of that element, resulting in signal misalignment.

Higher gain is realized from the addition of more elements creating a longer and undoubtedly a more awkward handling antenna. The polarization of a yagi antenna can be changed by rotating the antenna mount 90 degrees so that internal elements run horizontal across the boom instead of vertically. Some yagi antennas come with a set polarization mounting, which can make changing polarization difficult. The radiation pattern for a 13.5 dBi Cisco yagi antenna is shown in figure 2-16.

Frequency Range	2.4-2.83GHz
VSWR	Less than 2:1, 1.5:1 Nominal
Gain	13.5
Front to Back Ratio	Greater than 30dB
Polarization	Vertical
Azimuth 3dB BW	30 degrees
Elevations 3dB BW	25 degrees
Antenna Connector	RP-TNC
Dimensions (H x W)	18 x 3 in.
Wind Rating	110MPH

Figure 2-15 Cisco 13.5 dBi Yagi specifications (Cisco Aironet Antennas 2004 b, 27)

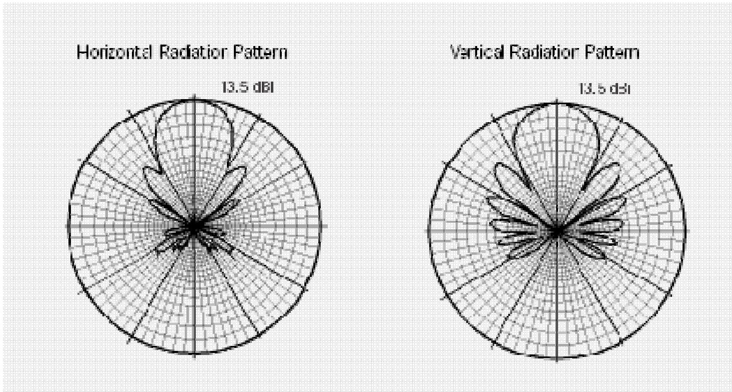


Figure 2-16 Cisco 13.5 dBi Yagi radiation patterns (Cisco 2004 b, 27)

A vagi antenna is a less well known antenna design, but works very well and is shorter than a yagi of equal gain. A vagi antenna is simply a split yagi with two sets of elements running in parallel after an initial v-shaped separation point. This produces a higher gain in a shorter antenna (PacWireless Yagi 2004). The vagi antenna is shown in figure 2-17, and the combined H and V plane radiation patterns are shown in figure 2-18.

*16dBi Directional Vagi Antenna – Horizontal

2400 – 2485 MHZ	VA24-16
Gain	16dB
3db Beam Angle (E-Plane) Vertical Polarity	25 deg
3dB Beam Angle (H-Plane) Horizontal Polarity	30 deg
Front to Back	> 19dB
Rated Wind Velocity	125mph (56m/sec)
Weight	1.5 Lbs (0.56 Kg)
Dimension L x W x H	22" x 3" x 4" (559 x 76 x 102mm)

Figure 2-17 Pacific Wireless 16 dBi Vagi specifications (PacWireless Vagi 2004)

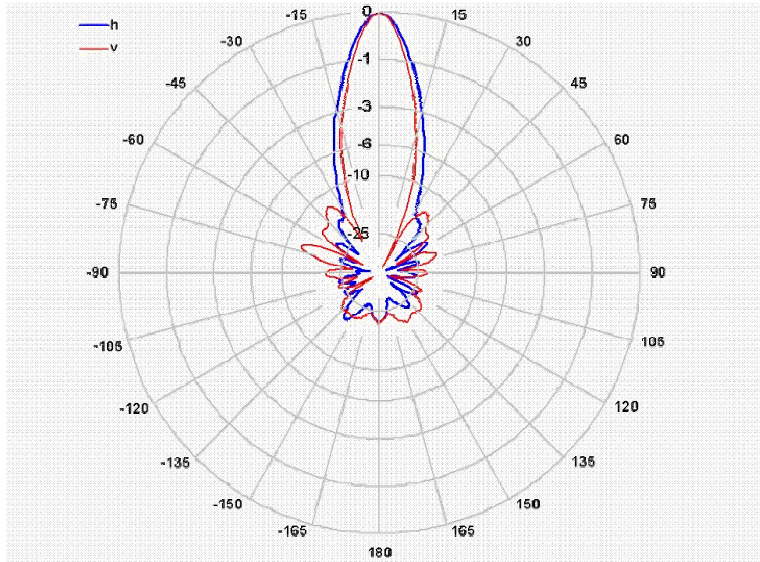
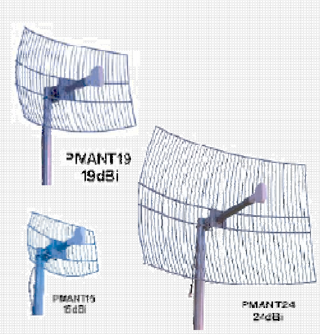


Figure 2-18 Pacific Wireless 16 dBi Vagi radiation patterns (PacWireless Vagi 2004)

Parabolic dish antennas are more directional than the yagi design, making them more difficult to aim with their tighter radiation pattern. Parabolic antennas can have a wire grid or solid metal dish reflector, but aside from wind load, a well designed wire grid should perform as well as a solid dish (Gast 2002, 319). Three sizes of the parabolic dish antenna are shown in figure 2-19. Figure 2-20 shows a different flat (instead of 360 degree circular) radiation pattern for the parabolic dishes.



1700 – 2700 MHz	PMANT15	PMANT19	PMANT24
Gain	15 dB	19 dB	24 dB
3dB Beam Angle	19 deg	17 deg	8 deg
Cross Pole	21 dB	32 dB	26 dB
Front to Back	> 19 dB	> 22 dB	> 24 dB
Side Lobe	-15 dB	-17 dB	-20 dB
Wind Loading *100MPH*	8.2 Lbs	16.6 Lbs	40 Lbs
140MPH	16.1 Lbs	32.5 Lbs	78 Lbs
100MPH: ½" Radial Ice	33.2 Lbs	72.4 Lbs	166 Lbs
Weight	2.6 Lbs	3.9 Lbs	8.2 Lbs
Dimension (LxW)	14" x 11.5"	23.6" x 16.7"	34" x 28"
Focal Length	7"	9.5"	16"

Figure 2-19 Pacific Wireless parabolic dish specifications (PacWireless Dish 2004)

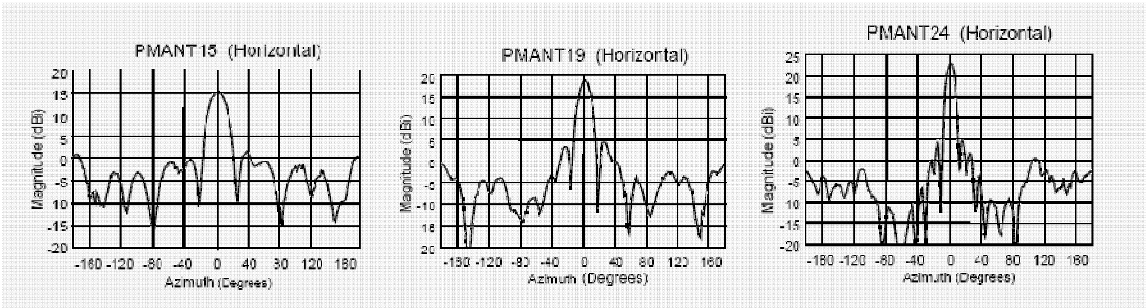


Figure 2-20 Pacific Wireless parabolic dish radiation patterns (Pacific Wireless Dish 2004)

Two other types of antennas worth mentioning are the patch and echo backfire. Patch antennas (figures 2-21 and 2-22) are similar to sector antennas with the exception that the vertical beam width (or really, height) is much more directional. Patch antennas can have equally high gain like sector antennas. Patch antennas can be used effectively for client side bridges, but the wider beam width allows for more noise to be received than with more directional antenna options. The wind load is also quite high because of the solid plate design. Gain can vary from 6 to 19 dBi.

Parameter	Model	Min	Typ	Max	Units
Frequency Range		2400		2483	MHz
Gain	PA24-13 PA24-19		13 19		dBi
Horizontal Beamwidth	PA24-13 PA24-19		35 17.5		Deg
Vertical Beamwidth	PA24-13 PA24-19		35 17.5		Deg
Front to Back	PA24-13 PA24-19	20 30			dB
Cross Polarization			20		dB
Input Return Loss (S_{11})			-14		dB
VSWR *Impedance*			1.5:1 50		OHM
Input Power				100	W
Operating Temperature		-40		+70	Deg C
Pole Size		1" (25)		2.5" (64)	In (mm)
Weight	PA24-13 PA24-19	17.6 (0.5) 60 (1.7)			oz (kg)
Dimension (Dia x Depth)	PA24-13 PA24-19	7.5" x 7.5" x 0.8" (190 x 190 x 20) 15.4" x 10.6" x 0.8" (390 x 270 x 21)			In (mm)
Bracket Tilt		45			Deg

Figure 2-21 Pacific Wireless patch specifications (PacWireless Patch 2004)

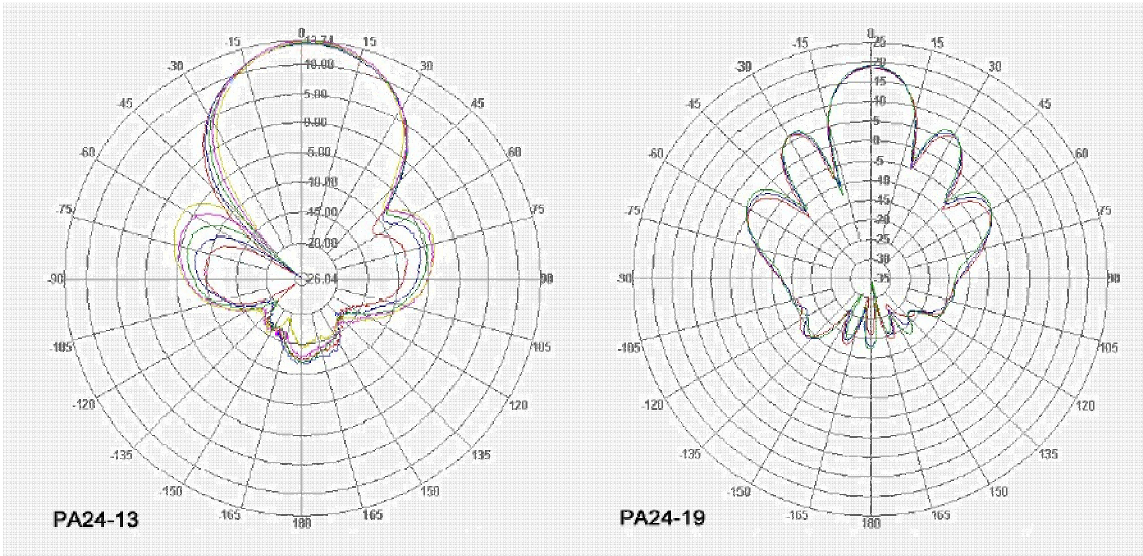


Figure 2-22 Pacific Wireless patch radiation patterns (PacWireless Patch 2004)

The echo backfire antenna (figures 2-23 and 2-24) has a design which works well for eliminating noise emitted from sources behind the antenna. This is known as front to back ratio and is measured in dB. Higher dB levels signify better shielding from these noise sources and better directivity for eliminating stray signals. The echo backfire antenna is similar in front to back ratios to the Cisco 13 dBi yagi and Pacific Wireless 19 dBi patch. Wind load on the Echo backfire is also quite high (PacWireless Echo 2004).

2400 - 2483 MHZ	ES24-14
Gain	14dB
3db Beam Angle	26 deg
Front to Back	> 30dB
Rated Wind Velocity	125mph
Weight	3 Lbs (1.2Kg)
Dimension (Diameter)	10.24" (260mm)

Figure 2-23 Pacific Wireless Echo Backfire specifications (PacWireless Echo 2004)

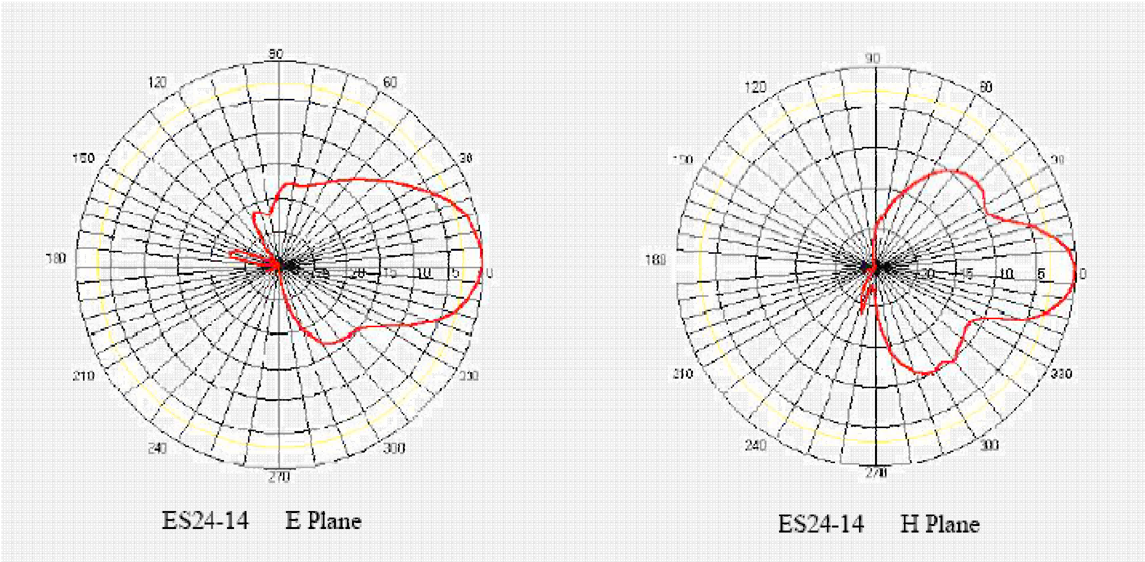


Figure 2-24 Pacific Wireless Echo Backfire radiation patterns (PacWireless Echo 2004)

Each of the directional antennas covered in this section can be turned on their side to achieve different polarization. One positive result from changing polarization is that it can reduce reflection of electromagnetic waves. An electromagnetic wave is more likely to glance off of a flat surface if the waves are traveling parallel to the surface, which will cause multipath distortion. This also depends on the angle of incidence at which the waves meet the surface. If there is a lot of flat ground or water, vertical polarization is recommended. If there are vertical reflectors such as buildings and cliffs, horizontal polarization is recommended. Noise is also an influencing factor in which case horizontal polarization tends to have fewer problems. Horizontal polarization has also been shown to penetrate through trees better. The only way to get the best possible signal is to experiment with each polarization and different heights in order to change the angle of incidence (McLarnon 2004 and WLANAntennas a 2004).

2.4.3 Amplifiers

Amplifiers are an interesting piece of equipment that most systems can do well without. There are two types of amplifiers. Low noise amplifiers (LNAs) amplify the incoming signal coming into the radio and reduce the effects of noise occurring in the receiver cables. High power amplifiers (HPAs) are used to amplify the transmitted signal going from the radio out the antenna (Gast 2002, 160). In most scenarios, using high-gain directional antennas and good quality radios will be enough. Amplifiers also introduce another point of failure into an already complex system.

As 802.11 radios are only half-duplex, signals are received and transmitted through the same coaxial cable in one direction at a time. An important factor to remember is that most amplifiers will only amplify the transmitted signal or the received signal -- not both. This means that extra care must be used in choosing an amplifier. Smart amplifiers must switch quickly from amplifying the transmitting signal to complete pass-through to allow for the best possible reception of the received signal. A sloppy switching system can introduce latency and do much more harm than good (Flickenger 2002, 78).

Another property of amplifiers is that they will amplify whatever signal is fed into them. If noise is fed into them, it will also be amplified. If using a receiving amplifier, the best place for it is close to the antenna before all of the noise and cable loss. If using a high-power transmit amplifier, the best place is going to be close to the radio, so that the noise from the cable is not amplified (Flickenger 2002, 78 and Pozar 2002).

Since most amplifiers only amplify the outgoing signal, it is necessary that there are amplifiers on both sides of the link. This makes point-to-point links the only really useful application for power amplifiers. Point-to-multipoint systems could use amplifiers on each end of every link, but it would be quite expensive and usually smaller cell sizes which will not need amplifiers are more desirable (Flickenger 2002, 78).

In order to make Part 15 devices (which includes 802.11 equipment) as fool-proof as possible, the FCC has a rule that can be interpreted to mean that only complete "certified" systems can be used with each other. The FCC Rules, Section 15.204-Part C, states "*External radio frequency power amplifiers shall not be marketed as separate products...*" Part D states, "*Only the antenna with which an intentional radiator (transmitter) is originally authorized may be used with the intentional radiator*." This means that the manufacturer of the amplifier must certify the amplifier as a packaged system with the radio, an antenna, and coaxial cabling. It also must be installed this same way (Cisco 2004 b, 14).

In most systems, amplifier use is not recommended. They are costly, difficult to work with and troubleshoot, can create power and certification problems with the FCC, and oftentimes introduce more problems than solutions.

2.4.4 Coaxial Cable and Connectors

To achieve maximum performance from a town area wireless network it is important to use high quality low-loss cable and connectors. In 1989, the FCC amended the rules for spread spectrum to discourage the use of amplifiers, high-gain antennas, "home brew" systems, and other means of significantly increasing RF radiation. The amendment states that products manufactured after June 1994 which are designed to use the 2.4 and 5 GHz ISM bands must either use connectors that are unique, and nonstandard or be designed to be professionally installed by a trained RF installation technician (Cisco 2004 b, 8).

The most common connectors used in 802.11b/g systems are RP-SMA, RP-TNC, N-type, RP-N-type, and a plethora of additional PC card miniature connectors such as MC, MMC, MCX, MMCX, and RP-MMCX. “RP” stands for reverse polarity, making the connectors “non-standard” and meeting the requirement for the FCC amendment in 1994. Today, however, the connecters are quite common and can be found at most electronics supply stores. Figure 2-25 illustrates the most popular types of connectors available.

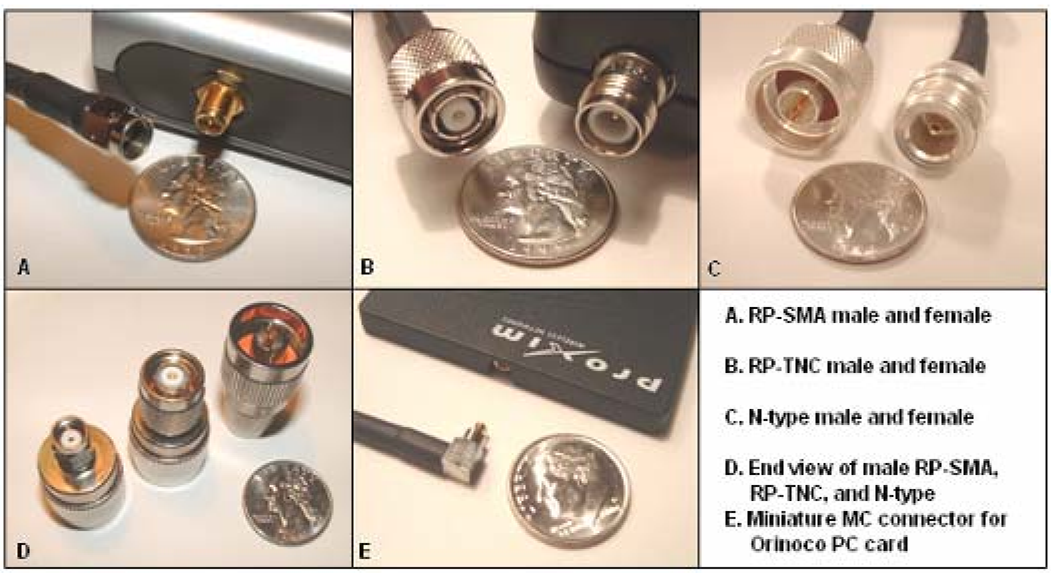


Figure 2-25 Connectors used in 802.11b/g applications (photo by Jae Theobald)

N-type connectors are rarely used on 802.11 radios. However, they are quite common on pigtails, amplifiers and antennas, because they are a readily available low-loss connector type. The FCC “unique connector” limitation is only applicable to the actual radio; not to the antennas, pigtails, or other accessory equipment (Cisco 2004 b, 8).

Cable selection is very important as this can be one of the major sources of signal attenuation. The most commonly used cable type is produced by Times Microwave. Several sizes are available for use where lower loss values are necessary. All cables have at least a braided outer shield, a second inner shield of foil, and a solid center conductor. Bends in the cable must not exceed the bend radius, which is about average for that type of cable. An Ultraflex style for tighter bends and more flexibility is also available in most sizes with a stranded inner core and rubber jacket for tighter bends. As a general cabling rule, always use the best quality cable based on cost and application length and make the runs as short as possible. It is strongly recommended that client bridges be placed no further than a few feet from the antenna. A weatherproof enclosure should be used for the bridge if not otherwise protected from the elements (Flickenger 2002, 70). Table 2-4 shows some of the available types of low-loss cable.

Table 2-4 Coaxial cable specifications (TimesMicrowave 2002, Fab-Corp 2004 b and EcommWireless 2004)

Cable Type	Diameter (in.)	Loss (dB/100 ft.) @ 2500 MHz	Approximate price/ft.
LMR-100A	.110	40	$0.27
LMR-195	.195	19	$0.36
LMR-240	.24	12.9	$0.44
LMR-400	.405	6.8	$0.60
LMR-600	.590	4.42	$1.15
LMR-900	.870	2.98	$3.19
LMR-1200	1.200	2.26	$4.19
LMR-1700	1.670	1.71	$5.99
Belden 9913	.405	8.2	$0.97
LDF1-50	.250	6.1	$1.66
LDF4-50A	.500	3.9	$3.91
LDF5-50A	.875	2.3	$2.27
LDF6-50	1.250	1.7	$10.94
LDF7-50A	1.625	1.4	$15.76

As mentioned earlier, another point of failure in the system is oxidation and water intrusion into the cables and connectors. If making the cables yourself, be sure to clean off any flux used in the soldering process, and make sure collars are crimped tightly. Seal off all collars with heat shrink tubing – preferably the kind with glue or adhesive inside which melts and ensures a quality waterproof seal. If possible, test all cables before installation with a spectrum analyzer. At the very least, use an ohmmeter to test for shorts and continuity. Whenever possible, it is recommended that professional pre-built cable be used (Flickenger 2002, 71)

When mating the outdoor connectors together, a non-hardening electrical grade silicone gel or spray can be used inside the connectors to increase conductivity, repel moisture, and prevent corrosion. Waterproofing connectors can be achieved by wrapping with a self amalgamating rubber tape which will bond to itself through an automatic vulcanizing action. Clean the cables and connectors of dirt and grease, and wrap, spiraling from the bottom upwards. Wrap a second time with electrical tape in the same manner. This will create overlapping shingle-like edges that will shed water rather than collect it (PacWireless waterproofing, 2004).

2.4.5 Lightning Protection

Using outdoor antennas mounted in high places demands respect for nature. Water can impair a system over time, but a bolt of lightning can destroy thousands of dollars in equipment and endanger lives in a fraction of a second. Grounded lightning rods can help to a certain extent, but metallic rods extending above antennas can adversely affect range, and there is a much easier way. Gas tube lightning arrestors are to be installed between antennas and equipment. A properly grounded solid copper wire (10 awg or less) must be connected to the arrestor to be effective. It is also a good idea to properly ground the mounting rod, as it is required by law for all outdoor antennas in the National Electronic Code. Lightning arrestors are directional, so make sure to mount the arrestor in the correct orientation. With the exception of some proprietary arrestors such as Cisco, most arrestors come with N-type connectors, so plan accordingly (Cisco 2004 b; Davis and Mansfield 2002, 101; and Flickenger 2002, 75).

2.4.6 Weatherproof Enclosures

Mounting equipment outside is a good idea for keeping cable runs as short as possible, but in some cases, it may not be very convenient for maintenance and upgrades. Most customer premise equipment will not require scheduled maintenance and can safely be mounted outdoors. Main access points are usually more expensive and will require some maintenance and occasional upgrades. In cases where it is very inconvenient or there is a possibility of theft, equipment can be located indoors.

If equipment is to be mounted outdoors, use outdoor rated equipment or an outdoor enclosure designed for electronic components. The main factors to consider in choosing or designing a box are: water intrusion, condensation, heat dissipation, and cleanliness.

The term "weatherproof" does not necessarily imply a watertight seal. Most boxes containing access points, bridges, switches, their multiple power adapters, and possibly an uninterruptible power supply (UPS) will generate enough heat to cause equipment malfunction. Ventilation is a very important consideration, especially if the box is to be located in direct sunlight and is a darker color. Fans can be used to circulate air through specially designed rain-proof openings. A 110 volt fan is the most convenient as it does not require installation of another bulky power adapter. It is also a good idea to install screens or filters on all openings to keep bugs and other flying debris out.

As far as client equipment is concerned, it is possible to mount the radio in a watertight box without ventilation holes. Condensation can be a problem over time and it is recommended that small drainage holes be available to avoid excess water pooling. A section of square vinyl tubing fitted with end caps may be used if the ends and entry/exit cabling holes are properly sealed with silicone caulking. Remember to leave one or two small holes on the bottommost point for drainage.

Overall, try to keep the equipment as clean and dry as possible. Try to keep the ambient temperature well within manufacturer operating specifications to avoid possible equipment malfunction and failure. This may include active ventilation in the summer and some kind of insulation during cold winter months. With proper care and maintenance, indoor equipment can last many years in an outdoor environment.

2.4.7 IEEE 802.11b/g Radio Feature Overview

Before jumping into a deep overview of radio characteristics, some basic principles must be covered. The two main types of network setups used in commercial WISPs are point-to-point and point-to-multipoint. The main characteristics and differences were explained earlier but the names really explain it well themselves. There are five different functionalities of wireless components. These are access point, access point client, point-to-point bridge, point-to-multipoint bridge, and repeater. Lately, many newer products are capable of configurations supporting each of the following capacities.

Access Points are the hardware used for the main distribution points in a point-to-multipoint system. They essentially act like a smart network hub, broadcasting all wired traffic to everyone within earshot. In access point mode, devices can communicate with associated clients, bridges and repeaters. Most devices in access point mode are not configured to communicate directly with other access points, although when enabled, Wireless Distribution System (WDS) access points can be configured to act in a bridged or repeater mode. Unfortunately, WDS is not included in any 802.11 standard, making interoperability between manufacturers difficult (Churchill 2002). Some APs are able to scan RF channels for traffic and automatically adapt to use the least congested channel. A few high-end access points are also able to discover competing and rogue access points. Generally, access points will have one or two radios and an Ethernet uplink port. In a point to multipoint network, the access point dictates which client can talk and correspondingly divides usage time between clients (Flickenger 2002, 10)

Client units are configured to communicate with access points when in Basic Service Set (BSS) mode or to each other when configured in an Independent Basic Service Set (IBSS) or Ad-Hoc mode. It is unusual for a client to be able to speak to a point-to-point or point-to-multipoint bridge system, but there are some that have the capability. Clients can be connected to a PC through USB, PCI slot, PC card, or bridges with an “AP client” mode. The majority of laptops sold currently have built-in 802.11b or g radios pre-installed.

Point-to-Point Bridge systems are a simple network link that is built as an Ethernet extension from point A to point B, essentially connecting two LANs together. A point-to-point bridge may be thought of as a wireless cable where cables would not or could not be run (Vaughan-Nichols 2003). In choosing a wireless bridge system, it is best to use equipment from a single manufacturer because, again, with WDS most bridges are incompatible with each other due to non-standard bridge protocols.

Point-to-multipoint bridge setups consist of point-to-point bridges in an ad-hoc configuration; there are usually three or more, but no more than ten. There is no central point, instead the system works in a mesh-like configuration, where packets may “hop” across adjacent access points if necessary, essentially routing packets to their destination through the other bridges (Maria 2004). Once again, cross manufacturer compatibility is an issue.

Repeaters are similar to a wireless client and access point in a single unit. Repeaters increase range by receiving the weak broadcast signal from a distant access point and re-transmitting again at full signal strength to local clients. As most repeaters only incorporate a single radio, throughput is reduced by at least 50% due to successive receive and rebroadcast radio usage. Again, cross-vendor compatibility is an issue.

When choosing long-range wireless radio equipment, there are several factors that are important to look for. High power radios (150+ mW) are advantageous to creating long range wireless networks, but constraint should be used to broadcast only what is necessary for a strong link. Smaller, low-power cells are more desirable for area saturation because there will be fewer effects from noise and more access points will be available for sites blocked by trees and other objects. Most units come with variable power levels, so it is advisable to use the lowest setting which will achieve the final goal (Flickenger 2002, 12).

Receive sensitivity is another very important quality that must be researched when purchasing equipment. Amplifiers, high-gain antennas, and clear line of sight may all be present in a system, but if the receiving radios have a poor receive sensitivity, network communication speeds will suffer. When calculating range, receive sensitivity is equally as important as power output. Sensitivity will usually be presented with the corresponding network throughput speeds as negative decibel values. Sensitivity is measured in dBm at a Bit Error Rate (BER) of 10E-5 or 8% Frame Error Rate (FER), meaning that a limited amount of errors are acceptable. Radios with lower sensitivity values perform better (i.e., -95 is three dB better than -92, resulting in better distance). This is because received signals that have faded will be more likely to be usable to a system with lower receiving sensitivity. Currently, the best access points available can achieve full 11 Mbps throughput with receive sensitivity ranges of -86 to -91 dBm, with one Mbps throughput at -93 dBm or lower (FreeNetworks 2004). Conversely, 802.11g networks require much stronger signals. Receive sensitivity for full 54 Mbps OFDM operation is -72 dBm or higher for the Cisco 1200 access point (Cisco 2004 c, 18).

Many access points on the market have diversity antenna capabilities. This is usually characterized by two antenna connectors. Access points with a single connector may also have diversity capabilities by using a second internal antenna. However, these access points are rather useless for long range diversity antenna configurations because of the lack of a second external antenna connection.

A diversity antenna setup is basically a system for selecting the best antenna to receive the incoming signal, one radio packet at a time. The system cannot use both antennas at once, so rapid switching takes place while in receive mode to listen and compare packet sync reception values. The radio then assigns the antenna which has better reception to receive the remaining packet segment. That same antenna is then assigned to be the dedicated transmit antenna for packets going to that client. If the packet transmission fails, the radio will retry the transmission, using the other antenna (Cisco 2004 b, 7).

Diversity antenna connections should not be used as two separate antennas covering different areas, but rather two antennas providing redundant coverage for a single area. If the antennas are covering separate areas, all communication attempts from the second area to the radio while it is busy with the first antenna will simply be dropped and vice versa (Cisco 2004 b, 7). Antennas should be mounted two to three meters apart with one antenna one to two meters higher than the other. This offsets the pseudo Brewster angle created from ground reflections and will drastically decrease the effects of multipath distortion (McLarnon 2004).

The main factors in choosing which radios to use are power output, receive sensitivity, and diversity antenna capability. However, radios should also be chosen based upon the desired security feature set, robustness, upgradeability, interoperability with other vendors, and the company’s reputation for supporting their products.

2.5 Review of Literature Conclusions

The need for broadband access in remote locations is growing at a rate that conventional DSL and cable broadband ISPs are not able to supply. Installation costs to supply services to sparsely populated areas also play a strong part in determining future product rollout. Unlicensed wireless equipment is enabling the creation of inexpensive, broadband-speed, long range links--without burying any additional cable, paying for upgrades to the transmission medium, or dealing with monopolistic line ownership issues.

To design and implement a solid wireless network, there are many concerns that cannot be ignored. Even though equipment frequency use is unlicensed and thus does not require an RF engineer for installation, it does require a certain amount of understanding and skill to achieve quality links and stay within legal limits. With the number of problems and hang-ups that can be presented when dealing with RF links, it may be a good idea to at least have an RF engineer available.

The task of settling on a standard and the equipment that supports it is an arduous process that requires researching the geographic location and perhaps some preliminary testing. One standard may be better suited for deployment in a given circumstance. Likewise, one type of radio/antenna combination may outperform another (of similar gain) when faced with terrain layouts, obstacles and background noise.

Chapter 3

3 RESEARCH PROCEDURES

3.1 Wireless Network Preparation Practices

This chapter is written in three parts. Section 3.1 will discuss some general methodologies and suggestions for designing a wireless town area network. Section 3.2 will discuss some of the setup procedures used in installing an outdoor wireless network. Some of these procedures are tried and true methods that are in print and widely used; others are recommendations extracted from personal experiences while the author was working with a local WISP. In section 3.3 some of the specific technical problems encountered while working with the local WISP will be addressed as well as the troubleshooting steps taken to identify the problems and the proposed solutions that worked to remedy the problems. In sections 3.4 and 3.5, the setup procedures used for implementing a test network for this research and the testing procedures used for measuring the test configurations will be given.

There are many factors involved in setting up a wireless network. First and foremost is the selection of the technology that is to be used. This may change as design needs and installation procedures progress. For now, it is safe to assume that 802.11b is the standard of choice, and will therefore be used in all subsequent examples.

3.1.1 Selecting a Location

Once the technology has been selected, the next step in planning a commercial wireless startup is location selection. Access point locations aside, the overall geographical area must be chosen carefully -- if at all possible. A new WISP may have the option to start in a specific section of town or may want to start growing outward from their central place of business. Although it may seem like one of the most trivial procedures in the planning and setup process, it remains one that can make a huge difference in a startup wireless ISP. If possible, plan deployments in newer development areas which do not have high speed internet access available but where demand for broadband is high.

The preference of planning deployments in recently built areas is based on the general fact that newer areas have fewer full grown trees to work around (from a rooftop point of view). Recall that trees can pose a significant problem to reception. Therefore, the area should be chosen on tree population and growth. Rooftops client antennas should have clear line-of-sight to access point antennas.

Hills and valleys can also be difficult to plan around. Hills can be excellent placement points for access points if an installation location can be secured, and will save on the cost of installing towers or renting space on an existing tower. Otherwise, working around hills will require installing at least twice as many access points -- when compared to similar hill-mounted coverage. Valleys are somewhat easier, where antennas can be mounted on the high outer ridges of the valley providing better coverage, less noise around the access point antenna, and a greater likelihood of client links.

As a general rule, efforts should be made to mount any access point antennas higher than their surrounding client antennas. Ideally, all client antennas should aim upwards to the access point antenna. This causes the excess client ‘overshot’ signal to be dissipated overhead instead of flooding the area behind the access point. Logically, this is preferable because the noise received at the clients, and radiated from the clients to other users of the 2.4 GHz range on the opposing sides is reduced.

3.1.2 Topographical Maps

Another useful resource in choosing an area and planning a wireless network is a topographical map of the area. Topographical maps give a general layout of the terrain using altitude readings. Maps can be obtained through the USGS. If maps are unavailable with elevation readings for current areas where development has occurred, look for older maps that will be more likely to contain the values for the areas. There are also a number of topographical mapping software programs from DeLorme, Map Tech, National Geographic and others which can at least help rule out any impossible links. Useful software should include the abilities of showing cross-section views of a route or drawn trail and mark up capability. Some packages will also include the ability to map tagged points recorded from a GPS unit.

The USGS also provides Digital Orthophoto Quadrangles (DOQs), which are actual aerial photos of an area. Free DOQs are available on their website at www.usgs.gov, but are usually 8-10 years old. Newer photos are also possibly available, but are costly and may not even contain relevant data. While topographical maps, DOQs, and software are very useful for getting a “birds-eye” view of the area, they do not include tree height and buildings. These can only be positively determined by an on-site survey (Flickenger 2002, 51). The recommended way to plan for long distance links in a wireless network is to consult a USGS topographical map of the location, make a good link estimate, and then perform a preliminary site survey.

3.1.3 Access Point Planning

As explained earlier, hills can either aid or hinder the system planning, depending on how they are situated relative to the network subscriber density and the availability of using them as mounting points. A single access point on a hill can easily provide service to an area of several square miles. However, if a high concentration of users is expected, then the access bandwidth is divided by the user bandwidth to give the maximum number of users. Table 3-1 shows the maximum bandwidth available to each user who is simultaneously connected at full speed.

Table 3-1 Network capacity compared to sustained throughput per user (Gast 2002, 310)

Connection method and speed	Effective number of simultaneous users on 11 Mbps wireless network (6 Mbps data throughput)
Cellular Modem, 9.6 kbps	625
Modem, 50 kbps	120
Single ISDN, 64 kbps	93
100 kbps sustained usage	60
Dual ISDN, 128 kbps	46
150 kbps sustained usage	40
200 kbps sustained usage	30
300 kbps sustained usage	20

It may seem unlikely that everyone will connect at once and use all of the available bandwidth of their connection, but it will eventually happen. If a wireless ISP promises speeds of 512 kbps, then there should be no more than 5 to 10 clients per access point. Table 3.1 also makes the assumption that each connected client has adequate signal from the AP to enable full communication speed.

Access point channels and cell spacing will be determined after the initial site survey. Distance calculations for approximating cell size are given in section 3.1.5.

3.1.4 Backhaul Bridge Planning

In planning locations for access point placement, there are several design guidelines which should be followed. Unless placed at the main uplink site, access points must be fed through a wireless bridging network. This means that line of sight between access points is necessary. Although some access points can simultaneously bridge between themselves and act as an access point, this is not recommended since any communication time spent bridging to another access point is time that another client could be using. Also, since every packet being sent or received will be received and then retransmitted down the line, it divides the overall throughput in half. To achieve the greatest backhaul throughput and maximize AP-to-client talk time, it is advisable to use a separate point-to-point bridging radio system for backhaul links to each access point location. Ideally, each access point should have its own bridged backhaul link connected to the main uplink site using directional antennas on each end.

During the design process, it is important to remember that several access points covering small cells will work better than a single access point attempting to cover a large area (Flickenger 2002, 12). This small-cell scheme creates a bridging issue where several connections converge on a single uplink site causing troublesome radio interference. The possibility of hopping from the uplink site to an access point bridge and then from there to another bridge is possible and can be of use for reaching around obstacles. The tradeoff is that clients associated with access points located at the end of several bridge hops from the uplink site will see slower network speeds. Also, the likelihood of failures and the complexity of troubleshooting them increase with each bridged hop.

3.1.5 Link Distance/Path Loss Calculations

There are many factors that determine the effective link distance for a given system. The maximum distance is established by the physical characteristics of free space, and the equipment being used. Factors that will influence the actual range are:

- receive sensitivity,
- transmit power,
- the coaxial cable quality and effective loss,
- connectors and other intervening equipment,
- antenna gain,
- the amount of surrounding noise,
- multipath distortion,
- and weather.

The calculation below in equation 3.1 is for approximating loss in free space radio links.

Path loss can be estimated by:

$$L = 20\,log(d) + 20\,log(f) + 36.6 \tag{3.1}$$

Where L is the loss in dB, d is the distance in miles between sites, and f is the frequency in megahertz.

For example, suppose a 15 mile bridge link is required. Assume that channel 11 (2462 MHz from figure 2.3) is the least congested channel in a horizontal antenna polarization. The free space loss is given by 20*log*(15) + 20*log*(2462) + 36.6. This gives an approximate loss of 127.95 dB between sites. If we assume similar systems on each end with 100mW (20 dBi) radios, no amplifiers, 24 dBi parabolic dish antennas, 30 feet of LMR400 cable (6.8 dB loss per 100 feet), and a short jumper cable connecting to a lightning arrestor, the following values can be calculated for each site using equation 2.2.

Actual single site gain = 20 - 1 – 1.25 - .25 – (.30 x 6.8) - .25 + 24

Actual single site gain = 39.21 dB

By adding the total gains and losses from one site and the gains and losses (minus the radio and transmitting amplifier -- if present) from the second site, we see that a one-way broadcast produces 58.42 dB total system gain. Subtract the total path loss from the gain to get 58.42 – 127.95 = -69.53 dB. For a viable link this final result should be greater than the specified receive sensitivity. If, for example, a pair of Cisco 350 bridges are used, the specifications sheet gives receive sensitivity values as shown in table 3-2.

Table 3-2 Cisco 350 bridge receive sensitivity (Cisco 2004 d)

1 Mbps	-94 dBm
2 Mbps	-91 dBm
5.5 Mbps	-89 dBm
11 Mbps	-85 dBm

To achieve a full 11 Mbps link, the total signal received must be greater than -85 dBm, which it is. There is a difference of approximately 15.5 dB (-69.53 - -85.0). This is a relatively good “fudge factor” for unforeseen impediments in real world links which will adversely affect the link such as rain, noise, mild multipath distortion, earth curvature, etc. It is recommended that for a solid link, a difference of at least 20 dBi above the desired speed sensitivity is adequate. Otherwise, larger antennas, stronger radios, or radios with better receive sensitivity could be used to achieve the link at the desired speed (Flickenger 2002, 77).

3.1.6 Initial Site Survey

Prior to conducting the initial site survey, a detailed area map of the area should be created highlighting:

- proposed AP locations showing cell size and antenna radiation patterns,
- backhaul link plan to main uplink site, and
- geographic obstacles such as forests, bodies of water, etc.

An effective site survey will record several things. First, the pre-mapped points should be verified and recorded on a handheld GPS unit. At each proposed location, a set of factors should be recorded, including notes on other antennas in the area and potential RF sources, notes on objects that may cause multipath distortion, high-resolution backhaul path link pictures, and an evaluation of channel usage and RF noise in the area (Pozar 2002, 21-22).

High-resolution pictures of proposed link paths are useful for later inspection and allow for convenient zooming. They should show an accurate depiction of line-of-sight and Fresnel zone clearance. Photos can also reveal better line of sight locations for access point installation or alternates if the primary location is not available for use. Pictures should be accompanied by notes of towers, tall buildings and/or homes on hills or ridges for possible access point mounting locations. Binoculars are also useful for visually scanning the surrounding area for other antennas and reflective surfaces.

If a spectrum analyzer is available, it can be a very valuable tool in finding how much noise exists in a specific frequency in the surrounding area. If an analyzer and technician to operate it are not readily available, free software can be used in combination with a notebook computer and wireless card to determine channel usage. NetStumbler is a free software tool available on the web that can request and listen for surrounding wireless networks and reports both signal and noise strengths. A scaled-down version is also available for use on wireless-ready pocketPC devices, which can be much easier to carry than a notebook PC. A wireless enabled pocketPC with external antenna connector can be an extremely useful tool for aiming antennas in client installations. Channel-usage data gathered from each area should be stored in separate files for later analysis and channel planning. When scanning for the least congested channels with NetStumbler or an equivalent – be sure to try different polarities. Competing noise levels are usually lower when using a horizontal antenna polarization. First, use a tall mast with an omnidirectional antenna for general signal usage data collection, and then use a dish to pinpoint location and polarization of higher level signal sources (Pozar 2002, 22).

After analyzing the data gained in the initial site survey, there should be enough data to show whether the link is possible, or at least should show that there are no major foreseeable problems in completing the link. If it does not, further surveying or redesign is necessary. This may include making calculations and measurements for Fresnel zone clearance or creating a temporary radio link for analysis and observation. There is also the option of using microwave path engineering software, which can be quite expensive (Pozar 2002, 21).

When looking for places to mount access points, remember that many homeowners and businesses are willing to allow access to their roof in exchange for free or discounted broadband access. In cases where no suitable buildings are available, leasing space on smokestacks, billboards, and other existing structures may be cheaper than installing a new tower. However, installing a new tower can also create income by leasing space to others providers using different frequencies.

When attempting a link that will need a tower installed, it is often difficult to determine how tall the tower will need to be. An inexpensive method to determine height necessity can be achieved by two people and a large helium balloon (two to three foot diameter) on a calm day. Suppose that at the intended tower site (A), an individual raises the tethered balloon until the person at site B can clearly see it (allowing some Fresnel zone clearance) from the position of the future antenna. The person at site A marks on the string where it touches the ground. The string is then measured when the balloon is lowered again, thus giving the towers minimum height requirement. Be careful when using this method as the smallest amount of wind can change the proposed position and disrupt height measurements. This should be used as an approximation method only.

3.2 Wireless Network Setup Procedures

After the planning process and the initial site survey are complete and link viability is confirmed, it is time to start installing and testing equipment. Although most problems should have been addressed during the planning stages, new issues will undoubtedly surface and plans will need to be adapted accordingly.

3.2.1 Uplink Site Characteristics

If using a DSL supplier, the main uplink site should be located as close as possible to the telephone company's central office. This will allow for the greatest availability of uplink speeds. The lines should be tested prior to signing any lease contracts for the space. All that is needed is some closet space large enough to house a few computers, a switch, the wireless bridges and possibly an access point. If the space is really small, make sure that there is adequate ventilation for cooling the equipment. The ideal location would be a private utility closet on the top floor of a tall building. Roof access is necessary for deploying antennas and can usually be gained through running cables through ventilation pipes, AC/heating ducts, or new holes may need to be drilled through the attic. Remember that coax cable runs should be as short as possible to avoid signal loss.

3.2.2 Cabling Setup Practices

If pre-built cables are being used, make sure to accurately measure distances and order cables with appropriate end connections. If making the cable assemblies, the cable should be run without connectors wherever possible to avoid catching them while pulling, and preventing other cable damage.

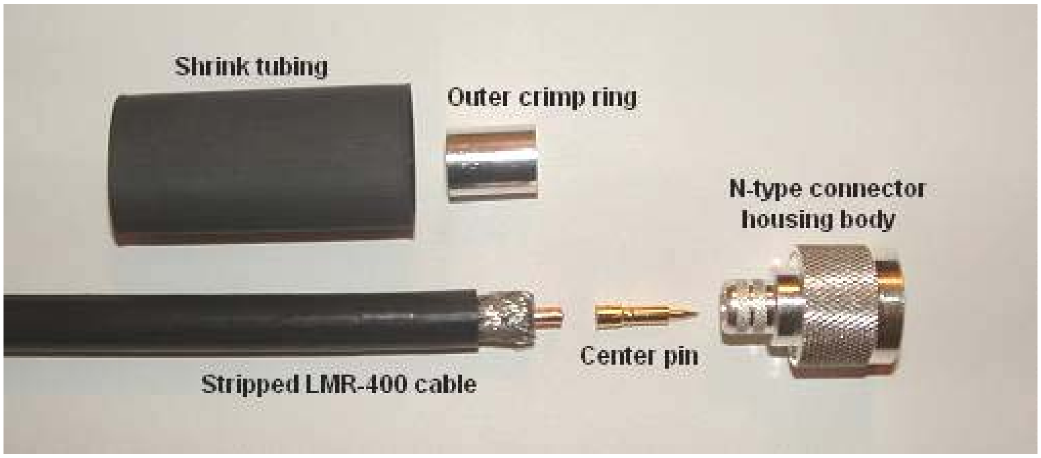


Figure 3-1 N-type connector assembly for LMR-400 coaxial cable (photo by Jae Theobald)

Cable should be cut cleanly back and stripped to specified measurements using the appropriate stripping tools. A razor blade will work as a stripper, but can cut too far into the shielding and center conductor, causing unnecessary distortion. When soldering the center conductor, use a liquid water-soluble flux to clean the connections and ensure a clean solder job. Do not apply too much solder as this will cause problems when inserting the center pin through the connector insulator. Apply heat with the pin connector already on the center conductor wire. Allow solder to enter into the "seep hole" on the center pin and keep all visible solder smooth. Rough areas of solder will cause signal distortion and cause higher loss. Remove excess flux after soldering to prevent corrosion. Thread the outer crimp ring and a two inch piece of shrink tubing over the cable and slightly flare the wire braid out to allow connector body to slide between braid and foil shield. Insert the center pin into the connector body. Slide crimp ring over the braid and crimp securely using hexagonal crimpers specified for the specific cable size. Slide the heat-shrink tubing over the crimp collar and lower part of the connector body and shrink evenly to a tight fit. The shrink tubing should be high quality outdoor rated with a heat activated glue inside to ensure a watertight seal. The tubing should fit so that the threaded collar on the connector body can still rotate freely. Connectors should be mated and waterproofed using self amalgamating tape and electrical tape wrapping from the lower side upwards, as described previously in section 2.4.4.

3.2.3 Antenna Mounting

Rooftop antennas should be mounted securely enough to withstand high wind loads and may require a tripod or other type of secure mounting mast. Antennas should be located away from other metal objects and as high as possible without compromising stability or breaking local height limits. Use guy wires to secure freestanding masts and to prevent excess antenna movement in areas with high winds.

The mast needs to be grounded for lightning protection as well as using inline lightning arrestors on the coaxial cable to protect from equipment surges and possible fire. Arrestors should be located close to the equipment with a properly grounded solid copper wire.

Directional antennas may be aimed and calibrated once the opposing antenna is connected and is broadcasting a signal. The best way to align point-to-point antenna links is to arrange for an installer at each site. Each location should have a phone, the intended bridge equipment, and either a wireless enabled pocketPC or laptop with a wireless card, pigtail and sniffer program like NetStumbler to measure signal strength. The person at site A will connect the bridge to the antenna pointed at site B. The person at site B will use the wireless device and sniffer program to align and secure the antenna to receive the best signal strength possible. The roles will then reverse and the person at site B will connect their bridge and broadcast. The installer at site A will disconnect the bridge and align the antenna using their signal strength meter and secure their antenna.

3.2.4 Channel Spacing and Allocation

During the antenna aligning process, signal and noise values can be measured and a final channel frequency and polarity can be assigned for backhaul bridges. If it seems that there is simply too much noise to ensure a good connection, remember IEEE 802.11a at 5.8 GHz, is usually less congested than the 2.4 GHz channels and may be used to create less congested backhaul links.

One of the main problems presented when using large cells is local sources of noise near the client or access point. It is unlikely that a single channel will be completely available in all areas within a given access point radius. Some access points (like the Cisco 1200) can automatically adjust to use the least congested channel. This is convenient for small hot-spot wireless networks where any noise is heard by all users, but in larger networks, not all noise is audible to everyone. This is another reason to implement smaller access point coverage cells. If there is too much noise on the channel used by one access point, simply aim towards a different access point in the area using a less congested channel. In extreme cases, a separate access point in the same location may be used on a different channel. An extreme possibility is to use an entirely different frequency range. An access location using two access point radios in 802.11a and

802.11b/g would have little trouble creating a solid connection with any client source and would offer great flexibility.

To ensure non-overlapping channel spacing between access points, the following schemes in figure 3-2 can be used as layout guides for the three available channels in 802.11b/g.

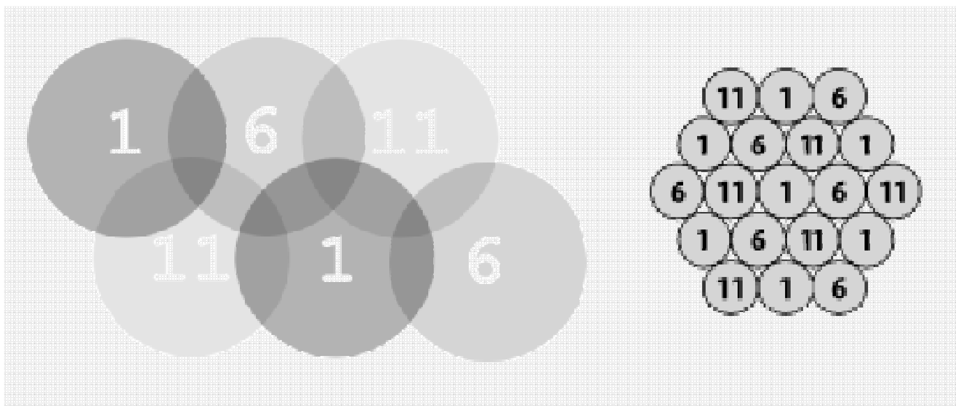


Figure 3-2 Access point channel spacing schemes (Flickinger 2002, 11, and Gast 2002, 324)

3.2.5 Network Security

There are two types of security in wireless networks. These are authentication and privacy. The first keeps unwanted users from using the network. The second keeps the data secure from being overheard and understood until it reaches a more secure physical line.

The physical security of a wired network is often less of an issue because they are usually contained within a secure structure or buried underground. On the other hand, wireless networks are (electrically) wide open to anyone within broadcast antenna reach. In view of the fact that a wireless network can potentially be accessed from anywhere within the antenna range, authentication is necessary to keep intruders out.

Authentication can be done by using MAC address filtering on the access point, using a radius authentication server, or similar authentication or filtering method.

The second security concern on most networks is protecting the network traffic from unauthorized access and therefore potential data theft. Usually, in a commercial wireless network, little or no data security is used. Wired Equivalency Protocol (WEP) can be cracked, which is often the excuse for not using it. It also requires processing power and effectively slows the transmission. Adding security measures for transmitted data often results in configuration problems and can be more of a hindrance than a help. If data security methods are not implemented, it is imperative to inform end users of the unsecured connection. Additional customer services may include an offsite VPN connection or setting up a secure tunnel to a host location for more security-conscious individuals.

3.2.6 Gateways, Firewalls, Monitoring, and Portal Software

Similar to normal LANs, a gateway is also needed for providing wireless service. The gateway setup may include a firewall, network address translation (NAT), and/or a means of forwarding ports to internal addresses. All of this depends on how much control the supplier wants to give the end user and whether or not other services will be available on internal servers (such as email, web hosting, and online storage space). Configuring this equipment is beyond the scope of this paper and therefore will not be covered in depth.

Network monitoring software can also increase reliability through providing system checking and automated alarms. There are many free tools available on the

Internet that are highly customizable. One widely used software package is OpenNMS, which is a relatively easy to install software for Linux. Additional modules can be added to continually monitor the network and send alerts when links fail. There are many available so the user can select one that best suits their needs. A word of caution when using monitoring software with wireless links: dropped packets are inevitable, so set the reporting tolerance level lower than it would be on a traditional wired network.

Portal software for wireless networks can prove to be useful for network management, bandwidth allocation, and security. Some versions can also function as authentication servers on the network edge and as a router/gateway/firewall combination. Some versions advertise to be complete all-in-one solutions which also include billing and automated account management tools. Suffice it to say that there are many options available and most are available for a limited trial period so look around and find one that works well.

3.2.7 Naming and Addressing Schemes

There is some discussion about whether assigned or dynamic IP addressing functions better for a wireless network. It really depends on the network infrastructure and what the final objective of the network is. In a wireless fixed-point network, a system using static addresses is more convenient for management and tracking. In an area serving a wireless hot spot, a dynamic addressing scheme is easier to use because clients are logging in and out and addresses can be easily recycled.

Since most WISPs offer a fixed-wireless solution, it is safe to assume that a static addressing scheme should be used. Experience suggests using a scheme that is easy to remember, say, using a class B subnet in the 10.0.X.X range. An organized IP/MAC scheme is essential for hardware management and troubleshooting. Table 3-3 shows a possible example scheme.

Table 3.3 Example IP address subnet scheme

Equipment	IP Address Range/Subnet Mask
All network management equipment (minus radios) such as routers, firewalls, managed switches, etc.	10.0.1.1 – 10.0.1.254
Backhaul bridges	10.0.2.1 – 10.0.2.254
Access points	10.0.3.1 – 10.0.3.254
Client PC’s connected to bridge	10.0.100.1 – 10.0.100.254
Rooftop client bridges	10.0.101.1 – 10.0.101.254
All data and application servers	10.0.254.1 – 10.0.254.255

The reason for using a .101 address for the client bridges and a .100 address for the client computer is that it is an easy way for installers to remember that the higher subnet is located on the roof. This assumes the use of matching numbers in the fourth octet for corresponding bridge and computer (if the bridge is 10.0.101.21, then the computer would be 10.0.100.21). Any neighboring subsets in the third octet could be used and it may even be advantageous to organize subnets by the particular access point they are associated with. For example, all clients associated to the access point at IP address 10.0.3.5 could fall within the range of 10.0.105.X, thus matching .5 and .105. Of course, using this scheme, the progressing access points would need to skip numbers to stay odd numbered (to allow for the side-by-side bridge/computer schema).

In the end, there is no specific addressing scheme that is going to be perfect for all situations. Organization and documentation are key functions that must be kept in mind at all times. Disorganization amongst installers using IP address may result in duplicate addresses which may require an on-site visit for reconfiguration. Address blocks may be given to installers to avoid network conflicts of this nature.

Every access point broadcasts a name which clients use to specify which signal they should use. This name is called the service set identifier, or SSID. Access points can either enable or disable the broadcast of the SSID, usually for security and masking. Using a broadcast with a recognizable SSID can be a method of advertising. WISPs will usually broadcast their company name as the SSID, allowing anyone with a wireless card to see them. Several providers even add their service sign-up phone number after their company name as a further advertising method.

3.3 Problems and Troubleshooting with a Local WISP

Choosing the right standard to use and buying the right equipment for the job are important steps in the process to building a solid wireless network. However, equipment can only compensate for user error to a certain extent. Employing capable network designers and competent installers to design, build, and maintain the network is an equally important decision.

While working with a local WISP as an intern, several problems were identified in several problem categories. Many of these problems could have been avoided with the correct initial installation setup and maintenance procedures. The problems encountered can be grouped into three basic categories: equipment, frequency limitations, and environmental and weather concerns.

3.3.1 Equipment Problems

Mismatched equipment due to lack of compatibility testing, changing firmware versions and lack of a defined 802.11b bridging standard between vendors makes cross-vendor use difficult and can create unstable links. This also makes user support nearly impossible due to the vendor's unwillingness to troubleshoot their product when used with products from other manufacturers. From the field trials symptoms that were exhibited by incompatible access points and client bridges ranged from not being able to connect at all to associating for a few minutes and then dropping the link unexpectedly. This occurred after using the Linksys WET11 bridge for several months. The initial network was built by using off-the-shelf Linksys WAP11 units. The WAP11 units obviously communicated well with the WET11 client bridges as they are also built by Linksys. After an acquisition of the WISP by another company, the WAP11 units were replaced with Cisco 1200 access points because of better stability and greater user capacity. The existing WET11 bridges worked well with the Cisco 1200s, but the newly installed WET11 units would drop the link signal randomly. After some troubleshooting, the cause was pinpointed to be different firmware versions on the WET11 units. The new units shipped with a newer firmware version which was not compatible with the Cisco 1200 access points. From that point on, all new units needed to have the firmware rolled back to the previous firmware version 1.32 to be compatible with the Cisco 1200.

Recommended solution: Design the entire network backbone using a single manufacturer. Choose one with a good track record and a wide variety of products that will fit the needs of the network. This should include access points, bridges, and repeaters at the very least. Client bridges may be a different brand, but test for interoperability before investing too much time and money.

Another problem which has been addressed here that was an issue at the aforementioned WISP is access point availability. The company was initially set up using the homes of three friends as the backbone. This was a faulty design to begin with and was never modified to accommodate for higher bandwidth usage or a more diverse area of users. In the initial setup, the access points formed a chain, and the access points themselves were used as the bridges. The uplink was a 1.5 Mbps T1 line, but those users connected off of the end of the four-hop line could not expect anything greater than 200 Kbps total (up and down combined, since wireless is half duplex). This capacity would be even lower given any additional network traffic.

Solution: Install more access points in a looser cluster pattern (all three APs were within five blocks of each other). Increasing the number of available access points will increase the likelihood that a potential subscriber can receive a clear signal during the qualifying site survey. No only will it provide greater redundancy for getting around obstructions, but can also provide a backup channel source if noise in the area prevents clear signal reception on the primary AP's channel.

Increasing the number of available access points would have solved several other problems as well. As mentioned in chapter one, an amplifier was connected to several of the main access points using 12 dBi omnidirectional antennas. Although this seemed to increase the range of the signal and expand the coverage radius, it only created problems. Qualifying site surveys would show a strong signal but after installation the bridge radios would have trouble communicating. This occurred because only one side of the broadcast was amplified; the weaker receiver did not have enough native power to communicate back to the access point from its position.

When installing extra access points, use separate bridge radios to supply bandwidth to each of them. If a direct bridge from the uplink site to each AP is not possible, use two bridges back to back connected through a small wired switch instead of a single repeating bridge to accomplish any necessary hops. This will undoubtedly increase costs, as it requires an additional bridge and a small switch to connect both bridges and the access point together, but the bandwidth will not suffer as much latency (approximately less than 5% versus more than 50% with a single radio repeater).

All of the equipment problems to this point have been on the access point and bridge side. The client bridges had their share of problems as well. Since the coaxial cable runs are to be as short as possible, the bridges were mounted on the roof. To get power to the radio, a second CAT5 cable was run up to supply power. In several installations there were problems where the radio would stop functioning and after a reboot would come back up. This was usually due to one of two common occurences. First, water may have entered the enclosure and caused a short which unplugging the unit would sometimes remedy. Second, after inspecting the length of cable printed on the CAT5 jacket, it was discovered that the length of the cable was causing such a voltage drop that the voltage arriving to the bridge was much less than the required 5 volts and brief fluctuations in the power were causing “brown-outs.”

Recommended solution: Keep the cable runs short if using power over Ethernet or running a second cable. If a longer cable run is necessary, either a thicker cable may be used, or a power supply with a higher output can be used to compensate for the voltage drop.

3.3.2 Frequency Problems

The crowded spectrum usage at 2.4 GHz has been addressed earlier. It comes as no surprise that there were problems with people using 2.4 GHz phones, home networking access points and other appliances causing interference. At 2.4 GHz, interference is practically inevitable, but changes to the system could have been made that would have reduced the effects.

Recommended solution: Using horizontally polarized antennas reduces the effect from vertically polarized sources, which the majority of competing signals are. Sector antennas could have been used instead of omnis to divide areas into smaller pieces. Smaller omni antennas with higher downtilt angles could have been used more effectively to cover smaller lower usage areas. Using IEEE 802.11a to overcome noise is also an option, but antennas are difficult to come by, signals do not travel as far, and FCC restrictions are stricter.

3.3.3 Weather and Environmental Problems

It is doubtful that falling rain by itself ever caused complete outages as it only caused a slightly noticeable lag which most users would likely attribute to normal/high network usage. Connections would slow overall, but most outages were caused afterwards by water intrusion into the electronics and cables. Poorly designed enclosures and badly caulked seals allowed water to enter and caused several equipment malfunctions. There were some occasions where wind was suspected to have moved antennas off focus, but there are many other things more likely to have moved antennas, including the homeowners themselves.

A concern which would usually show up several months after the initial wireless network install is the need for well designed outdoor enclosures. The boxes must be water resistant, yet also allow for ventilation and keep insects and other debris out at the same time. It may need a cooling fan in the summer to prevent overheating and may even need a heat source or insulation in the winter to prevent freezing. Equipment failure can occur in changing temperatures due to solder cracks on the circuit board. This may result in erratic function outages during temperature changes or even complete failure.

Access points and bridges designed for outdoor use are available, as well as weatherproof electronics enclosures. These are not absolutely necessary and a high premium will be paid for their use. Indoor equipment can be used in an outdoor setting provided it is inside a weatherproof (not waterproof) box.

Access points are usually placed on customer premises in exchange for free or discounted access to the service. Homeowner restrictions and residents who are unwilling to mount antennas on their homes can result in limited access point placement. Customer desires are one thing to deal with, but the FCC has released a “Preemption of Local Law” which allows the use of dish antennas less than one meter diameter for fixed wireless applications - including wireless internet. End user antennas can usually be hidden quite easily (Pozar 2004, 14).

3.4 Proposed Test Network

In order to validate some of the problems and proposed solutions encountered while working with the local WISP, a test network was designed and built using similar procedures and equipment. The objectives of the test network were to validate the usage of wireless networks as a means to complete the last mile and to determine which variables in the setup procedure result in the most stable and fastest network. To arrive at this end, the test network was designed and built from scratch following the outlined procedures and proposals mentioned thus far. Several constraints had to be followed, including budget, temporary-use construction, testing flexibility, and location. The given equipment and network requirements were as follows:

- The BYU School of Technology (SOT) supplied the uplink through their lab network which was to be kept secure from attacks and unauthorized use.
- Faculty members from the School of Technology volunteered use of their roofs and homes as available client test nodes
- Roof access to the Crabtree building (CTB) was granted for broadcast use
- A Cisco 1230 AP unit and several bridges were available for temporary use

3.4.1 Setup Design

After reviewing the link possibilities from the roof of the Crabtree building to the faculty homes, it was determined that an alternate broadcast location was necessary. After several phone calls, permission was obtained to use the roof of the Spencer W. Kimball Tower (SWKT) as a taller broadcast point. This change would add the requirement of a wireless bridge from the Crabtree building to the Kimball tower, but would enable a clear line of sight to the roof of at least one faculty member.

In following with setup procedures, the general location was given to be Provo, Utah; more specifically, centered on BYU campus. The available uplink site was the Crabtree building, home of the IT department in the School of Technology. The main broadcast access point location was to be the Kimball tower. The equipment selection consisted of the newer Cisco 1230AP and the Linksys WET11 bridge as an end client. This setup was very similar to the equipment setup used at the local WISP.

3.4.2 Equipment Testing and Selection

In choosing a wireless bridge to supply the signal from the Crabtree to the Kimball tower, two bridges were tested. Tests consisted of using a pair of bridges communicating in a “radio-free” environment at close range using 2 dBi rubber duck antennas. A second set of tests were also conducted at a more realistic distance of .623 miles (approx 3289 ft.) using 16 dBi directional Vagi antennas in horizontal polarization. Actual throughput was measured by transferring large files using an FTP server/client model using a Windows XP IIS FTP server to a WS-FTP remote client. The reported values are the averages of five individual tests to ensure accuracy. Since security would be used in this setup, different levels of WEP encryption were also tested. Signal strength at the .623 mile range was measured at 64.4 dBm using NetStumbler with an Orinoco silver card and the 15 dBm D-Link radio at the opposite end.

Table 3-4 Comparison of D-Link 900 AP+ and Linksys WET11 in bridged modes

		D-Link 900 AP+ (2x point-to-point bridged mode)		Linksys WET11 bridge (Ad-Hoc bridge mode)	
Range	Encryption	Time	Throughput	Time	Throughput
5 feet	256 bit	14.52 sec.	6.79 Mbps	N/A	N/A
5 feet	128 bit	14.01 sec.	7.03 Mbps	19.47 sec.	5.07 Mbps
5 feet	None	13.78 sec.	7.16 Mbps	18.90 sec.	5.22 Mbps
.623 mi.	256 bit	18.23 sec.	5.45 Mbps	N/A	N/A
.623 mi.	128 bit	17.92 sec.	5.51 Mbps	33.44 sec.	2.95 Mbps
.623 mi.	None	17.77 sec.	5.57 Mbps	32.42 sec.	3.05 Mbps

Based on the test results, the D-Link 900AP+ was chosen for its higher point-to-point bandwidth, 256 bit WEP availability, and more available configuration options. The distance from the top of the Crabtree building to the Kimball tower is approximately 1225 feet with a 100 foot rise to the Kimball tower.

3.4.3 Final Network Layout and Assembly

The final layout for the proposed network called for Cat5 running an Ethernet signal to the roof of the Crabtree building, which was broadcasted over the bridged link to the Kimball tower and rebroadcast using a Cisco 1230AP.

The D-Link 900AP+ units were placed in bridged mode on channel one at full power with 2x enhanced mode enabled for better throughput. WEP was enabled at full 256 bit strength with MAC address filtering, which allowed for association between the two bridges only. Antennas were both Pacific Wireless 16 dBi yagi style using horizontal polarity. Cables lengths were kept less than five feet and therefore LMR195 was used for the cable jumpers.

The enclosure on the Crabtree was a small 6x6x4 inch marine quality sealed PVC box made by Carlon Inc. The enclosure used on the roof of the Kimball tower was a larger 12x12x6 inch box of the same quality and manufacturer. It being January, the cable openings were plugged and the interior of each of the boxes was lined with fiberglass insulation. This method relied on the heat from the electronics to keep them from freezing, which could have caused solder cracks on the mainboard.

The antenna setup for the Cisco access point was designed to use a diversity setup using two 12 dBi Pacific Wireless vertically polarized omnidirectional antennas. The antennas were mounted on the side of a metal bracket of a larger antenna (which operated between 806 and 869 MHz, so no interference was noticed). The omni antennas were mounted on a bracket 32 inches apart. The directional vagi antenna was mounted on a lower crossbar section of the bracket. See figures 3-3 and 3-4 for pictures of the full mounted assembly.

Figure 3-3 Close-up of antenna mounting bracket for two omnidirectionals and vagi


Figure 3-4 Full antenna mounting assembly on Kimball tower

3.4.4 Baseline Testing

After both bridges and the access point were installed, a baseline test was run from the roof of the Kimball tower. The basis for these tests was to determine the best case throughput for the entire system. These results are shown in table 3-5 in a comparison to test results from the equipment before installation equipment while in the same room. These results show the times for the complete route from the FTP server, over the wireless bridge link, rebroadcast from the access point, and finally received by a Linksys WET11 connected to the laptop running the WS-FTP client. With an Orinoco card and a 2.2 dBi rubber duck antenna the signal level 15 feet from the omni antennas was approximately -45 dB (as a side note, when the antenna was placed within 5 inches of the right omni, the signal strength increased to almost -10 dB, which shows how quickly a signal can fade with distance).

Table 3-5 Baseline network comparison

	Indoor test case	After final installation
Ping test statistics	0.000% packet loss Min ping: 1 ms Average ping: 2 ms Max ping: 6 ms	0.004% packet loss 2/500 Min ping: 1 ms Average ping: 10 ms Max ping: 206 ms
Average FTP throughput	3.62 Mbps	1.62 Mbps

3.4.5 Client Setup

After completing the installation of the main network, the remaining client bridge was installed at the home of the faculty member. His home is located .866 miles from the Kimball tower, allowing for a very reliable link. A 13.5 dBi Cisco yagi antenna was mounted on the roof with a short jumper cable to the Linksys WET11. The Wet11 was enclosed in the same type of 6x6x4 inch box used at the Crabtree building. Power was supplied over a second length of Cat5 cable which was less than 100 feet long.

3.5 Measurement Tools and Procedures

The overall test objective of the wireless network is to determine if there is a configuration of equipment which works better than others. To this end, the following were tested as integral parts in the successful wireless infrastructure:

1. To what extent can poor weather degrade throughput, and can severe weather completely break a link?
2. How important is Fresnel zone clearance, and are there certain circumstances where obstructions in the line of sight and Fresnel zone can be ignored?
3. Is there one type of antenna that will perform better (regardless of gain), in any given circumstance?
4. Is it worth spending four to six times more money to implement a full network of enterprise class hardware, or can a reliable network be built using properly installed off-the-shelf equipment?
5. Is there a combination of access point-antenna and antenna-bridge configuration that performs better than another? If so, what is it?

As the majority of the tests required gathering measurements from remote locations, a portable wireless testing kit was designed to provide all necessary connections and equipment. The kit included several jumper cables with various connector types, connector adapters, five different antennas, three bridges, and a wireless enabled laptop with NetStumbler and an Orinoco silver card. A heavy duty tripod and 300 watt 12 volt power inverter were also added to provide easier mounting and a steady power supply for the laptop and bridges.

Prior to each test, a precise setup procedure was performed in which the antenna was aimed using NetStumbler to get the highest signal strength possible. Each test setup log includes the cabling and connectors used, in addition to the calculated loss for the system. These figures will be compared to the actual gain as recorded by NetStumbler and a percentage of error calculated to show antenna reliability. Bandwidth was determined by large file transfers using the aforementioned FTP server/client setup. Ping tests were used to determine the number of dropped packets and the response time. A program called PingPlotter was later implemented to show network health along with any outages to the client. It was used as a tool to continually monitor each device in the route to show any weaknesses. The results for each of these tests and corresponding conclusions will be reviewed in the following chapter.

Chapter 4

4 RESULTS AND DATA ANALYSIS

4.1 Wireless Performance Analysis

In this chapter, data collected from several tests will be presented and analyzed. These results include data gathered from the test network which was documented in the final section of the previous chapter. The tests were designed to evaluate the effectiveness of long range wireless networks and to determine which system factors detract from a reliable and fast wireless network. Variables which were tested include antenna types, bridge equipment with varying sensitivities, and different environmental factors such as weather and buildings and foliage landscapes which impede complete Fresnel zone clearance.

In cases where applicable, a baseline test was run using conditions as close to perfect as possible with the intent to show the best case scenario. Every effort was made to perform the tests with precision in test scenarios using equally fixed variables.

The complete results for each of the tests performed are included in its own separate appendix. Each appendix displaying tests results will include (where applicable):

- photos of the link path
- street map of the area with latitude, longitude, and altitude measurements
- estimated path loss and signal calculations
- actual measured signal strength and local competing signals

4.1.1 Effects of Inclement Weather

The bridge from the Crabtree building to the Kimball tower and the client bridge stationed at the faculty member's home were used to conduct ping tests during different forms of inclement weather such as snow, rain, and thick fog. The test attempts to determine the actual effects of weather on a wireless link and formally assess how much consideration weather storms actually require. A simple ping test was used to measure dropped packets and response times. Complete test results and map layout are shown in Appendix A.

Table 4-1 Complete ping test results to Wet11 client node during inclement weather

Temp (C)	Humidity	Condition	Date	AP % Loss	AP Min	AP Max	AP Ave	Received	Client Node % loss	Node Min	Node Max	Node Ave
-9	48%	Fair	2/11	2.43%	3	773	4	N/A	N/A	N/A	N/A	N/A
7	41%	Fair	2/16	1.10%	3	717	3	N/A	N/A	N/A	N/A	N/A
13	38%	Fair	3/15	1.55%	3	872	4	14606	2.63%	4	4026	9
14	33%	Fair	3/25	0.19%	3	1003	5	4668	8.54%	4	2013	9
0	87%	Fair	2/23	0.58%	3	693	4	14795	1.37%	4	1913	7
1	70%	Fair	3/2	0.61%	3	988	9	14320	4.53%	4	4425	17
1	70%	Fair	3/8	0.43%	3	551	8	14809	1.27%	4	2427	13
8	66%	Fair	3/15	0.61%	3	559	3	14429	3.81%	4	2600	7
7	66%	Fair	3/15	0.19%	3	910	8	14139	1.61%	4	2615	13
7	53%	Cloudy	2/25	0.87%	3	899	21	12802	14.65%	4	3174	17
13	51%	Cloudy	4/9	1.35%	3	566	14	7821	2.24%	4	2568	16
1	87%	Cloudy	2/22	1.61%	3	710	5	14298	4.68%	4	1790	8
6	76%	Cloudy	2/23	1.89%	3	698	10	14529	3.14%	4	4293	21
-2	91%	Cloudy	3/1	0.33%	3	988	8	13304	11.31%	4	3223	13
21	31%	Hazy	3/21	0.15%	3	768	5	14054	3.94%	4	4302	10
8	62%	Hazy	3/22	0.01%	3	535	3	11980	1.02%	4	3790	12
13	51%	Hazy	4/16	0.42%	3	384	3	7964	0.45%	4	38	6
11	41%	Dust storm	4/27	1.23%	3	38	4	2962	1.27%	4	43	6
2	81%	Wet	4/18	0.70%	3	220	3	6810	14.88%	4	1009	6
3	70%	Foggy	3/10	2.47%	3	672	4	14452	3.65%	4	3325	10
16	34%	Rain L	4/1	1.13%	3	179	3	0	100.00%	N/A	N/A	N/A
5	81%	Rain L	3/26	1.65%	3	864	9	7664	4.20%	4	2434	8
15	31%	Rain L	4/17	1.11%	3	418	3	7913	1.09%	4	1156	6
6	62%	Rain L	4/17	1.31%	3	40	3	6377	20.29%	4	3225	9
-6	82%	Snow L	2/11	1.05%	3	563	4	N/A	N/A	N/A	N/A	N/A
9	71%	Rain M	3/26	1.61%	3	376	4	7641	4.49%	4	2444	8
-6	63%	Snow M/H	2/7	0.12%	3	441	3	N/A	N/A	N/A	N/A	N/A
1	87%	Snow H	2/28	1.03%	3	1003	10	14744	1.71%	4	4481	16
0	93%	Snow H	2/28	0.91%	3	941	11	11671	22.19%	4	4195	8

Table 4-1 shows the complete results of ping tests run during inclement weather conditions that are suspected of causing latency and failed packet transfers.

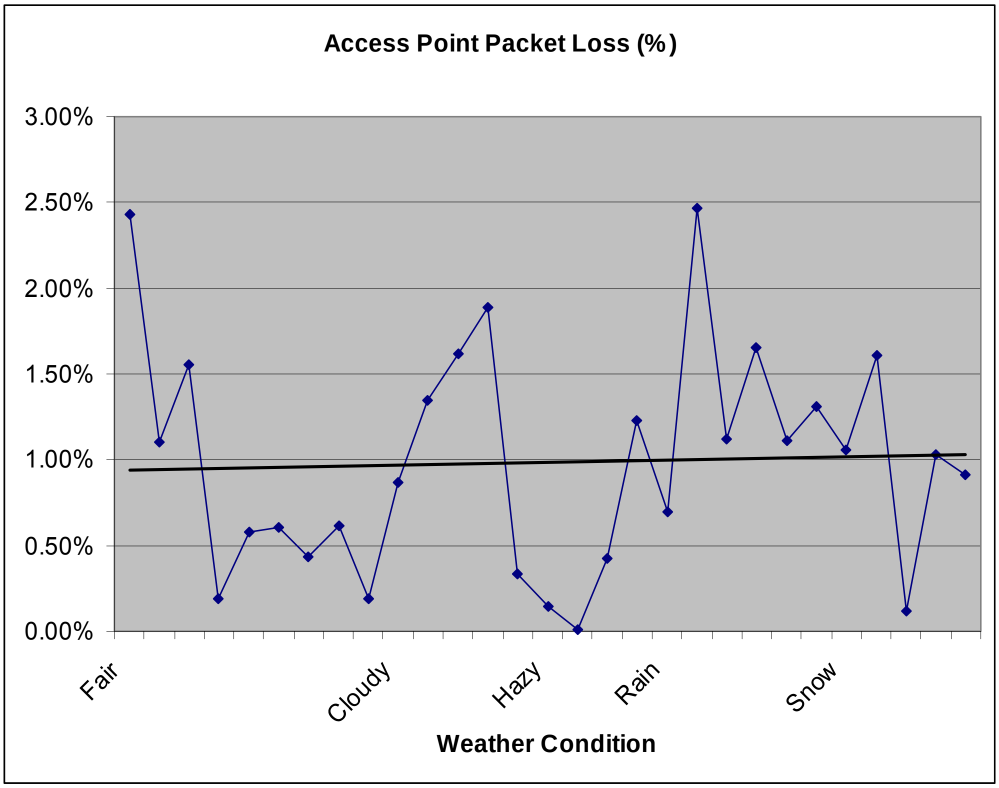


Figure 4-1 Packet loss during communications over CTB to SWKT bridges (373 meters)

The graphed results shown in figure 4-1 are arranged in coordination with bridge to bridge data from table 4-1. The weather patterns have been arranged from top to bottom in order of increasingly suspect weather conditions. The black line indicates the small increase in packet loss as weather conditions worsen.

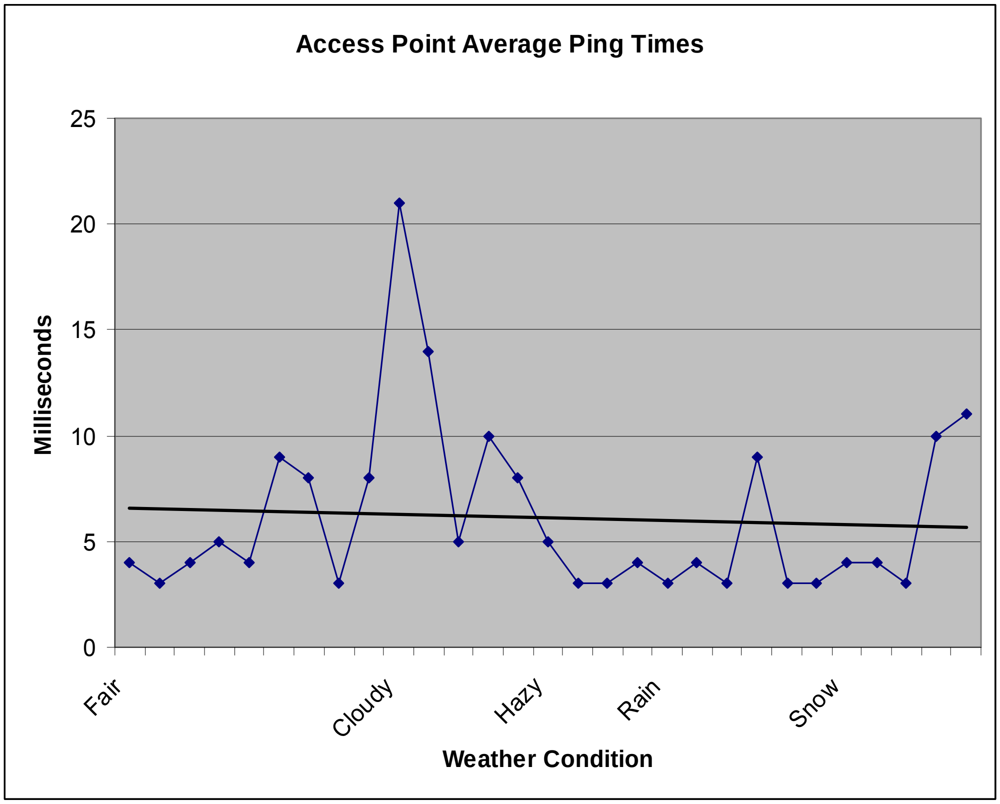


Figure 4-2 Average ping times during communications over CTB to SWKT bridge (373 meters)

During testing procedures, there were occurrences in which multiple packets were dropped in series between the access point and client node. Initially, this was thought to be the result of weather conditions. However, upon further inspection, the same losses would show up during clear weather. After some investigation it was determined that by changing the channel on the broadcasting access point, the link would resume communication. This was a good indication that the outages were being caused by competing channel usage near the client rather than the weather. To counteract this effect, the results which showed signs of noise have been modified to reflect only series where dropped packets showed up in groups of less than ten in a row. All groups larger than ten were assumed to be caused by interference from an unknown source and removed from the totals to reflect a more accurate depiction of weather effects on the wireless link.

Figure 4-2 shows the average ping times during conditions on the same 373 meter link from the Crabtree building to the Kimball tower. An interesting note is that the average ping times actually decrease during the more inclement weather conditions. It is also interesting that cloudy and hazy weather seems to have more of an effect on this short bridged link than previously thought. Perhaps this was a case of multipath distortion created by low clouds.

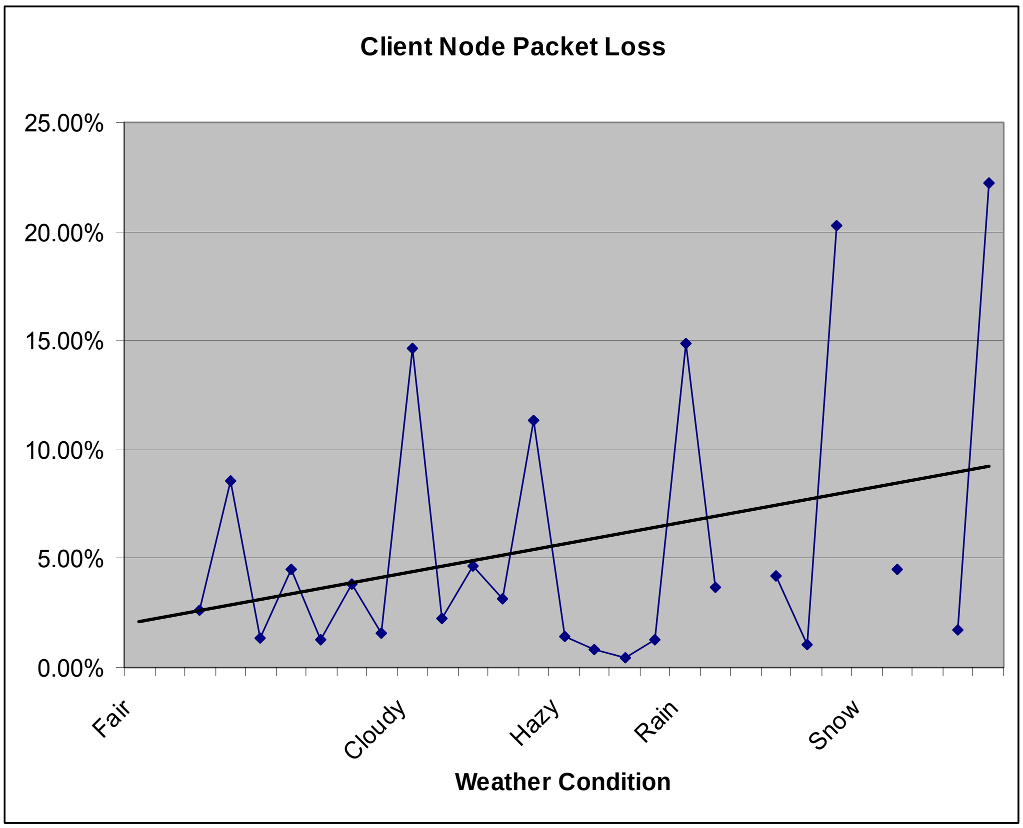


Figure 4-3 Packet loss on access point to client node connection (approximately 1.43 km)

The results shown in figure 4-3 are taken from the longer link from the access point to the client node (approximately 1.43 km). They show a more erratic pattern of behavior for dropped packets. These results show the actual packet loss figures before the issue with competing noise was found. The values that could be adjusted (by having the complete set of pings) were adjusted by removing those values that exhibit higher than expected values. This was done to create a more accurate representation of the link in figure 4-4. Notice the line representing the average loss changes from an increase in figure 4-3 to a slight decrease after adjusting the data and removing extremely high ping times attributed to channel noise in figure 4-4.

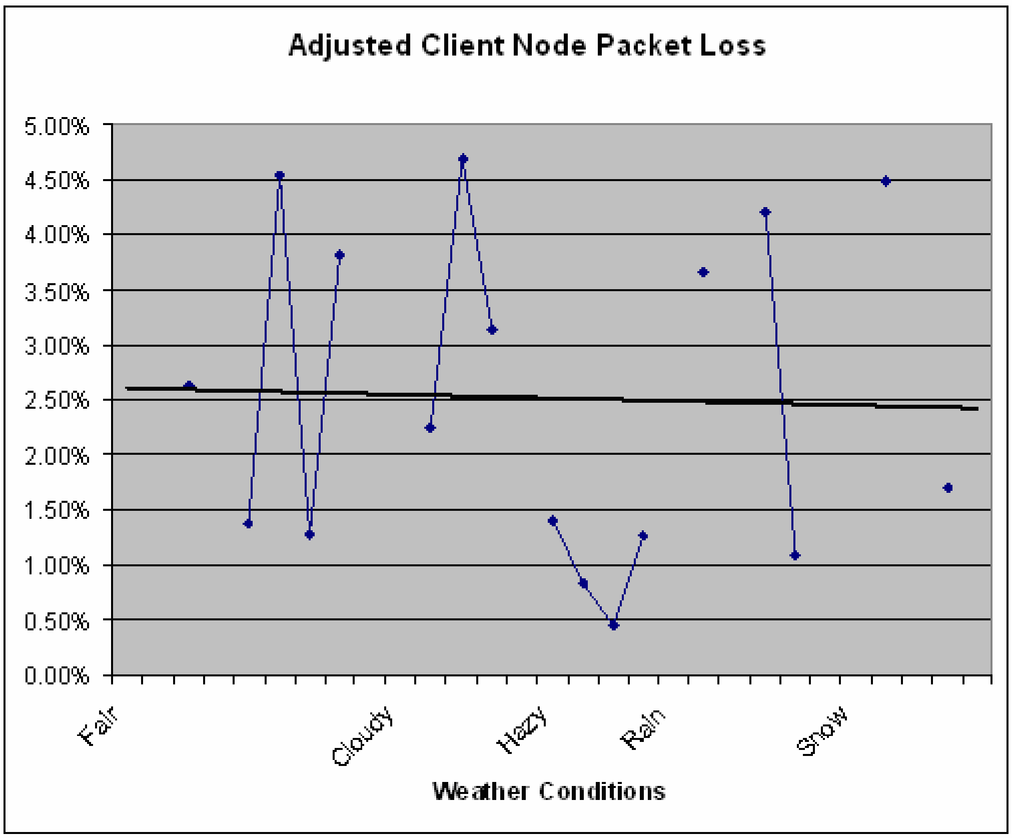


Figure 4-4 Adjusted values for client node packet loss over 1.43 km link

The results shown in figure 4-5 are the original numbers from testing without any changes. Although competing noise may have increased the number of dropped packets in the series, this did not affect the average ping times recorded. Similar to the data from the bridge link, the average ping times tend to decrease in bad weather. Once again, there was also some sign of erratic behavior during cloudy and hazy conditions.

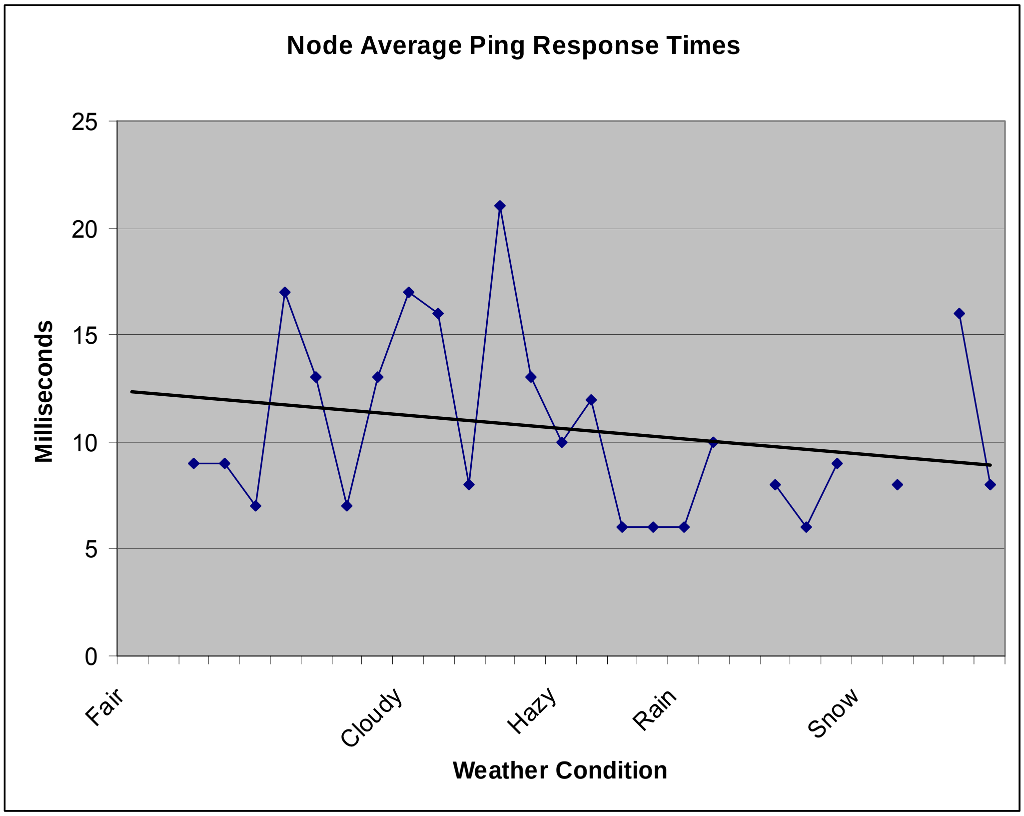


Figure 4-5 Access point to client node average ping times

As one might assume, the data shown in figure 4-4 is less reliable because of the omitted and repaired results. However, these tests do provide data that shows the estimated overall effect of bad weather is quite small when compared to problems encountered from noise and other competing signals.

This conclusion does not factor in the effects of water damage on the systems themselves or water entering into a poorly made cable or badly sealed connection. These effects will not be tested in this thesis. Scenarios of water intrusion can be avoided if proper cabling and waterproofing practices are followed during setup procedures.

4.1.2 Fresnel Zone Intrusion and Non Line-of-Sight Link Results

To determine the necessity of Fresnel zone clearance, a test was designed to take measurements from two locations of similar distances from the access point. The first test location was in a parking lot behind a building where only the antenna could be seen. The purpose was to create an environment where the Fresnel zone would effectively be cut in half. The second location was in a parking lot behind a tree. At the time of testing, the tree did not have any leaves on it. There were also some power lines in the link path. The baseline test was performed from a location where a clear line of sight with 100% first Fresnel zone clearance. Complete results can be found in appendix B.

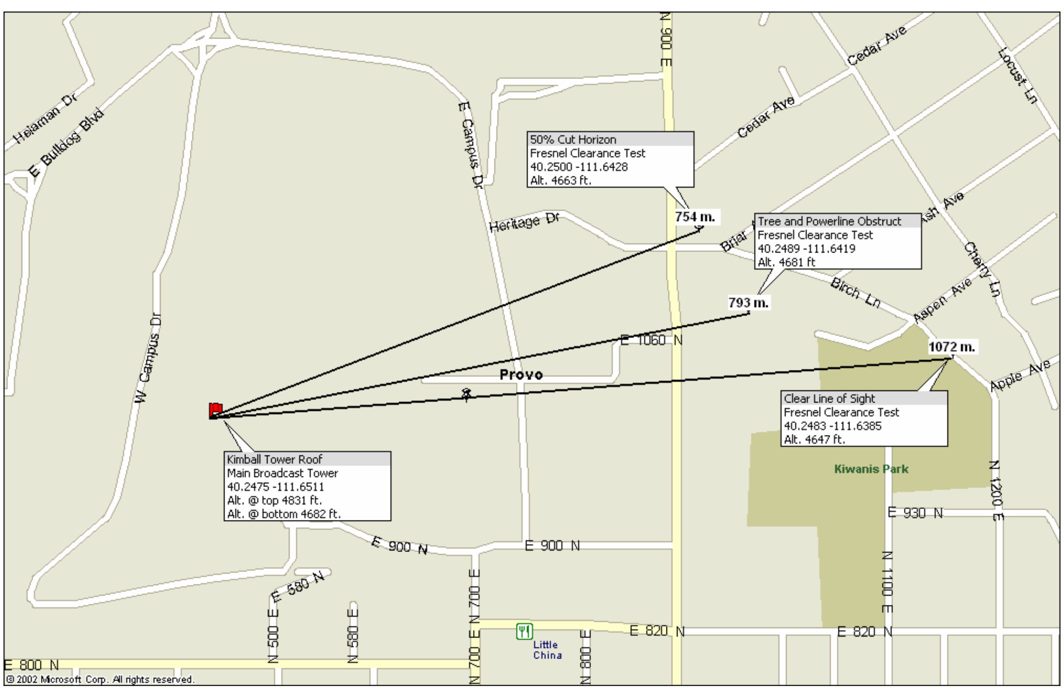


Figure 4-6 Street map showing test locations and distances

As shown in figure 4-6, the distances from each location to the access point broadcasting location are not equivalent. This exhibits another of the major drawbacks to wireless systems. The test area is an older part of the city where tall trees limit coverage availability to very few clear locations. Each of the tests used the 16dBi Vagi antenna paired to an Orinoco Silver client card in a laptop PC. All tests were performed on the same day in clear weather conditions. Path signal calculations are made using the method described in section 3.1.5.

Table 4-2 below shows a comparison of calculated distance link strength and the actual measured strength from each of the three test areas. It also shows the error percentage between the calculated and measured signal strengths. Notice the lower percentage on the clear line of sight link as compared to the others where only partial signal reception was possible. The higher signal strength seen in the clear line of sight area translates directly into higher throughput, as seen in table 4-3 and figure 4-7.

Table 4-2 Link summary of test areas

	50% Split Horizon (754 m.)	Tree/Power Lines (793 m.)	Clear Line of Sight (1072 m.)
Link Distance	754 meters	793 meters	1072 meters
Calculated signal	-59.11 dB	-59.54 dB	-62.17 dB
Measured signal	-69 dB	-67 dB	-65.5 dB
Percent difference	14.33%	11.13%	5.08%

Table 4-3 Summary of test results

Trial Number (at each site)	50% Split Horizon (754 m.)	Tree/Power Lines (793 m.)	Clear Line of Sight (1072 m.)
1	770.18 Kbps	1105.92 Kbps	1361.92 Kbps
2	1034.24 Kbps	1126.40 Kbps	1269.76 Kbps
3	736.31 Kbps	1157.12 Kbps	1269.76 Kbps
4	804.38 Kbps	1136.64 Kbps	1208.32 Kbps
5	774.62 Kbps	947.39 Kbps	1146.88 Kbps
Average	**823.95 Kbps**	**1094.69 Kbps**	**1251.33 Kbps**

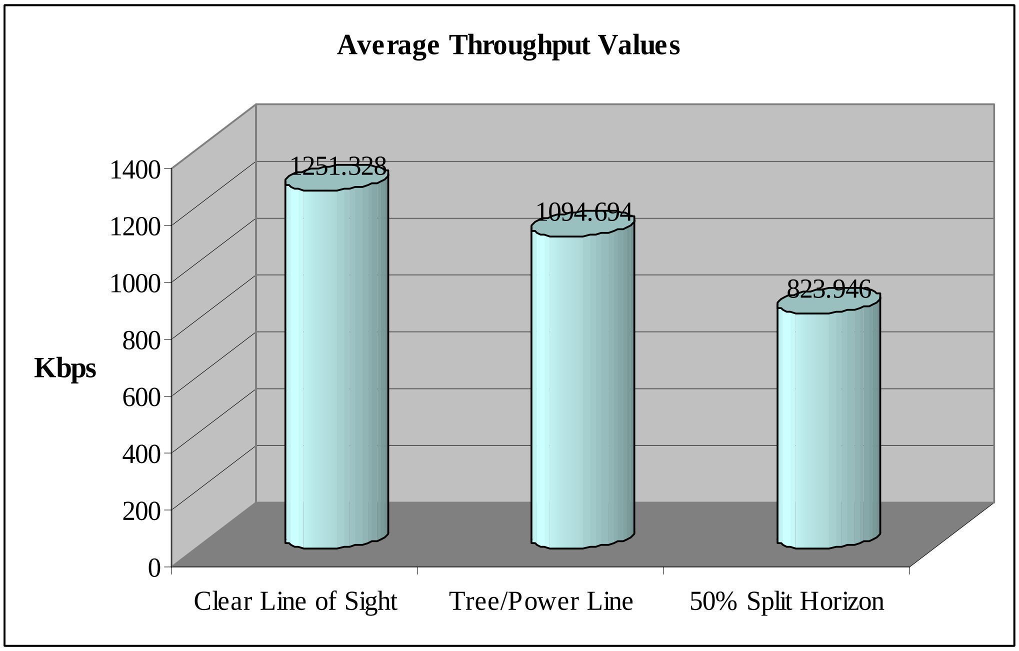


Figure 4-7 Average throughput comparisons of obstruction tests

The data presented in these tests indicates several interesting points. Obstructions do not always completely block the signal from being received, but do degrade the calculated signal strength to a certain degree, which translates into lower overall throughput. The percent difference between calculated signal and actual received signal for each location also shows that objects in the line of sight and Fresnel zone do reduce the signal received at the antenna.

4.1.3 Antenna and Distance Comparison Results

One purpose of this testing was to determine whether any specific type of antenna is better in any given situation, or if it is all determined by gain alone. Of course, it would be very difficult to obtain antennas of different designs of the same gain. With this in mind, five antennas were chosen to measure signal strength, throughput, and link reliability from several different locations. The complete results are found in appendix C.

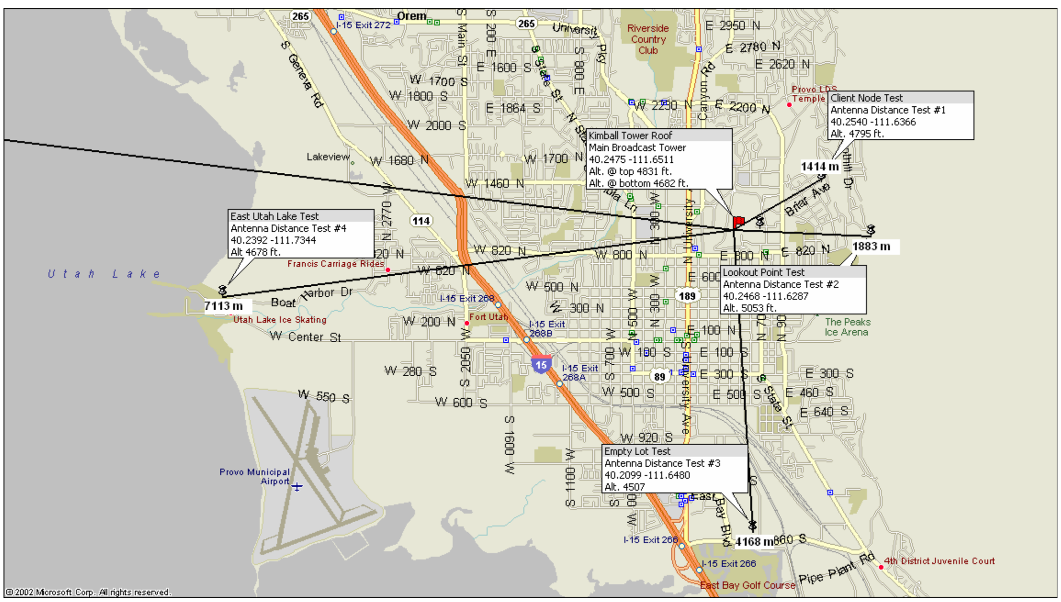


Figure 4-8 Site map of antenna test points

Similar to the tests performed in section 4.3, a parallel approach has been used to quantify the signal strength by using the percentages of calculated signal strength as a measurement for comparison. These results are shown in figure 4-8.

Table 4-4 Calculated versus measured signal strength results

	Site #1 (1414 meters)				
	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
Calculated	-67.42	-61.97	-60.97	-59.97	-57.97
Measured	-71.00	-77.00	-66.00	-65.00	-63.00
% Difference	**12.01%**	**19.52%**	**7.62%**	**7.73%**	**7.98%**
	Site #2 (1883 meters)				
	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
Calculated	-64.95	-64.45	-63.45	-62.45	-60.45
Measured	-78.00	-85.00	-70.00	-69.00	-65.00
% Difference	**16.73%**	**24.18%**	**9.36%**	**9.49%**	**7.00%**
	Site #3 (4168 meters)				
	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
Calculated	-71.85	-71.35	-70.35	-69.35	-67.35
Measured	-82.00	-82.00	-84.00	-80.00	-78.00
% Difference	**12.38%**	**12.99%**	**16.25%**	**13.31%**	**13.65%**
	Site #4 (7113 meters)				
	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
Calculated	-76.50	-76.00	-75.00	-74.00	-72.00
Measured	-88.00	-85.00	-86.00	-82.00	-79.00
% Difference	**13.07%**	**10.58%**	**12.79%**	**9.76%**	**8.86%**
Average %	**13.55%**	**16.82%**	**11.51%**	**10.07%**	**9.37%**

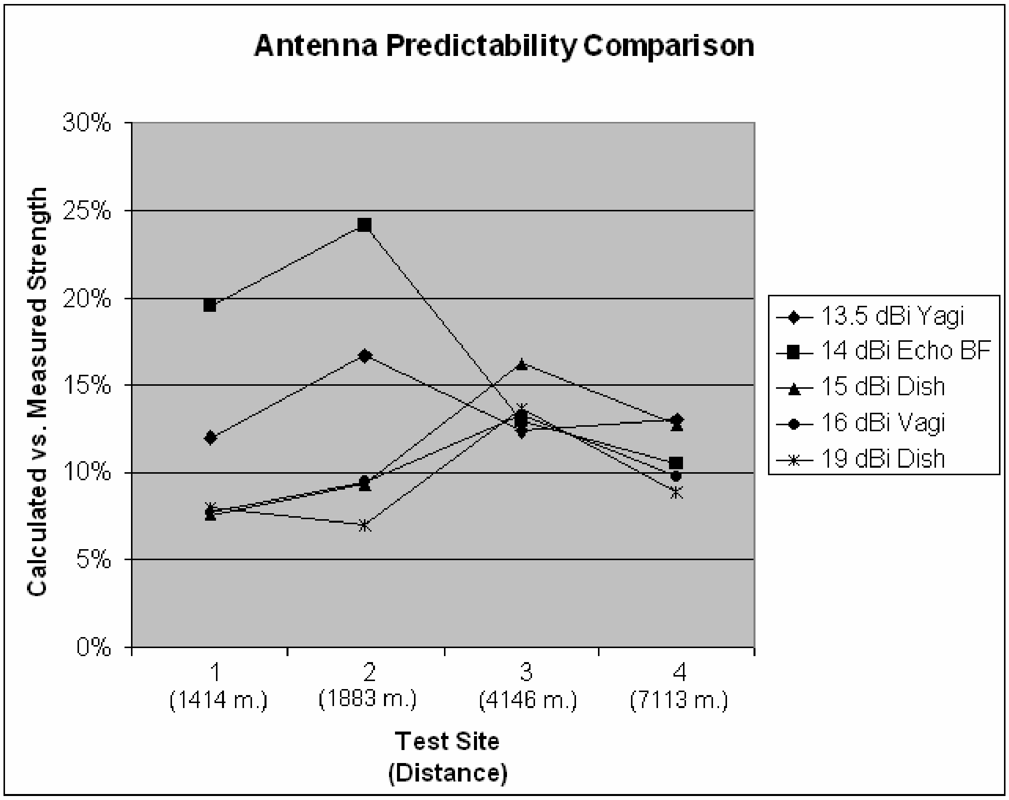


Figure 4-8 Antenna predictability by error percentage comparison

The results show that the 19 dBi wire grid parabolic dish remains the closest to its calculated value by having the lowest error percentages. The 14 dBi echo backfire has the highest average deviation from its calculated value. It is clear to see that each of the antennas has some deviation -- which is accounted for by the aforementioned "fudge factor."

It is interesting to note that the highest deviation was encountered at the first two sites, within 1 ½ miles of the access point. This may be attributed to higher levels of ambient noise or antenna directionality, but the root cause is unknown. In principal, all five antennas are similar because they are either a type of dish or a type of yagi. If one type had shown consistently higher percentages than another, it would be easy to assume that one type is better. However, this is not the case, because the two highest percentages belong to an antenna in each group.

The throughput comparison was performed using each of the antennas connected to an Orinoco card in a laptop PC. The results are given in table 4-5. All FTP throughput values are given in Kbps.

Table 4-5 Summary of FTP throughput testing

	Site 1 (1414 m.)				
	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
SNR	-71	-77	-66	**-65**	-63
FTP	753.33	209.08	1000.42	1464.32	1607.68
	1044.48	191.32	1136.64	1177.60	1607.68
	1095.68	146.05	1116.16	1341.44	1740.80
	954.34	120.07	857.73	1679.36	1720.32
	801.58	No connect	842.6	1515.52	1546.24
Average	**929.882**	**166.63**	**990.71**	**1435.65**	**1644.54**
	Site 2 (1883 m.)				
	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
SNR	-78	-85	-70	-69	**-65**
FTP	162.99	No connect	441.62	249.44	821.17
	162.30	No connect	359.09	469.96	869.96
	114.06	No connect	190.47	213.67	663.98
	No connect	No connect	393.43	363.24	828.82
	No connect	No connect	378.17	232.30	796.78
Average	**146.45**	**N/A**	**352.56**	**305.72**	**796.14**
	Site 3 (4168 m.)				
	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
SNR	-82	-82	Intermittent -84	-80	-78
FTP	24.82	62.29	No connect	97.80	227.84
	13.41	57.06	No connect	118.66	198.77
	No connect	113.76	No connect	113.53	313.53
	No connect	65.06	No connect	No connect	297.00
Average	**19.12**	**74.54**	**N/A**	**110.00**	**259.29**
	Site 4 (7113 m.)				
	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
SNR	Sparse -88	Sparse -85	Sparse -86	-82	-79
FTP	No connect	No connect	No connect	371.22	876.60
	No connect	No connect	No connect	563.70	540.23
	No connect	No connect	No connect	591.20	353.20
	No connect	No connect	No connect	436.24	432.01
	No connect	No connect	No connect	427.25	556.47
Average	**N/A**	**N/A**	**N/A**	**477.92**	**550.51**

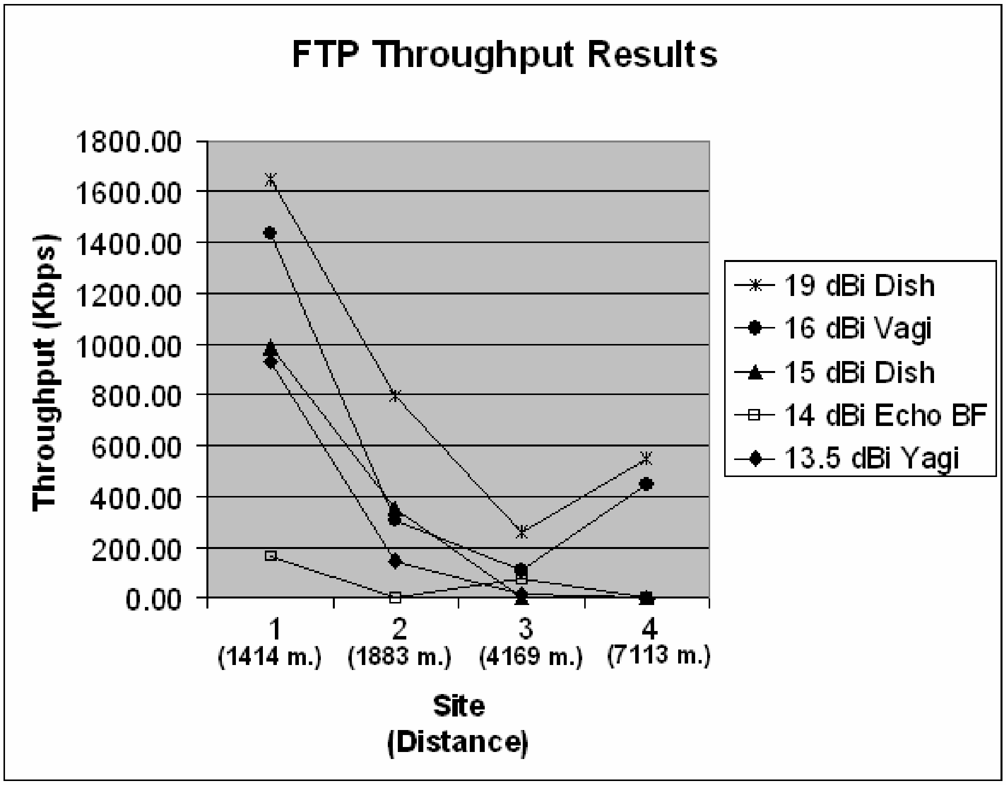


Figure 4-9 Antenna throughput comparison

The results from this test show an interesting trend at site number three. The antennas exhibit a drop in throughput at site three, and then the 16 dBi vagi and the 19 dBi dish both jump back up at site four. It is assumed that it is the result of the flat ground (causing multipath distortion) and some distant power lines running through the line-of-sight noticed after the test. Another interesting point is the increase seen by the Echo Backfire antenna at site three. The cause of this behavior is unknown.

Throughput can be seen as a function of signal strength and distance combined as shown from these results. The 16 dBi Vagi at site one and the 19 dBi dish at site two both have average signal strengths of -65 dB, but the throughput results are almost 45% lower for the longer link. Therefore, longer distance links will have lower throughput than a shorter link even if the signal strength is the same.

Ping tests were also conducted with each set of antennas at each location; however, an analysis of those results will not be included in this thesis. The results provided from the signal predictability and FTP throughput tests will be considered sufficient evidences to show the antenna performances. The complete ping test results can be found in appendix C.

One extra “experimental” antenna test was also performed to see how far the link could reach. A 21 dBi Dish antenna was used at a distance of 11.3 miles from across Utah Lake. Although only a temporary link could be obtained, it was enough to pass two files through at 114.35 and 69.74 Kbps. These experimental link results can also be found in appendix C.

4.1.4 Bridge Sensitivity Comparison Results

To quantify the importance of using quality bridges with a high receive sensitivity, three bridges were chosen, each exhibiting a different receive sensitivity threshold. The bridges used in this comparison were the D-Link 900AP+, the Linksys WET11, and the Cisco 350 Workgroup Bridge. Each of the tests was performed using the 16 dBi Vagi antenna and necessary jumper cables. An additional adapter was also used to change the unit’s connector type to N-male so that each setup would use an identical cabling setup. The adapter is included in the calculations as well as the pigtail used for the Orinoco card. Complete link results can be found in appendix D.

Table 4.6 shows the resultant throughput rate for the bridge link given the strength of the received signal. Bridges will automatically adjust the throughput speeds to reflect the received signal strength. As seen in this testing, these data rates are not always accurate in real world scenarios and a 15 to 20 dB allowance should be given as a buffer.

Table 4-6 Bridge receive sensitivities

Orinoco Silver PC Card (used as a comparison)	• 1 Mbps: -94 dBm • 2 Mbps: -91 dBm • 5.5 Mbps: -87 dBm • 11 Mbps: -82 dBm
D-Link 900 AP+	• 1Mbps: -89 dBm • 5.5Mbps: -83 dBm • 11Mbps: -79 dBm
Linksys WET11	• ?? -85 dBm (no data rate given)
Cisco 350 WG Bridge	• 1 Mbps: -94 dBm • 2 Mbps: -91 dBm • 5.5 Mbps: -89 dBm • 11 Mbps: -85 dBm

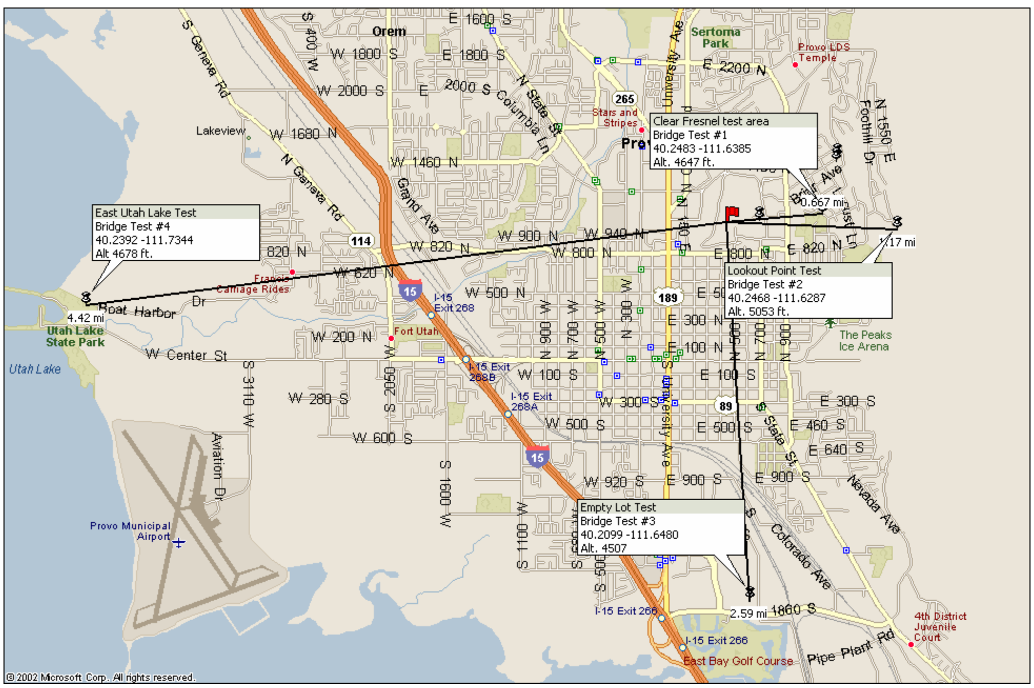


Figure 4-10 Bridge testing locations

Table 4.7 Bridge test FTP throughput results

Test Site #1 Clear Fresnel (1414 m.) Approx. -66 dBi				
	Orinoco	D-Link	Linksys	Cisco
	1464.32 Kbps	Unavailable	2088.96 Kbps	2355.2 Kbps
	1454.08 Kbps	for testing	2088.96 Kbps	2355.2 Kbps
	1484.80 Kbps		2027.52 Kbps	2037.76 Kbps
	1433.60 Kbps		2099.20 Kbps	2242.56 Kbps
	1392.64 Kbps		2109.44 Kbps	2109.44 Kbps
Average	1445.89 Kbps		2082.82 Kbps	2220.03 Kbps
Test Site #2 Lookout Point (1883 m.) Approx. -73 dBi				
	Orinoco	D-Link	Linksys	Cisco
	1075.20 Kbps	645.26 Kbps	2027.52 Kbps	2007.04 Kbps
	1054.72 Kbps	660.24 Kbps	2017.28 Kbps	1935.36 Kbps
	1136.64 Kbps	673.78 Kbps	1966.08 Kbps	1884.16 Kbps
	1136.64 Kbps	653.05 Kbps	1925.12 Kbps	1945.6 Kbps
	977.36 Kbps	616.22 Kbps	1986.56 Kbps	1996.8 Kbps
Average	1076.11 Kbps	649.71 Kbps	1984.51 Kbps	1953.79 Kbps
Test Site #3 Empty Lot (4168 m.) Approx. -81 dBi				
	Orinoco	D-Link	Linksys	Cisco
	945.46 Kbps	340.42 Kbps	1218.56 Kbps	1925.12 Kbps
	730.51 Kbps	376.68 Kbps	1116.16 Kbps	1935.36 Kbps
	745.63 Kbps	316.70 Kbps	1443.84 Kbps	1751.04 Kbps
	684.71 Kbps	335.27 Kbps	1290.24 Kbps	1761.28 Kbps
	824.19 Kbps	314.43 Kbps	1187.84 Kbps	1832.96 Kbps
Average	786.10 Kbps	336.70 Kbps	1251.33 Kbps	1841.15 Kbps
Test Site #4 East Lake (7113 m.) Approx. -83				
	Orinoco	D-Link	Linksys	Cisco
	110.60 Kbps	No Connect	121.57 Kbps	712.52 Kbps
	111.77 Kbps	No Connect	102.89 Kbps	755.37 Kbps
	93.73 Kbps	No Connect	228.07 Kbps	888.21 Kbps
	1445.89 Kbps	No Connect	238.63 Kbps	729.27 Kbps
	No connect	No Connect	242.83 Kbps	762.79 Kbps
Average	440.50 Kbps	No Connect	186.80 Kbps	769.63 Kbps

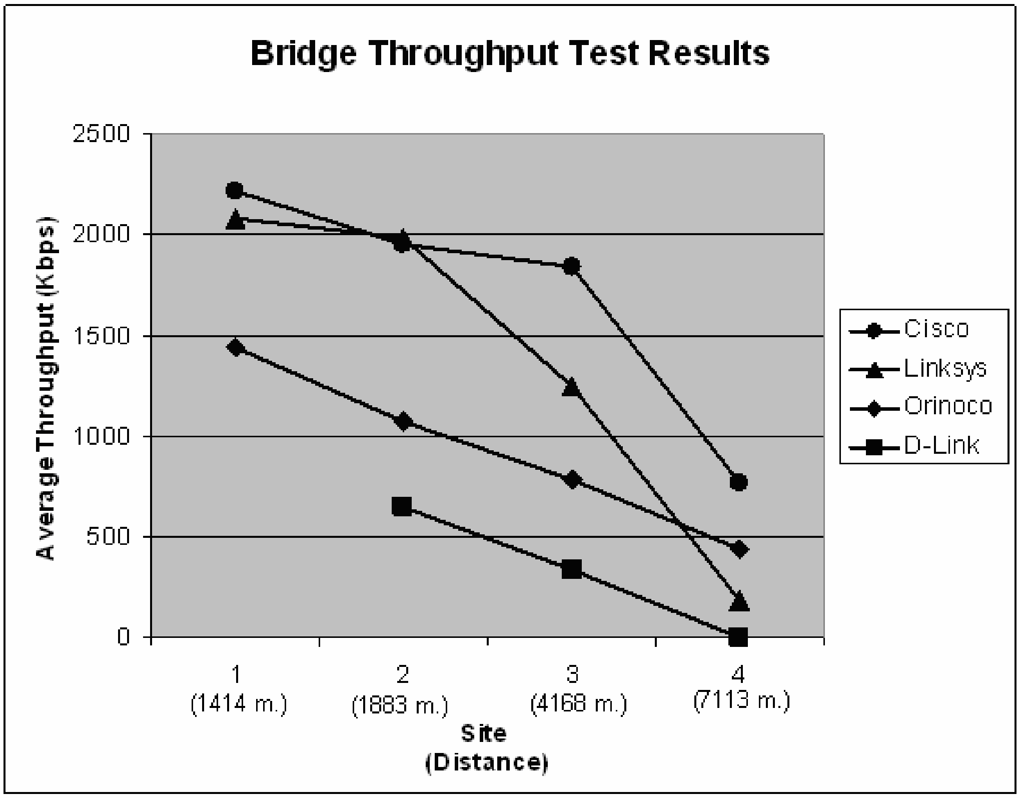


Figure 4-11 Bridge throughput tests using FTP

Unfortunately, the D-Link bridge was not included in the first set of tests from site one because it would not associate with the Cisco access point. After some extensive experimenting, it was discovered that the 900AP+ uses the MAC address from the network adapter it is connected to by Ethernet. To remedy the problem, the laptop Ethernet MAC address was entered into the Cisco access point MAC address filter table. After this was done, the bridge was able to connect.

As the graph in figure 4-11 shows, the Orinoco PC card that was used for the baseline test proved to be a reliable standard for comparison. The results show that the Linksys WET11 bridge is as reliable as the Cisco 350 Workgroup bridge at distances shorter than approximately 1.5 miles, after which speeds drop off slightly quicker than the Cisco. This is good news because the WET11 costs about 1/6th of the price of a new

Cisco 350 WG bridge. The WET11 will work at greater distances, but where throughput is a concern, the Cisco should be used because of the higher receive sensitivity. The poor results produced from the D-Link unit serve as a very good example of why choosing bridges with high receive sensitivity is important.

Ping tests were also conducted with each set of bridges at each of the four locations; however, similar to the results of the antenna tests in section 4.4, an analysis of those results will not be included in this thesis. The results provided from the FTP throughput tests will be used as sufficient evidence to show the importance of receive sensitivity when choosing client bridge equipment. The complete ping test results can be found in appendix D.

Chapter 5

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Research and Test Results Summary

The demand for broadband internet is increasing and IEEE 802.11 wireless network technology provides inexpensive infrastructure possibilities to bridge the last mile. If executed properly, wireless networks can provide reliable and fast broadband service to customers at a fraction of the cost of upgrading or installing new land lines. Wireless town area networks can be easily deployed using off the shelf equipment provided procedures are followed to ensure quality setup and maintenance. To answer some of the questions presented throughout this thesis, the test results offer the following responses.

To what extent can poor weather degrade throughput, or can it even completely break a link? The effects of weather in most normal short range cases can be ignored, as snow, rain, and fog have little effect on the signal quality when using DSSS in the 2.4 GHz band. Wind was not thoroughly tested, as it was difficult to monitor ping times during short wind gusts. However, it is rather safe to assume that wind does not play a large role unless antennas are improperly mounted.

Are there certain obstructions that can be in the line of sight and Fresnel zone that have more impact than others? The tests used to determine the effects of obstacles show that although a strong enough signal can still be received, throughput suffers. The longer the link distance is, the greater the effect obstacles will have on the link. This was noticed through a completely separate test for the bridges at site three. After the power lines were noticed, it was assumed that they were the cause of the low throughput response. Also of note, the same area which was used for testing through a bare tree and power lines was revisited after the tree was full with leaves. From this same site no signal could even be detected from the Kimball tower access point. Every effort should be made to install equipment during the spring or summer while leaves are out and fairly predictable. If winter installations are necessary, it is highly advisable to use binoculars to check for any bare trees that may become troublesome in the springtime. Plan ahead for ample Fresnel zone clearance, as trees will grow new branches and extend their reach, which may block line-of-sight radio links.

Is there one type of antenna that will perform better (regardless of gain), in any given circumstance? There are many antenna types and gains available to choose from for use in point-to-point and point-to-multipoint applications. Of the five that were tested in section 4.4, the best performing antenna was the 19 dBi wire grid parabolic dish from Pacific Wireless. This is an excellent antenna for use in point-to-point link applications and as a long distance client antenna. However, it is a rather large antenna for a rooftop, being 73.5 cm. in diameter, and may give some homeowners pause. As far as price, gain, and physical size goes, the 16 dBi vagi, at only 10 cm wide and less than half the weight, is an excellent alternative to the larger 19 dBi dish if the signal strength allows. The 16 dBi vagi is also very easy to assemble and mount because the two piece bracket hooks together and tightened using a single “crank-style” bolt. The test performance numbers for the two antennas were very similar, insomuch that if a signal attenuator were used to lower the signal strength for the 19 dBi dish, the throughput test results would look almost identical (The use of a signal attenuator in combination with the different antennas for better normalization could achieve more accurate results is discussed in section 5.3).

The 14 dBi echo backfire showed the most interesting results in which it acted opposite of what was expected in several cases. When the gain should have decreased with the rest of the antennas, it actually increased. Otherwise, the throughput numbers showed below-average performance for an antenna of the advertised gain, performing even worse than the lower gain 13.5 dBi Yagi. At one point, it was thought that the antenna was possibly broken inside which would render lower results than it normally would. However, this antenna has been disassembled and checked for continuity and all connections appear to be intact.

Is it worth spending four to six times more money to implement a full network of enterprise class hardware, or can a reliable network be built using properly installed off-the-shelf equipment? The importance of choosing bridges based on receive sensitivity was shown through the results of the bridge throughput tests. The Orinoco PC card proved to be a good baseline test standard to judge the other bridges by. The results obtained from the bridge FTP throughput tests showed the difference between high, mid, and low receive sensitivity. The Linksys WET11 proved to be a reliable counterpart to the much more expensive Cisco at shorter ranges. Although speeds steadily dropped off with increases in distance, the WET11 may also serve as a reliable bridge at longer distances. Where link reliability is a concern, the Cisco or another comparable bridge should be used based on its high receive sensitivity and reliability.

5.2 Conclusions

An analysis of the tests performed leads to several conclusions for designing the links used in wireless town area networks:

- The use of highly focused directional antennas will increase the range and throughput of a wireless link given the received signal strength is greater than the necessary receive sensitivity.
- Throughput is a function of receive sensitivity, signal strength, Fresnel zone obstructions, and overall distance. Longer distance links will have lower throughput than a shorter link even if the signal strength is the same. It is also assumed that the longer link distance uses more time and lowers the effective number of users with guaranteed throughput.
- Using small access point cell sizes reduces the amount of noise that both access point and client radio equipment must manage. Noise and competing channel usage can cripple a small area of client links and can be undetectable to the access point. Perhaps a dual broadcast point could be used using two radios on different channels.
- Less expensive off-the-shelf bridges with the necessary sensitivity levels can be effectively deployed up to a given distance where throughput drops off. If links are necessary at longer distances, then bridges with higher receive sensitivities and larger antennas may be used.

5.3 Recommendations for Further Research

One of the major problems that occurred with the local WISP could not be studied in this case due to lack of resources. A further study of the number of connections that can be made simultaneously to a single access point and the load that each connection can support would be useful information in designing a wireless town area network.

Similar tests to those included in this thesis could be performed with an effort to normalize the antenna gains to achieve more precise results. This could be realized by using an attenuator to create a more accurate correlation between signal strength and throughput. This same method could be employed to calculate the effect on throughput comparing actual distance versus a simulated distance through attenuation. This methodology could be used to create a more accurate equation for calculating throughput using link distance, free space loss, and acceptable number of users.

Further testing could also be performed on the throughput numbers comparing IEEE 802.11b and 802.11g in long distance links. As covered in chapter two, the receive sensitivity while using OFDM with 802.11g equipment is lower due to EVM. This would be an interesting study to show whether using 802.11g would offer any throughout or other advantages over 802.11b.

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APPENDIX

Appendix A - Weather Test Results

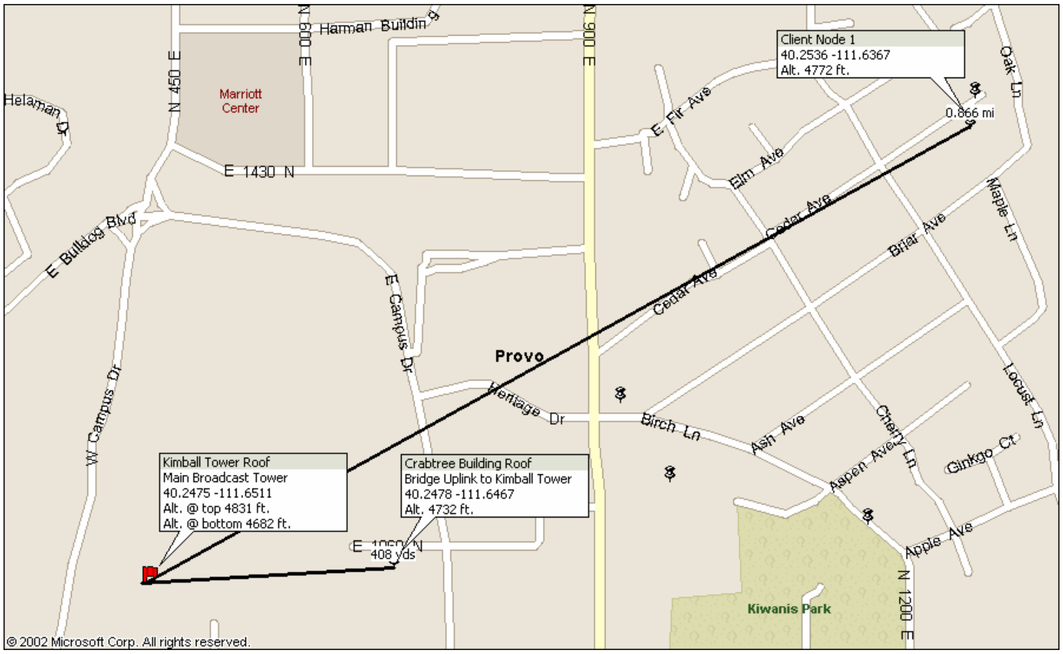

Figure A-1 Link map of Crabtree to Kimball tower and to client node

Weather link test:
CTB to SWKT 408 yards (.232 miles)
SWKT to Client Node: .866 miles
****

Crabtree building to Kimball tower

Free space path loss @ 2.437 (channel 6): -<u>91.65dB</u>

Gain: 15 dBm radio – 5 ft LMR 195 jumper (~1.5 dB) + 16 dBi Vagi + 16 dBi Vagi – 8 ft LMR-195 jumper (~2 dB) = <u>43.5 dB</u>

Total path calculation: <u>-48.65dB</u>

****

Kimball tower to client node

Free space path loss @ 2.437 (channel 6): 103.09dB

Gain: 15 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 13.5 dBi Yagi – 5 ft. LFigure B.1-1MR-195 jumper (~1.5 dB) = 36.75 dB

Total path calculation: 66.34 dB

MAC	SSID	Chan	Vendor	Enc...	Signal+	Noise-	SNR+
0040962A6537	reslink1	3	Cisco		-64	-100	36
004096345F8D	ocht	6	Cisco		-68	-100	32
00022D213488	14SILVER	7	Proxim (Agere) ORiNOCO	WEP	-71	-100	29
00022D32F182	14SILVER	10	Proxim (Agere) ORiNOCO	WEP	-72	-100	28
00409632D611	exec-link	10	Cisco		-72	-100	28
0009E8BF768F	14SILVER	10	Cisco	WEP	-73	-100	27
00062525747F	linksys	6	Linksys		-74	-100	26
001091004438	BrentBrown	6	No Wires Needed	WEP	-74	-100	26
000D8880A015	default	6	D-Link		-76	-100	24
0040963435A2	exec-link	10	Cisco		-76	-100	24
0040962975E4	cp-ne	6	Cisco		-77	-100	23
00409657AD09	byuc0ug4rs	1	Cisco		-77	-100	23
0002B3C653BC	digis-000	1	Intel		-77	-100	23
0002B3CF25B0	digis-000	6	Intel		-78	-100	22
0002B3BA78CB	digis-000	9	Intel		-78	-100	22
000625580F89	madkey45	1	Linksys	WEP	-78	-100	22
000D88861A0D	r4chnbr4d	11	D-Link	WEP	-79	-100	21
00409633C40A	Harmony	6	Cisco		-79	-100	21
0040962646B6	access-ranch-s	6	Cisco		-81	-100	19
004005C5537B	BigDogDaddy23	6	D-Link		-81	-100	19
00022D28B337	OAKS AP SFCN 1	3	Proxim (Agere) ORiNOCO		-81	-100	19
0002B3C650CC	digis-000	1	Intel		-82	-100	18
00022D04C110	14SILVER	3	Proxim (Agere) ORiNOCO	WEP	-82	-100	18
0050F2CA1C0E	Sturgis Main	6	Microsoft	WEP	-82	-100	18
0002B3060987	SNS-3	11	Intel		-82	-100	18
0006258D4615	tiawna	1	Linksys		-82	-100	18
0030BD93555C	belkin54g	11	Belkin		-83	-100	17
0002B3C3A568	rfburst.com_491-3177r	1	Intel		-83	-100	17
00022D01AA10	KFC AP SFCN 1	2	Proxim (Agere) ORiNOCO		-83	-100	17
0002B3C3B7D8	digis-000	8	Intel		-83	-100	17
0002B305A233	digis-br	1	Intel		-84	-100	16
00022D047D86	047d86	1	Proxim (Agere) ORiNOCO	WEP	-84	-100	16
000D8880A7B1	default	6	D-Link		-84	-100	16
0040963454D1	ocht	11	Cisco		-84	-100	16
000C413D58FC	linksys	6	Linksys		-85	-100	15
00022D04C0EE	14SILVER	3	Proxim (Agere) ORiNOCO	WEP	-85	-100	15
000625259197	thegirls	6	Linksys	WEP	-85	-100	15
000625BAB8B1	linksys	6	Linksys		-86	-100	14
000347B4C51A	radioburst.com	4	Intel		-87	-100	13

Figure A2 Kimball Tower Netstumbler Scan

MAC	SSID	Chan	Vendor	Enc...	Signal+	Noise-	S.
00409634E99A	ppth	10	Cisco		-74	-100	26
0002B3C653BC	digis-000	1	Intel		-78	-100	22
0040963435A2	exec-link	10	Cisco		-79	-100	21
00062525747F	linksys	6	Linksys		-80	-100	20
004096341B60	ocht	7	Cisco		-81	-100	19
0040964748DD	byuc0ug4rs	1	Cisco		-82	-100	18
0040964829EC	byuc0ug4rs	1	Cisco		-83	-100	17
0002B3060987	SNS-3	11	Intel		-83	-100	17
0090D1013D81	bellan2	11	Addtron		-86	-100	14
0040964073B5	byuc0ug4rs	6	Cisco		-86	-100	14
0002B3BA6B04	rfburst.com_491-3177_westmtn	1	Intel		-86	-100	14
0040965A5B8A	byuc0ug4rs	6	Cisco		-88	-100	12
000D292EFEA9	flyingj	1	Cisco		-88	-100	12

Figure A3 Crabtree Building Netstumbler scan

MAC	SSID	Chan	Vendor	Type	Enc...	Signal+	Noise-	S.
000DBDDAC13E	SWKT-skynet	1	Cisco	AP	WEP	-71	-100	29
0040055C9C23	Bot II	6	D-Link	AP		-78	-100	22
000C4177C131	linksys	6	Linksys	AP		-79	-100	21
00409656CF49	kimballtower	4	Cisco	AP		-81	-100	19
0050DA943EE9	3com_BOLT	3	3Com	AP		-82	-100	18
00095B347BC1	Wireless	11	Netgear	AP		-85	-100	15
00095B39EE47		6	Netgear	AP		-87	-100	13
00409634573E		3	Cisco	AP		-89	-100	11
004096333298		3	Cisco	AP		90	100	10
000785B3CED2		1	Cisco	AP	WEP	-91	-100	9
00095B85738E	vaud01s	11	Netgear	AP	WEP	-91	-100	9

Figure A4 Client Node Netstumbler scan

Figure A5 Link view from Crabtree antenna to Kimball tower

Figure A6 Zoomed in line of sight link to client node location

Raw Ping Test Results
****

During light/moderate snowstorm on Feb 7 10:00 PM
22 degrees 63% Humidity

Ping statistics for 192.168.201.1:
Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 689ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 15000, Received = 14970, Lost = 30 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 926ms, Average = 2ms

Ping statistics for 192.168.201.3:
Packets: Sent = 15000, Received = 14982, Lost = 18 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 3ms, Maximum = 441ms, Average = 3ms

****

Wed Feb 11 10:30 am - cold –
16 degrees clear 48% Hum.

Ping statistics for 192.168.201.1:
Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 749ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 15000, Received = 14648, Lost = 352 (2% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 772ms, Average = 3ms

Ping statistics for 192.168.201.3:
Packets: Sent = 15000, Received = 14636, Lost = 364 (2% loss),
Approximate round trip times in milli-seconds:
Minimum = 3ms, Maximum = 773ms, Average = 4ms

****

Feb 11 6:00 p.m. light snow
21 deg. 82% hum

Ping statistics for 192.168.201.1:
    Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 322ms, Average = 0ms

Ping statistics for 192.168.201.2:
    Packets: Sent = 15000, Received = 14851, Lost = 149 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 463ms, Average = 2ms

Ping statistics for 192.168.201.3:
    Packets: Sent = 15000, Received = 14842, Lost = 158 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 3ms, Maximum = 563ms, Average = 4ms

****

Feb 16th 2:30 p.m. clear day warm 45 deg.

Ping statistics for 192.168.201.1:
    Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 915ms, Average = 0ms

Ping statistics for 192.168.201.2:
    Packets: Sent = 15000, Received = 14858, Lost = 142 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 708ms, Average = 3ms

Ping statistics for 192.168.201.3:
    Packets: Sent = 15000, Received = 14835, Lost = 165 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 3ms, Maximum = 717ms, Average = 3ms

****
****************CLIENT NODE 1 HAS BEEN INSTALLED ****************
ALL SUBSEQUENT WEATHER REPORTS ARE GIVEN FROM WEATHER.COM
****

Feb 22 9:30
34°F Partly Cloudy 34°F
UV Index: 0 Minimal
Dew Point: 30°F

Humidity: 87%
Visibility: 2.0 miles
Pressure: 29.86 inches and steady
Wind: calm

Ping statistics for 192.168.201.1:
Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 496ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 15000, Received = 14763, Lost = 237 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 925ms, Average = 3ms

Ping statistics for 192.168.201.3:
Packets: Sent = 15000, Received = 14758, Lost = 242 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 3ms, Maximum = 710ms, Average = 5ms

Ping statistics for 192.168.201.5:
Packets: Sent = 15000, Received = 14298, Lost = 702 (4% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 1790ms, Average = 8ms

****

Feb 23 4:00 PM
43°F
Partly Cloudy Feels Like
43°F
UV Index: 1 Minimal
Dew Point: 36°F
Humidity: 76%
Visibility: Unlimited
Pressure: 29.78 inches and steady
Wind: calm

Ping statistics for 192.168.201.1:
Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 329ms, Average = 0ms

Ping statistics for 192.168.201.2:
    Packets: Sent = 15000, Received = 14771, Lost = 229 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 675ms, Average = 14ms

Ping statistics for 192.168.201.3:
    Packets: Sent = 15000, Received = 14717, Lost = 283 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 3ms, Maximum = 698ms, Average = 10ms

Ping statistics for 192.168.201.5:
    Packets: Sent = 15000, Received = 14529, Lost = 471 (3% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 4293ms, Average = 21ms

****

Feb 23 10:33 PM
32°F
Fair Feels Like
32°F
UV Index: 0 Minimal
Dew Point: 28°F
Humidity: 87%
Visibility: Unlimited
Pressure: 29.85 inches and rising
Wind: calm

Ping statistics for 192.168.201.1:
    Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 867ms, Average = 0ms

Ping statistics for 192.168.201.2:
    Packets: Sent = 15000, Received = 14914, Lost = 86 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 776ms, Average = 2ms

Ping statistics for 192.168.201.3:
    Packets: Sent = 15000, Received = 14913, Lost = 87 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 3ms, Maximum = 693ms, Average = 4ms

Ping statistics for 192.168.201.5:
Packets: Sent = 15000, Received = 14795, Lost = 205 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 1913ms, Average = 7ms

****

Feb 25th 11:30 PM Clear night
45°F
Cloudy Feels Like
40°F

UV Index: 0 Minimal
Dew Point: 28°F
Humidity: 53%
Visibility: Unlimited
Pressure: 29.89 inches and falling
Wind: From the Southeast at 9 mph

Ping statistics for 192.168.201.1:
Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 471ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 15000, Received = 14874, Lost = 126 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 895ms, Average = 12ms

Ping statistics for 192.168.201.3:
Packets: Sent = 15000, Received = 14870, Lost = 130 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 3ms, Maximum = 899ms, Average = 21ms

Ping statistics for 192.168.201.5:
Packets: Sent = 15000, Received = 12802, Lost = 2198 (14% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 3174ms, Average = 17ms

****

Feb 28th Heavy Snow storm about 4 inches 3:30
34°F
Cloudy Feels Like
34°F
UV Index: 1 Minimal

Dew Point: 30°F
Humidity: 87%
Visibility: Unlimited
Pressure: 29.79 inches and steady
Wind: From the West at 3 mph

(Accuweather: 5.7 inches)

Ping statistics for 192.168.201.1:
Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 235ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 15000, Received = 14901, Lost = 99 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 770ms, Average = 14ms

Ping statistics for 192.168.201.3:
Packets: Sent = 15000, Received = 14846, Lost = 154 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 3ms, Maximum = 1003ms, Average = 10ms

Ping statistics for 192.168.201.5:
Packets: Sent = 15000, Received = 14744, Lost = 256 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 4481ms, Average = 16ms

****

Feb 28th during moderate/heavy Snow Winter storm warning in effect 9:32P.M.
32°F
Cloudy Feels Like
32°F
UV Index: 0 Minimal
Dew Point: 30°F
Humidity: 93%
Visibility: 2.5 miles
Pressure: 29.85 inches and falling
Wind: From the Southwest at 3 mph

NOTE:
Something seems to be wrong with the test radio at 192.168.201.5 at Client Node 1.
Destination is unreachable and remote management will not log in.

Ping statistics for 192.168.201.1:
Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 7ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 15000, Received = 14844, Lost = 156 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 1004ms, Average = 7ms

Ping statistics for 192.168.201.3:
Packets: Sent = 15000, Received = 14863, Lost = 137 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 3ms, Maximum = 941ms, Average = 11ms

Ping statistics for 192.168.201.5:
Packets: Sent = 15000, Received = 11671, Lost = 3329 (22% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 4195ms, Average = 8ms

****

March 1 12:20 A.M. Very clear, no fog, just cold
28°F
Mostly Cloudy Feels Like
28°F
UV Index: 0 Minimal
Dew Point: 27°F
Humidity: 91%
Visibility: 5.0 miles
Pressure: 30.03 inches and steady
Wind: calm

Ping statistics for 192.168.201.1:
Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 532ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 15000, Received = 14958, Lost = 42 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 987ms, Average = 8ms

Ping statistics for 192.168.201.3:
    Packets: Sent = 15000, Received = 14950, Lost = 50 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 3ms, Maximum = 988ms, Average = 8ms

Ping statistics for 192.168.201.5:
    Packets: Sent = 15000, Received = 13304, Lost = 1696 (11% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 3223ms, Average = 13ms

****

March 2nd 7:30 PM
34°F
Fair Feels Like
24°F

UV Index: 0 Minimal
Dew Point: 25°F
Humidity: 70%
Visibility: Unlimited
Pressure: 29.97 inches and rising
Wind: From the Northwest at 14 mph

Ping statistics for 192.168.201.1:
    Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 1001ms, Average = 3ms

Ping statistics for 192.168.201.2:
    Packets: Sent = 15000, Received = 14899, Lost = 101 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 1003ms, Average = 7ms

Ping statistics for 192.168.201.3:
    Packets: Sent = 15000, Received = 14909, Lost = 91 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 3ms, Maximum = 988ms, Average = 9ms

Ping statistics for 192.168.201.5:
    Packets: Sent = 15000, Received = 14320, Lost = 680 (4% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 4425ms, Average = 17ms

****

March 8 8:30 PM
39°F
Fair Feels Like
34°F

UV Index: 0 Minimal
Dew Point: 30°F
Humidity: 70%
Visibility: Unlimited
Pressure: 30.48 inches and steady
Wind: From the North Northwest at 8 mph

Ping statistics for 192.168.201.1:
Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 490ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 15000, Received = 14927, Lost = 73 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 552ms, Average = 6ms

Ping statistics for 192.168.201.3:
Packets: Sent = 15000, Received = 14935, Lost = 65 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 3ms, Maximum = 551ms, Average = 8ms

Ping statistics for 192.168.201.5:
Packets: Sent = 15000, Received = 14809, Lost = 191 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 2427ms, Average = 13ms

****

March 10 11:30 PM Foggy
37°F
Fair Feels Like
37°F
UV Index: 0 Minimal
Dew Point: 28°F
Humidity: 70%
Visibility: < 1 mile
Pressure: 30.34 inches and steady
Wind: From the East Southeast at 3 mph

Ping statistics for 192.168.201.1:
Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 498ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 15000, Received = 14593, Lost = 407 (2% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 807ms, Average = 4ms

Ping statistics for 192.168.201.3:
Packets: Sent = 15000, Received = 14630, Lost = 370 (2% loss),
Approximate round trip times in milli-seconds:
Minimum = 3ms, Maximum = 672ms, Average = 4ms

Ping statistics for 192.168.201.5:
Packets: Sent = 15000, Received = 14452, Lost = 548 (3% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 3325ms, Average = 10ms

****

March 11 1:00 PM Clear sunny day
48°F
Fair Feels Like
46°F
UV Index: 5 Moderate
Dew Point: 32°F
Humidity: 54%
Visibility: Unlimited
Pressure: 30.27 inches and falling
Wind: From the West at 6 mph

All Access points and bridges were timing out. After further inspection, the transformer that powers the roof outlets was being replaced. Hopefully it will be back up tomorrow.

****

March 15 12:40 A.M.
46°F
Fair Feels Like
46°F
UV Index: 0 Minimal
Dew Point: 36°F
Humidity: 66%
Visibility: Unlimited

Pressure: 30.24 inches and steady
Wind: calm

It seems as though the WET11 at 201.5 is down again. Tomorrow it will be checked for inconsistencies. After approximately 520 lost packets, it started to respond again.

Ping statistics for 192.168.201.1:
Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 797ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 15000, Received = 14884, Lost = 116 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 1002ms, Average = 2ms

Ping statistics for 192.168.201.3:
Packets: Sent = 15000, Received = 14908, Lost = 92 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 3ms, Maximum = 559ms, Average = 3ms

Ping statistics for 192.168.201.5:
Packets: Sent = 15000, Received = 14429, Lost = 571 (3% loss), (BACK ONLINE!)
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 2600ms, Average = 7ms

****

March 15 2004 2:30 P.M. Clear sunny day
55°F
Fair Feels Like
55°F
UV Index: 4 Low
Dew Point: 30°F
Humidity: 38%
Visibility: Unlimited
Pressure: 30.27 inches and steady
Wind: From the West Southwest at 7 mph

Ping statistics for 192.168.201.1:
Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 435ms, Average = 0ms

Ping statistics for 192.168.201.2:
    Packets: Sent = 15000, Received = 14784, Lost = 216 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 1003ms, Average = 3ms

Ping statistics for 192.168.201.3:
    Packets: Sent = 15000, Received = 14767, Lost = 233 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 3ms, Maximum = 872ms, Average = 4ms

Ping statistics for 192.168.201.5:
    Packets: Sent = 15000, Received = 14606, Lost = 394 (2% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 4026ms, Average = 9ms

****

March 15 9:40 P.M. Clear
45°F
Fair Feels Like
45°F
UV Index: 0 Minimal
Dew Point: 34°F
Humidity: 66%
Visibility: Unlimited
Pressure: 30.25 inches and rising
Wind: calm

Ping statistics for 192.168.201.1:
    Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 15ms, Average = 0ms

Ping statistics for 192.168.201.2:
    Packets: Sent = 15000, Received = 14979, Lost = 21 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 909ms, Average = 7ms

Ping statistics for 192.168.201.3:
    Packets: Sent = 15000, Received = 14971, Lost = 29 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 3ms, Maximum = 910ms, Average = 8ms

Ping statistics for 192.168.201.5:
Packets: Sent = 15000, Received = 14139, Lost = 861 (5% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 2615ms, Average = 13ms

***** About 630 of these dropped packet occurred in a row, indicating some kind of failure***

****

March 21 2004 3:00 P.M.
70°F
Fair Feels Like
70°F
UV Index: 4 Low
Dew Point: 37°F
Humidity: 31%
Visibility: 10.0 miles
Pressure: 30.18 inches and falling
Wind: From the West at 5 mph

Ping statistics for 192.168.201.1:
Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 235ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 15000, Received = 14988, Lost = 12 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 771ms, Average = 3ms

Ping statistics for 192.168.201.3:
Packets: Sent = 15000, Received = 14978, Lost = 22 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 3ms, Maximum = 768ms, Average = 5ms

Ping statistics for 192.168.201.5:
Packets: Sent = 15000, Received = 14424, Lost = 576 (3% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 4302ms, Average = 10ms

Approx: 370 lost in a row

****

March 22 1:25 A.M.
46°F
Fair Feels Like
46°F

UV Index: 0 Minimal
Dew Point: 34°F
Humidity: 62%
Visibility: 10.0 miles
Pressure: 30.08 inches and steady
Wind: calm

Ping statistics for 192.168.201.1:
    Packets: Sent = 15000, Received = 15000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 183ms, Average = 0ms

Ping statistics for 192.168.201.2:
    Packets: Sent = 15000, Received = 14999, Lost = 1 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 378ms, Average = 2ms

Ping statistics for 192.168.201.3:
    Packets: Sent = 15000, Received = 14998, Lost = 2 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 3ms, Maximum = 535ms, Average = 3ms

Ping statistics for 192.168.201.5:
    Packets: Sent = 15000, Received = 11980, Lost = 3020 (20% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 3790ms, Average = 12ms

******Approximately 1776, 240, and 880 packets were lost in a row over several intervals***
*****Beyond that, the connection itself lost many random packets*****

****
*************Ping Plotter was started to pinpoint outages************
****

Number of pings was reduced to 8,000 enabling a full history to be stored within the command window****

****

March 25, 11:20 P.M.
57°F
Fair Feels Like
57°F
Humidity: 33%
Pressure: 29.82 inches
Wind: From the South Southeast at 9 mph

Ping statistics for 192.168.201.1:
Packets: Sent = 8000, Received = 8000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 297ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 8000, Received = 7988, Lost = 12 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 1002ms, Average = 5ms

Ping statistics for 192.168.201.3:
Packets: Sent = 8000, Received = 7985, Lost = 15 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 3ms, Maximum = 1003ms, Average = 5ms

Ping statistics for 192.168.201.5:
Packets: Sent = 8000, Received = 6814, Lost = 1186 (14% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 2013ms, Average = 9ms

Approx 750 time outs in a row

****

March 26 9:30 a.m. Raining
48°F
Cloudy Feels Like
43°F

UV Index: 0 Minimal
Dew Point: 39°F
Humidity: 71%
Visibility: 10.0 miles
Pressure: 29.90 inches and rising
Wind: From the Northwest at 12 mph

(Accuweather .15 inches in approx 5 hours)

Ping statistics for 192.168.201.1:
Packets: Sent = 8000, Received = 8000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 204ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 8000, Received = 7847, Lost = 153 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 555ms, Average = 3ms

Ping statistics for 192.168.201.3:
Packets: Sent = 8000, Received = 7871, Lost = 129 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 3ms, Maximum = 376ms, Average = 4ms

Ping statistics for 192.168.201.5:
Packets: Sent = 8000, Received = 7641, Lost = 359 (4% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 2444ms, Average = 8ms

****

March 26 12:25 P.M. Light Rain
41°F
Cloudy Feels Like
38°F

UV Index: 1 Minimal
Dew Point: 36°F
Humidity: 81%
Visibility: 10.0 miles
Pressure: 29.98 inches and steady
Wind: From the South Southeast at 5 mph

Ping statistics for 192.168.201.1:
Packets: Sent = 8000, Received = 8000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 108ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 8000, Received = 7870, Lost = 130 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 864ms, Average = 10ms

Ping statistics for 192.168.201.3:
    Packets: Sent = 8000, Received = 7868, Lost = 132 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 3ms, Maximum = 864ms, Average = 9ms

Ping statistics for 192.168.201.5:
    Packets: Sent = 8000, Received = 7664, Lost = 336 (4% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 2434ms, Average = 8ms

************No grouping in the time outs, all were randomly placed*****

****

April 1, 10:35 a.m. *******Light Rained during test*****
61°F
Fair Feels Like
61°F
Humidity: 34%
Pressure: 29.85 inches
Wind: From the West Southwest at 16 mph

(Accuweather .04 inches off and on)

Ping statistics for 192.168.201.1:
    Packets: Sent = 8000, Received = 8000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 1ms, Average = 0ms

Ping statistics for 192.168.201.2:
    Packets: Sent = 8000, Received = 7908, Lost = 92 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 396ms, Average = 2ms

Ping statistics for 192.168.201.3:
    Packets: Sent = 8000, Received = 7910, Lost = 90 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 3ms, Maximum = 179ms, Average = 3ms

Ping statistics for 192.168.201.5:
    Packets: Sent = 5067, Received = 0, Lost = 5067 (100% loss),

****

April 6th-
After having checked the antenna and receiver at the residence of Dr. Helps, the unit seemed to be in good working order, and was picking up several other signals from surrounding access points. The access point on top of the Kimball tower was checked via the remote login and it seemed that the radio interface hardware was down. Several attempts were made to restart the radio and nothing worked. Finally after consulting the Cisco site, the entire unit was rebooted and the radio did return to its functioning state. The following morning we physically checked the box that the two units were in on top of the SWKT and we found that the outer casing of the D-Link bridge had actually melted due to the heat of the two units together. A plan is now being devised to calculate and introduce some kind of air flow system onto the unit to prevent future "meltdowns."

It has also been noticed that the Linksys has what seems to be a sleep feature or something, such that when the unit is "pinged" it takes it a while to wake up and respond.

****

April 7th 9:30 p.m. After a light rain
50°F
Partly Cloudy Feels Like
47°F
Humidity: 82%
Pressure: 30.01 inches
Wind: From the South Southeast at 7 mph

The first three points all responded within a reasonable amount of time, but the end point once again is unreachable. Upon further investigation, the radio of the main broadcast unit is down again. It is suspected that the heat issue is at play again. Tomorrow a visit will be scheduled to see the unit and install a ventilation system. As a precaution against further damage, the radio on the bridge has been reduced to 12.5% of its power which is 10 dBm. As a test, the other bridge was also set to 10 dBm. Communication is still possible at this level.

****

April 9, 2004 11:51 a.m.

***The access point was successfully rebooted after leaving the radio disabled for the night and the radio hardware/software came up. The client bridge can once again be reached. ***

55°F
Partly Cloudy Feels Like
55°F
Humidity: 51%
Pressure: 30.04 inches
Wind: From the Northwest at 17 gusting to 24 mph

Ping statistics for 192.168.201.1:
Packets: Sent = 8000, Received = 8000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 3ms, Average = 0ms

Ping statistics for 192.168.201.2:
Packets: Sent = 8000, Received = 7911, Lost = 89 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 2ms, Maximum = 1002ms, Average = 11ms

Ping statistics for 192.168.201.3:
Packets: Sent = 8000, Received = 7892, Lost = 108 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 3ms, Maximum = 566ms, Average = 14ms

Ping statistics for 192.168.201.5:
Packets: Sent = 8000, Received = 7821, Lost = 179 (2% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 2568ms, Average = 16ms

****

April 16th 2004

Several issues with the Cisco access point have also hopefully been resolved. The access point radio had been going down on the hardware side, which then had to be disabled for a time, and the access point had to be restarted. The radio could then be enabled and it stood a pretty good chance (4/6 times exactly) of coming back up. After the initial inspection, it was noted that the case was very hot. It was approximately 116 degrees inside the box while ambient was only 64. Also notable: it was only 9:00 a.m. and direct sunlight had been on it for less than two hours. Conclusion: most of the internal temperature is coming from the two electronic units. In the sun, this temperature could easily rise above the 130 degree threshold listed for the access points.

A new ventilation system was designed and installed. To minimize installation time spent on the roof, a system was designed to be completely mounted on the box's lid. This way, the original lid can be removed, and the new airflow lid installed. After some simple searching on the web, and asking several professors, it was apparent that the box needed forced airflow because any box in the sunlight could not keep cool enough by heat convection airflow alone. A 110 volt fan was located and mounted on the inside of the lid opposite a smaller 4x4x2 inch box with one side removed for water shedding outlet port. The in ports were made from two-two inch PVC elbows mounted to the lid using screw-on collars with four inch extensions at a 45 degree downward angle to keep water out. Screens were implemented to keep bugs and other debris out.

The access point also had a small hiccup because the feature used to find the least congested channel seemed to be disabling broadcast signals while the radio was still enabled. The radio would say it was enabled, but the signal could not be seen. It was also questionable as to whether or not some kind of hack was being used to disable the signal.

****

April 16th 2004 9:00 p.m.
55°F
Fair Feels Like
55°F
UV Index: 0 Minimal
Dew Point: 37°F
Humidity: 51%
Visibility: 10.0 miles
Pressure: 29.82 inches and rising
Wind: From the West Northwest at 10 mph

Ping statistics for 192.168.201.1:
  Packets: Sent = 8000, Received = 8000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
  Minimum = 0ms, Maximum = 1ms, Average = 0ms

Ping statistics for 192.168.201.2:
  Packets: Sent = 8000, Received = 7965, Lost = 35 (0% loss),
Approximate round trip times in milli-seconds:
  Minimum = 2ms, Maximum = 47ms, Average = 3ms

Ping statistics for 192.168.201.3:
  Packets: Sent = 8000, Received = 7966, Lost = 34 (0% loss),
Approximate round trip times in milli-seconds:
  Minimum = 3ms, Maximum = 384ms, Average = 3ms

Ping statistics for 192.168.201.5:
  Packets: Sent = 8000, Received = 7964, Lost = 36 (0% loss),
Approximate round trip times in milli-seconds:
  Minimum = 4ms, Maximum = 38ms, Average = 6ms

****

April 17th 2004 12:06 p.m. Light rain
59°F
Fair Feels Like
59°F
UV Index: 6 Moderate
Dew Point: 28°F
Humidity: 31%
Visibility: 10.0 miles
Pressure: 29.80 inches and steady
Wind: From the West Southwest at 18 gusting to 38 mph

NOTE: Now that PingPlotter is running, it is possible to see if the access point ever goes down. This morning it did from about 10:04 to 10:52. It is an unexplained outage.

Ping statistics for 192.168.201.1:
  Packets: Sent = 8000, Received = 8000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
  Minimum = 0ms, Maximum = 1ms, Average = 0ms

Ping statistics for 192.168.201.2:
  Packets: Sent = 8000, Received = 7917, Lost = 83 (1% loss),
Approximate round trip times in milli-seconds:
  Minimum = 2ms, Maximum = 39ms, Average = 2ms

Ping statistics for 192.168.201.3:
  Packets: Sent = 8000, Received = 7911, Lost = 89 (1% loss),
Approximate round trip times in milli-seconds:
  Minimum = 3ms, Maximum = 418ms, Average = 3ms

Ping statistics for 192.168.201.5:
  Packets: Sent = 8000, Received = 7913, Lost = 87 (1% loss),
Approximate round trip times in milli-seconds:
  Minimum = 4ms, Maximum = 1156ms, Average = 6ms

****

April 17th 2004 8:30 p.m. Light Rain
50°F
Partly Cloudy Feels Like
43°F
UV Index: 0 Minimal
Dew Point: 37°F
Humidity: 62%
Visibility: 10.0 miles
Pressure: 29.73 inches and rising
Wind: From the Northwest at 21 mph

Upon further investigation, it has been realized that part of the reason that the access point loses signal with it's client bridge is that there are other broadcasting stations on that specific channel (channel 11) at which the access point on top of the tower sees as the least congested frequency and automatically assigns to be the broadcast frequency for use. This creates a problem in large networks because the main broadcast tower does not have the capability to choose the least congested frequency at the client locations as well as it's own location.

This is what the Cisco reports as far as channel traffic:

Hostname SWKT-Roof 20:46:33 Sat Apr 17 2004
Network Interfaces: Radio0-802.11B Carrier Busy Test
Carrier Busy Test:

Carrier Busy Test Output
Frequency Carrier Busy %
2412 26
2417 38
2422 55
2427 56
2432 54
2437 46
2442 38
2447 72
2452 75
2457 83
2462 39

This is what the Linksys WET11 see as far as traffic

SWKT-skynet

Channel:	1
BSSID:	00:0D:BD:DA:C1:3E
Transmission Rate:	11
Link Quality (%):	59
MAC address:	00:06:25:12:58:C6
IP Address:	192.168.201.5
Firmware Revision:	1.3.2.107.136

Results of the most recent scan

SSID	MAC address	Channel	Signalstrength (%)	Mode
SWKT-skynet	00:0D:BD:DA:C1:3E	1	93	Infra,WEP
14SILVER	00:02:2D:21:34:88	7	73	Infra,WEP

vaud01s	00:09:5B:85:73:8E	11	73	Infra,WEP
Wireless	00:09:5B:34:7B:C1	11	64	Infra
FHSS_WiFi	00:06:25:E8:F9:F1	11	45	Infra
kimballtower	00:40:96:56:CF:49	4	80	Infra

So, it stands to reason that since the access point cannot see the congested channels at the clients location, a channel may be chosen that may be least congested at the access point, but very congested at the client location.

Test Results 9:00 p.m.
Note: after a long timout period (approx. 10:11 p.m. to 12:27 a.m.) between the access point and the bridge, the channel was changed on the access point from channel 6 to channel 1. The client came right back up and the results are as follows:

Ping statistics for 192.168.201.1:
    Packets: Sent = 8000, Received = 8000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 1ms, Average = 0ms

Ping statistics for 192.168.201.2:
    Packets: Sent = 8000, Received = 7891, Lost = 109 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 49ms, Average = 3ms

Ping statistics for 192.168.201.3:
    Packets: Sent = 8000, Received = 7895, Lost = 105 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 3ms, Maximum = 40ms, Average = 3ms

Ping statistics for 192.168.201.5:
    Packets: Sent = 8000, Received = 6377, Lost = 1623 (20% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 3225ms, Average = 9ms

Another interesting note is that the Cisco access point has the capability to detect radio jammers. In this instance alone, 32 have been detected. Some other numbers and their definitions:

	Total	Last 5 sec.
Protocol Defers	48350	1
Energy Detect Defers	149530	3
Jammer Detected	32	0

Protocol Defers - The number of times sending a packet was deferred because a received 802.11 duration field detected another transmitting device.

Energy Detect Defers - The number of times we deferred sending a packet because the energy detect circuitry indicates that another radio was transmitting.

Jammer Detected - The number of times we detected an interference source which lasted longer than a legal 802.11 packet. The interference source was ignored and the transmission was repeated.

Source:
http://www.cisco.com/warp/public/779/smbiz/prodconfig/help/eag/ivory/1100/h_ap_network-if_802-11_b.htm

It has also been brought to light that the access point is having reduced throughput rates due to a large number of CRC errors.

CRC Errors	11642927	292
Header CRC Errors	40455305	2651

To test a proposed resolution to this problem, the fragmentation threshold and RTS threshold will be changed from 2346 and 2312 to 1000 and 1000 respectively.

****

April 18 10:41 p.m.
41°F
Fair Feels Like
36°F
UV Index: 0 Minimal
Dew Point: 36°F
Humidity: 81%
Visibility: 10.0 miles
Pressure: 30.12 inches and steady
Wind: From the South at 7 mph

Ping statistics for 192.168.201.1:
    Packets: Sent = 8000, Received = 8000, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 20ms, Average = 0ms

Ping statistics for 192.168.201.2:
    Packets: Sent = 8000, Received = 7933, Lost = 67 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 45ms, Average = 2ms

Ping statistics for 192.168.201.3:
   Packets: Sent = 8000, Received = 7944, Lost = 56 (0% loss),
Approximate round trip times in milli-seconds:
   Minimum = 3ms, Maximum = 220ms, Average = 3ms

Ping statistics for 192.168.201.5:
   Packets: Sent = 8000, Received = 6810, Lost = 1190 (14% loss),
Approximate round trip times in milli-seconds:
   Minimum = 4ms, Maximum = 1009ms, Average = 6ms

******Once again the bridge had an unexpected outage. This occurred between the times of 11:55 p.m. and 1:30 a.m. Several other outages have been captured on ping plotter. These times are:

4/17 from 10:04 am to 10:53 am and 7:50 pm to 8:45 pm and 10:10 pm to 12:27 a.m.
4/18 from 7:15 am to 9:47 am and 6:07 pm to 9:08 pm and 11:52 pm to 1:37 am
4/19 from 6:50 am to 7:27 am

****

4/27 Very windy - dust storm < 1 mile visibility
52°F
Fair and Windy Feels Like
52°F
UV Index: 7 High
Dew Point: 28°F
Humidity: 41%
Visibility: less than 5.0 miles
Pressure: 29.57 inches and rising
Wind: From the North Northwest at 38 gusting to 51 mph

Ping statistics for 192.168.201.3:
   Packets: Sent = 3000, Received = 2963, Lost = 37 (1% loss),
Approximate round trip times in milli-seconds:
   Minimum = 3ms, Maximum = 38ms, Average = 4ms

Ping statistics for 192.168.201.5:
   Packets: Sent = 3000, Received = 2962, Lost = 38 (1% loss),
Approximate round trip times in milli-seconds:
   Minimum = 4ms, Maximum = 43ms, Average = 6ms

Appendix B - Fresnel Zone Effect Testing

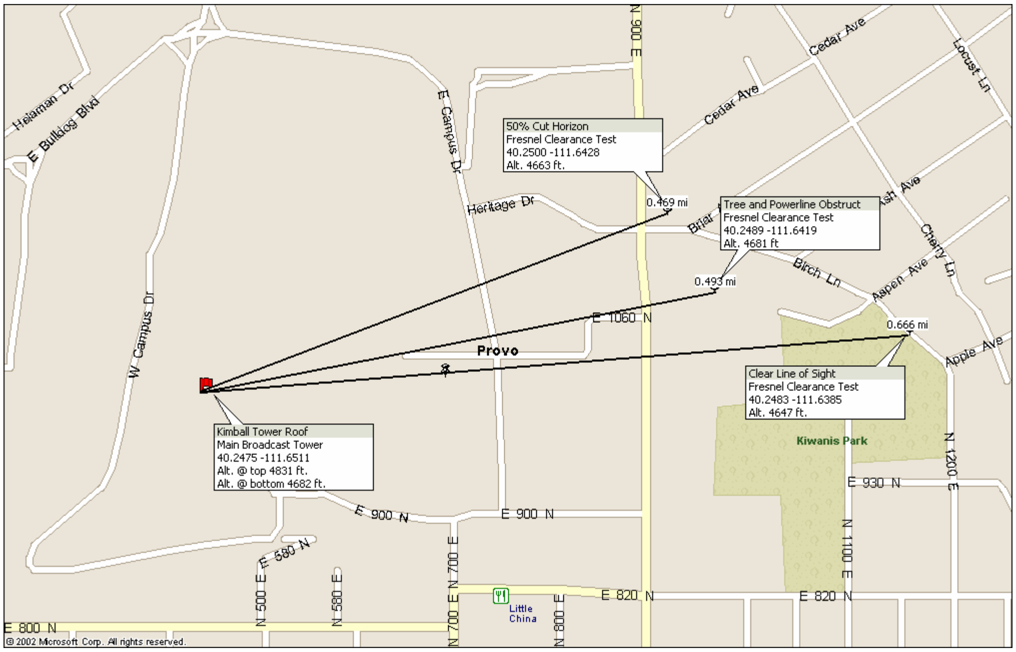

Figure B-1 Link map for Fresnel clearance testing

B.1 50% Fresnel Clearance – Blocked by a Building

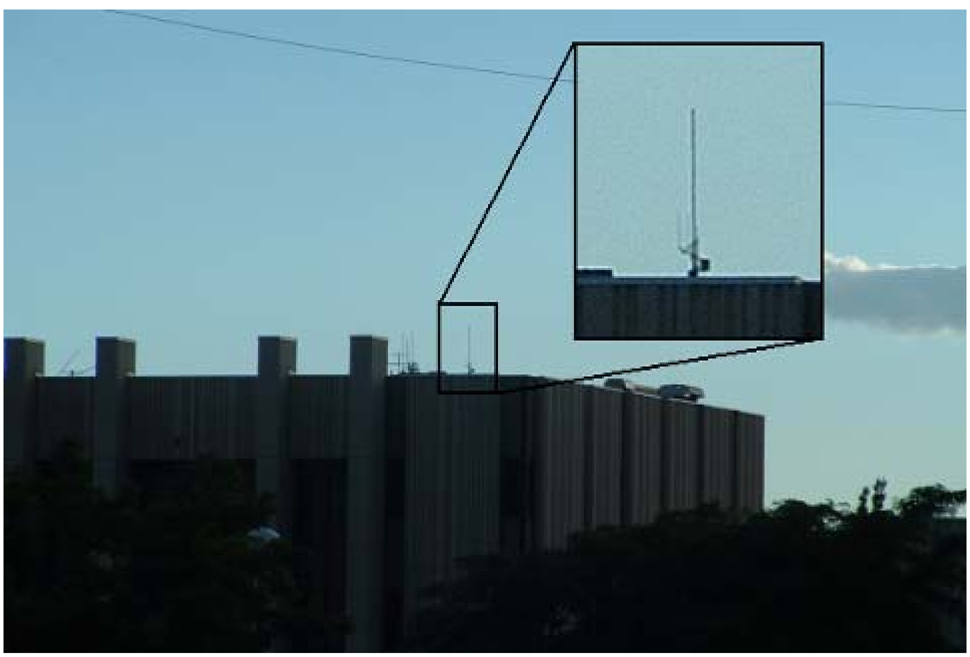

Figure B-2 “Split Horizon” with blocking building giving about 50% Fresnel clearance

MAC	SSID	Chan	Vendor	Encryption	SNR+	Signal+	Noise-
0030BD97BED0	HelpDesk	6	Belkin		6	-94	-100
004005CA7FF7	CTBSWKT	1	D-Link	WEP	9	-91	-100
004096476CD8	byuc0ug4rs	1	Cisco		9	-91	-100
0040964772CF	byuc0ug4rs	6	Cisco		9	-91	-100
000E837C34E0	byuc0ug4rs	1	Cisco		10	-90	-100
66A44D87F023	xp1	11	(User-defined)	WEP	10	-90	-100
00095B421A5F	FSW-WiFi	11	Netgear	WEP	13	-87	-100
000D88202162	default	6	D-Link		13	-87	-100
004096483288	byuc0ug4rs	1	Cisco		16	-84	-100
0080C8125222	tlrbwirelessrec	1	D-Link		17	-83	-100
00409656CF49	kimballtower	4	Cisco		20	-80	-100
004096477AD5	byuc0ug4rs	11	Cisco		20	-80	-100
000DED4CF948	IT_WL_365	3, 14	Cisco		22	-78	-100
000DBDDAC13E	IT_WL_335	8, 14	Cisco	WEP	29	-71	-100
0040965A5B8A	byuc0ug4rs	6, 14	Cisco		31	-69	-100
000DED4CF93D	SWKT-skynet	14, 5	Cisco	WEP	33	-67	-100

Figure B-3 "Split horizon" NetStumbler surrounding area noise

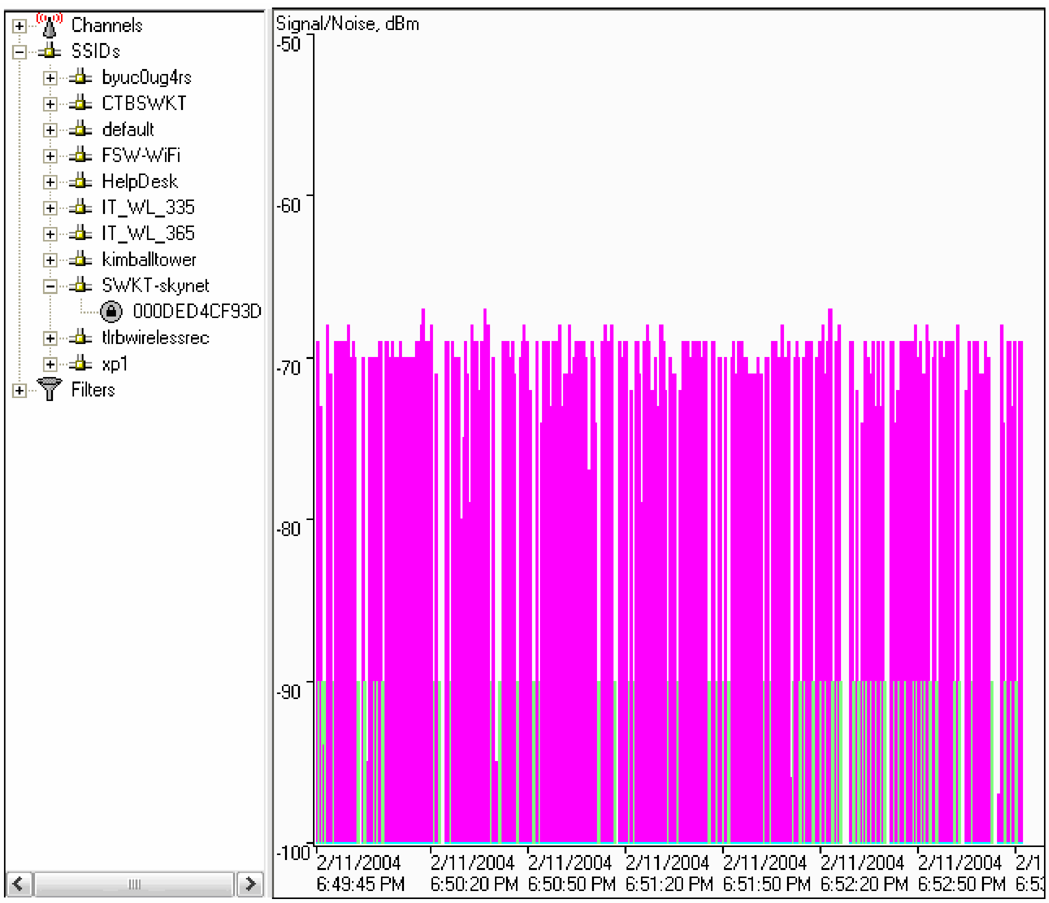

Figure B-4 "Cut horizon" Signal to noise graph for SWKT-skynet signal from Kimball tower

Calculated Signal Gain and Path Loss:

Kimball tower to 50% Split Horizon Test area (.469 miles)

Free space path loss @ 2.437 (channel 6): -97.76 dB

Gain: 15 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 16 dBi Vagi – 3 ft LMR-195 jumper (~1.1 dB) – 12 in. pigtail (~1dB) = 38.65 dB

Total path calculation: -59.11dB
Actual Measured: approx. -69 dB
Percent Error: 14.33%

FTP Log for 50% Cut Horizon test

PASV
227 Entering Passive Mode (192,168,201,10,4,4).
connecting to 192.168.201.10:1028
- -
connecting to 192.168.201.10:1028
Connected to 192.168.201.10 port 1028
LIST
125 Data connection already open; Transfer starting.
Received 215 bytes in 0.1 secs, (20.00 Kbps), transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
TYPE I
200 Type set to I.
PASV
227 Entering Passive Mode (192,168,201,10,4,5).
connecting to 192.168.201.10:1029
- -
connecting to 192.168.201.10:1029
Connected to 192.168.201.10 port 1029
RETR segment5.swf
125 Data connection already open; Transfer starting.

Received 7679963 bytes in 97.8 secs, **(770.18 Kbps)**, transfer succeeded

226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV

227 Entering Passive Mode (192,168,201,10,4,20).
connecting to 192.168.201.10:1044
- -
connecting to 192.168.201.10:1044
Connected to 192.168.201.10 port 1044
RETR segment5.swf
125 Data connection already open; Transfer starting.

Received 7679963 bytes in 72.4 secs, **(1.01 Mbps)**, transfer succeeded

226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,4,26).
connecting to 192.168.201.10:1050
- -
connecting to 192.168.201.10:1050
Connected to 192.168.201.10 port 1050
RETR segment5.swf
125 Data connection already open; Transfer starting.

Received 7679963 bytes in 102.3 secs, **(736.31 Kbps)**, transfer succeeded

226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,4,35).
connecting to 192.168.201.10:1059
- -
connecting to 192.168.201.10:1059
Connected to 192.168.201.10 port 1059
RETR segment5.swf
125 Data connection already open; Transfer starting.

Received 7679963 bytes in 93.6 secs, **(804.38 Kbps)**, transfer succeeded

226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,4,35).
connecting to 192.168.201.10:1064
- -

connecting to 192.168.201.10:1064
Connected to 192.168.201.10 port 1064
RETR segment5.swf
125 Data connection already open; Transfer starting.

Received 7679963 bytes in 97.2 secs, **(774.62Kbps)**, transfer succeeded
226 Transfer complete.

B.2 Line of Sight Partially Blocked by Trees and Power Lines

Figure B-5 Fresnel zone disruption from tree and power lines (.493 Miles)

MAC	SSID	Chan	Vendor	Type	Enc...	S.	Signal+	Noise-
000ED7AC8F30	byuc0ug4rs	11	Cisco	AP		5	-95	-100
00C049CCB1EC	USR8054	6	US Robotics	AP		6	-94	-100
000E837034E0	byuc0ug4rs	1	Cisco	AP		7	-93	-100
000E38B8F290	byuc0ug4rs	11	Cisco	AP		7	-93	-100
000D291DE360	byuc0ug4rs	11	Cisco	AP		7	-93	-100
0080C8125222	tlrbwirelessrec	1	D-Link	AP		8	-92	-100
00022D04FC7D	PSDwireless	11	Proxim (Agere) ...	AP		11	-89	-100
00409647726F	byuc0ug4rs	6	Cisco	AP		12	-88	-100
004005CA7FF7	CTBSWKT	1	D-Link		WEP	14	-86	-100
000DBDDAC13E	IT_WL_335	8	Cisco	AP	WEP	15	-85	-100
000DED4CF948	IT_WL_365	3	Cisco	AP		26	-74	-100
00409656CF49	kimballtower	4, 14	Cisco	AP		33	-67	-100
000DED4CF93D	SWKT-skynet	5, 14	Cisco	AP	WEP	35	-65	-100

Figure B-6 Tree and Power line obstruction test NetStumbler surrounding area noise

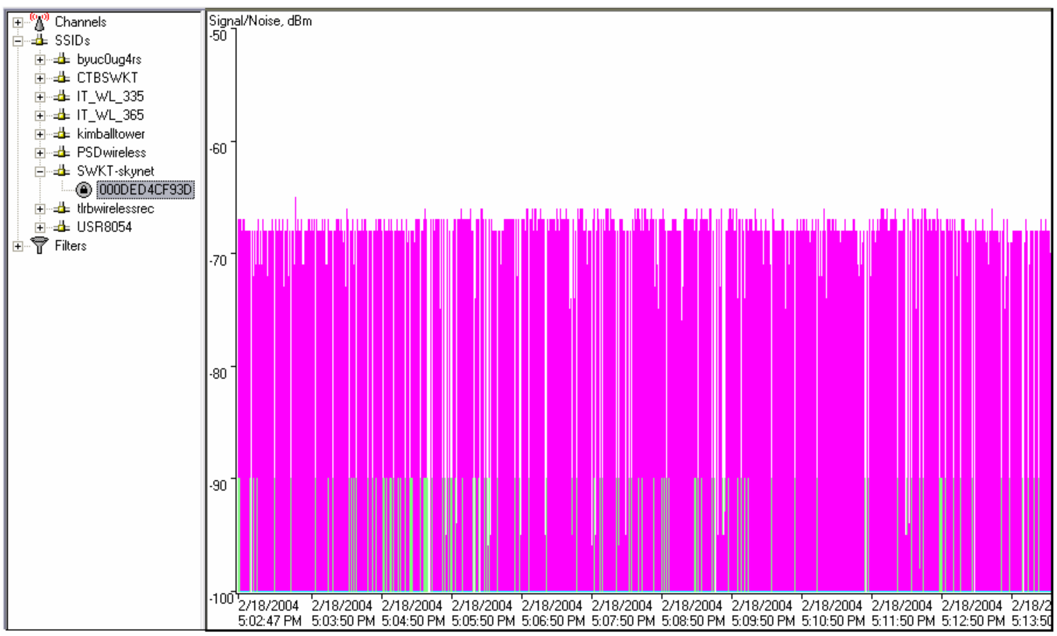

Figure B-7 Tree/Power line signal to noise graph for SWKT-skynet signal from Kimball tower

Calculated Signal Gain and Path Loss:

Kimball tower to tree and power line test area (.493 miles)

Free space path loss @ 2.437 (channel 6): -98.19 dB

Gain: 15 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 16 dBi Vagi – 3 ft LMR-195 jumper (~1.1 dB) – 12 in. pigtail (~1dB) = 38.65 dB

Total path calculation: -59.54 dB
Actual Measured: approx. -67 dB
Percent Error: 11.13%

FTP Log Tree and Power lines Obstructions Test

200 Type set to I.
PASV
227 Entering Passive Mode (192,168,201,10,4,5).
connecting to 192.168.201.10:1029
- -
connecting to 192.168.201.10:1029
Connected to 192.168.201.10 port 1029
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 68.1 secs, **(1.08 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,4,6).
connecting to 192.168.201.10:1030
- -
connecting to 192.168.201.10:1030
Connected to 192.168.201.10 port 1030
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 66.8 secs, **(1.10 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,4,7).
connecting to 192.168.201.10:1031
- -

connecting to 192.168.201.10:1031
Connected to 192.168.201.10 port 1031
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 65.2 secs, **(1.13 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV

227 Entering Passive Mode (192,168,201,10,4,8).
connecting to 192.168.201.10:1032
- -
connecting to 192.168.201.10:1032
Connected to 192.168.201.10 port 1032
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 66.3 secs, **(1.11 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,4,9).
connecting to 192.168.201.10:1033
- -
connecting to 192.168.201.10:1033
Connected to 192.168.201.10 port 1033
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 79.5 secs, **(947.39 Kbps)**, transfer succeeded
226 Transfer complete.

B.3 Clear Line of Sight (Baseline)

Figure B-8 Clear Fresnel zone clear line of sight shot (.667 miles)

MAC	SSID	Chan	Vendor	Type	Enc...	S.	Signal+	Noise-
000625F7543A	francisconet	11	Linksys	AP	WEP	6	-94	-100
000E38B8F4A0	byuc0ug4rs	6	Cisco	AP		7	-93	-100
000625E8F9F1	FHSS_WiFi	11	Linksys	AP		13	-87	-100
00022D30331F	PSDwireless	1	Proxim (Ag...	AP		14	-86	-100
000ED7AC8F30	byuc0ug4rs	11	Cisco	AP		15	-85	-100
000D8895758B	Chez Paul	6	D-Link	AP	WEP	16	-84	-100
004005CA7FF7	CTBSWKT	1	D-Link		WEP	16	-84	-100
00022D09F77D	PSDwireless	1	Proxim (Ag...	AP		16	-84	-100
00022D37ADAC	PSDwireless	11	Proxim (Ag...	AP		19	-81	-100
000DED4CF948	IT_WL_365	3	Cisco	AP		20	-80	-100
00095B6FC168	NETGEAR	11	Netgear	AP		21	-79	-100
0030AB1A2A6D	Wireless	6	Delta (Net...	AP		22	-78	-100
00409656CF49	kimballtower	4	Cisco	AP		33	-67	-100
000C414B482C	jefftopia	6, 14	Linksys	AP		34	-66	-100
0080C80A3D6C	Saige	6, 14	D-Link	AP	WEP	34	-66	-100
000DED4CF93D	SWKT-skynet	5, 14	Cisco	AP	WEP	37	-63	-100

Figure B-9 Clear Line of sight test NetStumbler surrounding area noise

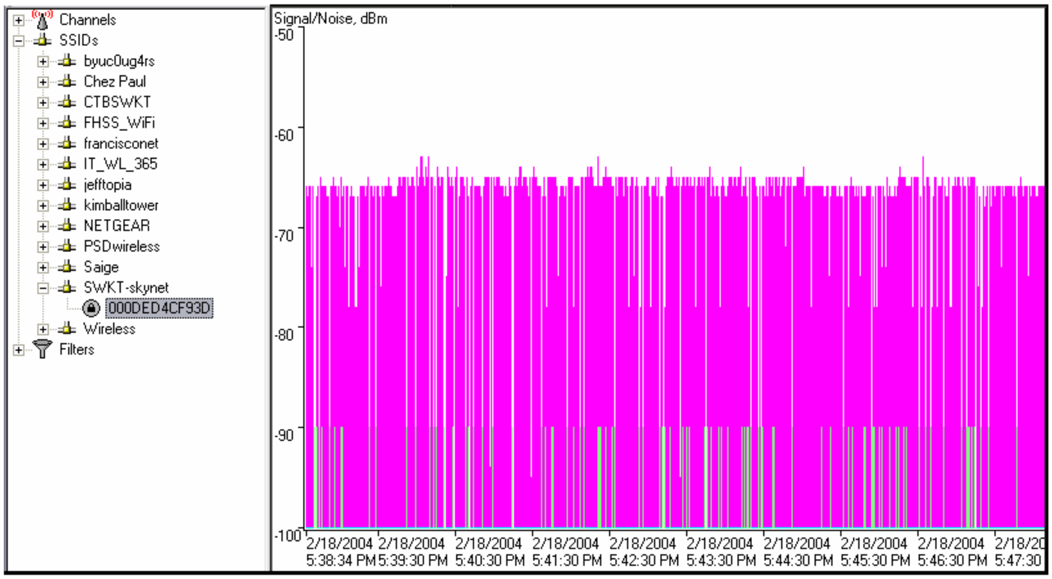

Figure B-10 Clear line of sight signal to noise graph for SWKT-skynet signal from Kimball tower

Calculated Signal Gain and Path Loss:

Kimball tower to clear line of sight test area (.667 miles)

Free space path loss @ 2.437 (channel 6): -100.82 dB

Gain: 15 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 16 dBi Vagi – 3 ft LMR-195 jumper (~1.1 dB) – 12 in. pigtail (~1dB) = 38.65 dB

Total path calculation: -62.17 dB
Actual Measured: approx. -65.5 dB
Percent Error: 5.08%

FTP Log Clear Line of Sight Test

connecting to 192.168.201.10:1037
Connected to 192.168.201.10 port 1037
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 55.4 secs, **(1.33 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,4,14).
connecting to 192.168.201.10:1038
- -

connecting to 192.168.201.10:1038
Connected to 192.168.201.10 port 1038
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 59.5 secs, **(1.24 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,4,15).
connecting to 192.168.201.10:1039
- -
connecting to 192.168.201.10:1039
Connected to 192.168.201.10 port 1039
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 59.2 secs, **(1.24 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,4,16).
connecting to 192.168.201.10:1040
- -
connecting to 192.168.201.10:1040
Connected to 192.168.201.10 port 1040
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 62.3 secs, **(1.18 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,4,17).
connecting to 192.168.201.10:1041
- -
connecting to 192.168.201.10:1041
Connected to 192.168.201.10 port 1041
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 65.7 secs, **(1.12 Mbps)**, transfer succeeded
226 Transfer complete.

B.4 Complete Summary of Test Results

Table B-1 Summary of test results

50% Split Horizon (.469 mi.)	Tree/Power Lines (.493 mi.)	Clear Line of Sight (.667 mi.)
770.18 Kbps	1105.92 Kbps	1361.92 Kbps
1034.24 Kbps	1126.40 Kbps	1269.76 Kbps
736.31 Kbps	1157.12 Kbps	1269.76 Kbps
804.38 Kbps	1136.64 Kbps	1208.32 Kbps
774.62 Kbps	947.39 Kbps	1146.88 Kbps

Appendix C - Antenna Comparison Results

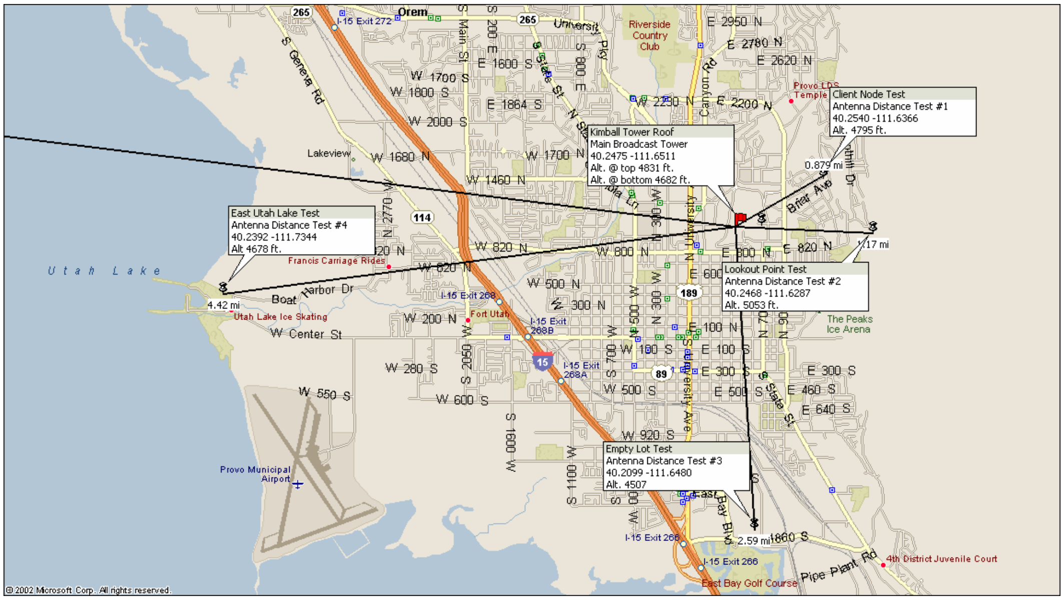

Figure C-1 Map of test point locations

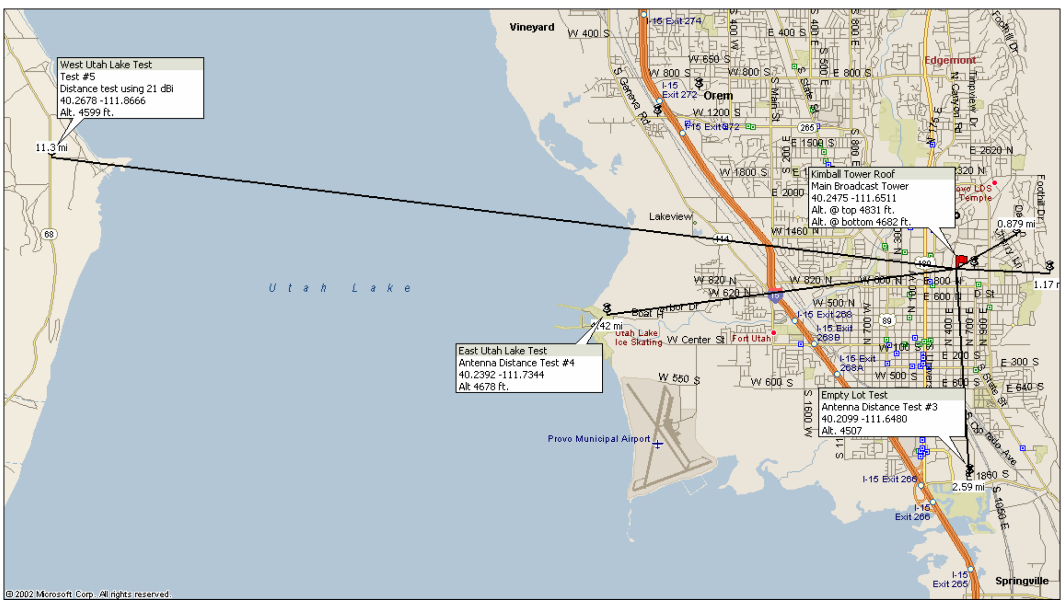

Figure C-2 Map showing distance of test point 5

Antenna Test points:
Main Uplink - Kimball tower
Alt. 4682 ft.

Test point #1 - Client Node
.879 mi. from Kimball tower
Alt 4795 ft. (~113 ft. above tower)

Test point #2 – Lookout Point
1.17 mi. from Kimball tower
Alt. 5053 ft. (~371 ft above tower)

Test point #3 – Empty Lot
2.59 mi. from Kimball tower
Alt. 4507 ft. (~175 ft. below tower)

Test point #4 – East Utah Lake
4.42 mi. from Kimball tower
Alt. 4678 ft. (~4 ft. below tower)

Test point #5 – West Utah Lake
11.3 mi. from Kimball tower
Alt. 4599 ft. (~83 ft. below tower)

C.1 Test Point 1 - Near Client Node

Figure C-3 Test point 1 (near client node) line of sight

C.1.1 13.5 dBi Cisco Yagi Test Results

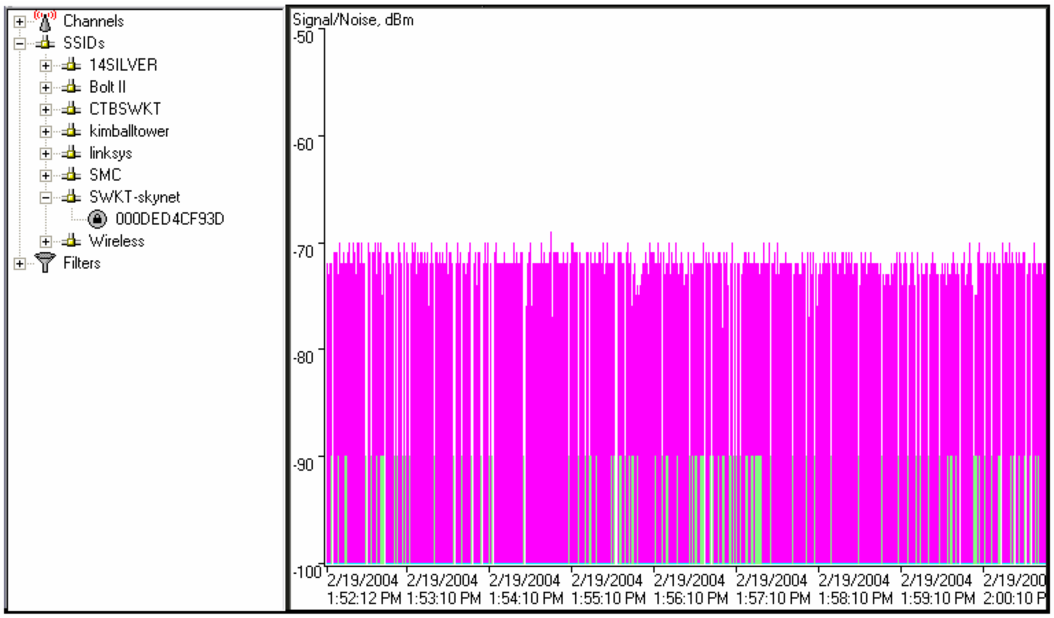

Figure C-4 Cisco Yagi (13.5 dBi) at test point 1 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 1 near client node (.879 miles)

Free space path loss @ 2.437 (channel 6): -103.22 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 13.5 dBi Yagi – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 40.75 dB

Total path calculation: -62.47 dB
Actual Measured: approx. -71 dB
Percent Error: 12.01%

13.5 dBi Cisco Yagi FTP Log

PASV
227 Entering Passive Mode (192,168,201,10,9,117).
connecting to 192.168.201.10:2421
- -

connecting to 192.168.201.10:2421
Connected to 192.168.201.10 port 2421
LIST
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 97.9 secs, **(753.33 Kbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
TYPE I
200 Type set to I.
PASV
227 Entering Passive Mode (192,168,201,10,9,122).
connecting to 192.168.201.10:2426
- -
connecting to 192.168.201.10:2426
Connected to 192.168.201.10 port 2426
Received 7679963 bytes in 72.1 secs, **(1.02 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
TYPE I
200 Type set to I.
PASV
227 Entering Passive Mode (192,168,201,10,9,124).
connecting to 192.168.201.10:2428
- -
connecting to 192.168.201.10:2428
Connected to 192.168.201.10 port 2428
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 68.8 secs, **(1.07 Mbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,9,130).
connecting to 192.168.201.10:2434
- -
connecting to 192.168.201.10:2434
Connected to 192.168.201.10 port 2434
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 34.6 secs, **(954.34 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe

PASV
227 Entering Passive Mode (192,168,201,10,9,133).
connecting to 192.168.201.10:2437
- -
connecting to 192.168.201.10:2437
Connected to 192.168.201.10 port 2437
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 41.2 secs, **(801.58 Kbps)**, transfer succeeded
226 Transfer complete.

13.5 dBi Cisco Ping Times

Ping statistics for 192.168.201.10:
    Packets: Sent = 500, Received = 430, Lost = 70 (14% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 930ms, Average = 53ms

C.1.2 14 dBi Echo Backfire Test Results

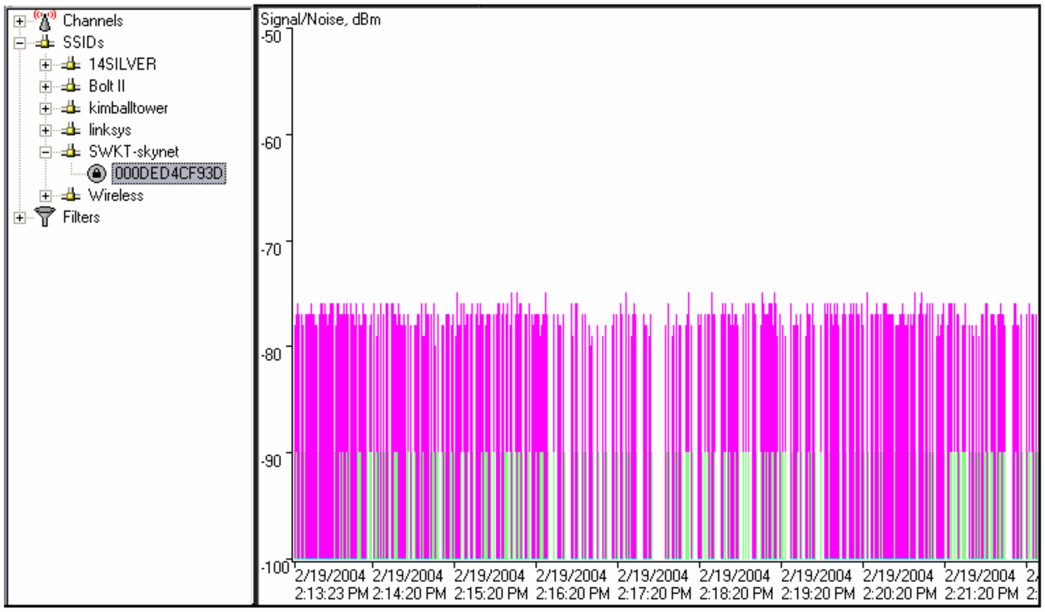

Figure C-5 Echo Backfire (14 dBi) at test point 1 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 1 near client node (.879 miles)

Free space path loss @ 2.437 (channel 6): -103.22 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 14 dBi Echo Backfire – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 41.25 dB

Total path calculation: -61.97 dB
Actual Measured: approx. -77 dB
Percent Error: 19.52%

14 dBi Echo Backfire FTP Results

- -
connecting to 192.168.201.10:2481
Connected to 192.168.201.10 port 2481
LIST
125 Data connection already open; Transfer starting.
Received 215 bytes in 0.1 secs, (18.18 Kbps), transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
TYPE I
200 Type set to I.
PASV
227 Entering Passive Mode (192,168,201,10,9,179).
connecting to 192.168.201.10:2483
- -
connecting to 192.168.201.10:2483
Connected to 192.168.201.10 port 2483
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 157.8 secs, **(209.08 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
+ Same verison of kazaalite243.exe already exists!
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,9,192).
connecting to 192.168.201.10:2496
- -

connecting to 192.168.201.10:2496
Connected to 192.168.201.10 port 2496
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 172.5 secs, **(191.32 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,9,205).

connecting to 192.168.201.10:2509
- -
connecting to 192.168.201.10:2509
Connected to 192.168.201.10 port 2509
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 226.0 secs, **(146.05 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,9,223).
connecting to 192.168.201.10:2527
- -
connecting to 192.168.201.10:2527
Connected to 192.168.201.10 port 2527
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 274.9 secs, **(120.07 Kbps)**, transfer succeeded
226 Transfer complete.

<u>14 dBi Echo Backfire Ping Tests</u>

Ping statistics for 192.168.201.10:
    Packets: Sent = 50, Received = 34, Lost = 16 (32% loss),
Approximate round trip times in milli-seconds:
    Minimum = 6ms, Maximum = 858ms, Average = 140ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 100, Received = 57, Lost = 43 (43% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 447ms, Average = 77ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 50, Received = 32, Lost = 18 (36% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 477ms, Average = 69ms

C.1.3 15 dBi Parabolic Grid Dish

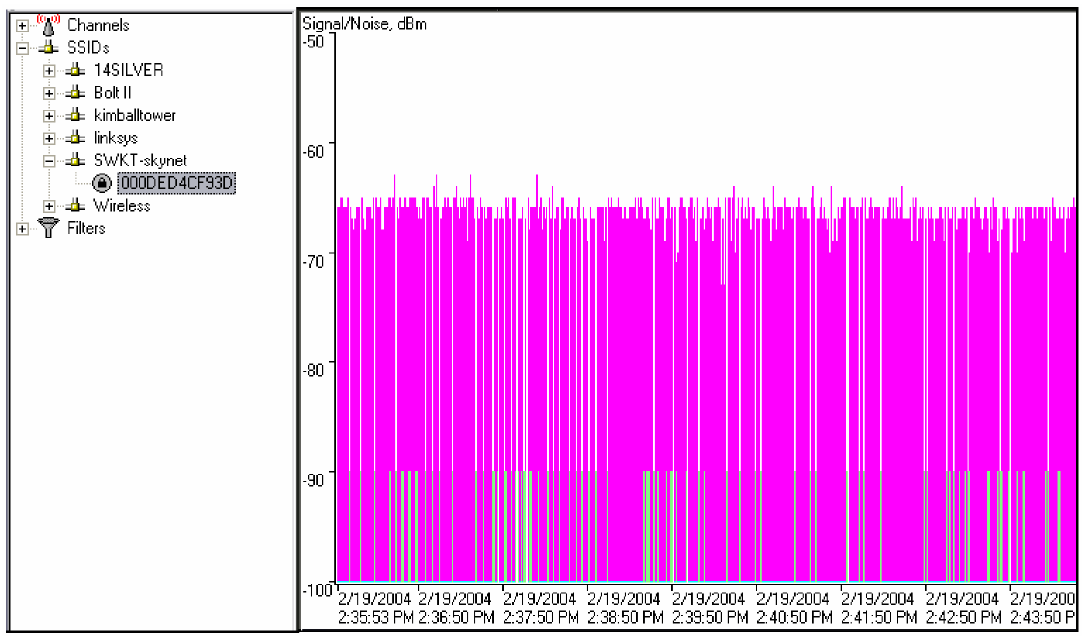

Figure C-6 Parabolic Dish (15 dBi) at test point 1 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 1 near client node (.879 miles)

Free space path loss @ 2.437 (channel 6): -103.22 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 15 dBi Dish – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 42.25 dB

Total path calculation: -60.97 dB
Actual Measured: approx. -66 dB
Percent Error: 7.62%

15 dBi Parabolic Dish FTP Results

receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,10,36).
connecting to 192.168.201.10:2596
- -
connecting to 192.168.201.10:2596
Connected to 192.168.201.10 port 2596
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 33.0 secs, **(1000.42 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,10,39).
connecting to 192.168.201.10:2599
- -
connecting to 192.168.201.10:2599
Connected to 192.168.201.10 port 2599
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 29.0 secs, **(1.11 Mbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,10,43).
connecting to 192.168.201.10:2603
- -
connecting to 192.168.201.10:2603
Connected to 192.168.201.10 port 2603
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 29.5 secs, **(1.09 Mbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,10,48).
connecting to 192.168.201.10:2608
- -
connecting to 192.168.201.10:2608
Connected to 192.168.201.10 port 2608

RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 38.5 secs, **(857.73 Kbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,10,57).
connecting to 192.168.201.10:2617
- -
connecting to 192.168.201.10:2617
Connected to 192.168.201.10 port 2617
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 89.4 secs, **(842.60 Kbps)**, transfer succeeded
226 Transfer complete.

15 dBi Parabolic Dish Ping Results

Ping statistics for 192.168.201.10:
  Packets: Sent = 300, Received = 268, Lost = 32 (10% loss),
Approximate round trip times in milli-seconds:
  Minimum = 4ms, Maximum = 395ms, Average = 39ms

C.1.4 16 dBi Vagi Test Results

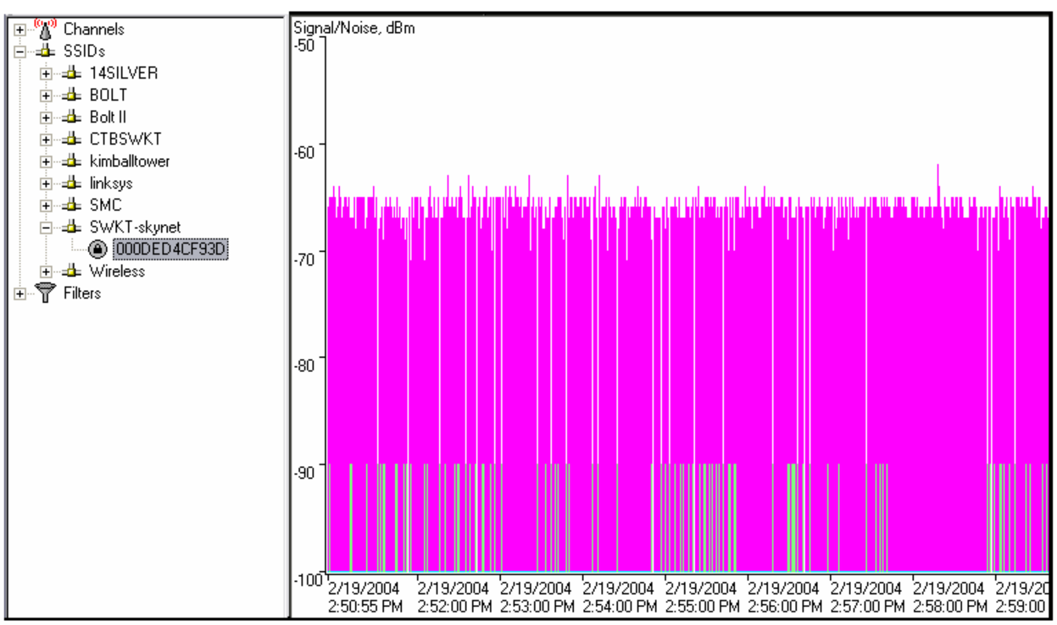

Figure C-7 Vagi (16 dBi) at test point 1 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 1 near client node (.879 miles)

Free space path loss @ 2.437 (channel 6): -103.22 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 16 dBi Vagi – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 43.25 dB

Total path calculation: -59.97 dB
Actual Measured: approx. -65 dB
Percent Error: 7.73%

16 dBi Vagi FTP Results

Saving restart info for CTB FTP - userGuide.pdf
PASV
227 Entering Passive Mode (192,168,201,10,10,132).
connecting to 192.168.201.10:2692
- -
connecting to 192.168.201.10:2692
Connected to 192.168.201.10 port 2692
RETR userGuide.pdf
125 Data connection already open; Transfer starting.
Received 5886444 bytes in 39.4 secs, **(1.43 Mbps)**, transfer succeeded
226 Transfer complete.
receiving userGuide.pdf as userGuide.pdf (1 of 1)
Saving restart info for CTB FTP - userGuide.pdf
PASV
227 Entering Passive Mode (192,168,201,10,10,136).
connecting to 192.168.201.10:2696
- -
connecting to 192.168.201.10:2696
Connected to 192.168.201.10 port 2696
RETR userGuide.pdf
125 Data connection already open; Transfer starting.
Received 5886444 bytes in 49.1 secs, **(1.15 Mbps)**, transfer succeeded
226 Transfer complete.
receiving userGuide.pdf as userGuide.pdf (1 of 1)
Saving restart info for CTB FTP - userGuide.pdf
PASV
227 Entering Passive Mode (192,168,201,10,10,141).
connecting to 192.168.201.10:2701

- -
connecting to 192.168.201.10:2701
Connected to 192.168.201.10 port 2701
RETR userGuide.pdf
125 Data connection already open; Transfer starting.
Received 5886444 bytes in 43.0 secs, **(1.31 Mbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,10,147).
connecting to 192.168.201.10:2707
- -
connecting to 192.168.201.10:2707
Connected to 192.168.201.10 port 2707
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 19.6 secs, **(1.64 Mbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,10,176).
connecting to 192.168.201.10:2736
- -
connecting to 192.168.201.10:2736
Connected to 192.168.201.10 port 2736
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 21.8 secs, **(1.48 Mbps)**, transfer succeeded
226 Transfer complete.

16 dBi Vagi Ping Test Results

Ping statistics for 192.168.201.10:
    Packets: Sent = 300, Received = 284, Lost = 16 (5% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 280ms, Average = 36ms

C.1.5 19 dBi Wire Grid Parabolic Dish Test Results

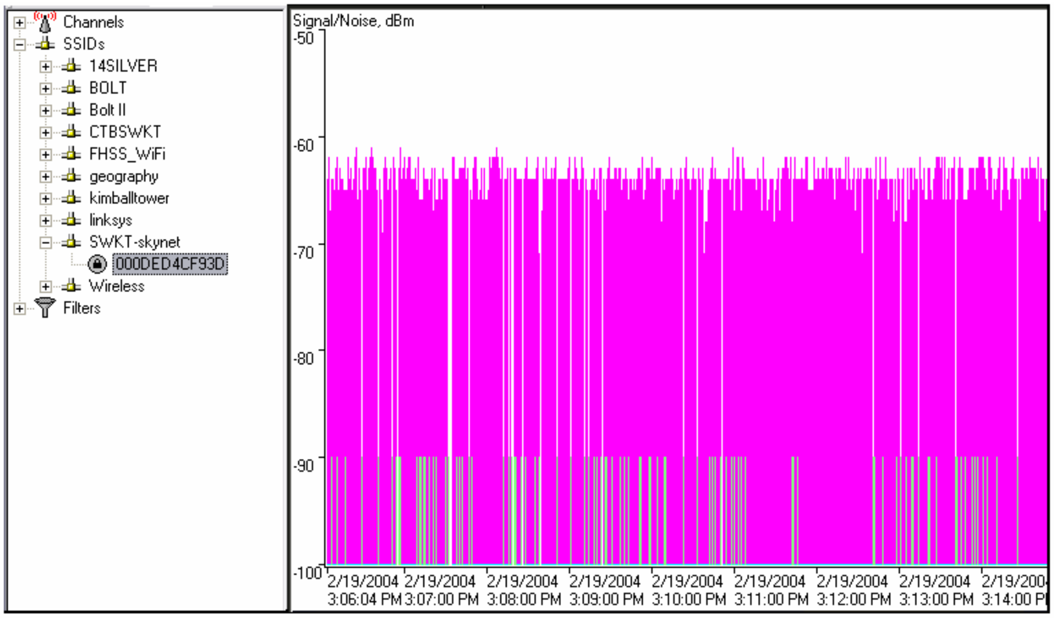

Figure C-8 Wire Grid Parabolic Dish (19 dBi) at test point 1 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 1 near client node (.879 miles)

Free space path loss @ 2.437 (channel 6): -103.22 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 19 dBi Vagi – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 45.25 dB

Total path calculation: -57.97 dB
Actual Measured: approx. -63 dB
Percent Error: 7.98%

19 dBi Parabolic Dish FTP Results

receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for CTB FTP - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,10,198).
connecting to 192.168.201.10:2758

- -
connecting to 192.168.201.10:2758
Connected to 192.168.201.10 port 2758
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 46.7 secs, **(1.57 Mbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,10,199).
connecting to 192.168.201.10:2759
- -
connecting to 192.168.201.10:2759
Connected to 192.168.201.10 port 2759
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 20.5 secs, **(1.57 Mbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,10,200).
connecting to 192.168.201.10:2760
- -
connecting to 192.168.201.10:2760
Connected to 192.168.201.10 port 2760
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 19.0 secs, **(1.70 Mbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,10,201).
connecting to 192.168.201.10:2761
- -
connecting to 192.168.201.10:2761
Connected to 192.168.201.10 port 2761
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 19.1 secs, **(1.68 Mbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV

227 Entering Passive Mode (192,168,201,10,10,202).
connecting to 192.168.201.10:2762
- -
connecting to 192.168.201.10:2762
Connected to 192.168.201.10 port 2762
RETR kazaalite243.exe
Received 3366186 bytes in 21.3 secs, **(1.51 Mbps)**, transfer succeeded
226 Transfer complete.

<u>19 dBi Wire Grid Parabolic Dish Ping Results</u>

Ping statistics for 192.168.201.10:
    Packets: Sent = 300, Received = 281, Lost = 19 (6% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 201ms, Average = 42ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 50, Received = 47, Lost = 3 (6% loss)
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 118ms, Average = 19ms

C.2 Test Point 2 – Lookout Point

Figure C-9 Test point 2 – lookout point line of sight

C.2.1 13.5 dBi Cisco Yagi Test Results

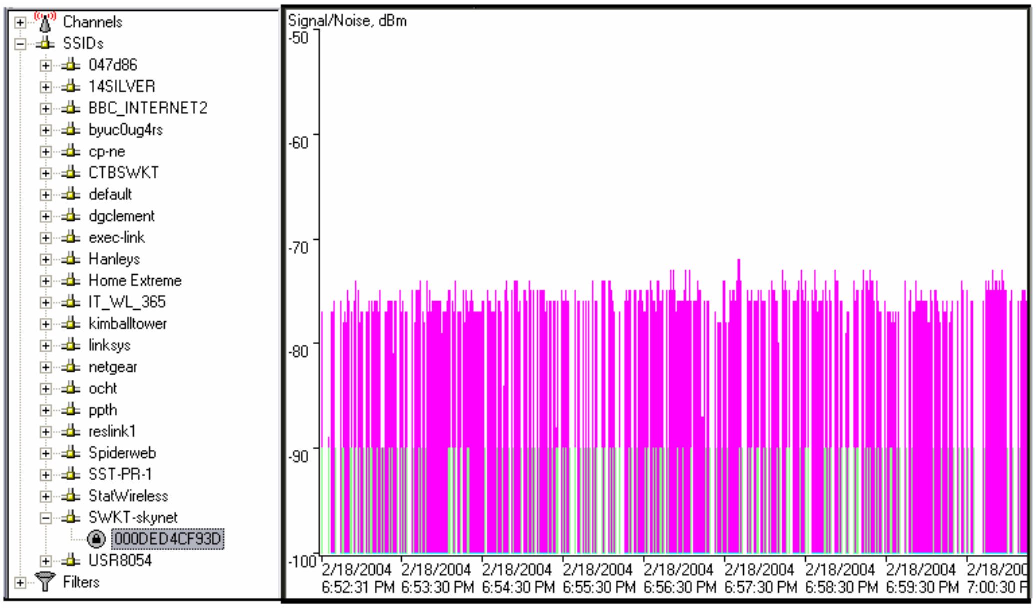

Figure C-10 Cisco Yagi (13.5 dBi) at test point 2 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 2 Lookout point (1.17 miles)

Free space path loss @ 2.437 (channel 6): -105.7 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 13.5 dBi Yagi – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 40.75 dB

Total path calculation: -64.95 dB
Actual Measured: approx. -78 dB
Percent Error: 16.73%

13.5 dBi Cisco Yagi FTP Results

receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,89).
connecting to 192.168.201.10:1113
- -

connecting to 192.168.201.10:1113
Connected to 192.168.201.10 port 1113
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 202.5 secs, **(162.99 Kbps)**, transfer succeeded
226 Transfer complete.

receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,121).
connecting to 192.168.201.10:1145
- -
connecting to 192.168.201.10:1145
Connected to 192.168.201.10 port 1145
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
! Receive error: connection reset
Received 1740484 bytes in 105.1 secs, **(162.30 Kbps)**, transfer succeeded
! Receive error: connection reset
- -
connecting to 192.168.201.10:1202
Connected to 192.168.201.10 port 1202
REST 1739776
350 Restarting at 1739776.
RETR /kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 1626410 bytes in 139.8 secs, **(114.06 Kbps),** transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
! Send error: connection reset
! Receive error: connection reset

PORT 0,0,0,0,12,146
! Send error: connection reset
! Receive error: connection reset

! Failed "port":
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
! Send error: connection reset
! Receive error: connection reset

PORT 0,0,0,0,12,153
! Send error: connection reset
! Receive error: connection reset

! Failed "port":
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
! Send error: connection reset
! Receive error: connection reset

PORT 0,0,0,0,12,154
! Send error: connection reset

13.5 dBi Cisco Yagi Ping Results

No ping results recorded – Connection Failed

C.2.2 14 dBi Echo Backfire Test Results

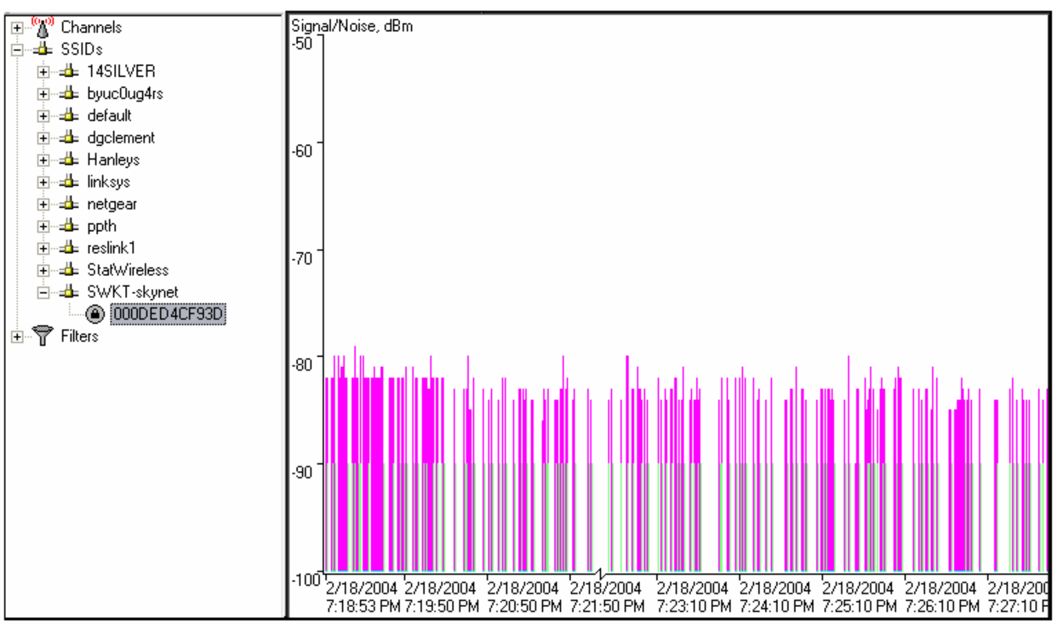

Figure C-11 Echo Backfire (14 dBi) at test point 2 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 2 Lookout point (1.17 miles)

Free space path loss @ 2.437 (channel 6): -105.7 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 14 dBi Echo Backfire – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 41.25 dB

Total path calculation: -64.45 dB
Actual Measured: approx. -85 dB
Percent Error: 24.18%

14 dBi Echo Backfire FTP Results

Link could not be maintained long enough to open FTP session. Link failed.

14 dBi Echo Backfire Ping Results

Connection so weak that only 3/20 pings responded.

C.2.3 15 dBi Wire Grid Parabolic Dish Test Results

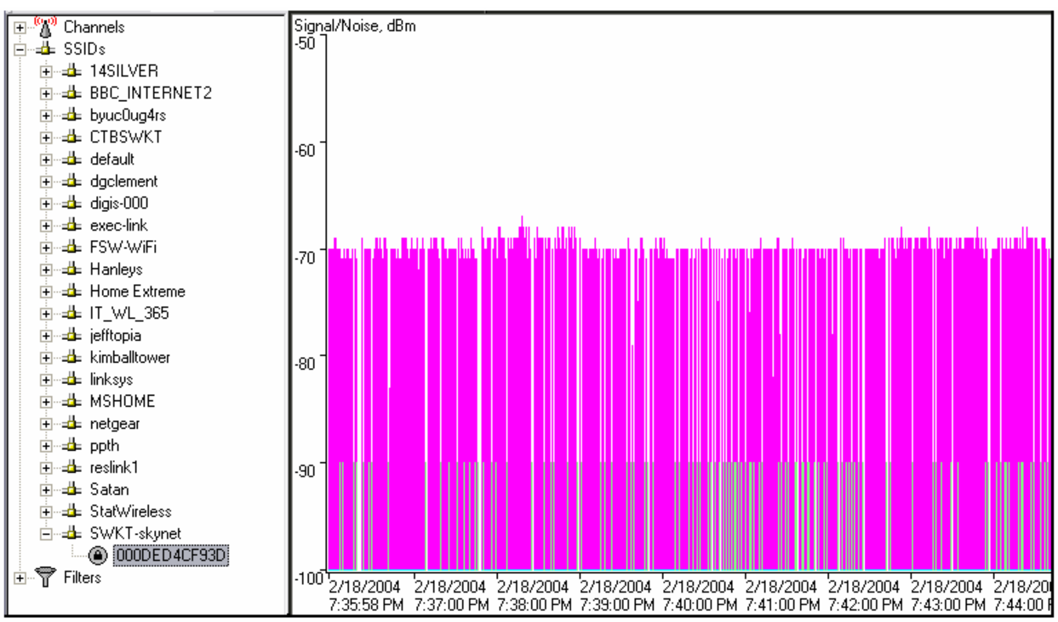

Figure C-12 Wire grid parabolic dish (15 dBi) at test point 2 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 2 Lookout point (1.17 miles)

Free space path loss @ 2.437 (channel 6): -105.7 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 15 dBi Dish – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 42.25 dB

Total path calculation: -63.45 dB
Actual Measured: approx. -70 dB
Percent Error: 9.36%

15 dBi Wire Grid Parabolic Dish FTP Results

Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,5,87).
connecting to 192.168.201.10:1367
- -
connecting to 192.168.201.10:1367
Connected to 192.168.201.10 port 1367
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 74.7 secs, **(441.62 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,5,93).
connecting to 192.168.201.10:1373
- -
connecting to 192.168.201.10:1373
Connected to 192.168.201.10 port 1373
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 91.9 secs, **(359.09 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,5,102).
connecting to 192.168.201.10:1382
- -

connecting to 192.168.201.10:1382
Connected to 192.168.201.10 port 1382
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 113.6 secs, **(290.47 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,5,111).
connecting to 192.168.201.10:1391
- -
connecting to 192.168.201.10:1391
Connected to 192.168.201.10 port 1391
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 83.9 secs, **(393.43 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,5,118).
connecting to 192.168.201.10:1398
- -
connecting to 192.168.201.10:1398
Connected to 192.168.201.10 port 1398
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 87.3 secs, **(378.17 Kbps)**, transfer succeeded
226 Transfer complete.

15 dBi Wire Grid Parabolic Dish Ping Results

Ping statistics for 192.168.201.10:
    Packets: Sent = 300, Received = 221, Lost = 79 (26% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 859ms, Average = 72ms

C.2.4 <u>16 dBi Vagi Test Results</u>

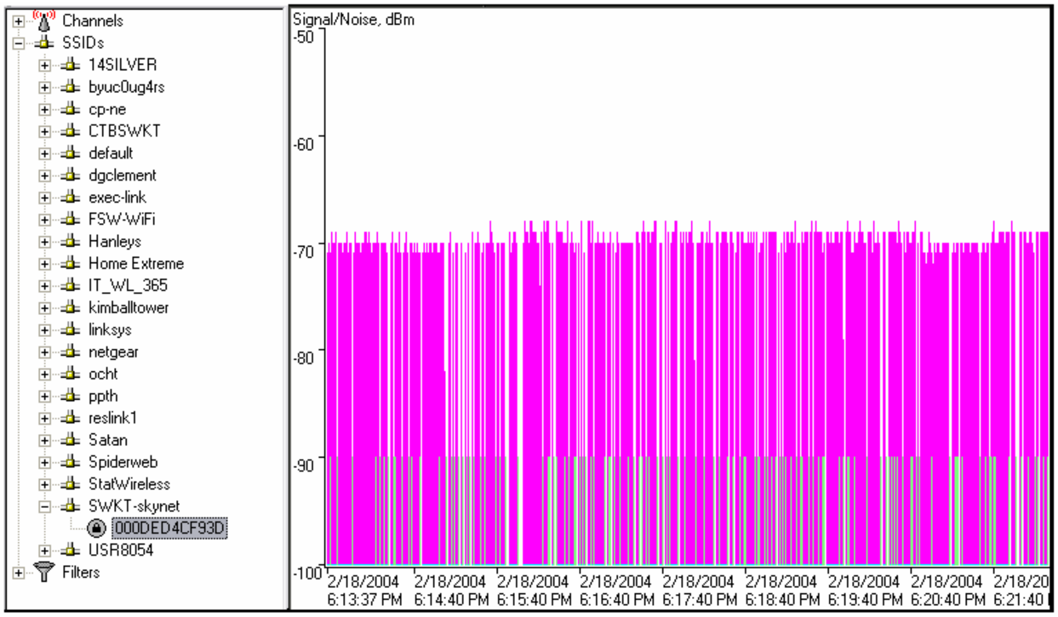

Figure C-13Vagi (16 dBi) at test point 2 SNR using NetStumbler

<u>Calculated Signal Gain and Path Loss:</u>

Kimball tower to Site 2 Lookout point (1.17 miles)

Free space path loss @ 2.437 (channel 6): <u>-105.7 dB</u>

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 16 dBi Vagi – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = <u>43.25 dB</u>

Total path calculation: <u>-62.45 dB</u>
Actual Measured: approx. <u>-69 dB</u>
Percent Error: <u>9.49%</u>

<u>16 dBi Vagi FTP Results</u>

200 Type set to I.
PASV
227 Entering Passive Mode (192,168,201,10,4,19).
connecting to 192.168.201.10:1043
- -
connecting to 192.168.201.10:1043
Connected to 192.168.201.10 port 1043

RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 301.8 secs, **(249.44 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,20).
connecting to 192.168.201.10:1044
- -
connecting to 192.168.201.10:1044
Connected to 192.168.201.10 port 1044
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 70.2 secs, **(469.96 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,21).
connecting to 192.168.201.10:1045
- -
connecting to 192.168.201.10:1045
Connected to 192.168.201.10 port 1045
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 154.5 secs, **(213.67 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,22).
connecting to 192.168.201.10:1046
- -
connecting to 192.168.201.10:1046
Connected to 192.168.201.10 port 1046
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 90.9 secs, **(363.24 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,23).
connecting to 192.168.201.10:1047
- -

connecting to 192.168.201.10:1047
Connected to 192.168.201.10 port 1047
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 142.1 secs, **(232.30 Kbps)**, transfer succeeded
226 Transfer complete.

16 dBi Vagi Ping Results

Ping statistics for 192.168.201.10:
  Packets: Sent = 300, Received = 267, Lost = 33 (10% loss),
Approximate round trip times in milli-seconds:
  Minimum = 5ms, Maximum = 393ms, Average = 34ms

C.2.5 19 dBi Wire Grid Parabolic Dish Test Results

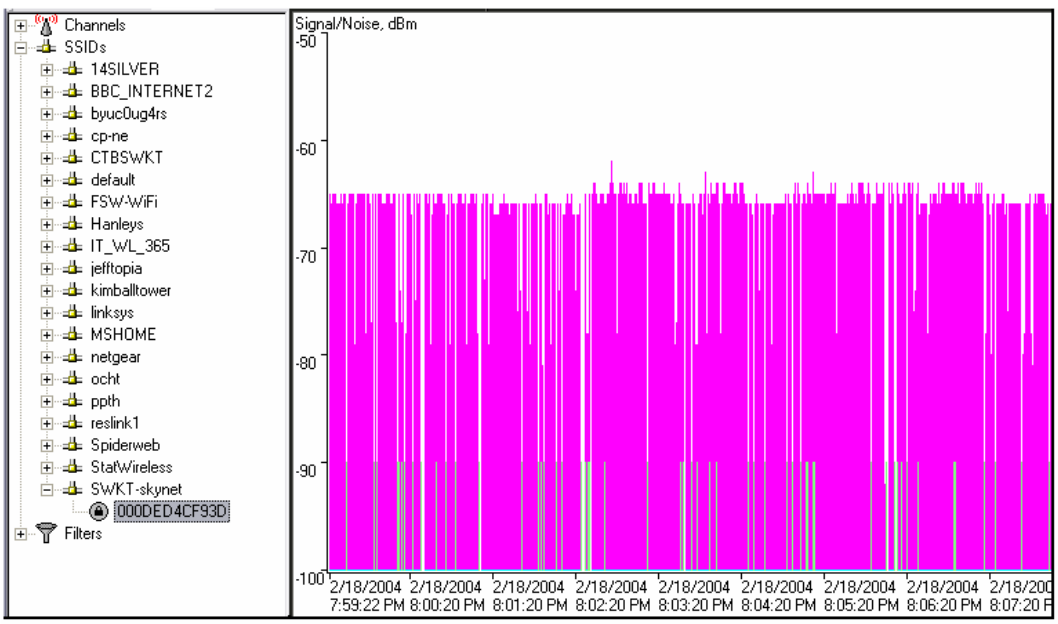

Figure C-14 Wire grid parabolic dish (19 dBi) at test point 2 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 2 Lookout point (1.17 miles)

Free space path loss @ 2.437 (channel 6): -105.7 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 19 dBi Dish – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 45.25 dB

Total path calculation: -60.45 dB
Actual Measured: approx. -65 dB
Percent Error: 7.00%

19 dBi Wire Grid Parabolic Dish FTP Results

Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,5,231).
connecting to 192.168.201.10:1511
- -
connecting to 192.168.201.10:1511
Connected to 192.168.201.10 port 1511
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 40.2 secs, **(821.17 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,5,237).
connecting to 192.168.201.10:1517
- -
connecting to 192.168.201.10:1517
Connected to 192.168.201.10 port 1517
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 37.9 secs, **(869.96 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,5,241).
connecting to 192.168.201.10:1521
- -
connecting to 192.168.201.10:1521
Connected to 192.168.201.10 port 1521
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 49.7 secs, **(663.98 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)

Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,5,246).
connecting to 192.168.201.10:1526
- -
connecting to 192.168.201.10:1526
Connected to 192.168.201.10 port 1526
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 39.8 secs, **(828.82 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,5,252).
connecting to 192.168.201.10:1532
- -
connecting to 192.168.201.10:1532
Connected to 192.168.201.10 port 1532
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 41.8 secs, **(796.78 Kbps)**, transfer succeeded
226 Transfer complete.

19 dBi Wire Grid Parabolic Dish Ping Results

Ping statistics for 192.168.201.10:
    Packets: Sent = 105, Received = 102, Lost = 3 (2% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 572ms, Average = 46ms

C.3 Test Point 3 – Empty Lot

Figure C-15 Test point 3 empty lot line of sight

C.3.1 13.5 dBi Cisco Yagi Test Results

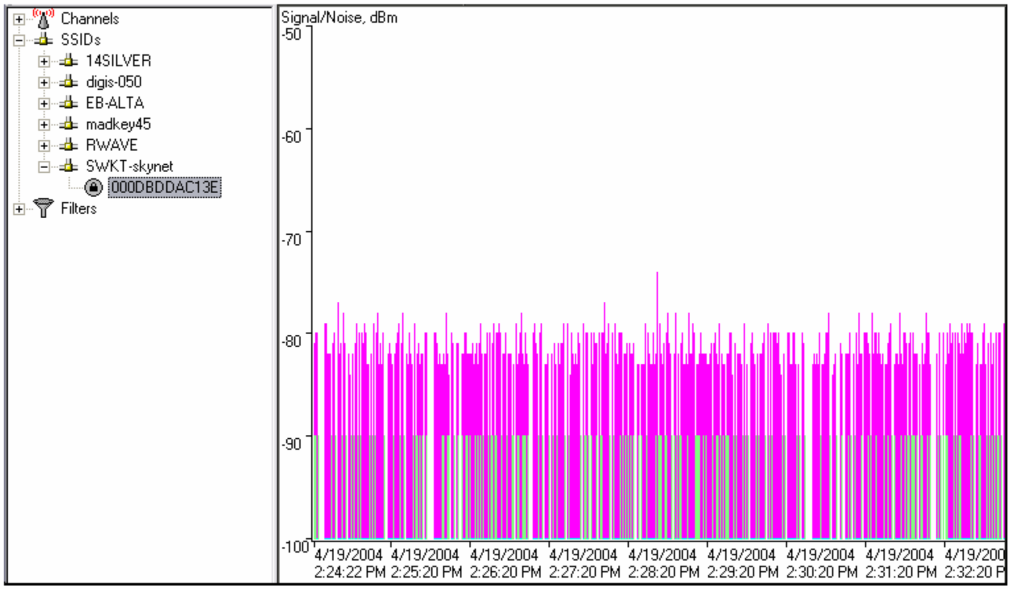

Figure C-16 Cisco Yagi (13.5 dBi) at test point 3 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 3 Empty Lot (2.59 miles)

Free space path loss @ 2.437 (channel 6): -112.60 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 13.5 dBi Yagi – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 40.75 dB

Total path calculation: -71.85 dB
Actual Measured: approx. -82 dB
Percent Error: 12.38%

13.5 dBi Cisco Yagi FTP Results

Note: Connection stayed up only long enough for two tests

SYST
215 Windows_NT
Host type (S): Microsoft NT
PASV
227 Entering Passive Mode (192,168,201,10,7,233).
connecting to 192.168.201.10:2025
- -
connecting to 192.168.201.10:2025
Connected to 192.168.201.10 port 2025
LIST
125 Data connection already open; Transfer starting.
Received 206 bytes in 0.1 secs, (20.00 Kbps), transfer succeeded
226 Transfer complete.
receiving fepdense.bin as fepdense.bin (1 of 1)
Saving restart info for BYU - fepdense.bin
TYPE I
200 Type set to I.
PASV
227 Entering Passive Mode (192,168,201,10,7,234).
connecting to 192.168.201.10:2026
- -
connecting to 192.168.201.10:2026
Connected to 192.168.201.10 port 2026
RETR fepdense.bin
125 Data connection already open; Transfer starting.
Received 1941504 bytes in 767.0 secs, **(24.82 Kbps)**, transfer succeeded
226 Transfer complete.

sending WS_FTP.LOG as WS_FTP.LOG (1 of 1)
PASV
227 Entering Passive Mode (192,168,201,10,7,235).
connecting to 192.168.201.10:2027
connecting to 192.168.201.10:2027
Connected to 192.168.201.10 port 2027
STOR WS_FTP.LOG
550 WS_FTP.LOG: Access is denied.
receiving fepdense.bin as fepdense.bin (1 of 1)
+ Same verison of fepdense.bin already exists!
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
PASV

227 Entering Passive Mode (192,168,201,10,7,236).
connecting to 192.168.201.10:2028
- -
connecting to 192.168.201.10:2028
Connected to 192.168.201.10 port 2028
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 896.9 secs, **(13.41 Kbps)**, transfer succeeded
226 Transfer complete.

13.5 dBi Cisco Yagi Ping Results

Ping statistics for 192.168.201.10:
Packets: Sent = 300, Received = 245, Lost = 55 (18% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 641ms, Average = 60ms

Ping statistics for 192.168.201.10:
Packets: Sent = 300, Received = 243, Lost = 57 (19% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 621ms, Average = 34ms

Ping statistics for 192.168.201.10:
Packets: Sent = 300, Received = 228, Lost = 72 (24% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 499ms, Average = 34ms

Ping statistics for 192.168.201.10:
Packets: Sent = 200, Received = 175, Lost = 25 (12% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 898ms, Average = 54ms

C.3.2 14 dBi Echo Backfire Test Results

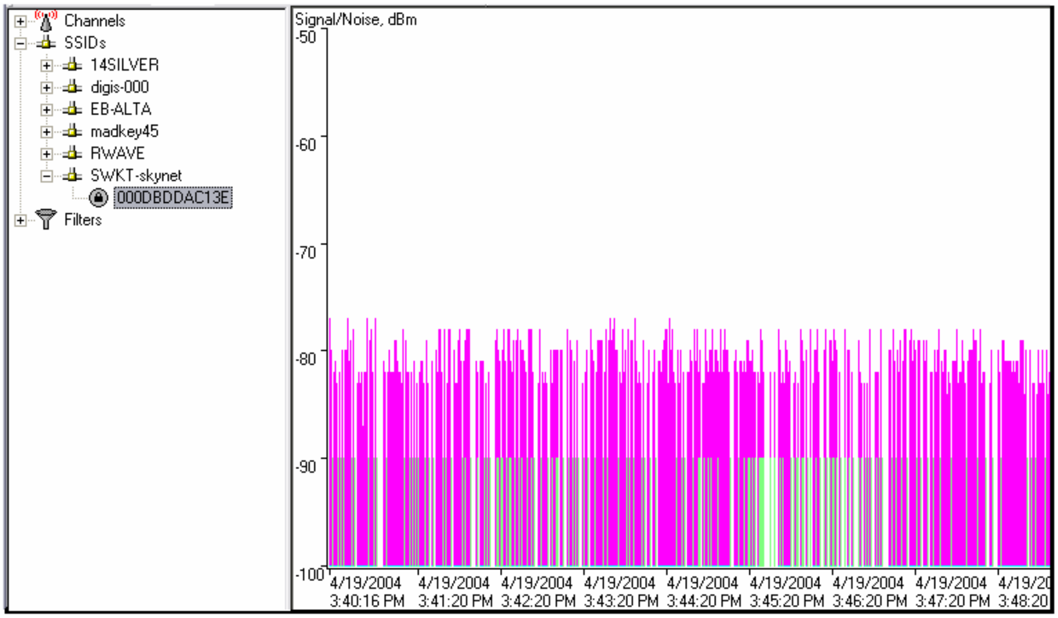

Figure C-17 Echo backfire (14 dBi) at test point 3 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 3 Empty Lot (2.59 miles)

Free space path loss @ 2.437 (channel 6): -112.60 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 14 dBi Echo Backfire – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 41.25 dB

Total path calculation: -71.35 dB
Actual Measured: approx. -82 dB
Percent Error: 12.99%

14 dBi Echo Backfire FTP Results

227 Entering Passive Mode (192,168,201,10,7,241).
connecting to 192.168.201.10:2033
- -
connecting to 192.168.201.10:2033
Connected to 192.168.201.10 port 2033
LIST

125 Data connection already open; Transfer starting.
Received 206 bytes in 0.1 secs, (20.00 Kbps), transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
TYPE I
200 Type set to I.
PASV
227 Entering Passive Mode (192,168,201,10,7,242).
connecting to 192.168.201.10:2034
- -
connecting to 192.168.201.10:2034
Connected to 192.168.201.10 port 2034
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 173.6 secs, **(69.29 Kbps)**, transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
PASV
227 Entering Passive Mode (192,168,201,10,7,243).
connecting to 192.168.201.10:2035
- -
connecting to 192.168.201.10:2035
Connected to 192.168.201.10 port 2035
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 210.8 secs, **(57.06 Kbps)**, transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
PASV
227 Entering Passive Mode (192,168,201,10,7,244).
connecting to 192.168.201.10:2036
- -

connecting to 192.168.201.10:2036
Connected to 192.168.201.10 port 2036
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 105.8 secs, **(113.76 Kbps)**, transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
PASV
227 Entering Passive Mode (192,168,201,10,7,245).

connecting to 192.168.201.10:2037
- -
connecting to 192.168.201.10:2037
Connected to 192.168.201.10 port 2037
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 184.9 secs, **(65.06 Kbps)**, transfer succeeded
226 Transfer complete.

14 dBi Echo Backfire Ping Results

Ping statistics for 192.168.201.10:
Packets: Sent = 200, Received = 164, Lost = 36 (18% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 667ms, Average = 67ms

Ping statistics for 192.168.201.10:
Packets: Sent = 200, Received = 162, Lost = 38 (19% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 452ms, Average = 26ms

C.3.3 15 dBi Wire Grid Parabolic Dish Test Results

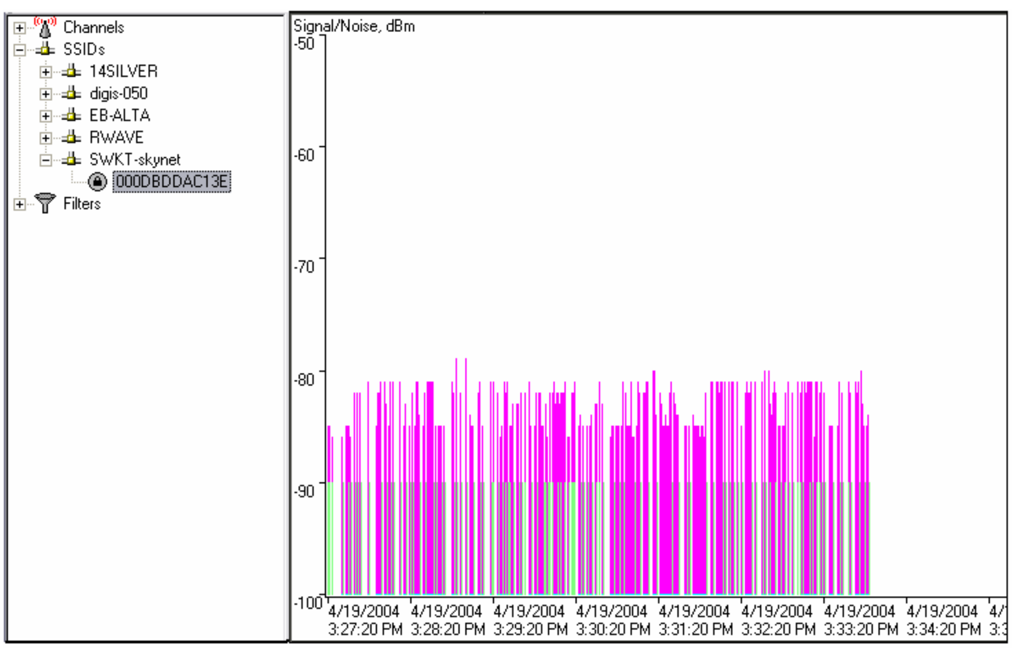

Figure C-18 Wire grid parabolic dish (15 dBi) at test point 3 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 3 Empty Lot (2.59 miles)

Free space path loss @ 2.437 (channel 6): -112.60 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 15 dBi Dish – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 42.25 dB

Total path calculation: -70.35 dB
Actual Measured: approx. -84 dB
Percent Error: 16.25%

15 dBi Wire Grid Parabolic Dish FTP Results

No Test Available - Link Failed

15 dBi Wire Grid Parabolic Dish Ping Results

No Test Available - Link Failed

C.3.4 16 dBi Vagi Test Results

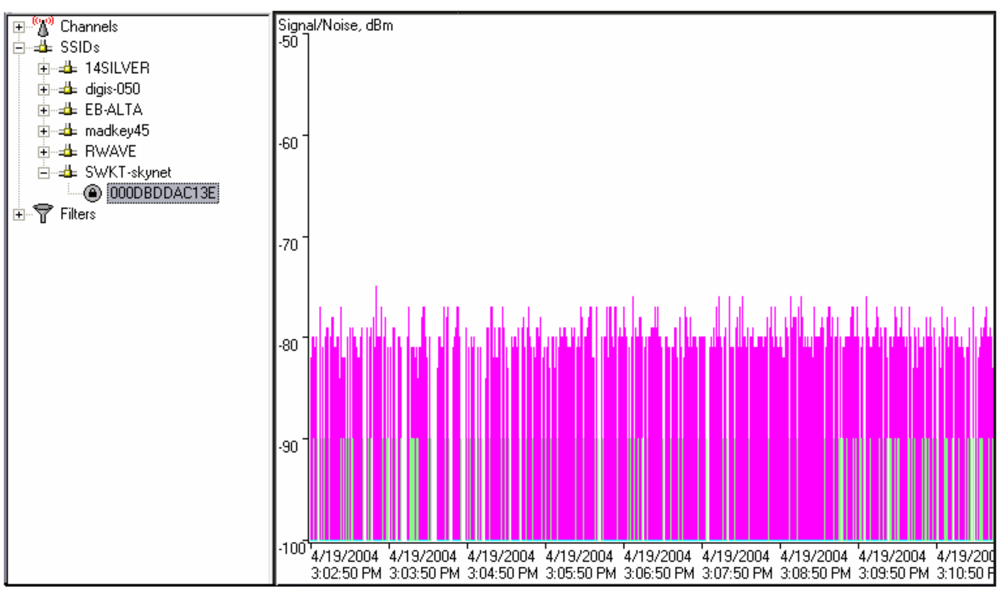

Figure C-19 Vagi (16 dBi) at test point 3 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 3 Empty Lot (2.59 miles)

Free space path loss @ 2.437 (channel 6): -112.60 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 16 dBi Vagi – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 43.25 dB

Total path calculation: -69.35 dB
Actual Measured: approx. -80 dB
Percent Error: 13.31%

16 dBi Vagi FTP Results

PASV
227 Entering Passive Mode (192,168,201,10,7,237).
connecting to 192.168.201.10:2029
- -
connecting to 192.168.201.10:2029
Connected to 192.168.201.10 port 2029
LIST
125 Data connection already open; Transfer starting.
Received 206 bytes in 0.1 secs, (20.00 Kbps), transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
TYPE I
200 Type set to I.
PASV
227 Entering Passive Mode (192,168,201,10,7,238).
connecting to 192.168.201.10:2030
- -
connecting to 192.168.201.10:2030
Connected to 192.168.201.10 port 2030
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 123.0 secs, **(97.80 Kbps)**, transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
PASV
227 Entering Passive Mode (192,168,201,10,7,239).

connecting to 192.168.201.10:2031
connecting to 192.168.201.10:2031
Connected to 192.168.201.10 port 2031
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 101.4 secs, **(118.66 Kbps)**, transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
PASV
227 Entering Passive Mode (192,168,201,10,7,240).
connecting to 192.168.201.10:2032
- -

connecting to 192.168.201.10:2032
Connected to 192.168.201.10 port 2032
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 106.0 secs, **(113.53 Kbps)**, transfer succeeded
226 Transfer complete.

<u>16 dBi Vagi Ping Results</u>

Ping statistics for 192.168.201.10:
    Packets: Sent = 200, Received = 164, Lost = 36 (18% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 667ms, Average = 67ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 200, Received = 162, Lost = 38 (19% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 452ms, Average = 26ms

C.3.5 19 dBi Wire Grid Parabolic Dish Test Results

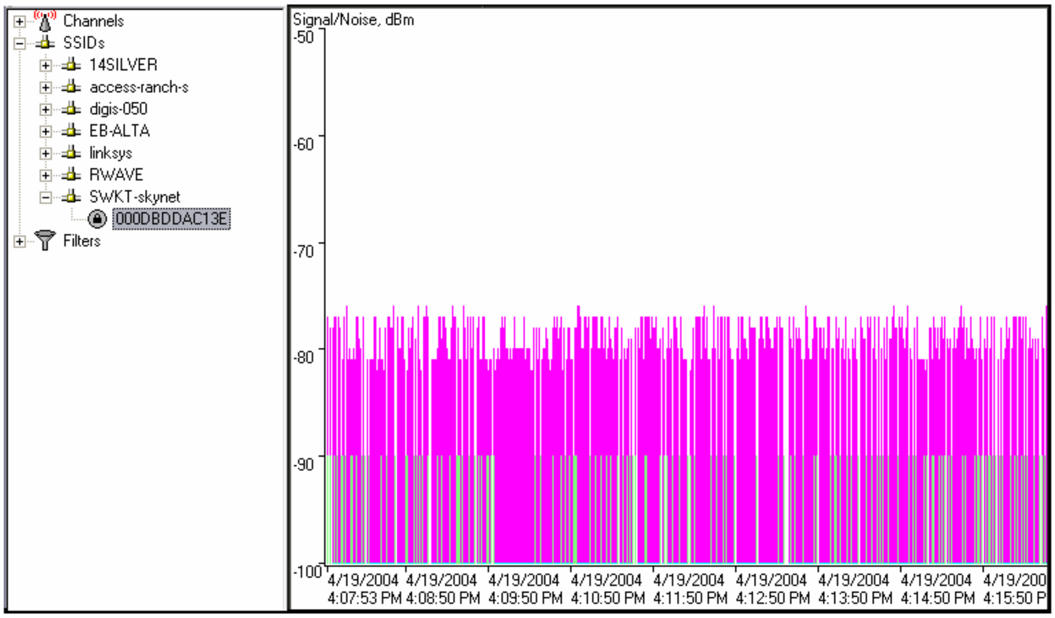

Figure C-20 Wire grid parabolic dish (19 dBi) at test point 3 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 3 Empty Lot (2.59 miles)

Free space path loss @ 2.437 (channel 6): -112.60 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 19 dBi Dish – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 45.25 dB

Total path calculation: -67.35 dB
Actual Measured: approx. -78 dB
Percent Error: 13.65%

19 dBi Wire Grid Parabolic Dish FTP Results

PASV
227 Entering Passive Mode (192,168,201,10,7,250).
connecting to 192.168.201.10:2042
- -
connecting to 192.168.201.10:2042
Connected to 192.168.201.10 port 2042

RETR fepdense.bin
125 Data connection already open; Transfer starting.
Received 1941504 bytes in 83.5 secs, **(227.84 Kbps)**, transfer succeeded
226 Transfer complete.
receiving fepdense.bin as fepdense.bin (1 of 1)
Saving restart info for BYU - fepdense.bin
PASV
227 Entering Passive Mode (192,168,201,10,7,251).
connecting to 192.168.201.10:2043
- -
connecting to 192.168.201.10:2043
Connected to 192.168.201.10 port 2043
RETR fepdense.bin
125 Data connection already open; Transfer starting.
Received 1941504 bytes in 95.8 secs, **(198.77 Kbps)**, transfer succeeded
226 Transfer complete.
receiving fepdense.bin as fepdense.bin (1 of 1)
Saving restart info for BYU - fepdense.bin
PASV
227 Entering Passive Mode (192,168,201,10,7,252).
connecting to 192.168.201.10:2044
- -
connecting to 192.168.201.10:2044
Connected to 192.168.201.10 port 2044
RETR fepdense.bin
125 Data connection already open; Transfer starting.
Received 1941504 bytes in 96.3 secs, **(197.63 Kbps)**, transfer succeeded
226 Transfer complete.
receiving fepdense.bin as fepdense.bin (1 of 1)
Saving restart info for BYU - fepdense.bin
PASV
227 Entering Passive Mode (192,168,201,10,7,253).
connecting to 192.168.201.10:2045
- -
connecting to 192.168.201.10:2045
Connected to 192.168.201.10 port 2045
RETR fepdense.bin
125 Data connection already open; Transfer starting.
Received 1941504 bytes in 60.7 secs, **(313.53 Kbps)**, transfer succeeded
226 Transfer complete.
receiving fepdense.bin as fepdense.bin (1 of 1)
+ Same verison of fepdense.bin already exists!
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,7,254).

connecting to 192.168.201.10:2046
- -
connecting to 192.168.201.10:2046
Connected to 192.168.201.10 port 2046
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 115.3 secs, **(297.00 Kbps)**, transfer succeeded
226 Transfer complete.

19 dBi Wire Grid Parabolic Dish FTP Results

Ping statistics for 192.168.201.10:
Packets: Sent = 200, Received = 179, Lost = 21 (10% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 502ms, Average = 103ms

Ping statistics for 192.168.201.10:
Packets: Sent = 200, Received = 166, Lost = 34 (17% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 287ms, Average = 65ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 92, Lost = 8 (8% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 16ms, Average = 7ms

C.4 Test Point 4 –East Side of Utah Lake

Figure C-21 East side of Utah Lake test location line of sight

C.4.1 13.5 dBi Cisco Yagi Test Results

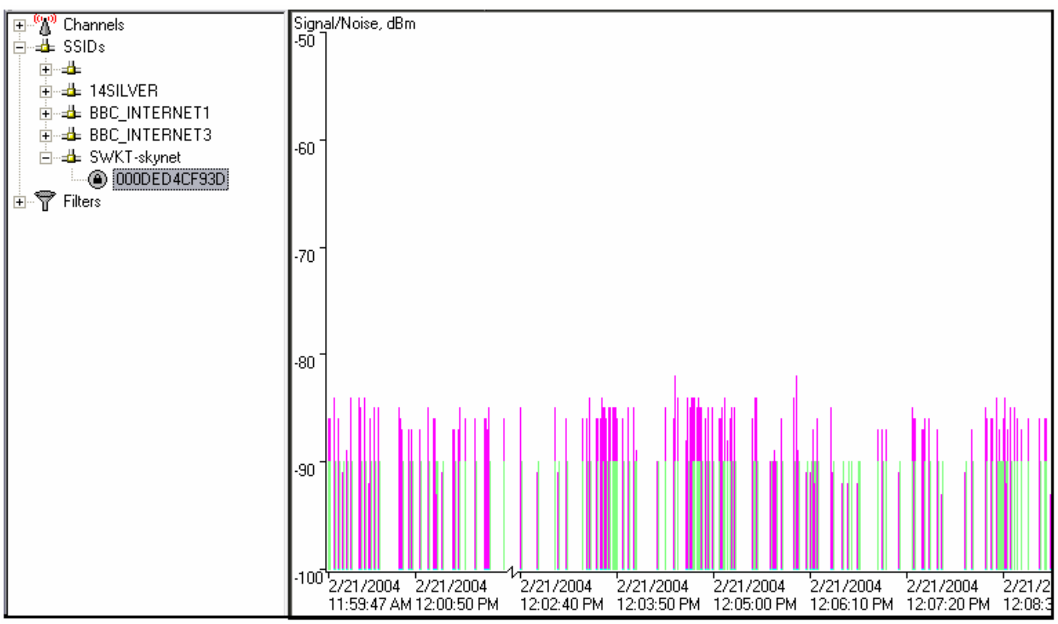

Figure C-22 Cisco Yagi (13.5 dBi) at test point 4 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 4 East side of Utah Lake (4.42 miles)

Free space path loss @ 2.437 (channel 6): -117.25 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 13.5 dBi Yagi – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 40.75 dB

Total path calculation: -76.5 dB
Actual Measured: approx. -88 dB
Percent Error: 13.07%

13.5 dBi Cisco Yagi FTP Results

No Test Performed – No Link Available

13.5 dBi Cisco Yagi Ping Results

No Test Performed – No Link Available

C.4.2 14 dBi Echo Backfire Test Results

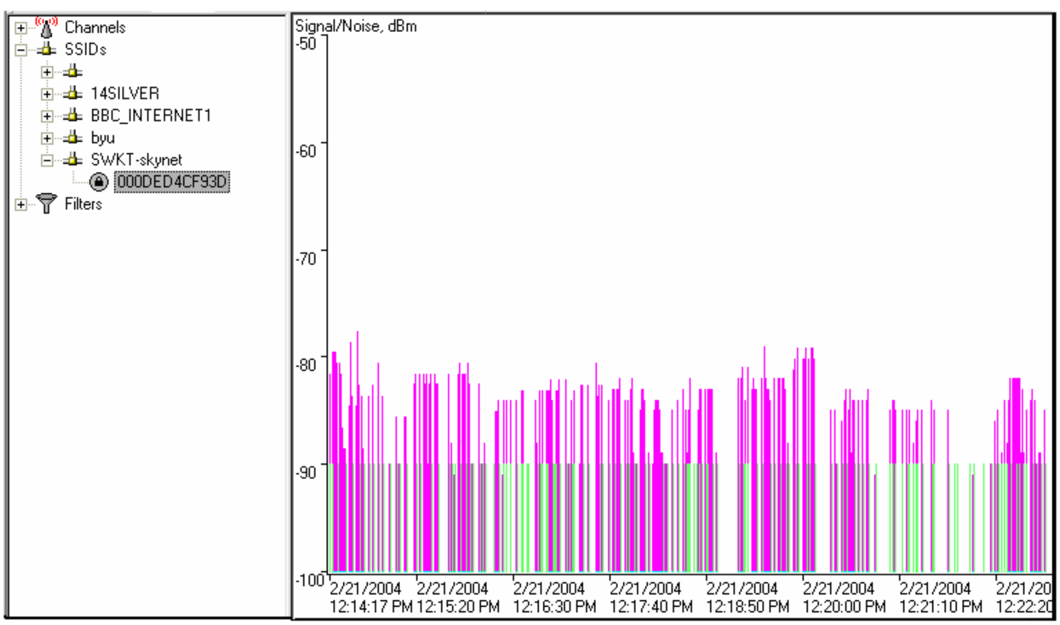

Figure C-23 Echo Backfire (14 dBi) at test point 4 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 4 East side of Utah Lake (4.42 miles)

Free space path loss @ 2.437 (channel 6): -117.25 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 14 dBi Echo Backfire – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 41.25 dB

Total path calculation: -76.0 dB
Actual Measured: approx. -85 dB
Percent Error: 10.58%

14 dBi Echo Backfire FTP Results

No Test Performed – No Link Available

14 dBi Echo Backfire Ping Results

No Test Performed – No Link Available

C.4.3 <u>15 dBi Wire Grid Parabolic Dish Test Results</u>

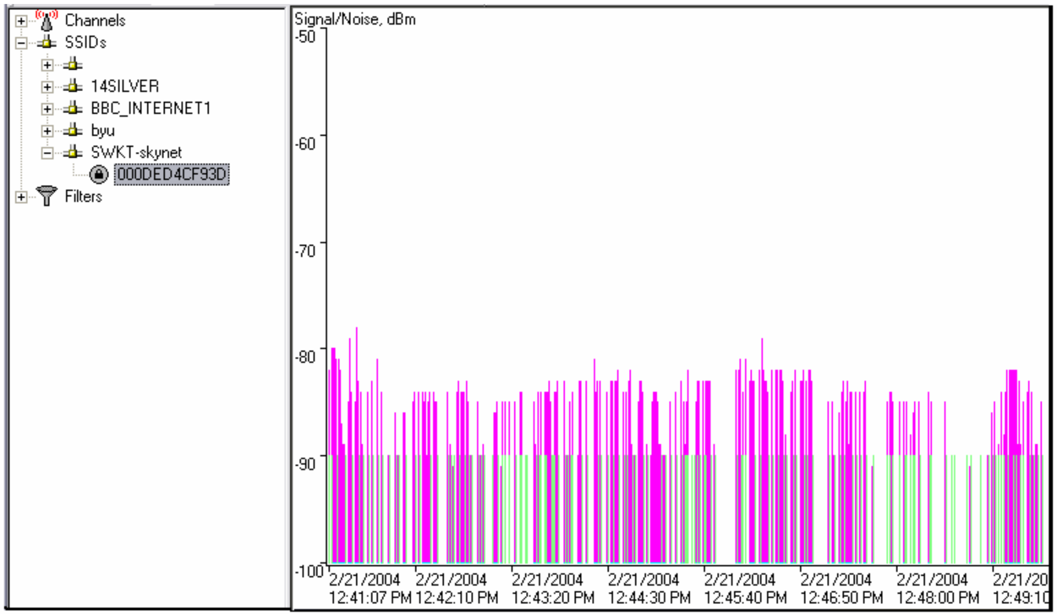

Figure C-24 Wire grid parabolic dish (15 dBi) at test point 4 SNR using NetStumbler

<u>Calculated Signal Gain and Path Loss:</u>

Kimball tower to Site 4 East side of Utah Lake (4.42 miles)

Free space path loss @ 2.437 (channel 6): <u>-117.25 dB</u>

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 15 dBi Dish – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = <u>42.25 dB</u>

Total path calculation: <u>-75.0 dB</u>
Actual Measured: approx. <u>-86 dB</u>
Percent Error: <u>12.79%</u>

<u>15 dBi Wire Grid Parabolic Dish FTP Results</u>

No link available – No test performed

<u>15 dBi Wire Grid Parabolic Dish Ping Results</u>

No link available – No test performed

C.4.4 16 dBi Vagi Test Results

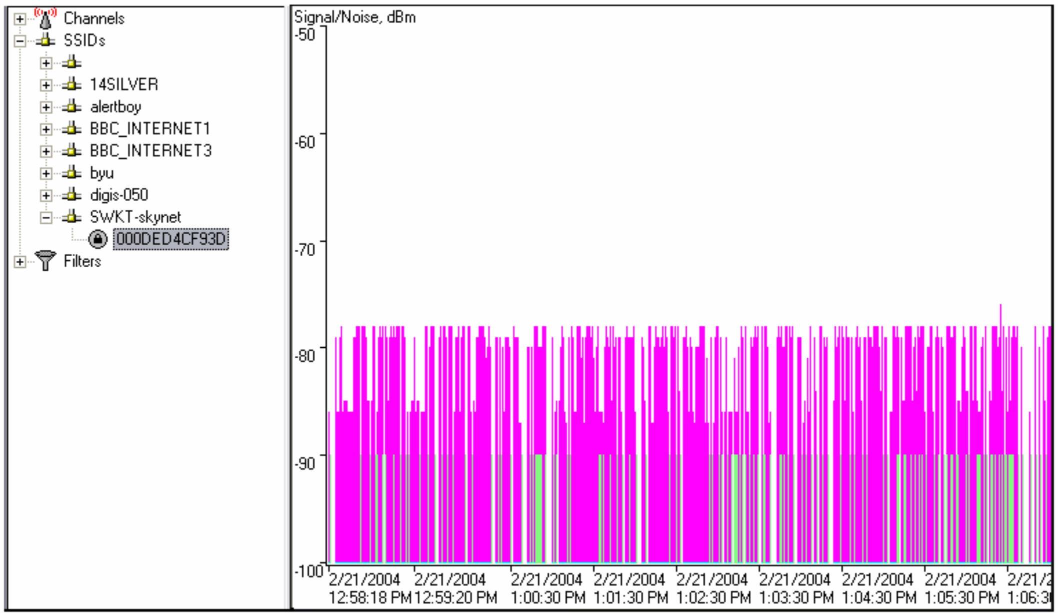

Figure C-25 Vagi (16 dBi) at test point 4 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 4 East side of Utah Lake (4.42 miles)

Free space path loss @ 2.437 (channel 6): -117.25 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 16 dBi Vagi – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 43.25 dB

Total path calculation: -74.0 dB
Actual Measured: approx. -82 dB
Percent Error: 9.76%

16 dBi Vagi FTP Results

receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,30).
connecting to 192.168.201.10:1054
- -

connecting to 192.168.201.10:1054
Connected to 192.168.201.10 port 1054
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 88.9 secs, **(371.22 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,31).
connecting to 192.168.201.10:1055
- -
connecting to 192.168.201.10:1055
Connected to 192.168.201.10 port 1055
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 58.5 secs, **(563.70 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,32).
connecting to 192.168.201.10:1056
- -
connecting to 192.168.201.10:1056
Connected to 192.168.201.10 port 1056
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 55.8 secs, **(591.20 Kbps)**, transfer succeeded
226 Transfer complete.
receiving userGuide.pdf as userGuide.pdf (1 of 1)
Saving restart info for CTB FTP - userGuide.pdf
PASV
227 Entering Passive Mode (192,168,201,10,4,33).
connecting to 192.168.201.10:1057
- -
connecting to 192.168.201.10:1057
Connected to 192.168.201.10 port 1057
RETR userGuide.pdf
125 Data connection already open; Transfer starting.
Received 5886444 bytes in 132.3 secs, **(436.24 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,34).

connecting to 192.168.201.10:1058
- -
connecting to 192.168.201.10:1058
Connected to 192.168.201.10 port 1058
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 77.2 secs, **(427.25 Kbps)**, transfer succeeded
226 Transfer complete.

16 dBi Vagi Ping Results

Ping statistics for 192.168.201.10:
    Packets: Sent = 300, Received = 221, Lost = 79 (26% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 859ms, Average = 72ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 300, Received = 214, Lost = 86 (28% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 804ms, Average = 85ms

C.4.5 19 dBi Wire Grid Parabolic Dish Test Results

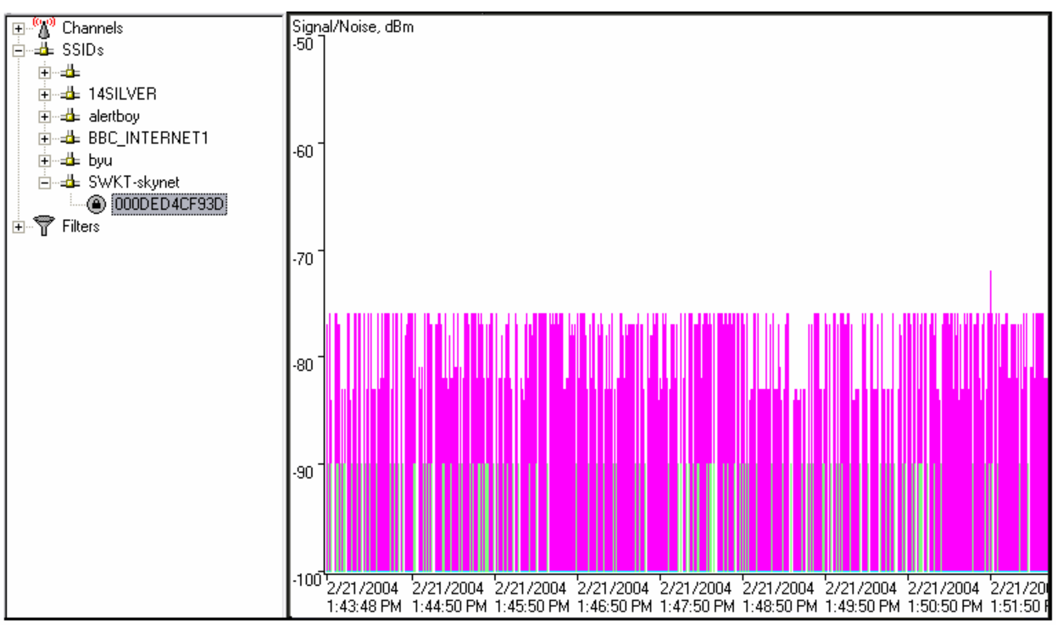

Figure C-26 Wire grid parabolic dish (19dBi) at test point 4 SNR using NetStumbler

Calculated Signal Gain and Path Loss:

Kimball tower to Site 4 East side of Utah Lake (4.42 miles)

Free space path loss @ 2.437 (channel 6): -117.25 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 16 dBi Vagi – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 45.25 dB

Total path calculation: -72.0 dB
Actual Measured: approx. -79 dB
Percent Error: 8.86%

19 dBi Wire Grid Parabolic Dish FTP Results

226 Transfer complete.
receiving userGuide.pdf as userGuide.pdf (1 of 1)
Saving restart info for CTB FTP - userGuide.pdf
PASV
227 Entering Passive Mode (192,168,201,10,4,38).

connecting to 192.168.201.10:1062
- -
connecting to 192.168.201.10:1062
Connected to 192.168.201.10 port 1062
RETR userGuide.pdf
125 Data connection already open; Transfer starting.
Received 5886444 bytes in 65.8 secs, **(876.60 Kbps)**, transfer succeeded
226 Transfer complete.
receiving userGuide.pdf as userGuide.pdf (1 of 1)
Saving restart info for CTB FTP - userGuide.pdf
PASV
227 Entering Passive Mode (192,168,201,10,4,39).
connecting to 192.168.201.10:1063
- -
connecting to 192.168.201.10:1063
Connected to 192.168.201.10 port 1063
RETR userGuide.pdf
125 Data connection already open; Transfer starting.
Received 5886444 bytes in 106.8 secs, **(540.23 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV

227 Entering Passive Mode (192,168,201,10,4,40).
connecting to 192.168.201.10:1064
- -
connecting to 192.168.201.10:1064
Connected to 192.168.201.10 port 1064
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 93.4 secs, **(353.20 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,41).
connecting to 192.168.201.10:1065
- -
connecting to 192.168.201.10:1065
Connected to 192.168.201.10 port 1065
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 76.4 secs, **(432.01 Kbps)**, transfer succeeded
226 Transfer complete.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,42).
connecting to 192.168.201.10:1066
- -

19 dBi Wire Grid Parabolic Dish Ping Results

Ping statistics for 192.168.201.10:
    Packets: Sent = 300, Received = 236, Lost = 64 (21% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 724ms, Average = 68ms

C.5 Test Point 5 –West Side of Utah Lake – Experimental

Figure C-27 West side of Utah Lake

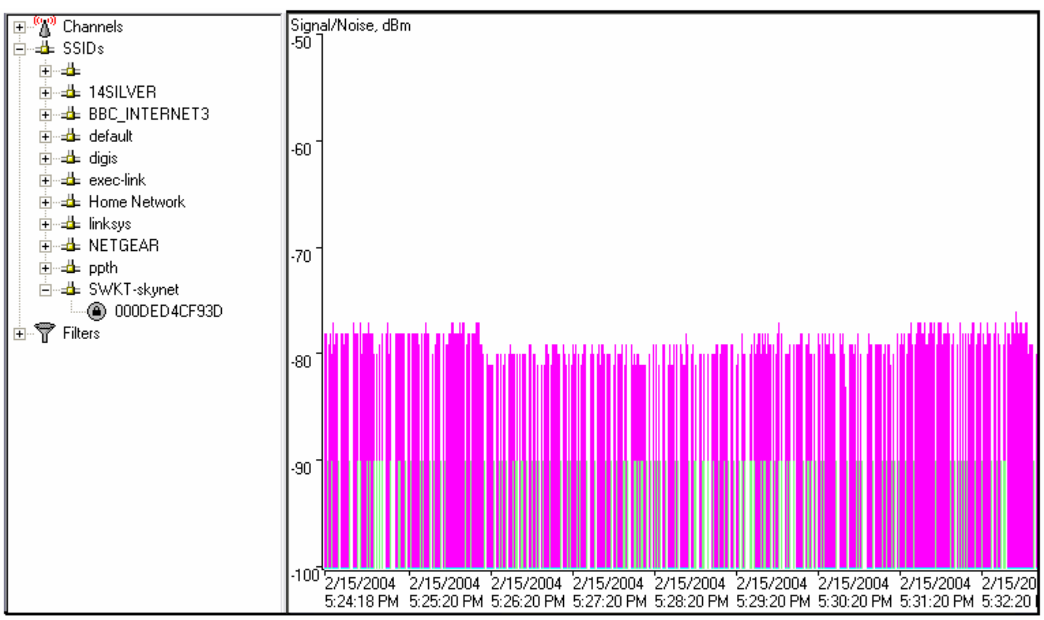

Figure C-28 Experimental Link using wire grid parabolic dish (21 dBi)

Calculated Signal Gain and Path Loss:

Kimball tower to Site 4 West side of Utah Lake (11.3 miles)

Free space path loss @ 2.437 (channel 6): -125.40 dB

Gain: 20 dBm radio – 8 ft LMR 400 jumper (~1 dB) - Arrestor (~1.25 dB) + 12 dBi Omni + 21 dBi Dish – 3 ft LMR-195 jumper (~1.5 dB) – 12 in. pigtail (~1dB) = 48.25 dB

Total path calculation: -77.15 dB
Actual Measured: approx. -79 dB
Percent Error: 2.34%

21 dBi Wire Grid Parabolic Dish FTP Results

connecting to 192.168.201.10:1063
Connected to 192.168.201.10 port 1063
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
Received 3366186 bytes in 288.6 secs, **(114.35 Kbps)**, transfer succeeded
226 Transfer complete.
sending Simpsons.mp3 as Simpsons.mp3 (1 of 1)
PASV
227 Entering Passive Mode (192,168,201,10,4,68).
connecting to 192.168.201.10:1092
- -
connecting to 192.168.201.10:1092
Connected to 192.168.201.10 port 1092
STOR Simpsons.mp3
550 Simpsons.mp3: Access is denied.
sending Simpsons.mp3 as Simpsons.mp3 (1 of 1)
PASV
227 Entering Passive Mode (192,168,201,10,4,71).
connecting to 192.168.201.10:1095
- -
connecting to 192.168.201.10:1095
Connected to 192.168.201.10 port 1095
STOR Simpsons.mp3
550 Simpsons.mp3: Access is denied.

sending segment5.swf as segment5.swf (1 of 1)
+ newer or same version of segment5.swf already exists!
sending Simpsons.mp3 as Simpsons.mp3 (1 of 1)
PASV
227 Entering Passive Mode (192,168,201,10,4,73).

connecting to 192.168.201.10:1097
- -
connecting to 192.168.201.10:1097
Connected to 192.168.201.10 port 1097
STOR Simpsons.mp3
550 Simpsons.mp3: Access is denied.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,75).
connecting to 192.168.201.10:1099
- -
connecting to 192.168.201.10:1099
Connected to 192.168.201.10 port 1099
RETR kazaalite243.exe
425 Can't open data connection.
receiving kazaalite243.exe as kazaalite243.exe (1 of 1)
Saving restart info for CTB FTP - kazaalite243.exe
PASV
227 Entering Passive Mode (192,168,201,10,4,78).
connecting to 192.168.201.10:1102
- -
connecting to 192.168.201.10:1102
Connected to 192.168.201.10 port 1102
RETR kazaalite243.exe
125 Data connection already open; Transfer starting.
! Receive error: connection reset
Received 2535424 bytes in 356.4 secs, **(69.74 Kbps)**, transfer succeeded
! Receive error: connection reset

21 dBi Wire Grid Parabolic Dish Ping Results

Ping statistics for 192.168.201.3:
    Packets: Sent = 500, Received = 392, Lost = 108 (21% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 3521ms, Average = 443ms

C.6 Results Summary

Table C-1 Calculated versus measured results

	Site #1 (.879 miles)				
	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
Calculated	-67.42	-61.97	-60.97	-59.97	-57.97
Measured	-71.00	-77.00	-66.00	-65.00	-63.00
% Difference	12.01%	19.52%	7.62%	7.73%	7.98%
	Site #2 (1.17 miles)				
	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
Calculated	-64.95	-64.45	-63.45	-62.45	-60.45
Measured	-78.00	-85.00	-70.00	-69.00	-65.00
% Difference	16.73%	24.18%	9.36%	9.49%	7.00%
	Site #3 (2.59 miles)				
	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
Calculated	-71.85	-71.35	-70.35	-69.35	-67.35
Measured	-82.00	-82.00	-84.00	-80.00	-78.00
% Difference	12.38%	12.99%	16.25%	13.31%	13.65%
	Site #4 (4.42 miles)				
	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
Calculated	-76.50	-76.00	-75.00	-74.00	-72.00
Measured	-88.00	-85.00	-86.00	-82.00	-79.00
% Difference	13.07%	10.58%	12.79%	9.76%	8.86%
Average %	**13.55%**	**16.82%**	**11.51%**	**10.07%**	**9.37%**

Table C-2 Summary of FTP throughput testing

Site 1 Client Node

	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
SNR	-71	-77	-66	-65	-63
FTP	753.33	209.08	1000.42	1464.32	1607.68
	1044.48	191.32	1136.64	1177.60	1607.68
	1095.68	146.05	1116.16	1341.44	1740.80
	954.34	120.07	857.73	1679.36	1720.32
	801.58		842.6	1515.52	1546.24
Average	929.882	166.63	990.71	1435.65	1644.54

Site 2 Lookout Point

	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
SNR	-78	-85	-70	-69	-65
FTP	162.99	0	441.62	249.44	821.17
	162.30	0	359.09	469.96	869.96
	114.06	0	190.47	213.67	663.98
		0	393.43	363.24	828.82
		0	378.17	232.30	796.78
Average	146.45	0	352.56	305.72	796.14

Site 3 Empty Lot

	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
SNR	-82	-82	Intermittent -84	-80	-78
FTP	24.82	62.29	0.00	97.80	227.84
	13.41	57.06	0.00	118.66	198.77
		113.76	0.00	113.53	313.53
		65.06	0.00		297.00
Average	19.12	74.54	0.00	110.00	259.29

Site 4 East Lake

	13.5 dBi Yagi	14 dBi Echo BF	15 dBi Dish	16 dBi Vagi	19 dBi Dish
SNR	Sparse -88	Sparse -85	Sparse -86	-82	-79
FTP	0.00	0.00	0.00	371.22	876.60
				563.70	540.23
				591.20	353.20
				436.24	432.01
				427.25	
Average	0	0	0	477.92	550.51

Site 5 West Lake

SNR	-79
	114.35
	69.74
Average	92.05

Table C-3 Summary of ping tests

Site 1 Client Node

	Received	Sent	% Loss	Min	Max	Average
Cisco 13.5 dBi	430	500	14.00%	4	930	53
Echo Backfire 14dBi	34	50	32.00%	6	858	140
	57	100	43.00%	5	447	77
	32	50	36.00%	5	477	69
Parabolic Dish 15 dBi	268	300	10.67%	4	395	39
Vagi 16 dBi	284	300	5.33%	4	280	36
Parabolic Dish 19 dBi	281	300	6.33%	4	201	42
	47	50	6.00%	4	118	19

Site 2 Lookout Point

	Received	Sent	% Loss	Min	Max	Average
Cisco 13.5 dBi	Failed	Failed	Failed	Failed	Failed	Failed
Echo Backfire 14dBi	2	20	90.00%	230	1033	632
Parabolic Dish 15 dBi	221	300	26.33%	5	859	72
Vagi 16 dBi	227	300	24.33%	5	1393	67
Parabolic Dish 19 dBi	102	105	2.86%	4	572	46

Site 3 Empty Lot

	Received	Sent	% Loss	Min	Max	Average
Cisco 13.5 dBi	245	300	18.33%	5	641	60
	243	300	19.00%	4	621	34
	228	300	24.00%	4	499	34
	175	200	12.50%	4	898	54
Echo Backfire 14dBi	164	200	18.00%	5	667	67
	162	200	19.00%	5	452	26
Parabolic Dish 15 dBi	0	1	100.00%	0	0	0
Vagi 16 dBi	164	200	18.00%	5	667	67
	162	200	19.00%	5	452	26
Parabolic Dish 19 dBi	179	200	10.50%	5	502	103
	166	200	17.00%	4	287	65
	92	100	8.00%	5	16	7

Site 4 East Lake Test

	Received	Sent	% Loss	Min	Max	Average
Cisco 13.5 dBi	0	1	100.00%	0	0	0
Echo Backfire 14dBi	0	1	100.00%	0	0	0
Parabolic Dish 15 dBi	0	1	100.00%	0	0	0
Vagi 16 dBi	221	300	26.33%	5	859	72
	214	300	28.67%	5	804	85
Parabolic Dish 19 dBi	236	300	21.33%	5	724	68
	398	466	14.59%	5	1695	133

Appendix D - Bridge Sensitivity Comparison Results

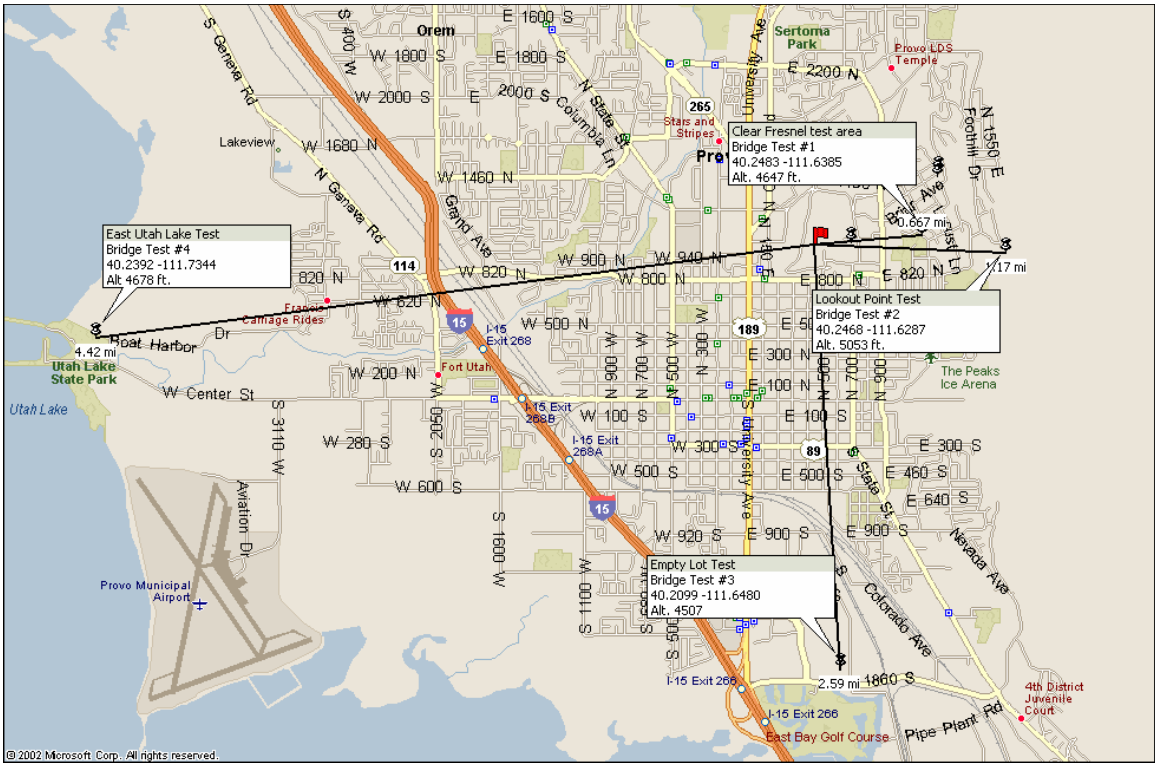

Figure D-1 Bridge link test areas

Antenna Test points:
Main Uplink - Kimball tower
Alt. 4682 ft.

Test point #1 – Clear Fresnel test area
.667 mi. from Kimball tower
Alt 4647 ft. (~35 ft. below tower)

Test point #2 – Lookout Point
1.17 mi. from Kimball tower
Alt. 5053 ft. (~371 ft above tower)

Test point #3 – Empty Lot
2.59 mi. from Kimball tower
Alt. 4507 ft. (~175 ft. below tower)

Test point #4 – East Utah Lake
4.42 mi. from Kimball tower
Alt. 4678 ft. (~4 ft. below tower)

Note: the 16 dBi Vagi was used for each of the bridge tests

D.1 Clear Fresnel Area Bridge Test (Site 1)

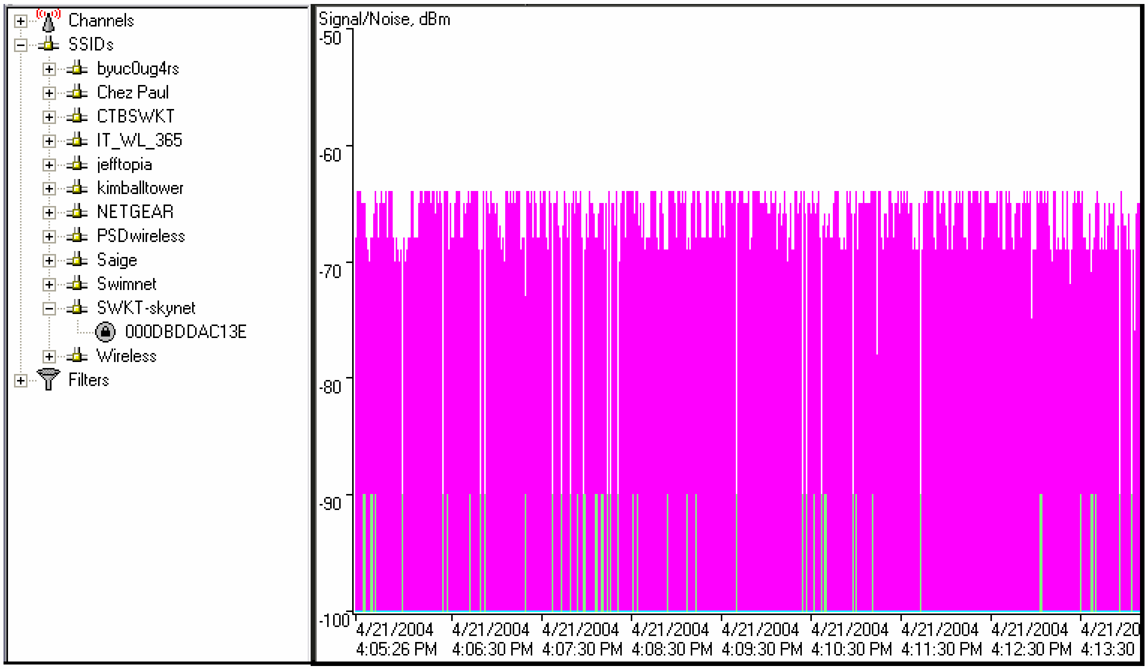

Figure D-2 Signal levels for tests performed at site #1

D.1.1 Orinoco FTP Test (used for baseline)

Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,8).
connecting to 192.168.201.10:3336
- -
connecting to 192.168.201.10:3336
Connected to 192.168.201.10 port 3336
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 51.4 secs, **(1.43 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,9).
connecting to 192.168.201.10:3337
- -
connecting to 192.168.201.10:3337

Connected to 192.168.201.10 port 3337
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 51.9 secs, **(1.42 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,10).
connecting to 192.168.201.10:3338
- -
connecting to 192.168.201.10:3338
Connected to 192.168.201.10 port 3338
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 50.8 secs, **(1.45 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,11).
connecting to 192.168.201.10:3339
- -
connecting to 192.168.201.10:3339
Connected to 192.168.201.10 port 3339
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 52.4 secs, **(1.40 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,12).
connecting to 192.168.201.10:3340
- -
connecting to 192.168.201.10:3340
Connected to 192.168.201.10 port 3340
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 53.9 secs, **(1.36 Mbps)**, transfer succeeded
226 Transfer complete.

D.1.2 Orinoco Ping Test (used for baseline)

Ping statistics for 192.168.201.10:
 Packets: Sent = 200, Received = 199, Lost = 1 (0% loss),
Approximate round trip times in milli-seconds:
 Minimum = 4ms, Maximum = 66ms, Average = 11ms

Ping statistics for 192.168.201.10:
 Packets: Sent = 200, Received = 200, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
 Minimum = 4ms, Maximum = 181ms, Average = 45ms

D.1.3 Linksys WET 11 FTP Test

receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,45).
connecting to 192.168.201.10:3373
- -
connecting to 192.168.201.10:3373
Connected to 192.168.201.10 port 3373
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 36.0 secs, **(2.04 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,46).
connecting to 192.168.201.10:3374
- -
connecting to 192.168.201.10:3374
Connected to 192.168.201.10 port 3374
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 36.0 secs, **(2.04 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,47).
connecting to 192.168.201.10:3375
- -

connecting to 192.168.201.10:3375
Connected to 192.168.201.10 port 3375
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 37.2 secs, **(1.98 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,48).
connecting to 192.168.201.10:3376
- -
connecting to 192.168.201.10:3376
Connected to 192.168.201.10 port 3376
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 35.9 secs, **(2.05 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,49).
connecting to 192.168.201.10:3377
- -
connecting to 192.168.201.10:3377
Connected to 192.168.201.10 port 3377
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 35.8 secs, **(2.06 Mbps)**, transfer succeeded
226 Transfer complete.

D.1.4 Linksys WET 11 Ping Tests

Ping statistics for 192.168.201.10:
   Packets: Sent = 200, Received = 197, Lost = 3 (1% loss),
Approximate round trip times in milli-seconds:
   Minimum = 5ms, Maximum = 68ms, Average = 23ms

Ping statistics for 192.168.201.10:
   Packets: Sent = 200, Received = 200, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
   Minimum = 4ms, Maximum = 65ms, Average = 13ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 200, Received = 197, Lost = 3 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 34ms, Average = 6ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 200, Received = 199, Lost = 1 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 13ms, Average = 6ms

D.1.5 Cisco 350 Workgroup Bridge FTP Test

receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,17).
connecting to 192.168.201.10:3345
- -
connecting to 192.168.201.10:3345
Connected to 192.168.201.10 port 3345
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 31.9 secs, **(2.30 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,18).
connecting to 192.168.201.10:3346
- -
connecting to 192.168.201.10:3346
Connected to 192.168.201.10 port 3346
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 32.0 secs, **(2.30 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,19).
connecting to 192.168.201.10:3347
- -
connecting to 192.168.201.10:3347
Connected to 192.168.201.10 port 3347

RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 37.0 secs, **(1.99 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,20).
connecting to 192.168.201.10:3348
- -
connecting to 192.168.201.10:3348
Connected to 192.168.201.10 port 3348
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 33.6 secs, **(2.19 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,13,21).
connecting to 192.168.201.10:3349
- -
connecting to 192.168.201.10:3349
Connected to 192.168.201.10 port 3349
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 35.7 secs, **(2.06 Mbps)**, transfer succeeded
226 Transfer complete.

D.1.6 Cisco 350 Workgroup Bridge Ping Test

Ping statistics for 192.168.201.10:
    Packets: Sent = 200, Received = 199, Lost = 1 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 55ms, Average = 15ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 200, Received = 199, Lost = 1 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 65ms, Average = 18ms

D.2 Summary of Results

FTP Throughput tests

Table D-1 FTP Throughput results for site #1

Test Site #1 Clear Fresnel - Approx -66 dBi (Mbps)			
Orinoco	D-Link	Linksys	Cisco
1464.32	N/A	2088.96	2355.2
1454.08		2088.96	2355.2
1484.80		2027.52	2037.76
1433.60		2099.2	2242.56
1392.64		2109.44	2109.44

Ping Tests

Table D-2 Ping time results for site #1

Test Site #1 Clear Fresnel	Received	Sent	% Loss	Min	Max	Average
Orinoco	199	200	0.50%	4	66	11
	200	200	0.00%	4	181	45
D-Link 900AP+ (not tested)	0	0	0.00%	0	0	0
Linksys Wet11	197	200	1.50%	5	68	23
	200	200	0.00%	4	65	13
	197	200	1.50%	4	34	6
	199	200	0.50%	4	13	6
Cisco 350 WG Bridge	199	200	0.50%	5	55	15
	199	200	0.50%	5	65	18

D.3 Lookout Point Area Bridge Test (site 2)

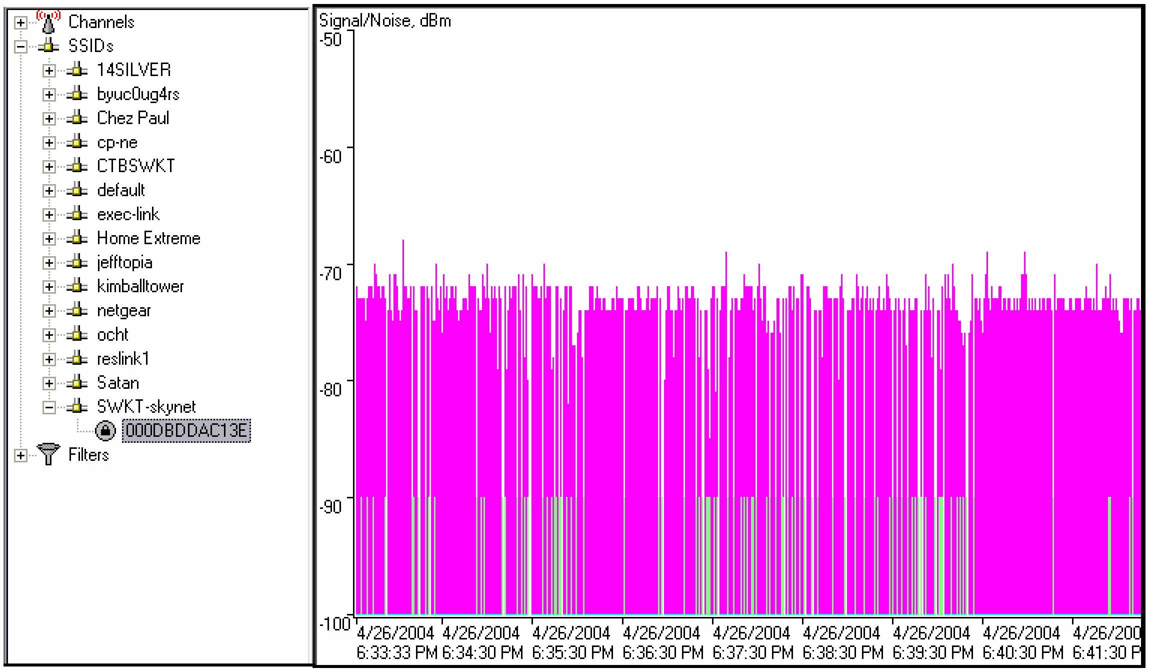

Figure D-3 Signal levels for tests performed at site #2

D.3.1 Orinoco FTP Test (as baseline)

227 Entering Passive Mode (192,168,201,10,16,184).
connecting to 192.168.201.10:4280
- -
connecting to 192.168.201.10:4280
Connected to 192.168.201.10 port 4280
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 69.9 secs, **(1.05 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,16,185).
connecting to 192.168.201.10:4281
- -
connecting to 192.168.201.10:4281
Connected to 192.168.201.10 port 4281
RETR segment5.swf
125 Data connection already open; Transfer starting.

Received 7679963 bytes in 71.7 secs, **(1.03 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
+ Same verison of segment5.swf already exists!
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,16,186).

connecting to 192.168.201.10:4282
- -
connecting to 192.168.201.10:4282
Connected to 192.168.201.10 port 4282
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 30.1 secs, **(1.11 Mbps)**, transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
227 Entering Passive Mode (192,168,201,10,16,187).
connecting to 192.168.201.10:4283
- -
connecting to 192.168.201.10:4283
Connected to 192.168.201.10 port 4283
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 30.2 secs, **(1.11 Mbps)**, transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,16,188).
connecting to 192.168.201.10:4284
- -
connecting to 192.168.201.10:4284
Connected to 192.168.201.10 port 4284
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 35.0 secs, **(977.36 Kbps)**, transfer succeeded
226 Transfer complete.

D.3.2 Orinoco Ping Test (as baseline)

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 98, Lost = 2 (2% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 299ms, Average = 139ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 97, Lost = 3 (3% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 248ms, Average = 44ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 95, Lost = 5 (5% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 217ms, Average = 16ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 220ms, Average = 9ms

D.3.3 D-Link 900AP+ FTP Test

200 Type set to I.
PASV
227 Entering Passive Mode (192,168,201,10,16,198).
connecting to 192.168.201.10:4294
- -
connecting to 192.168.201.10:4294
Connected to 192.168.201.10 port 4294
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 116.7 secs, **(645.26 Kbps)**, transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,16,199).
connecting to 192.168.201.10:4295
- -
connecting to 192.168.201.10:4295
Connected to 192.168.201.10 port 4295

RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 51.9 secs, **(660.24 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,16,200).
connecting to 192.168.201.10:4296
- -

connecting to 192.168.201.10:4296
Connected to 192.168.201.10 port 4296
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 50.8 secs, **(673.78 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,16,201).
connecting to 192.168.201.10:4297
- -
connecting to 192.168.201.10:4297
Connected to 192.168.201.10 port 4297
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 52.4 secs, **(653.05 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,16,202).
connecting to 192.168.201.10:4298
- -
connecting to 192.168.201.10:4298
Connected to 192.168.201.10 port 4298
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 55.6 secs, **(616.22 Kbps**), transfer succeeded
226 Transfer complete.

D.3.4 D-Link 900AP+ Ping Test

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 98, Lost = 2 (2% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 696ms, Average = 132ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 94, Lost = 6 (6% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 391ms, Average = 126ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 92, Lost = 8 (8% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 222ms, Average = 39ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 94, Lost = 6 (6% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 30ms, Average = 7ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 93, Lost = 7 (7% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 287ms, Average = 19ms

D.3.5 Linksys WET 11 FTP Tests

receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,16,208).
connecting to 192.168.201.10:4304
- -
connecting to 192.168.201.10:4304
Connected to 192.168.201.10 port 4304
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 37.1 secs, (**1.98 Mbps**), transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf

PASV
227 Entering Passive Mode (192,168,201,10,16,209).
connecting to 192.168.201.10:4305
- -
connecting to 192.168.201.10:4305
Connected to 192.168.201.10 port 4305
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 37.4 secs, **(1.97 Mbps**), transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,16,210).
connecting to 192.168.201.10:4306
- -
connecting to 192.168.201.10:4306
Connected to 192.168.201.10 port 4306
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 38.3 secs, **(1.92 Mbps**), transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,16,211).
connecting to 192.168.201.10:4307
- -
connecting to 192.168.201.10:4307
Connected to 192.168.201.10 port 4307
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 39.1 secs, **(1.88 Mbps)**, transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,16,212).
connecting to 192.168.201.10:4308
- -
connecting to 192.168.201.10:4308
Connected to 192.168.201.10 port 4308
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 37.9 secs, **(1.94 Mbps**), transfer succeeded
226 Transfer complete.

D.3.6 Linksys WET 11 Ping Tests

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 59ms, Average = 20ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 67ms, Average = 25ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 99, Lost = 1 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 64ms, Average = 26ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 26ms, Average = 7ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 26ms, Average = 7ms

D.3.7 Cisco 350 Workgroup Bridge FTP Tests

Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,16,192).
connecting to 192.168.201.10:4288
- -

connecting to 192.168.201.10:4288
Connected to 192.168.201.10 port 4288
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 17.0 secs, **(1.96 Mbps)**, transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV

227 Entering Passive Mode (192,168,201,10,16,193).
connecting to 192.168.201.10:4289
- -
connecting to 192.168.201.10:4289
Connected to 192.168.201.10 port 4289
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 17.7 secs, **(1.89 Mbps**), transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,16,194).
connecting to 192.168.201.10:4290
- -
connecting to 192.168.201.10:4290
Connected to 192.168.201.10 port 4290
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 39.9 secs, **(1.84 Mbps**), transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,16,195).
connecting to 192.168.201.10:4291
- -
connecting to 192.168.201.10:4291
Connected to 192.168.201.10 port 4291
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 38.7 secs, **(1.90 Mbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,16,196).
connecting to 192.168.201.10:4292
- -
connecting to 192.168.201.10:4292
Connected to 192.168.201.10 port 4292
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 17.2 secs, **(1.95 Mbps**), transfer succeeded
226 Transfer complete.

D.3.8 Cisco 350 Workgroup Bridge Ping Tests

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 98, Lost = 2 (2% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 235ms, Average = 26ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 71ms, Average = 22ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 99, Lost = 1 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 318ms, Average = 28ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 13ms, Average = 6ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 9ms, Average = 6ms

D.3.9 Summary of Results

FTP Throughput tests

Table D-4 FTP Throughput results for site #2

Test Site #2 Lookout Point - Approx. -73 dBi (Mbps)			
Orinoco	D-Link	Linksys	Cisco
1075.2	645.26	2027.52	2007.04
1054.72	660.24	2017.28	1935.36
1136.64	673.78	1966.08	1884.16
1136.64	653.05	1925.12	1945.6
977.36	616.22	1986.56	1996.8

Ping Tests

Table D-5 Ping time results for site #2

Test Site #2 Lookout Point	Received	Sent	% Loss	Min	Max	Ave.
Orinoco	98	100	2.00%	4	299	139
	97	100	3.00%	4	248	44
	95	100	5.00%	4	217	16
	100	100	0.00%	4	220	9
D-Link 900 AP+	98	100	2.00%	5	696	132
	94	100	6.00%	5	391	126
	92	100	8.00%	5	222	39
	94	100	6.00%	4	30	7
	93	100	7.00%	5	287	19
Linksys Wet 11	100	100	0.00%	4	59	20
	100	100	0.00%	5	67	25
	99	100	1.00%	4	64	26
	100	100	0.00%	4	26	7
	100	100	0.00%	5	26	7
Cisco 350 WG Bridge	98	100	2.00%	5	235	26
	100	100	0.00%	5	71	22
	99	100	1.00%	5	318	28
	100	100	0.00%	5	13	6
	100	100	0.00%	5	9	6

D.4 Empty Lot Area Bridge Test (site 3)

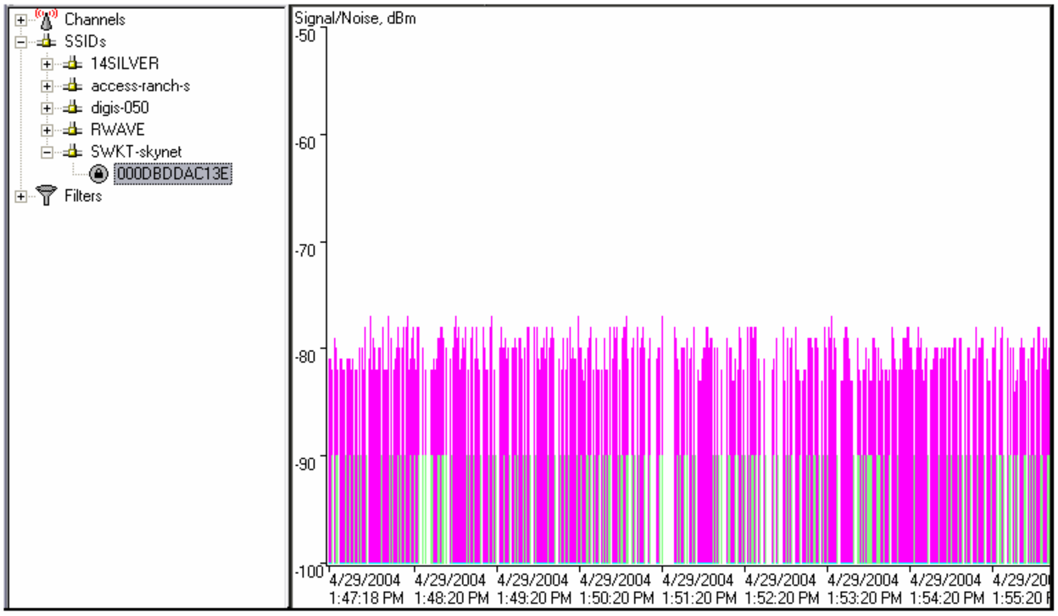

Figure D-4 Signal levels for tests performed at site #3

D.4.1 Orinoco FTP Test (as baseline)

Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,6,163).
connecting to 192.168.201.10:1699
- -
connecting to 192.168.201.10:1699
Connected to 192.168.201.10 port 1699
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 36.2 secs, **(945.46 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,6,164).
connecting to 192.168.201.10:1700
- -
connecting to 192.168.201.10:1700
Connected to 192.168.201.10 port 1700
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 46.9 secs, **(730.51 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,6,165).
connecting to 192.168.201.10:1701
- -
connecting to 192.168.201.10:1701
Connected to 192.168.201.10 port 1701
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 45.9 secs, **(745.63 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,6,166).
connecting to 192.168.201.10:1702
- -
connecting to 192.168.201.10:1702
Connected to 192.168.201.10 port 1702
RETR music.wma

125 Data connection already open; Transfer starting.
Received 3492199 bytes in 50.0 secs, (**684.71 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,6,167).
connecting to 192.168.201.10:1703
- -
connecting to 192.168.201.10:1703
Connected to 192.168.201.10 port 1703
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 41.5 secs, **(824.19 Kbps**), transfer succeeded
226 Transfer complete.

D.4.2 Orinoco Ping Test (as baseline)

Ping statistics for 192.168.201.10:
  Packets: Sent = 100, Received = 70, Lost = 30 (30% loss),
Approximate round trip times in milli-seconds:
  Minimum = 4ms, Maximum = 51ms, Average = 9ms

Ping statistics for 192.168.201.10:
  Packets: Sent = 100, Received = 79, Lost = 21 (21% loss),
Approximate round trip times in milli-seconds:
  Minimum = 4ms, Maximum = 495ms, Average = 39ms

Ping statistics for 192.168.201.10:
  Packets: Sent = 100, Received = 81, Lost = 19 (19% loss),
Approximate round trip times in milli-seconds:
  Minimum = 4ms, Maximum = 288ms, Average = 100ms

Ping statistics for 192.168.201.10:
  Packets: Sent = 100, Received = 90, Lost = 10 (10% loss),
Approximate round trip times in milli-seconds:
  Minimum = 4ms, Maximum = 65ms, Average = 8ms

Ping statistics for 192.168.201.10:
  Packets: Sent = 100, Received = 85, Lost = 15 (15% loss),
Approximate round trip times in milli-seconds:
  Minimum = 4ms, Maximum = 247ms, Average = 64ms

D.4.3 D-Link 900AP+ FTP Test

Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,6,186).
connecting to 192.168.201.10:1722
- -
connecting to 192.168.201.10:1722
Connected to 192.168.201.10 port 1722
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 100.6 secs, **(340.42 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,6,188).
connecting to 192.168.201.10:1724
- -

connecting to 192.168.201.10:1724
Connected to 192.168.201.10 port 1724
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 90.9 secs, (**376.68 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,6,189).
connecting to 192.168.201.10:1725
- -
connecting to 192.168.201.10:1725
Connected to 192.168.201.10 port 1725
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 108.1 secs, (**316.70 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,6,190).
connecting to 192.168.201.10:1726
- -
connecting to 192.168.201.10:1726

Connected to 192.168.201.10 port 1726
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 102.1 secs, (**335.27 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,6,191).
connecting to 192.168.201.10:1727
- -
connecting to 192.168.201.10:1727
Connected to 192.168.201.10 port 1727
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 108.9 secs, (**314.43 Kbps**), transfer succeeded
226 Transfer complete.

D.4.4 D-Link 900AP+ Ping Test

Ping statistics for 192.168.201.10:
    Packets: Sent = 100, Received = 76, Lost = 24 (24% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 460ms, Average = 58ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 100, Received = 81, Lost = 19 (19% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 708ms, Average = 243ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 100, Received = 74, Lost = 26 (26% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 908ms, Average = 138ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 100, Received = 62, Lost = 38 (38% loss),
Approximate round trip times in milli-seconds:
    Minimum = 4ms, Maximum = 26ms, Average = 10ms

D.4.5 <u>Linksys WET 11 FTP Tests</u>

receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,6,179).
connecting to 192.168.201.10:1715
- -
connecting to 192.168.201.10:1715
Connected to 192.168.201.10 port 1715
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 28.0 secs, **(1.19 Mbps),** transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,6,180).
connecting to 192.168.201.10:1716
- -
connecting to 192.168.201.10:1716
Connected to 192.168.201.10 port 1716
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 30.8 secs, **(1.09 Mbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,6,181).
connecting to 192.168.201.10:1717
- -
connecting to 192.168.201.10:1717
Connected to 192.168.201.10 port 1717
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 23.7 secs, **(1.41 Mbps**), transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,6,182).
connecting to 192.168.201.10:1718
- -
connecting to 192.168.201.10:1718

Connected to 192.168.201.10 port 1718
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 58.5 secs, (**1.26 Mbps**), transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,6,183).
connecting to 192.168.201.10:1719
- -
connecting to 192.168.201.10:1719
Connected to 192.168.201.10 port 1719
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 63.6 secs, (**1.16 Mbps**), transfer succeeded
226 Transfer complete.

D.4.6 Linksys WET 11 Ping Tests

Ping statistics for 192.168.201.10:
  Packets: Sent = 100, Received = 91, Lost = 9 (9% loss),
Approximate round trip times in milli-seconds:
  Minimum = 5ms, Maximum = 79ms, Average = 20ms

Ping statistics for 192.168.201.10:
  Packets: Sent = 100, Received = 87, Lost = 13 (13% loss),
Approximate round trip times in milli-seconds:
  Minimum = 5ms, Maximum = 307ms, Average = 25ms

Ping statistics for 192.168.201.10:
  Packets: Sent = 100, Received = 94, Lost = 6 (6% loss),
Approximate round trip times in milli-seconds:
  Minimum = 5ms, Maximum = 169ms, Average = 22ms

Ping statistics for 192.168.201.10:
  Packets: Sent = 100, Received = 99, Lost = 1 (1% loss),
Approximate round trip times in milli-seconds:
  Minimum = 5ms, Maximum = 20ms, Average = 7ms

Ping statistics for 192.168.201.10:
  Packets: Sent = 100, Received = 98, Lost = 2 (2% loss),
Approximate round trip times in milli-seconds:
  Minimum = 5ms, Maximum = 32ms, Average = 9ms

D.4.7 Cisco 350 Workgroup Bridge FTP Tests

227 Entering Passive Mode (192,168,201,10,6,170).
connecting to 192.168.201.10:1706
- -
connecting to 192.168.201.10:1706
Connected to 192.168.201.10 port 1706
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 39.0 secs, **(1.88 Mbps**), transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,6,171).
connecting to 192.168.201.10:1707
- -

connecting to 192.168.201.10:1707
Connected to 192.168.201.10 port 1707
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 38.8 secs, **(1.89 Mbps**), transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,6,172).
connecting to 192.168.201.10:1708
- -
connecting to 192.168.201.10:1708
Connected to 192.168.201.10 port 1708
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 42.9 secs, **(1.71 Mbps**), transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,6,173).
connecting to 192.168.201.10:1709
- -
connecting to 192.168.201.10:1709
Connected to 192.168.201.10 port 1709
RETR segment5.swf

125 Data connection already open; Transfer starting.
Received 7679963 bytes in 42.8 secs, (**1.72 Mbps**), transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
Saving restart info for BYU - segment5.swf
PASV
227 Entering Passive Mode (192,168,201,10,6,174).
connecting to 192.168.201.10:1710
- -
connecting to 192.168.201.10:1710
Connected to 192.168.201.10 port 1710
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 41.0 secs, (**1.79 Mbps**), transfer succeeded
226 Transfer complete.
receiving segment5.swf as segment5.swf (1 of 1)
+ Same verison of segment5.swf already exists!

D.4.8 <u>Cisco 350 Workgroup Bridge Ping Tests</u>

Ping statistics for 192.168.201.10:
    Packets: Sent = 100, Received = 99, Lost = 1 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 81ms, Average = 23ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 276ms, Average = 41ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 100, Received = 99, Lost = 1 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 322ms, Average = 33ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 100, Received = 99, Lost = 1 (1% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 50ms, Average = 8ms

Ping statistics for 192.168.201.10:
    Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 5ms, Maximum = 543ms, Average = 12ms

D.4.9 Summary of Results

FTP Throughput tests

Table D-6 FTP Throughput results for site #3

Test Site #3 Empty Lot - Approx. -81 dBi (Mbps)			
Orinoco	D-Link	Linksys	Cisco
945.46	340.42	1218.56	1925.12
730.51	376.68	1116.16	1935.36
745.63	316.7	1443.84	1751.04
684.71	335.27	1290.24	1761.28
824.19	314.43	1187.84	1832.96

Ping Tests

Table D-7 Ping time results for site #3

Test Site #3 Empty Lot	Received	Sent	% Loss	Min	Max	Average
Orinoco	70	100	30.00%	4	51	9
	79	100	21.00%	4	495	39
	81	100	19.00%	4	288	100
	90	100	10.00%	4	65	8
	85	100	15.00%	4	247	64
D-Link 900 AP+	76	100	24.00%	5	460	58
	81	100	19.00%	5	708	243
	74	100	26.00%	5	908	138
	62	100	38.00%	4	26	10
Linksys Wet 11	91	100	9.00%	5	79	20
	87	100	13.00%	5	307	25
	94	100	6.00%	5	169	22
	99	100	1.00%	5	20	7
	98	100	2.00%	5	32	9
Cisco 350 WG Bridge	99	100	1.00%	5	81	23
	100	100	0.00%	5	276	41
	99	100	1.00%	5	322	33
	99	100	1.00%	5	50	8
	100	100	0.00%	5	543	12

D.5 East Lake Area Bridge Test (site 4)

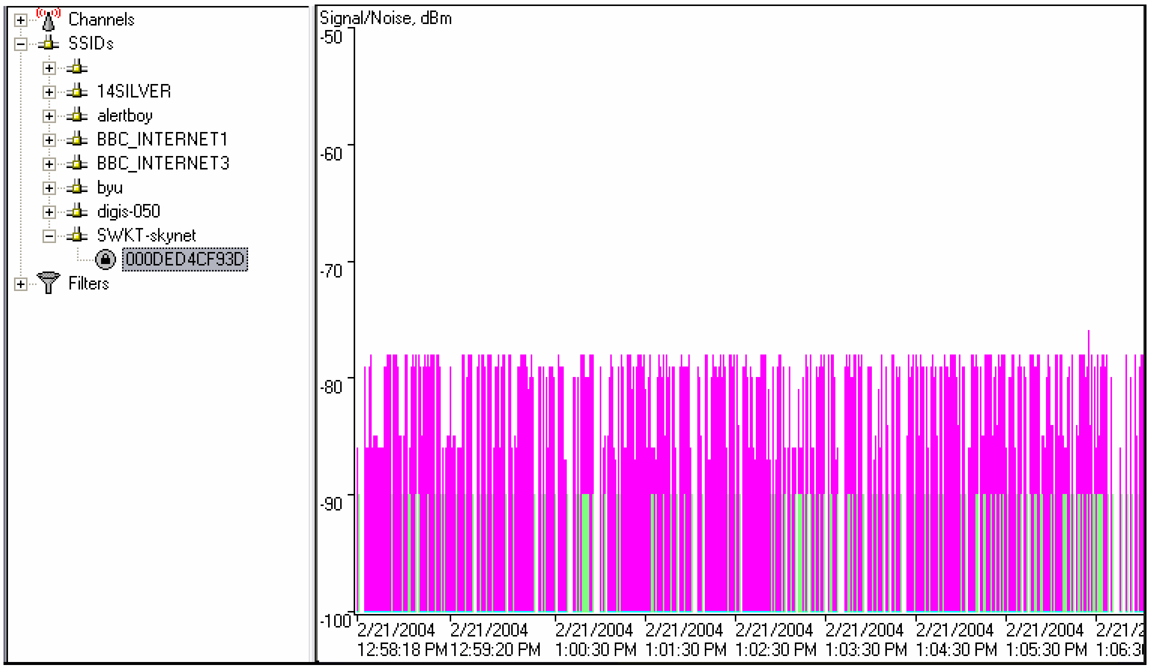

Figure D-5 Signal levels for tests performed at site #4

D.5.1 <u>Orinoco FTP Test (as baseline)</u>

USER anonymous
331 Anonymous access allowed, send identity (e-mail name) as password.
PASS (hidden)
230 Anonymous user logged in.
CWD /Ipswitch/Product_Downloads
550 /Ipswitch/Product_Downloads: The system cannot find the path specified.
PWD
257 "/" is current directory.
SYST
215 Windows_NT
Host type (S): Microsoft NT
PASV
227 Entering Passive Mode (192,168,201,10,15,235).
connecting to 192.168.201.10:4075
- -
connecting to 192.168.201.10:4075
Connected to 192.168.201.10 port 4075
LIST
125 Data connection already open; Transfer starting.

Received 206 bytes in 0.1 secs, (20.00 Kbps), transfer succeeded
226 Transfer complete.
receiving fepdense.bin as fepdense.bin (1 of 1)
Saving restart info for BYU - fepdense.bin
TYPE I
200 Type set to I.
PASV
227 Entering Passive Mode (192,168,201,10,15,236).
connecting to 192.168.201.10:4076
- -
connecting to 192.168.201.10:4076
Connected to 192.168.201.10 port 4076
RETR fepdense.bin
125 Data connection already open; Transfer starting.
Received 1941504 bytes in 172.1 secs, (**110.60 Kbps**), transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
PASV
227 Entering Passive Mode (192,168,201,10,15,237).
connecting to 192.168.201.10:4077
- -
connecting to 192.168.201.10:4077
Connected to 192.168.201.10 port 4077
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 107.6 secs, (**111.77 Kbps**), transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
PASV
227 Entering Passive Mode (192,168,201,10,15,238).
connecting to 192.168.201.10:4078
- -

connecting to 192.168.201.10:4078
Connected to 192.168.201.10 port 4078
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 128.3 secs, (**93.73 Kbps**), transfer succeeded
226 Transfer complete.

D.5.2 Orinoco Ping Test (as baseline)

Ping statistics for 192.168.201.10:
Packets: Sent = 200, Received = 194, Lost = 6 (3% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 1808ms, Average = 343ms

Ping statistics for 192.168.201.10:
Packets: Sent = 200, Received = 196, Lost = 4 (2% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 2530ms, Average = 400ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 124ms, Average = 20ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 99, Lost = 1 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 4ms, Maximum = 74ms, Average = 13ms

D.5.3 D-Link 900AP+ FTP Test

Could not connect to FTP server

D.5.4 D-Link 900AP+ Ping Test

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 14, Lost = 86 (86% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 188ms, Average = 23ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 2, Lost = 98 (98% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 153ms, Average = 79ms

D.5.5 Linksys WET 11 FTP Tests

Received 1227075 bytes in 99.0 secs, **(121.57 Kbps**), transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
PASV
227 Entering Passive Mode (192,168,201,10,15,249).
connecting to 192.168.201.10:4089
- -
connecting to 192.168.201.10:4089
Connected to 192.168.201.10 port 4089
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 116.9 secs, (**102.89 Kbps**), transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
PASV
227 Entering Passive Mode (192,168,201,10,15,250).
connecting to 192.168.201.10:4090
- -
connecting to 192.168.201.10:4090
Connected to 192.168.201.10 port 4090
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 52.7 secs, (**228.07 Kbps**), transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
PASV
227 Entering Passive Mode (192,168,201,10,15,251).
connecting to 192.168.201.10:4091
- -
connecting to 192.168.201.10:4091
Connected to 192.168.201.10 port 4091
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 50.4 secs, (**238.63 Kbps**), transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
PASV
227 Entering Passive Mode (192,168,201,10,15,252).
connecting to 192.168.201.10:4092

- -
connecting to 192.168.201.10:4092
Connected to 192.168.201.10 port 4092
RETR ntart.chm
125 Data connection already open; Transfer starting.
Received 1227075 bytes in 49.5 secs, (**242.83 Kbps**), transfer succeeded
226 Transfer complete.
receiving ntart.chm as ntart.chm (1 of 1)
Saving restart info for BYU - ntart.chm
PASV
227 Entering Passive Mode (192,168,201,10,15,253).
connecting to 192.168.201.10:4093
- -
connecting to 192.168.201.10:4093
Connected to 192.168.201.10 port 4093
RETR ntart.chm
125 Data connection already open; Transfer starting.

D.5.6 Linksys WET 11 Ping Tests

Ping statistics for 192.168.201.10:
 Packets: Sent = 100, Received = 80, Lost = 20 (20% loss),
Approximate round trip times in milli-seconds:
 Minimum = 5ms, Maximum = 434ms, Average = 15ms

Ping statistics for 192.168.201.10:
 Packets: Sent = 100, Received = 72, Lost = 28 (28% loss),
Approximate round trip times in milli-seconds:
 Minimum = 5ms, Maximum = 669ms, Average = 31ms

Ping statistics for 192.168.201.10:
 Packets: Sent = 100, Received = 73, Lost = 27 (27% loss),
Approximate round trip times in milli-seconds:
 Minimum = 5ms, Maximum = 166ms, Average = 13ms

Ping statistics for 192.168.201.10:
 Packets: Sent = 100, Received = 70, Lost = 30 (30% loss),
Approximate round trip times in milli-seconds:
 Minimum = 5ms, Maximum = 146ms, Average = 17ms

Ping statistics for 192.168.201.10:
 Packets: Sent = 100, Received = 58, Lost = 42 (42% loss),
Approximate round trip times in milli-seconds:
 Minimum = 5ms, Maximum = 459ms, Average = 24ms

D.5.7 Cisco 350 Workgroup Bridge FTP Tests

200 Type set to I.
PASV
227 Entering Passive Mode (192,168,201,10,15,240).
connecting to 192.168.201.10:4080
- -
connecting to 192.168.201.10:4080
Connected to 192.168.201.10 port 4080
RETR segment5.swf
125 Data connection already open; Transfer starting.
Received 7679963 bytes in 105.7 secs, (**712.52 Kbps),** transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,15,241).
connecting to 192.168.201.10:4081
- -
connecting to 192.168.201.10:4081
Connected to 192.168.201.10 port 4081
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 45.3 secs, (**755.37 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,15,242).
connecting to 192.168.201.10:4082
- -

connecting to 192.168.201.10:4082
Connected to 192.168.201.10 port 4082
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 38.5 secs, (**888.21 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,15,243).
connecting to 192.168.201.10:4083
- -
connecting to 192.168.201.10:4083
Connected to 192.168.201.10 port 4083

RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 46.9 secs, (**729.27 Kbps**), transfer succeeded
226 Transfer complete.
receiving music.wma as music.wma (1 of 1)
Saving restart info for BYU - music.wma
PASV
227 Entering Passive Mode (192,168,201,10,15,244).
connecting to 192.168.201.10:4084
- -
connecting to 192.168.201.10:4084
Connected to 192.168.201.10 port 4084
RETR music.wma
125 Data connection already open; Transfer starting.
Received 3492199 bytes in 44.9 secs, (**762.79 Kbps**), transfer succeeded
226 Transfer complete.

D.5.8 Cisco 350 Workgroup Bridge Ping Tests

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 586ms, Average = 88ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 608ms, Average = 94ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 8ms, Maximum = 530ms, Average = 128ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 99, Lost = 1 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 473ms, Average = 32ms

Ping statistics for 192.168.201.10:
Packets: Sent = 100, Received = 99, Lost = 1 (1% loss),
Approximate round trip times in milli-seconds:
Minimum = 5ms, Maximum = 336ms, Average = 26ms

D.5.9 Summary of Results

FTP Throughput tests

Table D-8 FTP Throughput results for site #4

Test Site #4 East Lake Test - Approx. -83 (Mbps)			
Orinoco	D-Link	Linksys	Cisco
110.6	No Connect	121.57	712.52
111.77		102.89	755.37
93.73		228.07	888.21
		238.63	729.27
		242.83	762.79

Ping Tests

Table D-9 Ping time results for site #4

Test Site #4 East Lake Test	Received	Sent	% Loss	Min	Max	Average
Orinoco	194	200	3.00%	4	1808	343
	196	200	2.00%	4	2530	400
	100	100	0.00%	4	124	20
	99	100	1.00%	4	74	13
D-Link 900 AP+	14	200	93.00%	5	188	23
	2	100	98.00%	5	153	79
Linksys Wet 11	80	100	20.00%	5	434	15
	72	100	28.00%	5	669	31
	73	100	27.00%	5	166	13
	70	100	30.00%	5	146	17
	58	100	42.00%	5	459	24
Cisco 350 WG Bridge	100	100	0.00%	5	586	88
	100	100	0.00%	5	608	94
	100	100	0.00%	8	530	128
	99	100	1.00%	5	473	32
	99	100	1.00%	5	336	26