Purdue West Lafayette. Indiana

School of Technology

Golf Course Wireless Network Design

In partial fulfillment of the requirements for the
Degree of Master of Science in Technology

A Directed Project Report
By

Kevin Hendress Jr

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Committee Member	**Approval Signature**	**Date**
Phil Rawles, Chair	______________________	__________
Jeff Brewer	______________________	__________
Kyle Lutes	______________________	__________

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Abstract

This project is part of a bigger project researching the best method to implement a wireless network on the Ackerman Hills golf course at Purdue University. This project dealt with 802.11b technology using a hub and spoke network architecture. Cisco and Intel access points were tested. Yagi and omni antennas were used on the access points. The project developed a wireless network on two holes at the golf course to show proof-of-concept and to determine if the task was technically feasible.

Introduction

This project was one part of a larger project involving the Birch Boilermaker Golf Complex at Purdue University. The larger project is looking at multiple network architectures available to see which would be the best to implement. After the network architecture has been selected then applications such as the maintenance request application will be developed to aid maintenance personnel in requesting, submitting, reviewing, and responding to maintenance requests. Technologies planned to be evaluated with the overall project include Mesh Architecture, Nextel, Motorola Canopy System, and the 802.16 technology, in addition to the 802.11b technologies investigated in this directed project.

The objective of the overall project is to allow the maintenance department to submit maintenance requests via a wireless enabled device while on the course. Additional applications that utilize the wireless infrastructure could be created to increase the return on investment (ROI) of the project. Such applications could include slow golfer complaints, beverage & food requests or new equipment requests.

This project implemented a proof of concept 802.11b network on two holes at the Ackerman Hills golf course. Using a hub and spoke design the out come of this project was a determination of the technical feasibility of this technology and the cost required to implement it. The scope of this project did not include an exhaustive ROI evaluation. Once it is determined that creating a network on the golf course is possible, cost and ROI can be calculated as part of the overall project.

Metrics were used in this study to help decide if implementing a wireless network could be implemented on the golf course. The initial holes chosen for this project are some of the most difficult areas in which to provide wireless signals to due to their hilly layout with large trees.

This directed project dealt with implementing a hub and spoke network design on one hole at a time. Testing was not done with multiple holes interconnected. The actual hub backend connection was not tested. The testing was limited to coverage on the actual hole not how it would interact with other holes: based on the results of this project a follow up study on deploying coverage across the course as a whole is warranted.

Statement of the Problem

IEEE 802.11b has the range required for a golf course of up to 300 feet when outdoors using omni-directional antennas (Gast, 2002). Devices are plentiful and inexpensive for 802.11b wireless networks (*Making Sense*, 2003). Research has not been done on implementing a hub and spoke network outdoors at a golf course with a hilly and wooded environment. However there are no published guidelines for deploying an 802.11b network in a hilly, wooded outdoor environment such as the Ackermann Hills golf course.

Significance of the Problem

Managing a golf course requires significant communication around the course. Maintenance personnel would like to be able to access work order requests, place work order requests and perform other tasks from the course without needing to stop in at their desk or contact the office via radio. Creating a way for the maintenance department to electronically submit and review maintenance requests from the course itself is the main driving force for a wireless network to be implemented.

An application running over the wireless network would allow maintenance personnel to respond quicker to maintenance requests allowing an increase in the productivity level of employees. Employees' no longer would need to check in with the main office for current maintenance requests. They could easily check maintenance status from the golf course using a wireless device.

Other potential uses of the wireless network include: ordering food or drinks while out golfing, checking e-mail or stock prices or requesting additional equipment. These potential applications can be reviewed once the initial network is designed. These can be reviewed in another part of the larger project.

This directed project deals with 802.11b equipment which can be obtained inexpensively from multiple sources. The equipment for the client side is also easy to obtain and is also inexpensive. IEEE 802.11b technology is capable of providing the needed bandwidth to transfer data for a maintenance request application. The technology is also capable of providing the needed range to cover a larger area such as a golf course. The spectrum that 802.11b operates on is unlicensed and therefore does not require a license to operate. With the IEEE 802.11b technology the solution is owned and is not a service with recurring cost. Collectively these items made this a logical solution to review first. Without the network infrastructure in place the application can not be implemented.

Review of Literature

Methodology of the Review

Multiple sources were consulted to discover what was available. Research was done to see if there were any solutions readily available for the perceived problem. A variety of sources were used to get the best level of information available. A source consulted was the Academic Search Elite from the Purdue Library system. This was able to provide industry and academic references. Google.com was also used to search for available articles pertaining to wireless networks and wireless security. See Table 1 for search terms used with www.google.com and www.bitpipe.com.

Wireless security	802.11b Wireless networks
PGA Wireless	Mesh Networks
Industrial Wireless Equipment	Golf Courses & Wireless
802.11b	Outdoor 802.11 applications
Roaming	Multipath

Table 1 - Search Terms

Bitpipe Inc. (www.bitpipe.com) was also used to search for white papers and other articles on wireless networks available to the public. Specialized websites for wireless hacking were also reviewed to learn about hacking activities. The two wireless hacking sites that were visited are www.netstumbler.com and www.kismetwireless.net.

Findings of the Review of Literature

Outdoor 802.11 Applications

There are multiple examples of current 802.11 applications being used in outdoor environments. One example is the new initiative that Purdue University has rolled out at the football stadium providing wireless access for home football games. According to About e-Stadium (2003), IEEE 802.11b equipment is used to allow users to connect and look at scores as well as order drinks and food. Purdue University has also rolled out wireless networks to the majority of campus buildings to allow the students and faculty to access the network from within the buildings. While doing this they have also setup the network to allow some outdoor access for students and faculty.

802.11b Information

There are presently two IEEE standards available, the 802.11a and 802.11b standard. They are approved by the Institute of Electrical and Electronics Engineers, Inc. (IEEE). IEEE 802.11b has been widely accepted within the public and industry while 802.11a has not caught on as quickly. The main reason that the 802.11a has not been as widely accepted is that the costs of the 802.11a equipment are much higher. Both standards operate in a similar manner with the major difference being that 802.11a has a bandwidth speed of 54Mbps and a range of 50 feet where 802.11b has a bandwidth speed of 11Mbps and a range of 150 feet. Because of the increased price for 802.11a and other factors many users are still sticking with 802.11b.

802.11b operates in the 2.4 GHz band. This is the same band used by cordless phones and other devices. According to Massaro (2002), a typical setup in an office with 802.11b can reach 400 feet using an omni antenna. "With proper antennas and clear line of sight" it is possible to obtain access over a distance of 20 miles using 802.11b equipment with a yagi antenna doing point-to-point connectivity (Flickenger, 2003, p. 12). IEEE 802.11a has a shorter range and thus is not a good choice when needing to cover a longer distance.

According to the article Comparing Performance (2001), 802.11b uses 2.4 GHz frequency band while 802.11a uses 5.2 GHz frequency. 2.4 GHz is the same frequency that many portable phones use. Using the 2.4 GHz frequency one can achieve "11 Mbps" on the wireless network (Geier, 01/2002). Using the 2.4 GHz allows one to achieve a longer range however the throughput limit is lower than if you were using 5.2 GHz. According to Geier (01/2002), using 2.4 GHz one can achieve a range of 300 feet where as with the 5.2 GHz you are limited to 60 feet.

802.11g is supposed to take the best aspects of both 802.11a and 802.11b and implement them into 802.11g. However this is yet to be determined. There are other versions being developed and it will be interesting to see what they deliver once they are standardized. "802.11 incorporates positive acknowledgements" (Gast, 2002, p.25). Positive acknowledgements means that all transmitted frames must be acknowledged or they will be re-sent. This is done with the link layer protocol. IEEE 802.16a could be a possible alternative for this project. However at this time the technology is not available and thus is not presently feasible for the application.

Multi-Path Signal Propagation

Multipath can be a problem for wireless networks and thus should be reviewed prior to installing any wireless equipment. According to Geier, “Multipath propagation occurs when an RF signal takes different paths when propagating from a source” (05/2002). What happens is the signal hits an object which causes it to bounce around the environment and therefore bounce in all different directions. Part of the signal may go directly to the destination while the other may take a different route as stated by Geier (05/2002). The problem is caused when there is a delay in the signal and the signals do not both arrive at the same time.

According to the author Geier (05/2002), multipath delay can confuse the receiver because of signal overlap. This will cause a retransmission of data and thus the user will not be able to obtain the high level of throughput originally anticipated. In a manufacturing plant the delay could be as high as 300 nanoseconds where in a house or office the delay could be around 50 nanoseconds (Geier, 05/2002). The 802.11b network is very susceptible to Multipath problems as it uses DSSS (Direct Sequence Spread Spectrum).

According to Geier (05/2002), “The differences in reflectivity will cause a wider range of signal paths”. According to the author Gast (2002) most 802.11 equipment uses omni directional antennas. These antennas simply broadcast the signal in all directions (p. 161). The book 802.11 Wireless networks: the definitive guide states that many times

"Multipath interference can be resolved by changing the orientation or position of the receiver" (Gast, 2002, p. 161). One way to fight multi-path problems is to use two antennas on the receivers. By using multiple antennas the equipment can simply choose the best reception coming into the two antennas. Figure 1 is an example of a multipath problem. The signal transmits from location 1 to location 2. Location 1 has three paths that the signal takes as seen in the figure. Trees and hilly areas can also cause multipath problems as the signal will bounce off of the trees and hills then taking multiple paths to the intended target.

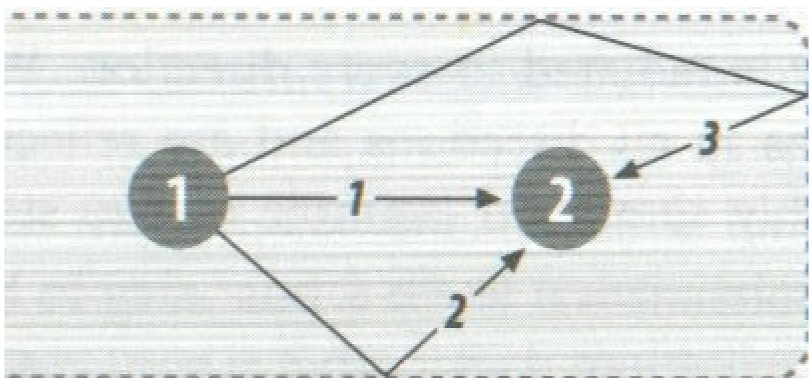

Figure 1 - Multipath[1]

Signal Propagation & Range

Because the signal coming out of the access points has a limited amount of strength and range there are a few ways to increase the signal range. An amplifier can be installed to make the "signal bigger" (Gast, 2002, p. 160). According to the article RF Propagation Basics (2004) "omni-directional antennas are generally better for 'area' coverage, whereas directional antennas offer greater 'range' in a given direction which may be useful for linking access points to each other". In an open outdoors environment a

[1] From: 802.11 Wireless Networks: The Definitive Guide, Figure 9-5, Pg 162

“200mW transmit power access point with 8dBi omni-directional antenna can cover about 45 acres for connectivity to a standard WiFi-enabled laptops” (*RF Propagation Basics*, 2004). However in an environment with “lightly populated clutter of trees, the estimated area drops to about 10 acres” (*RF Propagation Basics*, 2004). Attenuation happens as the signal passes through solid objects like trees. The signal is also scattered when it hits objects. Attenuation happens when the “signal passes through solid objects; some of the signal power is absorbed” (*RF Propagation Basics*, 2004). According to the article RF Propagation Basics (2004) trees may account for 10 to 20 dB of loss per tree. Loss from trees depends on the size and type of tree that is in the direct signal path.

An example of the channel selection can be seen in Figure 2. When saturating the area with wireless signals the administrator must keep from selecting channels that will conflict with each other. According to Flickenger (2003) by using the setup seen in Figure 2 an infinite area can be covered without channel overlap. “A single channel can easily support 50 or more simultaneous users” (Flickenger, 2003, p. 17).

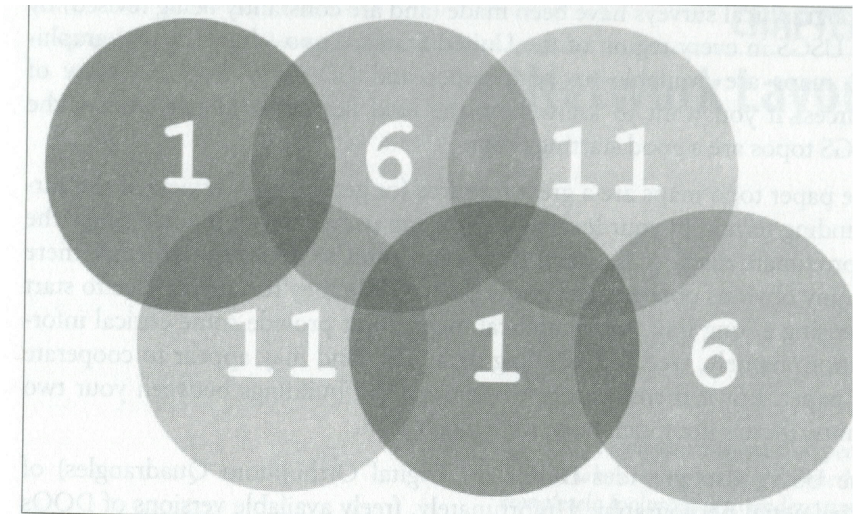

Figure 2 - Channel Coverage[2]

Antennas

There are a few different items related to antennas that need to be addressed prior to purchasing and setting up antennas on a wireless network. Antenna type, gain and half-power beam width are the three issues that the author of <u>802.11 Building Wireless Networks: Definitive Guide</u> mentions (Gast, 2002, p. 316). The antenna type deals specifically with the pattern of signal that is created from the antenna. Each type of antenna has is best uses and should be reviewed prior to installing.

Gain deals with the level that the signal is increased in the desired direction. Gain is measured in dBi (decibels relative to an isotropic radiator). “Directional antennas can have gains as high as 24 dBi” (Gast, 2002, p. 316). Half-power beam width is in relation to the point at the width of the antennas signal pattern where the signal drops to 50% of its maximum value. One needs to understand this to be able to plan for the coverage area that will be provided by the antenna.

[2] From: Building Wireless Community Networks (2nd Ed), Pg 17, Figure 2-2

Vertical antenna types are often called omni directional antennas. The coverage area from an omni directional antenna looks similar to a doughnut. The dBi available from a vertical antenna can range from 10 dBi to 3 dBi according to Gast (2003, p.317). The vertical antennas are often used to cover confined areas such as a courtyard area or a lunch room area at a factory. An example of a vertical antenna can be seen in Figure 3.

Dipole antennas look very similar to vertical antennas and are often called vertical antennas. “A dipole antenna has a figure eight radiation pattern” (Gast, 2002, p. 317). These antennas are often used for long thin areas like a hallway. An example of a dipole antenna can be seen in Figure 3.

Yagi antennas are specialized antennas that are “moderately high-gain unidirectional antennas” (Gast, 2002, p. 317). Yagi antennas look similar to TV antennas if you remove the normal enclosure; otherwise they look like a large plastic pipe. These antennas have “gains between 12 and 18 dBi” (Gast, 2002, p. 319). A yagi antenna is capable of “15 degrees to as much as 60 degrees” for the beam width (Flickenger, 2003, p. 79). An example of a yagi antenna can be seen in Figure 3.

Parabolic antennas are “very high-gain antennas” (Gast, 2002, p. 319). They can have a gain up to 24 dBi which means that they have a very small beam width. Some manufacturers have claimed that they can send a signal up to 20 miles using parabolic antennas. These are best used for point-to-point connectivity between physical locations but not actual connection to mobile users. “One commercial product has a published beam width of only 6.5 degrees” (Gast, 2002, p. 319). Parabolic dishes have a higher gain than yagi antennas however their beam width is usually much smaller and normally only used for point-to-point connections over a long distance. An example of a parabolic antenna can be seen in Figure 3.

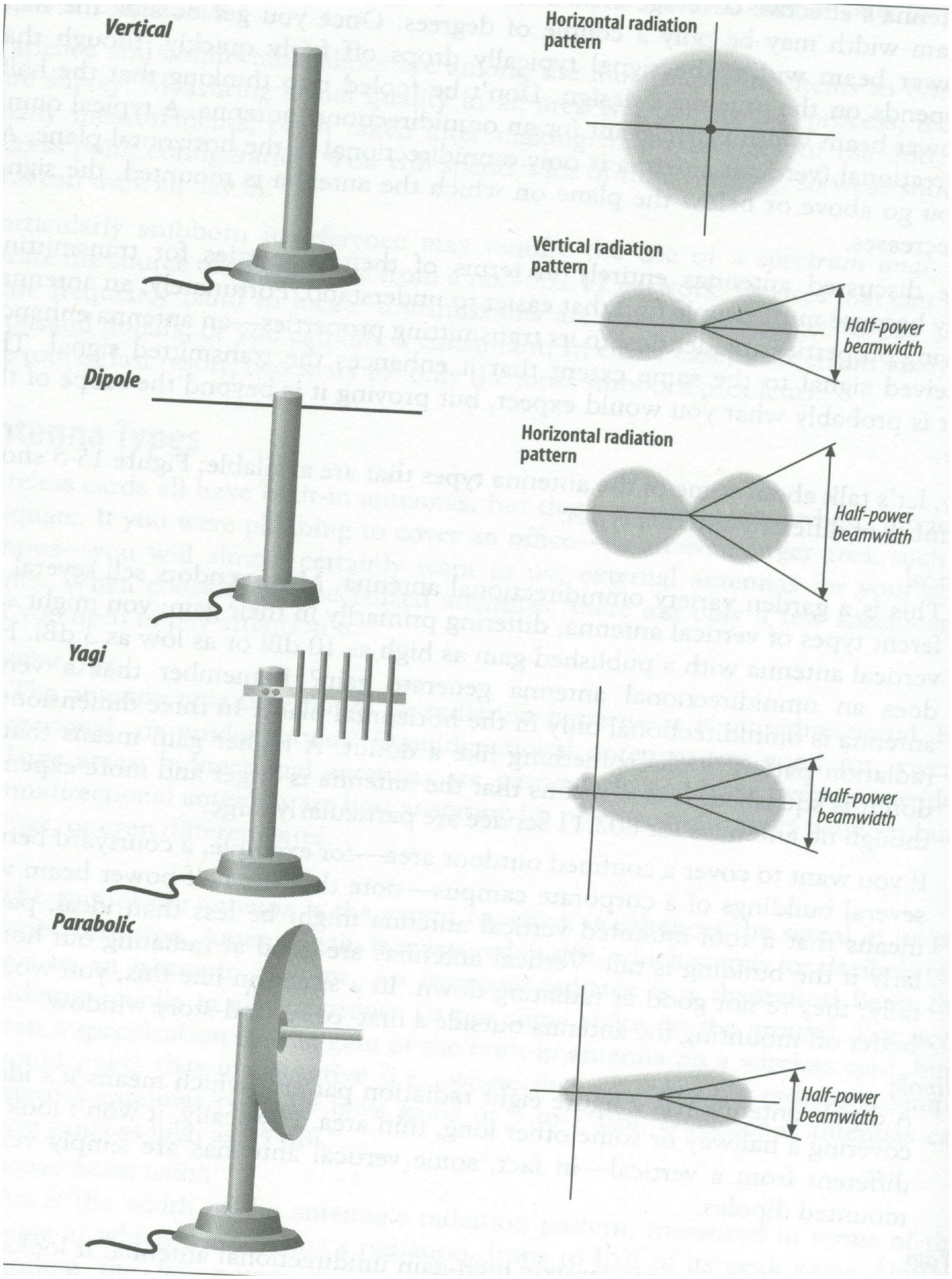

Figure 3 - Antenna Designs[3]

[3] From: 802.11 Wireless Networks: The Definitive Guide, Figure 15-5, Pg 318

According to Gast (2002) it is recommended that access points use multiple antennas to fight against multipath problems and provide antenna diversity (p.321). Most access points come with two antennas installed by default and therefore are able to provide antenna diversity. Flickenger (2003) states that "Antenna selection has a tremendous impact on the range and usability of your wireless network" and should not be taken lightly (p. 74). According to Flickenger (2003) the range of standard 802.11b equipment can reach more than 20 miles by using specialized antennas on a point-to-point connection such as a yagi or a parabolic dish (p. 3).

Limitations

According to Gast (2002), a general rule of thumb for outdoors is that you can provide up to 300 feet of coverage with an access point when using an omni-directional antenna (p. 314). However the range is closer to 150 feet in normal implementations. 802.11b equipment is limited to a maximum bandwidth of 11 Mbps. However the actual data rate is closer to 6 Mbps (*Making Sense*, 2003).

Another limitation of 802.11b is it offers only three available non-overlapping channels (*Making Sense,* 2003). Because it only offers three non-overlapping channels interference can be a problem. Also, both upstream and downstream traffic use the same frequency and therefore they can not occur at the same time; reducing the actual throughput possible on the network (*Making Sense,* 2003). Metal buildings can cause problems with Multipath and reflection of the signal according to the article Making Sense. This is a problem if the access point is placed inside the building or outside of the building (2003).

Roaming

According to the article What is roaming? Roaming is defined as "the ability to move from one access point coverage area to another without interruption in service or loss in connectivity" (2004). Roaming occurs when a device moves around in an area that has multiple access points and disassociates it's self with one access point and then associates its self with another access point that has a better signal. Flickenger (2003) states that "In order for roaming to be possible, your access points all need to be from the same manufacturer" (p. 49). According to Mandeville (n.d.) roaming can cause problems as it can be slow and disrupt a TCP/IP session. Roaming contains four steps that need to be done quickly to ensure that everything works properly. These steps are: disassociate, search, re-associate and authenticate (Mandeville, n.d.).

Leary & Roshan describe two different methods of roaming: seamless and nomadic roaming. Seamless roaming is the type of roaming that one experiences with a cell phone. You change towers yet never get dropped or lose service. Nomadic roaming is the type of roaming that most 802.11 wireless network users are familiar with. You are not using the network while roaming only once you stop and are settled down. "802.11 roaming is known as break before make" (Leary & Roshan, 2004). Break before you make means that you must disassociate from an access point before you can start to look for a new access point. This is what causes the network disruptions and problems.

"If 802.11 were make before break; meaning a station could associate to a new access point before disassociating from the old access point" then the user would not have problems with TCP/IP sessions timing out and losing connection (Leary & Roshan, 2004). With a make before you break method one would need to ensure that you did not have looping data or other issues. “Access points that are in the same broadcast domain and configured with the same service set identifier (SSID) are said to be in the same roaming domain” (Leary & Roshan, 2004). Also all access points should be on the same IP segment on the network. Creating the access points into a roaming domain is a good method to use when the users need to be able to roam between access points quickly and easily.

Wireless Security

Both 802.11a and 802.11b have a built-in encryption method that is called wired equivalent privacy (WEP), which can be used to encrypt the data passed along the wireless network to protect the data from interception. WEP was designed to provide the same level of “confidentiality that is equivalent to a wired network” (The Cable Guy, 2002, p. 4). WEP uses an RC4 symmetrical stream cipher with a 40-bit or 104-bit encryption key. However, Juitt (2003) states the WEP standard has many vulnerabilities.

Intel Corporation had two primary security concerns when implementing their internal wireless network. Strong authentication was needed to prevent unauthorized persons from accessing the corporate network and strong encryption to protect data in transit from prying eyes (*VPN and WEP*, 2003). Intel did not feel that WEP would provide the proper level of protection for their networks. Instead Intel implemented a virtual private network (VPN) solution for the wireless network.

VPN was initially created to secure systems over the Internet to servers within a company. This is done by creating a tunnel between the two end points and encrypting the data that is transferred. VPN is "protecting against intrusion for packets traversing the Internet" (*VPN and WEP*, 2003). The VPN technology has been widely accepted by industries and has been in use for over three years. When implementing a VPN technology you must be ready to manage it properly as at times it causes problems with your local firewalls. According to VPN and WEP (2003), when IT departments use VPN they can enable a single and consistent level of security throughout the company. According to Building a Secure Wireless Network (2003) VPNs are appropriate for wireless connections.

Architecture

Hub and Spoke Networks

With a hub and spoke network topology each access point must connect to a landline connection to provide access to the clients. However, there is a limit with this architecture in that the range is "limited by the range of the central access point's signal" (*Wireless Community Networks*, 2003). Hub and spoke networks are not able to change easily to new growth demands.

According to Fleishman (2001) by using wireless bridges a network can "span wireless networks by connecting the traffic from one or more access points to another". With the hub and spoke network architecture a single access point can be used to connect to multiple wireless bridges. The wireless bridges can then provide wireless connectivity to the local clients. Using a method like this is popular for outdoor applications where there is a need for a large area to be covered with a wireless signal.

Figure 4 shows an example of a hub and spoke network. The main access point sends a point-to-point signal to the secondary access points located in the area. The secondary access points then provide wireless coverage to the clients. As one can see, if the main access point were to go down the entire wireless network would be unable to function, as it is the single point of failure. The main access point is then connected via a hard line connection to the Internet.

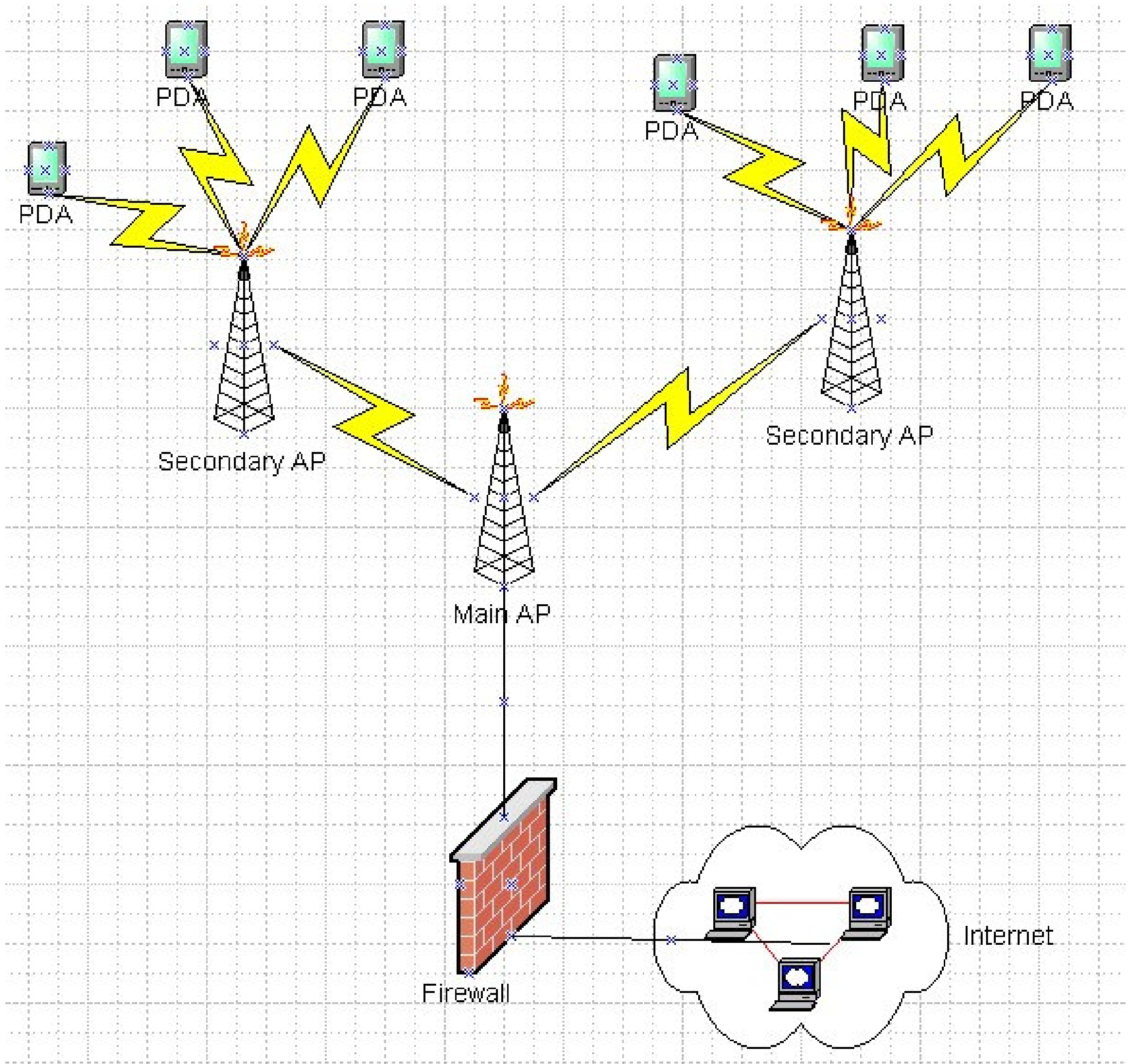

Figure 4 - Hub and Spoke Network

Mesh Networks

The mesh networks overcome certain limitations that the traditional hub and spoke networks experienced. The main point of a mesh network is the fact that access points are able to communicate with each other without the need for a landline connection. The network will have a few landline connections simply to provide access to the Internet. However, all of the other access points will connect to each other in something similar to the star topology.

According to the article Wireless Community Networks (2003), the access points “act like repeaters in a cellular network”. The access points on the network pass the packet along the network until it reaches its destination. According to the author Poor (2003), wireless networks using mesh architectures use each devices to assist each other in transmitting packets. Mesh networks help to provide a reliable and flexible system. When using mesh networks if there is a weak signal or dead zone it “can be fixed simply by dropping a repeater node into place” (Poor, 2003). An example of a mesh network can be seen in Figure 5.

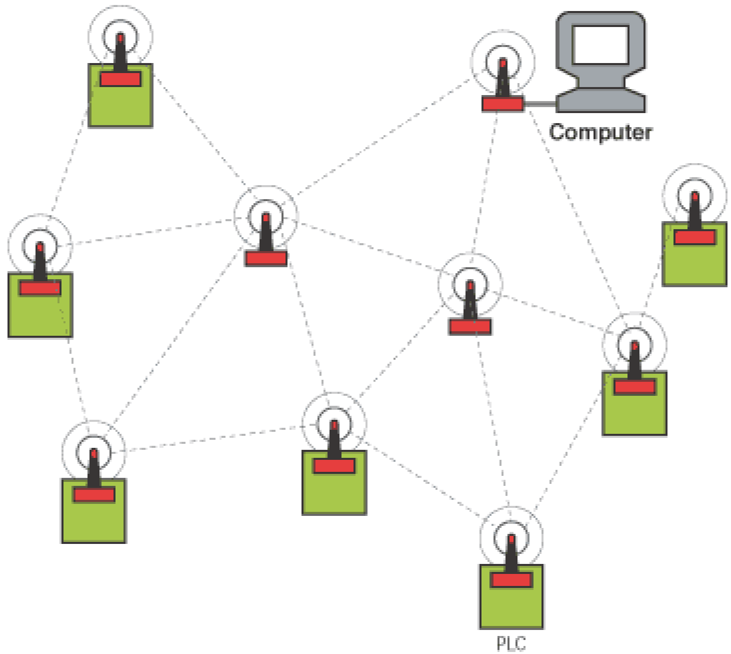

Figure 5 - Mesh Network[4]

According to the article Mesh Architecture, when using mesh networks the nodes are able to communicate in an intelligent fashion with one another. By using mesh networks the administrator can find the problems in the network faster by isolating them to a single node or cluster. This means shortened downtime for the network and increased performance. One of the key benefits to using mesh networks is the fact that the network is able to automatically discover any new node and add it to the network.

Each node is able to act more as a traditional router by passing the packets along to their neighbor nodes until the packet reaches its intended destination. Mesh networks also provide for multiple paths through out the network if configured properly. As seen in Figure 5, there are multiple paths through the network. Should one path go down, the nodes can then route the packets around the problem area thus reducing the affected area.

4 From: Wireless Mesh Network (Poor, 2003)

LocustWorld provides what is called a "MeshBox". This is a hardware application that a user can simply plug-in and start a mesh network (*What is the LocustWorld MeshBox?,* n.d.). The meshbox communicates with other meshboxes and packets from one box to the other until the packets reach their destination. Meshboxes use line-of-sight technology to work. However multiple boxes can be used to provide network access over a long distance.

These boxes have been used "on a not-for-profit basis" and "commercial" basis (*What is the LocustWorld MeshBox?,* n.d.). The boxes use "low power" and "no moving parts" which makes them reliable and economical to use (*What is the LocustWorld MeshBox?,* n.d.). "In a mesh network nodes get given their basic rules of the road and then they are left to establish their connections autonomously" (*LocustWorld Mesh Networks overview,* n.d*.).* According to What is the LocustWorld Meshbox (n.d.) article they use WEP along with point-to-point encryption using certificates and VPN connections. An administrator can monitor or do admin tasks to the meshboxes through a web interface making them easy to maintain remotely.

What Technology is Available

Sputnik produces an access point that is specifically created for rugged and harsh environments. The Sputnik Access Point 200 is a wireless access point with a 200 mWatt transmit output. It is specifically designed for implementation in environments such as hotels and outdoor public areas. The enclosure is "sealed with a heavy-duty gasket" which makes it ideal for outdoor applications as seen in Figure 6. (Sputnik AP 200, 2004). Any number of antenna designs can be installed on the Sputnik Access Point 200 making it versatile for multiple different applications. The Sputnik 200 Access Point can also act as a repeater and thus provide a range of several miles. The device will also work with Power over Ethernet (PoE) which allows the access point to be placed where access to AC power may be costly and difficult.

Figure 6 - Sputnik AP 200[5]

FireTide, Inc. has a product called HotPoint 1000S Wireless Mesh Router which is used for deploying wireless mesh networks. Using HotPoint routers eliminates the costly backhaul wiring which is needed for the wired devices (*HotPoint 1000S,* 2004). HotPoint mesh routers connect automatically to other HotPoint mesh routers and form a mesh network (*HotPoint 1000S,* 2004). FireTide has software available that allows for real-time views of the network and custom configuration (*HotPoint 1000S,* 2004). The HotPoint 1000S is capable of 200 meters at 11 Mbps in an open environment using the

[5] From: http://www.sputnik.com/products/aps/ap200.html

default antennas (*HotPoint 1000S,* 2004). As seen in Figure 7 is an image of the HotPoint 1000S wireless mesh router.

Figure 7 - HotPoint 1000S Wireless Mesh Router[6]

802.16

802.16 was approved on December 6, 2001 according to Flickenger (2003, p. 11). This was suppose to help with a lot of the problems that the 802.11 standard had in regards to providing access over a distance. According to Flickenger (2003) the 802.11 standard was never intended to be used for long-distance coverage (p. 11). The 802.16 standard uses the following frequencies "10 to 66 GHz to provide commercial-quality services to stationary locations" (Flickenger, 2003, p. 11). However, the prices for the new equipment will be much higher than the older 802.11b equipment which could hinder some from implementing the new technology quickly. The equipment presently is not commercially available for PDA devices.

[6] From: http://www.firetide.com/images/User_FilesImages/documents/HP1000S_DS_a104.pdf

Site Survey

When implementing a wireless network one important things is to have line of sight between the different devices. The book Building Wireless Community Networks (2003) states that line of sight is needed for optimal performance. A site survey is required before implementing the technology. A site survey is used to measure the signal strength and range over the proposed area of wireless coverage.

Procedures

The network architecture was tested at two holes at the Ackermann Hills golf course to see if the architecture would work effectively. The two holes were selected after visiting the golf course and discussing the potential holes with Phil Rawles. The solutions were setup, installed and tested by Kevin Hendress Jr. The following steps were followed for the project.

Site Survey

A site survey was completed on the two holes and the surrounding areas to properly prepare for implementation of the equipment. Access Points were setup at the two locations on the golf course where wireless coverage was planned and the signal strength and coverage was evaluated using site survey equipment bundled with Cisco wireless cards. Different antennas were tested on the access points to determine the optimal antenna and access point solution.

Course Map & Description

According to the Birch Boilermaker Golf Complex scoring sheet there are 18 holes at the Ackerman Hills golf course (2004). The scoring sheet has a small map of each hole with some obstacles shown. However the map is not set up to allow for a proper analysis of the entire golf course.

The golf course has a number of trees, hills and valleys that must be considered. There is a grove of trees that will not allow for line of sight through the grove, which causes problems with the network. According to Flickenger “For outdoor applications, trees are probably going to be your single biggest signal killer” (2003, p. 76). The planning and testing for the wireless network was done during the summer months which would be the worst case scenario for foliage. The summer months are the peak times for golf course usage.

The Ackermann Hills golf course layout can be seen in Figure 8. Holes five and eight, circled in Figure 8, were selected to be the holes that had the wireless network implemented due to their layout. The fifth hole has been chosen because of the elevation changes along the fairway. The eighth hole has been chosen due to the number and size of trees that are in the area. These two holes are the most difficult holes to provide wireless coverage on the course.

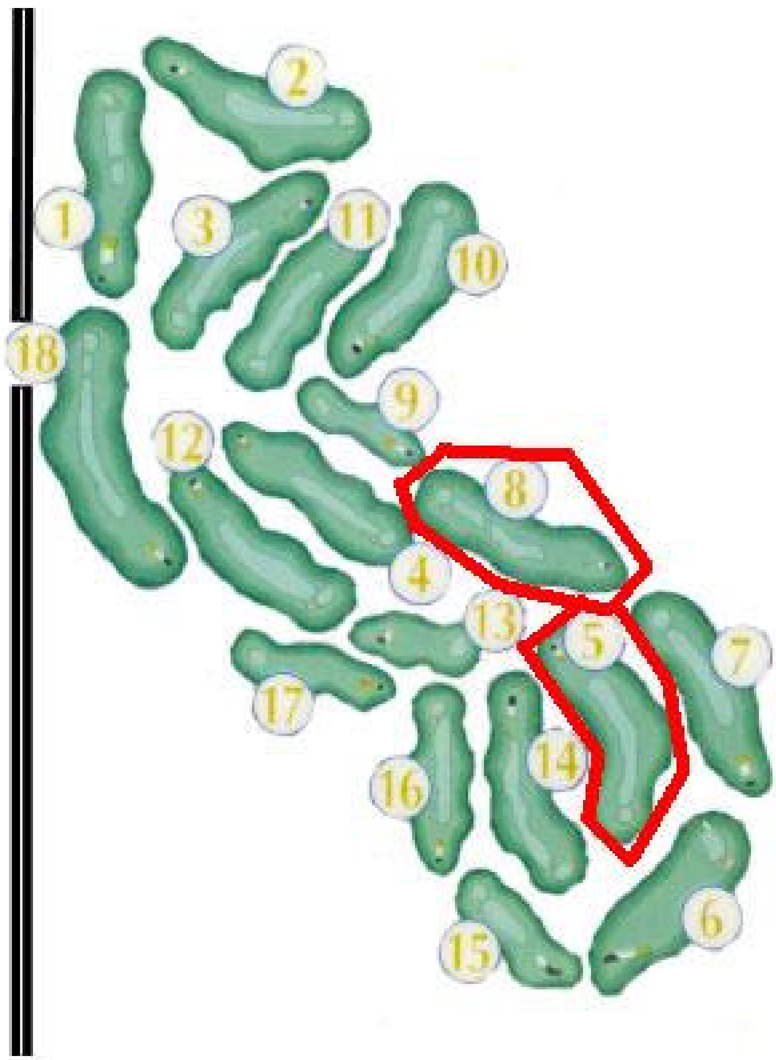

Figure 8 - Ackermann Hills Golf Course[7]

[7] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

Figure 9 shows the layout for the fifth hole on the Ackermann Hills golf course. Wireless coverage is required for the main fairway area, tee boxes and green area. It is desired that wireless coverage also cover the area near the fairway, which contains trees. The required and preferred areas are outlined in Figure 9.

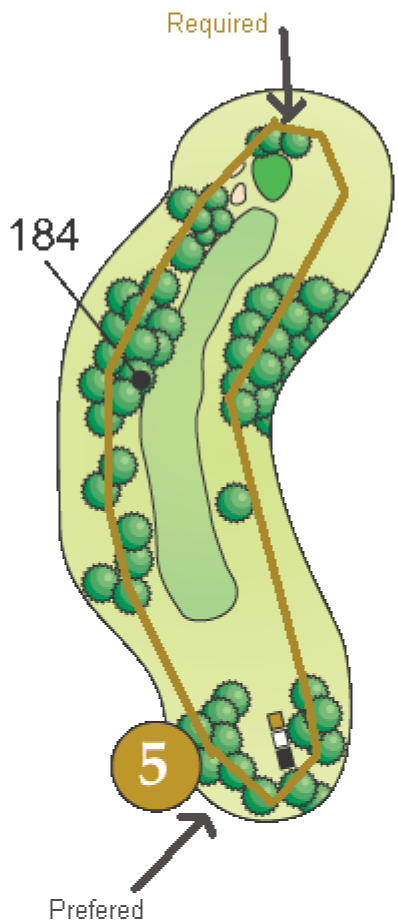

Figure 9 - Hole 5 Layout[8]

[8] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

Figure 10 shows the layout for the eighth hole on the Ackermann Hills golf course. As with the fifth hole, wireless coverage is required for the main fairway area, tee boxes and green area. It is desired that wireless coverage also cover the area near the fairway, which contains trees. The required and preferred areas are outlined in Figure 10.

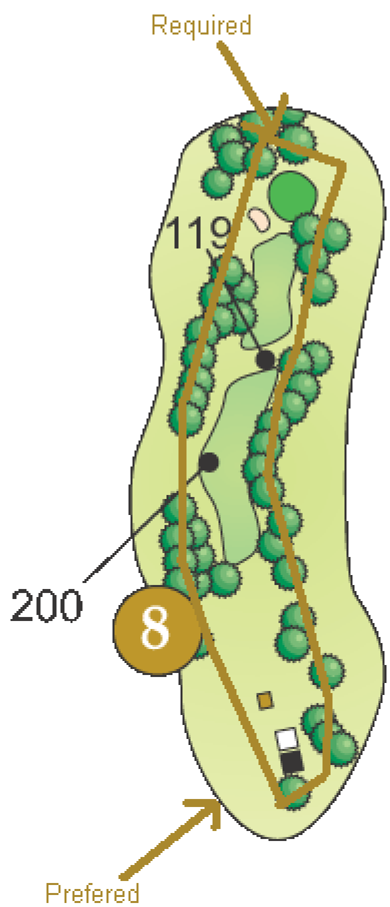

Figure 10 - Hole 8 Layout[9]

[9] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

Figure 11 show the aerial view of the golf course. The photo was taken in 1999 so it is slightly out of date but shows the general layout of the golf course. Figure 11 shows the terrain changes and layout of the trees throughout the course.

Figure 11 - Aerial Photo of Course[10]

Test Methodology

The hub and spoke architecture was implemented on each of the selected holes independently. The eighth hole was tested first.

The Aironet Client Utility Manager bundled with Cisco wireless network cards was used to measure connectivity between the client and the access points. A wireless enabled

[10] From: http://terraserver.homeadvisor.msn.com/image.aspx?t=1&s=11&x=1265&y=11190&z=16&w=2

notebook computer and a wireless enabled IPAQ were used as test clients. The IPAQ test was preformed using both Constantly Awake Mode (CAM) and Fast Power Save Mode (Fast PSP).

Weather should not have an affect on the wireless signal. Although when a heavy rain storm comes through with six inches per hour or more there could be an affect on the network (DC Access, 2004). No one will be golfing in weather like this. Therefore all tests were conducted during normal weather when conditions were favorable for golfing.

The survey was preformed from a golf cart located on the pathway and while standing on the fairway to provide coverage measurements throughout the course area. All measurements were taken from a stationary position.

Implementation

An IEEE 802.11b network architecture was tested to determine the best performance and coverage using various antenna designs. Two access points were implemented per hole for the project. During testing the hub and spoke design was only implemented on a single hole, not the entire system on the course. Inter-hole relationship was not tested nor was a connection to the Internet tested.

Five Intel access points were borrowed from the CPT department to be used for testing. All five access points were configured to allow for WLAP functionality. The priority level of each access point was also configured to allow for proper routing of packets.

The firmware on all of the access points was updated to the latest available from the Intel support website.

Once the Intel access points were configured they were then tested for connectivity and performance. These basic tests were performed at Kevin Hendress Jr.'s apartment. The goal was to ensure that the access points were working and that a client was able to connect to the access points and the data was routed properly.

Three Cisco access points were borrowed from the CPT department and configured. The setup included IP address assignment, WLAN configuration and Cisco IOS installation. Cisco IOS was installed on all three to allow for connectivity between each other. Once the Cisco access points were properly configured they were tested for connectivity and performance. These tests were again done at Kevin Hendress Jr.'s apartment.

A generic site survey of the golf course was preformed. There was a need to analyze the two holes that would be tested to discover any power outlets and other potential items that could be of assistance. While doing the site survey an Intel access point with the default antenna was placed in a golf cart and connectivity to the access point was checked.

Tri-pods were created to mount the access points. Tests were done at this time to discover the optimal height of the antennas when operating on a level environment. A dozen tri-pods were then created meeting the specifications created from this test. Creating the tri-pods and testing for optimal height was conducted. The optimal height for use on level ground was found to be 8 foot height. This was discovered after testing the range of the Intel access points using the default antennas by placing it at different heights on the tripod and measuring the overall link quality and the distance from the access point.

Testing was then done on the golf course on the eighth hole using the Cisco access points and the yagi antennas. Testing was also done on the fifth hole using the same solution.

Testing was done on the eighth hole using Intel access points and yagi antennas. The same equipment was then tested on the fifth hole.

Testing was also done on the eighth hole using Intel access points and omni antennas. Two different antenna placement designs were tested. The fifth hole was also tested using the same equipment. Two different antenna placement tests were tested.

The test data was then analyzed. After analyzing the data, summaries were created for each tested solution. The final report was then created. The results obtained from all of the testing done can be found in the Appendix section of the report.

Metrics

The following metrics were used to evaluate the best network methodology: signal strength, signal quality, overall link quality, roaming, number of access points needed, redundancy, ease of installation and solution cost. Table 2 shows the metrics and their values and cut-off points.

Metric	Values	Cut-off
Signal		
Signal Strength	Percentage of full strength	25%
Signal Quality	Percentage of full strength	31%
Overall Link Quality	Excellent, Good, Fair, Poor	Fair
Wireless Ability		
Roaming	Yes/No	Yes
Number of Access Points	Integer	2
Redundancy	Amount of redundant connections	0 links
Installation & Setup		
Ease of Installation	Time to install	2 days
Solution Cost	Money	$1140.00

Table 2 – Metrics

The minimum amount of signal strength and signal quality was experimentally determined. The value that allowed a connection to be maintained plus a 5% buffer was used as a minimum for the remainder of the work.

Ease of installation is measured in days to setup a single hole as it will take approximately two days to setup and install the equipment per hole. Once the equipment is setup there must be some time spent testing to ensure that the equipment has been properly setup and that coverage is available. The solution cost refers to the equipment cost, not labor or setup cost.

Equipment

Because power was not available where the access points were placed, portable power was required. A 350VA APC UPS unit was used on one of the access points to provide power. The second access point was powered with a 12V battery and an AC/DC converter. A third power option was a portable power pack used to jump start vehicles. An APC AC/DC cigarette lighter adapter was used to provide AC power.

Intel PRO 2011B LAN access points were used for testing yagi and omni directional antennas on the Ackerman course on holes five and eight. The tests were measured using a Cisco 340 PCMCIA card on a laptop computer and a PDA. Cisco 350 Rugged access points were also used to test the yagi antennas until it was discovered that the Intel equipment worked more efficiently.

The two omni Directional antennas that were used were Cisco model number AIR-ANT2506. They are capable of 5.2dBi gain according to their specifications sheet. The suggested application is outdoors with a short range. According to the specification sheet, the potential range at 11 Mbps is 1580 feet.

The yagi antennas used were Cisco models similar to the current yagi antennas sold by Cisco under the model number AIR-ANT1949. The yagi's used have a 12 dBi gain.

The Intel access points required special adapters to be able to use the Cisco Omni antennas and yagi Antennas. The adapters allowed a RP-TNC connector to convert over to an RP-BNC connector. The Intel access points were setup in the WLAN mode.

The Intel access points were configured to act in the WLAP function, with one acting as the root access point. Connectivity was tested with ping to ensure that there was a connection to the access points. All access points had a built in web interface. Connectivity was also tested by accessing the web interface on the access points to ensure end-to-end connectivity. An application was not tested over the network nor was files transferred over the network for testing.

Both the Cisco and Intel access points work in either a WLAP or WLAN mode, which allows for access points to provide connections to clients when the access points are not hardwired into a LAN. The access points connect to one or more access points to gain connection to the LAN. Both products use a "root" access point, which is connected to the LAN. The terms WLAN and WLAP can be used interchangeably.

The specification sheets for both the Intel and the Cisco access points offer similar information. There is a difference in range that is interesting and can be found in Table 3. However, the specs for the Cisco access points are using a 2.2dBi dipole antenna where the Intel specs are based on using a 1 dBi dipole antenna. Based on this information one can believe that if the Intel also had a 2dBi antenna as the Cisco did, then the Intel range would measure substantially more than the Cisco.

Cisco - Indoors	Intel - Indoors	Cisco - Outdoors	Intel - Outdoors	Mbps
350ft	300ft	2000ft	1500ft	1
130ft	100ft	800ft	400ft	11

Table 3 - Cisco and Intel Range

The Intel 2011B access points use the Intersil Prisim 2.5 Chipset according to the Intel website. I believe that the Cisco 350 access points uses proprietary chipsets created by Cisco. The research done to discover the chipset was unable to prove that other chipsets were used in their equipment.

The Cisco and Intel access points have the same maximum output power settings at 20 dBm. Because of this there should not be any difference in performance in the two different access points caused by the transmit power used. The Intel access points have a minimum power transmit setting of 18 dBm where the Cisco has a minimum setting of 0 dBm. Both access point brands were set to use the maximum power available.

The specifications for receive sensitivity for the Cisco and Intel access points are similar with some differences. As seen in Table 4 the minor differences in dBm between the Cisco and Intel access points.

Cisco	-94 dBm @ 1 Mbps	-91dBm @ 2 Mbps	-89dBm @ 5.5 Mbps	-85dBm @ 11 Mbps
Intel	-90dBm @ 1 Mbps	-88dBm @ 2 Mbps	-87dBm @ 5.5 Mbps	-83dBm @ 11 Mbps

Table 4 - Receive Sensitivity

Figure 12 shows the access point placed at the start of hole five using the yagi antenna. As you can see, the yagi antenna was mounted to the tri-pod to get the antenna in the air and pointed down the course way. Bags of birdseed were used as weight to keep the tri-pods from falling over or moving in the wind.

Figure 12 - Hole 5 AP Placement with Yagi

The yagi antenna at the beginning of the fifth hole was placed five feet high on the tri-pod due to the drastic drop in the terrain. The yagi at the end of the fifth hole was placed on the tri-pod at eight feet. The yagi's on the eighth hole were both placed at eight feet. The yagi's were also placed at eight feet on the tri-pods when implemented at the green box using the Cisco access points.

The access points were limited to the locations on the golf course that they could be placed. It was the desire of the staff at the golf course that the tri-pods not be placed in the tee area or on the playing green. The tri-pods were not to interfere with normal play or detract from the golf course area. These desires lead to the decreased opportunities to place the tri-pods around the course area. This is why the tri-pods were normally placed near trees and out of the playing area. There was also a concern that equipment could get damaged by golf balls or angry golfers should the equipment be in the way of normal play.

Figure 13 shows the placement of an omni antenna near the green box on hole five. The same location was used to place the Cisco access points with the yagi antennas when they were tested. The omni antennas were placed on the tri-pods at eight feet tall to provide the best possible coverage.

Figure 13 - Hole 5 AP placement with Omni

A golf cart was borrowed from the Birch Boilermaker Golf Course each day that testing was done. Equipment was hauled around to the locations needed using the golf cart.

Equipment Cost

Any property of the Computer Technology Department (CPT) was returned at the end of the project. Once the project is finished, equipment will be returned to the CPT department for use within the classes. Equipment was purchased such as portable power units and specialized antennas. A listing of equipment and prices can be found in Table 5.

Price	Description
$30	Porta-power Unit
$40	Power Adapter (Cigarette Lighter Type)
$100	APC UPS Unit
$35	Deep Cycle Battery
$45	AC/DC Converter
$900	Cisco 350 Rugged Access Point
$350	Intel Wireless Access Point
$90	Yagi Antennas
$90	Omni Antennas
$100	RP-BCN to RP-TNC Adapters
$100	2x2 & 2x4 wood products
$30	Miscellaneous Screws and Bolts
$30	Serial Cables & Adapters

Table 5 - Equipment Cost

Definition of Terms

- WEP is Wired Equivalent Privacy is the encryption method that by default is available on all the access points.
- An AP is an access point, which is used to connect to the wired network via the wireless connection.
- 802.11b is the wireless technology that this study will focus on.
- Hacker is a person who attempts to gain unauthorized access into a computer system or network. A hacker is also someone who looks for security vulnerabilities within a computer system or network.
- LAN is defined as a Wired Local Area Network
- WLAN is defined as a Wireless Local Area Network
- WLAN is the term used for Cisco APs when in a bridging or repeating mode
- WLAP is the term used for Intel APs when in a bridging or repeating mode
- IPAQ refers to a Compaq Pocket PC Device
- CAM refers to a Power consumption mode on IPAQ Devices
- Fast PSP refers to a Power consumption mode on IPAQ Devices

Assumptions

- All users will access the network using a wireless enabled PDA or Laptop
- The same technique used for this project can be used for other similar projects
- Proper training will be provided for the network administrator
- Users will be trained on how to use the wireless network

Delimitations

- Focus on 802.11b technology only for the project
- Desire to have a low cost implementation plan
- Project is limited to two holes at the golf course
- Power will be required from portable sources to power the access points, how to power the access points on a long term basis is not part of the scope of the project
- ROI is not part of this project
- Mesh Network Architecture will not be tested in this project, due to a lack of equipment
    - It was originally planned to test Mesh architecture along with hub and spoke, however the equipment requested never arrived
- All measurements were taken from a stationary position
- The placement of access points were limited on the course, as the access points were not to impede play on the course or deter from the look of the course
- No applications were tested over the network architecture
- No connections to the Internet were tested over the network architecture
- Testing was limited to the fairway on the selected holes
- The hub and spoke network design was only implemented on one hole at a time

Results

When reviewing the test results, all Signal Strength and Signal Quality readings should be reviewed with a ±5% due to the fluctuation of signal. The in-depth results for each access point, antenna and placement design can be found in the Appendix.

It was discovered that the overall link quality must be “Fair” or better to maintain a reliable connection. Thus if the connection quality is “Poor” more access points will need to be installed to allow for reliable connections. The minimal signal strength allowed for a reliable connection is 25% with signal quality at 31% or above to maintain a “Fair” connection quality.

The following maps were created from the test results found in the Appendix section of the report. The readings were recorded at various locations throughout the fairway. The scope of the project was to provide coverage on the fairway. The maps are separated by hole, access point, antenna, antenna placement and equipment used to test for connection. PDA using both the constantly awake mode and the fast power save mode results has been combined on the maps as a significant difference was not found in the results.

Coverage of hole eight using Intel access points and yagi antennas tested with a laptop is seen in Figure 14. The access points were placed at each end of the hole as shown in the figure. With this setup the area around the green near the hole and the hole itself was covered with excellent signal. The area at the beginning of the green around the creek and 250 yard marker was covered with fair signal. Also, fair signal was provided near the third tee off area. This was due to the terrain change as the hill drops off very quickly after the first tee off area. The data which was gathered during this test can be found in Appendix 1 – Hole 8 – Intel Access Points - Yagi on page 15.

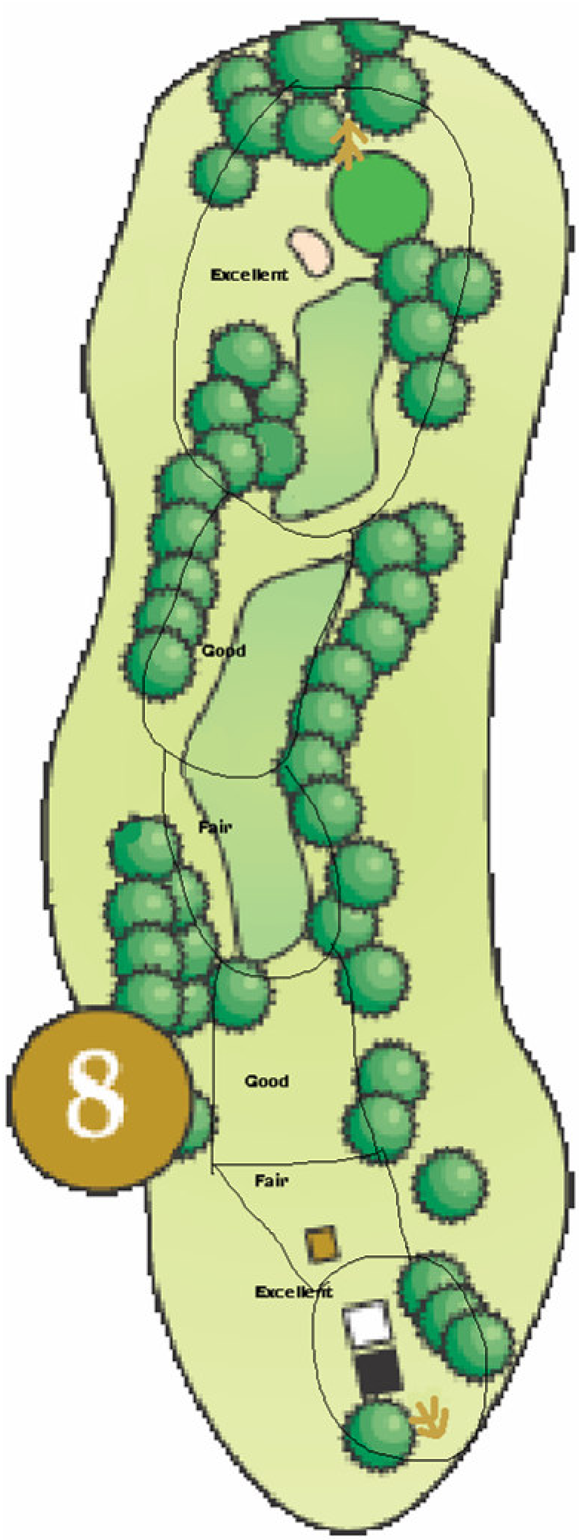

Figure 14 – Hole 8 Yagi & Intel APs[11]

[11] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

The coverage map of hole eight using Intel access points and yagi antennas tested with a PDA is seen in Figure 15. The access points were placed at each end of the hole as shown in the figure. In this figure good coverage was provided for the last green area and the hole. This solution provided fair coverage for the majority of the area. The data which was gathered during this test can be found in Appendix 1 – Hole 8 – Intel Access Points - Yagi on page 15.

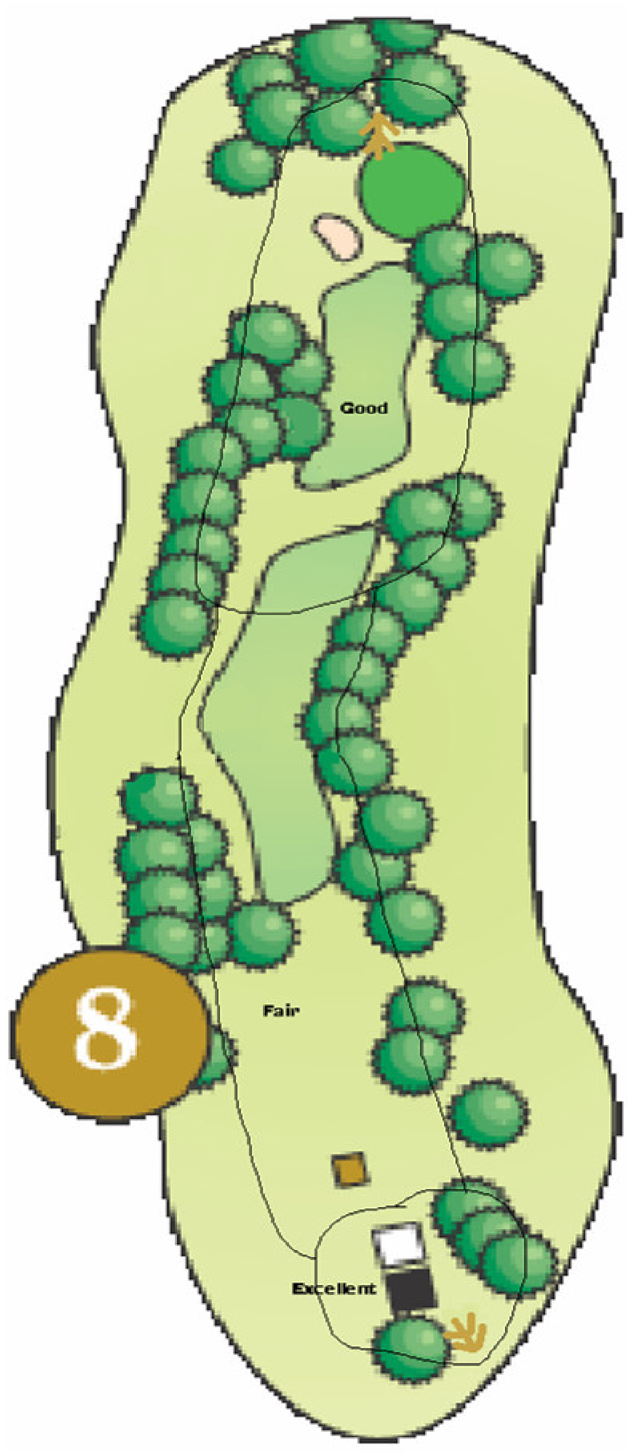

Figure 15 – Hole 8 Yagi & Intel APs[12]

[12] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

Coverage of hole eight using Cisco access points and yagi antennas is seen in Figure 16. The access points were placed at each end of the hole as shown in the figure. The Cisco access points provided only poor coverage around the 200 yard area in the green. Around the 200 yard area is a valley between the two ends of the hole with a grove of trees off to each side. The 250-yard area and creek area had fair coverage. With good coverage at each end the beginning of the hole had some excellent coverage zones. The data which was gathered during this test can be found in Appendix 2 – Hole 8 – Cisco Access Points - Yagi on page 15.

The Cisco access points and yagi antennas would provide minimal coverage on the eighth hole. However, with this solution there were areas where the overall link quality was poor; thus providing an unreliable signal. At times the secondary access point would drop the client as the connection to the root was not reliable.

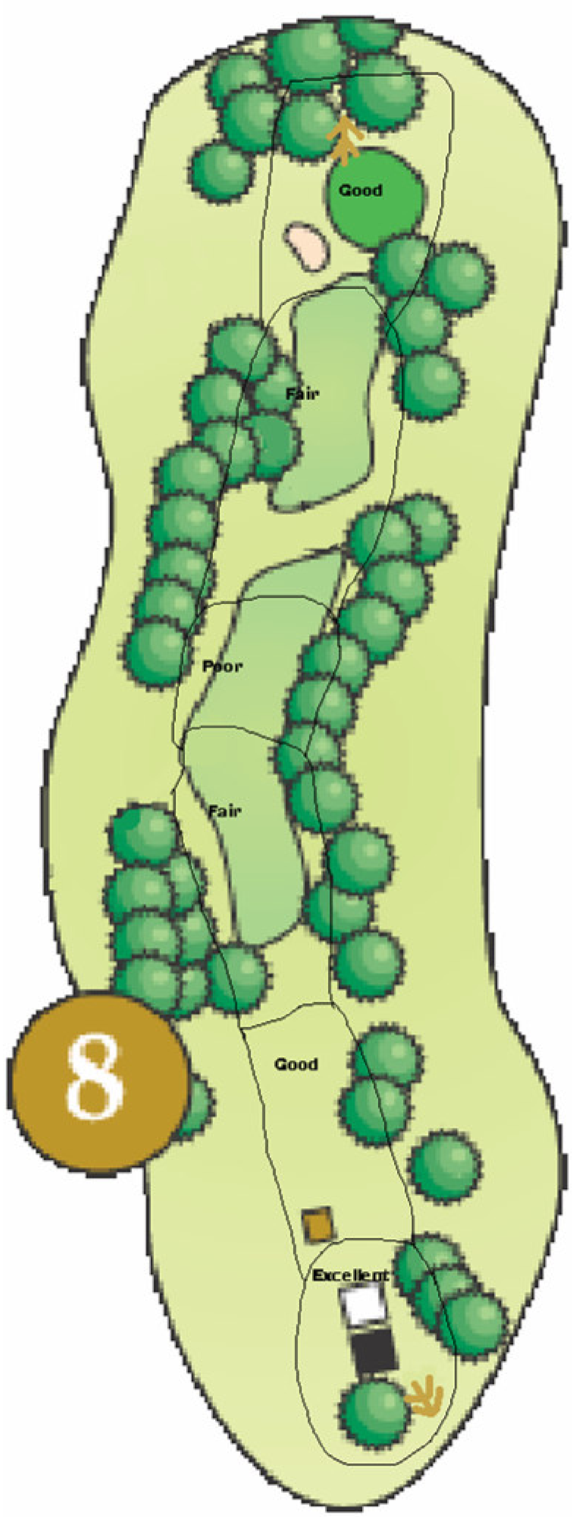

Figure 16 – Hole 8 Yagi & Cisco APs[13]

[13] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

Coverage of hole eight using omni antennas and Intel access points tested with a laptop is seen in Figure 17. The access points were placed at each end of the hole as shown in the figure. Using omni antennas there was an area of poor coverage near the 250-yard marker and the creek. Most of the hole was covered in fair or good signal. Another area of poor coverage was at the third tee-off area. This is where the hill starts a substantial drop off which levels out near the green. The data which was gathered during this test can be found in Appendix 3 – Hole 8 – Intel Access Points - Omni – v1 on page 15.

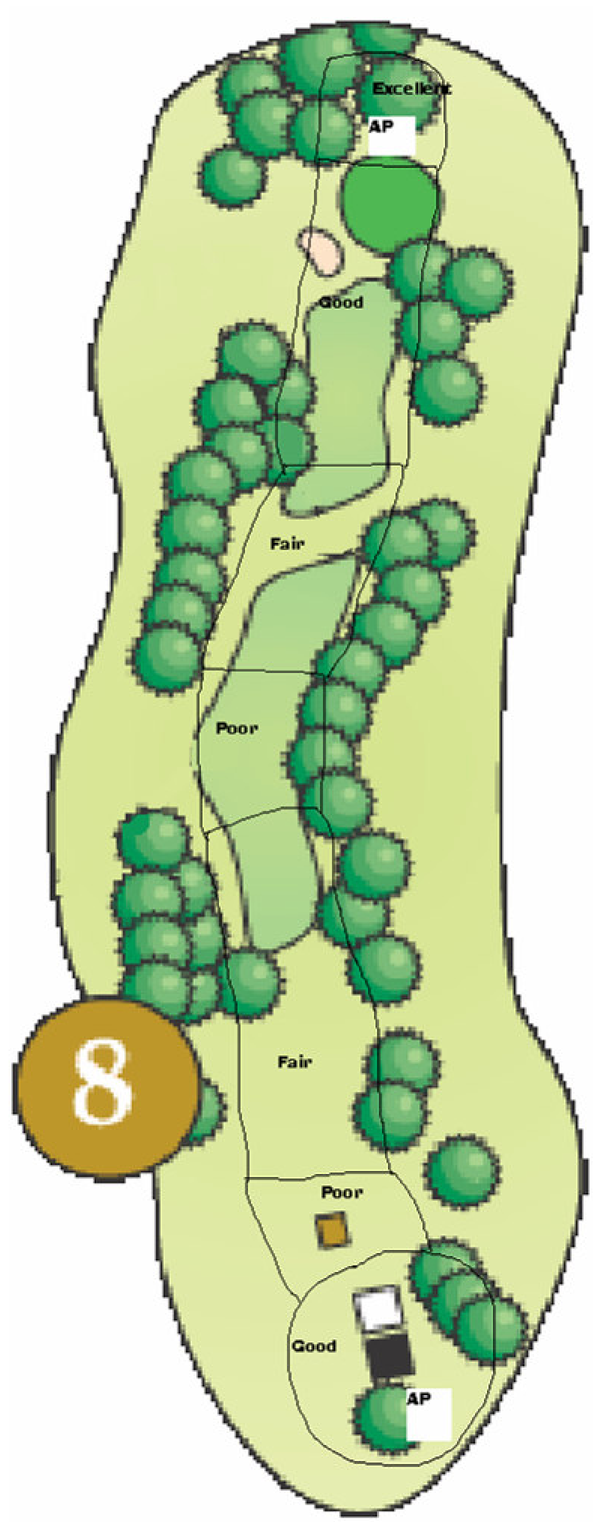

Figure 17 – Hole 8 Omni & Intel APs[14]

[14] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

Coverage of hole eight using omni antennas and Intel access points tested with a PDA is seen in Figure 18. The access points were placed at each end of the hole as shown in the figure. Using omni antennas and a PDA, each end of the hole was recorded to have a minor area of excellent coverage. There was a smaller area with poor coverage near the 250 yard marker and the creek. This area has trees on both sides of the green and is in a valley. Around fifty percent of the area was covered in fair coverage. The last green and part of the hole had good signal coverage. The data which was gathered during this test can be found in Appendix 3 – Hole 8 – Intel Access Points - Omni – v1 on page 15.

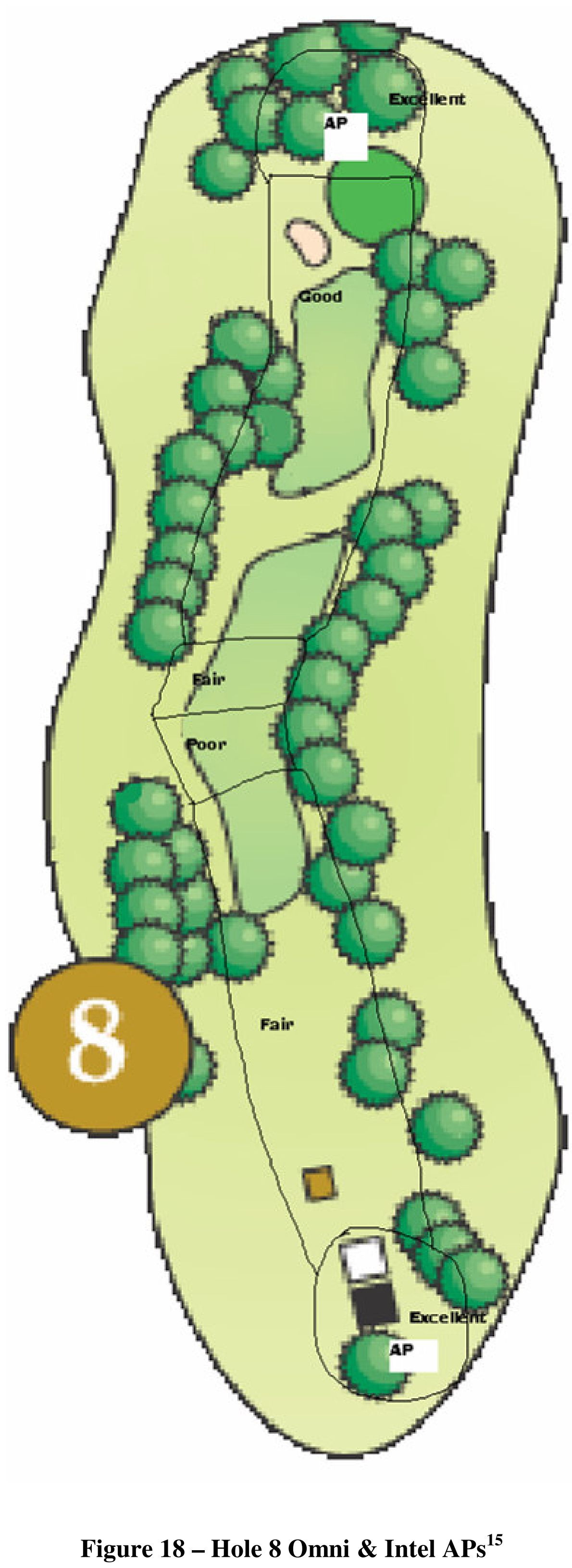

Figure 18 – Hole 8 Omni & Intel APs[15]

[15] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

Coverage of hole eight seen in Figure 19 shows the coverage provided with Intel access points placed at the end and near the middle. The test was measured using a laptop computer. In an attempt to provide better coverage on the hole the second access point was placed near the middle of the hole where previously poor coverage had been recorded. With this setup there were no poor coverage areas. However, the area near the start of the hole only received fair coverage; this starts the climb back up the hill. Excellent coverage was provided near both access points. The data which was gathered during this test can be found in Appendix 4 – Hole 8 – Intel Access Points - Omni – v2 on page 15.

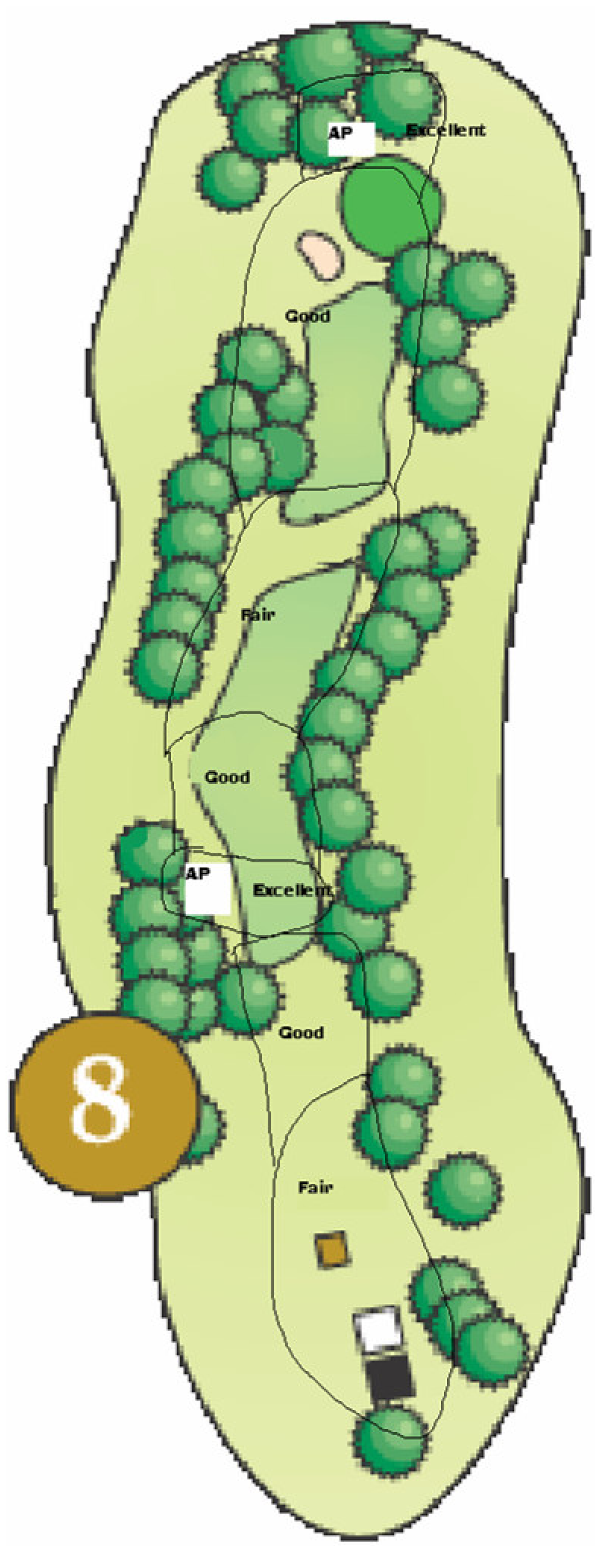

Figure 19 – Hole 8 Omni & Intel APs[16]

[16] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

Coverage of hole eight seen in Figure 20 shows the coverage provided with Intel access points placed at the end and near the middle. The test was measured using a PDA. Using the PDA on the test recorded some poor coverage around the tee-off area which is at the top of a hill because the access point is located down the hill in the valley area. The majority of the hole shows fair coverage. Some good coverage is recorded near the hole and near the second access point. The data which was gathered during this test can be found in Appendix 4 – Hole 8 – Intel Access Points - Omni – v2 on page 15.

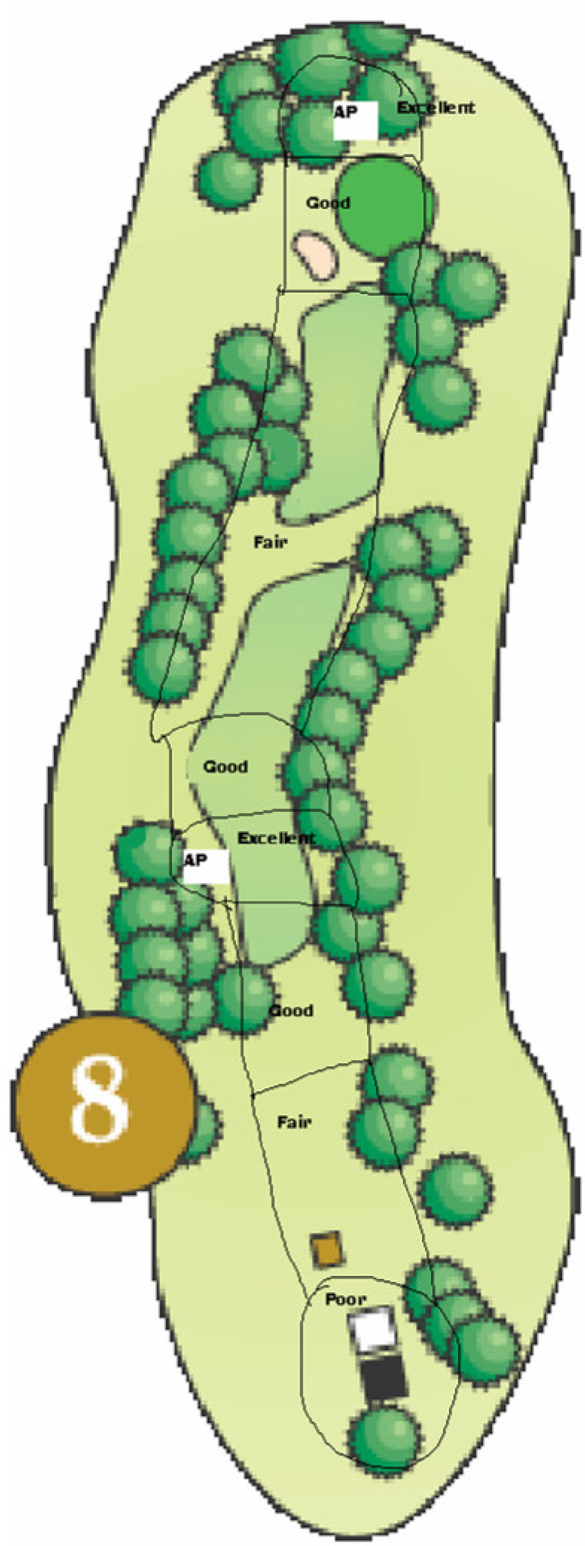

Figure 20 – Hole 8 Omni & Intel APs[17]

[17] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

On the eighth hole Intel access points and omni antennas were placed at each end of the hole for one set of testing. Then one access point was placed at the end of the hole with the second access point being placed near the creek along the cart path. The test with the second access point placed near the cart path provided good signal for most of the green area. The tee box area received a fair to poor signal coverage creating an unreliable connection.

Figure 21 shows the coverage provided with Intel access points placed at both ends of the fifth hole using yagi antennas. The test was measured using a PDA. A small area of poor coverage was recorded near the 250 yard marker which is in a deep valley. A majority of the hole received good coverage. One area received fair coverage which would be near the 200 yard marker. Excellent coverage is provided at each end of the hole with the access points. There is a substantial drop off from the tee-off area once you hit the green. You stay lower until you work near the 100 yard area and then start going up. There is a decent amount of fluctuation on this hole. The data which was gathered during this test can be found in Appendix 5 – Hole 5 – Intel Access Points - Yagi on page 15.

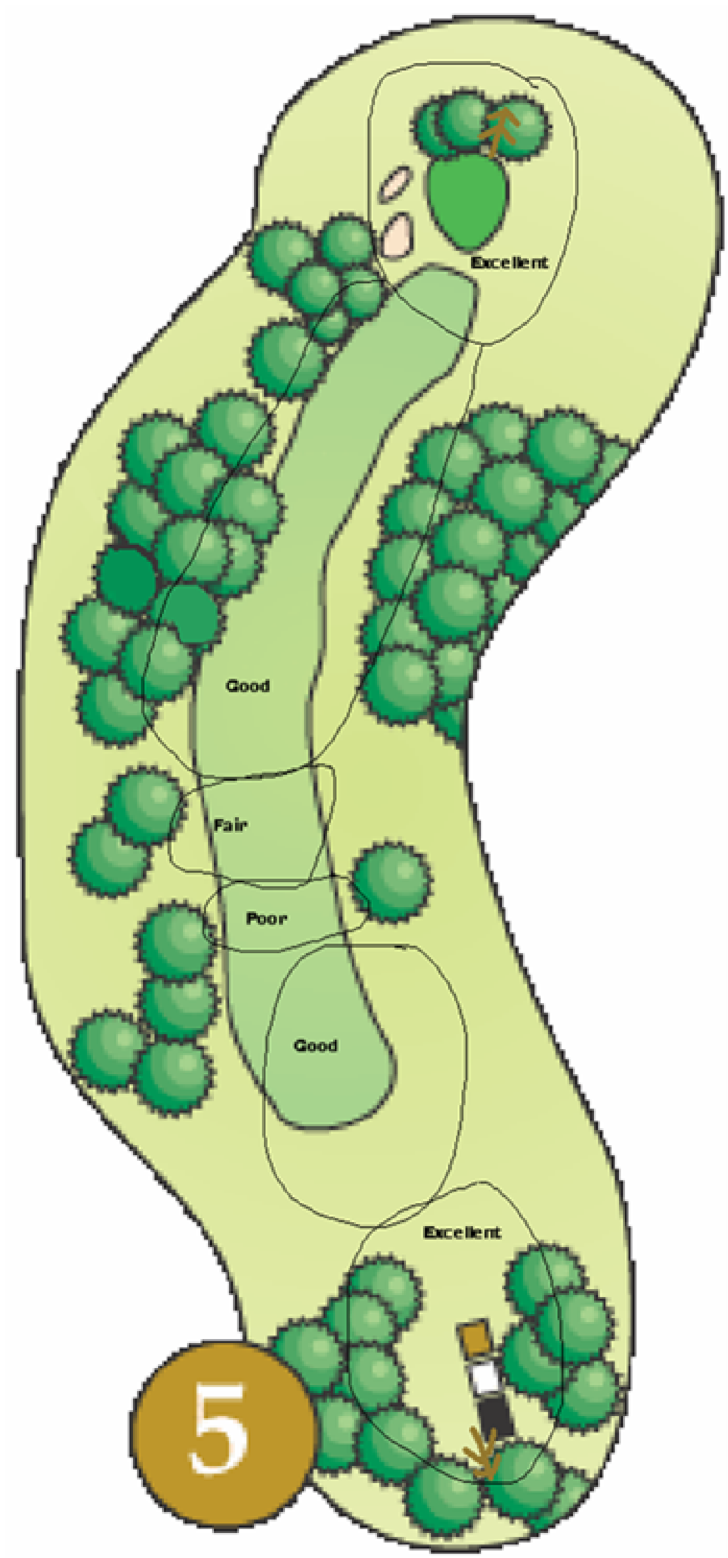

Figure 21 – Hole 5 Yagi & Intel APs[18]

[18] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

Figure 22 shows the coverage provided with Intel access points placed at both ends of the fifth hole using yagi antennas. The test was measured using a laptop. Excellent coverage is recorded at each end of the hole. The second access point has a larger area of excellent coverage going near the 100 yard marker. A small area of poor coverage was also recorded near the 250 yard area, which is a major valley in the green. The data which was gathered during this test can be found in Appendix 5 – Hole 5 – Intel Access Points - Yagi on page 15.

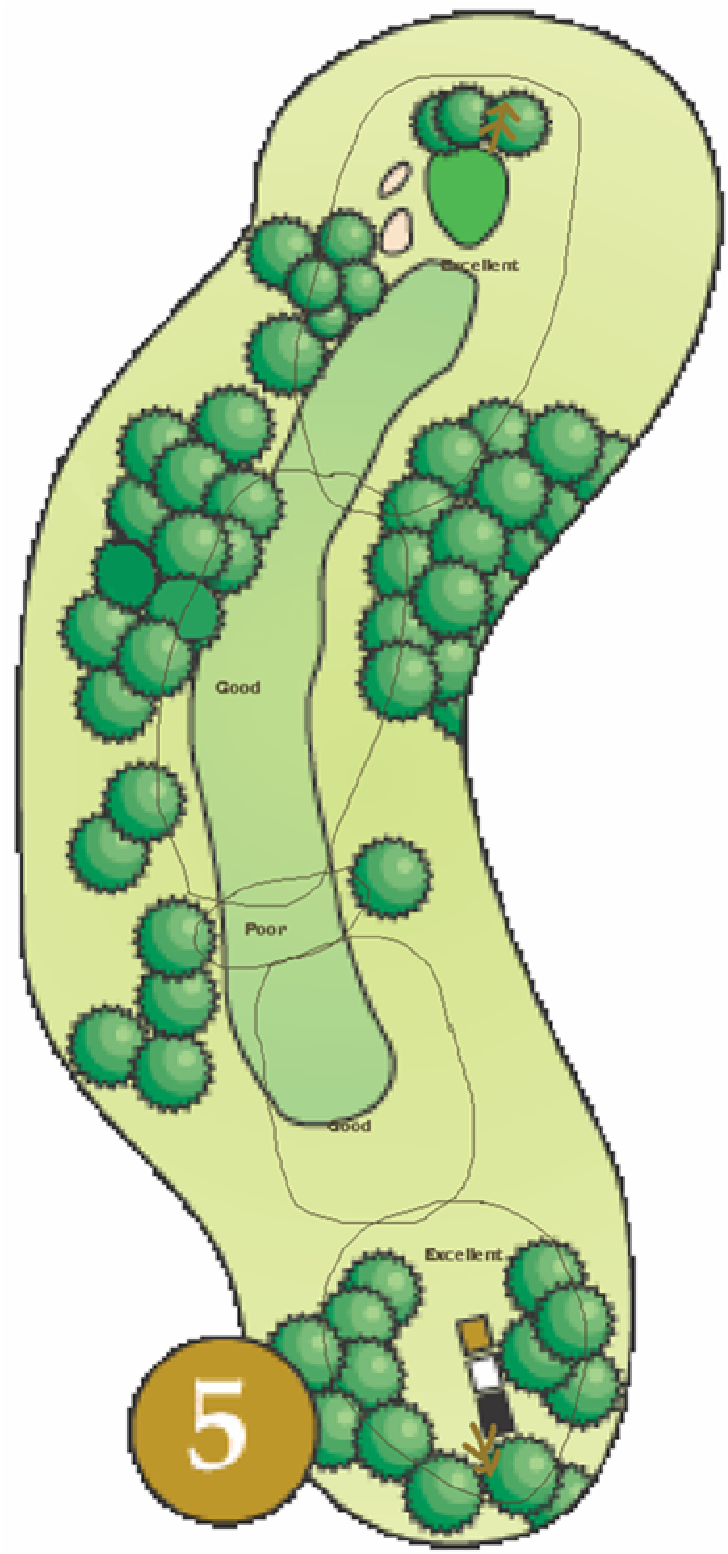

Figure 22 – Hole 5 Intel APs & Yagi[19]

[19] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

Figure 23 shows the coverage provided with Cisco access points placed near the green box using yagi antennas. The test was measured using a PDA and laptop. The Cisco access points would not authenticate with each other if placed at each end of the hole. Therefore they were placed back-to-back at the green box. There was enough signal leakage out the back of the yagi antennas to allow them to authenticate with each other. Poor coverage was recorded around the tee-off area up towards the first curve in the cart path. This area is within line of sight of the access points and is also on level ground. A small area of excellent coverage was recorded around the actual access points. Most of the area was covered in good signal with two patches of fair signal coverage areas.

With the Cisco access points and yagi antennas placed at each end on the fifth hole coverage was not provided, as the secondary access point would not associate with the root access point. When a Cisco secondary access point becomes disassociated with the root, the access point immediately drops all clients and refuses client connections until connection to a root access point can be obtained. The Cisco access points with yagi antennas were placed back-to-back at the green box on the fifth hole to provide coverage. With this setup there was poor coverage to the area near the tee box which would be an area that needs to have a higher level of coverage. The data which was gathered during this test can be found in Appendix 6 – Hole 5 – Cisco Access Points - Yagi on page 15.

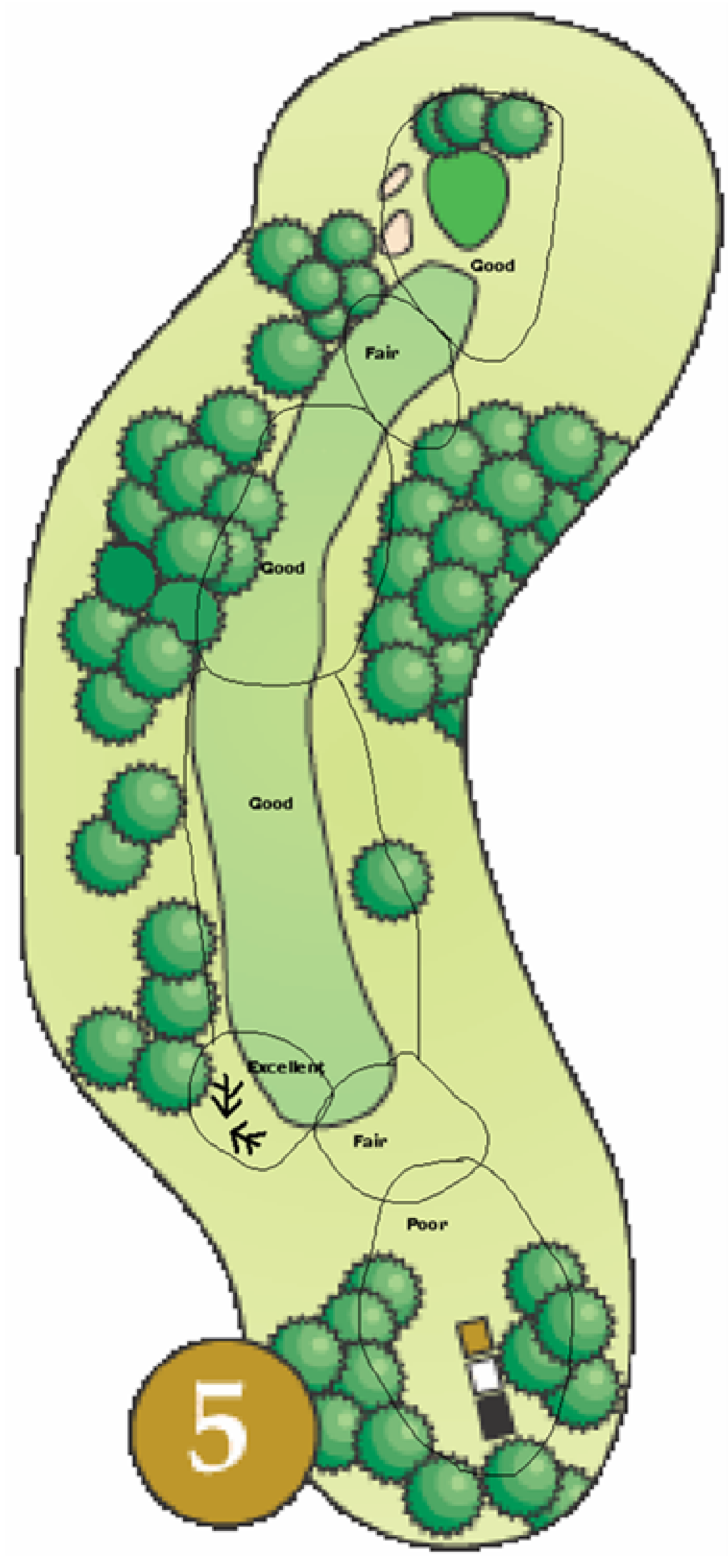

Figure 23 - Cisco APs & Yagi[20]

[20] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

Figure 24 shows the coverage provided with Intel access points placed at both ends of the fifth hole using omni antennas. The test was measured using a laptop. A small area at each end of the hole had excellent signal coverage. A large area of the green had poor signal coverage from near the first curve in the cart path to near the 200 yard marker. The area receiving poor signal has a couple of good valleys and is substantially lower than the location that holds the access points. The area from near the 200 yard marker towards the 100 yard marker was a coverage area of fair coverage. The data which was gathered during this test can be found in Appendix 7 – Hole 5 – Intel Access Points – Omni – v1 on page 15.

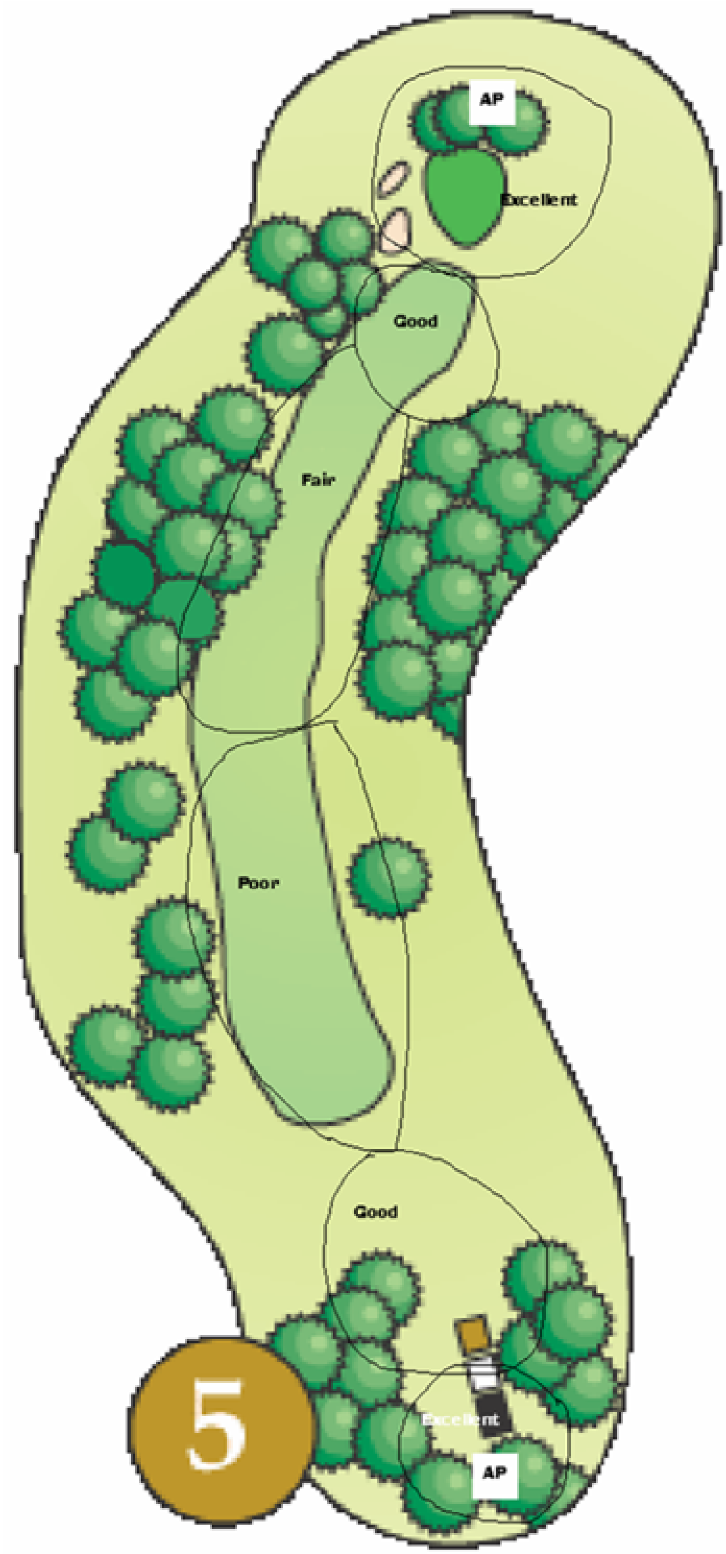

Figure 24 – Hole 5 Omni & Intel APs[21]

[21] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

Figure 25 shows the coverage provided with Intel access points placed at both ends of the hole using omni antennas. The test was measured using a PDA. A small area of excellent coverage was measured near each access point. Poor coverage was recorded from near the second curve in the cart path to near the 200 yard marker. The area receiving poor signal has a couple of good valleys and is substantially lower than the location that holds the access points. Fair coverage was provided from near the 200 yard marker to near the 100 yard marker. The data which was gathered during this test can be found in Appendix 7 – Hole 5 – Intel Access Points – Omni – v1 on page 15.

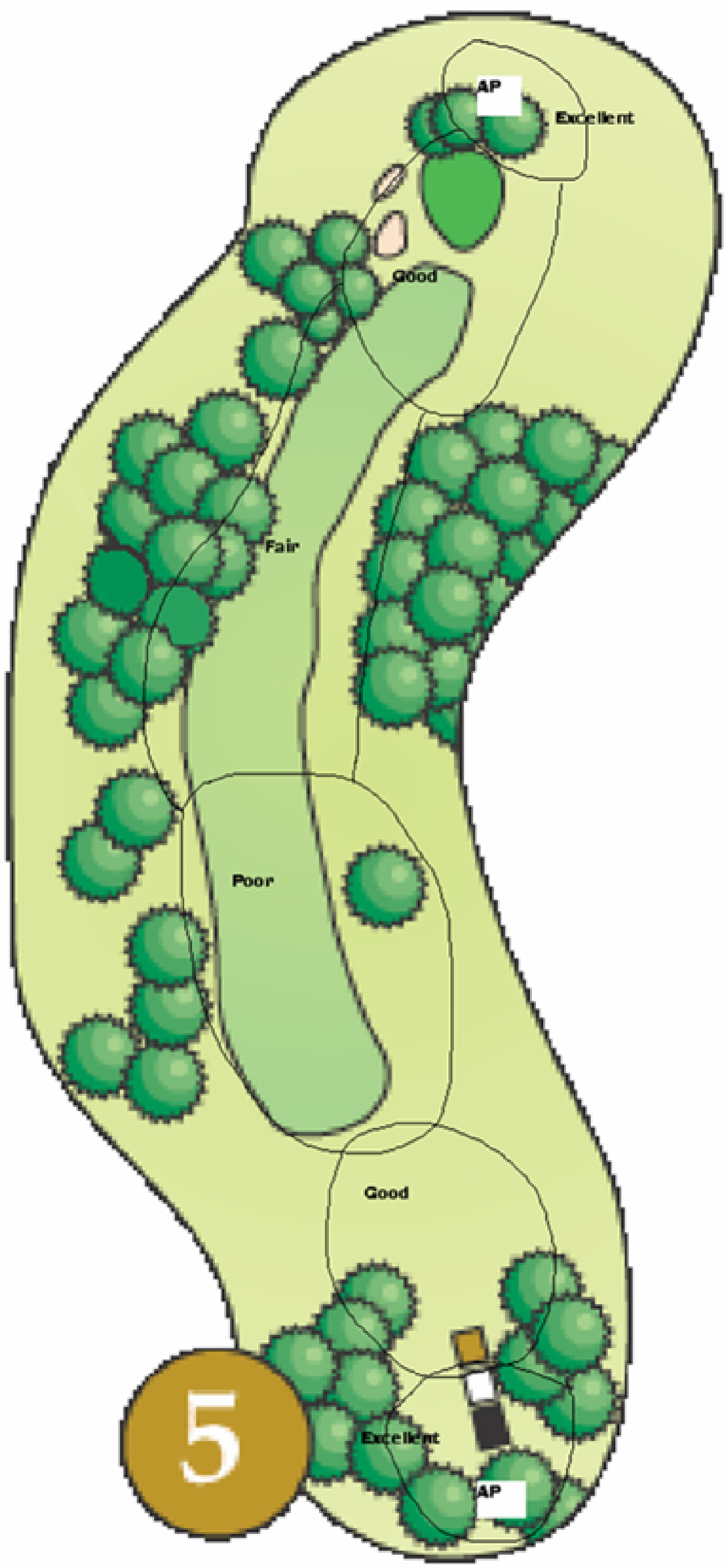

Figure 25 – Hole 5 Omni & Intel APs[22]

[22] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

When the two access points were placed at each end of the hole, some areas were not provided with coverage. The two access points were able to associate with each other; however coverage was not universal throughout the hole. Coverage around the 250 yard area was either poor or unavailable. There was also a decent amount of area that only received a fair overall link quality signal.

Figure 26 shows the coverage provided with Intel access points placed at near the green box using omni antennas. The test was measured using a laptop. By placing the root access point near the green box with the second access point still placed at the end of the hole a different coverage pattern was obtained. Most of the green was covered with fair signal as seen in the figure. Also, the area around the tee-off area was provided with fair signal. Only three smaller areas were provided with good coverage. The data which was gathered during this test can be found in Appendix 8– Hole 5 – Intel Access Points - Omni – v2 on page 15.

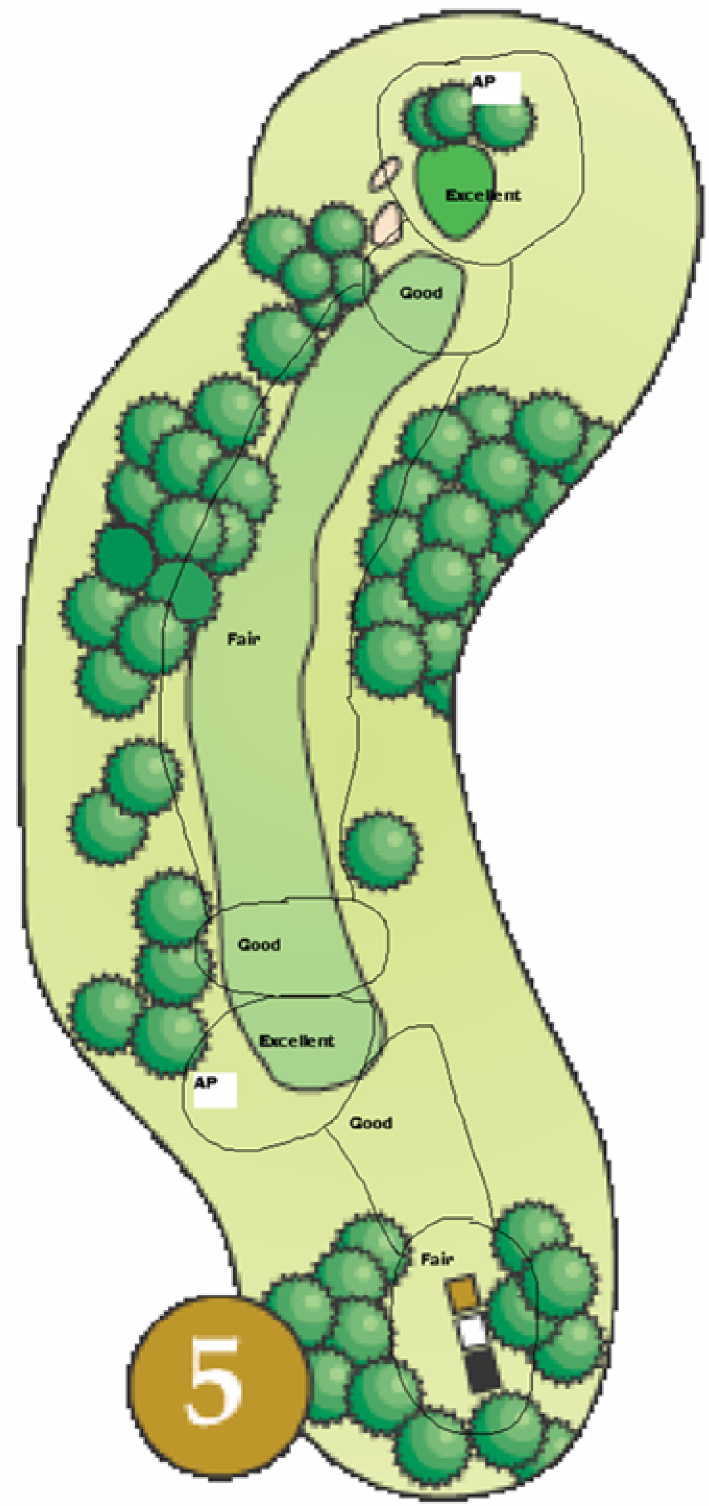

Figure 26 – Hole 5 Omni & Intel APs[23]

[23] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

Figure 27 shows the coverage provided with Intel access points placed near the green box using omni antennas. The test was measured using a PDA. Again the root access point was placed near the green box and the secondary access point was placed at the end of the hole. Good coverage was provided from the start of the hole up to near the bell. Fair coverage was then provided up towards the 100 yard marker. The data which was gathered during this test can be found in Appendix 8– Hole 5 – Intel Access Points - Omni – v2 on page 15.

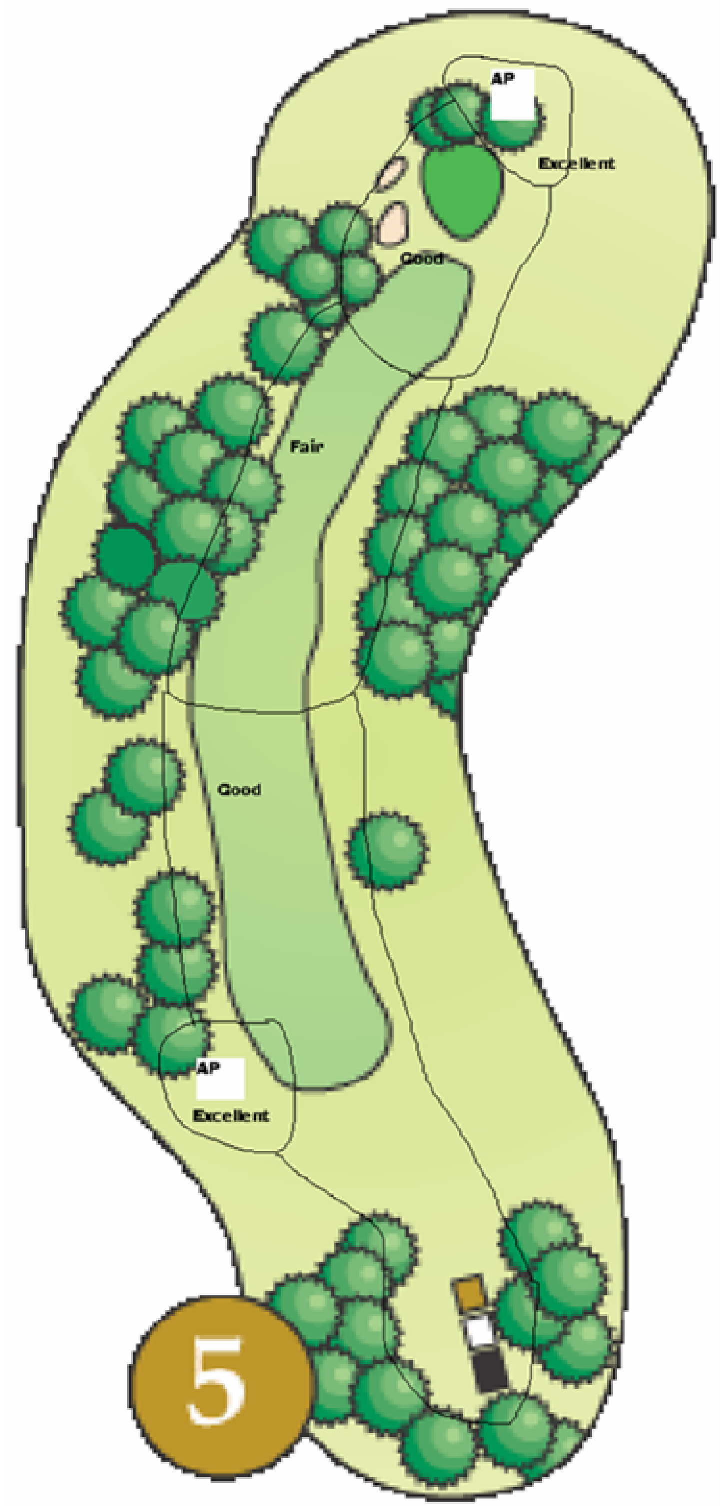

Figure 27 – Hole 5 Omni & Intel APs[24]

[24] From: http://www.purdue.edu/Athletics/golf/ackerman.htm

On hole five with an access point placed at the green box and one placed at the end coverage improved substantially. Areas throughout the hole no longer had poor coverage. There was some fair link quality recorded. However the tee box area was tested and received a fair to good overall link quality. A person would prefer to receive a good overall link quality at that area as clients are more likely to be sitting there waiting for other golfers to play through the hole.

Conclusions

Testing was conducted with a laptop computer and a PDA using CAM and Fast PSP power consumption modes. Because there is a ±5% for all of the readings it was found that there was not a significant difference in signal received using the different power modes. There was some difference noted between the laptop computer and the PDA in regards to signal.

With both Cisco access point implementations there were problems noted with accessing the built in web interface on the access points, such as a considerable delay in browsing through the pages. There were also unreliable ping response times and extended ping response times. Because of the delayed ping response times and other problems more Cisco access points would need to be implemented than Intel access points. This would drive up the cost of the implementation, potentially making the project economically unfeasible.

The Intel access points were tested on both the fifth hole and the eighth hole using yagi antennas. These units were setup at the beginning and the end of the hole aiming the yagi down the fairway. On the fifth hole the yagi antennas provided good signal throughout the course. The only area that was weak was around the 250 yard marker. The 250 yard marker was down in a valley area between the two access points. To provide a better signal one could add a third access point in the weaker area. The eighth hole also had good signal coverage throughout the area. One area that could have used better coverage was the creek at the path. Near this area signal was weaker and not as reliable. However, there was still enough signal provided to facilitate the needs of users.

Omni directional antennas were also tested with the Intel access points on both holes five and eight. These were tested at different locations on each hole to discover if there was a better location to place the access points to provide for reliable coverage.

Using omni antennas the area covered with good/excellent overall link quality was substantially decreased compared to using yagi antennas. When the omnis were setup at each end of the course poor signal was recorded near the creek on the cart path. A large area was only covered with fair overall link quality. Although fair can provide reliable signal, it is recommended that good be provided for the area to insure reliable coverage.

Omni antennas were also tested on the fifth hole in two different setups. One setup had both omni antennas placed at each end of the course in the same format as the yagi antennas previously. The second setup for the omnis has one placed near the end of the hole with the root access point placed near the green box.

The recommendation is that the Intel access points and yagi antennas be used to provide coverage as the area covered and link quality provided was substantially better than with any other solution tested. Another access point that preformed similarly to the Intel access points would also be a feasible solution.

Because of the signal spread created from the yagi antennas they worked most effectively on the course. If one looks at the hole layout it is somewhat in a straight line. The yagi antennas are designed for point-to-point connection covering a large span. If one is not covering the normal 20 mile span you can achieve connection to clients. It was proved that clients can connect to yagi antennas and maintain connection in a hilly environment with the proper access point placement.

Because of the environment, the yagi antennas proved to be a good solution due to their ability to “aim” the coverage. These results should be able to be used on the other holes since the two selected holes are believed to be the most difficult to implement a wireless network.

Because of the strong signal gain achieved with the yagi antennas proper coverage is provided. The yagi antennas used did have a higher gain than the tested omni antennas. Using an omni directional antenna with a larger gain could have increased the coverage. However the omni does not concentrate the coverage pattern like the yagi antennas. With the omni antennas you are not able to direct or aim the signal coverage.

Because of the ±5% on the signal strength and signal quality the overall link quality changed at times. A good reading could have bumped up to excellent or down to fair very easily. Each reading was done as accurately as possible. Movement was halted to allow for a reliable reading. However the numbers received still would change during measurement.

Using Cisco access points and yagi antennas on the fifth hole located at each end did not work due to the line of sight issue. On this hole there is no direct line of sight from one end to the other. There is also a substantial degree of elevation change. Elevation changes such as that found on the fifth hole has a negative impact on overall signal quality. The angle that separates the end of the hole also causes a negative impact on signal propagation. Because of the way that Cisco access points associate with the root, the problem of disassociating with the root was quickly evident.

Because of the elevation changes found on both holes there were negative impacts to the propagation of the signal. When hills are involved wireless coverage is negatively impacted. A shadow type affect is created when going down a hill towards a valley, resulting in a degradation of signal coverage. Therefore more access points will be required in an environment such as this; regardless of the distance involved.

Intel and Cisco access points were tested for effectiveness on the golf course. Both brands have similar specifications. The Cisco equipment had longer ping response times and decreased throughput. The Intel equipment provided better ping response times.

Testing showed a significant difference between Intel access points with yagi antennas and Cisco access points with the same antennas. Using Cisco equipment on the fifth hole provided more poor coverage areas whereas Intel equipment provided for good coverage at the same areas. One can also see a difference in the coverage provided. The Cisco access points were not able to be placed in the same position as the Intel access points as the Cisco access point would not associate with the root reliably.

If you look at the same technology on the eighth hole you can see the differences easier as the placement of the access points are the same. There were problems with the secondary Cisco access point disassociating with the root access point; however tests could still be conducted. Using the Cisco equipment with this setup there is an area of poor coverage, whereas with the Intel equipment that same area good to fair coverage.

If you compare the Intel access points using the yagi antennas to the omni antennas placed at the same location on both holes you can see the coverage difference. On the eighth hole using omni antennas you get poor coverage in areas that received fair to good coverage with yagi antennas. On the fifth hole substantial areas are covered in poor signal with the omni antennas whereas with yagi antennas the poor coverage area is significantly reduced. From this information you can see that yagi antennas are a better solution than omni antennas.

The cost with implementing a hub and spoke network on the golf course would not be prohibitive as this project proved that the task can be done using two access points per hole. From the results of the project it is believed that one could provide wireless coverage through the course by using an average of two access points with yagi antennas on each hole. Each access point must be set for WLAN/WLAP mode and the correct priority so that they can connect to the root access point.

The cost of implementation per hole is $1140 for two access points with yagi antennas. Other equipment needed would be a way to mount the access points and antennas, and a method to power the access points. The referenced cost only includes the network equipment and does not include labor.

Further Study Areas

The following items are included in the larger project at the Birch Boilermaker Golf Complex at Purdue University. The items include: Mesh Network Architecture, 802.11b hub and spoke network architecture dealing with the interaction between holes, Nextel cellular coverage, and connection to the local area network. Once the network architecture is chosen and implemented then the actual applications can be designed and implemented.

Mesh Network Architecture should be tested to see the coverage that could be provided with the equipment. Mesh Network Architecture is a new architecture that could be very interesting to test and to see what can be created using the technology. Mesh Equipment similar to the FireTide Equipment or the Locust Equipment would be interesting to test. As the mesh network theory is similar to what is desired on the golf course, to cover the entire area with wireless signal. By using mesh equipment it looks like this could be done reliably and quickly. However, more research and testing needs to be done with mesh equipment to discover if this is a feasible option.

Analyze how the different holes would be able to interact with each other and if coverage from one specific hole could be used to provide coverage for other areas. Research was not done on the amount of coverage provided to other holes that were not the direct target of the access point's coverage. How the access points would interoperate with each other on the different holes needs to be reviewed. Coverage from one hole might also help cover a nearby hole.

Another area that could be tested would be the Nextel cellular coverage. Research into the solutions provided and the setup involved would need to be done. Very little research has been done for the Nextel coverage potential. Research should be done into cost and implementation time. What type of applications can be used over the network and what type of equipment is used with this network?

Evaluating the best method of obtaining access to the Internet is needed. Should one base unit be connected to a wired connection or should multiple units be connected to a wired connection? Because of the vast area covered by wireless coverage the number of LAN required needs to be researched. There is a 255 hop limit on TCP/IP packets so as long as the internal network did not have 255 or more hops technically the traffic could still access the Internet. However, an ideal network implementation decreases the number of hops needed to access the Internet as much as possible.

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Appendix

The following pages contain the actual numbers generated from the test that were conducted on the Ackerman Hills Golf Course through out the summer of 2004. The equipment used to measure each test and equipment used for testing can be found with each test. The following data was used to create the previously seen maps of overall link quality provided on holes five and eight.

Appendix 1 – Hole 8 – Intel Access Points - Yagi

Hole 8	**AP Placed at each end of the hole**								
Equipment:	Yagi & Intel & PDA - PSP			Yagi & Laptop & Intel			Yagi & PDA & Intel - CAM		
Location	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality
2nd AP	95	78	Excellent	100	78	Excellent	100	78	Excellent
442 - Path	88	81	Excellent	36	59	Fair	33	65	Fair
Cotton Wood Tree by road	25	50	Fair	50	62	Good	32	65	Fair
Culvert Dump	32	62	Fair	39	62	Fair	35	75	Fair
Sewer Manhole	40	75	Fair	41	59	Good	33	62	Fair
Drain in green	41	75	Good	32	40	Fair	25	50	Fair
ditch - from road	28	50	Fair	30	31	Fair	33	62	Fair
on Hill by white posts	50	65	Good	n/a	n/a		60	68	Good
on Hill by white posts	53	78	Good	n/a	n/a		n/a	n/a	
200 - in green	18	37	Poor	41	71	Good	50	75	Good
150 - in green	23	62	Fair	75	81	Good	30	62	Fair
150 - Path	n/a	n/a		n/a	n/a		70	78	Good
at Y on path	75	84	Excellent	45	78	Good	n/a	n/a	
drain on Y	42	81	Good	100	81	Excellent	70	75	Good
100 - Green	64	81	Good	88	81	Excellent	85	78	Excellent
Hole	68	84	Excellent	94	84	Excellent	88	75	Good
Root	38	62	Fair	100	84	Excellent	100	75	Good
Average:	49.4667	69.53		59.3077	66.6923		56.2667	69.5333	
Max	95	84		100	84		100	78	
Min	18	37		30	31		25	50	

Appendix 2 – Hole 8 – Cisco Access Points - Yagi

Hole 8	**AP Placed at each end of the hole**					
Equipment:	Yagi & Cisco & Laptop			Yagi & Cisco & PDA - PSP		
Location	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality
2nd AP	98	87	Excellent	98	87	Excellent
442 - Path	42	53	Good	30	60	Fair
Cotton Wood Tree by road	47	78	Good	47	80	Good
Culvert Dump	45	71	Good	45	78	Good
Sewer Manhole	38	71	Fair	39	71	Fair
Drain in green	36	68	Fair	32	71	Fair
ditch - from road	25	43	Fair	35	75	Fair
on Hill by white posts	n/a	n/a		1	18	Poor
on Hill by white posts	n/a	n/a		35	75	Fair
200 - in green	n/a	n/a		44	84	Good
150 - in green	n/a	n/a		18	37	Poor
150 - Path	25	50	Fair	n/a	n/a	
at Y on path	20	31	Poor	64	87	Good
drain on Y	n/a	n/a		35	81	Fair
100 - Green	n/a	n/a		36	78	Fair
Hole	n/a	n/a		30	71	Fair
Root	98	87	Excellent	64	84	Good
Average:	41.7778	61.333		39.2667	70.2	
Max	98	87		98	87	
Min	20	31		1	18	

Appendix 3 – Hole 8 – Intel Access Points - Omni – v1

Hole 8	**Omni Located at both ends of hole**								
Equipment:	Omni & Intel & Laptop			Omni & Intel & PDA - PSP			Omni & Intel & PDA - CAM		
Location	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality
2nd AP	95	75	Good	98	81	Excellent	83	78	Excellent
442 - Path	20	21	Poor	32	62	Fair	18	25	Poor
Cotton Wood Tree by road	23	34	Fair	23	50	Fair	28	40	Fair
Culvert Dump	30	53	Fair	20	37	Poor	32	62	Fair
Sewer Manhole	30	59	Fair	25	56	Fair	20	40	Fair
Drain in green	25	25	Fair	13	31	Poor	23	46	Fair
ditch - from path	15	6	Poor	10	3	Poor	20	31	Poor
on Hill by white posts	36	62	Fair	30	62	Fair	n/a	n/a	
200 - in green	23	15	Poor	35	68	Fair	23	46	Fair
150 - in green	36	56	Fair	37	75	Fair	45	78	Good
150 - Path	41	68	Good	48	71	Good	45	78	Good
at Y on path	28	50	Fair	20	40	Poor	50	70	Good
drain on Y	39	75	Fair	40	75	Fair	60	81	Good
100 - Green	64	78	Good	47	78	Good	53	81	Good
100 - Path	44	78	Good	45	75	Good	53	81	Good
Hole	41	65	Good	53	71	Good	73	81	Good
Root	88	78	Excellent	93	81	Excellent	98	78	Excellent
Average:	39.8824	52.82		39.3529	59.7647		45.25	62.25	
Max	95	78		98	81		98	81	
Min	15	6		10	3		18	25	

Appendix 4 – Hole 8 – Intel Access Points - Omni – v2

Hole 8	**Omni, one at end, 1 near creek**								
Equipment:	Omni & Intel & PDA - CAM			Omni & Intel & PDA - PSP			Omni & Intel & Laptop		
Location	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality
T Box	28	59	Fair	10	18	Poor	25	9	Poor
442 - Path	30	71	Fair	47	71	Good	38	65	Fair
Cotton Wood Tree by road	35	68	Fair	37	62	Fair	36	62	Fair
Culvert Dump	45	78	Good	37	68	Fair	61	75	Good
Sewer Manhole	40	68	Fair	60	75	Good	67	75	Good
Drain in green	53	75	Good	50	68	Good	61	71	Good
2nd AP	83	75	Excellent	80	78	Excellent	85	78	Excellent
ditch - from path	70	81	Good	35	75	Good	75	75	Good
200 - in green	60	78	Good	60	78	Good	70	78	Good
200 - Path	30	50	Fair	30	56	Fair	67	75	Good
150 - in green	45	75	Good	33	71	Fair	64	78	Good
150 - Path	38	75	Fair	35	65	Fair	39	59	Fair
at Y on path	32	71	Fair	30	62	Fair	42	62	Good
drain on Y	30	65	Fair	28	65	Fair	78	75	Good
100 - Green	40	75	Good	20	53	Fair	56	78	Good
100 - Path	40	75	Good	33	56	Fair	41	71	Good
Hole	67	78	good	47	71	Good	98	78	Excellent
Root	100	78	Excellent	100	78	Excellent	88	81	Excellent
Average:	46.125	72.38		41.375	67.125		61.125	72.1875	
Max	83	81		80	78		98	78	
Min	30	50		20	53		36	59	

Appendix 5 – Hole 5 – Intel Access Points - Yagi

Hole 5	AP placed at each end of hole								
Equipment:	Yagi & Intel & Laptop			Yagi & Intel & PDA - PSP			Yagi & Intel & PDA - CAM		
Location	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality
AP2	100	81	Excellent	64	65	Good	80	78	Excellent
Hole	88	84	Excellent	100	84	Excellent	88	78	Excellent
100 - Green	78	84	Excellent	70	84	Good	57	75	Good
100 - Path	45	75	Good	42	78	Good	50	68	Good
Trees along side - Left	n/a	n/a		56	81	Good	33	68	Fair
150 - Green	47	75	Good	70	84	Good	67	75	Good
150 - Path	38	68	Fair	45	75	Good	60	78	Good
Bell - Green	67	81	Good	67	81	Good	57	65	Good
200 - Green	75	84	Good	75	81	Good	70	75	Good
200 - Path	44	65	Good	39	75	Fair	48	75	Good
250 - Green	33	31	Fair	23	43	Fair	28	59	Fair
250 - Path	18	0	Poor	36	78	Fair	35	71	Fair
1st Valley - Green	59	78	Good	20	40	Poor	28	53	Fair
1st Curve - Path	70	81	Good	80	84	Good	53	71	Good
485 - Path	95	84	Excellent	80	81	Excellent	80	75	Good
T Box	n/a	n/a		n/a	n/a		n/a	n/a	
Root	100	81	Excellent	100	84	Excellent	100	78	Excellent
Average:	63.8	70.13		60.4375	74.875		58.375	71.375	
Max	100	84		100	84		100	78	
Min	18	0		20	40		28	53	

Appendix 6 – Hole 5 – Cisco Access Points - Yagi

Hole 5	AP placed at Green box					
Equipment:	Yagi & Cisco & Laptop			Yagi & Cisco & PDA - PSP		
Location	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality
AP2	80	84	Excellent	70	87	Good
Hole	50	81	Good	50	81	Good
100 - Green	48	75	Good	73	87	Good
100 - Path	35	59	Fair	33	71	Fair
Trees along side - Left	n/a	n/a		n/a	n/a	
150 - Green	85	75	Excellent	70	87	Good
150 - Path	61	84	Good	80	87	Excellent
Bell - Green	50	81	Good	42	78	Good
200 - Green	75	87	Good	73	87	Good
200 - Path	75	87	Good	100	87	Excellent
250 - Green	84	87	Excellent	15	43	Poor
250 - Path	47	75	Good	70	87	Good
1st Valley - Green	61	84	Good	30	68	Fair
1st Curve - Path	25	31	Fair	20	46	Poor
485 - Path	31	18	Poor	20	40	Poor
T Box	n/a	n/a		25	40	Fair
Root	80	84	Excellent	70	87	Good
Average:	59.1333	72.8		52.5625	72.688	
Max	85	87		100	87	
Min	25	18		15	40	

Appendix 7 – Hole 5 – Intel Access Points – Omni – v1

Hole 5	AP placed at each end of hole								
Equipment:	Omni & Intel & Laptop			Omni & Intel & PDA - PSP			Omni & Intel & PDA - CAM		
Location	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality
AP2	98	84	Excellent	83	81	Excellent	80	75	Good
Hole	80	81	Excellent	75	78	Good	63	81	Good
100 - Green	64	81	Good	45	75	Good	67	75	Good
100 - Path	35	68	Fair	57	81	Good	38	71	Fair
150 - Green	32	59	Fair	37	71	Fair	48	68	Good
150 - Path	25	25	Fair	33	75	Fair	47	78	Good
Bell - Green	41	65	Fair	35	65	Fair	40	68	Fair
200 - Green	67	78	Good	35	71	Fair	30	62	Fair
200 - Path	23	25	Fair	30	62	Fair	42	78	Good
250 - Green	0	0	0	0	0	0	13	3	Poor
250 - Path	0	0	0	5	0	Poor	0	0	0
1st Valley - Green	0	0	0	0	0	0	25	46	Fair
1st Curve - Path	56	75	Good	42	68	Good	38	62	Fair
485 - Path	61	78	Good	73	78	Good	48	78	Good
Root	83	78	Excellent	95	78	Excellent	90	78	Excellent
Average:	41.5714	51.36		39.2857	57.5		41.3571	60.3571	
Max	98	84		83	81		80	81	
Min	0	0		0	0		0	0	

Appendix 8– Hole 5 – Intel Access Points - Omni – v2

Hole 5	AP placed at end & at Green Box								
Equipment:	Omni & Intel & Laptop			Omni & Intel & PDA - PSP			Omni & Intel & PDA - CAM		
Location	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality	Signal Strength	Signal Quality	Overall Link Quality
AP2	98	84	Excellent	83	81	Excellent	95	81	Excellent
Hole	78	81	Excellent	60	81	Good	63	78	Good
100 - Green	50	75	Good	40	65	Good	60	78	Good
100 - Path	38	46	Fair	35	75	Fair	38	75	Fair
150 - Green	25	21	Fair	35	75	Fair	25	53	Fair
150 - Path	42	62	Good	40	78	Good	30	65	Fair
Bell - Green	39	68	Fair	30	62	Fair	35	71	Fair
200 - Green	41	68	Fair	67	71	Good	28	62	Fair
200 - Path	35	50	Fair	47	71	Good	45	78	Good
250 - Green	35	53	Fair	57	75	Good	35	75	Fair
250 - Path	47	75	Good	45	65	Good	60	81	Good
1st Valley - Green	78	78	Excellent	67	78	Good	67	78	Good
Root	93	78	Excellent	98	78	Excellent	93	81	Excellent
1st Curve - Path	56	71	Good	60	81	Good	60	78	Good
485 - Path	33	43	Fair	35	56	Fair	42	71	Good
T Box	36	62	Fair	42	68	Good	30	59	Fair
Average:	51.5	63.44		52.5625	72.5		50.375	72.75	
Max	98	84		98	81		95	81	
Min	25	21		30	56		25	53	