Key Factors in Wireless LANs Signal Characteristics in Infrastructure Mode

by
Ms. Patcharee Khemsatitanant

A Final Report of the Three-Credit Course
CE 6998 Project

Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Science
in Computer and Engineering Management
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Project Title	Key Factors in Wireless LANs Signal Characteristics in Infrastructure Mode
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The Graduate School of Assumption University has approved this final report of the three-credit course, CE 6998 PROJECT, submitted in partial fulfillment of the requirements for the degree of Master of Science in Computer and Engineering Management.

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ABSTRACT

This report outlines the studies of Wireless LANs signal characteristics. The signal characteristics depend on the environment and have been recognized to be difficult to calculate and predict. These key factors such as plane angles, antenna orientation, over distance, line of sight, wall types and interchannel interference characteristics are presented not only to measure and consider the signal in such obstructions but also to find the best solution for wireless LANs installation in many kinds of environment.

The experiments were taken consistently in this project to collect data. Results from these experiments were analyzed and compared with the wireless LANs signal theory.

In this project, Wireless LANs signal data in A-Building (floor 5 and floor 6) at Assumption University (Huamark campus) was collected to be the case study to support some theories of Wireless Signal Characteristics. This information can help in understanding of wireless connection in A-Building and planning for the next installation.

The outcomes of this project can be an aid to learning and understanding wireless communication and being guideline to make a plan for wireless LANs installation.

ACKNOWLEDGEMENTS

Many people have helped with the process of creating this project, without them, this project would not have been complete.

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I. INTRODUCTION

1.1 Introduction

The popularity of wireless networking for computers and related devices has increased significantly in recent years, as the technology has matured and become more affordable for the consumer. Compared to traditional wired networks, wireless networking provides increased mobility and flexibility of network access for users, and significantly reduces the costs of installing and maintaining network cabling. This is accomplished while offering data transfer rates that, while generally slower than for wired networks, are more than adequate for the majority of network use. One major trend in the implementation of networking is the increased adoption of wireless networks, primarily due to the advantages it offers over its wired brethren. Current generation of wireless networking is considerably slower than conventional wired networks. More important, is wireless signals susceptibility to the electromagnetic propagation in an omnidirectional manner. This gives rise to the characteristics of wireless propagation (e.g. interference and attenuation) and the resulting objects (e.g. metallic objects and others) that can hinder or impair wireless network transmissions. This ultimately results in higher loss rates, which reduces the bandwidth available to the end user. Thus understanding wireless characteristics is fundamental for improving transport protocols leading to a reduction in errors and resulting in increased network throughput and determining an optimum position to achieve maximum wireless performance.

1.2 Motivation

Wireless LAN (WLANs) technology, in particular 802.11b and 802.11g technology, has been gaining prominence in its use and deployment. In this technology, wireless communication in the 2.4 GHz band is used for digital communication at the rates of 11 Mbps for 802.11b and up to 54 Mbps for 802.11g. The current technology supports access to the wireless network through the deployment of Access Point (APs), which can be accessed within a radius of a few hundred feet (both indoor and outdoors). The range and the quality of the connection depend on the walls, the distances, the angles, the antenna orientation and other obstruction, that are there in the path from the transmitter to the receiver.

In this project, the key factors in WLANs signal characteristics for infrastructure mode are considered. Not only to measure and consider the signal in such obstruction, but also to use the characteristic of these signals for other purposes such as determining installation of WLANs in A-building (floor 5 and floor 6) at Assumption University (Huamark campus).

1.3 Objective

To identify key factors that can affect to WLANs signal characteristics in Infrastructure mode. The project outcome will analyses and evaluate the influential factor of wireless signal strength and other parameter that will produce much better results for wireless LAN installation.

1.4 Scope

To measure and characterize the occurrence of signal in the transmissions of IEEE 802.11g wireless networks in Infrastructure mode. This is achieved by the Wireless

LAN Testers from Fluke Network, Inc. Through experimentation, sufficient samples of data would be collected.

1.5 Structure of the project

This report is structured as follows. Chapter 2 provides an overview of the wireless local area network (WLANs) basics. Chapter 3, contains the experimentation of signal characteristics in other obstructers. Chapter 4 the study of WLANs in A-building at ABAC and Chapter 5 is conclusion

II. WIRELESS LOCAL AREA NETWORK (WLANs) BASICS

2.1 Wireless Background

Guglielmo Marconi invented the wireless telegraph in1896. In 1901, he sent telegraphic signals across the Atlantic Ocean from Cornwall to St. John's Newfoundland; a distance of about 3200 km. His invention allowed two parties to communicate by sending each other alphanumeric characters encoded in an analog signal. Over the last century, advances in wireless technologies have led to the radio, the television, the mobile telephone, and communications satellites. All types of information can now be sent to almost every corner of the world. Recently, a great deal of attention has been focused on satellite communications, wireless networking, and cellular technology. Communications satellites were first launched in the1960s. Those first satellites could only handle 240 voice circuits. Today, satellites carry about one third of the voice traffic and all of the television signals between countries. Modern satellites typically introduce a quarter second propagation delay to the signals they handle. Newer satellites in lower orbits, with less inherent signal delay, have been deployed to provide data services such as Internet access. Wireless networking is allowing businesses to develop WANs, MANs, and LANs without a cable plant. The IEEE has developed 802.11 as a standard for WLANs. The Bluetooth industry consortium is also working to provide a seamless wireless networking technology. The cellular or mobile telephone is the modern equivalent of Marconi's wireless telegraph, offering two parties, two-way communication. The first generation wireless phones used analog technology. These devices were heavy and coverage was patchy, but they successfully demonstrated the inherent convenience of mobile communications. The current generation of wireless devices is built using digital technology. Digital networks carry much more traffic and provide better reception and security than analog networks. In addition, digital technology has made possible value added services such as caller identification. Newer wireless devices connect to the Internet using frequency ranges that support higher information rates. The impact of wireless communications has been and will continue to be profound. Very few inventions have been able to "shrink" the world in such a manner. The standards that define how wireless communication devices interact are quickly converging and soon will allow the creation of a global wireless network that will deliver a wide variety of services (Stalling 2005).

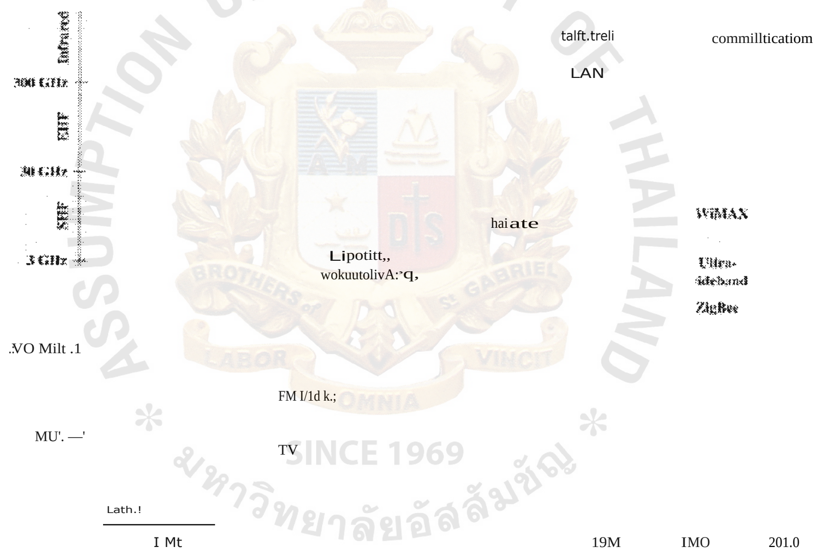


Figure 2.1 Some Milestones in Wireless Communications

2.2 Wireless Just Replaces Wire

If you understand basically how a wired LAN works, you will understand the WLANs. **In** a conventional wired LAN (Figure 2.1), you must have a network interface card (NIC) installed in your computer, plus a hub or switch to allow you to connect to other local computers, and perhaps a bridge or a router to connect to the Internet. All of these network items are connected by cabling. A wireless network has all of these same components but one. The only item missing from this scene with a wireless network cable.

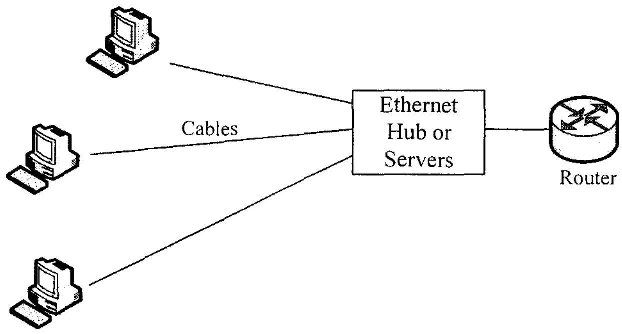


Figure 2.2 conventional wired LAN connection

Of course, because a wired LAN is tethered to the walls, the cables from each workstation must first run to a permanently mounted data jack. The data jack, in turn, is permanently wired through a patch panel to an Ethernet hub or switch in some central location (called a telecommunications room). This part of the LAN cabling runs up through the walls, across the ceiling space, and down to the patch panel. As long as the cable remains unbroken, it can run through wood, wallboard, metal vents, concrete, and even steel. Wired LANs do have the advantage of being able to run around and through obstacles that might block wireless signals.

But, when it is all said and done, you still have the cumbersome wire and cables between you and the hub. WLANs, as we will see, allow you to make the same connection, at comparable speeds, without wires. The main components of a WLANs (Figure 2.2) include the wireless NIC (W-NIC), the wireless hub or access point (AP), and if needed, the antennas and cables. As you can see, the WLANs signals go directly to the wireless access point, avoiding the bends and corners of the network cables in the wired LAN. This illustrates the line-of-sight nature of wireless networking. This concept is very important in understanding WLANs operation.

Although the components of a WLANs system are analogous to those of the wired system, there are important differences you need to know for a successful WLANs installation. For example, a WLANs connection occurs on one of eleven or so WLANs channels. You must ensure that the wireless NICs are set to the proper channel to connect to the access point. Some W-NICs are frequency agile, that is, they can scan through a range of channels to locate an access point. However, the access point is always set to one particular channel, and the W-NICs may be as well. As you see, you must be concerned about a number of additional factors when you install a WLANs. In this chapter, we cover each of those items in some detail. In addition, we help you visualize the WLANs connection and talk about potential source of interference.

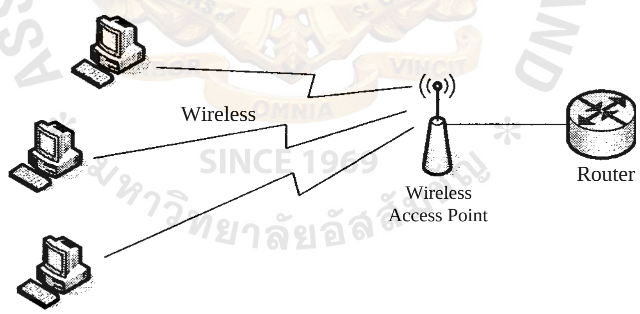


Figure 2.3 typical WLANs

Installing a WLANs is really not difficult. If you were to purchase a commercially available WLANs kit and install it in your home or office, it is likely that you would meet with total success at least 50 percent failure rate, which is obviously not acceptable. To reach a favorable outcome, you need to have some specialized knowledge regarding wireless networks. A WLANs uses a type of radio transmission to send network data back and forth between two points. These WLANs transmissions are in a frequency band at 2.4 GHz or 5.2 GHz. At these frequencies and at the low-power levels used by WLANs, the signal attenuated by walls and ceiling and is easily blocked by metallic objects, such as air ducts or metal scaping can attenuate or block the WLANs signal. We need to have an understanding of all of these matters so that we can arrange our network in a way that will allow it to operate properly (Trulove 2002).

Table 2.1 Differences between Wired Networks and Wireless Networks (Unger 2003)

Network Characteristics	**Wire Network**	**Wireless Network**
Visual determination of network connectivity	If you see the network cable going to a location, that location can be connected to the networks.	Wireless networks sometimes connect locations that you cannot visibly see. Additionally, wireless networks might not connect locations that you can see visibly.
Visibility node-to-node on the same network	All of the nodes on a wired network can hear all other nodes.	Many nodes on a wireless network cannot hear all of the other wireless nodes on the same network.
Visibility network-to-network	Wired networks are invisible to other wired networks. The presence of one wired network has no effect on the performance of another wired network.	Wireless networks are often visible to other wireless networks. One wireless network can affect the performance of other wireless networks.
Atmospheric properties	Wired network performance is not affected by the properties of the atmosphere.	Wireless network performance can be affected by the properties of the atmosphere.
Terrain properties	Wired network performance is not affected by the properties of the earth's terrain.	Wireless network performance strongly affected by the properties of the earth's terrain.
User connectivity and mobility	Connectivity is possible only to or from those physical locations where the network cabling extends	Connectivity is possible beyond the bounds of physical network cabling

2.3 Wireless LAN Standards

The first 802.11 standard was created as a method of extending the 802.3 (wired Ethernet) to venture into the wireless domain. The 802.11 standard, also referred to as Wi-Fi, as it is the Wi-Fi alliance (an independent organisation) that provides Wi-Fi certification to products that conform to the 802.11 standard. Current 802.11 standards that have been certified and are in use include:

Table 2.2 current 802.11 certified standards

Standard	**Data Rate**	**Frequency**	**Modulation Scheme**	**Rang**	**Security**	**Certified**
802.11	1 or 2 Mbps	2.4 GHz	FHSS or DSSS	< 25 m	WEP&WPA	1997
802.11a	Up to 54 Mbps	5 GHz	OFDM	< 20 m	WEP&WPA	**1999**
802.11b	Up to 11 Mbps	2.4 GHz	DSSS	< 100 m	WEP&WPA	1999
802.11g	Up to 54 Mbps	2.4 GHz	OFDM above 20 Mbps, DSSS below 20 MHz	< 100 m	WEP, WPA& WPA-PSK	2003

- 802.11 IEEE 802.11 was the first WLANs standard to be published. It defines a network operating at the 2.4 GHz unlicensed frequency. The maximum throughput for this technology is between 1 and 2 Mbps. 802.11 also allows the choice between frequency hopping or direct sequence spread modulation. 802.11 is slowly becoming obsolete as the 802.11b standard has taken over most of the market.

- 802.11a This standard was also published in late 1999 as a supplement to 802.11. It operated in the 5 GHz band instead of the 'traditional' 2.4 GHz that the earlier WLANs standards used, thus being subjected to less interference. It uses orthogonal frequency division multiplexing or OFDM for short and supports data rates up to 54 Mbps. 802.11a is not compatible with 802.11b and therefore its emergence has been quite slow. However, recently several manufacturers have come out with dual mode products, supporting both the 802.11a+b standards and this way trying to make the transfer easier. A disadvantage with the 5 GHz frequency is the reduced working distance.

- ***802.11b*** IEEE 802.11b is the most widespread WLANs standard today. The standard is also branded as Wi-Fi. It was published in late 1999 as a supplement to 802.11. It still operates in the 2.4 GHz band, but data rates can be as high as 11 Mbps, which is basically the same as the regular Ethernet connection. 802.11 does not support frequency hopping, it only specifies or direct sequence spread modulation.

- ***802.11g*** This project aims to develop a higher speed PHY extension to the 802.11b standard. The new standard will be compatible with the IEEE 802.11 MAC. This provides at least 20 Mbps connectivity and claims that even 50 Mbps connectivity is possible on 2.4 GHz band. If this true then it might make the 5 GHz products obsolete because the lower band has a longer carrying distance.

- ***802.11d task group*** The 802.11d is an ongoing project for defining the physical layer requirements (e.g. channelization, hopping patterns) to extend the operation of 802.11 to new countries.

- ***802.11e*** The purpose of this ongoing project is to enhance the current 802.11 MAC to expand support for applications with Quality of Service (QoS) requirements, and in the capabilities and efficiency of the protocol. This project also aims to add a 128-bit AES encryption.

- ***802.11f*** The scope of this project is to develop recommended practices for an Inter Access Point Protocol (IAPP), which provides the necessary capabilities to achieve multi-vendor Access Point interoperability across a Distribution System supporting IEEE P802.11 Wireless LAN links This standard has not been released yet, as the project is still going on.

2.4 Wireless LAN Architecture

The IEEE 802.11 standard permits devices to establish either peer-to-peer (P2P) networks or networks based on fixed access points (AP) with which mobile nodes can communicate. Hence, the standard defines two basic network topologies: the infrastructure network and the ad hoc network (Trulove 2002).

In Infrastructure mode wireless hosts communicate with a base station which allows the broadcasting, forwarding, coordination, synchronization and bridging of packets. The area covered by an AP (a cell) is technically referred to as a Basic Service Set (BSS). A Service Set Identifier (SSID) identifies every BSS, and is ultimately the identification given to devices within a specific cell to enable wireless communication. A SSID however, need not be unique and thus a Basic Service Set Identifier (BSSID) was needed, which uniquely identifies an access point, and is usually the AP's Media Access Control (MAC) address.

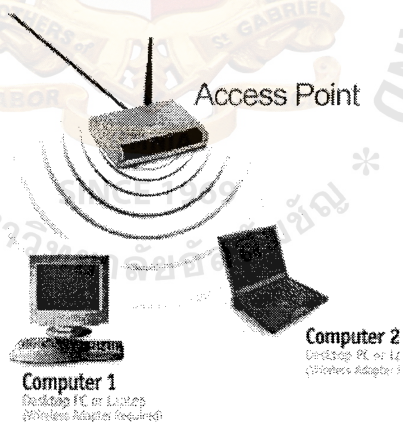


Figure 2.4 BSS of an infrastructure network

In an Ad hoc network, (called an Independent Basic Service Set (IBSS) by the 802.11 standard), allows a group of 802.11 wireless stations to communicate with each in peer-to-peer mode without the need for an access point.

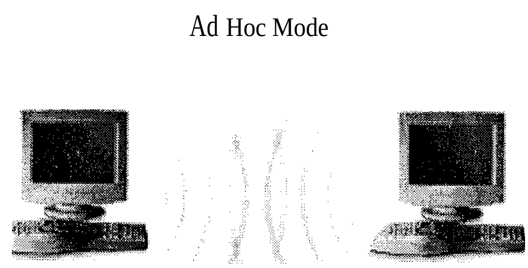


Figure 2.5 BSS of Ad-Hoc network

2.5 Wireless LAN Topologies

2.5.1 Basic Service Set (BSS)

The Basic Service Set (BSS) consists of a group of any number of communicating stations. It is a basic building block of an 802.11 wireless LAN.

2.5.2 Independent Basic Service Set (IBSS)

This represents a set of stations connected to each other via a peer to peer network. This form of network topology is referred to as Independent Basic Service Set (IBSS) or an Ad-hoc network. In an IBSS, the mobile stations communicate directly with each other provided they are within the range of each other.

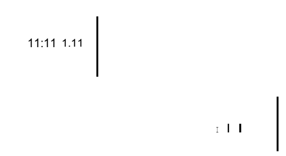


Figure 2.6 Independent Basic Service Set (IBSS)

2.5.3 Infrastructure Basic Service Set

An infrastructure basic service set is a BSS with a component called an Access Point (AP). All stations in the BSS communicate with the access point and no longer communicate directly. All frames are replayed between stations by the access point. The access point may also provide connection to a distribution system. There is no restriction on for the distribution system to be wired or wireless.

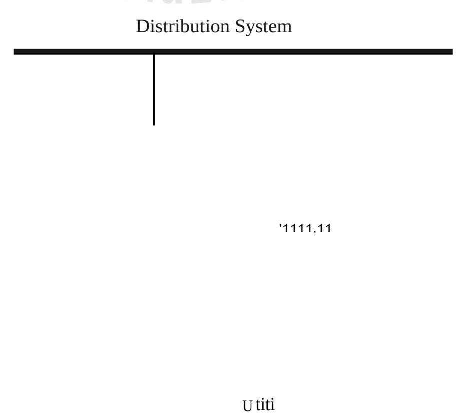


Figure 2.7 Infrastructure Basic Service Set

2.5.4 Extended Service Set (ESS)

802.11 extended the range of mobility to an arbitrary range through the Extended Service Set (ESS). An extended service set is a set of infrastructure BSS's, where the access points communicate amongst themselves to forward traffic from one BSS to another to facilitate movement of stations between BSS's. The access point performs this communication through the distribution system. The distribution system is the backbone of the wireless LAN and may be constructed of either a wired LAN or wireless network.

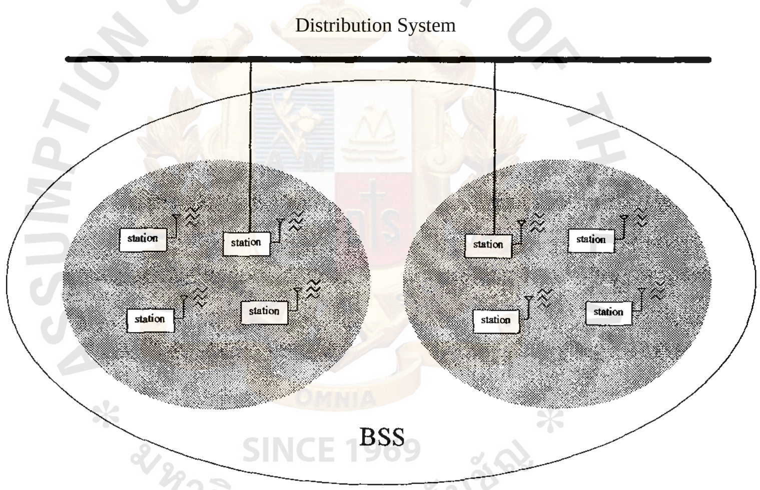


Figure 2.8 Extended Service Set (ESS)

2.6 Properties that affect wireless propagation

Wireless networking provides a convenient and flexible solution to networking without cables, however, with this freedom comes a sacrifice. This sacrifice is the inability to control the path of the wireless signal, as current generation of wireless signals are transmitted in an omnidirectional manner. This gives rise to the characteristics of wireless propagation and the resulting objects that can interfere or impair wireless network transmissions, and include:

2.6.1 Characteristics of wireless propagation

These impairments are due to the fundamental and physical methods in which a wireless signal propagates and include:

Atmosphere absorption contributes to impairments due to water vapor and oxygen.

Noise can be divided into thermal noise and surrounding noise.

- Thermal noise is the motion of electrons caused by heat. This is present in all electronic equipments and cannot be eliminated, only reduced.

- Surrounding noise, as the name implies includes noise from the surrounding indoor and outdoor environment. When the noise maintains a level that is significantly higher that the received signal, errors will be produced.

Interference encompasses three aspects:

- Multi-path interference can be destructive or constructive where obstacles reflect and or scatter the transmitted wave, which could result in multiple copies with varying delays at the receiver, or

- Other devices sharing the same frequency spectrum, or

- Inter-symbol interference results when multiple signals are received at the same time,and the receiver cannot reliably distinguish between these two signals, resulting in interference, which can cause errors.

Attenuation is the loss of a transmitted signal.

- Antennas in WLANs are omnidirectional (transmit a signal in all directions) as apposed to directional antennas. The transmitted energy that is transmitted by the sender decreases by the inverse square of the distance traveled by the wave.

- Due to objects being situated in the path from the transmitter to receiver, where each can potentially absorb the signal and a loss in signal strength can result.

Reflection, diffraction, and scattering due to objects that exist in the physical environment.

- Reflection occurs when the transmitted signal bounces back of a conducting object, such that the angle of incidence equates to the angle of reflection. If many waves are reflected, it is referred to as multipath fading, and the signal is often referred to as a Rayleigh distributed.

- Diffraction occurs when there is no direct Line of Sight (LOS) from sender to receiver and the signal encounters an impenetrable body (opaque) and the signal changes path and direction and continues traveling around the impenetrable object.

- Scattering occurs when the radio channel contains objects of dimensions that are on the order (or less) of the electromagnetic wavelength, causing the signal from the transmitter to be radiated in more than one direction.

Doppler shift occurs when the transmitter and/or receiver are physically moving and causes the frequency to shift, and thus complicates the reception of the signal.

2.6.2 Physical properties within the environment

Objects within the path of a wireless signal can fundamentally alter the characteristics of the signal. The table below outlines the varying attenuation, noise sources and interference for a variety of different objects.

Table 2.3 Degree of attenuation for some objects (Tzannes 2005)

Attenuation factor	*Object*
Very high	Metallic objects, Reinforced concrete
High	Concrete
Medium	Water, Bricks, Stone
Low	Glass, Plaster, Wood
Minimal	Air

Table 2.3 Degree of attenuation for some objects (Continued)

Noise sources	*Object*
Indoor	Motors, Microwaves
Outdoor	Power lines, railway
Environment	Lightning, Solar flares
Interference	*Object*
Unlicensed Spectrum	Other WLANs, Bluetooth devices, Coreless phones
Multipath Interference	Reflection/diffraction/scattering of metallic objects

2.7 Antenna Systems

The most significant factor that influences WLAN coverage is the performance of the antenna system. We say "system" because much more is critical to the strength of the wireless signals than the individual antenna component. In this section, we cover the basic types of antennas and compare their characteristics. In addition, we talk about the other components that make up an antenna system: cables, mounts, lightning protection, and amplifiers. With a properly configured antenna system, you can maximize your WLAN coverage from your APs. In addition, with simple antenna systemic accessories, you can bring coverage to a station in a poor coverage area.

- *Antenna Styles*

Practical antennas can be divided into two primary categories: direction-al and omnidirectional. In addition, there is a third, theoretical, category, called a point source. It is useful to consider this theoretical antenna first because the comparisons of all other types of antennas are based on the mathematical performance of the point source.

A point source is a perfect antenna. The concept presumes that, if you constructed an antenna that could couple energy into space from a single point, it would propagate EM energy equally in all directions. We have a name for the imaginary embodiment of the point source. It is formally called an isotropic antenna. This theoretical isotropic antenna is what all other antennas are measured against. It is considered to have unity gain, so the directional gain of any other antenna may be expressed in decibels relative to the isotropic antenna (dBi). Now back to the two categories of real antennas. An omnidirectional antenna is considered to be one that propagates radio waves (or EMI energy) equally in all directions within a plane. You will recall from geometry that a plane is an infinite flat surface. An example of a typical omnidirectional antenna is the vertical antenna on many cars. Another example is the small wire antenna you see on police and public service vehicles. A third example is the pull-up antenna on some cellular phones or that little antenna that folds out on some WLAN cards and APs.

This type of omnidirectional antenna is intended to function equally in all horizontal directions, that is, all directions radially outward from side of the antenna. In other words, the antenna is oriented orthogonally from its plane of radiation. An example of an omnidirectional antenna is shown in Figure 2.9

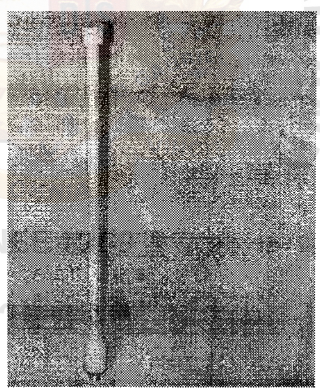


Figure 2.9 An omnidirectional antenna

Omnidirectional antennas radiate some of their energy above and below the plane of orientation. Different versions of omnidirectional antennas have slightly different radiation patterns in the horizontal plane. Some have a fairly broad pattern in the vertical direction and some have a relatively flat pattern.

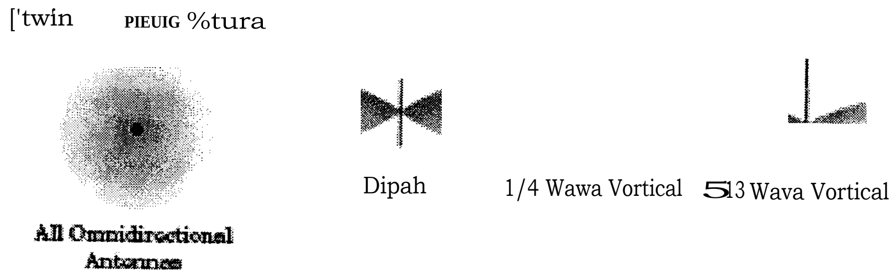


Figure 2.10 The patterns of typical ominidirectionl antennas.

The other basic antenna category is called a directional antenna. Simply stated, a directional antenna is one that concentrates its radiated energy primarily in one direction. From a practical standpoint, a directional antenna's pattern ranges from very broad to very narrow and concentrated. Directional antennas present the widest variety of styles. Some of the directional antenna styles in common use with WLANs include the Yagi and the parabolic antennas. Examples of these types of antennas are shown in Figure 2.11

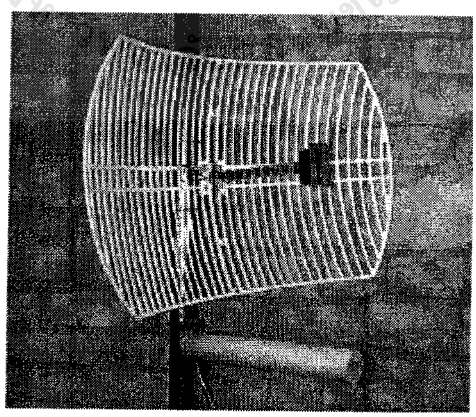


Figure 2.11 Directional antennas (the yagi and the parabolic).

A Yagi antenna is constructed from a driven element (typically a sim-ple dipole), a reflector, and array of one or more directors. These additional elements are called parasitic elements because they steal some of the energy from the driven element. Conveniently, they also reradiate that energy in such a way as to concentrate in the direction of the director elements. Yagi antennas for WLAN use are frequently encased in a plastic housing, resembling a cylinder. The plastic enclosure is sometimes called a radome, after the name given the dome-like coverings for radar antennas. This housing is transparent to the radio waves and presents a more appealing antenna assembly. It also physically protects the antenna from the effects of wind and moisture.

This WLAN Yagi antenna uses 14 directors and produces approximately 12 dBi of directional gain. This is about average for Yagis in this frequency range. "Stacking," or using multiple antennas mounted in the same orientation, may add gain. The parabolic antenna is constructed as an end section of a paraboloid. From geometry, you might recall that a parabola has a focal point. If an EM radiator, such as s simple dipole, is placed at the focus of a metallic parabolic surface, the radio waves will be reflected more or less in the same direction. The effect is to produce a highly collimated beam of RF energy.

The parabolic antenna is very useful for concentrating the coverage pattern of an antenna to a very narrow area. This concentration produces an effective gain of 18 to 25 dBi for the smaller "dish" antennas used with WLANs. For even more gain, larger parabolic surfaces pro-duce proportionally more gain. It is possible to get as much as 50 to 60dBi gain from a parabolic dish, but such an antenna would have a much larger parabolic surface and probably be undesirable. In addition, the signal feeds and geometry of these very high gain antennas are critical, so these antennas are much more expensive.

2.8 Application of WLANs

WLANs frequently augment rather than replace wired LAN networks-often providing the final few meters of connectivity between a wired network and the mobile user. The following list describes some of the many applications made possible through the power and flexibility of WLANs:

- Doctors and nurses in hospitals are more productive because hand-held or notebook computers with wireless LAN capability deliver patient information instantly.

- Consulting or accounting audit teams or small workgroups increase productivity with quick network setup.

- Students holding class on a campus greensward access the Internet to consult the catalog of the Library of Congress.

- Network managers in dynamic environments minimize the overhead caused by moves, extensions to networks, and other changes with WLANs.

- Training sites at corporations and students at universities use wireless connectivity to ease access to information, information exchanges, and learning. Network managers installing networked computers in older buildings find that WLANs are a cost-effective network infrastructure solution.

- Trade show and branch office workers minimize setup requirements by installing pre-configured wireless LAN needing no local MIS support.

- Warehouse workers use WLANs to exchange information with central databases, thereby increasing productivity.

- Network managers implement WLANs to provide backup for mission-critical applications running on wired networks.

- Senior executives in meetings make quicker decisions because they have real-time information at their fingertips.

2.9 Benefits of WLANs

By using radio frequencies instead of conventional wires, WLANs enable organizations to realize flexibility and real-time access to information for people who need to be connected. The ease and speed of connecting and disconnecting wireless devices gives organizations a reliable, scalable and easy-to-integrate tool to increase productivity and save money. WLANs combine the power of freedom and information so people can access the resources of corporate information, the Internet and E-mail whenever they need it.

- ***Mobility :*** Wireless LAN systems can provide users access to real-time information anywhere within the organization. This extra mobility supports productivity and service opportunities not possible with wired networks.
- ***Flexibility& Scalability :*** Deploying a wireless network eliminates the need to pull wires or cables through walls and ceilings. Wireless LAN gives organizations the flexibility to move people from office to office, re-organize departments or even entire campuses almost effortlessly. Once Wireless LAN base units are located in a building, users can simply insert an adapter card into their computer and are free to move about.
- ***Cost Savings :*** With the simple and flexible architecture of WLANs, organizations can save network management costs related to adds, moves and changes, guaranteeing a short term return on investment.

III. RESEARCH METHODOLOGY

The research method of this project, "Key Factors in Wireless LANs Signal Characteristics in Infrastructure mode, is experimental research that collects data to perform the experiment with a concise and consistent experimental plan.

Phase I : Equipment Preparation

1. Wireless Analyzer (Model : ES-WLAN)

Handheld wireless network assistant from Fluke Network was used in this project. The model is ES-WLAN. This tester can support 802.11 a/b/g

Figure 3.1 Wireless Analyzer (Fluke Model: ES-WLAN)

2. Access Point (AP)

Netgear Wireless Access Points model :WG602 V3.

Antenna : Single detachable 2 dBi antenna, Transmit Power: 16 dBm

Data Transfer Rate : 54 Mbps

Figure 3.2 Access Point (Netgear model: WG602 V3.)

3. Laptop computers with wireless 802.11 b/g adapter.
4. 3 m. Cross over UTP cable for access point configuration
5. Cerberus FTP Server software (Installed in 1 laptop computer)

Phase II : Experimentation

The test is performed with hardware and software to test for signal levels and throughput in various environments.

3.1 To perform the signal level reference

Objective : Create the signal level stability data for being the reference level

Method : Find the place that there is the least interference or no interfere then measure signal strength at a position of 3 meters far from access point in the open environment. (To eliminate the multipath condition) The signal and noise are measured at 5 second time interval in 20 times to see the variation of signal strength at the same position

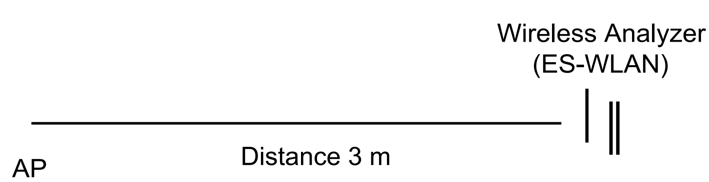


Figure 3.3 Signal level reference experimental setup

Results:

Table 3.1 The signal level reference at 3 m.

The signal level reference		
Time.	Signal strength (dBm)	Noise (dBm)
1	-39	-88
2	-38	-86
3	-38	-86
4	-44	-87
5	-45	-87
6	-46	-86
7	-44	-86
8	-45	-86
9	-45	-86
10	-45	-86
11	-45	-86
12	-43	-86
13	-44	-87
14	-44	-86
15	-44	-86
16	-43	-86
17	-43	-86
18	-44	-87
19	-42	-86
20	-43	-86
Avg.	-43.2105	-86.3
Standard Deviation (SD)	**2.307**	**0.571**

Conclusion : Distance at 3 meters

The average signal level is -43.2105 , The average noise level is -86.3

The standard deviation of signal level is 2.307

The standard deviation of noise level is 0.571

This reference will be used for the experiment 3.2 (Signal levels for wireless adapter orientation of ES-WLAN at various horizontal plane angles). If any signal level measured at a distance of 3 meters has standard deviation less than 2.307 it will be concluded that it has no significant level of difference. If any noise levels measured at a distance of 3 meters has standard deviation less than 0.571 it will be concluded that it has no significant level of difference.

3.2 Signal levels for wireless adapter orientation of ES-WLAN at various horizontal plane angles

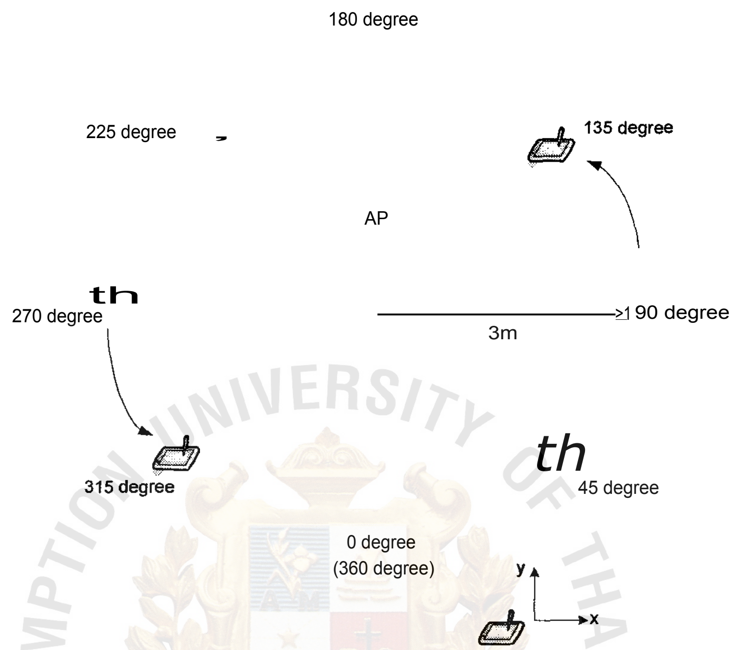
Objective :

- The effect of the wireless adapter's orientation in received and noise signal is investigated to see the variation in signal level when wireless adapter of ES-WLAN is set in horizontal plane at various horizontal plane angles.
- The effect of the wireless adapter's orientation in received and noise signal is investigated to see the variation in signal level when wireless adapter of ES-WLAN is set in vertical plane at various horizontal plane angles.

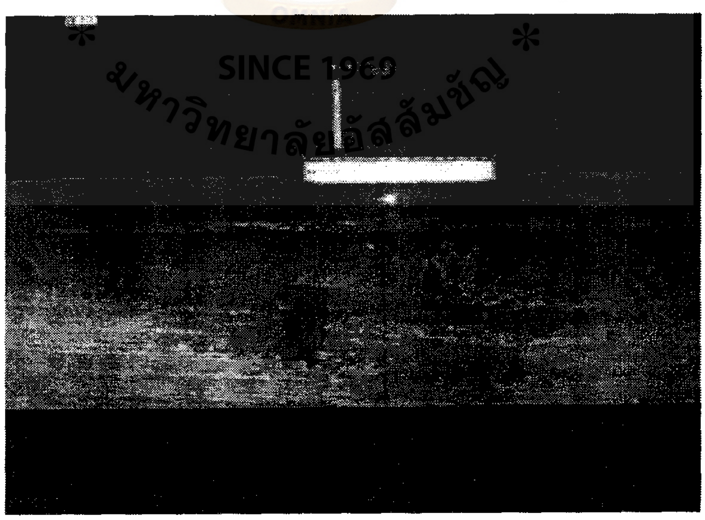
Method:

- The access point is fixed in a location, at a height of one meter from the ground. ES-WLAN is set at a range of approximately five meters from the access point, at a height of one meter.
- Wireless adapter of ES-WLAN is set in a horizontal plane at various horizontal plane angles with an unobstructed line of sight to emulate the most common orientations and signal measurements are taken. Signal and noise data were collected in 20 times at various angles in dB unit then average to plot data in graphical view.
- Wireless adapter of ES-WLAN is set in a vertical plane at various horizontal plane angles with an unobstructed line of sight to emulate the most common orientations and signal measurements are taken. Signal and noise data were collected 20

20 times at various angles in dB unit then the average was computed to plot data in a graphical view.

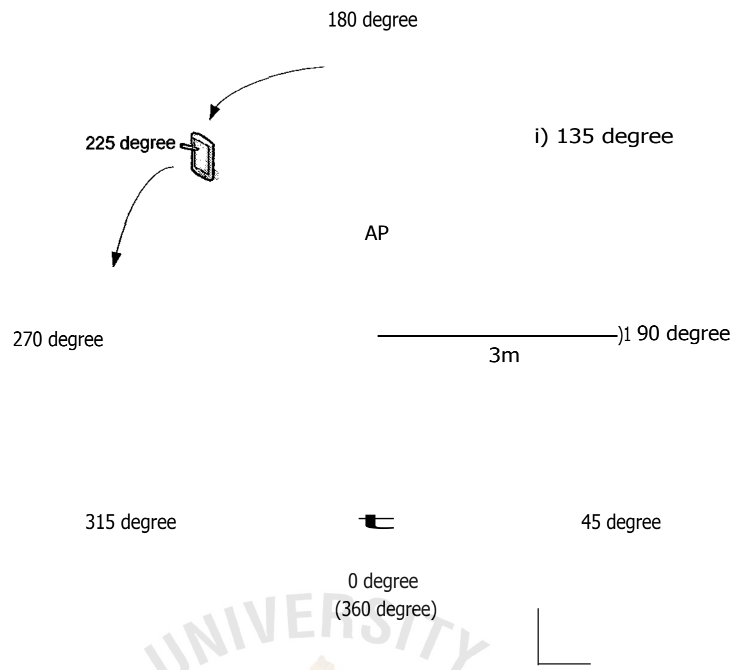


(a)



(b)

Figure 3.4 Signal levels of horizontal wireless adapter experimental setup



(a)

(b)

Figure 3.5 Signal levels of vertical wireless adapter experimental setup

Results :

- Effect of angle (Horizontal ES-WLAN)

Table 3.2 Effect of angle by Horizontal ES-WLAN wireless adapter experiment

Angle (degree)	**Signal (dBm)**	**Noise .(dBm)**
0 (360)	-45.67	-88
45	-44.33	-88
90	-46	-88
135	-45.33	-88
180	-45.67	-88
225	-46	-88
270	-45.6	-88
315	-44.32	-88
Stand Div	0.67	0

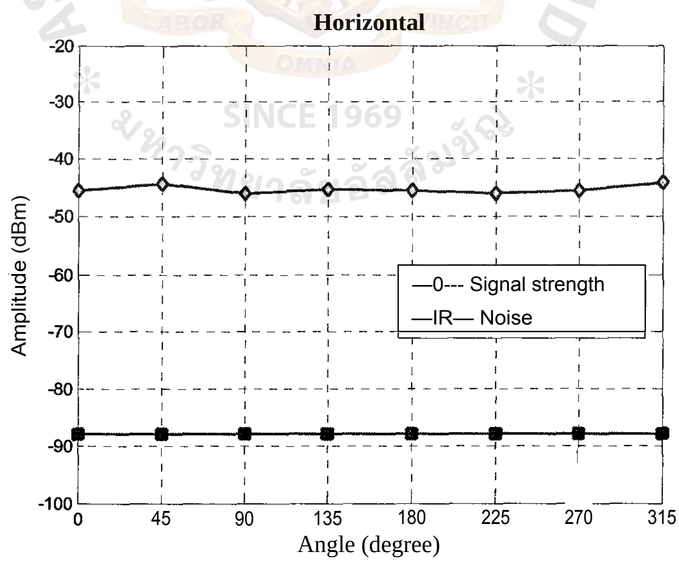


Figure 3.6 Graphical report of signal strength and noise from horizontal wireless adapter

- *Effect of angle (Vertical ES-WLAN)*

Table 3.3 Effect of angle by Vertical ES-WLAN wireless adapter experiment

Angle (degree)	**Signal (dBm)**	**Noise (dBm)**
0 (360)	-45	-88
45	-42.3	-88
90	-43.33	-88
135	-46	-88
180	-44	-88.27
225	-46.71	-88.3
270	-47.66	-88.31
315	-45.28	-88.33
Stand Div.	1.78	0.16

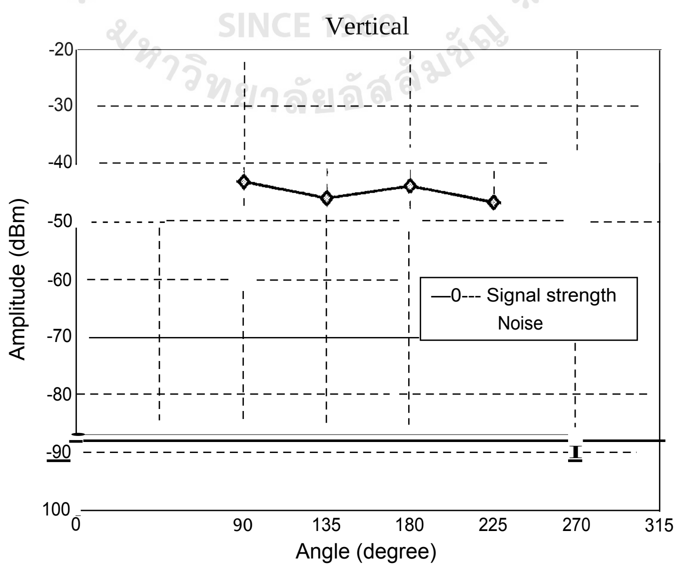


Figure 3.7 Graphical report of signal strength and noise from vertical wireless adapter

Conclusion :

- No significant variation in received signal level and noise level are present when the orientation of the horizontal ES-WLAN wireless adapter is set at any horizontal plane angle. (Standard deviations of these results are less than standard deviation references from experiment 3.1)

- No significant variation in received signal level and noise level are present when the orientation of the vertical ES-WLAN wireless adapter is set at any horizontal plane angle. (standard deviations of these results are less than standard deviation references from experiment 3.1)

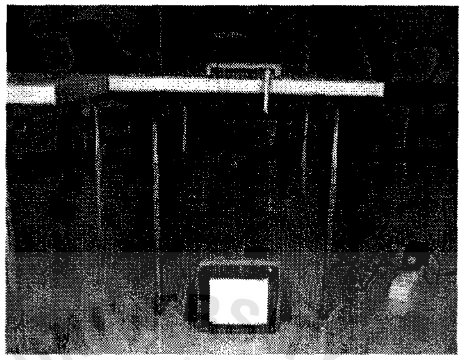
This can be described from the radiation pattern of omnidirectional antenna (Balanis 1982). It transmits their signals in all horizontal directions almost equally. The radiation pattern has the shape of a large donut around the vertical axis (Ohrtman and Roeder 2003). Details will be explained in the next experiment.

3.3 Signal levels for antenna orientation

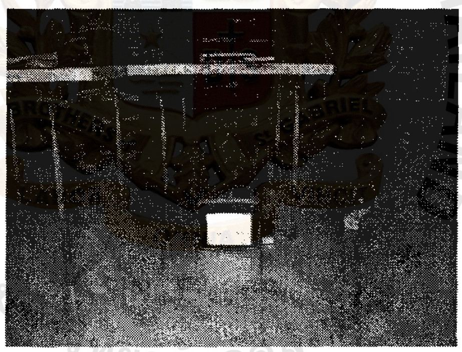
Objective: The effect of antenna orientation is investigated in **4** side . The signal strength of various antenna orientations is observed.

Method: Antenna of access point that is tested in this experiment is omnidirectional. The access point is fixed in location, at a height of 30 cm. from the ground. ES-WLAN is fixed at the ground in the same vertical plane of access point.

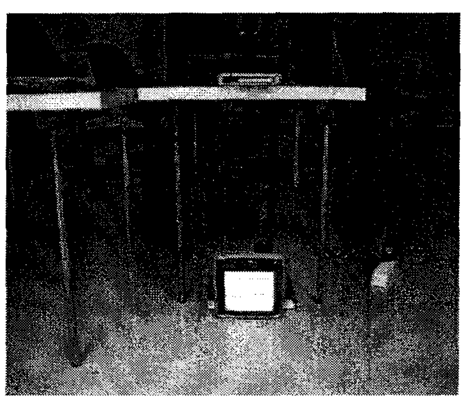
Antenna of access point are rotated in 4 side, these are downside, right side, left side and upside. Signal and noise data were collected 20 times at each side in dB unit then average all 20 values of each side to plot data in a graphical view.



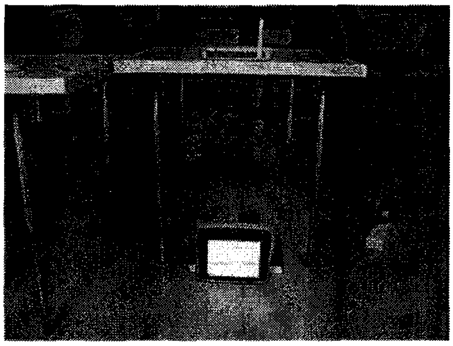
(a) Down side



(b) Right side



(c) Left side



(d) Up side

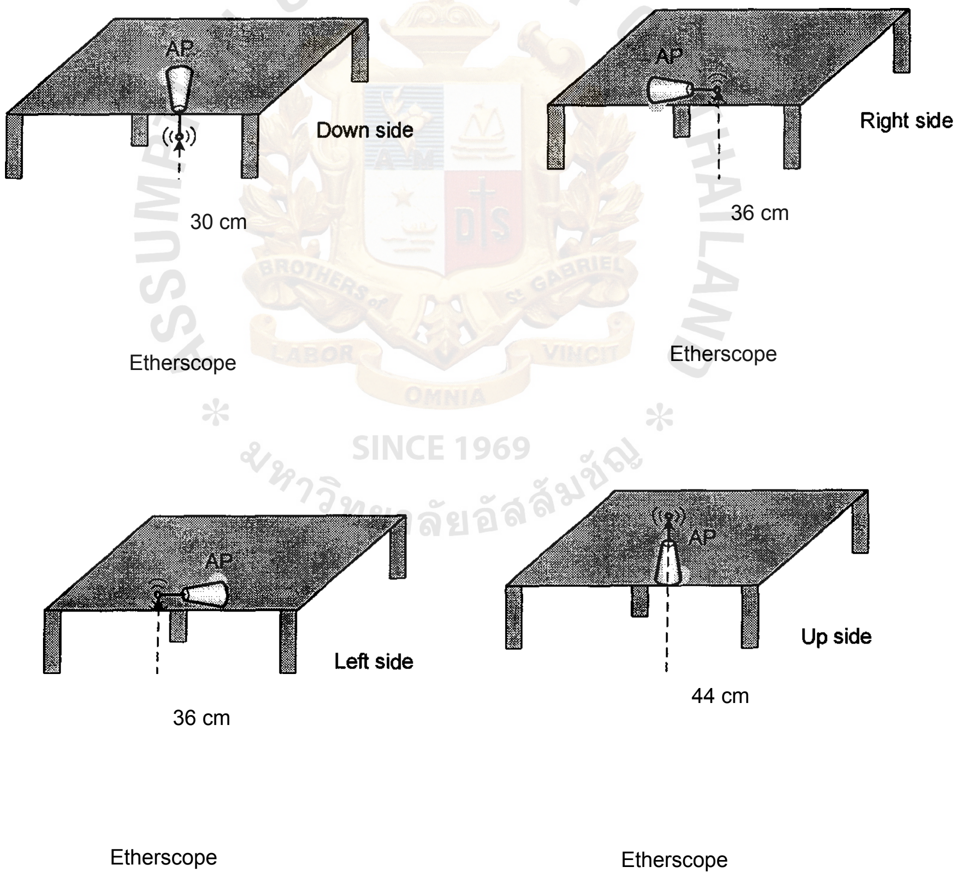


Figure 3.8 Signal levels for antenna orientation experimental setup

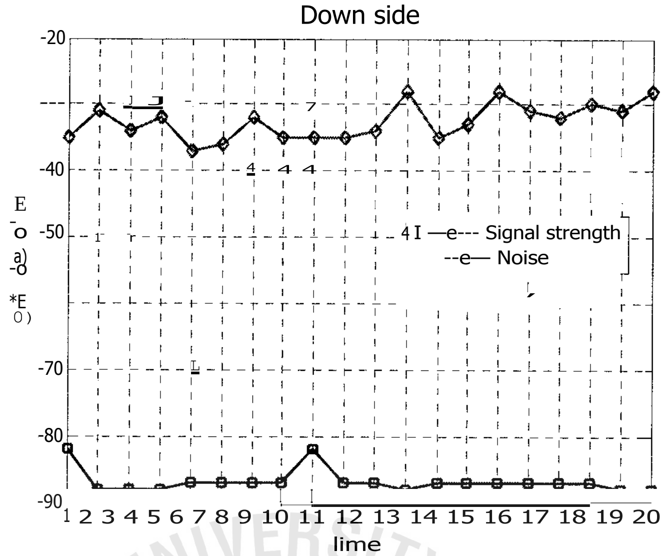
Results:

Table 3.4 Results of antenna orientation

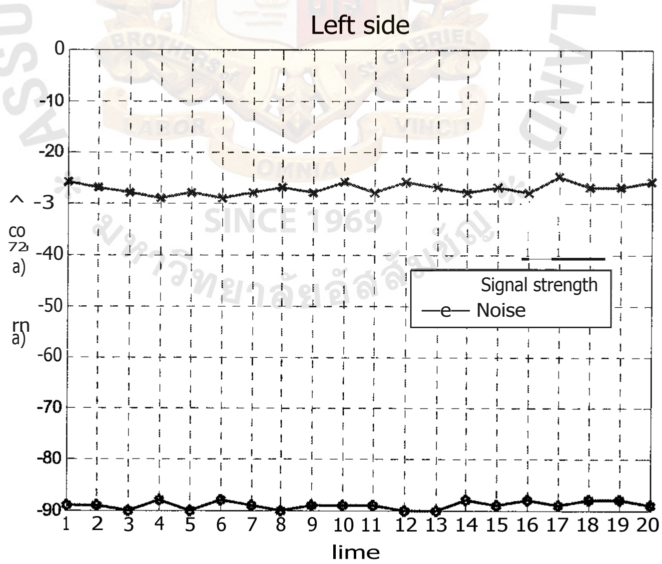
Time.	Down side		Left side		Right side		Up side	
	Signal (dBm)	Noise (dBm)	Signal (dBm)	Noise (dBm)	Signal (dBm)	Noise (dBm)	Signal (dBm)	Noise (dBm)
1	-35	-82	-26	-89	-26	-87	-37	-89
2	-31	-88	-27	-89	-30	-87	-42	-88
3	-34	-88	-28	-90	-29	-87	-38	-89
4	-32	-88	-29	-88	-24	-87	-38	-89
5	-37	-87	-28	-90	-29	-88	-44	-89
6	-36	-87	-29	-88	-20	-88	-42	-89
7	-32	-87	-28	-89	-15	-87	-41	-89
8	-35	-87	-27	-90	-26	-88	-41	-88
9	-35	-87	-28	-89	-28	-88	-40	-89
10	-35	-87	-26	-89	-27	-86	-39	-89
11	-34	-87	-28	-89	-27	-88	-38	-89
12	-28	-88	-26	-90	-22	-88	-42	-89
13	-35	-87	-27	-90	-24	-86	-44	-90
14	-33	-87	-28	-88	-24	-87	-41	-89
15	-28	-87	-27	-89	-24	-88	-40	-89
16	-31	-87	-28	-88	-23	-88	-41	-90
17	-32	-87	-25	-89	-26	-87	-41	-88
18	-30	-87	-27	-88	-23	-89	-37	-89
19	-31	-88	-27	-88	-22	-88	-40	-88
20	-28	-88	-26	-89	-27	-89	-38	-89
Average.	**-32.6**	**-87**	**-27**	**-89**	**-25**	**-88**	**-40**	**-88.9**

Table 3.5 Summary Table

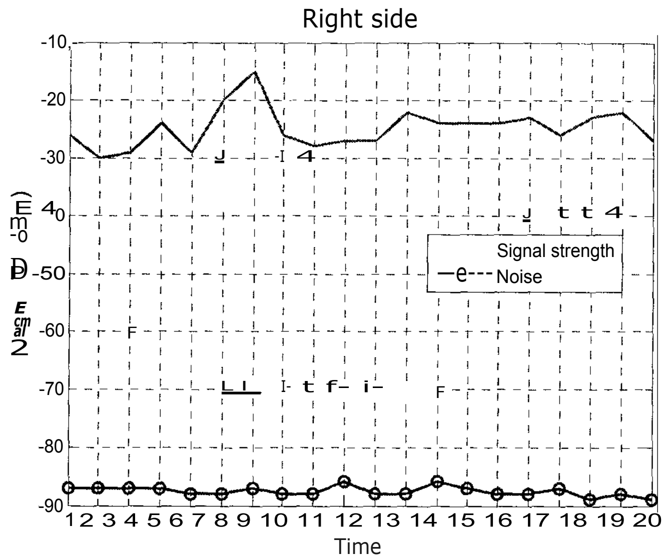
Side	Avg. Signal (dBm)	Avg. Noise (dBm)
Down	-32.6	-87
Left	-27	-89
Right	-25	-88
Up	-40	-88.9



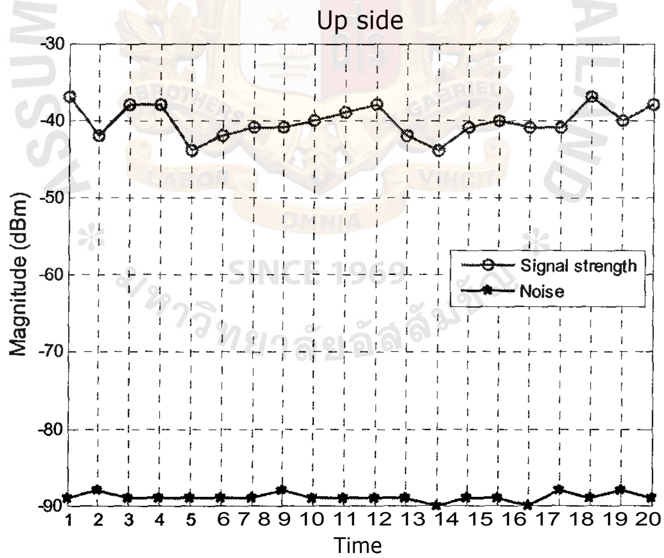
(a) Down side



(b) Left side



(c) Right side



(d) Up side

Figure 3.9 Graphical report of signal strength and noise from antenna orientation

Conclusion : From the figures, Omnidirectional antenna of Netgear access point is investigated. It shows that signal strength of left and right side antenna are stronger than signal strength of down and upside. This can be described from antenna type and its radiation pattern of Omnidirectional Antenna that radiates like the shape of donut.

Omnidirectional Antenna radiates in all horizontal directions almost equally. The radiation pattern has the shape of a large donut around the vertical axis. So the signal near the vertical axis is so weak. The gain is in the horizontal direction at the expense of coverage above and below the antenna. The rubber duckies (the flexible antenna structures on popular access point units) that come with many access points are dipoles that usually have 2.2 dBi of gain. Some access points have integrated dipole antennas and are suitable for both walls and ceilings (Ohrtman and Roeder 2003).

The style of Netgear access point is vertical. Vertical antennas are good at radiating out horizontally; they are not good at radiating up or down. ES-WLAN is fixed in the vertical side (Wireless adapter of ES-WLAN is set in vertical plane) at same plane as Netgear antenna to see the radiation by measuring the signal strength. In the experiment above It can be observed that when wireless adapter is set in up side or down side. It shows weaker signal strength than right or left side. 802.11 networks typically use omnidirectional antennas for both ends of the connection.

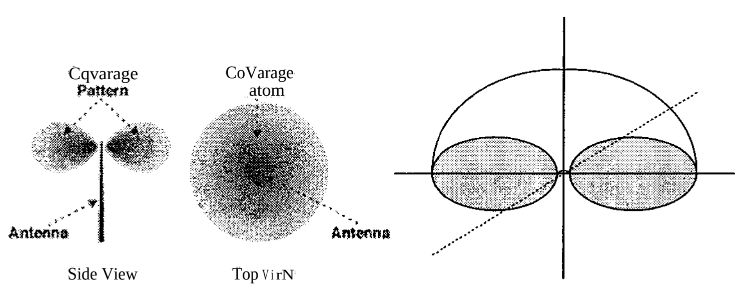
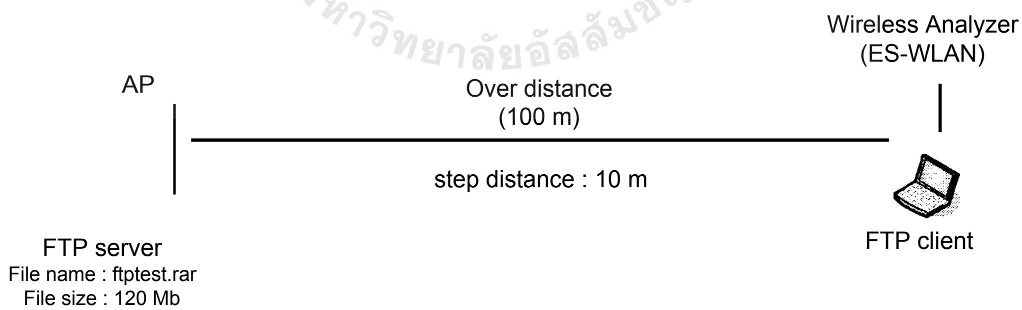


Figure 3.10 Omnidirectional Antenna and Coverage Patterns

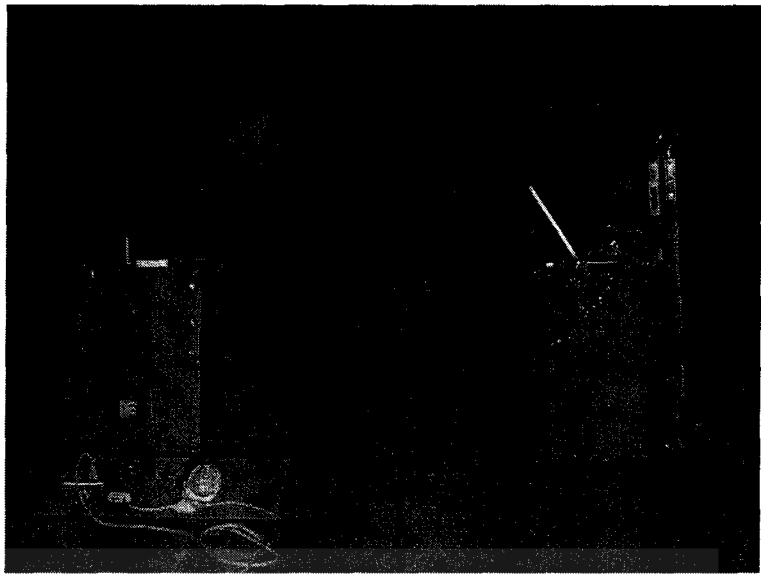
3.4 Signal level and communication Over Distance

Objective: The effect of distance on 802.11g communication is investigated. The performance of Omnidirectional over range is observed.

Method: In this experiment, the maximum distance is 100 meters. Measurement begins at starting point then step up 10 meters until 100 meters. The access point, sender, receiver and ES-WLAN are set in a flat, open area (to reduce the multipath and shadow effect) with line of sight. Signal strength, retries, errors are tested via ES-WLAN for 20 times (because the signal will vary from time to time with a slight difference, so a lot of data is collected and averaged to find the best value) then average to be input in the result table. Throughput is tested by FTP program from FTP client to download a file from FTP server 5 times then average to be input in the table This file name is ftptest.rar which is 120 MB in size.



(a)



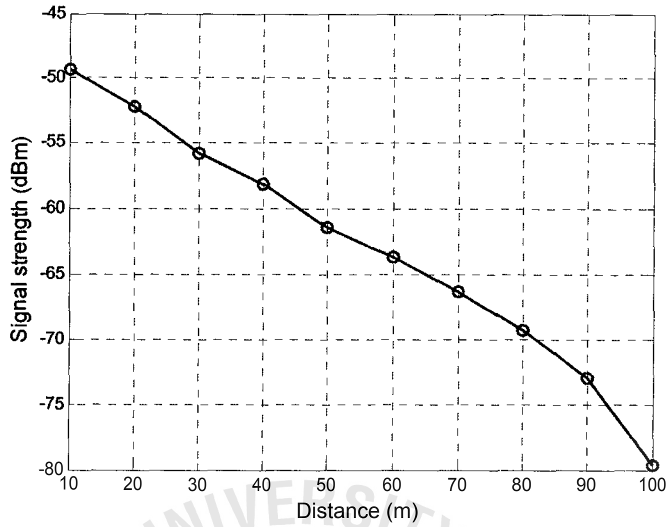
(b)

Figure 3.11 Signal level and communication over distance experimental setup

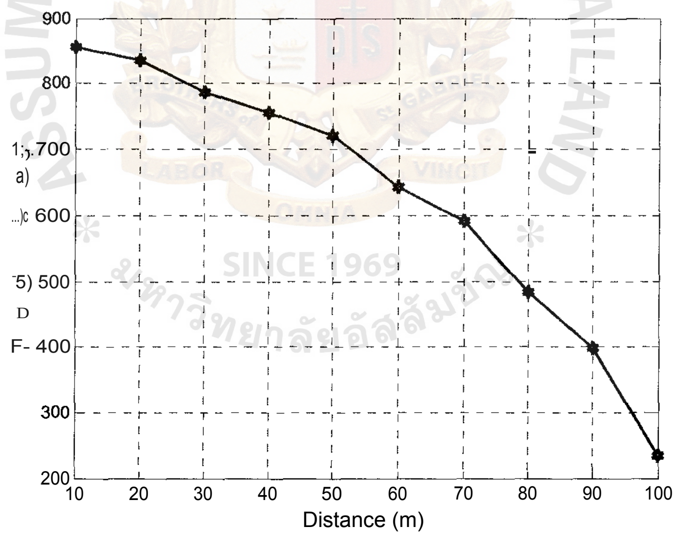
Results:

Table 3.6 Results of over distance

Distance (m)	Signal	Throughput	Retire	Error
10	-49.33	855.99	8.67	4.17
20	-52.25	835.64	9.17	0.6
30	-55.75	785.72	10.34	0.63
40	-58.20	754.98	11.07	20.41
50	-61.40	720.83	12.61	11.97
60	-63.67	644.03	12.92	12.06
70	-66.33	591.09	13.44	7.35
80	-69.33	483	16.47	5.73
90	-73.00	398.4	17.51	2.65
100	-79.67	232.89	18.69	2.39

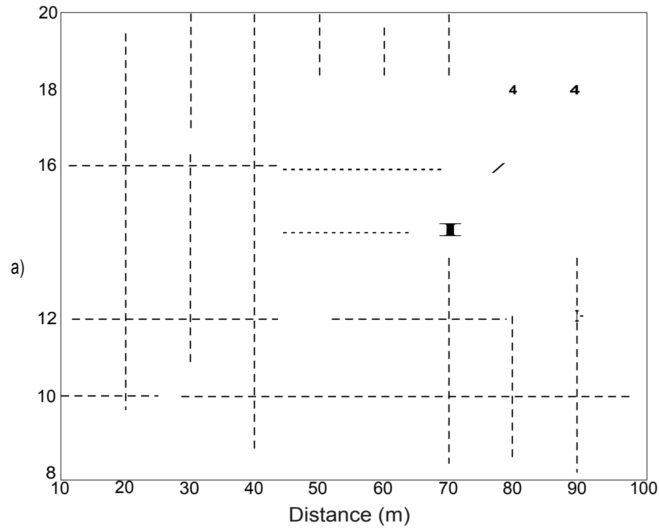


(a) Signal strength

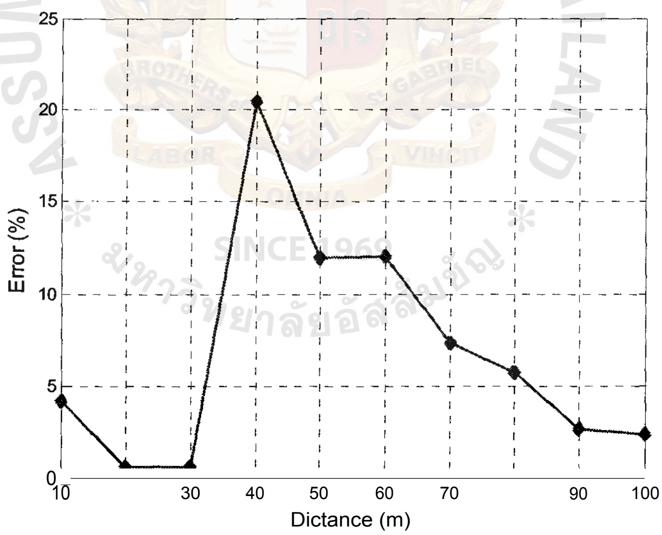


(b) Throughput

Figure 3.12 Graphical report of signal strength and throughput over distance



(c) Retires



(d) Error

Figure 3.13 Graphical report of retires and error over distance

Conclusion: The increase in distance will decrease signal strength and throughput. Received noise power is relatively constant over distance, remaining at low levels. Percent of Retries gradually increased when rising in distance. Error looked increasingly in first some distance after that it looks more slow down.

From the figure, error is the parameter that can not be concluded with the distance relation. These sample size of data is not enough to summarize. So to find relation about distance and error, more experiments is need.

The signal strength and speed of 802.11 systems are distance dependent. The farther away the remote device from the base station, the lower the signal strength and speed are. Also, the actual data throughput is generally no more than half of the rated speed because 802.11 use a collision "avoidance" technology (CSMA/CA) rather than the collision "detection" method (CSMA/CD) in wired Ethernet. Wired systems can detect a collision, but wireless cannot, thus, the CSMA/CA (Gast 2002) method waits for an acknowledgment from the other end to determine if the packet was transmitted properly. A 54 Mbps rated speed yields only about 27 Mbps in real throughput. In addition, access points that support a mixed b and g network drop the throughput to 18 Mbps to start with and wind up with approximately 6 to 9 Mbps total when clients are transmitting.

3.5 Line of Sight (Los) and Non Line of sight (Non-Los) in multipath environment

Objective: 802.11g signal strength and throughput is tested in an enclosed environment with many reflective surfaces, where multipath interference may occur. The signal level in Los and Non-Los environment is shown.

Method : Set access point and one laptop computer with FTP server program installed at one side then set ES-WLAN and one laptop computer with FTP Client installed in the other side Signal Strength and noise are test for 20 times where throughput is tested in 5 times. ES-WLAN is used to test signal strength and noise and FTP program from FTP client is used to download file from FTP server. This file name is ftptest.rar which is 120MB in size. There are 2 patterns of experiment which are Line-of-Sight and Non line-of-sight.

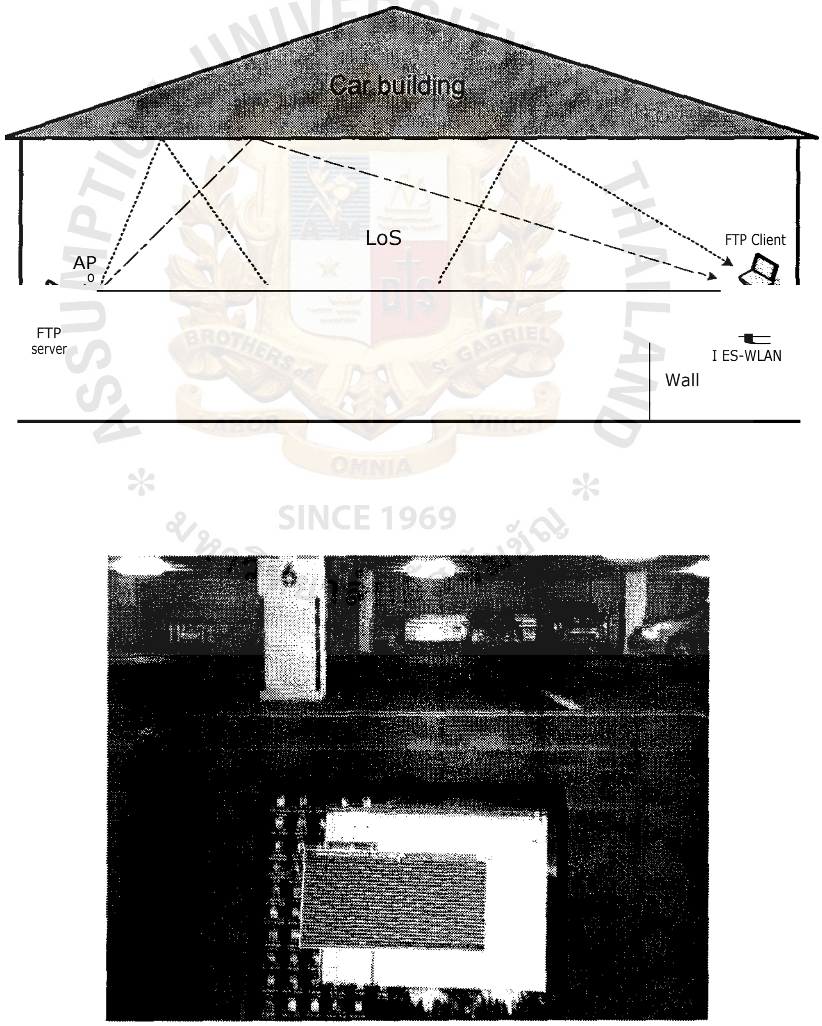


Figure 3.14 Multipath LOS experimental setup

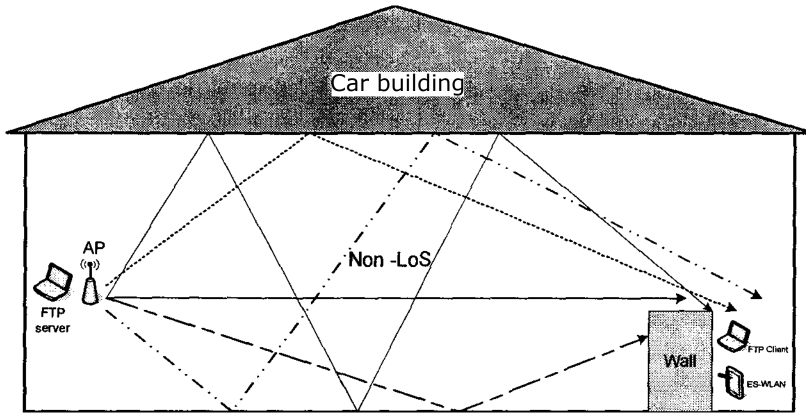


Figure 3.15 Multipath Non-LOS experimental setup

Results :

Table 3.7 Results of multipath LoS experiment

Time	Signal strength (dBm)	Noise (dBm)	Throughput (kbyte/s)
1	-63	-87	962.1
2	-58	-89	991.85
3	-57	-88	1003.01
4	-51	-87	994.01

Table 3.8 Results of multipath Non-LoS experiment

Time	Signal strength (dBm)	Noise (dBm)	Throughput (kbyte/s)
1	-78	-89	632.3
2	-75	-88	757.97
3	-74	-88	741.95
4	-74	-89	769.43

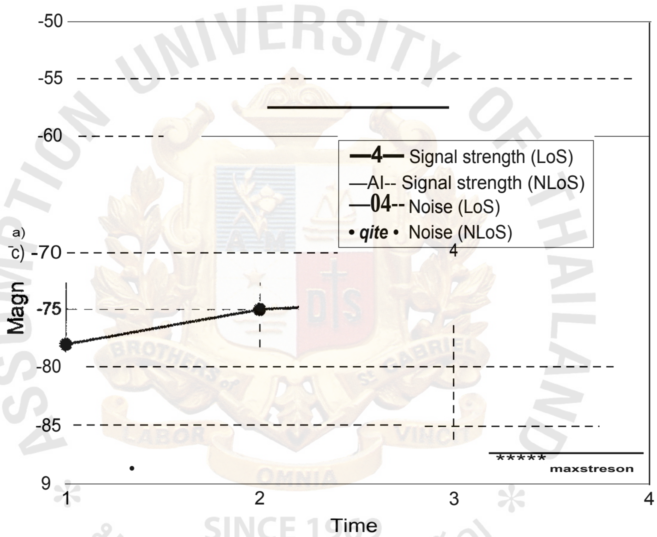


Figure 3.16 Graphical report of signal strength and noise from multipath LOS and multipath Non-LOS

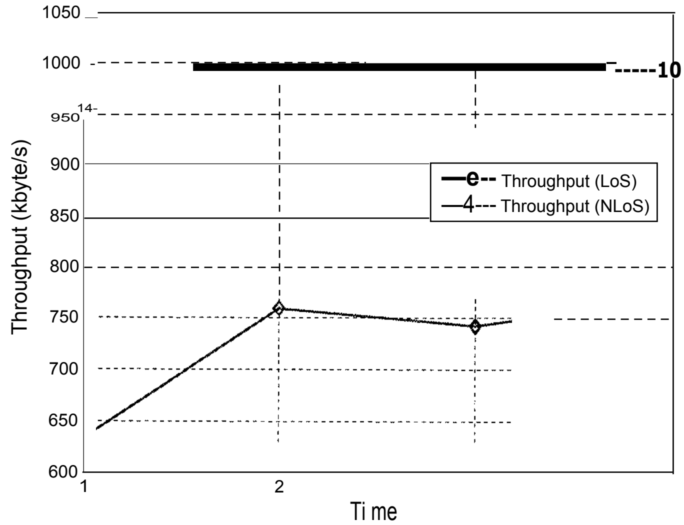


Figure 3.17 Throughput of multipath LOS and multipath Non-LOS

Conclusion : From the experiments, **It** can conclude that signal strength of LOS is stronger than Non-LOS where noise is similar. Throughput performance of LOS is better than Non-LOS.

Line of sight means a direct, unobstructed path exists from the transmitter to the receiver. This usually means in any wireless network that the transmission will suffer less degradation than it would if an object(s) was obstructing that path. Line of sight is the best possible configuration for transmission on 802.11 networks

Line of sight in microwave includes an area around the path called the Fresnel zone (Ohrtman and Roeder 2003). The Fresnel zone is an elliptical area immediately surrounding the visual path. It varies depending on the length of the signal path and the frequency of the signal. The Fresnel zone can be calculated and must be taken into account when designing a wireless link Any object within the Fresnel zone attenuates the transmission path between tow points The maximum radius of the Fresnel zone can be calculated by the following formula (Ohrtman and Roeder 2003);

$$R = 43.3 \ X \ sqrt(d/41)$$

Where d is the distance in miles, f is the frequency in GHz and R is the length in feet.

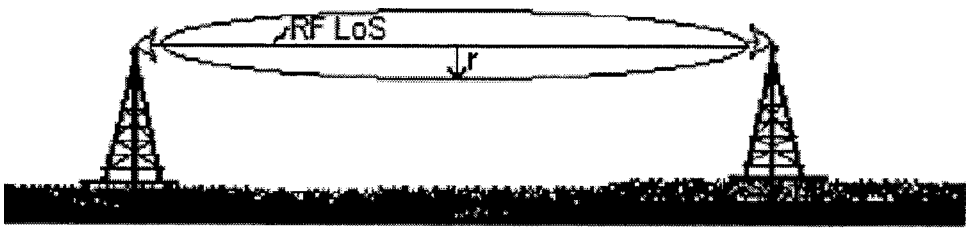


Figure 3.18 Fresnel zone

Non line of sight means the radio link is blocked. However, with proper engineering, it is possible to receive 802.11services without having a direct line of sight to the service provider's transmitter. This term usually applies where the service provider has deployed its transceivers in a cell network where a backbone services individual cells. If a subscriber is in a location that is non line of sight, he or she will not be served by the WISP. To reach that prospective customer, the service provider would have to deploy a new, costly base station.

One alternative to a new base station would be any-point or an ad hoc peer-to-peer network. In the case of any-point-to-multipoint network topology, any node already in the network can be used as a relay point to reach the central site. Ad hoc peer-to-peer technology, also known as mesh networks, can also provide cost-effective means of providing service to non-line-of-sight locations.

Usually, in a wireless environment, there is not a direct line of sight between the transmitting and receiving stations. This results in what is known as path loss or multipath loss. Path loss is the loss of signal power between the AP and client as the distance between them increases. Obstacles such as walls, ceilings, trees, fish tanks, furniture and tined glass can affect path loss. Transmission frequency can also affect path loss. Generally, higher frequencies can not achieve as great a transmission as lower frequencies. Radio signals bounce off objects within the environment such as walls and furniture, which means that the signal can take multiple paths to its destination. When this occurs, the signal received may come from different directions with different strengths and the receiver must combine these reflections to arrive at the originally sent message.

The main problem with multipath is that it creates delay spread. Depending on the number of reflections and the speed differences between signals, the signals arrive at slightly different times at the receiver, creating an echo effect. This can create destructive interference when the echo of the previous signal corrupts the current signal Because the various parts of the signal vary in amplitude and phase, the resulting rebuilt signal may be combined in a manner that severely degrades the signal's strength. The AP must properly demodulate and decode the signal into the originally sent transmission.

3.6 Attenuation of 802.11g Signals (Wall types)

Objective: Test the signal loss and penetrate abilities of 802.11g signals through a variety of materials.

Method I (Outdoor): Set access point inside the foam box. Foam box is used in this experiment because foam is the material in which wireless signals can pass through all sides. So reflection or refraction effects would be decreased inside the box. Foam box is used only to hold back the wall types. Set ES-WLAN at a distance of 5 meters far away from access point.

Close the foam box at front side by each wall type. Signal strength of access point is measured 20 times for each wall type then the average of these values is to be input in the table and then plot the graph

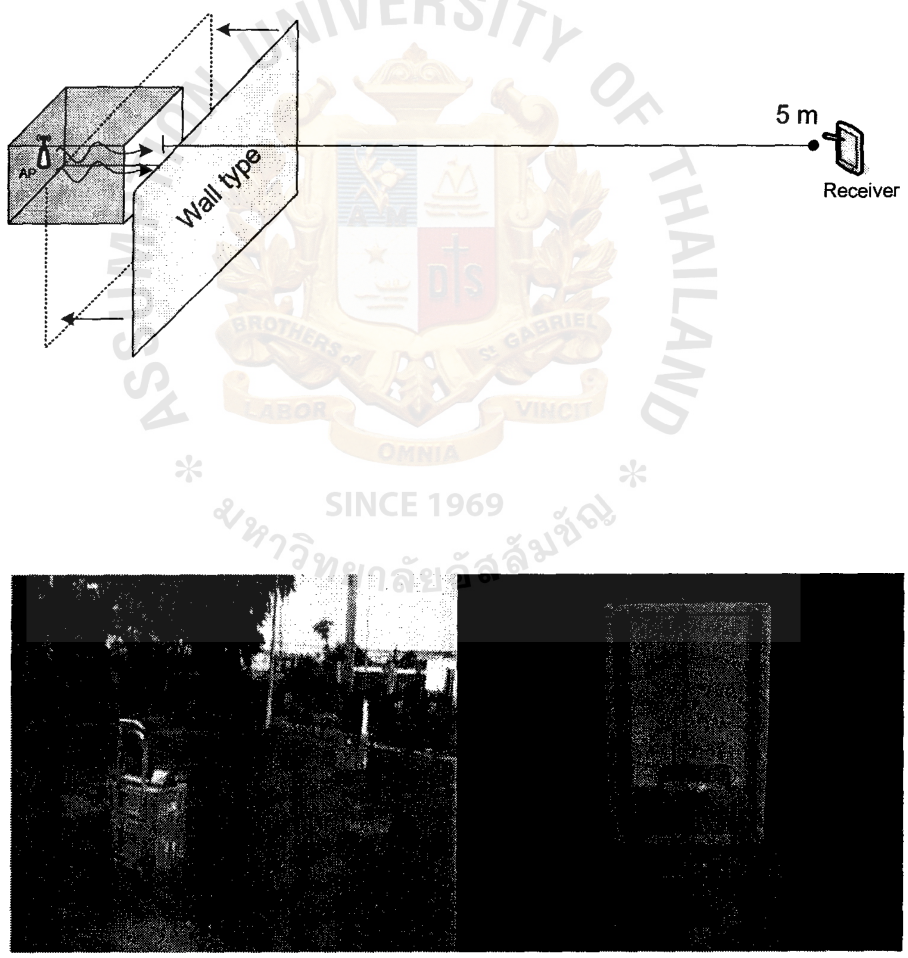
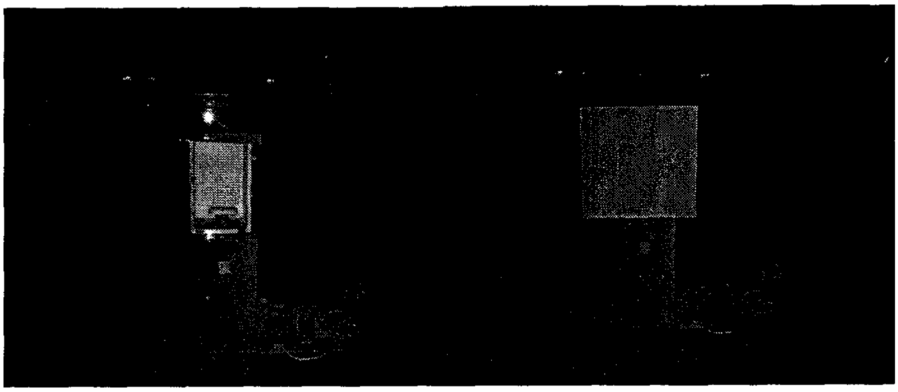
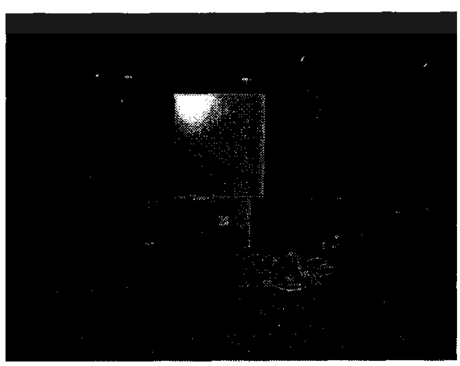


Figure 3.19 Attenuation of 802.11g Signals (Wall types) experimental setup



(a) Glass (b) Gypsum board

(c) Wood (d) Concrete



(e) Metal

Figure 3.20 Wall types setup

Results:

Table 3.9 Results of wall type experiment

Wall types	Thickness (mm)	Signal (dBm)	Noise (dBm)	Attenuation (dB)(calculation)
Open Air	-	-48.5	-88	-
Gypsum Board	9	-49.5	-88	1
Glass	5	-51.0	-88	2.5
Wood	10	-52.5	-88	4
Concrete	40	-54.4	-88	5.9
Metal	1	-60.00	-88	11.5

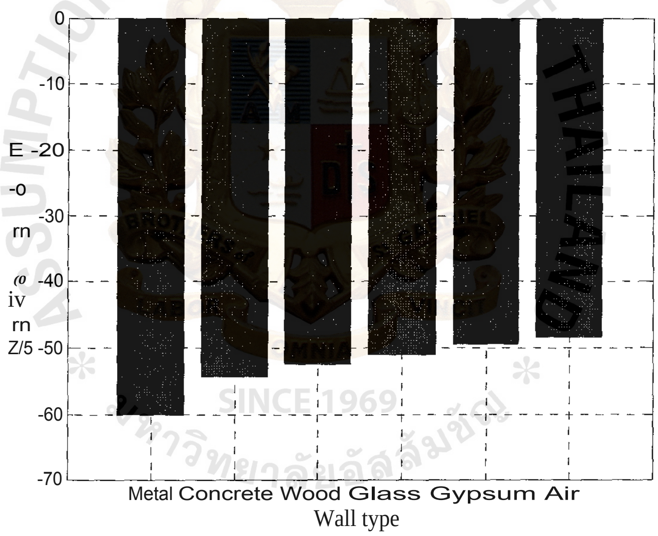


Figure 3.21 Graphical report of 802.11g Signals attenuation from wall types

Conclusion: In this experiment, the thickness of each material is not equal so signal level passing through each wall type is compared with signal strength passing through open air. From the figure, attenuation of 1 mm metal is so high whereas attenuation from 9 mm gypsum or 5 mm glass is a little bit more than air. 40 mm concrete show 5.9 dB attenuated signal. Attenuation from 10 mm wood is 4 dB.

Method II (Indoor):

-Glass door in office wall (The distance of experiment is 5 m.)

Set equipments same as figure 3.22 and figure 3.23

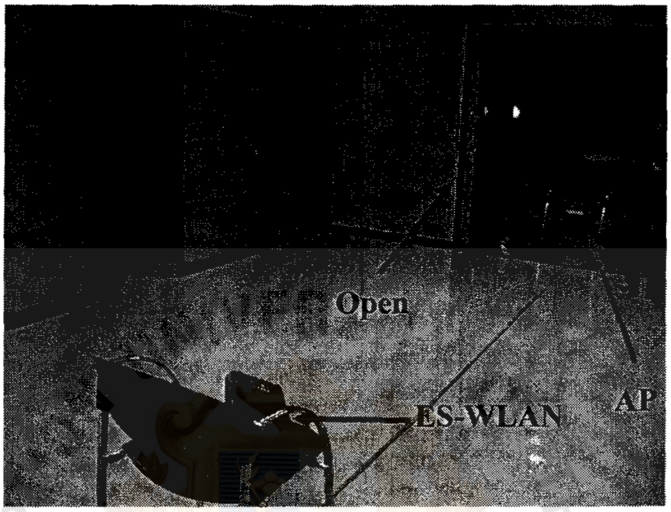


Figure 3.22 Opened glass door in office wall experimental setup

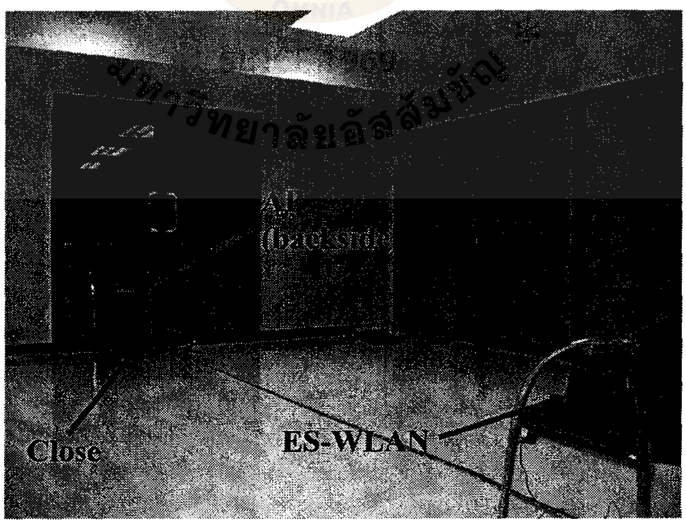


Figure 3.23 Closed glass door in office wall experimental setup

Result of glass door in office wall

Table 3.10 Results of glass door in office wall experiment

Open			Close		
Time	Signal (dBm)	Noise (dBm)	Time	Signal (dBm)	Noise (dBm)
1	-42	-88	1	-48	-88
2	-41	-88	2	-47	-88
3	-42	-88	3	-49	-88
4	-42	-88	4	-47	-88
5	-42	-88	5	-47	-88
6	-42	-88	6	-47	-88
7	-43	-88	7	-48	-88
8	-43	-88	8	-47	-89
9	-42	-88	9	-48	-88
10	-42	-88	10	-48	-88
11	-42	-88	11	-47	-89
12	-42	-88	12	-48	-88
13	-42	-88	13	-49	-88
14	-41	-88	14	-47	-88
15	-42	-88	15	-48	-88
16	-42	-88	16	-49	-88
17	-42	-88	17	-47	-88
18	-41	-88	18	-48	-88
19	-42	-88	19	-47	-88
20	-41	-88	20	-48	-88
Average	-41.9	-88	Average	-47.7	-88.1

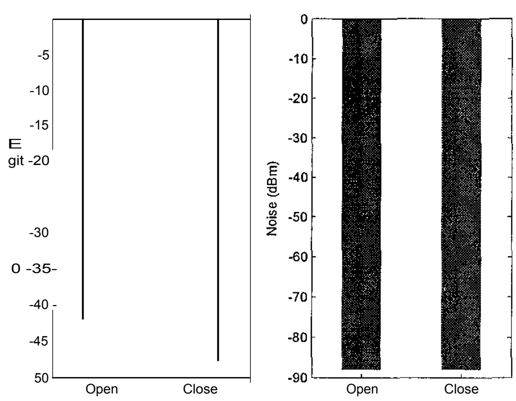


Figure 3.24 Graphical report of signal strength and noise from glass door attenuation

- *Wooden door in office wall (the distance of experiment is 5 m.)*

Set equipments same as figure 3.25 and 3.26

Figure 3.25 Opened wooden door in office wall experimental setup

Figure 3.26 Closed wooden door in office wall experimental setup

- Result of wooden door in office wall

Table 3.11 Results of wooden door in office wall experiment

Open			Close		
Time	Signal (dBm)	Noise (dBm)	Time	Signal (dBm)	Noise (dBm)
1	-46	-88	1	-59	-89
2	-47	-89	2	-59	-89
3	-46	-89	3	-59	-89
4	-47	-89	4	-61	-89
5	-46	-89	5	-61	-89
6	-46	-89	6	-62	-89
7	-46	-87	7	-62	-89
8	-48	-87	8	-62	-89
9	-48	-88	9	-62	-89
10	-46	-88	10	-61	-89
11	-46	-89	11	-61	-89
12	-45	-89	12	-61	-89
13	-45	-89	13	-62	-89
14	-48	-89	14	-62	-89
15	-46	-89	15	-62	-89
16	-46	-89	16	-62	-89
17	-46	-88	17	-62	-89
18	-47	-89	18	-61	-89
19	-47	-89	19	-61	-89
20	-46	-89	20	-61	-89
Average	**-46.4**	**-88.6**	**Average**	**-61.15**	**-89**

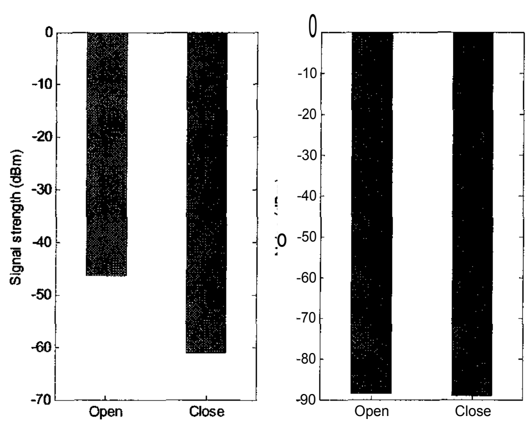


Figure 3.27 Graphical report of signal strength and noise from wooden door attenuation

- *Metal door (Lift) (The distance of experiment is 3.5 m.)*

Set equipments same as figure 3.28 and 3.29

Figure 3.28 Opened and closed metal door (lift) in office wall experimental setup

Figure 3.29 Side view of closed metal door (lift)

- Result of Metal door (Lift)

Table 3.12 Results of Metal door (Lift) experiment

Open			**Close**		
Time	**Signal (dBm)**	**Noise (dBm)**	**Time**	**Signal (dBm)**	**Noise (dBm)**
1	-34	-89	1	-71	-88
2	-34	-89	2	-73	-88
3	-34	-88	3	-73	-88
4	-34	-89	4	-73	-88
5	-34	-89	5	-72	-88

Table 3.12 Results of Metal door (Lift) experiment (Continued)

Open			**Close**		
Time	Signal (dBm)	Noise (dBm)	Time	Signal (dBm)	Noise (dBm)
6	-34	-89	6	-74	-87
7	-35	-89	7	-74	-88
8	-34	-89	8	-73	-88
9	-34	-89	9	-72	-88
10	-36	-86	10	-72	-88
11	-35	-89	11	-73	-88
12	-35	-88	12	-73	-88
13	-35	-89	13	-73	-88
14	-35	-88	14	-72	-88
15	-34	-88	15	-72	-88
16	-34	-88	16	-72	-88
17	-33	-89	17	-72	-88
18	-33	-89	18	-72	-88
19	-35	-88	19	-72	-88
20	-35	-88	20	-72	-88
Average	**-34.35**	**-88.5**	**Average**	**-72.5**	**-87.95**

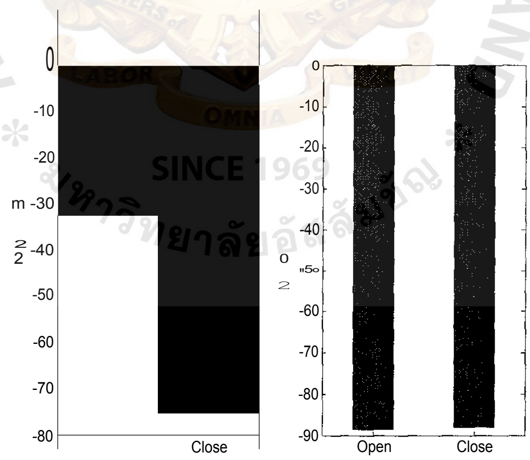


Figure 3.30 Graphical report of signal strength and noise from Metal door (lift) Attenuation

Radio waves don't really travel the same distance in all directions. Walls, doors, elevator shafts, people, and other obstacles offer varying degrees of attenuation, which cause the Radio Frequency (RF) radiation pattern to be irregular and unpredictable. Attenuation is simply a reduction of signal strength during transmission. Attenuation is registered in decibels (dB), which is ten times the logarithm of the signal power at a particular input divided by the signal power at an output of a specified medium. For example, an office wall (i.e. medium) that changes the propagation of an RF signal from a power level of 200 mill watts (the input) to 100 mill watts (the output) represents 3 dB of attenuation. The following provides some examples of the attenuation values of common office construction:

Attenuation of various building materials (Ohrtman and Roeder 2003)

Plasterboard wall: 3dB

Glass wall with metal frame: 6dB

Cinder block wall: 4dB

Office window: 3dB

Metal door: 6dB

Metal door in brick wall: 12.4dB

Other factors that will reduce range and affect coverage area include concrete fiberboard walls, aluminum siding, pipes and electrical wiring, microwave ovens, and cordless phones.

3.7 Interchannel Interference — AP traffic

Objective: As 802.11 employs Direct Sequences Spread Spectrums with overlapping channels, we may observe impact of Interchanger interference in 802.11g by generating traffic in adjacent channels.

Method: 3 access points and laptop computers are used, alongside the sending and receiving equipment. The access points (AP 1 and AP2) are connected via UTP cable such that data can be routed between the two wireless networks. These 3 access points would be set in different channels following Table 3.7 Data is transferred between the two wireless networks in order to generate continuous channel traffic by ping function in Microsoft Windows XP Operating System. In this experiment, this ping command line is used between Client of AP1 and Client of AP2. Both clients use ping to send packet to the other client.

1. Configuration Solution

Set Channel of access points following table 3.7

AP1 : Channel 1, AP2 : Channel 7, AP3 : Channel 13

Client of AP1: set IP: 192.168.201 and link to AP1

Client of AP2: set IP: 192.168.202 and link to AP2

Client of AP3: FTP Server: set IP: 192.168.203 and link to AP3

Client of AP3: FTP Client: set IP: 192.168.204 and link to AP3

2. Command Solution

At Client of AP1 use command --> C:\> ping —t —165500 192.168.0.202

At Client of AP2 use command -> C:\> ping —t —1 65500 192.168.0.201

At Client of AP3: FTP Server: Install Cerberus FTP Server and copy ftptest.rar into the ftproot folder

At Client of AP3: FTP Client : Use FTP function of Windows XP to transfer ftptest.rar from FTP Server

3. Measured signal level, crosstalk rate and throughput of FTP Client

4. Change Channel of each access point to other channels following Table 3.7

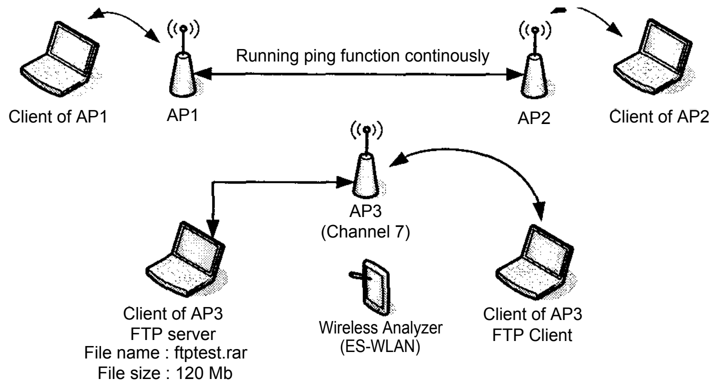
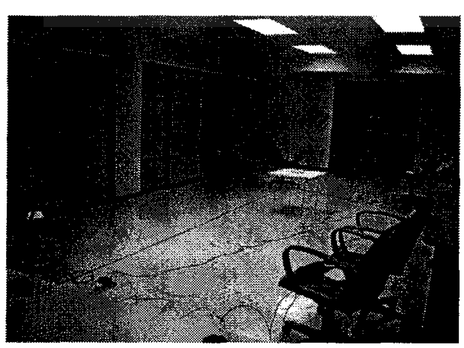


Figure 3.31 Interchannel Interference experimental setup

Signal, noise and crosstalk rate measurements were performed for the following channel combinations:

Table 3.13 channel allocations

Pattern	AP1	Sender (AP3)	AP2
1	1	7	13
2	4	7	10
3	6	7	8



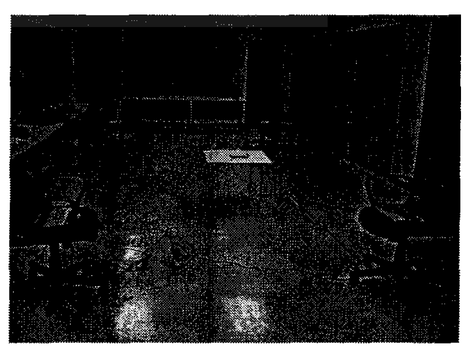


Figure 3.32 Experiment of Interchannel Interference

Results:

Table 3.14 Results of Interchannel interference experiment

1, 7, 13	**Time**	**AP3 Signal(dBm)**	**Crosstalk Rate(%)**	**Throughput (kbyte/s)**
	1	-45	0	883.48
	2	-45	0	885.17
	3	-37	0	820.5
	4	-44	0	886.73
	5	-43	0.9	843.99
	6	-39	0	774.86
	7	-46	0	745.56
	8	-40	0	775.7
	9	-42	0	771.2
	10	-46	0	739.83
	Avg.	**-42.7**	**0.09**	**812.702**
4, 7, 10	**Time**	**AP3 Signal(dBm)**	**Crosstalk Rate(%)**	**Throughput (kbyte/s)**
	1	-47	3.37	632.99
	2	-48	2.33	678.82
	3	-45	0	736.38
	4	-43	0.3	729.98
	5	-43	0	709
	6	-40	0	718.16
	7	-47	0	742.06
	8	-44	0	758.96
	9	-52	0	712.46
	10	-49	0	657.98
	Avg.	**-45.8**	**0.6**	**707.679**
6, 7, 8	**Time**	**AP3 Signal(dBm)**	**Crosstalk Rate(%)**	**Throughput (kbyte/s)**
	1	-40	2.73	515.02
	2	-40	0.95	521.07
	3	-42	2.59	628.61
	4	-40	3.8	609.54
	5	-39	53.31	477.57
	6	-41	5.35	596.68
	7	-44	66.61	628.66
	8	-41	3.1	547.03
	9	-38	44.92	502.31
	10	-45	0.95	530.44
	Avg.	**-41**	**18.431**	**555.693**

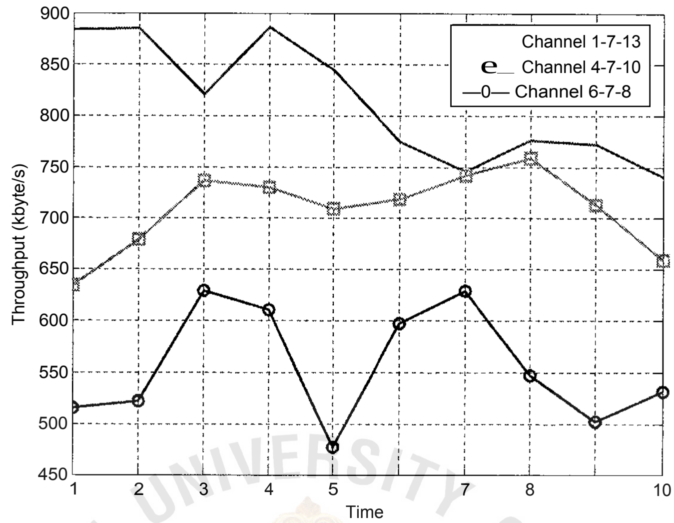


Figure 3.33 Graphical Report of throughput from Interchannel Interference experiment

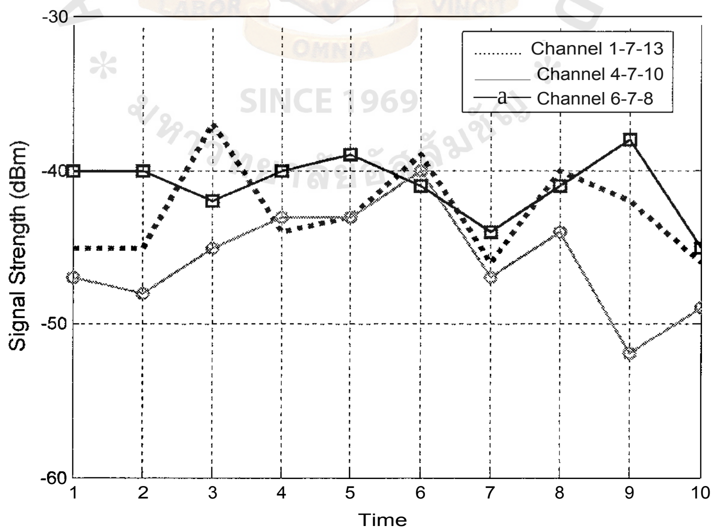


Figure 3.34 Graphical report of signal strength from Interchannel Interference experiment

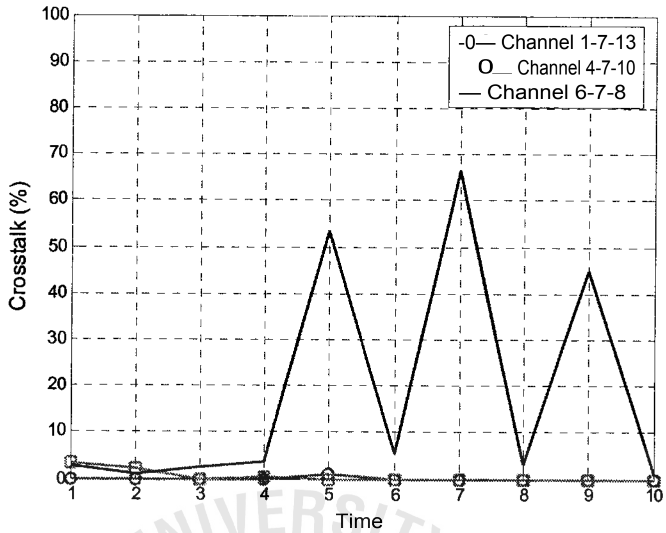


Figure 3.35 Crosstalk rate of Interchannel Interference experiment

Conclusion: From the results, the signals from each channel allocation pattern are not different. Noise level from each channel allocation looks very little bit difference, so no significant level in noise level in each allocation. Crosstalk rates of each frequency combination are very interesting.

In pattern 1, the channels are nonoverlapping. Crosstalk rate is the least and throughput is the most when compare to the others. In pattern 2, the channels are partially overlapping. Crosstalk rate from pattern 2 is much more than crosstalk rate from pattern 1 and throughput is less. In pattern 3, the channels are heavily overlapping Crosstalk rate is the most while throughput is the least. It is also observed from other experiment that the signal and noise power levels are good indicators as to the performance and reliability of a wireless link, but should not be the sole consideration when anticipating the characteristics of the channel. Interchannel interference has a definite impact on the performance and reliability of the wireless link.

Wi-Fi uses the spectrum near 2.4 GHz, which is standardized and *unlicensed* by international agreement, although the exact frequency allocations vary slightly in different parts of the world, as does maximum permitted power. However, channel numbers are standardized by frequency throughout the world, so authorized frequencies can be identified by channel numbers. The frequencies for 802.11 b/g span 2.400 GHz to 2.487 GHz. Each channel is 22 MHz wide yet there is a 5 MHz step to the next higher Three nonoverlapping channels are available. The maximum number of available channels for wi-fi enabled devices is 13 for Europe, 11 for North America and 14 for Japan. Thailand uses the same channels as Europe.

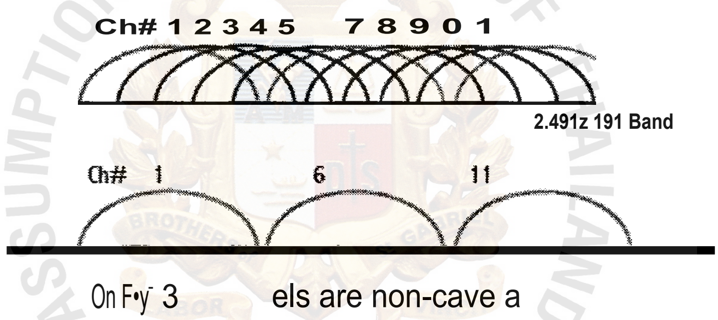


Figure 3.36 11 Channels are available in the U.S. for 802.11 b/g

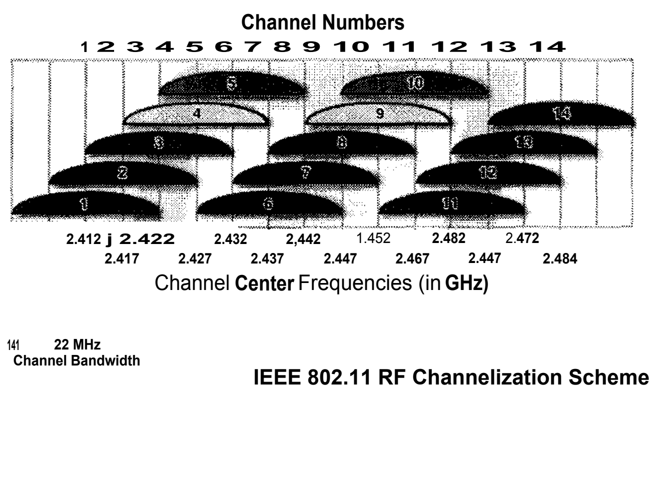


Figure 3.37 IEEE 802.11 RF Channelization scheme

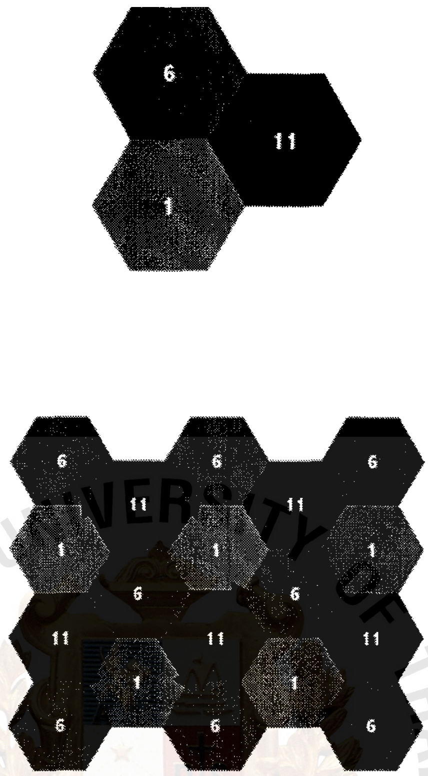


Figure 3.38 Frequency Re-use Cell planning

Channel available of 802.11 b/g is 3. Distance to cell with same channel is less than a single cell. Inter-cell Interference from other cells on the same channel greatly reduces overall network capacity. Bleed-over retards higher data rates

For a simple project like one or two APs, simply assign the least used frequencies from the site survey. For more complex projects involving three or more APs, pick a frequency reuse pattern for the frequencies that are used for the project; with the most complicated part of your site survey and start assigning frequencies. Plan the location of APs initially for coverage, not capacity. Avoid overlapping channels if possible. However, if an area has to be overlapped, plan it such that it is naturally an area where the most capacity would be required, such as in a library, conference room, or lecture hall.

For multiple-floor installations, if more than 30 dB of isolation is used between floors (such as concrete and rebar floors), try not to use the same frequency directly above or below a cell that has already been allocated. Where less than 30 dB of isolation is used between floors (such as a two-by-four framed apartment building), the plan needs to take the three-dimensionality of the cell into account.

Some of the most complex problems are areas where not enough channels are available to plan out the space. In a two-dimensional space, this can happen in areas where a central room has to be covered with surrounding classrooms or offices, such as a library or lab. In three-dimensional spaces, this can happen in a tri-level portion of a building.

The signals from different floors can overlap and intrude on another. In some case when you have no way around two cells that use the same frequency being bordered against each other, plan the seam to be in areas where no coverage is necessary, such as equipment rooms, restrooms, wiring closets, stairwells and janitorial supply rooms.

IV. THE CASE STUDY OF WLANs IN A-BUILDING AT ABAC

In this chapter, The effects of the obstacle to the signal strength and channel allocation in the 5th floor and 6th floor of A-building, Assumption University, (Huamark Campus) are considered. In this case only 3 Access Points will be investigated. These are AuAP-A5, AuAP-A6 and AuAP-A6-2.

(The experiments were taken on 26 July 2006)

4.1 The 5th floor of A-building.

4.1.1 Experimental Setup

The experiments were conducted in several positions on the 5th floor of the A-building. The position layout is shown in Fig. 4.1

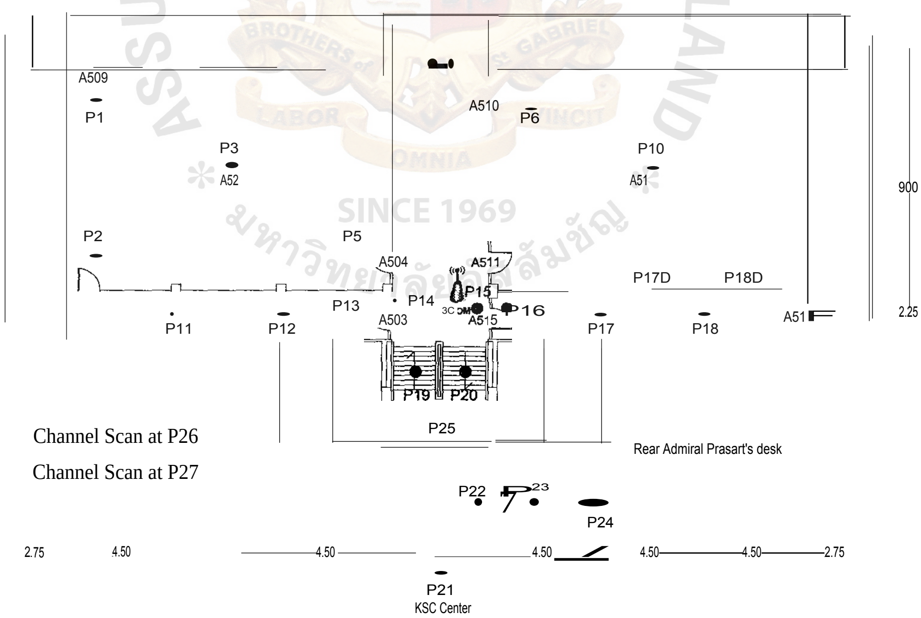


Figure 4.1 Layout of the 5th floor

In Figure 4.1, the 5th floor of A-building, 27 positions were measured for signal strength, noise and signal to noise ratio (SNR). The AP (AuAP-A5) is marked in the layout at A515.

Figure 4.2 Position of AuAP-A5

4.1.2 Results

Table 4.1 Signal strength, Noise and SNR of the 5th floor

AP	Position	signal (dBm)	noise (dBm)	SNR (dB)	AP	signal (dBm)	noise (dBm)	SNR (dB)	AP	signal (dBm)	noise (dBm)	SNR (dB)
AuAP-AS	PI	-74.5	-87	12.5	AnAP-A6	-81	-88	7	AuAP-A6-2	-80.5	-86	5.5
	P2	-81	-89	8		-84.5	-86.5	2		-84.5	-87	2.5
	P3	-76	-76	0		-86	-87.5	1.5		-78.5	-86.5	8
	P4	-68	-89	21		-82	-87	5		-69.5	-87.5	18
	P5	-68.5	-89	20.5		-78.5	-85	6.5		-78	-87.5	9.5
	P6	-67	-87.5	20.5		-81	-85.5	4.5		-71.5	-87.5	16
	P7	-77.5	-87	9.5		-87	-87	0		-80.5	-86.5	6
	P8	-70	-76.5	6.5		-82.5	-83.5	1		-69	-87.5	18.5
	P9	-78.5	-87.5	9		-91.5	-86.5	-5		-79	-86.5	7.5
	P10	-77	-87.5	10.5		-86	-86	0		-70	-87	17
	P11	-61	-90	29		-83	-88	5		-87	-88	1
	P12	-63	-89	26		-71	-87	16		-85	-88	3
	P13	-51	-89	38		-65	-87.5	22.5		-76	-88	12
	P14	-46	-89	43		-65.5	-87.5	22		-76.5	-88.5	12
	P15	-48.5	-84.5	36		-65	-76	11		-78.5	-88.5	10
	P16	-50	-79	29		-65	-75	10		-72	-90	18
	P17	-62	-84	22		-72	-90	18		-70	-86	16
	P18	-75	-88	13		-74	-89	15		-83	-87	4
	P19	-60	-89	29		-62	-88	26		-70	-88	18
	P20	-54	-89	35		-69	-87	18		-76	-88	12

Table 4.1 Signal strength, Noise and SNR of the 5th floor (Continued)

AP	**Position**	signal **(dBm)**	noise **(dBm)**	SNR **(dB)**	**AP**	signal **(dBm)**	noise **(dBm)**	SNR **(dB)**	**AP**	signal **(dBm)**	noise **(dBm)**	SNR **(dB)**
AuAP-A5	P21	-78	-90	12	**AuAP-** A6	-86	-89	3	**AuAP-** A6-2	-81	-86	5
	P22	-76	-88	12		-85	-88	3		-77	-87	10
	P23	-89	-89	0		-85	-85	0		-77	-88	11
	P24	-90	-89.5	-0.5		-90	-88	-2		**-81**	**-88.5**	7.5
	P25	-62	-89	27		-74	-86	12		-85	-87	2
	P26	-59	-89	30		-68	-88	20		-70	-87	17
	P27	-57	-89	32		-73	-88.5	15.5		-71	-86.5	15.5

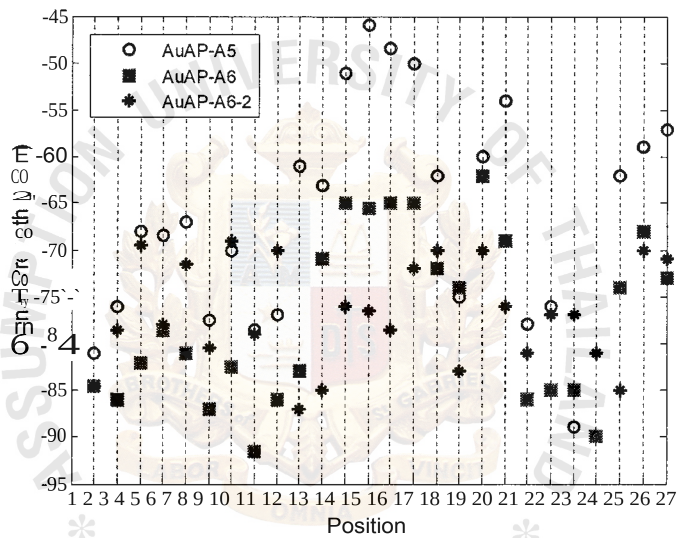


Figure 4.3 Graphical report of signal strength from AuAP-A5, AuAP-A6 and AuAP-A6-2 on the 5th floor at different positions

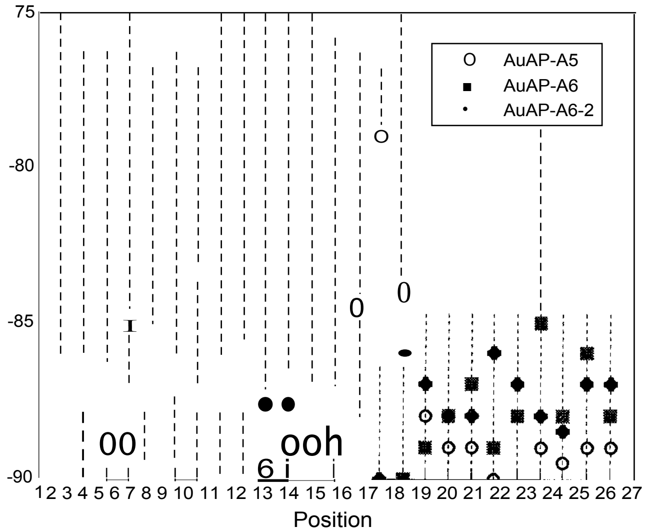


Figure 4.4 Graphical report of noise from AuAP-A5, AuAP-A6 and AuAP-A6-2 on the 5th floor at different positions

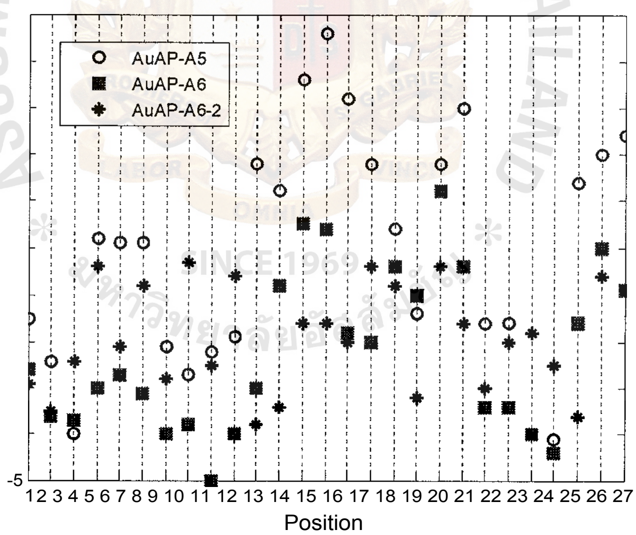


Figure 4.5 Graphical report of SNR from AuAP-A5, AuAP-A6 and AuAP-A6-2 on the 5th floor at different positions

The position that is investigated is the position number 24 (Rear Admiral Prasart's desk), the signal strength of AuAP-A5 and AuAP-A6 is -90 dBm which is very low signal while the signal strength of AuAP-A6-2 is -81 dBm. So the wireless client always connects to an access point which has the strongest signal that is from AuAP-A6-2.

(a) (b)

(c) (d)

(e) (f)

(g) (h)

Figure 4.6 Path of signal from AuAP-A5 to Rear Admiral Prasart's desk

Please consider this signal level, -81 dBm from Au-Ap-A6-2 at P24 is very quite low so the wireless connection at this position will not be stable and sometimes may connect to the other access points from other building where signal level is stronger. At P24 , signal to noise ratio value (Gibilisco 1998) is 7.5 that means the received signal is consistently higher than the level of the received noise.

From fig 4.6, the path from AuAp-A5 to Rear Admiral Prasart's desk is set at a Non line-of-sight position and signal must pass through many things. At picture (c), it must pass through the 20 cm. of concrete that access point is attached to, then pass through the 11 cm big concrete wall (d), after that signal pass through the glass wall to go inside Graduate School of computer Information System then pass through the concrete wall to go inside Graduate school Internet & E-commerce (Rear Admiral Prasart's room). From passing through these building materials, Non line-of-sight position, and multipath effect, a lot of signals are attenuated.

Signal of AuAP-A5 at this position (P24) is just only -90 dBm and SNR value is -0.5. while signal of AuAP-A6 at this position (P24) is -90 dBm and SNR value is -2 Wireless client at this position will not be able to connect to AuAP-A5 or AuAP-A6 because of very low SNR value.

4.2 The 6th floor of the A-building.

4.2.1 Experimental Setup

The experiments were conducted in several positions on the 6th floor of the A-building. The position layout is shown in Fig. 4.5.

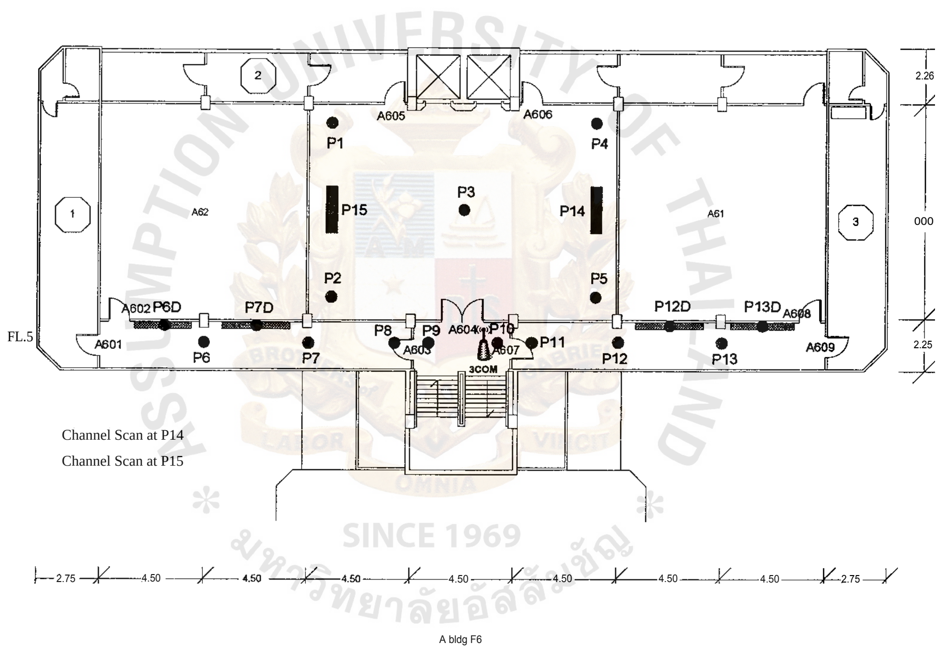


Figure 4.7 Layout of the 6th floor

In Fig. 4.6 the 6th floor of A-building, 19 positions were measured for signal strength, noise and SNR value. The AP (AuAP-A6) is marked in the layout at A607.

Figure 4.8 position of AuAP-A6

4.2.2 Results

Table 4.2 Signal strength, Noise and SNR of the 6th floor

AP	Position	signal (dBm)	noise (dBm)	SNR (dB)	AP	signal (dBm)	noise (dBm)	SNR (dB)	AP	signal (dBm)	noise (dBm)	SNR (dB)
AuAP-AS	PI	-71	-90	19	AuAP-A6	-71	-83	12	AuAP-A6-2	-56	-89	33
	P2	-68	-89	21		-64	-90	26		-58	-86	28
	P3	-79	-84	5		-57	-90	33		-57	-88	31
	P4	-72	-88	16		-77	-89	12		-54	-87	33
	P5	-76	-67	-9		-62	-90	28		-55	-89	34
	P6	-72	-88	16		-61	-90	29		-69	-90	21
	P6D	-72	-89	17		-74	-87	13		-73	-86	13
	P7	-73	-89	16		-63	-90	27		-64	-87	23
	P7D	-71	-89	18		-67	-83	16		-69	-88	19
	8	-70	-91	21		-51	-90	39		-60	-89	29
	9	-52	-88	36		-51	-89	38		-59	-91	32
	10	-50	-84	34		-37	-89	52		-58	-79	21
	11	-57	-88	31		-48	-90	42		-50	-88	38
	12	-65	-87	22		-62	-81	19		-64	-89	25
	12D	-69	-90	21		-67	-87	20		-67	-86	19
	13	-78	-83	5		-69	-89	20		-67	-88	21
	13D	-78	-88	10		-73	-88	15		-67	-88	21

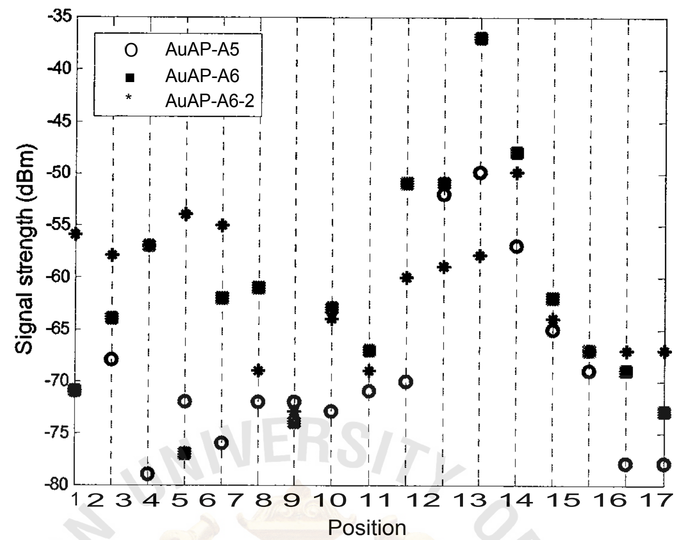


Figure 4.9 Graphical report of signal strength from AuAP-A5, AuAP-A6 and AuAP-A6-2 on the 6th floor at different positions

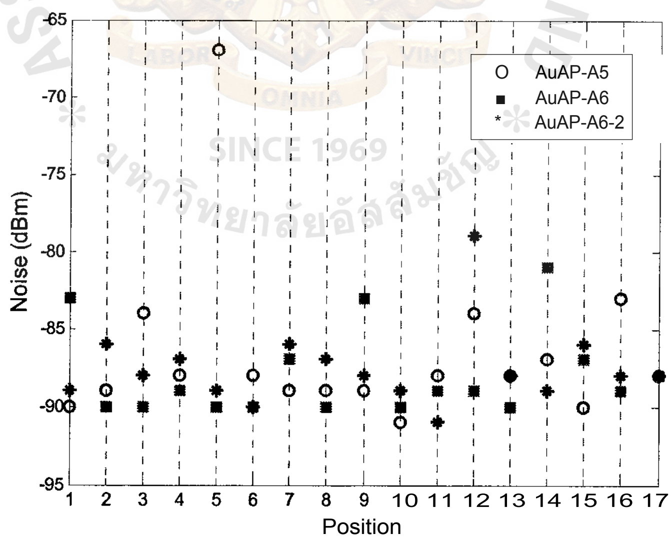


Figure 4.10 Graphical report of noise from AuAP-A5, AuAP-A6 and AuAP-A6-2 on the 6th floor at different positions

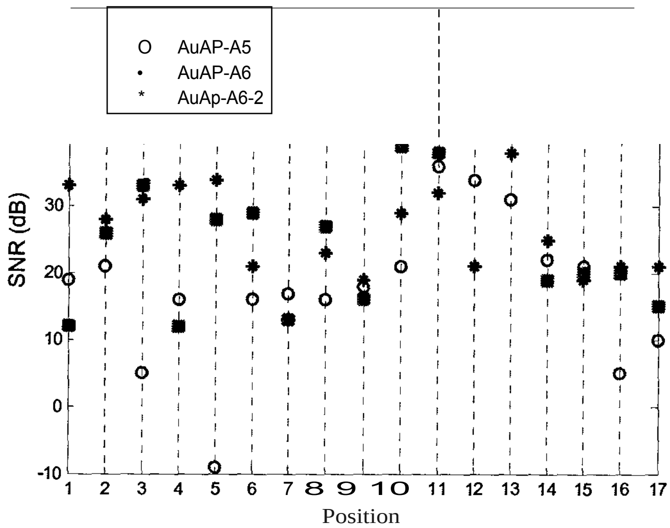


Figure 4.11 Graphical report of SNR from AuAP-A5, AuAP-A6 and AuAP-A6-2 on the 6th floor at different positions

Table 4.3 Position Mapping between Table 4.2 and Fig 4.8, Fig 4.9, Fig 4.10

Table 4.2	P1	p2	N	P4	P5	P6	P6D	P7	P7D	P8	P9	P10	P11	P12	P12 D	PI3	P13 D
Figure 4.8,4.9,4.10 Position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

The position which is investigated is P3, the signal strength of AuAP-A5 and AuAP-A6 is -79 dBm which is very low signal while the signal strength of AuAP-A6 and AuAP-A6-2 is -57 dBm. So the wireless client always connects to AuAP-A6 or AuAP-A6-2.

(a) (b)

(c) (d)

Figure 4.12 Path of signal from AuAP-A6 to Position P3

From fig 4.12, the path from AuAp-A6 to P3 is set at a Non line-of-sight position At picture (b), it must pass through the 20 cm of concrete and 5 mm of glass wall to go inside the graduated student's room. With attenuated signals from wall type, Non line-of-sight position and multipath effect, some signal is attenuated but signal still not be quite low. It is -57 dBm which is a healthy signal because of not many obstructions exist there.

The omnidirectional antenna of AuAP-A6 is pointed to the graduation room. From the theory, the omnidirectional Antenna radiates in all horizontal directions almost equally like the shape of a large donut around the vertical axis. So it can radiates well to P3

Although the signals from AuAP-A6 and AuAP-A6-2 are equal, the SNR values of these two access point at P3 are not equal. SNR value from AuAP-6 is bigger. So it is more potential that wireless client at P3 will connect to AuAP-A6 better than connect to AuAP-A6-2 or AuAP-A5. This wireless connection depends on the SNR Value.

A strong signal alone is not enough for a wireless connection to work reliably. To work well, the level of the received signal must be consistently higher than the level of the received noise; in other words, the SNR must be high. For example, it is possible to have high signal strength and still have poor wireless performance if there is strong interference or a high noise level (Unger 2003).

A high SNR requires that both of the following conditions be met simultaneously:

- *The receiver must receive a signal that is at or above the receiver's threshold level* --- The threshold is the level where the receiver wakes up, detects that a signal is present, and begins to successfully decode the signal.
- *The noise level at the receiver input must be lower than the desired incoming signal* --- If the noise is high, the signal strength of the signal must be higher than the incoming noise level. Once an incoming signal is lower than the noise level, it will not be successfully decoded. The other signal is higher than the noise level and will be successfully decoded.

When performing a radio frequency (RF) site survey, it's important to define the range boundary of an access point based on signal-to-noise (SNR) ratio, which is the signal level (in dBm) minus the noise level (in dBm). For example, a signal level of -53 dBm measured near an access point and typical noise level of -90dBm yields a SNR of 37dB, a healthy value for wireless LANs.

The SNR of an access point signal, measured at the user device, decreases as range to the user increases because the applicable free space loss between the user and the access point reduces signal level. An increase in RF interference from microwave ovens and cordless phones, which increases the noise level, also decreases SNR.

SNR directly impacts the performance of a wireless LAN connection. A higher SNR value means that the signal strength is stronger in relation to the noise levels, which allows higher data rates and fewer retransmissions -- all of which offers better throughput. Of course the opposite is also true. A lower SNR requires wireless LAN devices to operate at lower data rates, which decreases throughput (Goldsmith 2005).

To summarize, for reliable receiver operation, there must be a good SNR at the receiver antenna input. The SNR allows the receiver to separate the signal from the noise. To design and operate a reliable wireless network, it is important to simultaneously maximize the desired signal level and to minimize the existing (and future) noise and interference level.

4.3 Frequency allocation in A-Building

The 2.4 GHz 802.11 channel to frequency mapping. There are 14 total frequency sub-channels available for the wireless radios in the 2.4 GHz band, as listed in Fig. 4.9. Although there are several different frequency channel settings, there is a slight overlap between the channels. For example, there are three non-overlapping channels available in the FCC regulatory domain. When choosing frequency channels for wireless stations in the vicinity of each other, you should choose frequency channels that are several channels apart from each other (e.g. Channels 1, 6, and 11). Channels 12-14 are for use outside the US.

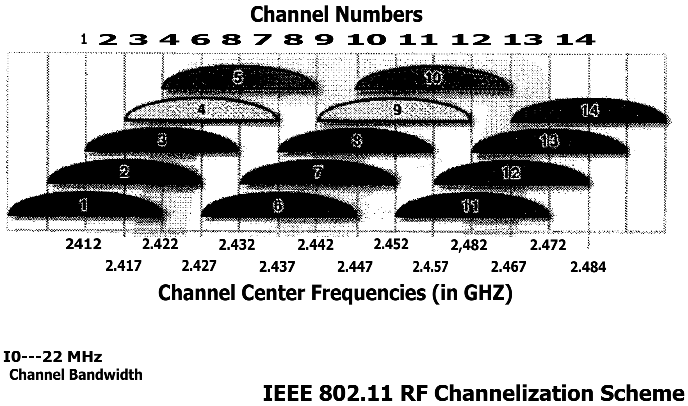
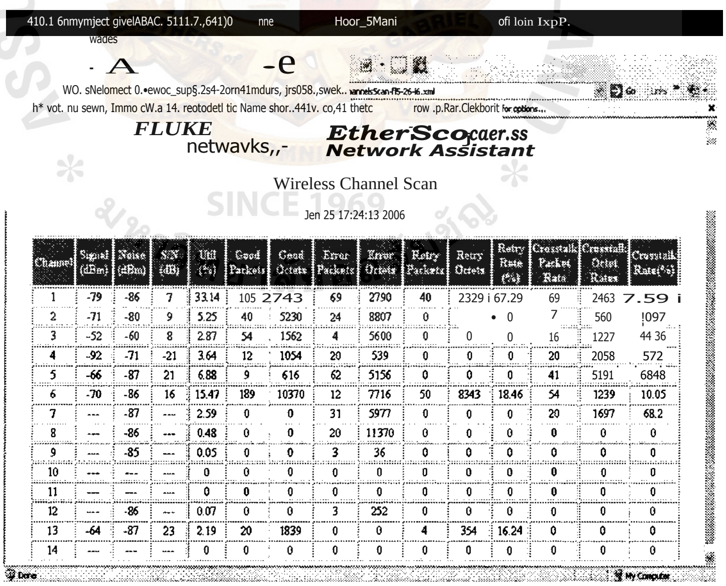


Figure 4.13 IEEE 802.11 RF Channelization scheme

In this topic, the frequency channel of the A-building on at position P26, 6th floor is considered by wireless channel scan function from ES-WLAN. Overlapping channels observed in A-Building are shown in the Fig. 4.12



Wireless Channel Scan

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Channel	Signal (dBm)	Noise (dBm)	S/N (dB)	Util (%)	Good Packets	Good Octets	Error Packets	Error Octets	Retry Packets	Retry Octets	Retry Rate (%)	Crosstalk Packet Rate	Crosstalk Octet Rates	Crosstalk Rate(%)
1	-79	-86	7	33.14	105	2743	69	2790	40	2329	67.29	69	2463	7.59
2	-71	-80	9	5.25	40	5230	24	8807	0		0	7	560	!097
3	-52	-60	8	2.87	54	1562	4	5600	0	0	0	16	1227	44 36
4	-92	-71	-21	3.64	12	1054	20	539	0	0	0	20	2058	572
5	-66	-87	21	6.88	9	616	62	5156	0	0	0	41	5191	6848
6	-70	-86	16	15.47	189	10370	12	7716	50	8343	18.46	54	1239	10.05
7	---	-87	---	2.59	0	0	31	5977	0	0	0	20	1697	68.2
8	---	-86	---	0.48	0	0	20	11370	0	0	0	0	0	0
9	---	-85	---	0.05	0	0	3	36	0	0	0	0	0	0
10	---	---	---	0	0	0	0	0	0	0	0	0	0	0
11	---	---	---	0	0	0	0	0	0	0	0	0	0	0
12	---	-86	---	0.07	0	0	3	252	0	0	0	0	0	0
13	-64	-87	23	2.19	20	1839	0	0	4	354	16.24	0	0	0
14	---	---	---	0	0	0	0	0	0	0	0	0	0	0

Figure 4.14 The wireless channel scan at P26 on the 5th floor

The position which is investigated in wireless channels is P26 on the 5^{th} floor.

As can be seen from the Fig. 4.12, at the first column, the signal from different channel overlaps and intrudes another. These overlapping channels are channel 1, 2, 3, 4, 5 and 6. These channels are not allocated in Frequency reuse pattern of IEEE 802.11 RF Channelization scheme. Cross talk rate (the last column) is very high. That may affect the performance of the wireless network.

V. CONCLUSION

5.1 Research Summary

This project aimed to identify key factors in wireless LANs signal characteristics in Infrastructure mode. Many experiments were taken to collect the data and analyze the result compared with wireless LANs theory. From the data collected and analyzed, it can help us in understanding about wireless LANs communication that is very useful for wireless LANs Installation.

From the experiments in chapter III, it can be concluded as follows,

1. When wireless LAN signal is measured at the same position for some time to perform the signal level reference in open environment, the signal measured will not be fixed in only one value but it was variable in one range from time to time because of wireless LAN signal will depend on environment at that time. In this experiment, the place that has no other access point and has the least interference was selected to be the place of experiment. Standard deviation is used to calculate the distribution of data.

2. The results of signal level of horizontal and vertical wireless adapter at many horizontal plane angles show that there is no significant level in difference at variable horizontal plane angles. This will confirm the radiation pattern of omnidirectional antenna which transmits their signals in all horizontal directions almost equally. The radiation pattern has the shape of a large donut around the vertical axis.

This type of omnidirectional antenna is intended to function equally in all horizontal directions, that is, all directions radially outward from side of the antenna. In other words, the antenna is oriented orthogonally from its plane of radiation (Trulove 2002).

3. The results of 4 side antenna orientation show the radiation pattern of Omnidirectional Antenna. Omnidirectional Antenna radiates in all horizontal directions almost equally. The radiation pattern has the shape of a large donut around the vertical axis. So the signal near the vertical axis is so weak. The gain is in the horizontal direction at the expense of coverage above and below the antenna

4. The results of signal level and communication Over a Distance shows that the increase in distance will decrease signal strength and throughput. Percent of Retries gradually increased when rising in distance. Errors looked to be increasing at first in some distance but after that it looks to be slower down. In this experiment, error is the parameter that can not be concluded with the distance relation. These sample size of data are not enough to summarize. So to find relation of distance and errors, more experiment and research is needed.

5. Line of Sight (LOS) and Non Line of sight (Non-LOS) in multipath environment, from the experiments, It can be concluded that signal strength of LOS is stronger than Non-LOS where noise is similar. Throughput performance of LOS is better than Non-LOS. This results in what is known as path loss or multipath loss (Larocca and Larocca 2002).

6. Attenuation of 802.11g Signals (Wall types), from the experiments, Walls, doors, elevator shafts, people, and other obstacles offer varying degrees of attenuation, which cause the Radio Frequency (RF) radiation pattern to be irregular and unpredictable. Attenuation is simply a reduction of signal strength during transmission.

7. Interchannel Interference — AP traffic experiment, From the results, the signals Crosstalk rates of each frequency combination are very interesting.

When the channels are nonoverlapping. Crosstalk rate is the least and throughput is the most when compared to the others. When the channels are partially overlapping, crosstalk rate is much more than crosstalk rate from nonoverlapping channels and throughput is less. When the channels are heavily overlapping, crosstalk rate is the most while throughput is the least. It is also observed from other experiments that the signal and noise power levels are good indicators as to the performance and reliability of a wireless link, but should not be the sole consideration when anticipating the characteristics of the channel. Interchannel interference has a definite impact on the performance and reliability of the wireless link.

8. From the case study, the effects of the obstacle to the signal strength and channel allocation in the 5th floor and 6th floor of A-building, Assumption University, (Huamark Campus) are considered

At 5th floor, the position that is investigated is the position number 24 (Rear Admiral Prasart's desk), the signal strength of AuAP-A5 and AuAP-A6 is -90 dBm which is very low signal while the signal strength of AuAP-A6-2 is -81 dBm. So where the wireless client always connects to the access point has the most strong signal which is from AuAP-A6-2.

At 6th floor the position which is investigated is the P3, the signal strength of AuAP-A5 and AuAP-A6 is -79 dBm which is very low signal while the signal strength of AuAP-A6 and AuAP-A6-2 is -57 dBm. So the wireless client always connects to AuAP-A6 or AuAP-A6-2.

Although the signals from AuAP-A6 and AuAP-A6-2 are equal, the SNR values of these two access point at P3 are not equal. SNR value from AuAP-6 is bigger. So it is more potential that wireless client at P3 will connect to AuAP-A6 better than connecting to AuAP-A6-2 or AuAP-A5. This wireless connection will depend on SNR Value.

A strong signal alone is not enough for a wireless connection to work reliably. To work well, the level of the received signal must be consistently higher than the level of the received noise; in other words, the SNR must be high. For example, it is possible to have high signal strength and still have poor wireless performance if there is strong interference or a high noise level

For this case study, the frequency channel of the A-building on at position P26, 6th floor is considered by wireless channel scan function from ES-WLAN. Overlapping channels observed in A-Building are investigated. The signals from different channels overlap and intrude one another. These overlapping channels are channel 1, 2, 3, 4, 5 and 6. These channels are not allocated in Frequency reuse pattern of IEEE 802.11 RF Channelization scheme. Cross talk rate of each channel is very high. That may affect the performance of the wireless network.

5.2 Implication for Further Research

Tools and methodology that is developed in the course of this project will be of use in conducting of further experiments and via the collection of additional experimental data. The results can be used as a good reference for further research study. It is recommended that further studies be done to examine other factors that influence the performance of WLANs. Work that could potentially be performed in this area in the future includes:

- Further experimentation in a wider range of environments
- Wireless LAN signal in a running car.
- Channel Roaming of wireless client.

VI. RECOMMENDATIONS

According to the study in the project, the suggestions in performing wireless signal experiments and wireless LANs installation would be recommended as follows.

1. Tools and methodologies that were used in this project.

Tools and methodologies that were used in this project are very important. Etherscope Wireless LAN Analyzer that was used is the commercial test tool which was developed by Fluke Network Company. However this Wireless LAN tester which is used in this project is limited in some features. To get the better results, additional tools may be required. The tool that can help in performing experiment may be the software that can make the wireless signal coverage area map. This software is used to show wireless signal at different locations in the map so this can help in overview of signal coverage and optimize the wireless performance. The other tool that is useful for the experiment and wireless LAN installation is the 2.4 GHz spectrum analyzer, this tool can show the source and power of interference in wave form by time domain and frequency domain.

Although the best tools are used, the other important considerations are environment and a large group of data. The environment for each experiment should be the same location and the same time (or nearly the same time) because signal may vary at different location and from time to time. Furthermore it should be the place that is less interfered.

The last important thing is the volume of collected data. The more collected data would lead to the more accurate in interpreting results and conclusion

2. The planning process in wireless LANs installation

Every building is different and while the plan is made how things might work inside a structure, a site survey after the building is built in the only way to insure that all necessary areas are covered completely by Wireless LAN signals.

The key to implement a large wireless network is to do through planning. One could also say that a good design is an integral part of the plan.

The planning process

To generate a meaningful plan for WLAN project, it is needed to gather all of the raw materials for planning. These raw materials are:

1. WLAN coverage requirements
2. Building and site drawing
3. Installation guideline
4. Manufacture's specification
5. Performance guidelines
6. Budget restraints

WLAN coverage requirements. Let's talk about these issues individually. The first item is the coverage requirements for your proposed WLAN. If you are providing a WLAN for a single office space within a multitenant building, your equipment and installation needs will be vastly different than if you must cover an entire multistory building or perhaps several buildings on a campus. (By the way, the term campus has come to mean a group of related commercial buildings in addition to its traditional university meaning.) In any environment, set out your planned WLAN coverage requirements in writing. Be sure to note any areas that are of little or no value. More than anything, this is to protect you later, when your WLAN will not reach the lobby or the courtyard. If it was not in the plan as a requirement, you cannot be blamed for a lack of coverage there. Of course, you may incidentally provide coverage in areas that are not required. That is a side benefit of the "wandering wireless waves." Sometimes you get some coverage areas for free, whether you want them or not.

Building and site drawings. The next item that you need to obtains a set of drawings for the buildings your WLAN will cover. If there are multistory buildings, you will need a "plan drawing" for each floor, which shows the overall layout of the floor, including all the office walls and other structures. If you have multiple buildings to cover, be sure to get the site drawings. The building management office should have these drawings available. If you are in leased space, you can probably get the drawings from the leasing agent. In general, building permits and occupancy licenses are required for all commercial construction, so the documents may also be on file with the city or county. Architects are another good source for drawings. The purpose of obtaining the drawings is to plan where you expect to have WLAN coverage and estimate where APs need to be to provide the desired coverage. The drawings may be copied to the size you need. You normally will not need to keep full-size drawings, but your copies will need to be large enough to be legible. It is a good idea to make several copies, so you can mark up your plans as you go through the design process and the field-measurement verification. Then you will have an extra set to mark the final AP placements and the final coverage areas. It is best to have a dimensionally accurate drawing because it will allow you to make measurements on paper of the coverage distances. If all else fails, you can make a fairly accurate sketch of the office space based on physical measurements and inspection of the space. Keep track of metal objects, such as structural steel, air ducts, elevator shafts, stairwells, and restroom facilities. These building features may cause coverage problems for your WLAN. Metal screen, railings, and metallic decorations are also potential problems for your WLAN, as are metallic reflective coatings on glass windows.

Installation guidelines. Find out the installation guidelines to which you will have to adhere. This is most important when you install the APs and their antennas. Many ideal AP locations will be along walls or on ceilings where aesthetic considerations prohibit such objects. APs and antennas are not necessarily desirable objects to decorators, and you may have to make accommodations in your design to provide WLAN coverage without offending the eye. If you have written guidelines, agreed to by building management, you will have a defense for the placement of the WLAN components and a valid reason for why complete coverage may not be feasible. At this phase, you should be able to determine whether APs with certain features are needed for your installation. For example, if the installation guidelines prohibit direct mounting of an AP on a wall or ceiling, you must specify APs that allow external antennas. You also may find that dual W-NIC—APs, which are available for commercial use, have the advantage of covering two areas at once: within the same room and, via a short cable and external antenna, into an adjacent room. Just remember that these two W-NICs should operate on different frequencies because they surely will interfere with each other on the same or nearby frequencies. This is also a good time to start evaluating the appearance and performance characteristics of external antennas. In most large networks, you will definitely need the flexibility of an external antenna, so you might as well get the options in mind. Once you have determined your coverage requirements, you can look into the different suppliers of WLAN gear. It is surprising to most people familiar with computer net-working that there are wide variations in the performance of WLAN components. This is not to say that some products are inferior by nature, although it is always possible that you might get a bad W-NIC card or AP.

However, these devices differ in design and capabilities, so you will have to determine which brands provide the best combination of performance, price, and support for your needs. Commercial-quality WLAN components are a requirement for a commercial installation. As with anything we buy, some goods are designed for commercial use and some are designed for consumer use. This is just as true of WLAN components. If you get your WLAN APs and W-NICs from a recognized commercial-quality source, you can expect to get more consistent performance, advanced features, expandability, compatibility, and support. Manufacturer support is a critical issue in a large WLAN network. Designing and installing these systems are not easy. You may want to take advantage of a manufacturer's certified dealer for design assistance and installation. Commercial manufacturers have extensive partnering programs to train and authorize wireless system integrators. Some of these integrators can do the very specialized field-strength measurements that are needed for coverage verification in a complex installation. These wireless system integrators also will have the needed antenna system accessories, such as gain antennas, cables, and amplifiers.

Performance guidelines. Performance guidelines should be deter-mined from the placement of the APs and the building layout drawings. You can determine the expected range from the AP's specifications. Each manufacturer will give its nominal operating ranges for each data rate: 1, 2, 5.5, and 11 Mbps (and possibly 22 to 54 Mbps). These ranges will generally be specified for indoor and outdoor (also called the "clear" range). If you are planning coverage within an open space in a building, such as a large meeting room or an auditorium, you can probably use the outdoor range, if the area is clear of obstructions. If you are in a dense office environment, with lots of obstructions, the indoor range will be more appropriate. A good way to start is to cut out circular patterns of transparent Mylar or acetate. The common plastic sheet protector is fine for this purpose. Determine the radial length of each data-rate range with the scale of the layout drawing you will be using. With a marking pen, mark each range of interest as a set of concentric circles on the plastic sheet and cut out the outer ring of the circle to use for your pattern. Make several of these. Working from the building drawing, position the centers of the circle patterns to simulate AP placement. Use as many circles as you need to cover the entire area, placing the circle center at an appropriate wall or ceiling location. Unless you are working on an open area, you should use the indoor ranges to mark the circles. Remember that solid walls can attenuate signals considerably. You may wish to neglect outside areas for the purposes of AP placement. Your goal is to gain adequate coverage of the interior building areas, not to necessarily sacrifice interior coverage to prevent outdoor signal leakage. That being said, it is not a bad idea to bias the AP placement toward the inside of the building as long as you can still get good signal strength up to the inside of your building's outside walls. You will be able to determine how dense to place the APs based on the data-rate rings on your pattern circles. Remember that actual installations may vary considerably due to internal structures and building materials. You should err on the conservative side, if you can. In other words, if you plan for a minimum signal strength that will allow 5.5-Mbps operation in the weaker areas, you will be pleased if some of those areas achieve 11 Mbps and won't be in too much trouble if some dip to 2 Mbps.

Budget restraints. The final planning item is to take your system budget into account. Budget restraints will keep you from over engineering your WLAN. Frankly, having too many closely spaced APs may decrease system performance due to interference. If you have doubts about coverage areas, determine whether you need to use the incremental pay-as-you-go method. When you do this, you provide the minimum number of APs you think you will need, with the proviso that more will be added to bolster WLAN coverage, when necessary. By all means, you should do field measurements and link testing to confirm your paper design. You may be surprised to find differences from your predictions when you do the actual test simulation. If so, you can adjust your patterns and AP placement to match your measurements. But remember that W-NICs have power and sensitivity variations from unit to unit. So you may need to be conservative when you setup your permanent AP locations.

APPENDIX A

WIRELESS LAN GLOSSARY

Term	Definition
bridge	A LAN product that allows connection of networks or subnetworks with similar architectures.
Channel	frequency used to direct communication between an 802.11 radio card and an access point.
client	The computer from which you will access drives directories, files, and programs that are stored on the server. See also *server*.
compression	Reducing the size of data to be stored or transmitted in order to save transmission time, capacity or storage space.
Crosstalk	An indication that packets sent on one channel have been received on another channel due to channel overlap.
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance. CSMA/CA is the medium access method used by IEEE 802.11 WLANs.
DSSS	Direct-Sequencing Spread-Spectrum.
encryption	The transformation of data, for the purpose of privacy, into an unreadable format until reformatted with a decryption key.
Ethernet	A type of LAN that allows the transmission of computer data, audio data and video data. *Ethernet* uses the access method known as CSMA/CD (carrier sense multiple access with collision detection).
FCS errors	indications that corrupted packets have been received.
FHSS	Frequency-Hopping Spread-Spectrum.
gateway	A LAN product that allows devices on two different subnets to communicate with each other.
HotSpot	A location where you can access Wi-Fi service via a wireless-enabled device. HotSpots are often found within coffee shops, airports, train stations, convention centers, hotels, or similar public gathering places.
IEEE	Abbreviation of *Institute of Electrical and Electronics Engineers,* pronounced *I-triple-E.* Founded in 1884 as the AIEE, the IEEE was formed in 1963 when AIEE merged with IRE. IEEE is an organization composed of engineers, scientists and students. The IEEE is best known for developing standards for the computer and electronics industry.

Term	Definition
Infrastructure Mode	A client setting providing connectivity to an Access Point (AP). As compared to Ad-Hoc Mode where PCs communicate directly with each other, clients set in Infrastructure Mode all pass data through a central AP.
IP (Internet Protocol)	A set of rules used to send and receive messages at the Internet address level.
IP address	A 32-bit number that identifies each sender or receiver of information that is sent across the Internet. An IP address has two parts: an identifier of a particular network on the Internet and an identifier of the particular device (which can be a server or a workstation) within that network.
LAN (Local Area Network)	*Local area network*. A network that is within a small radius, such as an office building. Compare to WAN. See also Ethernet and peer-to-peer network.
LOS	Line of sight.
Noise	Unwanted, interfering RF energy that disrupt normal system operations. Noise level impacts connectivity and performance.
Non-LOS	Non-Line of sight.
Network Interface Card (NIC)	Commonly referred to as a *"NIC."* An adapter card that is installed in the controller that allows it to connect to a network (for example, Ethernet). The card contains both the hardware to accommodate the cables and the software to use the network's protocols. The NIC is also called a network adapter card.
OFDM	Orthogonal Frequency-Division Multiplexing.
OSI	Open Systems Interconnection. A set of international standards for networking.
retries	Typically sent when a receiving station fails to acknowledge a packet.
RF	*Radio frequency*. A frequency at which coherent electromagnetic radiation of energy is useful for communications purposes.
roaming	In wireless networking, *roaming* refers to the ability to move from one access point coverage area to another without interruption in service or loss in connectivity.

Term	**Definition**
Security	represents the level of 802.11 packet encryption and network authentication for which a device is configured.
server	A computer that is configured to provide services to the network, such as files and programs. See also *client.*
Signal	**The** transmission of 802.11 frames by radiating RF energy at a given strength. The stronger the signal the better the coverage and connection.
SSID	Service Set Identifier - wireless network name. Typically, the wireless network comprised of an AP and wireless stations is given an SSID name. This uniquely identifies a WLAN and is used when configuring security options.
SNR	Signal to noise ratio.
standard protocol	A communications protocol capable of controlling communications between two devices connected by a single data communication line.
TCP/IP	Transmission Control Protocol / Internet Protocol.
Topology	Describes how a network is structured.
WAN (Wide Area Network)	*Wide area network,* which is distributed over a large area and involves routing nodes. Compare to LAN.
WEP	Short for *Wired Equivalent Privacy,* a security protocol for wireless local area networks (Weans) defined in the 802.11b standard. WEP aims to provide security by encrypting data over radio waves so that it is protected as it is transmitted from one end point to another.
WECA	The Wireless Ethernet Compatibility Alliance.
Wi-Fi	Wi-Fi is short for *wireless fidelity.* It is a trade term promulgated by the Wireless Ethernet Compatibility Alliance (WECA). Products certified as Wi-Fi by WECA are interoperable even if they are from different manufacturers. A user with a Wi-Fi product can use any brand of access point with any other brand of client hardware that is built to the Wi-Fi standard.

Term	Definition
wireless LAN	*Wireless local area network.* A flexible data communication system implemented as an extension to, or alternative for, a wired LAN within a building or campus. Using electromagnetic waves, a WLAN transmits and receives data through the air, minimizing the need for wired connections. A WLAN combines data connectivity with user mobility, which enables mobile LANs through simplified configuration.
WLAN	Acronym for *wireless local-area network.* A type of local-area network that uses high-frequency radio waves rather than wires to communicate between nodes.

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