RADIO PROPAGATION MEASUREMENT FOR BROADBAND SYSTEM

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The interest for wireless multimedia services is growing rapidly. Designers of wireless systems will face difficulties such as highly varying user concentrations and vastly different demands on quality of service. Demands for capacity with high quality of services in wireless communications, driven by cellular mobile, Internet and multimedia services have been rapidly increasing worldwide. On the other hand, the available radio spectrum is limited and the communication capacity needs cannot be met without a significant increase in communication spectral efficiency. Significant further advances in spectral efficiency are available through increasing the number of antennas at both the transmitter and the receiver. In this research, we derive and discuss capacity limitations for transmission of radio over broadband channels in wireless local area network (WLAN) system. We investigate indoor radio propagation inside the Faculty of Electronic and Computer Engineering. This study let us know how much signal loss due to engineering design of the interior of a building in which the aspects such as local location environment, location of WLAN access point, coordination and position of receiver take into consideration. These study show the current implemented WLAN system inside faculty building and the quality receive signal in the *bilik kuliah* area and suggestion for improvement of the performance and quality of received signal inside building of Faculty of Electronic and Computer Engineering.

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CHAPTER 1

1.0 INTRODUCTION

Wireless broadband system or wireless local area network (WLAN) system is network connection that provides wireless network communication over short distances using radio or infrared signals instead of traditional network cabling. A WLAN typically extends an existing wired local area network. WLANs are built by attaching a device called the access point (AP) to the edge of the wired network. Clients communicate with the AP using a wireless network adapter similar in function to a traditional Ethernet adapter.

For example for a WLANs that connect to the Internet, Wireless Application Protocol (WAP) technology allows Web content to be more easily downloaded to a WLAN and rendered on wireless clients like cell phones and PDAs as shown in Figure 1.1.

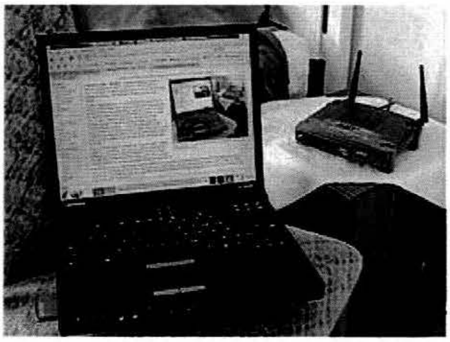
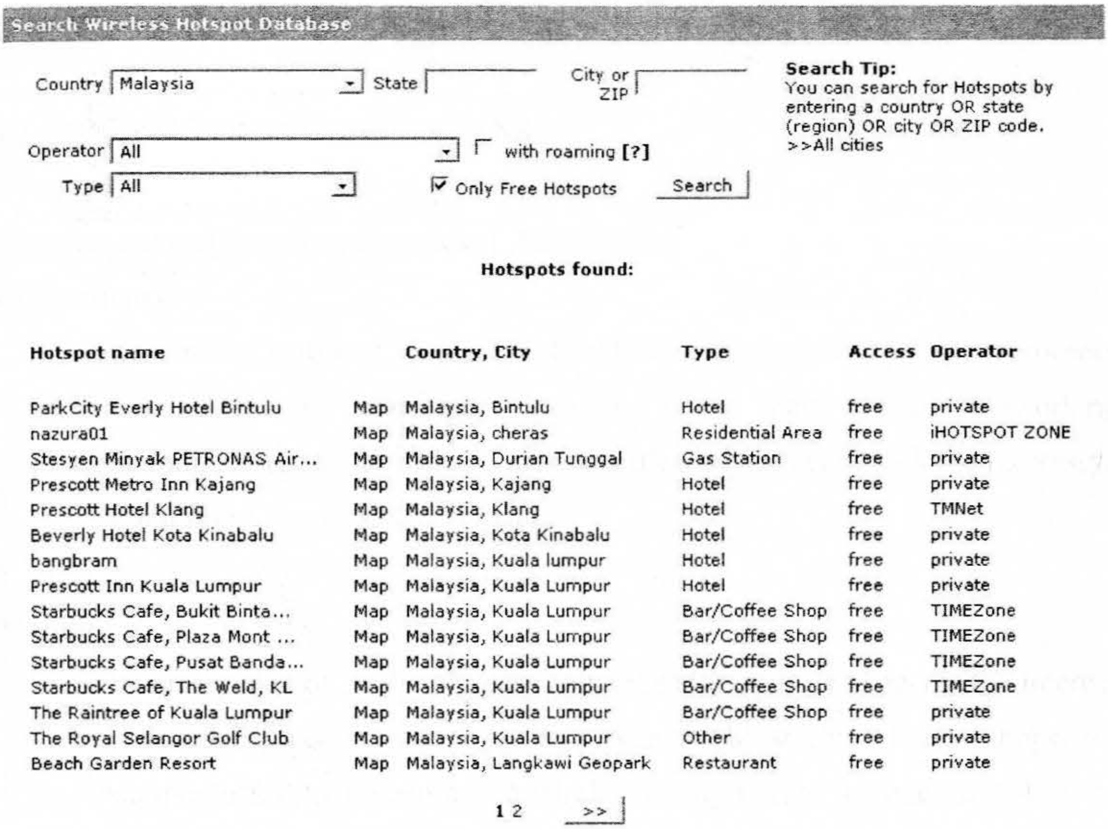


Figure 1.1: An example of WLAN connection. The notebook is connected to the wireless access point (AP)

For the home user, wireless has become popular due to ease of installation and location freedom with the gaining popularity of laptops. Public businesses such as coffee shops or malls have begun to offer wireless access to their customers; for examples Melaka International Trade Centre (MITC) areas, KFC, McDonald, Coffee Bean and some are even provided as a free service. Large wireless network projects are being put up in many major cities. Figure 1.2 shows examples of free hotspot in Malaysia from different type of service locations such as hotel, residential area, gas station and bar/coffee shop.



Search Wireless Hotspot Database

Country Malaysia State City or ZIP

Operator All ☐ with roaming [?]

Type All ☑ Only Free Hotspots Search

Search Tip:
You can search for Hotspots by entering a country OR state (region) OR city OR ZIP code.
>>All cities

Hotspots found:

Hotspot name		**Country, City**	**Type**	**Access**	**Operator**
ParkCity Everly Hotel Bintulu	Map	Malaysia, Bintulu	Hotel	free	private
nazura01	Map	Malaysia, cheras	Residential Area	free	iHOTSPOT ZONE
Stesyen Minyak PETRONAS Air...	Map	Malaysia, Durian Tunggal	Gas Station	free	private
Prescott Metro Inn Kajang	Map	Malaysia, Kajang	Hotel	free	private
Prescott Hotel Klang	Map	Malaysia, Klang	Hotel	free	TMNet
Beverly Hotel Kota Kinabalu	Map	Malaysia, Kota Kinabalu	Hotel	free	private
bangbram	Map	Malaysia, Kuala lumpur	Hotel	free	private
Prescott Inn Kuala Lumpur	Map	Malaysia, Kuala Lumpur	Hotel	free	private
Starbucks Cafe, Bukit Binta...	Map	Malaysia, Kuala Lumpur	Bar/Coffee Shop	free	TIMEZone
Starbucks Cafe, Plaza Mont ...	Map	Malaysia, Kuala Lumpur	Bar/Coffee Shop	free	TIMEZone
Starbucks Cafe, Pusat Banda...	Map	Malaysia, Kuala Lumpur	Bar/Coffee Shop	free	TIMEZone
Starbucks Cafe, The Weld, KL	Map	Malaysia, Kuala Lumpur	Bar/Coffee Shop	free	TIMEZone
The Raintree of Kuala Lumpur	Map	Malaysia, Kuala Lumpur	Bar/Coffee Shop	free	private
The Royal Selangor Golf Club	Map	Malaysia, Kuala Lumpur	Other	free	private
Beach Garden Resort	Map	Malaysia, Langkawi Geopark	Restaurant	free	private

1 2 >>

Figure 1.2: List of free hotspot taken from http://www.hotspot-locations.com/ in June 2008

The popularity of wireless LANs is a testament primarily to their convenience, cost efficiency and ease of integration with other networks and network components. The majority of computers sold to consumers today come pre-equipped with all necessary wireless LAN technology. As shown in Figure 1.2, there are many people and organization interested to install a WLAN system but implementing a WLAN involves more than selecting the desired standard and selecting a security mechanism. Access point placement can have more effect on throughput than standards. It is essential to understand how the efficiency of a WLAN is affected by such issues as topology, distance and access point location.

Speed and distance can be important factors in scalability of a WLAN. As an organization grows, they will add more users. In addition, they most likely need more bandwidth for the transfer of larger files and for higher bandwidth technologies such as streaming audio/video and real-time conferencing. Therefore, more bandwidth gives better performance of a system.

1.1 BENEFITS OF WIRELESS LANS

There are several benefits of wireless LANs include:

Convenience

The wireless nature of such networks allows users to access network resources from nearly any convenient location within their primary networking environment (home or office). This is particularly relevant with the increasing saturation of laptop-style computers.

Mobility

The emergence of public wireless networks allows users to access the internet even outside their normal work environment. Most chain coffee shops, for example, offer their customers a wireless connection to the internet at little or no cost.

Productivity

Users connected to a wireless network can maintain a nearly constant affiliation with their desired network as they move from place to place. For a business, this implies that an employee can potentially be more productive as his or her work can be accomplished from any convenient location. For example, a hospital or warehouse may implement Voice over WLAN applications that enable mobility and cost savings.

Deployment

Initial setup of an infrastructure-based wireless network requires little more than a single access point. Wired networks, on the other hand, have the additional cost and complexity of actual physical cables being run to numerous locations (which can even be impossible for hard-to-reach locations within a building).

Expandability

Wireless networks can serve a suddenly-increased number of clients with the existing equipment. In a wired network, additional clients would require additional wiring.

Cost

Wireless networking hardware is at worst a modest increase from wired counterparts. This potentially increased cost is almost always more than outweighed by the savings in cost and labor associated to running physical cables.

Other then the benefit of WLAN system, there are several factors should be considered such as security since WLAN utilize air medium, almost all people can access the medium. It is important to know how to make sure only the legitimate or authorize users can use these facilities. How reliable these system because like any radio frequency transmission, wireless networking signals are subject to a wide variety of interference, as well as complex propagation effects such as multipath, or especially in this case Rician fading, that are beyond the control of the network administrator.

These studies will provide better understanding of a phenomenon when a WLAN system been implemented in particular building like the Faculty Electronic and Computer Engineering, UTeM.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

Indoor use of wireless systems poses one of the biggest design challenges. This study will try to shed some answer on this mysterious subject and will seek to quantify for use of wireless systems inside typical buildings at 2.4 GHz frequency band especially in local Malaysia environment.

To show the performance of WLAN system in indoor environments, it is necessary to provide an overview of how signals propagate. In this chapter, the basic of the propagation mechanisms for indoor scenarios are discussed. Figure 2.1 shows a simulation of radio frequency (RF) signal energy distributed within a typical office. This views a cross-section of an office at desktop level. As shown, RF signal dispersion for indoor wireless areas is highly disturbed. Reflection, diffraction and scattering of the RF signal are dynamic and difficult to predict. Small changes in position or direction of a receiver with relative to a transmitter may result in wide variations in signal strength. Within office structures, RF propagation is dependent on office dimensions, obstructions, materials, and signal frequency. Consequently, WLAN range data performance is highly dependent upon the surrounding physical environment. The physical environment can also be classified into both static and dynamic elements. Static elements comprise a variety of natural and manmade materials, geometrical boundaries, and spatial configurations. Dynamic elements comprise mobile objects such as oscillating fans, people and cars seen through windows.

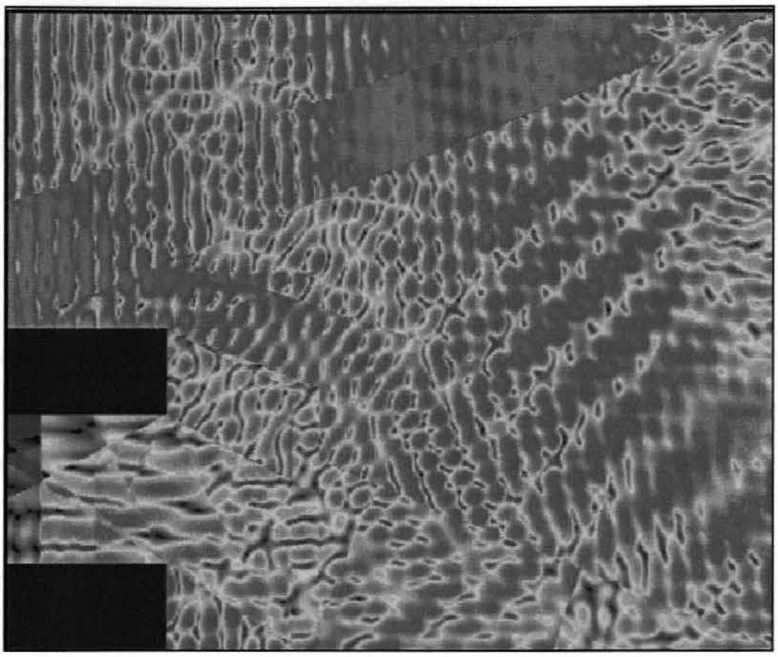


Figure 2.1: Indoor Office Signal Intensity Map

In general, when a signal propagated from the transmitter, antenna will experience many different signal transformations and paths with a fraction or small portion reaching the receiver antenna and most part of the signal loss through the propagation process. Awareness of this process will assist a better understanding on radio performance limitations for any broadband system.

2.1 BASIC RADIO PROPAGATION

The most basic model of radio wave propagation involves so called "free space" radio wave propagation. In this model, radio waves emanate from a point source of radio energy, traveling in all directions in a straight line, filling the entire spherical volume of space with radio energy that varies in strength with a $1/(\text{range})^2$ rule or 20 dB per decade increase in range.

Real world radio propagation rarely follows this simple model. The three basic mechanisms of radio propagation are attributed to reflection, diffraction and scattering. All three of these phenomenon cause radio signal distortions and give rise to signal fades, as well as additional signal propagation losses. Outdoors, with mobile units, movements over very small distances give rise to signal strength fluctuations because the composite signal is made up of a number of components from the various sources of reflections called "multipath signals" from different directions as well as scattered and / or diffracted signal components. These signal strength variations amount to as much as 30 to 40 dB in frequency ranges useful for mobile communications and account for some of the difficulty presented to the designer of reliable radio communications systems. The basic signal attenuation with range noticed in the real world gives rise to what are termed "large scale" effects, while the signal strength fluctuations with motion are termed "small scale" effects.

Indoors situation is even worse. It is very difficult to design an "RF friendly" building that is free from multipath reflections, diffraction around sharp corners or scattering from wall, ceiling, or floor surfaces. The closest one could probably get to an "RF friendly" building would be an all wooden or all fiberglass structure -- but even this must have a structurally solid floor of some kind and this more ideal RF building will still have reflections, multipath and other radio propagation disturbances as the materials properties section below shows, which will prove to be less than ideal. Indoors then, the simple free space model fails to account for the small and large scale fading that is observed in real world radio links as Figure 2.2 below readily shows.

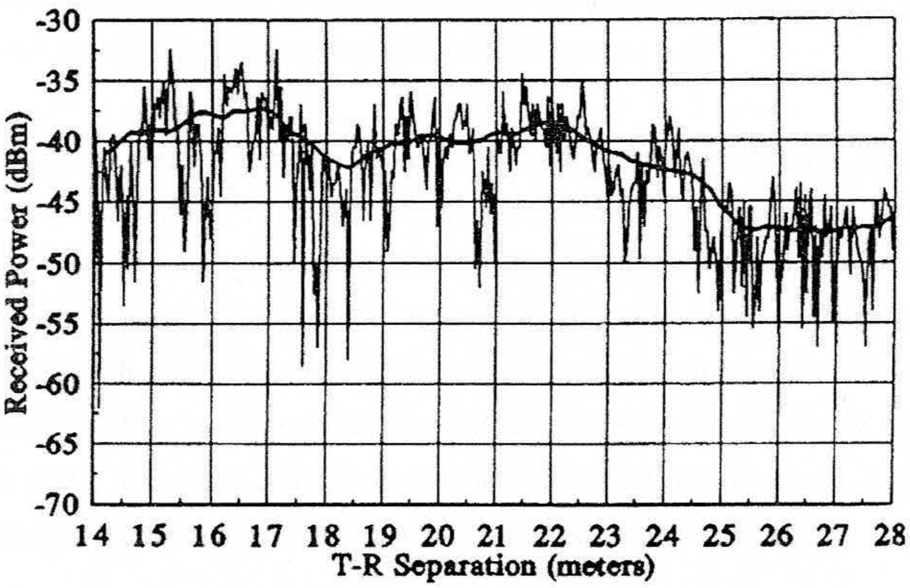


Figure 2.2: Received RF Power plot indoors versus range in meters.

Radio wave propagation inside smooth walled metal buildings can be so bad that radio "dead spots" or non signal areas can exist where the signal is virtually nonexistent. These dead spots arise because of almost perfect, lossless reflections from smooth metal walls, ceilings or fixtures that interfere with the direct radiated signals. The dead spots exist in 3 dimensional spaces within the building and motions of only a few inches can move from no signal to full signal. It will be the main purpose of this study to try to recommend solutions for this kind of problem.

2.2 MULTIPATH

In the real world, multipath occurs when there is more than one path available for radio signal propagation. The phenomenon of reflection, diffraction and scattering all give rise to additional radio propagation paths beyond the direct optical "line of sight" path between the radio transmitter and receiver. As Theodore S. Rappaport describes the phenomenon in Wireless Communications — Principles and Practice: "*Reflection occurs when a propagating electromagnetic wave impinges upon an object which has very large* *dimensions when compared to the wavelength of the propagating wave"*. Reflections occur from the surface of the earth and from buildings and walls.

The propagated electromagnetic signal in the indoor environment can undergo three primary physical modes. These are reflection, diffraction, and scattering. The following definitions assume small signal wavelength, large distances with relative to wavelength and sharp edges for a typical indoor scenario. As shown in equation (2) below, the free space wavelength at 2.4 GHz is 4.92 inches. This wavelength relative to flat surfaces is sufficiently small for wave propagation mechanisms to hold true. Typically, the distances between walls, floors and ceilings are on the order of 10 feet or greater, and the office environment contains many vertical and horizontal edges and surfaces

2.2.1 DIFFRACTION

This phenomenon occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities edges or when obstacles are impenetrable by the radio waves. Based on Huygens's principle, secondary waves are formed behind the obstructing body even though there is no line of site. Indoor environments contain many types of these edges and openings, both orientated in the vertical and horizontal planes. Thus the resultant diffracted signal is dependent on the geometry of the edge, the spatial orientation, as well as dependent on the impinging signal properties such as amplitude, phase and polarization. The result of diffraction of a wave a tan obstacle edge is that the wave front bends around and behind the obstacle edge. Diffraction is best demonstrated by the radio signal being detected close to the inside walls around corners and hallways. This phenomenon can also be attributed to the waveguide effect of signals propagating down hallways. As shown in Figure 2.3, a diffracted wave front is formed when the impinging transmitted signal is obstructed by sharp edges within the path.

At high frequencies, diffraction, like reflection, depends on the geometry of the object, as well as the amplitude, phase and polarization of the incident wave at the point of diffraction.

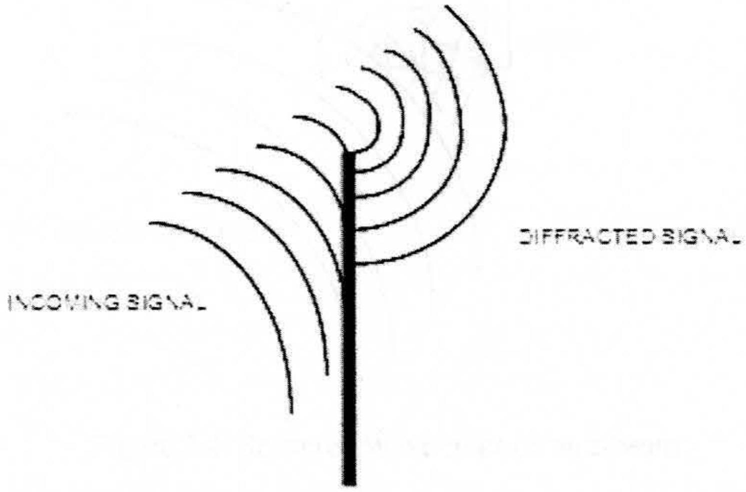


Figure 2.3: Diffraction of a Signal

2.2.2 SCATTERING

Scattering occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength, and where the number of obstacles per unit volume is large. If there are many objects in the signal path, and the objects are small relative to the signal wavelength, then the propagated wave front will break apart into many directions. The resultant signal will scatter in all directions adding to the constructive and destructive interference of the signal that is illustrated in Figure 2.4. Most modern office construction contains pressed steel I-beams throughout the wall supports. Furthermore, construction materials such as conduit for electrical and plumbing service can add to the scattering effect.

Scattered waves are produced by rough surfaces, small objects, or by other irregularities in the channel. In practice, foliage, street signs, and lamp posts induce scattering in a mobile communications system."

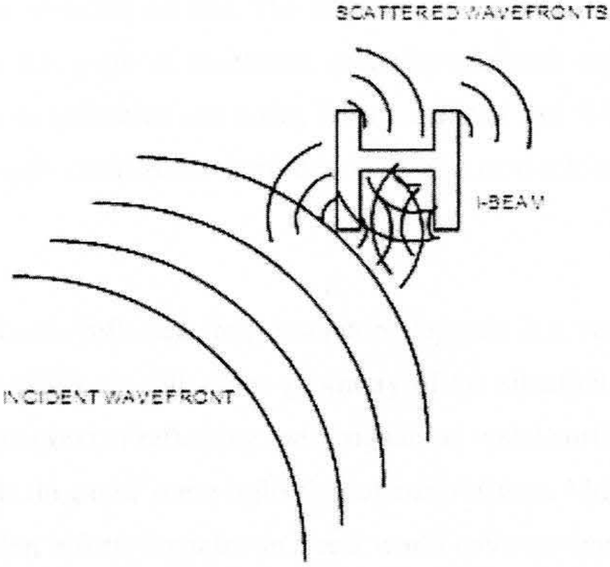


Figure 2.4: Scattered Wave front on an I-beam

2.2.3 REFLECTION

Reflection occurs when the propagated signal striking a surface will either be absorbed, reflected, or be a combination of both as shown in Figure 2.5. This reaction depends on the physical and signal properties. Physical properties are the surfaces' geometry, texture and material composition. Signal properties are the arriving incident angle, orientation, and wavelength.

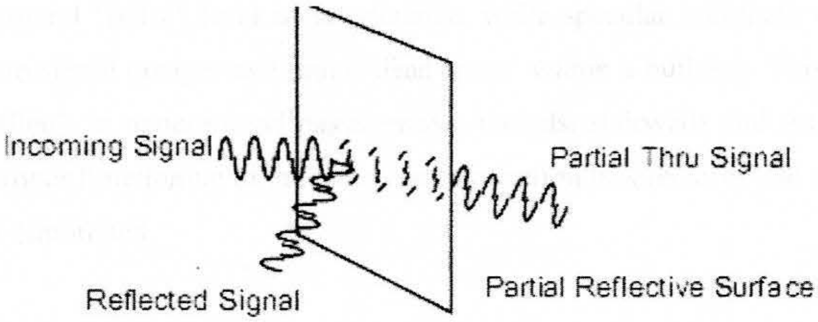


Figure 2.5: Reflected Signal

Perfect conductors will reflect the entire signal. Other materials will reflect part of the incident energy and transmit the rest. The exact amount of transmission and reflection is also dependent on the angle of incidence, material thickness and dielectric properties. Major contributors to reflection are walls, floors, ceilings and furniture. In practice, not only metallic materials cause reflections, but dielectrics or electrical insulators also cause reflections.

The actual signal levels reflected from insulators depends in a very complicated way on the above characteristics as well as the geometry of the situation. Suffice it to say, that insulators are not as good at reflecting radio signals as metal surfaces, but even common insulating materials do cause some reflection of radio waves. Multipath occurs when all the radio propagation effects combine in a real world environment. In other words, when multiple signal propagation paths exist, caused by whatever phenomenon, the actual received signal level is the vector sum of the entire signals incident from any direction or angle of arrival. Some signals will aid the direct path, while other signals will subtract (or tend to vector cancel) from the direct signal path. The total composite phenomenon is thus called multipath. Two kinds of multipath exist: specular multipath -- arising from discrete, coherent reflections from smooth metal surfaces; and *diffuse* multipath -- arising from diffuse scatterers and sources of diffraction (the visible glint of sunlight off a choppy sea is an example of diffuse multipath).

Both forms of multipath are bad for radio communications. Diffuse multipath provides a sort of background "noise" level of interference, while specular multipath can actually cause complete signal outages and radio "dead spots" within a building. This problem is especially difficult in underground passageways, tunnels, stairwells and small enclosed rooms. The proper functioning of the radio communication link requires that multipath be minimized or eliminated.

2.3 INDOOR PATH LOSS

Path loss is difficult to calculate for an indoor environment. Again, because of the variety of physical barriers and materials within the indoor structure, the signal does not predictably lose energy. The path between receiver and transmitter is usually blocked by walls, ceilings and other obstacles. Depending on the building construction and layout, the signal usually propagates along corridors and into other open areas. In some cases, transmitted signals may have a direct path or Line-of-Site (LOS) to the receiver. LOS examples of indoor spaces are; warehouses, factory floors, auditoriums, and enclosed stadiums. In most cases the signal path is obstructed.

2.3.1 FREE SPACE LOSS

Fundamental to indoor path loss analysis is the free space loss. If the transmitting antenna were ideally a radiating point source in space, the propagated surface wave front will exit the point source in a spherical pattern as shown in Figure 2.6. The spherical signal energy reduces as the square of the distance. Free Space Path Loss (FSPL) is defined as:

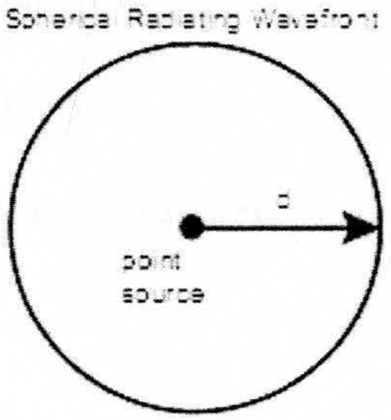


Figure 2.6: Free Space Radiating Point Source

$$\mathrm{FSPL} = (4pd/l)^2 \qquad (1)$$

Where d is distance in meters between the transmitter and receiver, and l(lambda) is the wavelength in meters. This equation also implies that as the frequency increases the loss will be proportionally higher. Relating frequency to wavelength:

$$\lambda = c/f \qquad (2)$$

Where c is the speed of light, $c = 3\text{x}10^8$ m/s, and frequency, f = cycles per second. For example, the wavelength of the 2.4 GHz sinusoid is:

$\therefore \lambda = .125$ meters, l=12.5 centimeters or λ=4.92inches. Free space loss defined in decibels is:

$$\text{Free Space Loss} = 10 \cdot \log(\text{FSPL}) \qquad (3)$$

where FSPL is from equation 1.

$\therefore$ Free Space Loss (FSL) = 40 dB @ 1 meter

$\therefore$ Free Space Loss (FSL) = 60 dB @ 10 meter.

Therefore, the free space loss 1 meter away from the transmitter is 40 dB. Thereafter, the signal attenuates at a rate of 20 dB per decade

2.3.2 LINE OF SITE PATH LOSS

For a LOS office scenario, the path loss is given by:

$$PL = FSL_{ref} + n_1 \cdot 10 \cdot \log(d_{tr}) \qquad (4)$$

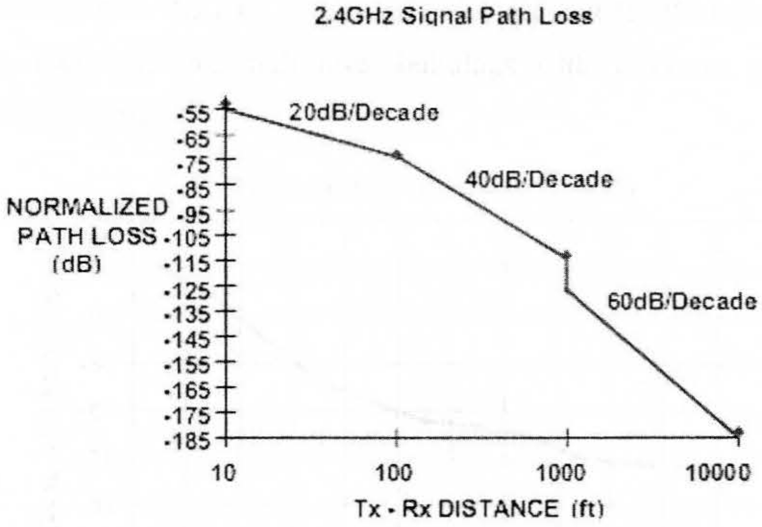


Figure 2.7: 2.4GHz Typical Path Loss

Where FSL_{ref} is the free space loss in dB determined in the far field of the antenna. Usually for indoor environments, this is calculated to be 1 or 10 meters as shown in equation (3). "d_{tr}" is the distance between the receiver and transmitter. The symbol "n_1" is a scaling correction factor which is dependent on the attenuation of the propagation environment. In this case, equation (4) is for large indoor spaces. The n_1 factor has been determined from empirical data collected and can be found in the book references by; T. Rappaport and A. Santamaria, Lopez-Hernandez. For line of site application in hallways the n_1 factor has been determined to be less than 2. This is due to the waveguide effect provided by properties of hallways or corridors. Figure 2.7 shows the free space attenuation in dB for a typical indoor application. The curve represents various LOS path losses. The first segment represents the path loss due to free space. The second and last segments represent amore loss path. The instantaneous drop demonstrates the loss due to obstruction of the LOS path.

2.3.3 OBSTRUCTED PATH LOSS

Obstructed path loss is much more difficult to predict, especially for the myriad of different indoor scenarios and materials. Therefore, different path loss models exist to describe unique dominant indoor characteristics. Based on free space loss and the three propagation phenomenon, the path loss models also account for the effects of different building types. Examples are multi-level buildings with windows, or single level buildings without windows.

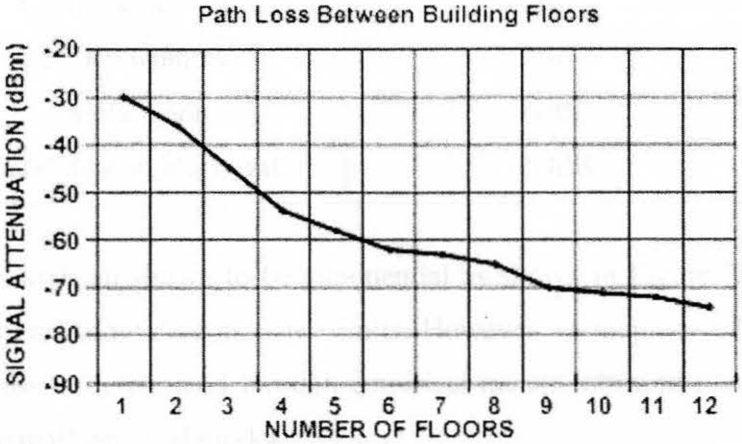


Figure 2.8: Multiple Floors Indoor Path Loss

It has been shown in Figure 2.8 that the propagation loss between floors begins to diminish with increasing separation of floors non-linearly. The attenuation becomes less per floor as the number of floors increases. This phenomenon is ought to be caused by diffraction of the radio waves along side of a building as the radio waves penetrate the building's windows. Also, a variety of different indoor configurations can be categorized for buildings with enclosed offices, or office spaces consisting of a mix of cubicles and enclosed rooms. Examples of attenuation through obstacles for various materials are shown in the Table 2.1 for typical office obstacles such as doors, windows and walls offer fairly known levels of attenuation. These values of attenuation are in addition to the path loss mentioned earlier. The following provides some examples of the attenuation values of common office construction:

Table 2.1 : Signal attenuation at 2.4GHz

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

Indoor path loss has been shown to be exponential as shown in Figure 2.7. In specific cases the models can show deterministic limits. However, in majority of the cases the obstructed path loss is determined through empirical means followed by corresponding refinements to the mathematical model.

2.4 MULTIPATH AND FADING EFFECTS

As a transmitted radio wave undergoes the transformation process presented in the indoor environment, it reaches the receiving antenna in more than one path, thus giving rise to multipath. Relating multipath to propagation models and pathless employs stochastic theory and probability distribution functions (pdf). A somewhat understated view of the multipath effect is; signal variations within a building, where there are no clear line of site signal paths between the receiver and transmitter, approximate a Rayleigh distribution. For receivers and transmitters that have line of site signal paths, the distributions are Rician. A Rayleigh distribution function describes a process where a large number of incident rays as seen at the receiver antenna will add randomly with respect to amplitude and time. A Rician distribution is similar to a Rayleigh pdf except that a Rician pdf contains a strong dominant component. Usually the dominant component is the direct line of sight or ground reflection ray. Multipath introduces random variations in the received signal amplitude over a frequency bandwidth. Multipath effects also vary depending on the location of the antenna as well as the type of antenna used. The observed result of random signal distributions, as seen by the WLAN radio receiver, will be the “in and out” variation fading of the signal which as shown in