HEURISTIC BASED PLANNING APPROACH FOR IMPROVING WIRELESS NETWORK COVERAGE OF MULTI-STOREY BUILDING

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HEURISTIC BASED PLANNING APPROACH FOR IMPROVING WIRELESS NETWORK COVERAGE OF MULTI-STOREY BUILDING

by

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
AP	Access Point
APs	Access Points
ART1	Adaptive Resonance Theory 1
BSSID	Basic Service Set Identifier
DECT	Digital Enhanced Cordless Telecommunications
DSSS	Direct Sequence Spread Spectrum
dB	Decibel
dBm	Decibel Referenced to Milliwatts
dBi	Decibel Isotropic
EM	Electromagnetic
ESSID	Extended Service Set Identifier
FHSS	Frequency Hopping Spread Spectrum
GA	Genetic Algorithm
GHz	Gigahertz
GPS	Global Positioning System
GUI	Graphical User Interface
GB	Gigabyte

HIPERLAN	High Performance Radio LAN
IEEE	Institute of Electrical and Electronics Engineers
IR	Infrared
ISM	Industrial, Scientific and Medical
J2SE	Java 2 Standard Edition
km	Kilometers
LAN	Local Area Network
LOS	Line-of-Sight
LWAPP	Lightweight Access Point Protocol
MHz	Megahertz
MIMO	Multiple-In, Multiple-Out
MOGA	Multi-Objective Genetic Algorithm
MAC	Media Access Control
MOP	Multi-Objective Problem
MWF	Multi-Wall-and-Floor
Mbps	Megabits Per Second
m	Meters
NAv6	National Advanced IPv6
NDIS	Network Driver Interface Specification
NIC	Network Interface Card

NLOS	Non Line-of-Sight
NN	Neural Network
NSGA2	Non-Dominated Sorting Genetic Algorithm 2
OFDM	Orthogonal Frequency Division Multiplexing
OLOS	Obstructed Line-of-Sight
OOAD	Object Oriented Analysis and Design
OS	Operating System
PC	Personal Computer
PDAs	Personal Digital Assistants
PDF	Probability Density Function
P2P	Peer-to-Peer
RF	Radio Frequency
RMS	Root-Mean-Squared
RSSI	Received Signal Strength Indication
TGa	Task Group a
TGb	Task Group b
TGg	Task Group g
TGn	Task Group n
UNII	Unlicensed National Information Infrastructure
USM	Universiti Sains Malaysia

WiMAX	Worldwide Interoperability for Microwave Access
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WLL	Wireless Local Loop
WPAN	Wireless Personal Area Network
2D	Two-Dimension
3D	Three-Dimension
3G	3rd Generation

LIST OF SYMBOLS

lim	limit
θ	angle in radians
λ	wavelength (speed of light/frequency)
π	ratio of a circle's circumference to its diameter (approximately 3.14)
β	constant loss in dB
$\sum$	sum
α	the co-efficient associated to the distance effect
$\log_{10}$	base-10 logarithm

PENDEKATAN PERANCANGAN BERASASKAN HEURISTIK UNTUK MENINGKATKAN LIPUTAN TANPA WAYAR DALAM BANGUNAN BERTINGKAT

ABSTRAK

Tesis ini menilai Rangkaian Tempatan Tanpa Wayar (WLAN) dari segi liputan, kadar data, dan gangguan pertindihan bersama saluran. Matlamat penyelidikan ini ialah untuk meningkatkan liputan WLAN dengan melaksanakan simulasi perancangan rangkaian tanpa wayar dalam banguanan bertingkat. Kerja terlibat dalan tesis ini dilaksanakan dalam tapak uji sebenar dan secara simulasi. Model kehilangan jalan berdasarkan teori yang diubahsuai telah diberi untuk menganggar kehilangan jalan antara pemancar dan penerima dalam simulasi. Keputusan model empirikal telah dibandingkan dengan model teoritikal dan keputusan dipaparkan dalam visualisasi kontur. Reka bentuk ini terhad kepada titik akses (AP) WLAN yang beroperasi pada frekuensi 2.4 dan 5 Gigahertz (GHz) yang menyokongi standard 802.11n. Kajian ini mencadangkan satu pendekatan baru dengan kombinasi Kepintaran Buatan (AI) yang berdasarkan Teori Resonance Bersesuaikan Diri 1 (ART1) dan Algoritma Genetik Berbagai Objektif (MOGA) untuk pemberian saluran yang lebih efektif, dan kedudukan peralatan titik akses yang lebih baik dalam simulasi. Dengan cara yang dicadangkan ini, penyelesaian yang lebih baik untuk letak-atur WLAN dapat dicapai. Daripada keputusan simulasi, liputan yang lebih baik telah dicapai dengan sekurang-kurangnya perletakan tiga AP, dan liputan meningkat dari -85 Desibel Dirujuk kepada Milliwatts (dBm) hingga -70 dBm dan ke atas untuk lokasi yang dikaji (makmal NAv6), sebagaimana dibandingkan dengan lokasi perletakan AP yang asal.

HEURISTIC BASED PLANNING APPROACH FOR IMPROVING WIRELESS NETWORK COVERAGE OF MULTI-STOREY BUILDING

ABSTRACT

This thesis evaluates Wireless Local Area Network (WLAN), in terms of coverage, data rate, and overlapping co-channel interference. The aim of this research is to improve the WLAN coverage by implementing a wireless network planning simulation in multi-storey building. The work presented in this thesis was conducted on both on-site measurement and simulation. A modified theoretical path loss model was presented to estimate the path loss between the transmitter and receiver in the simulation. The results of empirical model were compared with the results of theoretical model and display them in the form of contour visualization. This design is limited to WLAN Access Points (APs) that operate at 2.4 and 5 Gigahertz (GHz) frequencies, supporting 802.11n standard. This research proposed a new approach to combine Artificial Intelligence (AI) using Adaptive Resonance Theory 1 (ART1) and Multi-Objective Genetic Algorithm (MOGA) for more effective channel assignments and better equipment placements of simulated APs. By means of this proposed approach, better solution for WLAN deployment can be achieved. From the simulation results, better coverage was achieved by deploying at least three APs, and the coverage value was increased from -85 Decibel Referenced to milliwatts (dBm) to -70 dBm and above for the test location (NAv6 laboratory), as compared to the original AP placement locations.

CHAPTER 1

INTRODUCTION

1.1 Introduction to Wireless Network

The wireless networks are expanding rapidly as the benefits of access without cables are discovered. Over the past decades, wireless network technologies have been used for data, voice and video. Now, they are the mainstream internet connectivity solution for business, education and personal usage.

There are a few types of wireless Radio Frequency (RF) networks, including the Institute of Electrical and Electronics Engineers (IEEE) 802.11 Wireless Local Area Network (WLAN), Wireless Personal Area Network (WPAN), and High Performance Radio LAN (HIPERLAN) (Pahlavan and Krishnamurthy, 2002). These wireless networks operate on Industrial, Scientific and Medical (ISM) and Unlicensed National Information Infrastructure (UNII) frequency domains, such as ISM 900 Megahertz (MHz), ISM 2.0 Gigahertz (GHz) to 2.5 GHz, UNII 5.1 GHz to 5.8 GHz, and 60 GHz to 66 GHz. The IEEE created a working group called the 802.11 working group to set the 802.11 wireless standards. The 802.11 WLAN Standard, also known as Wireless Fidelity (Wi-Fi), is one of the most active areas of research and development in recent years. Originally, the research of wireless networks was driven primarily by the demand of cost effectiveness for Personal Computer (PC) related usages, and this led to the developments of other kinds of services such as video transmission, Internet telephony, gaming and music streaming (Somolinos, 2009). All necessary considerations for deployment of a WLAN are difficult compared to the wired networks due to varying factors, including multipath fading and interference. Thus, research activities on wireless networks are becoming the primary focus of designers to ensure wireless network reliability and good performance.

1.2 Background of the Research

Designing a WLAN, especially an enterprise computer network, can be a daunting task. It requires an understanding of how the 802.11 standards work, the differences between vendor implementations, the varying obstructions of both indoor and outdoor environments, as well as sources of interference that affect a WLAN's performance.

Before an initial WLAN deployment, many network administrators are not aware that there is a need to invest enough time to identify the best locations for the base stations or Access Points (APs) to be deployed and to be monitored for optimum WLAN performance. While a wireless system will enable mobility, the supporting infrastructure is not mobile and its placement for performance and coverage must be carefully planned. The exact design steps needed depend on the organization's critical requirements for performance coverage and future growth.

According to Smith et al. (2000), it is essential to classify hierarchical cellular infrastructure supporting different cell sizes for wireless networks. There are three types of cells for both outdoor and indoor channel allocations of radio propagation: macrocell, microcell, and picocell. These different types of cells are categorized for different sizes of propagation cells. The macrocell covers the radius from 2 Kilometers (km) to about 30 km, whereas microcell has the radius between 200 Meters (m) and 2 km. The picocell, which is referred as the indoor WLAN propagation cell in this thesis, has less than 200 m radius.

1.3 Problem Statement

Although a picocell is not influenced by weather conditions like the rain, smoke and fog, WLAN performance can be affected by the surrounding obstructions inside a building. The varieties of in building materials and structures, such as walls, windows and floors are obstructions and they can create a phenomenon called path-loss (Saunders and Aragon-Zavala, 2007). Therefore, it is important to place each Access Point (AP) in a strategic place. The phenomenon of radio propagation degradation such as reflection, diffraction and scattering that are caused by the mentioned obstructions also must be considered. Most office environments and modern homes are constructed with materials that are relatively translucent to radio waves at 2.4 GHz, so the range will not be greatly limited (Blaunstein and Christodoulou, 2007). However, some materials do tend to present very reflective and refractive environments, and the ultimate limitation will probably be some severe multipath problems.

A good WLAN coverage is definitely essential, but nowadays, users are demanding for good WLAN capacity as well. According to Huang et al. (2005), a good WLAN coverage with good capacity is hard to be achieved concurrently. Due to the capacity demand, the WLAN deployment must be planned carefully for good coverage and capacity.

Surprisingly, the channel assignment strategy is mostly neglected when wireless designers are deploying WLAN, especially the 2.4 GHz band. Due to the limited channels of 2.4 GHz frequency band provided, the deployment can be costly if lack of WLAN planning solution or without a WLAN channel assignment strategy for solving overlapping co-channel interference issue. Furthermore, proper APs placements are important, because different WLAN placements can create different WLAN coverage, capacity and possible co-channel interference.

1.4 Research Objectives

The research objectives can be summarized as the points below:

- **To perform on-site measurement for obtaining actual coverage of the deployed WLAN at the test location (NAv6 laboratory).**
- **To evaluate the accuracy of existing indoor propagation model, to account for various obstructions in a multi-storey building for manual planning and heuristic planning simulation.**
- **To develop a new heuristic WLAN planning approach.**
- **To compare the coverage results of on-site measurement against heuristic planning simulation with different algorithms.**

For heuristic planning, the goal of the Artificial Intelligence (AI) is to provide a solution to obtain the simulated APs with the coverage of -at least -70 dBm and above, and overlapping co-channel interference of -75 dBm and below.

1.5 Research Scope and Limitations

This research is about conducting a proper study of WLAN indoor propagation in a multi-storey building. Therefore, the research scope is specifically on picocell and the IEEE 802.11 standards, consisting of 802.11n standard, operating at 2.4 GHz and 5 GHz bands. Outdoor environment can be experimented by using on-site measurement approaches called automated and assisted site survey for monitoring the WLAN Mesh deployment. However, the cost of outdoor WLAN Mesh deployment is significantly higher than the indoor WLAN deployment, and the size of outdoor cells are normally at least in microcell size. Due to these limitations, wireless networks at outdoor environment will not be studied.

Certain rooms are not opened during non-working hours. Therefore, it is not possible to run the full WLAN on-site measurement in all of the rooms and labs in the experimented building. It is also a tedious task to identify the upper rails or metals installed on each floor, because all rails are hidden objects above the ceilings. Therefore, the signal absorption and reflection on the rails are omitted.

Other wireless networks such as bluetooth, Wireless Local Loop (WLL), Worldwide Interoperability for Microwave Access (WiMAX), Hyper-LAN and Digital Enhanced Cordless Telecommunications (DECT) technologies are not included, as these technologies are not part of IEEE 802.11 standards.

1.6 Organization of Thesis

This thesis is organized into six chapters. In this chapter, the research background of wireless networks and an overview of problem statement were covered along with the research objectives, research scope and limitations.

In Chapter 2, the literature review and fundamental concepts of RF propagation and issues related to this research are discussed. Some particular propagation models for indoor environment are discussed as well.

Chapter 3 highlights the research design that shows how the WLAN on-site measurement and planning can be carried out. It provides the procedures for WLAN on-site measurement, manual planning, and automated planning that uses AI for WLAN heuristic-based planning.

Chapter 4 details the proposed on-site measurement and simulation methodology. It gives in-depth explanation of the research methodology, including the visualization, the suggested propagation models for simulation, and the WLAN heuristic-based planning.

The analysis and discussion of the results after each experiment are the primary content of Chapter 5. The experiments are the contour visualization, the on-site measurement, manual planning using original Multi-Wall-and-Floor (MWF) model and adjusted MWF model, and the heuristic-based planning using AI.

Chapter 6 summarizes this thesis. The research contributions are visited. And finally, discussion and suggestion for future work directions pertaining to this research are presented.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, literature review of the related research is presented. Section 2.2 covers the technology of WLAN, IEEE 802.11 standards and the advantages of using WLAN. In Section 2.3, the theoretical framework is explained, and this section highlights the critical elements for this research. Section 2.4 is about wireless propagation in brief, specifically for picocell or indoor environment, while Section 2.5 explores the multipath propagation effects, followed by the detailed explanations of multiplicative and additive noise in Section 2.6. Lastly, Section 2.7 covers the Artificial Intelligence (AI) for WLAN simulation.

2.2 WLAN

WLAN is a generic term to refer to different technologies providing local area networking via RF link. It is a system of data transmission specifically for mobile computing devices, using radio waves instead of cable infrastructure. The IEEE 802.11, HIPERLAN, and DECT are part of the WLAN technology. A WLAN AP can be connected to wireless clients such as laptops with Electromagnetic (EM) wave propagation as the transmission medium. A WLAN can work independently in ad hoc mode, but it is usually connected to an existing wired Local Area Network (LAN) such as an Ethernet. In today's computing world, WLAN is usually used as the last connection medium between an existing wired network and a group of clients.

WLAN is widely accepted as an industry standard, which is named by IEEE as 802.11

standard, and commonly known as Wi-Fi. The objective of the IEEE 802.11 is to develop a specification for wireless connectivity for fixed, portable, and moving stations within a local area.

Generally, WLAN can be operated in two modes, namely infrastructure and ad hoc, as illustrated in Figure 2.1 (Chen et al., 2003). The infrastructure mode consists of some of network equipments and devices, such as AP, wireless controller, Ethernet switch, wireless bridges, routers, and the wireless adapters that are connected to the WLAN receiving clients. These devices are connected from an infrastructure network. A Peer-to-Peer (P2P) wireless connection without a central AP and connected independently within a short range is considered an ad hoc network.

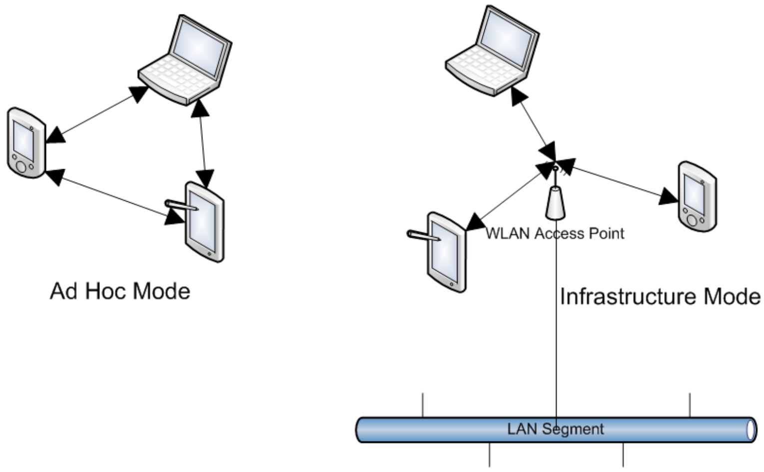


Figure 2.1: A Comparison between Wireless Ad Hoc and Wireless Infrastructure Network

2.2.1 The Legacy 802.11 Standards

In 1997, IEEE ratified 802.11, which is the first widely recognized wireless network. It supported three spectrums, namely Infrared (IR), Frequency Hopping Spread Spectrum (FHSS), and Direct Sequence Spread Spectrum (DSSS). Initially, it has less than a few hundred meters radius of coverage area with only 2 Megabits Per Second (Mbps) of data rate. As an effort to increase throughput, IEEE established two separated task groups, namely Task Group a (TGa) and Task Group b (TGb). The task of TGa was to discover the usability of the 5 GHz band, while TGb explored the 2.4 GHz band. Later, another group called Task Group g (TGg) improved the speed in the 2.4 GHz band, to operation at 54 Mbps maximum speed, and released the 802.11g standard that can be interoperable with 802.11b.

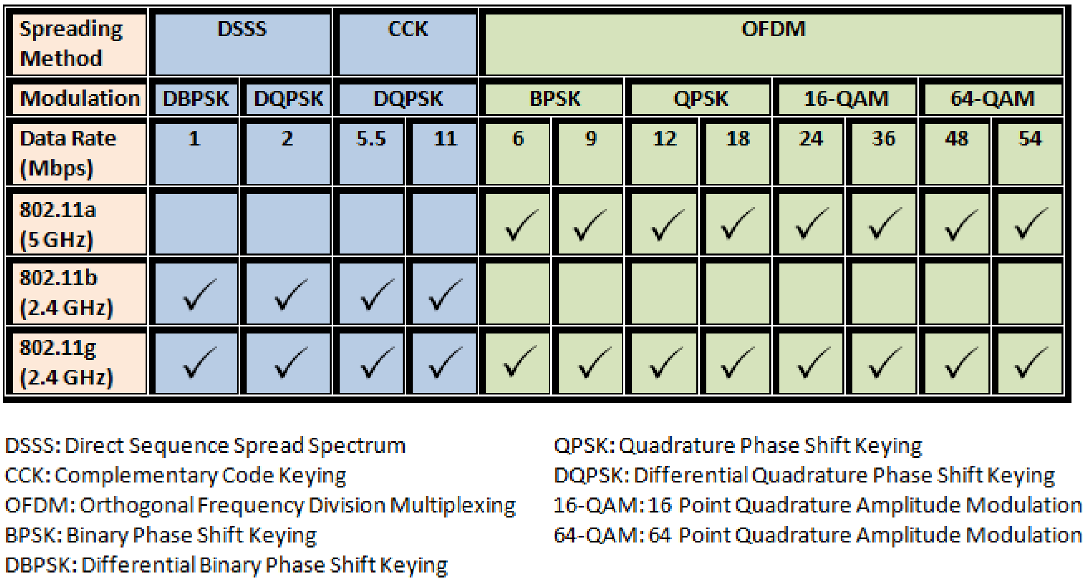
IEEE 802.11a is using the 5 GHz ISM frequency band, which is different from the frequency used by 802.11b and 802.11g. 802.11a is not compatible with 802.11b and g, but they can coexist. IEEE 802.11a works with Orthogonal Frequency Division Multiplexing (OFDM), which is a multiple-carrier signal technique with data rate up to 54 Mbps. As the other standards are not interoperable with 802.11a, this standard is not as widely used as 802.11g. However, being interoperable with 802.11n, the 802.11a adapter cards can be used if dual-band 802.11n APs are deployed. 802.11a uses channel data rate of 6, 9, 12, 18, 24, 36, 48, and 54 Mbps.

IEEE 802.11b is still used by home and small-scale wireless networks. It is also interoperable with the 802.11g standard, thus making it a widely-used standard at this moment. It operates at the 2.4 GHz ISM frequency band, but the transfer rate is only up to 11 Mbps. This made the 802.11b standard subsequently superseded by 802.11g standard. However, compared with the 5 GHz 802.11a standard, its downside is in a higher possibility of overlapping co-channel interference due to limited availability of non-overlapping channels. Additionally, because of the lower frequency, 802.11b standard has a lower capacity compared with 802.11a standard.

The IEEE 802.11g is the most widely used standard at this time, as there are many enhancements compared with 802.11b and 802.11a, and the cost of 802.11g APs deployment is lower. Instead of DSSS used for 802.11b standard, it works with the same modulation as IEEE 802.11a, which is OFDM. With this method, it allows data rate of up to 54 Mbps to be achieved. Another advantage is that it has better range than 802.11a as it is operating with

2.4 GHz, instead of 5 GHz. It is also backward compatible with 802.11b standard. Unfortunately, like the 802.11b standard, there are limited non-overlapping channels can be operated for 802.11g standard.

Figure 2.2 summarizes the supported data rate and modulation techniques of the legacy 802.11 standards.



Spreading Method	**DSSS**		**CCK**		**OFDM**							
Modulation	**DBPSK**	**DQPSK**	**DQPSK**		**BPSK**		**QPSK**		**16-QAM**		**64-QAM**	
Data Rate (Mbps)	**1**	**2**	**5.5**	**11**	**6**	**9**	**12**	**18**	**24**	**36**	**48**	**54**
802.11a (5 GHz)					✓	✓	✓	✓	✓	✓	✓	✓
802.11b (2.4 GHz)	✓	✓	✓	✓								
802.11g (2.4 GHz)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

DSSS: Direct Sequence Spread Spectrum
CCK: Complementary Code Keying
OFDM: Orthogonal Frequency Division Multiplexing
BPSK: Binary Phase Shift Keying
DBPSK: Differential Binary Phase Shift Keying
QPSK: Quadrature Phase Shift Keying
DQPSK: Differential Quadrature Phase Shift Keying
16-QAM: 16 Point Quadrature Amplitude Modulation
64-QAM: 64 Point Quadrature Amplitude Modulation

Figure 2.2: The Data Rate for 802.11abg Standards (Xirrus, 2008)

2.2.2 802.11n

In 2003, Task Group n (TGn) was formed and the 802.11n standard was rectified in September 2009. Pollin and Bahai (2009) explained that there are two different kinds of 802.11n transceivers, one only operates on one frequency band, which is 2.4 GHz, while the other operates on two frequency bands simultaneously, which are 2.4 GHz and 5 GHz. Users with dual-band receivers can have better capacity of WLAN, due to the availability of the 5 GHz band.

Together with Multiple-In, Multiple-Out (MIMO) support, 802.11n allows channel bonding or channel bundling that can double the normal data rate (Perahia and Stacey, 2008). Most first generation 802.11n systems support two spatial streams. By combining all of the enhancements of the first generation 802.11n, it is expected that 130 Mbps is the highest data rate in a 20 MHz channel and 300 Mbps with channel bonding, 40 MHz channel with short guard interval. The second generation 802.11n systems that incorporate additional spatial streams can deliver up to 600 Mbps with channel bonding and short guard interval. Table 2.1 explains the supported channels for 802.11n channel bonding (Perahia and Stacey, 2008). Figure 2.3 shows the calculation formula for the highest data rate of the 802.11n standard (Perahia and Stacey, 2008).

Table 2.1: Channels that can be Bonded for 40 MHz Channel Allocation

Channel 1 (20 MHz)	**Channel 2 (20 MHz))**	**New 40 MHz Channel Frequency**
36	40	5190
44	48	5230
52	56	5270
60	64	5310
100	104	5510
108	112	5550
116	120	5590
124	128	5630
132	136	5670
149	153	5755
157	161	5795

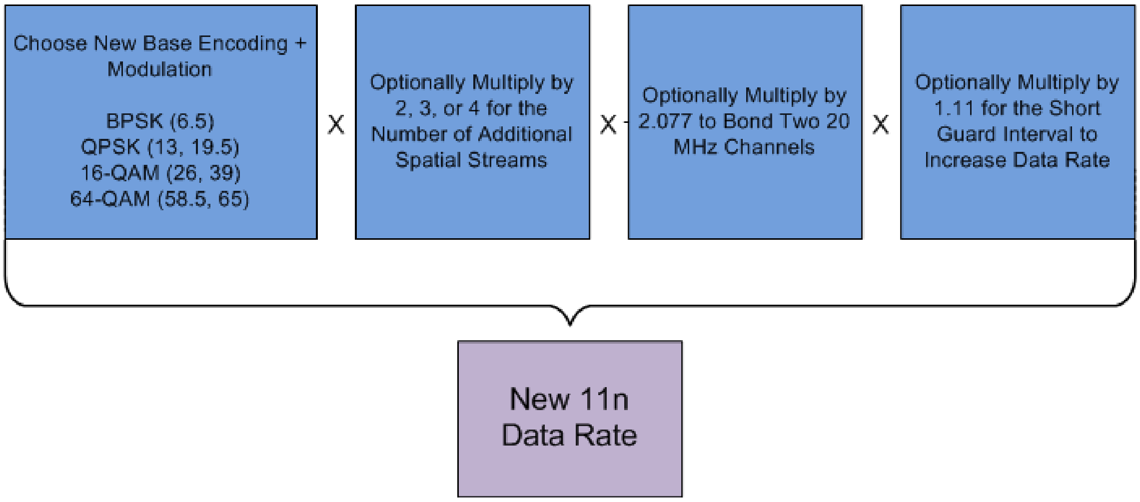


Figure 2.3: The Formula to Obtain Highest Data Rate of 802.11n

However, Shrivastava et al. (2008) showed a disadvantage of the rectified 802.11n, which is the throughput of 802.11n can be degraded with the presence of 802.11g link and the increased amount of interference due to wider channel bandwidths.

2.2.3 Advantages of WLAN

In certain areas, it is difficult for wired cables to be laid. Thus WLAN is a good solution when dealing with cable installation difficulty. Additionally, it will be much easier for users to move their laptops if it is connected to the WLAN and users still can enjoy connectivity while on the go. WLAN Internet connectivity is great for any company where its site is not beneficial to LAN wiring because of the budget limitations or building structure like old buildings, leased space, or temporary sites.

When dealing with a new environment, cost of purchasing and time of installing the network cables for a wired system are definitely more than for a WLAN system. While the initial investment required for WLAN hardware can be higher than the cost of traditional wired LAN hardware, overall installation expenses and life-cycle costs can be significantly lower. Long-term cost benefits are greatest in dynamic environments that require frequent moves and changes. The WLAN concept ensures that not only the regular desktop and laptop users can be benefitted from wireless access via Internet, other devices such as mobile computers, printers, Personal Digital Assistants (PDAs), mobile phones and other Wi-Fi enabled mobile devices can be fully utilized with WLAN connections.

2.3 Theoretical Framework

The first issue every network administrator has to face is to accurately describe the quality of a network, based on realistic propagation predictions. The second issue is to implement an optimization plan that provides efficient deployment strategies. The essence of measuring or monitoring a wireless network is to have a clearer view of the current status of wireless network. On the other hand, by doing wireless network planning, a network administrator can proactively deal with potential problems without the cost of actual deployment. According to Pahlavan and Krishnamurthy (2002), the wireless network on-site measurement and planning can be defined as a set of measurements and practices on wireless networks that are employed to be observed and analyzed by people for better performance, coverage, capacity, and other aspects of the wireless networks.

WLAN planning is much more convenient and cost-effective way to deploy a wireless network, compared with the WLAN on-site measurement with lots of measurements and empirical decisions. It is not convenient to measure the signal strength in each and every measurement points for all space in the design region. Some efficient propagation models are required to analyze and optimize a wireless network. With simulation, different configurations of the wireless network can be tested at almost no expense to find an optimal solution.

Figure 2.4 shows the critical elements for this research. The critical elements are the database used by the simulator, the simulation process, the on-site measurement process, the propagation model used, and assumptions and analysis to be made from the obtained results. The WLAN on-site measurement is also referred as WLAN monitoring throughout this research.

Variables can be identified from the WLAN devices. The Variables are signal strength, data rate, and co-channel interference. Signal strength is the value of each measurement point or calculated point, and the signal strengths collected within an area are called coverage. Similarly, the data rate is the value of each point, and the accumulated values within the same area are called capacity. These three variables are critical for determining the WLAN performance.

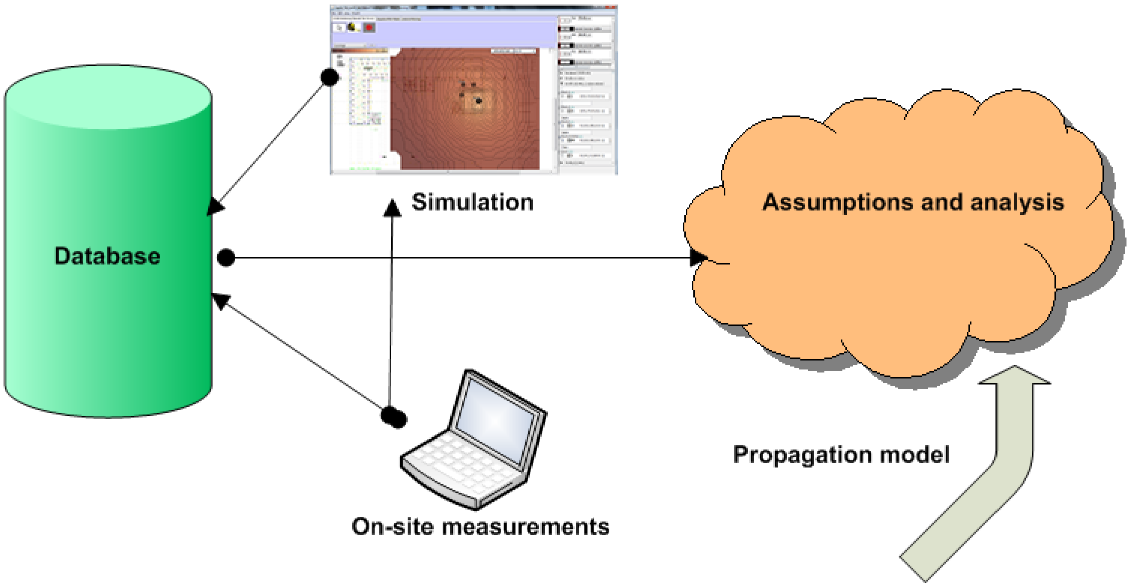


Figure 2.4: Critical Elements of Wireless Network Monitoring and Planning(Pahlavan and Krishnamurthy, 2002)

Table 2.2 shows the relationship between the variables and the factors involved.

Table 2.2: The Factors and Variables of WLAN Monitoring and Planning

Variables	Factors
Signal Strength	1. Distance between the transmitter and receiver. 2. Physical obstructions in the path of the WLAN transceivers. 3. Power supported by WLAN transceivers.
Data Rate	1. Distance between the transmitter and receiver. 2. Physical obstructions in the path of the WLAN transceivers, which can also interfere with signal quality. 3. Power supported by WLAN transceivers. 4. Radio interference in the path of the WLAN device.
Co-Channel Interference	1. Distance between the transmitter and receiver. 2. Physical obstructions in the path of the WLAN transceivers. 3. Power supported by WLAN transceivers. 4. Selected channel on each AP.

According to Alexander (2004), there are three types of WLAN measurement approaches, namely manual site survey, automated site survey and assisted site survey, as shown in Figure 2.5. Manual site survey is a site survey on a physical site with an administrator walking around the site, whereas automated site survey is a controlled survey, fully accomplished by a wireless controller on connected Lightweight Access Point Protocol (LWAPP) enabled APs, and it is best to be applied to a wireless mesh network. Lastly, the assisted site survey is the combination of manual and automated, which means it extracts and uses the best features from both approaches. The best approach to be used in this research is manual site survey, because there is no wireless controller and LWAPP enabled APs in the experimental building for automated and assisted site survey approaches to be used.

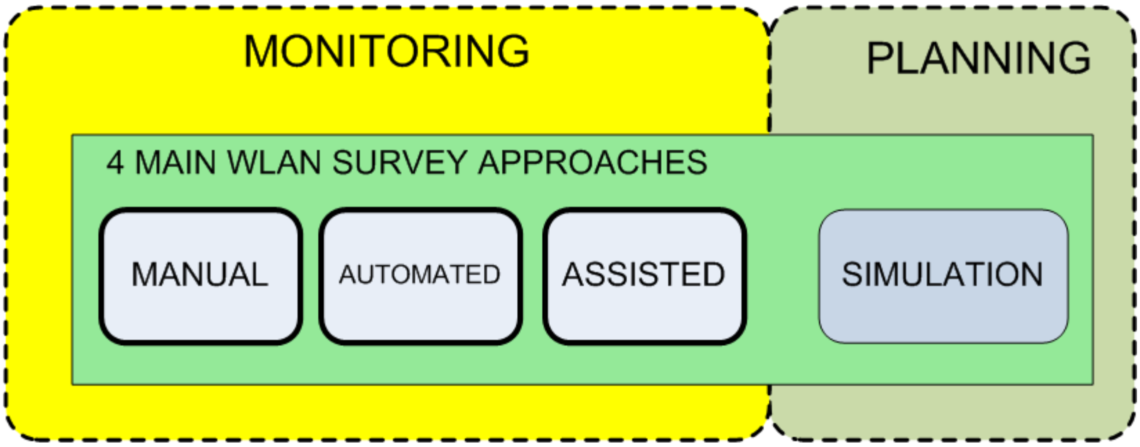


Figure 2.5: The Concept of WLAN Monitoring and Planning (Alexander, 2004)

2.3.1 Signal Strength

Signal strength and coverage are the same terms and they are used interchangeably in this research. The signal strength calculated based on path-loss predictions is usually called the link budget. The signal strength measured during a WLAN site survey is referred to as Received Signal Strength Indication (RSSI). The WLAN signal strength is an important value in WLAN on-site measurement and simulation works. The link budget result can be obtained from Equation 2.1 with inclusion of gain from Equation 2.2, with assumption that the environment is interference-free (Tanghe et al., 2009).

$$P_R = P_T + G_T - PL + G_R \tag{2.1}$$

$$Gain, G = \frac{P_{directional}}{P_{isotropic}} \tag{2.2}$$

In Equation 2.1, PL is the path-loss in Decibel (dB), P_R represents power at the receiver, P_T is the power at the transmitter, and G_T and G_R are the antenna gain of the transmitter and receiver respectively which can be obtained using Equation 2.2. In Equation 2.2, $P_{directional}$ is the power density of the directional antenna and $P_{isotropic}$ is the power density of an isotropic antenna.

2.3.2 Data Rate

Data rate or capacity of WLAN can be determined by the WLAN receiver with the Network Driver Interface Specification (NDIS) programmed to support WLAN modulation identification and RSSI of the transmitted packets in Decibel Referenced to Milliwatts (dBm) logged by a monitoring tool. Through the use of the signal strength parameter, it is possible to determine up to what distance from the AP a certain 802.11 data rate can be achieved. However, to calculate the new data rate of 802.11n AP with two spatial streams, formula in Figure 2.3 has to be used. The expected data rate from 802.11n AP is shown in Table 2.3.

2.3.3 Co-Channel Interference

Interference has been the main issue for WLAN deployment. Problems with signal interference are common. Gummadi et al. (2007) discussed the weaknesses of the 2.4 GHz over the less-used 5 GHz band, and their research also showed that sources in the ISM band, which are not

Table 2.3: Expected Data Rate for 802.11n Access Point with Two Spatial Streams

802.11a/802.11g Data Rate	**One Spatial Stream**	**With Channel Bonding (40 MHz)**	**With Short Guard Interval**	**Two Spatial Streams**	**With Channel Bonding (40 MHz)**	**With Short Guard Interval**
6	6.5	13.5	15	13	27	30
9	13	27	30	26	54	60
12	19.5	40.5	45	39	81	90
18	26	54	60	52	108	120
24	39	81	90	78	162	180
36	52	108	120	104	216	240
48	58.5	121.5	135	117	243	270
54	65	135	150	130	270	300

802.11 compliant, can degrade the performance of 802.11 Network Interface Card (NIC).

To avoid the co-channel interference and to maximize the channel reusability in wireless cell planning, Briggs and Tijmes (2009) suggested a few channel assignment strategies for 2.4 GHz band, such as combination of channel 1 6 11, channel 1 7 13, and channel 1 5 9 13. These strategies are suitable for a good WLAN channel planning.

According to Pahlavan and Krishnamurthy (2002), wireless network cells are of arbitrary shape or close to a circle, and some regular polygons are needed to represent the wireless network cell shape. Therefore, there can be three types of regular polygons, and they are equilateral triangle, square, or regular hexagon as shown in Figure 2.6.

Although the hexagonal cell shape is often chosen as the default cell shape for all wireless networks, the square and triangle shapes can be applied as well. In order to investigate the effects of co-channel interference, which changes with distances, there is a need to come up with an elegant way of determining distances and identifying cells.

According to (MacDonald, 1979), to maximize the capacity, co-channel cells must be placed as far apart as possible for a given cluster size. The relationship among the distance

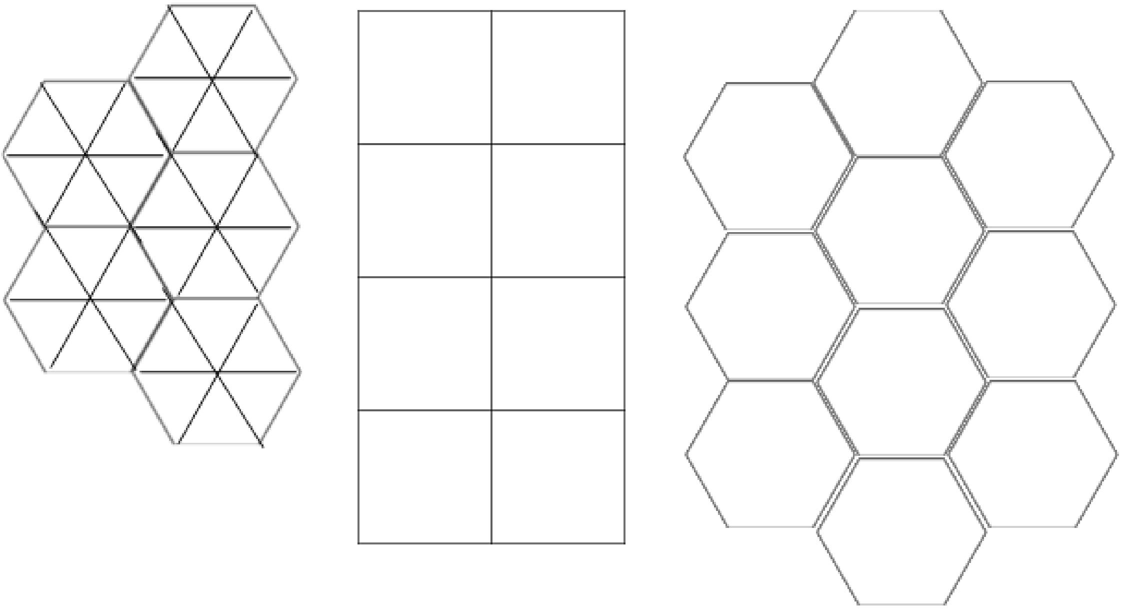


Figure 2.6: Triangular, Rectangular and Hexagon Cells

between co-channel cell centers, D, the cluster size, N, and the cell radius, R, can be represented in a co-channel reuse ratio formula, as shown in Equation 2.3.

$$\frac{D}{R} = \sqrt{3N} \tag{2.3}$$

Considering there are J_s interfering APs surrounding a given AP, the co-channel interference value can be calculated in the form of a ratio called signal-to-interference ratio, as shown in Equation 2.4.

$$S_R = \frac{\frac{1}{R^4}}{\sum_{k=1}^{J_s} \frac{1}{D^4}} \tag{2.4}$$

2.4 Indoor WLAN Radio Propagation

In general, indoor RF propagation can be divided into three topographies (Blaunstein and Christodoulou, 2007). The first is for transmission between a transmitter and a receiver that both are located near each other without any intervening obstruction. This topography is named Line-of-Sight (LOS). The second topography is where the transmitter and receiver are located in a same room, but with obstructions between them. This is known as Obstructed Line-of-Sight (OLOS). The last topography, Non Line-of-Sight (NLOS), involves walls and floors located between transmitter and receiver.

The Fresnel zone on LOS relies on visualizing an ellipsoid that surrounds the direct line joining the transmitter to the receiver on a radio link. The ellipsoid is constructed so that the sum of the lengths of the straight lines joining the point on the ellipse to each end of the link is a constant distance greater than the length of the straight line between the ends. In free-space and without any obstructions, only the first ellipsoid exists and determines the first Fresnel radius. This ellipsoid covers an area between two terminal points, the transmitter and the receiver as represented in Figure 2.7.

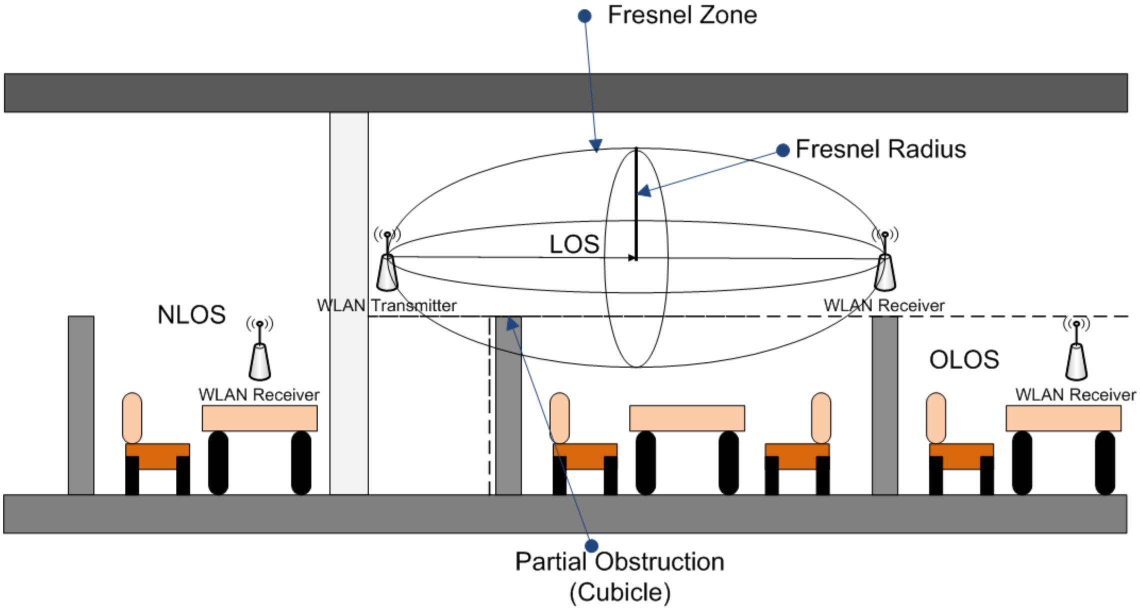


Figure 2.7: The First Fresnel Zone Covering Both Transmitter and Receiver under LOS

Understanding the indoor WLAN RF propagation can be as challenging as the outdoor WLAN RF propagation. Hashemi (1993) discussed the major challenges for understanding the indoor RF propagation environment. A thorough understanding of the propagation models to be examined and their unification to a better model can lead to better prediction and measurement of indoor WLANs. Path-loss calculation is difficult for an indoor environment as there are many kinds of physical obstructions within the indoor structure. The surrounding walls, ceilings, cubicles and other EM wave-propagation obstacles usually block the path between the transceivers.

2.5 Multipath Propagation Effects

Bidgoli (2003) explained that in a multipath propagation environment, all radio wave can undergo five obstacles, namely reflection, diffraction, scattering, refraction and absorption. Those five basic mechanisms cause radio signal distortion that makes a signal become stronger or lead to propagation losses. In real life, they create additional RF propagation paths beyond the direct optical LOS path between the radio transmitter and receiver. Among these five propagation effects, reflection, diffraction and scattering have a greater influence on the indoor WLAN performance, depending on local conditions and as a mobile unit moves through the area.

2.5.1 Reflection

When radio waves reflect off an object with dimensions very large compared to its wavelength, reflection occurs. This obstruction near the LOS can reflect the main wave causing duplication with a time delay at the receiver. As shown in Figure 2.8, this phenomenon can interfere constructively or destructively at the receiver, depending on whether it is in or out of phase with the signal travelling along the direct path.

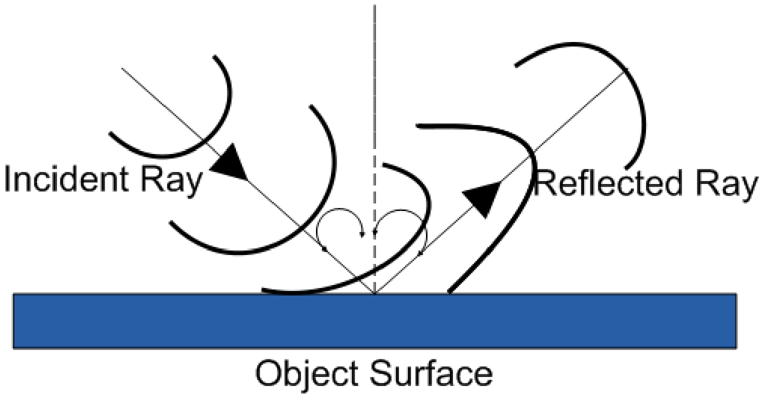


Figure 2.8: Reflected Signal on Reflective Surface

2.5.2 Diffraction

Diffraction of radio waves occurs when radio waves encounter the edge of an object that is large compared to the wavelength. In Figure 2.9, a portion of the wave's energy is bent around the object, causing a change in direction relative to the LOS path.

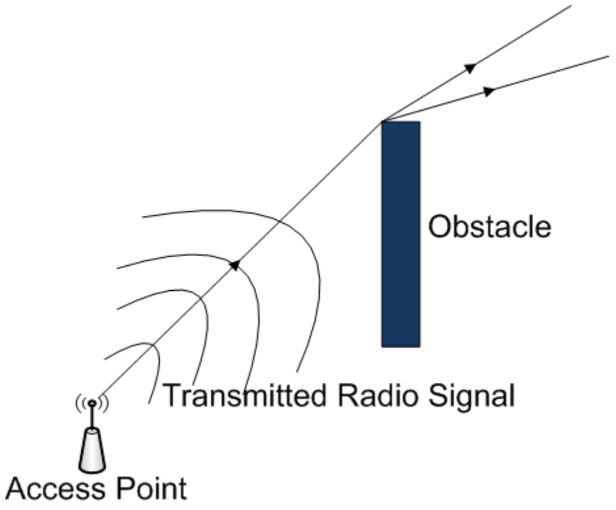


Figure 2.9: Diffraction of the Transmitted Signal

2.5.3 Scattering

As shown in Figure 2.10, scattering occurs when it encounters an irregular object which has rough surface and it is of a similar size relative to the wavelength. The energy distribution of the wave undergoes random changes in direction, phase, and polarization.

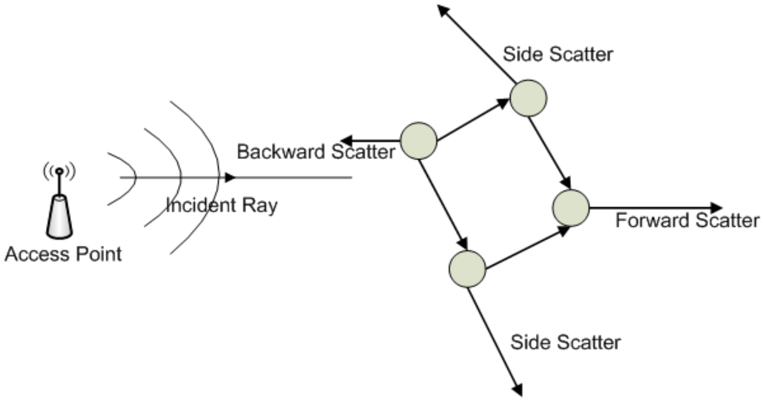


Figure 2.10: Scattering

2.5.4 Refraction

In Figure 2.11, refraction happens when there is a change in direction of an EM wave resulting from changes of the velocity of propagation in the medium through which it passes. This can result in only create a fraction or none of the LOS wave reaching the receiving antenna.

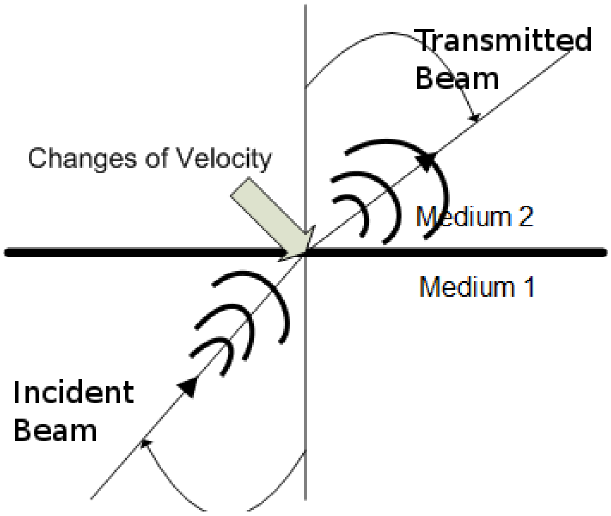


Figure 2.11: Refraction

2.5.5 Absorption

When radio waves meet an obstacle, some of the energy is absorbed and can be converted into heat. The wave energy that is not absorbed will reach the receiver, but the total beam will be attenuated. The amount of energy absorption and the attenuation very much depends on the material of the obstruction. Table 2.4 shows the attenuation losses for a selection of typical materials and structures (Anderson, 2003).

Table 2.4: Signal Losses/Attenuation Caused by Varying Material

Materials	**Typical Attenuation (Loss) (dB)**
Book Shelf	2
Brick Wall	10
Concrete Wall	12
Cubicle Wall	1
Dry Wall	3
Metal Partition	30
Glass Partition	3
Door (Wood)	2
Window	1

2.6 Multiplicative Noise and Additive Noise

All kinds of wireless networks, regardless of the operated frequency domains, can experience signal strength degradation that is caused by noise. A kind of noise, called multiplicative noise consists of path-loss, shadowing, and fast fading. Among these effects, path-loss is considered as the main contributor of signal strength degradation when the distance between the transmitter and receiver is increased and the height of the transmitter is changed (Alexander, 2004). The main problem is that there are many kinds of physical obstructions, which can give network designers hard time to evaluate EM wave propagation. Physical obstructions are the main contributors of multiplicative noise in between the transmitter and the receiver (Saunders and Aragon-Zavala, 2007). This problem leads to the WLAN AP placement problem for optimum WLAN coverage or capacity.

Shadowing, also known as slow fading happens due to varying nature of the certain obstructions between the base station and the mobile receiver, such as a tall building which has some obstructed and less obstructed paths. Fast fading or multipath fading happens when a transmitter and receiver are surrounded by objects that reflect and scatter the transmitted energy, causing several waves to arrive at the receiver via different routes.

Another noise contributor called additive noise, is caused by can be contributed by overlapping co-channel interference from surrounding APs. Overlapping co-channel interference happens when there are improper channels assigned to the APs, and this causes degradation of performance. Figure 2.12 illustrates the contribution of multiplicative noise and additive noise.

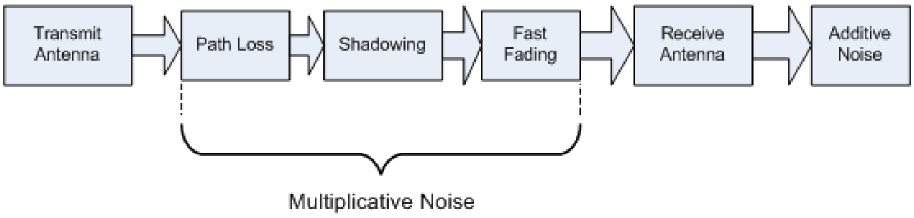


Figure 2.12: Contribution of Noise in Wireless Channel (Saunders and Aragon-Zavala, 2007)

As shown in Figure 2.4, the path-loss propagation model is critical for determining the coverage of the wireless network. Three main path-loss models are used for all wireless network research works, and they are empirical, physical and theoretical path-loss models. Among these three models, two models are related to this research, namely empirical and theoretical path-loss models. These two models are related because these models can be used to obtain the indoor coverage of the WLAN. For example, Tanghe et al. (2009) demonstrated a WLAN measurement and simulation work in an indoor factory, which it is about the utilization of a empirical and theoretical model to measure and predict the range of 802.11b and g, with path-loss, and temporal fading.

2.6.1 Empirical Path-Loss Models

Empirical models, also known as statistical models, fundamentally use experimental measurement data to produce a relationship between the propagation circumstances and expected signal