KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

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DEPARTMENT OF TELECOMMUNICATIONS ENGINEERING

STUDYING THE IMPACT OF THE ENVIRONMENT ON RADIO FREQUENCY SIGNAL QUALITY

A CASE STUDY OF KNUST WIRELESS LOCAL AREA NETWORK

SUBMITTED FOR FULFILMENT OF THE DEGREE OF MSc TELECOMMUNICATIONS ENGINEERING

BY

NGALA, DANIEL KUYOLI
(PG2653008)

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ABSTRACT

With the expansion of WLAN, and the proliferation of handheld mobile devices such as PDA, cell phones, laptops, etc there is growing interest in optimizing the WLAN infrastructure so as to increase productivity and efficiency in the various campuses, airports, hotels and other areas where access points (APs) are mostly found. This is achieved by effectively deploying APs to provide adequate signal coverage also to minimize co-channel interference and coverage overlap.

This study was conducted on the campus of Kwame Nkrumah University of Science and Technology, where received signal strength indicator (RSSI) measurements were collected from some selected APs on the campus in LOS and NLOS environment scenarios. Path loss exponents, standard deviation and root mean square error were determined for these environments scenarios using least-square regression analysis. The results were compared with those of other published results and showed good agreement. Empirical models (prediction) were derived for LOS and NLOS environments and validated by comparing them with some existing models such as COST231 Hata, Stanford University Interim and Free Space Loss model. The results from the comparison were found to be satisfactory indicating that the derived models can be used for effective deployment of wireless networks at KNUST.

Index Terms- NLOS, LOS, RSSI, Path loss exponents, environment scenario, WLAN

DECLARATION

I hereby declare that, this submission is my own work except for specific references which have been duly acknowledged, this work is the result of my own field research and it has not been submitted either in part or whole for any other degree in Kwame Nkrumah University of Science and Technology or any other educational institution elsewhere.

Signature……………………………… Date..

NGALA, Daniel Kuyoli

(Candidate)

Signature……………………………….. Date..

Dr. Kwasi DIAWUO

(Supervisor)

Signature……………………………….. Date ………………………….

Dr. P. Y. OKYERE

(Head, Department of Electrical and Electronics Engineering)

DEDICATION

This dissertation is dedicated to ALMIGHTY GOD and all the members of NGALA family

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LIST OF ABBREVIATIONS AND ACRONYM

2D	Two Dimensional
AFH	Adaptive Frequency Hopping
AP	Access Point
COST	Cooperate in Science and Technology
CPE	Customer Premise Equipment
CSMA/CA	Carrier Sense Multiple Access/ Collision Avoidance
d	Distance
d_o	Reference distance
DSSS	Direct Sequence Spread Spectrum
EDR	Enhanced Data Rate
f_c	Carrier frequency
FER	Frame Error Rate
FHSS	Frequency Hopping Spread Spectrum
FSL	Free Space Loss
GBSBM	Geometrically Based Single Bounce Macrocell
GPS	Global Position Satellite
G_r	Gain of Receiver
G_t	Gain of Transmitter
GMU	George Mason University Indoor-Outdoor Model
GUSSS	Ghana Universities Staff Superannuation Scheme
IEEE	Institute of Electrical and Electronic Engineers
Indece	Independence
ISM	Industrial, Medical and Scientific

KNUST	Kwame Nkrumah University of Science and Technology
LMDS	Local Multipoint-to-point Distribution Systems
LOS	Line of Sight
MMDS	Multipoint Microwave Distribution System
NLOS	Non line of Sight
PDA	Personal Digital Assistants
PFSL	Free Space Propagation Loss
PPDS	Point-to-Point Distribution Systems
$\mathbf{P_r}$	Received Signal Power
$\mathbf{P_t}$	Transmitted Signal Power
RF	Radio Frequency
RPG	Royal Parade Ground
RSSI	Received Signal Strength Indicator
SD	Standard Deviation
SINR	Signal to Interference and Noise Ratio
SRC	Student Representative Council
SSID	Service Set Identifier
SUI	Stanford University Interim
UHF	Ultra High Frequency
VHF	Very High Frequency
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WSSUS	Wide-Sense Stationary Uncorrelated Scattering

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CHAPTER ONE

INTRODUCTION

1.0. Introduction

Over the last few years, Wireless Local Area Networks (WLANs) have gained strong popularity in a number of vertical markets, including health-care, retail, manufacturing, warehousing, and academic areas. These industries have profited from the productivity gains of using hand-held terminals and notebook computers to transmit real time information to centralized hosts data processing [1].

Wireless communications offer users and organizations many benefits such as portability and flexibility, increase productivity, and lowers cost of installation. Wireless Local Area Network (WLAN) devices, for instance, allow users to move their mobile devices from place to place within their offices or campuses without the need for wires and also maintaining network connectivity [2]. Less wiring means greater flexibility, increase efficiency, and reduce wiring costs. Handheld devices such as Personal Digital Assistants (PDA) and cell phones allow remote users to synchronize personal databases and provide access to network services such as wireless e-mail, web browsing, and internet services [3].

Wireless Fidelity (Wi-Fi); it is also a way to connect to the internet without wires or cables. Wi-Fi technology is a set of standards for wireless local area networks based on the specifications known as the Institute of Electrical and Electronic Engineers 802.11 (IEEE 802.11), it was originally developed for use by wireless devices and local networks but it is now used for internet access as well [4].

Wireless technology in the IEEE 802.11 specification including the wireless protocols 802.11a, 802.11b, and 802.11g. The Wi-Fi Alliance was formed in 1999 as an industry consortium intended to promote the successful commercialization of 802.11 products [5]. As wireless signal traverse the path from a transmitter to a receiver, they will be diffracted, scattered, and absorbed by the terrain, trees, building, vehicles, people etc. that comprises the propagation environment [6]. The presence of obstructions along the path may cause signal to experience greater attenuation than it would under free space conditions [6]. Radio signal attenuation and path losses depend on the environment and have been recognized to be difficult to calculate and predict [2].

Past studies of the signal propagation, in both indoor and outdoor environment have used several models with varying degrees of success and or complexity, if we focus on the signals of WLANs; we have to consider the propagation environments we will run into. The quality of coverage of any wireless network design depends on the accuracy of the propagation model. For accurate design, the propagation models are estimated from signal strength measurement taken in the study area [7, 8]. This study examines how the environment affects the propagation of radio wave signal by using the measured signal data from the study area to determine propagation path loss exponents and empirical path loss models.

1.1 Aim/Objective of This Study

The main aim of this study is to investigate the impact of the environment on the signal quality in an outdoor environment. The study investigates the effect that obstructions and other interferences have on signal strength and path loss exponents, which has a relationship with the signal quality.

Received signal indicator empirical data will be taken from some selected access points at various locations on the campus of Kwame Nkrumah University of Science and Technology. Path loss exponents will be determined for these locations and based on that, propagation path loss models derived for the study area. The results of this study will be compared with existing results of other well known researchers to determine its accuracy and confidentiality.

1.2 Thesis structure

The first chapter basically introduces the study by elaborating on the aims/objectives of the study. The second chapter is the literature review which comprises of overview of related works on radio wave propagation modeling, the study of radio wave propagation and radio wave propagation modeling. Chapter three states the materials and methods used in this study such as the site description, surveying tools used and data collection procedure. The fourth chapter presents the results, analysis and discussions. Finally, chapter five comprises of the Conclusions and Recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The mean signal strength from an arbitrary transmitter-receiver (T-R) separation is useful in estimating the radio coverage of a given transmitter where as measures of signal variability are key determinants in system design issues such as antenna diversity and signal coding. In order to accurately estimate the spatial separation between transmitter and receiver, a propagation model must be used that is suitable to a specific operational environment. Radio propagation models are empirical in nature; they are developed based on large collections of data for the specific scenario. Like all empirical models, radio propagation models do not point out the exact behavior of a channel, rather they predict the most expected behavior the channel my exhibit under specified conditions [9].

In this chapter, a comprehensive review on the literature in the areas of related works on radio wave propagation modeling, radio wave propagation and a review of some known propagation models are presented.

2.1 Related Works on Radio Wave Propagation Modeling

The field of modeling radio wave propagation has been studied by many researchers, organizations and academic institutions [10-25]. In 1945, Herald T. Friis [10], a Danish-American radio engineer, one of the pioneers of radio wave propagation modeling derived a formula known as the transmission equation which is used in telecommunications engineering to predict the power received by a receiving antenna under idealized conditions given the transmitting antenna some distance away, and transmitting a known amount of power. This model can be used in a clear line-of-sight microwave link and also in satellite communication. In 1957, John Egli [11] introduced the Egli model, which is a terrain model for radio propagation. This model was derived from real-world data on ultra high frequency (UHF) and very high frequency (VHF) television transmission in several large cities; it is used to predict the total path loss for a point-to-point link. Okumura *et al*. in 1968 came out with prediction curves based on propagation measurement conducted in Kanto (near Tokyo), Japan [12]. This model presents signal strength prediction curves over distance in a quasi-smooth urban area (terrain undulation is less than 20m). In order to predict other types of area classifications, correction factors for suburban and open areas are given. Okumura *et al*. also provided correction factors for various terrain irregularities such as sloped terrain, hilly terrain, mixed land-sea path, and diffraction by ridges and mountains. In using Okumura prediction model, radio transmission parameters such as base station antenna height, terrain undulation height, slope, etc. must be determined according to [12]. Hata [13] in 1980 developed a mathematical formulation from Okumura prediction curves in order to obtain simple computational applications. Therefore, this model is then called Okumura-Hata model, it was developed based on the frequency 150 MHz to 1500 MHz [14]. Some research was also done by Cooperate in Science and Technology (COST) 231 group in the early 1990's [15], where the group took some measurements from some European cities and came out with a number of well-validated models from their measurements. COST-231 Hata model [15] was devised as an extension to the Hata-Okumura model. The COST-231 Hata is widely used for predicting path loss in mobile wireless system, it is designed to be used in the frequency band from 1500 MHz to 2000 MHz, and it also contains corrections for urban suburban and rural (flat) environments. In recent developments, Chen and Kobayashi in 2002 proposed a linear regression approach to determine the parameters of wave propagation models for WLANs based on the measured signal strengths at test points. The fitted regression model is used to estimate signal strengths for unknown points. Chen and Kobayashi [16] reported that, the quality of the estimation depends on the underlying wave propagation model. George Mason University (GMU) during the fall of 2007, developed an indoor-outdoor model in their campus in order to describe 802.11 b/g path losses between an outdoor receiver and indoor transmitter, with each located at a roughly ground level, measurements were taken with indoor transmitters and outdoor receivers and path losses obtained from their measurements [9].

Another major contribution to indoor propagation originates from the research of Smulders conducted at Eindhoven University of Technology in 1995 [17]. Other works in indoor channels are found in [18,19, 20]; however, other literature on outdoor channels are presented in [21,22, 23].

2.2 Radio Wave Propagation

Radio wave propagation as defined in [24], is the behavior of radio waves when they are transmitted or propagated from one point of the earth to another or various parts of the atmosphere. An understanding of radio propagation is essential for coming up with appropriate design, deployment, and management strategies for wireless networks. In effect, it is the nature of radio channel that makes wireless networks more complicated than their counterparts wired networks. Radio propagation is heavily site-specific [25] and can vary significantly depending on the terrain, frequency of operation, velocity of mobile device, interferences and other dynamic factors. Accurate characterization of the radio channel through key parameters and mathematical model is important for the predicting signal coverage, analysis of interference from different systems, and determining the optimum location for installing base station antennas [26].

2.2.1 Radio Wave Propagation Mechanisms

Reflection, diffraction, and scattering are the basic propagation mechanisms in wireless communication systems. These mechanisms cause radio signal to distort and give rise to signal fading, as well as additional propagation losses. The **Figure 2-1:** shows an illustration of reflection, diffraction, and scattering.

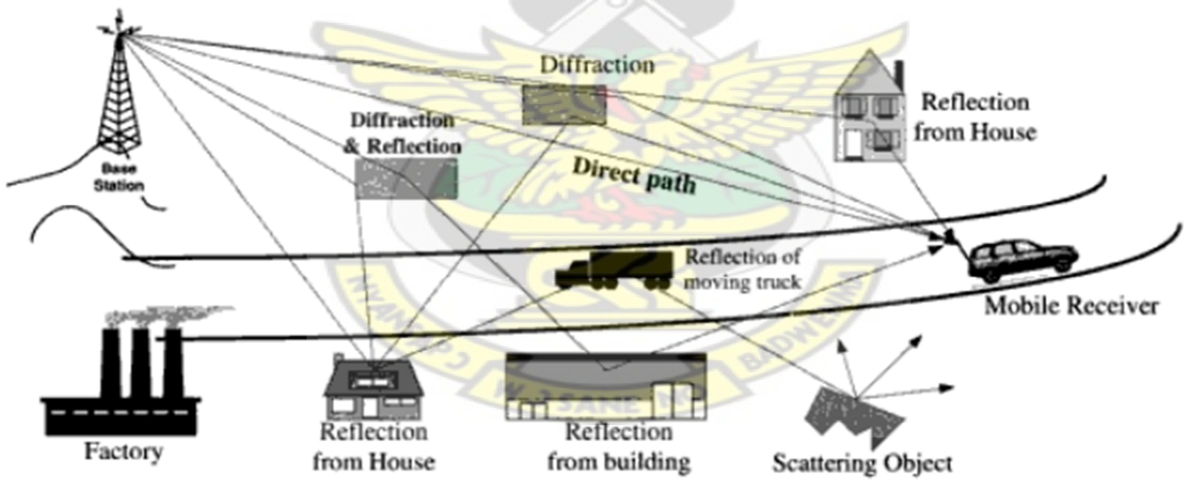

Figure 2-1: Illustration of reflection, diffraction, and scattering

2.2.1.1 ***Reflection:***

Reflection occurs when a propagating electromagnetic wave impinges upon an object that has very large dimensions compared to the wavelength of the propagating wave. Some of the reflected waves may also be partially refracted. The coefficients of reflection and refraction are functions of the properties of the materials of the medium, and generally depend on the wave polarization, angle of incidence and frequency of the propagating wave [27].

2.2.1.2 ***Diffraction:***

Diffraction is the bending and spreading of electromagnetic wave when it encounters an obstruction [24]. When the wave impinges upon some obstructions along their path, they tend to propagate around the corners, edges and behind the obstructions [28]. In many practical situations, propagation path may consist of more than one obstruction. Hence, Bullington's method [29] focused on the part of the field that is created by diffraction can be written as the product of the incident field with a phase factor. In Epstein-Peterson method [29], they suggested that line-of-sight be drawn between relevant obstacles and diffraction losses at each obstacle be added. Deyout's method [30] also focused on calculating the main edges determine by the isolated terrain features producing the greatest diffraction loss in the absence of other features between transmitting and receiving antennas. Also, Eibert *et al*. [31] combined the results of empirical models with their own measurements results and applied a modified diffraction algorithm in order to obtain a good radio propagation prediction with very low consumption of computational resources [31].

2.2.1.3 ***Scattering:***

Scattering is the phenomenon where by the energy of an electromagnetic wave is distributed in a propagation medium along several directions after meeting a rough surface or heterogeneities with small dimensions compared to the wavelength of the electromagnetic wave [32]. Scattering can happen in two ways. The first type of scattering is on small level and has a lesser effect on the signal quality and strength. This type of scattering may manifest itself when electromagnetic wave propagates through a substance and the individual electromagnetic waves are reflected off the minute particles within the medium. Smog in our atmosphere and sandstones in the desert can cause this type of scattering. The second type of scattering occurs when an electromagnetic wave encounters some type of uneven surface and is reflected into multiple directions. Chain like fences, tree foliage, and rocky terrain commonly cause this type of scattering [33].

2.2.2 **Multipath Fading**

The collective effect of reflection, refraction, diffraction and scattering leads to multipath propagation [34]. In most radio channels, the transmitted signal arrives at the receiver from various directions over a multiplicity of paths. The phase and amplitude of a signal arriving on each different path are related to the path length and conditions of the path. Yuhao *et al.* [35] in their studies in 2005 characterized multipath fading channel dynamics at the packet level and analyzed the corresponding data queuing performance in various environments.

Li Sun *et al.* [36] established a nonlinear dynamic model for multipath fading channels, their studies in 2007 was based on the nonlinear dynamical properties of wireless mobile communication channel; they used chaos and fractal theory. Hence, in order to be able to assess the performance capabilities of various wireless systems, root mean square (rms) delay spread is a good measure to grossly quantify the different multipath channels. The equation for rms delay spread (σ) used is given in **Equation 2.1**

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2} \qquad (2.1)$$

With mean excess delay($\bar{\tau}$)

$$\bar{\tau} = \frac{\sum_K P(\tau_K)\tau_K}{\sum_K P(\tau_K)} \qquad (2.2)$$

and

$$\overline{\tau^2} = \frac{\sum_K P(\tau_K)\tau_K{}^2}{\sum_K P(\tau_K)} \qquad (2.3)$$

Where $P(\tau)$ is the relative amplitude of the multipath components and is the time delay during multipath energy fall.

In outdoor environment, multipath can be caused by a flat road, large body water, building, trees or atmospheric conditions. Therefore, we have signals bouncing and bending in many different directions. The principal signal will still travel to the receiving antenna, but many of the bouncing and bent signals may also find their way to the receiving antenna via different paths [34].

2.3 Radio Interference in Wireless Local Area Network

Different wireless systems sharing the same frequency band and operating in the same environment are likely to interfere with each other and experience a severe decrease in throughput [33]. Studies conducted by Farpoint Group [37] in 2007 showed that, interference from microwave oven can reduce WLAN throughput of more than *62%*, about *89%* from another interfering WLAN and *20%* from interfering Bluetooth device. However, the use of unlicensed bands facilitates spectrum sharing and allowing for an open access to the wireless medium, but causes mutual interference between different radio systems and making spectrum utilization inefficient [36]. The main types of interference in WLAN are adjacent and co-channel interference, and Wireless Local Area Network (WLAN)/ Wireless Personal Area Network (WPAN) coexistence.

2.3.1 Adjacent and Co-channel Interference

Adjacent and Co-channel interference occurs when two or more RF signals interacting with each other and causing a degradation of performance [38]. Co-channel interference is caused by undesired transmissions carried out on the same frequency channel; and adjacent channel or partially overlapped channels [39]. The way nodes of a WLAN share the medium is similar to an Ethernet segment. A carrier sense multiple access with collision avoidance (CSM/CA) is used as medium access control scheme. Nodes sense the air interface before transmitting a frame, if the receiver is busy, the transmitting node will wait until the receiver is free before transmitting the frame. This makes the study of interferences in IEEE 802.11 WLANs quite different from what is done in other radio networks due to the particular influence of interferences produced by cells using the same channel (co-channel interference) in a cell suffering only from co-channel interference, even though there is no traffic on it [40]. The presence of adjacent channel interference reduces the effective Signal to Interference and Noise Ratio (SINR) and therefore, the number of errors in reception is increased. Communications in the unlicensed Industrial, Medical and Scientific (ISM) bands needs to implement spread spectrum techniques and limit their transmission power in order to minimize the impact of interference with other devices [41, 42]. Once spread, the resulting signal occupies a bandwidth of about *20MHz.* In addition, the signal available channels are defined with *5MHz* separation between consecutive carriers. There should be at least five channel of separation to guarantee that two simultaneous transmissions do not interfere with each other. Previous empirical studies showed that a separation of four channels can be used without reducing the performance of network [42], so possibilities could be opened to channel *1, 5,9* and *13* (where applicable) instead of the traditional channels *1,6* and *11.* The idea of using all available channels appears in [44] for the first time. Some studies have been done [45] to present an analytical study on the effects of adjacent channel interference in IEEE802.11 abg WLANs which is supported by practical measurements and simulations. The results provided are intended to assist different radio resource management mechanisms by providing hints on the use of partially overlapped channels, similar studies focused on Direct Sequence Spread Spectrum (DSSS) have been previously published in [46,47].

2.3.2 WLAN/WPAN Coexistence

Wireless Personal Area Networks (WPANs) typically consist of portable devices such as personal digital assistants (PDA), cell phones, headsets, computer keyboards, and mice. The performance of IEEE 802.11 wireless LANs can be affected when co-located with WPAN devices. The IEEE 802.15 standard addresses WPANs and includes Bluetooth and Zigbee networks. Bluetooth is one of the most popular WPAN network technologies and operates in the

2.4GHz ISM band using frequency hopping spread spectrum (FHSS) [38]. Early versions (v1.0 and v1.1) of Bluetooth devices can cause significant interference while operating in close proximity of IEEE 802.11 wireless LANs. Bluetooth was designed to hop at a rate of *1600* times per second across the entire *2.4GHz* band, potentially causing significant interference with IEEE 802.11 wireless networks. Newer versions (v1.2, v2.0+EDR and v2.1+EDR) of Bluetooth use Adaptive Frequency Hopping (AFH) and thus are less likely to interfere with IEEE 802.11 wireless networks, even though they still operate in the *2.4GHz* band. Devices that use adaptive frequency hopping will try to avoid using the same frequencies, decreasing the chance of interference. Since these devices operate in small, close-range, peer-to-peer networks [38]. Several researchers addressed radio interference effect in the context of short-range wireless networks. Crossbow Technology Inc, [48] and Steibei-Transfer Center [49] independently conducted experiments to measure the effect of interference on IEEE 802.15.4, the technical documents [48] from Crossbow Technology Inc. describes measurement results showing that the packet delivery rate in a MicaZ Mote sensor network is dropped significantly by the interference with 802.11b WLAN when they use closely located radio channels. The Steibeis-Transfer Center [49] also conducted a measurement study using commercial devices. According to the study, the radio interference effect of IEEE 802.11b can cause significant performance degradation to IEEE 802.15.4. Howit [50] analyzed the radio interference of IEEE 802.15.4 on IEEE 802.11b. Howit used both analysis and measurement to prove that the IEEE 802.15.4 has little or no effect on IEEE 802.11b performance and thus the coexistence of IEEE 802.15.4 and IEEE 802.11 needs to be approached to protect IEEE 802.15.4. Howit [51] studied the effect of interference using experiments and analytical models. The experiment intended to evaluate the impact of the interference between Bluetooth and IEEE 802.11b. Howit also built analytical models for the interference caused by IEEE 802.11b on Bluetooth and for the interference caused by Bluetooth on IEEE 802.11b. Goldmie [52] proposed a dynamic scheduling algorithm for Bluetooth to relieve the radio interference effect between Bluetooth and WLAN. The dynamic scheduling algorithm extends the Bluetooth channel hopping mechanism in a dynamic way such that devices in the network maximize their throughput and get the fairness of access.

2.4 Radio Propagation Modeling

Radio propagation model is an empirical mathematical formulation for the characterization of radio wave propagation as a function of frequency, distance, and other dynamic factors. A single model is usually developed to predict the behaviour of propagation for all similar links under similar constraints. Propagation models are developed with the goal of formalizing the way radio waves propagate from one place to another, such models typically predict the path loss along a link or the effective coverage area of the transmitter. According to Rappaport and Sandhu [38] propagation models are not only needed for installation guidelines, but they are a key part of any analysis or design that strives to mitigate interference. Hence, propagation models can be categorized into three types, empirical models, deterministic models and theoretical models.

2.4.1 Empirical Model

Empirical models use experimental data and observations alone to predict loss [53]. Empirical models can be split into two subcategories, time dispersive and non-time dispersive [54]. The time dispersive model provides us with information about time dispersive characteristics of the channel like delay spread of the channel during multipath. The Stanford University Interim (SUI) model [54] is the perfect example of this type. COST 231 Hata model, Hata and ITU-R [54] model are example of non-time dispersive empirical model.

2.4.2 Deterministic or Physical Models

Deterministic models make use of the laws governing electromagnetic wave propagation in order to determine the received signal power in a particular location [55]. These models rely on basic principle of physics rather than statistical outcomes from the experiments. Deterministic models are also known as physical channel models; they are either site specific or not site specific. A physical not specific model uses physical principles of electromagnetic waves propagation to predict signal levels in a generic environment in order to develop a simple relationship between the characteristics of that environment and propagation. An example is the model developed by W. Ikegami and H. L. Bertoni for radio systems in urban areas [56]. In other hand, a physical and site specific model uses the physical law of electromagnetic wave propagation and a systematic technique for mapping the real propagation environment into the model propagation environment. Epstein-Peterson method, Deygout method, Longley Rice model and Anderson two dimensional (2D) model which only predict signal attenuation over terrain, and ray tracing model which provides time dispersion information and angle of arrival information are examples of physical and site specific channel model [57].

2.4.3 Theoretical models

Theoretical models are based on theoretical assumptions about the propagation environments. The channel parameters based on these model assumptions do not defined any particular environment or model any specific channel conditions. The theoretical models can not be used for planning and developing any communication systems as they do not reflect the exact propagation medium the signal will be experiencing. The Geometrically Based Single Bounce Macrocell (GBSBM) channel model by Petrus et al [58] and Quasai-Wide- Sense Stationary Uncorrelated Scattering (Quasai-WSSUS) channel model by Bello [59] are examples of theoretical models.

2.4.3.1 Free Space Propagation Model

Free space propagation model is used to predict the signal strength at a distance from the receiver when there is no obstruction between the transmitter and the receiver. It is the foundation for all other models. It is derived from Friis's free space equation given in **Equation 2.4.**

$$P_{r} = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \qquad (2.4)$$

The equation of path loss for Friis space model, is written as

$$P_{FSL} = \frac{P_t}{P_r} = \frac{1}{G_t G_r}\left(\frac{4\pi d}{\lambda}\right)^2 \qquad (2.5)$$

For λ = wavelength = $\frac{c}{f}$, c = speed of light ($3 * 10^8$ m/s)

Equation 2.5 can be simplified into **Equation 2.6**

$$P_{FSL}\,(dB) = 32.45 - 10logGt - 10logGr + 20logf + 20logd \qquad (2.6)$$

where

P_r = received power

P_t = transmitted power

f = carrier frequency in MHz

G_t = gain of the transmitter

G_r = gain of the receiver

d = antenna separation distance in kilometers

P_{FSL} = free space path loss

Equations 2.5 and **2.6** indicate that free space path loss is frequency dependence and is increasing against distance. The free space attenuation increases by *6dB* whenever the length of the path or the frequency is doubled [60].

This shows the classic square-law loss of signal energy as it propagates. It has been shown to be a good approximation of distance dependant loss in a wireless system [60]. To simplify this equation, we will reduce the distance and frequency units by a factor of 10^3 so the equation becomes:

$$P_{FSL}\,(dB) = 32.45 + 20log_{10}d + 20log_{10}f \qquad (2.7)$$

For *2.4GHz* WLAN systems, the **Equation 2.7** for free space loss using the distance in meters can be simplified to become [48]:

$$P_{FSL}(dB) = 40 + 20log_{10}d \qquad (2.8)$$

The frequency dependant portion of the equation can be explained since the path loss increase as a square of the frequency. The effective aperture of a ¼ wavelength isotropic antenna commonly used in WLAN systems varies inversely to frequency. Therefore, if we double the frequency, the linear size of the antenna decreases by one-half and the capture area by a factor one-quarter [60].

2.4.3.2 Hata Model

The Hata model is used to predict the path loss for cellular application in urban environments where diffraction and multipath fading are common **Equation 2.9** shows the standard equation for the average path loss in an urban environment, where *fc* is given in *MHz*. Transmitter-receiver separation d and transmitter height ht are both given in meters. α(hr) is the correction factor for receiver antenna height and is shown in **Equation 2.10**

$$PL(urban) = 69.55 + 26.16\log(fc) - 13.82\log(ht) - \alpha(hr) + (44.655\log(ht))\log(d) \qquad (2.9)$$

$$\alpha(hr) = 3.2(\log(11.75hr))^2 - 4.97 \qquad (2.10)$$

The Hata model also provides modifications to **Equation 2.9** in order to include suburban and rural areas, shown in **Equation 2.11** and **Equation 2.12**

$$PL(suburban = PL(urban) - 2\left[\log\left(\frac{fc}{28}\right)\right]^2 - 5.4 \qquad (2.11)$$

$$PL(rural) = PL(urban) - 4.78(\log(fc))^2 + 18.33\log(fc) - 40.96 \qquad (2.12)$$

For these models, the antenna height correction factor α(hr) is also modified in **Equation 2.13**

$$\alpha(hr) = (1.1logfc - 0.7)hr - (1.5logfc - 0.8) \qquad (2.13)$$

This model is valid for the following constraints:

fc : 150 MHz – 1500 MHz

hr: 1m – 10m

ht: 30m – 200m

d: 1Km – 20Km

However, these constraints are not met by IEEE 802.11 b/g network since they operates at *2.4GHz*, which exceeds the *1500MHz* limit of the Hata model and the receiver antenna height is below the 30m minimum height of the Hata model [13][9]. These constraints make this model not appropriate for this study.

2.4.3.3 Cooperate In Science and Technology (COST) 231 MODEL

The COST 231 model was developed as an extension to the Hata model in order to extend its frequency range to *1500MHz* to *2000MHz*, which is used in personal communication systems (PCS). The formula for this model is in **Equation 2.14**, where the equation for receiver antenna height correction α(hr) from the Hata model is used. The environment correction factor C_M is 0dB for suburban and rural areas and 3dB for urban areas. The same constraints apply to this model as the Hata model, except for the change in frequency [16].

.

$$PL = 46.3 + 33.9\log(fc) - 13.82\log(ht) - \alpha(hr) + (44.9 - 6.55\log(ht))\log(d) + C_M \tag{2.14}$$

Although the frequency constraint for COST 231 is relatively close to what is used by IEEE 802.11 b/g networks, a large difference still remains between the recommended antenna height and the antenna heights used in this study [14][9].

2.4.3.4 Stanford University Interim (SUI) Model

The proposed standards for the frequency bands below *11GHz* contain the channel models developed by Stanford University, namely the SUI models. Note that these models are defined for the Multipoint Microwave Distribution System (MMDS) frequency band which is from *2.5 GHz* to *2.7GHz.* This makes SUI a good candidate for use with IEEE 802.11b/g networks, their applicability to the *3.5GHz* frequency band that is in use in the United Kingdom (UK) has so far not been clearly established [54]. The SUI models are divided into three types of terrains, namely Type A, Type B and Type C. Type A is associated with minimum path loss and applies to flat terrain with light tree densities. Type B is characterized with either mostly flat terrain with moderate to heavy tree densities or hilly with light tree densities. The basic path loss equation with correction factors is presented in [61] [62].

$$PL = A + 10\gamma \log\left(\frac{d}{d_o}\right) + X_f + X_h + S\,,\ for\ d > d_0 \qquad (2.15)$$

Where, d is the distance between the Access Points (AP) and the Customer Premises Equipment (CPE) antennas in meters, *do* = 100 m and *S* is a log normally distributed factor that is used to account for the shadow fading owing to trees and other cluster and has a value between 8.2dB and 10.6dB [61]. The other parameters are defined as,

$$A = 20log_{10}\left(\frac{4\pi do}{\lambda}\right) \qquad (2.16)$$

$$\gamma = a - bh_b + \frac{c}{h_b} \tag{2.17}$$

Where, the parameters h_b is the base station height above ground in meters and should be between *10m* and *80m*. The constants used for a, b and c is given in **Table 2-1**. The parameter γ in **Equation 2.17** is equal to the path loss exponent. For a given terrain type the path loss exponent is determined by h_b.

Table 2-1: The Parameters of SUI Model in different types of environments

Model Parameters	**Terrain Type A**	**Terrain Type B**	**Terrain Type C**
a	4.6	4	3.6
b (m^{-1})	0.0075	0.0065	0.005
c (m)	12.6	17.1	20

The correction factors for the operating frequency and for the CPE antenna height for the model are [61] [54].

$$X_f = 6.0 log_{10}(\frac{f}{2000}) \tag{2.18}$$

and

$$X_h = -10.8 log_{10}\left(\frac{h_r}{2000}\right) \quad , for\ Terrain\ types\ A\ and\ B \tag{2.19}$$

$$= -20.0 log_{10}\left(\frac{h_r}{2000}\right) \quad , for\ Terrain\ type\ C \tag{2.20}$$

Where, *f* is the frequency in *MHz* and *hr* is the CPE antenna height above ground in meters. The SUI model is used to predict the path loss in all three environments, namely rural, suburban and urban. Although the frequency range for the SUI model is a close match for IEEE 802.11b/g, the model exhibits unexpected behavior when the transmit antenna height is below the recommended value [9], and therefore makes this model not suitable for this study.

2.4.3.5 George Mason University (GMU) Indoor-Outdoor Model

The GMU model [18] was created on campus at George Mason University during fall of 2007. It was produced in order to describe 802.11 b/g path losses between an outdoor receiver and indoor transmitter, which each located at roughly ground level. The collection site consisted of a mixture of parking lots, multi-story brick building, and lawn areas with light foliage. Suburban would be the best environment classification for the collection site. An AP was placed in an office with three or more cinder block walls separating it from the outdoors. The result was a modification to the COST 231 model **Equation 2.21** [14], with the adjusted values highlighted in **Equation 2.22.** The GMU model was created using *hr = 1.7m* and *ht = 0.7m* [9].

$$PL(COST231) = 46.3 + 33.9\log(fc) - 13.821\log(ht) - \alpha(hr) + (44.9 - 6.55\log(ht))\log(d) + C_M \quad (2.21)$$

$$PL(GMU) = 23 + 33.9\log(fc) - 13.82\log(ht) - \alpha(hr) + (22.655\log(ht))\log(d) \quad (2.22)$$

In this study, the transmitting antennas were located outdoor making this model not suitable for this study. The indoor location of the transmitter for this model is a constraint to the study.

2.4.3.6 Log-distance Path Loss Propagation Model

In both indoor and outdoor environments, the average path loss for an arbitrary Transmitter-Receiver (T-R) separation is expressed as a function distance by using a path loss exponent, *n*. [63,64,65]. The average path loss *PL(d)* for a transmitter and a receiver d is

$$PL(d) \propto (\frac{d}{d_o})^n \qquad (2.23)$$

Where d is the distance between transmitter and receiver, do is a reference distance (typically assumed to be 1m) and *n* is the attenuation factor. From this relationship the path loss function, in dB is defined by:

$$PL(d)[dB] = PL(d_o)[dB] + 10nlog\left(\frac{d}{d_o}\right) \qquad (2.24)$$

Equation 2.25 indicates that the path loss at a given distance d is the sum of the path loss observed at a reference distance d_o and the additional loss imposed by **Equation 2.24.** The attenuation factor *n* is found experimentally.

Log-distance path loss propagation model with shadow fading is given by

$$PL(d)[dB] = PL(d_o)[dB] + 10nlog\left(\frac{d}{d_o}\right) + S \qquad (2.25)$$

where:

n is path loss exponent with values between *2* to *4*, d is the distance between the mobile node and WLAN access point (AP) and S represents shadow fading modeled as Gaussian with mean $\mu = 0$ and standard deviation σ with values between *6* and *12dB* depending on the environment [51]. This model was used in this study.

The majority of RSSI localization algorithms that do not use full location profiling of the deployment environment make use of a signal propagation model that maps RSSI values to a distance estimate [66].

$$RSSI\ (d) = P_T - P_L(d)[dB] \tag{2.26}$$

where

RSSI are the measured data against distance at the various locations.

P_L *(d) [dB]* is the Log-distance propagation path loss, and

$P_T = 10 * \mathrm{Log}(\mathrm{P_t}(\mathrm{W_m}))$ With P_t as the transmitted power of 1W

P_T is the transmitter power in milliwatts.

P_L *(d) [dB]* is Log-distance path loss model with shadow fading.

Figure 2-5 illustrates the ratio of the received-to-transmit power in decibels *(dB)* versus log distance for the combined effects of path loss, shadowing, and multipath [26].

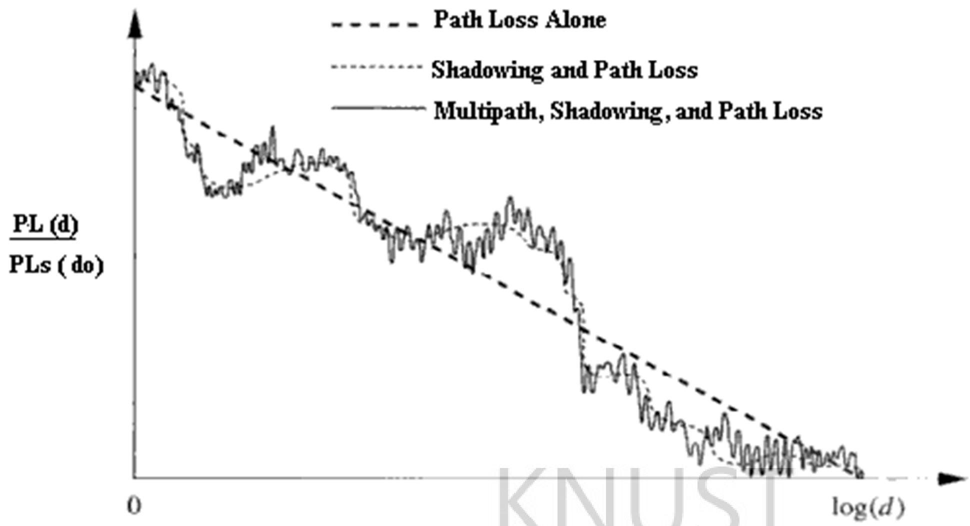

Figure 2-2: Path loss, shadowing, and multipath versus distance

2.5 Path Loss Exponents

Path loss exponents vary widely across propagation environments [67]. Therefore the bound on the hop distance and number is different for different types of propagation domains. For log-distance coverage the exponents for outdoor environments is around 4 except in non-line-of-sight situations when it could be bigger than *4*. **Table 2-2** provides typical values of *n* under different environments. The value of the path loss exponent is an indicator of how fast energy is lost between transmitter and receiver. $n < 2$ is a measure of the guiding effect of the channel and when $n > 2$ the channel is considered to be scattering energy [68].

Table 2-2: Path loss exponents' n for Different Environments [68]

Environment	Path loss exponent (n)
Free Space	2
Urban	4.2
Log-normally shadowing area	2 to 4
Shadowed Urban	3- 5
In building LOS	1.6 - 1.8
Obstructed in building	4 – 6
Obstructed factory	2 – 3

2.6 Conclusion

In this chapter, a comprehensive and unbiased review on literature in the areas of radio wave propagation modeling and radio wave propagation were provided, where theoretical and methodological contributions of other researchers in the areas of radio wave propagation and propagation modeling discussed critically.

CHAPTER THREE

MATRIALS AND METHODS

3.0 Introduction

Several methods and materials are employed in taking data from an access point or a base station, such methods includes drive test, RF survey etc. The method used depends greatly on the network coverage size and the size of the study area. For this study, the method of RF survey was employed and this chapter basically states the materials and methods used to accomplish this study.

3.1 Description of the study area

The scope of this study is limited to the campus of Kwame Nkrumah University of Science and Technology (KNUST), the university covers an area approximately sixteen square-kilometer of undulating land, about seven kilometers away from the city of Kumasi in the Ashanti region of Ghana. The majority of its area has a significant green-space with a lot of trees and other vegetation more than what is suppose to be in the average urban area. The access points (APs) used in this study are herein referenced with respect to which campus building they were mounted on, namely Africa Hall's Wi-Fi, Republic Hall's Wi-Fi, Independence Hall's Wi-Fi, Queens Hall's Wi-Fi, Royal Parade Ground's (RPG) Wi-Fi, University Hall's Wi-Fi, Unity Hall's Wi-Fi, Student Representative Council (SRC) Hostel's Wi-Fi, Postgraduates Hostel's Wi-Fi and Ghana Universities Staff Superannuation Scheme (GUSSS1) Hostel's Wi-Fi. These APs were chosen because of availability of their hardware specifications and configuration.

3.2 Radio Frequency Site Survey

A radio frequency (RF) site survey is the first step in the deployment of a Wireless network and the most important step to ensure desired operation. A site survey is a task-by-task process by which the surveyor studies the facility to understand the RF behavior, discovers RF coverage areas, checks for RF interference and determines the appropriate placement of Wireless devices. There is no substitute for measuring real-world interference, blockage and Received Signal Strength Indicator (RSSI) at a site, only on-site measurements and surveys can give the complete picture. RF site survey is conducted using surveying tools that enable data to be collected from a base station or an access point, example of such data is the received signal strength indicator.

3.2.1 Surveying Tools

In surveying, generally wireless sniffing tools are used to sniff wireless packets from an ad-hoc or infrastructure network setup using an access point. The software and hardware equipments used in this study are presented with their specification.

Software:

- Network stumbler version 0.4.0
- Matlab version 7 (R14)
- Microsoft windows xp professional

Hardware Equipments and Specifications

- Laptop
  - Vendor: Acer
  - Model: TravelMate 2420
  - CPU: 1.5GHz
  - Memory: 512MB
  - Wireless Card: Intel PRO/wireless 2200BG
- IEEE 802.11b/g Access Point
  - Vendor: Mikrotik
  - Model:133C
  - Transmitter Power 1W
  - Frequency Range: 2.4GHz to 2.4835GHz
- External Antenna:
  - Vendor: HyperGain
  - Model: HG2412U
  - Type: Omnidirectional
  - Gain: 12dBi
  - Operating Frequency: 2.4GHz to 2.5GHz.
  - Polarization: Vertical.
- Global Positioning Satellite (GPS)
  - Vendor: Magellan
  - Model: eXplorist 500
- 25-foot measuring tape.

3.3 Data Collection Methods

An Acer laptop equipped with a wireless card, running on Microsoft windows XP platform with netstumbler software installed was used to collect Received Signal Strength Indicator (RSSI) data from the selected APs at different locations on the campus of KNUST. The software observed the following privacy guide lines during data collection:

- No attempt is made by netstumbler software to gain access to the network.
- Access Points are detected only if they are publicly broadcasting their service set identifier (SSID), or the client card is configured to look for that specific SSID.
- Other traffic on the network is not intercepted or analyzed in any way.

Ten (10) APs were selected on Kwame Nkrumah University of Science (KNUST) Campus at different locations (Appendix A gives the information about the locations); the selected APs were from the same vendor and had the same technical specifications and operate using IEEE 802.11 b/g standard. At each AP, a straight path was mark-out at different directions from the AP to the mobile receiver (laptop) to cover for both main and side loops of the radiating antenna. On each of these paths, test points were manually measured at a 10m interval using a measuring tape measuring to a 100m mark from the AP. *60* samples of measured data of RSSI were taken randomly in 120 seconds at each 10m mark. Figure 3.1 shows a snap shot of network stumbler taken during data collection at independence hall AP.

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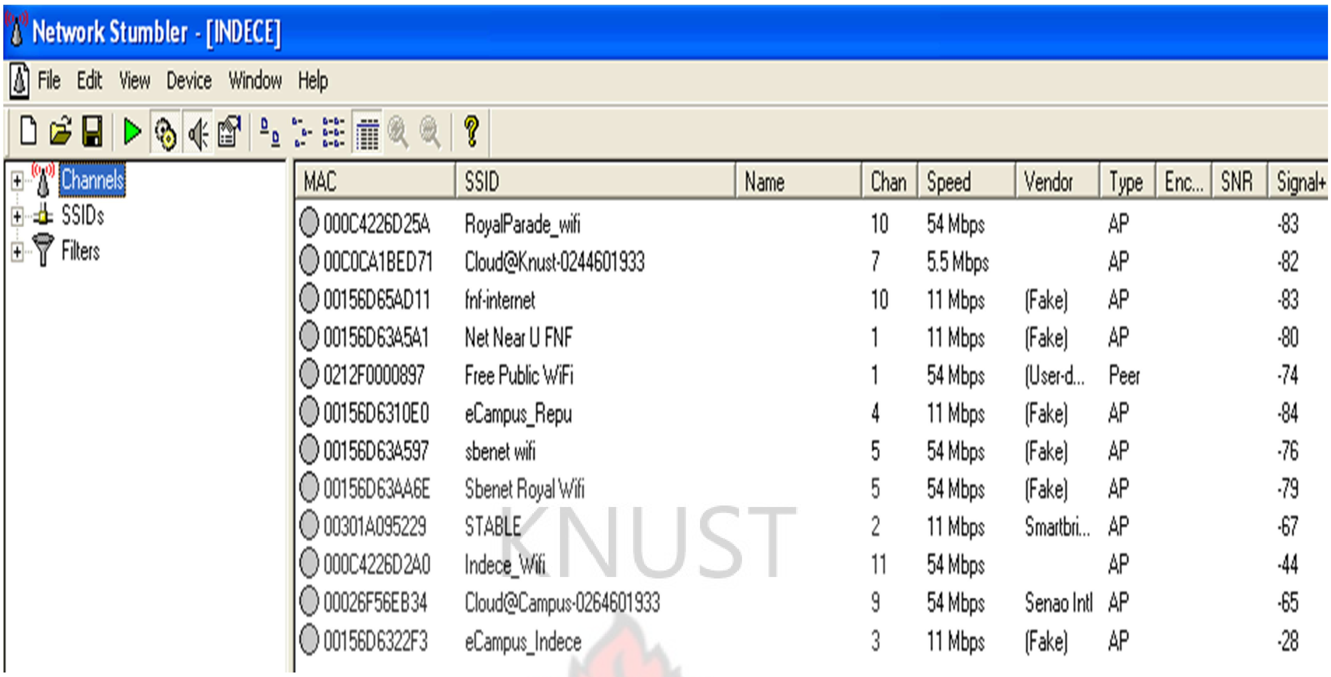

Figure 3-1: A snap shot of netstumbler software taken during data collection

3.3.1 Data Collection Procedure for a Line Of Sight (LOS) Environment Scenario

In a LOS environment scenario, the receiving antenna was visible to the transmitting antenna without or with very minimal obstruction. The sources of attenuations were basically from the movement of people and vehicles across the transmission path and attenuation due to the author’s body. Since the human body is made of about *70%* water, it absorbs some amount of signal thereby causing attenuation. Signal data with corresponding distances from the APs were measured, and at each measured distance, several values of RSSI were collected. The APs considered to be in a LOS environment scenario are: Africa Hall’s Wi-Fi, Republic Hall’s Wi-Fi, Independence Hall’s Wi-Fi, Queens Hall’s Wi-Fi and Royal Parade Ground’s Wi-Fi.

3.3.2 **Data Collection Procedure for a Non-Line of Sight (NLOS) Environment Scenario**

For NLOS environment scenario, there was no visual line of sight between the receiving and the transmitting antennas, the radio transmission path was partially or fully obstructed by the presence of physical objects such as buildings, trees, hills, human beings, vehicles etc., these objects causes signal attenuation by way of absorption, reflection, scattering, diffraction etc. RSSI values were collected from five selected APs on KNUST campus at measured distances from the APs in a NLOS environment scenario.

The APs are that were considered to be in a NLOS environment scenario are: University Hall's Wi-Fi, Unity Hall's Wi-Fi, GUSSS1 Hostel's Wi-Fi, SRC Hostel's Wi-Fi and Postgraduate Hostel's Wi-Fi.

3.4 Precautions Taken During Data Collection

The following precautions were taken to minimize errors during the data collection

- Data was collected during lecture hours (between 10 am to 12 pm and 2 pm to 4 pm) from Monday to Friday, were most students were having lectures; this is to minimize attenuation due to movement of people and vehicles.
- The laptop has an internal antenna located behind the screen, so the screen of the laptop was oriented toward the zenith sky in order to increase the likelihood that the direct-rays signal path falls within the half-power beamwidth of the antenna.

3.5 Conclusion

This chapter stated the methods and tools used to accomplish this study with detailed equipment specifications given; it also underlined the assumptions and precautions taken during the study. The method of RF survey which was employed in the collection of received signal strength indicator data from the selected access points and environment characteristics were also explained.

CHAPTER FOUR

RESULTS, DISCUSSION AND ANALYSIS

4.0 Introduction

In the study of data wireless communication networks, the path loss exponent is the main parameter of interest in path loss empirical models which depends on the environment. The higher the path loss exponent, the faster the signal strength drops with respect to distance, therefore in modeling the propagation of signal for a particular environment, there is the need to determine the path loss exponents for that environment. This chapter present results, discussion and analysis of data collected on received signal strength indicator from the study area. It also illustrates how the least-square regression analysis can be used to determine the propagation path loss exponents and also the mean path loss models.

4.1 PRESENTATION OF RESULTS

Table 4-1 presents the results of measurement of signal strength ranges and their corresponding signal quality from Netstumbler software.

Table 4-1: RSSI Measurement Survey.

Signal Strength Range (dBm)	Signal Quality
-60 ≤ RSSI ≤-20	Excellent Signal
-75 ≤ RSSI ≤ -60	Good Signal
-85 ≤ RSSI ≤ -75	Low Signal
-90 ≤ RSSI ≤ -85	Very Low Signal
-90 ≤ RSSI ≤-108	No Signal

A mobile user with signal strength within the ranges of *-60dBm* to *-20dBm* will experience an excellent signal quality, thus the mobile user will experience optimum radio transmission and signal reception which will support very high data rates with very low error rates and packets retransmission. For mobile users with signal strength between *-75dBm* to *-60dBm* will experience good signal quality indicating that the mobile user's current location provides adequate radio transmission and reception to support high data rates communications with low rate of errors and packets retransmission. A mobile user with signal strength between the ranges of *-85dBm* to *-75dBm* will experience low signal strength indicating they will experience high errors rates and packet retransmissions with low data rate. Signal strength within the ranges of *-90dBm* to *-80dBm* indicates very low signal quality; a mobile user will experience very high error rates and high packet retransmission with very low data rate. A user with these ranges must change location or may experience on and off connections. Finally a mobile user with signal strength between *-90dBm* to *-108dBm,* may not experience any connection to the network

[72].The signal strength obtained during the measurement survey for various access points (APs) are presented in **Tables 4-2** to **4-5.**

Table 4-2: Mean RSSI and Standard Deviation (SD) for LOS environment scenario

d(m)	Mean RSSI(dBm) Africa	SD(dBm) Africa	Mean RSSI(dBm) Repblic	SD(dBm) Republic	Mean RSSI(dBm) Indece	SD(dBm) Indece
10	-52.58	1.24	-54.25	1.76	-50.50	3.55
20	-53.64	1.12	-57.75	1.36	-51.75	1.22
30	-54.25	1.82	-58.58	1.78	-53.33	4.48
40	-56.67	1.50	-55.75	6.72	-52.92	2.50
50	-54.28	2.61	-62.58	1.71	-56.50	2.24
60	-58.58	0.62	-67.58	0.67	-57.67	5.16
70	-62.92	2.15	-66.67	2.10	-62.50	2.02
80	-68.17	0.72	-69.83	1.27	-66.75	4.09
90	-72.92	0.79	-74.75	1.60	-70.81	3.20
100	-71.95	1.14	-76.75	2.67	-75.21	1.50

Table 4-3: Mean RSSI and SD for LOS environment scenario

d(m)	Mean RSSI(dBm) Queens	SD(dBm) Queens	Mean RSSI(dBm) RPG	SD(dBm) RPG
10	-51.80	5.53	-50.08	2.19
20	-54.60	5.14	-57.42	2.54
30	-54.20	4.75	-58.33	1.92
40	-59.40	6.10	-64.92	7.50
50	-56.27	8.15	-65.33	7.24
60	-65.40	6.09	-68.50	3.63
70	-68.33	2.89	-72.50	6.91
80	-70.40	9.72	-76.00	3.69
90	-69.00	6.64	-71.92	1.83
100	-72.00	6.85	-78.42	3.20

Table 4-4: Mean RSSI and SD for NLOS environment scenario

d(m)	Mean RSSI(dBm) SRC	SD(dBm) SRC	Mean RSSI(dBm) Unity	SD(dBm) Unity	Mean RSSI(dBm) Postgrad	SD(dBm) Postgrad
10	-63.33	6.92	-53.25	3.05	-61.33	3.09
20	-61.83	5.44	-57.00	2.04	-57.83	1.68
30	-60.83	2.12	-59.42	2.89	-65.83	8.85
40	-73.67	2.67	-61.00	2.19	-73.67	3.07
50	-72.33	2.15	-75.83	1.75	-72.33	3.86
60	-79.58	1.93	-76.00	1.86	-74.58	2.71
70	-78.08	4.06	-74.83	2.12	-78.08	1.51
80	-84.17	1.03	-72.63	2.86	-80.17	1.68
90	-82.00	2.73	-76.58	3.20	-88.00	2.09
100	-85.25	1.54	-77.50	2.54	-83.25	1.21

Table 4-5: Mean RSSI and SD for NLOS environment scenario

d(m)	Mean RSSI(dBm) University	SD(dBm) University	Mean RSSI(dBm) GUSS1	SD(dBm) GUSS1
10	-52.58	3.45	-53.25	1.66
20	-54.75	1.06	-56.50	1.68
30	-58.92	1.51	-66.25	2.14
40	-66.00	3.54	-68.62	1.45
50	-69.25	3.52	-65.85	0.80
60	-63.75	1.29	-73.75	1.60
70	-76.00	2.86	-73.50	1.17
80	-78.75	2.96	-79.50	1.17
90	-75.58	2.87	-82.60	1.91
100	-78.42	5.57	-80.67	0.98

4.2 COMPUTATION OF PATH LOSS EXPONENTS AND STANDARD DEVIATIONS

Recalling the RSSI expression of **Equation 2.26** as given in **Equation 4.1**

$$P_{L(d)} = 30 - \text{RSSI} \tag{4.1}$$

By using **Equation 4.1, Tables 4-6** and **4-7** were computed.

Table 4-6: Path loss (PL) for LOS environment

Measured Distance (m)	P_L (dB) for Africa Hall	P_L (dB) for Republic Hall	P_L (dB) for Independence Hall	P_L(dB) for Queens Hall	P_L(dB) for RPG
10	82.58	84.25	80.50	81.80	80.08
20	83.64	87.75	81.75	84.60	87.42
30	84.25	88.58	83.33	84.20	88.33
40	86.67	85.75	82.92	89.40	94.92
50	84.28	92.58	86.50	86.27	95.33
60	88.58	97.58	87.67	95.40	98.50
70	92.92	96.67	92.50	98.33	102.50
80	98.17	99.83	96.75	100.40	106.00
90	102.92	104.75	100.81	99.00	101.92
100	101.95	106.75	105.21	102.00	108.42

Table 4-7: Path loss (PL) NLOS environment

Measured Distance (m)	P_L(dB) for SRC Hostel	P_L (dB) for Unity Hall	P_L (dB) for Postgraduate Hostel	P_L (dB) for University Hall	P_L(dB) for GUSS1 Hostel
10	93.33	83.25	91.33	82.58	85.25
20	91.83	87.00	87.83	84.75	86.50
30	90.83	89.42	95.83	88.92	96.25
40	103.67	91.00	103.67	96.00	98.62
50	102.33	105.83	102.33	99.25	95.85
60	109.58	106.00	104.58	93.75	103.75
70	108.08	104.83	108.08	106.00	103.50
80	114.17	102.63	110.17	108.75	109.50
90	112.00	106.58	118.00	105.58	112.60
100	115.25	107.50	113.25	108.42	110.67

4.2.1 THE STATISTICAL BEHAVIOR

The statistical behavior of the measured data was analyzed with several distribution functions, Rayleigh, Rician, Log-normal and Weibull for LOS and NLOS environments. Very good fittings, in general were obtained except for Rayleigh distribution function. Among them, the Log-normal offered the best fit in majority of the cases, Weibull and Rician functions being only marginally worst in many cases for LOS. At *87dB* in **Figure 4-1** Weibull, Rician and Log-normal distribution functions were almost indistinguishable whiles Rayleigh was observed to have the worst fit. In the case of NLOS environment, Weibull was observed to offer the best fit, followed by Rician and Log-normal functions also being marginally worst in many cases and at *108dB* in **Figure 4-2**, Rician, Weibull and Log-normal were indistinguishable. Rayleigh was observed to have the worst fit among the four distribution functions used.

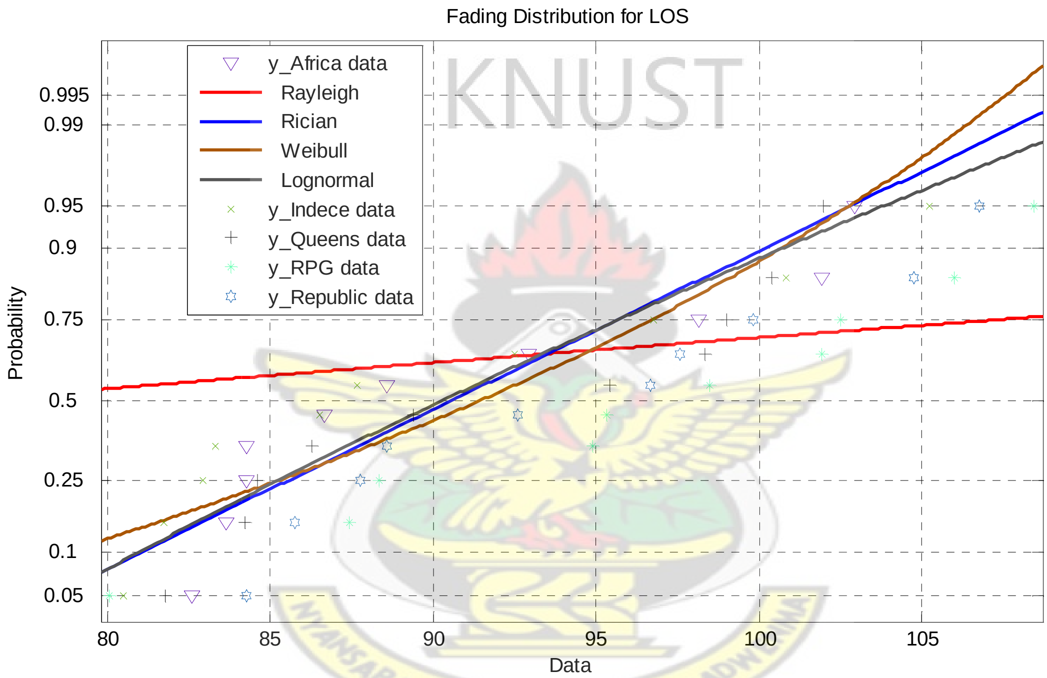

Figure 4-1: A comparison of fits to Log-normal, Rician, Weibull and Rayleigh Probability in LOS environment.

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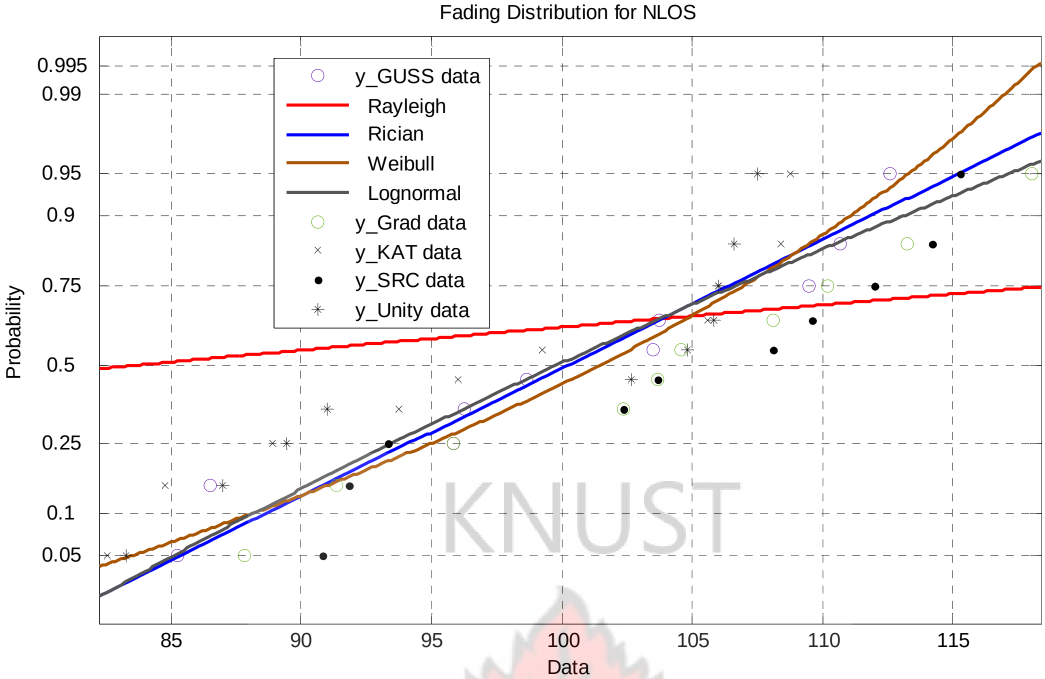

Figure 4-2: A comparison of fits to Log-normal, Rician, Weibull and Rayleigh Probability in NLOS environment

4.2.2 CURVE FITTING METHOD

Curve fitting method was used to evaluate the path loss exponent *n*, in Log-distance path loss model. The best-fitting curve can be obtained by the method of least squares.

The least-square uses a straight line equation of the form (**Equation 4.2**)

$$f(x) = \beta_1 x + \beta_2 \tag{4.2}$$

where

β_1 is the slope of the straight line

β_2 is the intersect of the straight line.

The coefficients can be found from least-square fittings as given in **Equations 4.3** and **4.4**

$$\beta_1 = \frac{M\sum_{i=1}^{M} \log d_i PL_i - (\sum_{i=1}^{M} \log d_i)(\sum_{i=1}^{M} PL_i)}{M\sum_{i=1}^{M} (\log d_i)^2 - (\sum_{i=1}^{M} \log d_i)^2} \quad (4.3)$$

$$\beta_2 = \frac{\sum_{i=1}^{M} PL_i - \beta_1 \sum_{i=1}^{M} (\log d_i)}{M} \quad (4.4)$$

To approximate the given set of data, (x_1, y_1), (x_2, y_2)…, (x_n, y_n), where n >=2. The best fitting curve f(x) has the least error (**Equation 4.5**)

$$\Pi = \sum_{i=1}^{n} [y_i - f(x_i)]^2 = \sum_{i=1}^{n} [y_i - (\beta_1 x_i + \beta_2]^2 \quad (4.5)$$

Figures 4-1 to **4-10** shows the linear curve fitting for the data collected from the study area in both LOS and NLOS environments.

Plots For LOS Environments

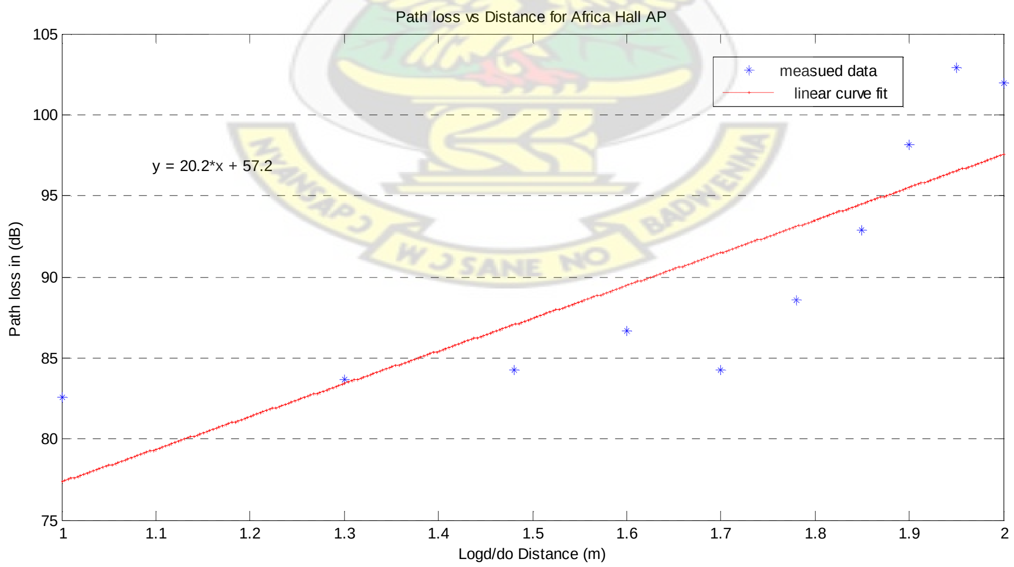

Figure 4-3: Line of Best fit for Africa Hall AP

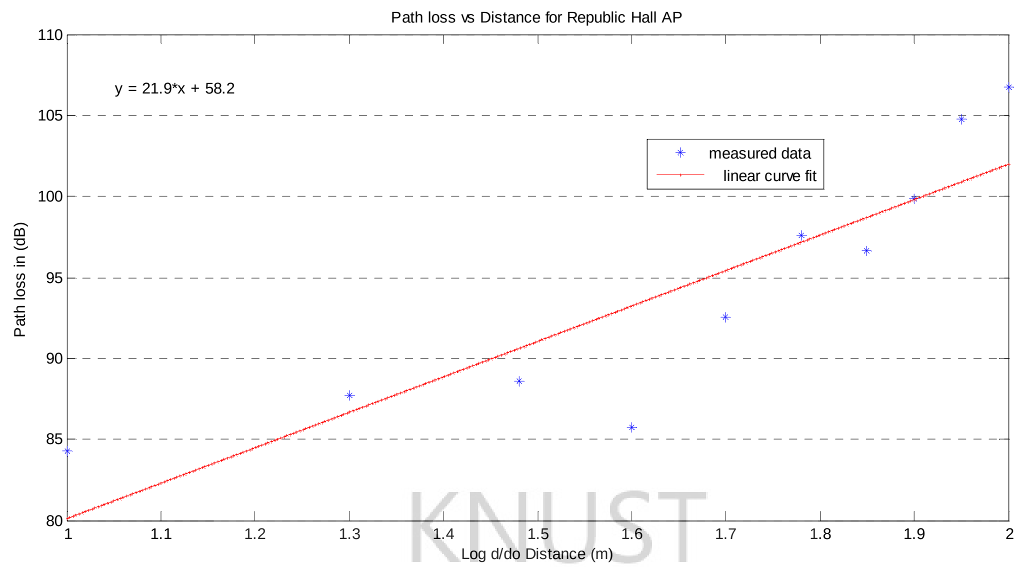

Figure 4-4: Line of Best fit plot Republic Hall AP

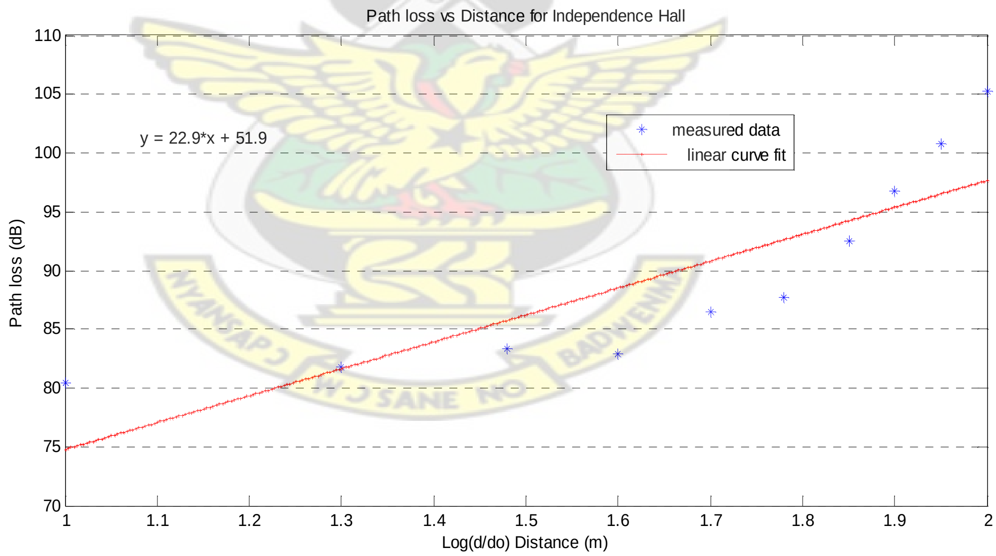

Figure 4-5: Line of Best fit plot for Independence Hall AP

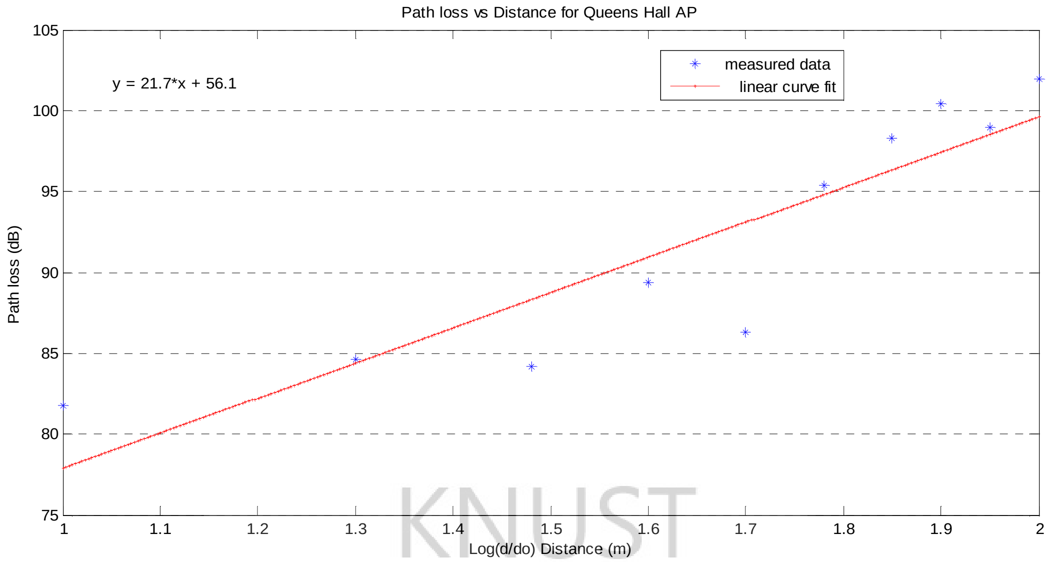

Figure 4-6: Line of Best fit plot for Queens Hall AP

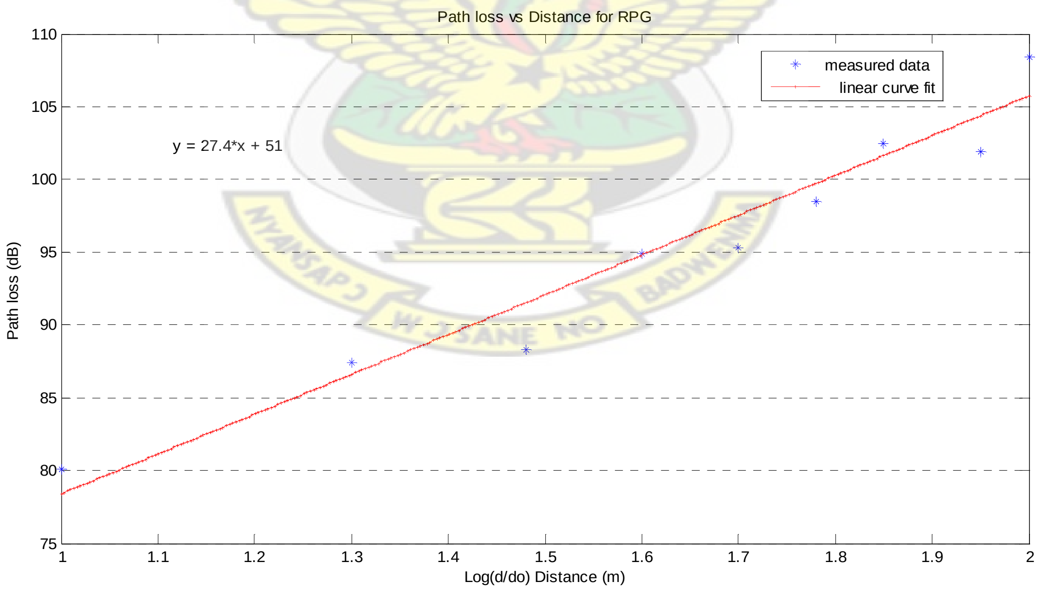

Figure 4-7: Line of Best fit plot for RPG AP

Plots For Non Line Of Sight (NLOS) Environment

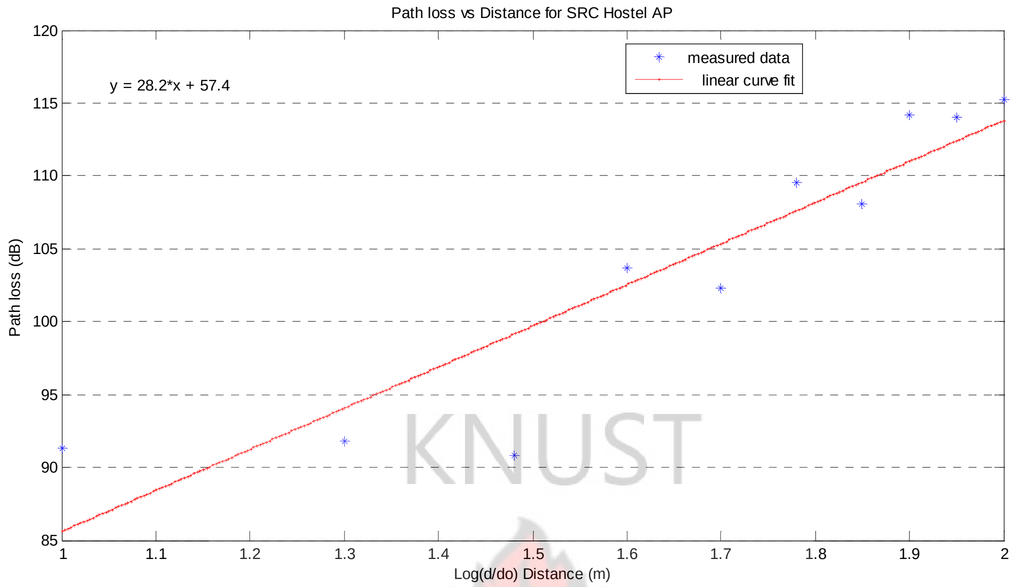

Figure 4-8: Line of Best fit plot for SRC Hostels AP

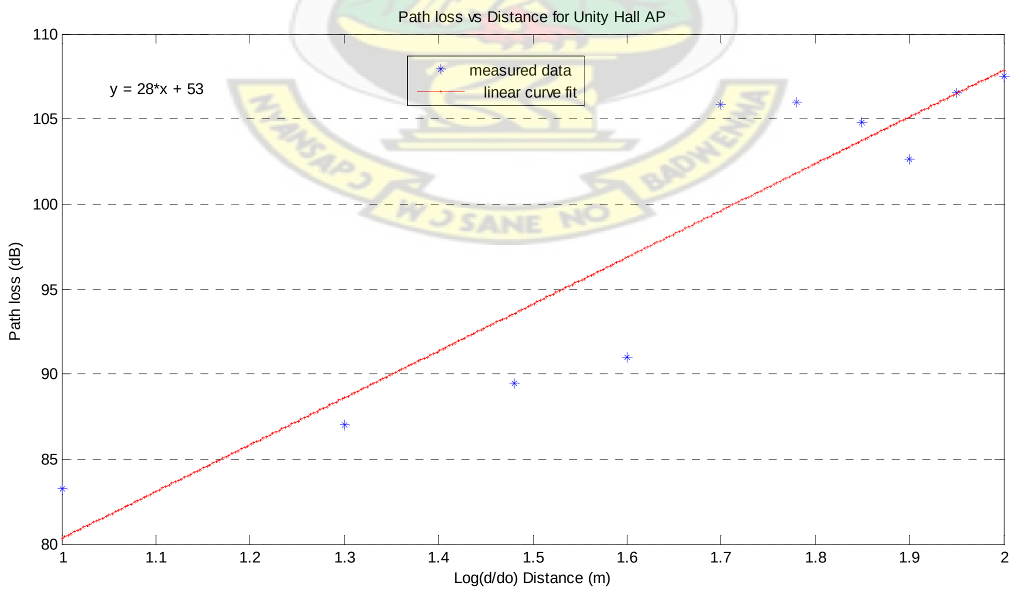

Figure 4-9: Line of Best fit plot for Unity Hall AP

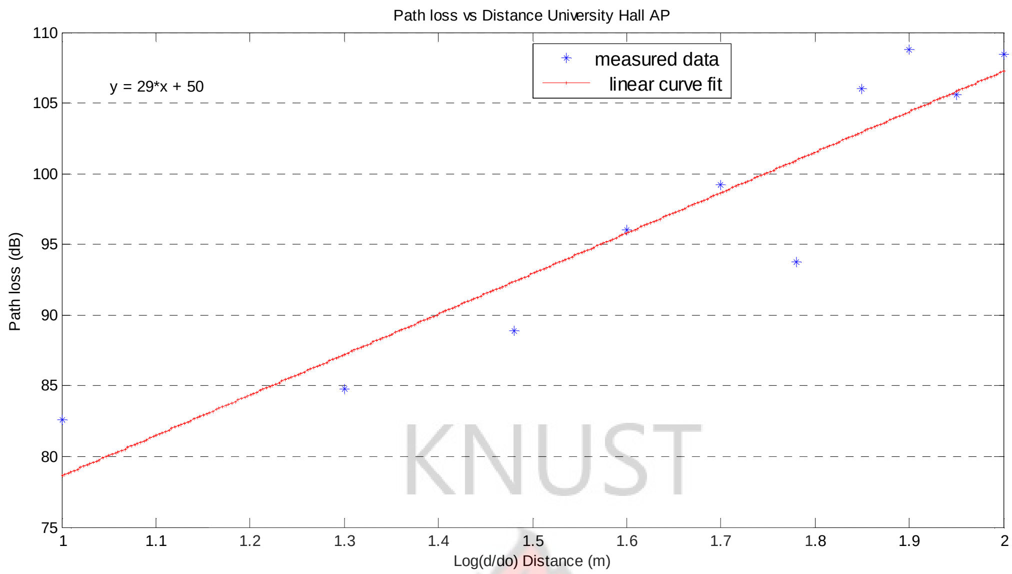

Figure 4-10: Line of Best fit plot for Postgraduate Hostel AP

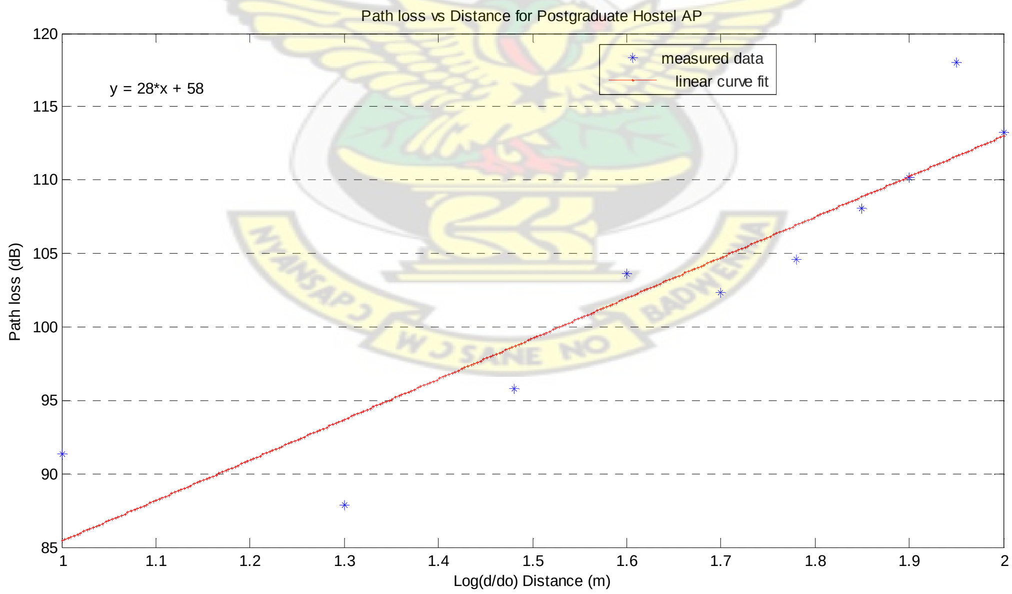

Figure 4-11: Line of Best fit plot for University Hall AP

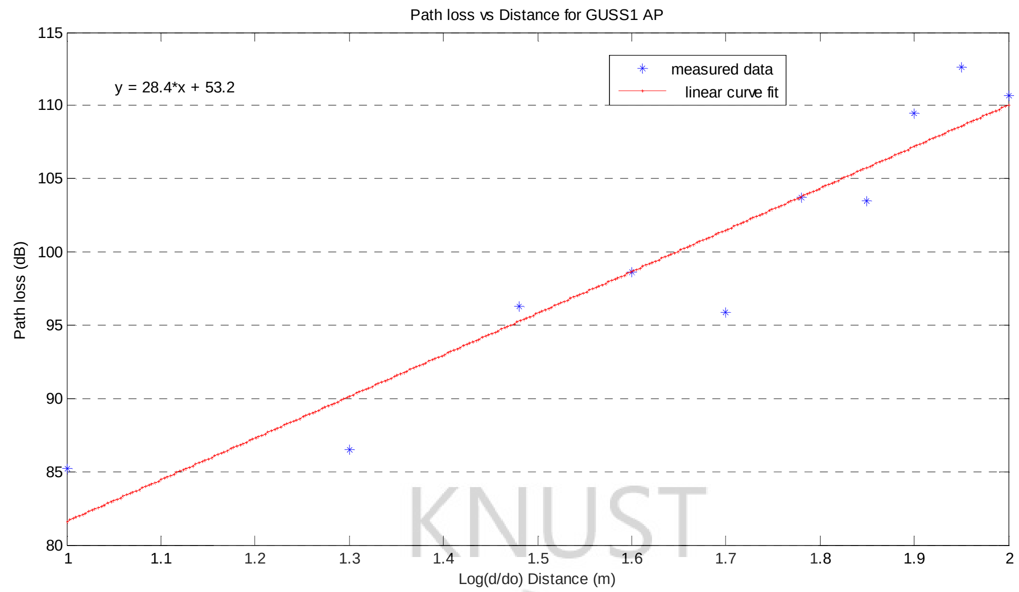

Figure 4-12: Line of Best fit plot for GUSS1 Hostel AP

The plot of distance *d* versus the path loss *PL* on a log-log scale is a straight line with a slope of *(10n)* by using **Equation 2.24.** The slope (β_1) of **Equation 4.3** from the curve fitting were compared to the slope of Log-distance path loss model and path loss exponents computed for both LOS and NLOS environments and presented in **Tables 4-8** and **4-9**. The standard deviations *(σ)*, coefficient of determination (R^2) and root mean square errors *(RMSE)* were determined by applying **Equations 4.6** to **4.8** using MATLAB tool and presented in **Tables 4-8** and **4-9**.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{M}(y_i - \bar{y}_i)^2}{M}} \qquad (4.6)$$

$$RMSE = \sqrt{\frac{1}{M}\sum_{i=1}^{M}(yi - \tilde{y}i)^2} \qquad (4.7)$$

Where $\tilde{y}_i$ denotes the estimate of data y_i , M is the data length and $\bar{y}_i$ is the mean of the measured data. The statistical measure R^2 on the other hand is given as in **Equation 4.8**

$$R^2 = 1 - \frac{\sum_{i=1}^{M}(yi - \tilde{y}i)^2}{\sum_{i=1}^{M}(yi - \bar{y}i)^2} \quad (4.8)$$

Table 4-8: Model parameters obtained from least-square regression analysis for LOS

Location	**Path loss exponent (n)**	**Standard Deviation (σ) dB**	**Coefficient of Determination (R^2)**	**RMSE (dB)**
Africa Hall	2.02	7.86	0.88	0.07
Republic Hall	2.20	7.91	0.93	0.13
Independence Hall	2.30	8.63	0.93	0.17
Queens Hall	2.20	7.68	0.91	0.36
RPG	2.7	8.97	0.93	0.23

Table 4-9: Model parameters obtained from least-square regression analysis for NLOS

Location	**Path loss exponent (n)**	**Standard Deviation (σ) dB**	**Coefficient of Determination (R^2)**	**RMSE (dB)**
SRC Hostel	2.82	9.31	0.88	0.18
Unity Hall	2.80	9.53	0.80	0.14
Postgraduate Hostel	2.80	9.58	0.90	0.17
University Hall	2.90	9.78	0.89	0.16
GUSS1 Hostel	2.84	9.55	0.92	0.09

4.3 DISCUSSION OF RESULTS

The standard deviations, root mean square error (RMSE) and coefficient of determination (R^2) of the derived models from the actual measurements were parameters used to evaluate the quality of the models. In this study, the over all mean standard deviations for LOS environment were less than 9dB. The coefficient of determination with a magnitude near 1 represents a good fit. As the fit gets worse, the coefficient of determination approaches zero, the range of values of coefficient of determination for LOS were 0.88 to 0.93 with a mean value of *0.92* indicating a good fit. The RMSE for LOS environment were less than *1dB* which is a satisfactory result.

The mean standard deviations for NLOS environment were less than *10dB.* The mean coefficient of determination was *0.88* indicating a good fit. The RMSE for NLOS environments were also less than *1dB*.

The most important model parameter obtained from the analysis is the path loss exponent. This path loss exponent provides significant insight into the distance dependent attenuation of the wireless signal, which is the largest path loss contributor in the path loss models being derived. In the analysis, it was observed that, the values for path loss exponent is systemically higher for NLOS environment than it is for LOS environment. This indicates that, as it is expected, the signal strength decreases faster for NLOS environment than for LOS environment due to the presence of obstacles such as buildings in the propagation path. The path loss exponents obtained were compared with existing results of some publishers under similar environment such as that of Xia *et al* [69], where they obtained a path loss exponent value in the range of *2.5* to *5.0* and standard deviation of *5.0* to *9.0dB* in their study of the Sun Francisco and Oakland area; Bertoni and Piazzi [70] also determined path loss exponents in ranges of *3.9* to *5.9* in their study of Trenton New Jersey; and Lorne C. Liechty [71] obtained path loss exponents values in the ranges of *2.54* to *3.11* and standard deviation of *5.0* to *6.5* in his study at the campus of George Institute of Technology

As shown, path loss exponents obtained in this study are in the ranges of published results of most researchers.

Table 4-10: summarizes the path loss exponents and intercepts for both LOS and NLOS environments, using least-square regression analysis.

Table 4-10: Summary of results from the regression analysis.

Environment	Mean Path loss exponent (n)	Mean Intercept
LOS	2.3	54.88
NLOS	2.8	54.32

Equations 4.9 and **4.10** are the derived mean path loss models for LOS and NLOS environments

$$PL(d)[LOS][dB] = 54.88 + 23\log(\frac{d}{d_o}) \quad (4.9)$$

$$PL(d)[NLOS][dB] = 54.32 + 28\log(\frac{d}{d_o}) \quad (4.10)$$

4.4 MODEL TESTING

Propagation path loss exponents obtained from the empirical measurements were compared with propagation path loss exponent in free space using **Equation 2.24** (refer Appendix B) and shown in **Figure 4-13**. As expected, the path loss exponents from the empirical measurements as compared with free space loss are shown to be higher, and this was observed to be caused by additional losses from the environment which attenuates the signal rapidly than in free space.

In **Figure 4.13**, it indicates a difference of *7dB* between the free space loss (FSL) exponents and the derived path loss exponent for LOS environment. One may apply the FSL model for future planning while considering a safe margin of *2 – 7dB* on the other hand; a *15dB* of difference is observed.

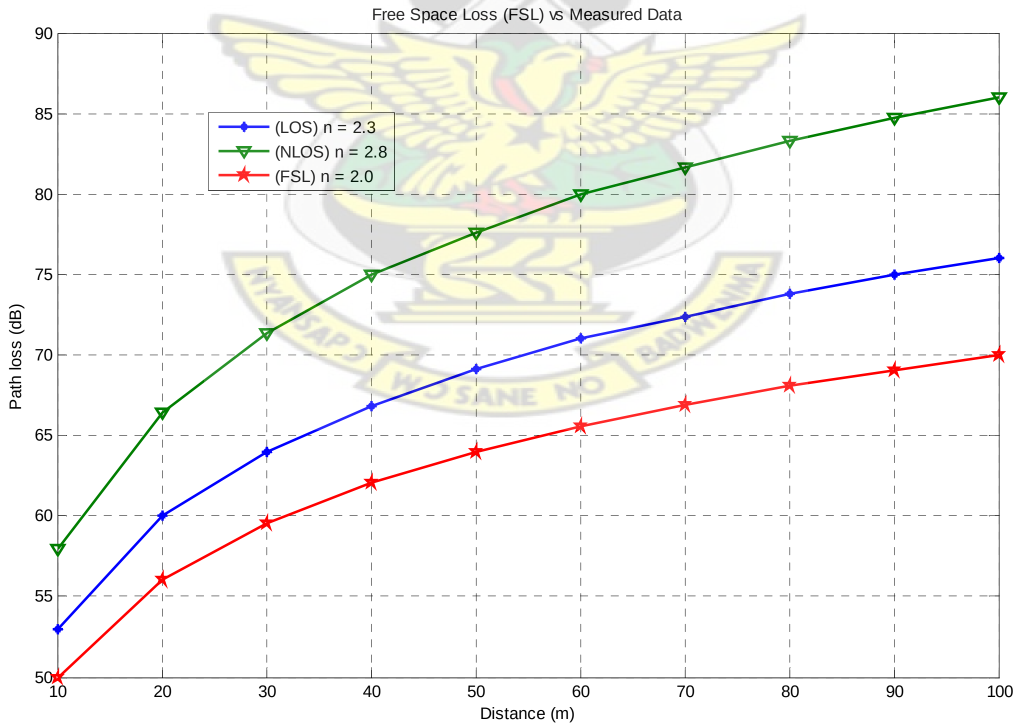

Figure 4-13: Comparison of path loss exponents from measured data to free space loss

4.5 MODEL PERFORMANCE AND EVALUATION

The derived propagation path loss models were compared with COST 231 Hata model, Stanford University Interim (SUI) model and Free Space Propagation Loss (FSPL) model as shown in **Figure 4-14**. The figure shows similarities and differences between models utilizing the same or nearly the same parameters. SUI model showed the highest path loss prediction at a base station antenna height (h_b) of 10m and a Terrain Type B environment which is similar to the environment of the study area. FSPL showed the least path loss prediction as expected, since it does not include any additional losses from the environment but only its loss depends on only distance and frequency. The derived models were observed to show good agreement with COST 231 Hata model with a mean deviation of *5.3dB* between PL[LOS] and *3.6dB* between PL[NLOS]. The figure also showed very little worst agreement between the path loss prediction by derived path models and SUI model, with a mean deviation of *76.6dB* between PL[LOS] and SUI model and also a mean deviation of *68.9dB* between PL[NLOS] and SUI model. The large deviation between derived models and SUI model could be explained by the small value of transmitting antenna $(h_b = 10m)$ chosen for this comparison.

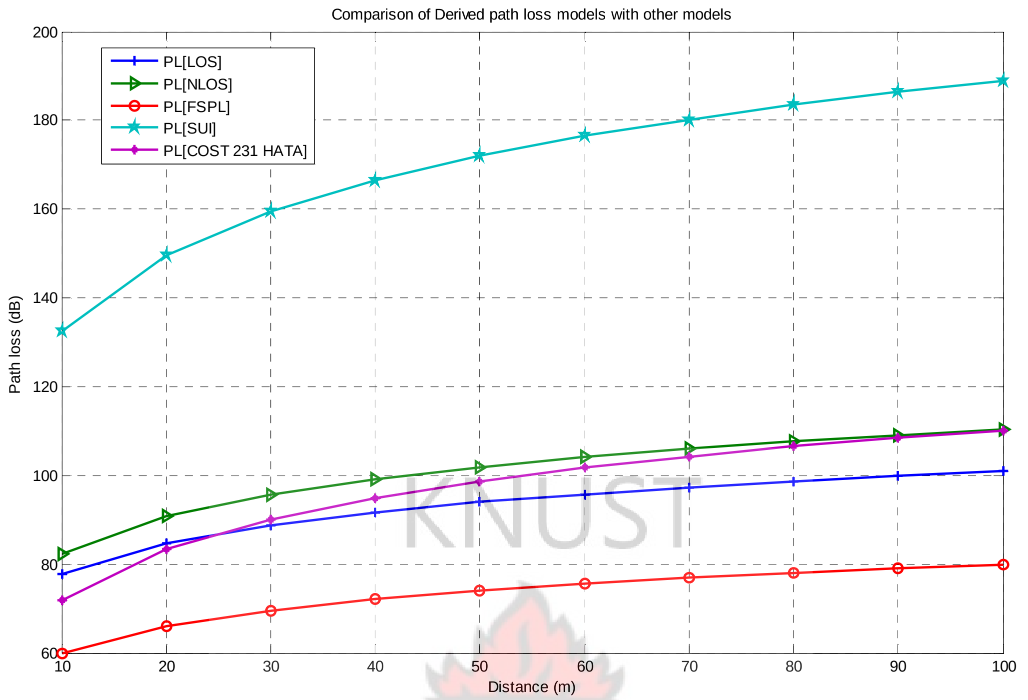

Figure 4-14: Comparison of Derived Models with Other Existing Models

4.6 Conclusion

Received signal strength indicator data were collected from different locations at the study area and was observed to vary significantly at these locations because of presence of obstacles that caused the RSSI values to attenuate. By using the method of least-squares logarithmic regression analysis, path loss exponents for the various locations were determined and propagation models proposed based on these values. Results indicated that the model could potentially be used successfully in wireless network deployment and planning at KNUST without propagation measurements which are expensive and time consuming.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.0 Conclusions:

The main objective of this study was to investigate the impact of the environment on radio frequency signal quality, it was observed in chapter four that the presence of obstructions in radio transmission path affects the quality of received signal. The presence of obstacles attenuates or weakens the signal power and this degrades the performance of the wireless network. RSSI data were collected in a LOS and NLOS environment scenarios. It is very important to determine RSSI at different locations in wireless networks, different values of RSSI for every location can show us whether that location have received good signal or not. The good signal strength meaning that the location has a good network performance. Propagation path loss exponents and standard deviations were determined for some selected locations at the study area using least-square analysis. The path loss exponents and standard deviations obtained for the obstructed environment (NLOS) were observed to be higher than that of those obtained for unobstructed (LOS) environment. This observation showed that the presence of obstacles really have impact on radio frequency signal quality since the path loss exponents for NLOS environment were found to be higher than that of LOS environment indicating obstructions and interferences may cause multipath effect thereby weakening the signal power level in the NLOS environment. Based on the empirical data collected, propagation models were derived for both NLOS and LOS environments scenario. The results obtained from the study were then compared with some existing works of other researchers and the values showed some level of agreement. Empirical models were derived and compared with other exiting models such as COST 231 Hata, Stanford University Interim model and Free Space Loss model. The results from the comparison were satisfactory, indicating the derived models can effectively be used to deploy APs at KNUST to achieve a maximum coverage and optimum performance.

5.1 Recommendations

Co-Channel and Adjacent Channel Interference

The study area (KNUST campus) have other private APs that are either operating in the same channel or very close channel as that of the studied APs, further studies can be conducted to investigate the impact that co-channel and adjacent channel interference have on radio signal quality.

Duration for taking Measurement

Increase the duration for the measurements by conducting more measurements and covering more data points on the study area. Additional data points could help increase the accuracy of the derived propagation models.

Improving the Accuracy of the Path Loss Model

To improve the accuracy of the path loss model, extensive measurements are to be performed with more accurate equipments required, to estimate a more accurate path loss exponent.

Using More Accurate Measuring Equipments

Using more accurate measuring equipments in *2.4GHz* frequency, we can make our measurements and model more accurate, such as radio frequency analyzer which can find both signal strength and signal impulse response used to predict frame error rate (FER).

Studying the Impact of Weather on RF Signal Quality

The accuracy of this thesis can also be further improved by studying the impact that weather such as wind, drizzle and rain has on RF signal quality.

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APPENDIX- A: INFORMATION ON THE SELECTED APs

Network Operation Center

Latitude 060 40.434N

Longitude 0010 34.016W

Elevation 261m

Accuracy 52m $_{WAAS}$

Tracking 8 satellites 3D

NAME : (old Brunei)

SSID: Bruneiold - wifi

IP add: Motorola Canopy: 192.168.1.142

Mikrotik Radio : 192.168.1.143

Frequency (MHz) : 2447

Wireless Interface: 192.168.103

Latitude 06^0 40.227N

Longitude 001^0 34.395W

Elevation 265m

Accuracy 265m $_{WAAS}$

Tracking 14 satellites 3D

NAME : POSTGRAD HOSTEL (Grasag)

SSID : Postgrad - wifi

IP add: Motorola Canopy: 192.168.1.150

Mikrotik Radio : 192.168.1.151

Frequency (MHz) : 2412

Wireless Interface: 192.168.102

Latitude 06^0 40.243N

Longitude 001^0 34.498W

Elevation 262m

Accuracy 56m W$_{AAS}$

Tracking 5 satellites 2D

NAME : SRC HOSTEL (SRC)

SSID : SRC - wifi — Latitude 06^0 40.871N

IP add: Motorola Canopy: 192.168.1.148 — Longitude 001^0 34.290N

Mikrotik Radio : 192.168.1.149 — Elevation 263m

Frequency (MHz : 2442 — Accuracy 5m $_{WAAS}$

Wireless Interface: 192.168.101 — Tracking 9 satellite 3D

NAME : UNITY HALL (Conti)

SSID : Conti – wifi — Latitude 06^0 40.778N

IP add: Motorola Canopy: 192.168.1.130 — Longitude 001^0 34.331W

Mikrotik Radio : 192.168.1.132 — Elevation 407m

Frequency (MHz) : 2452 — Accuracy 30m $_{WAAS}$

Wireless Interface: 192.168.108 — Tracking 6 satellites 3D

NAME : AFRICA HALL

SSID : Africa - wifi — Latitude 06^0 40.836N

IP add: Motorola Canopy: 192.168.1.132 — Longitude 001^0 34.509W

Mikrotik Radio : 192.168.1.133 — Elevation 288m

Frequency (MHz) : 2442 — Accuracy 30m$_{WAAS}$

Wireless Interface: 192.168.111 — Tracking 6 satellites 3D

NAME : UNIVERSITY HALL (Kat)

SSID : Kat - wifi — Latitude 06^0 40.360N

IP add: Motorola Canopy: 192.168.1.134 Longitude 001^0 34.356W

Mikrotik Radio : 192.168.1.135 Elevation 269m

Frequency (MHz): 2457 Accuracy 8m $_{WAAS}$

Wireless Interface: 192.168.107 Tracking 11 satellites 3D

<u>NAME : REPUBLIC HALL (Repu)</u>

SSID: Repu - wifi Latitude 06^0 40.703W

IP add: Motorola Canopy: 192.168.1.136 Longitude 001^0 34.423W

Mikrotik Radio : 192.168.1.137 Elevation 273m

Frequency (MHz) : 2447 Accuracy 6m $_{WAAS}$

Wireless Interface: 192.168.104 Tracking 11 satellites 3D

<u>NAME : QUEENS HALL (Qnx)</u>

SSID: Qnx - wifi Latitude 06^0 40.610W

IP add: Motorola Canopy: 192.168.1.138 Longitude 001^0 34.456W

Mikrotik Radio : 192.168.1.139 Elevation 272m

Frequency (MHz): 2440 Accuracy 10m $_{WAAS}$

Wireless Interface: 192.168.110 Tracking 10 satellites 3D

<u>NAME : INDEPENDENCE HALL (Indece)</u>

SSID: Indece - wifi Latitude 06^0 40.640N

IP add: Motorola Canopy: 192.168.1.140 Longitude 001^0 34.310W

Mikrotik Radio : 192.168.1.141 Elevation 263m

Frequency (MHz) : 2462 Accuracy 8m

Wireless Interface: 192.168.106 Tracking 8 satellites 3D

NAME : SRC HOSTEL (nickname SRC)

SSID: SRC - wifi

IP add: Motorola Canopy: 192.168.1.148

Mikrotik Radio : 192.168.1.149

Frequency (MHz): 2442

Wireless Interface: 192.168.101

Latitude 06^0 40.871N

Longitude 001^0 34.410W

Elevation 274m

Accuracy 4m$_{WAAS}$

APPENDIX- B PATH LOSS EXPNENTS COMPARISON

By using Equations (2.9)

$P_{L\,(d)\,[dB]} = P_{L\,(do)\,[dB]} + 10n\log\left(\frac{d}{d_o}\right)$ (2.9)

$P_{L\,(do)\,[dB]} =$ 30dB at a reference distance of 1m for 2.4 GHz WLAN systems

$P_{L\,(d)\,[dB]} = P_{L\,(do)\,[dB]} + 10n\log\left(\frac{d}{d_o}\right)$ therefore will become

$P_{L\,(d)\,[dB]} = 30 + 10n\log(d)$ (4.6)

Using Equation (4.6), Table 4.11 was computed

Table 4.11: Comparison between Free Space Loss and Measured Data

Distance [d] (m)	**$P_{L\,(d)\,[LOS]}$ For n = 2.3**	**$P_{L\,(d)\,[NLOS]}$ For n = 2.8**	**$P_{L\,(d)\,[FSL]}$ For n = 2.0**
10	53.00	58.00	50.00
20	60.00	66.4	56.02
30	64.00	71.36	59.54
40	66.84	75.00	62.04
50	69.1	77.6	63.98
60	71.0	80.00	65.56
70	72.40	81.66	66.9
80	73.8	83.28	68.06
90	75.00	84.72	69.08
100	76.00	86.00	70.00