ELECTROMAGNETIC COMPATIBILITY ASSESSMENT IN A DUAL RADIO FREQUENCY ENVIRONMENT

BY

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MARCH 2012

DECLARATION

I, hereby declare that this thesis was solely carried out by me and it is the result of my research. It has not, to the best of my knowledge, been presented anywhere for the award of a degree. All sources of information are duly acknowledged by means of references

……

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CERTIFICATION

This thesis entitled "Electromagnetic Compatibility Assessment in a Dual Radio Frequency Environment" by MAHMOOD Aliyu, meets the regulations governing the award of Master of Science Degree in Electrical Engineering in the Department of Electrical and Computer Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this work to my mother, my late brother and to the glory of Almighty Allah.

ACKNOWLEDGEMENTS

First and Foremost, my sincere gratitude goes to Almighty God who keeps me alive to witness this day.

I am very grateful for the guidance and support of my Major supervisor Dr. D. D. Dajab, and my Minor supervisor Dr. B. A. Adegboye who worked tirelessly in ensuring the success of the research. May God Almighty in his infinite mercy reward you abundantly and help in seeing more fruits of your labour- Ameen**.** My sincere appreciation goes to Prof. B.G. Bajoga whose critical inputs made it possible for me to surmount the hurdles I encountered during the course of this study. I am also greatful to Dr.Boyi Jimoh and Dr J.Y.Oricha.

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I sincerely hope that this work will contribute immensely to knowledge.

TABLE OF CONTENT

TITTLE PAGE i
DECLARATION i
CERTIFICATION ii
DEDICATION iii
ACKNOWLEDGEMENTS iv
TABLE OF CONTENT v
LIST OF FIGURES viii
LIST OF TABLES ix
LIST OF SYMBOLS AND ABBREVIATIONS x
ABSTRACT xii
1.1 INTRODUCTION TO EMC 1
1.1.1 Concept of Electromagnetic Compatibility 1
1.2 TYPES OF INTERFERENCE 2
1.2.1 Continuous Interference 2
1.2.2 Transient (Pulse) Interference 3
1.3 ELEMENTS OF AN EMC PROBLEM 4
1.4 WIRELESS NETWORKING STANDARDS 5
1.5 RESEARCH OBJECTIVE 7
1.6 PROBLEM STATEMENT 7
1.7 THESIS OUTLINE 8
CHAPTER TWO 9
LITERATURE REVIEW AND THEORETICAL BACKGROUND 9
2.1 LITERATURE REVIEW 9
2.2 RADIO PROPAGATION THEORY 13
2.3 NOISE FLOW 15
2.4 IMPULSIVE NOISE MODELLING 15
2.4.1 Middleton Class A Model: 16
2.5 AN EMPIRICAL STUDY OF ABU WIRELESS NETWORK 19
2.5.1 DEFINITION OF TERMS 19
2.5.2 Base Station 19

2.5.3 Client Stations 19
2.5.4 Satellite (VSAT) 19
2.5.5 Modem 19
2.6 IEEE802.11 STANDARDS USED ON THE ABU WLAN 19
2.6.1 IEEE 802.11 a 19
2.6.2 IEEE 802.11 b | g 20
2.6.3 IEEE 802.11 b |g versus IEEE 802.11a 20
2.7 ABU-ZARIA WIRELESS NETWORK LAYOUT 20
2.7.1 Senate West Base Station 22
2.7.2 Senate East Base Station 23
CHAPTER THREE: 26
3.1 INTRODUCTION 26
3.2.1 Data Acquisition 26
3.2.2 Procedure of Data Analyses 26
3.3 SIMULINK-BASED MODELLING 29
3.3.1 DEVELOPMENT OF SIMULINK MODEL 29
3.3.2 Simulink 31
3.3.3 Blocks Used in the Model 32
CHAPTER FOUR 34
RESULT AND ANALYSIS 34
4.1 INTRODUCTION 34
4.1.1 Data Calculations 34
4.2 RESULTS OBTAINED 36
4.3 RESULT ANALYSIS BASED ON SIMULINK MODEL DISPLAY 45
4.4 DISCUSSION OF RESULTS OBTAINED 47
CHAPTER FIVE 49
CONCLUSION AND RECOMMENDATION 49
5.1 INTRODUCTON 49
5.2 LIMITATIONS 49
5.3 SIGNIFICANCE OF WORK DONE 49
5.4 CONCLUSION 50

5.5 RECOMMENDATIONS FOR FURTHER WORK 50
REFERENCES 52
APPENDIX I: MATLAB PROGRAM 57
2.4GHz SENATE WEST MATLAB PROGRAM 57
5GHz matlab programme 63
APPENDIX II: 90 Days Signal Strength Data for ABU Network 66

LIST OF FIGURES

Figure 1.1: The Three Essential Elements of EMC Problem ……5

Figure 2.1: Signal and Noise Flow Pattern……15

Figure 2.2: Probability Density Function of The Amplitude of Class-A Noise……18

Figure 2.3: ABU Point to Point Diagram……..21

Figure 2.4: General Overview of Wireless LAN (ABU WLAN)……22

Figure 2.5: Senate West Base Station Diagram…….23

Figure 2.6: Senate East Base Station Diagram……..24

Figure 2.7: ABU Samaru Campus Initial Network Layout……25

Figure 3.1: Middleton Class A Model Flow Chart For Assessment…….28

Figure 3.2: MATLAB/SIMULINK Blocks for 2.4GHz Representative Model……..30

Figure 3.3: MATLAB/SIMULINK Blocks for 5GHz Representative Model…….31

Figure 4.1: Signal Strength Bar Chart of 2.4GHz Senate West Access Points…….37

Figure 4.2: Signal Strength Bar Chart of 2.4GHz Senate East Access Points……...38

Figure 4.3: Signal Strength Bar Chart of 5GHz Access Points……...39

Figure 4.4: Graph of SNR Against Pathloss for 2.4GHz Senate West Access Points……40

Figure 4.5: Graph of SNR Against Pathloss for 2.4GHz Senate East Access Points…….40

Figure 4.6: Graph of SNR Against Pathloss for 5GHz Access Points ……41

Figure 4.7: EMI Magnitude Plot of 2.4GHz Senate West Access Points…….42

Figure 4.8: EMI Magnitude Plot of 2.4GHz Senate East Access Points……..43

Figure 4.9: EMI Magnitude Plot of 5GHz Access Points…….44

Figure 4.10: EMI Distortion of Signal Display in 2.4GHz Network……..45

Figure 4.11: EMI Distortion of Signal Display in 5GHz Network……46

LIST OF TABLES

Table 1.1: IEEE WLAN Standards……5

Table 4.1: Average Signal Strength of Various Access Points in ABU Networks……34-35

LIST OF SYMBOLS AND ABBREVIATIONS

AWGN	Additive White Gaussian Noise
BPSK	Binary Phase Shift Keying
CDMA	Code-Division Multiple Access
DC	Direct Current
EMC:	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
ESD	Electrostatic Discharge
EUSIPCO	European Signal Processing Conference
FM	Frequency Modulation
GPS	Global Positioning System
GUI	Graphical User Interface
IEEE:	Institute of Electrical and Electronics Engineers
IWCMC	International Wireless Communications and Mobile Computing Comference
LEMP	Lightning Electromagnetic Pulse
LOS	Line-of-Sight
MATLAB	Matrix Laboratory
MIMO	Multiple Input Multiple Output
NLOS	Non Line-of-Sight
NEMP	Nuclear Electromagnetic Pulse

NNEMP	Non-Nuclear Electromagnetic Pulse
OFDMA	Orthogonal Frequency-Division Multiple Access
pdf	Probability density function
PIER	Progress In Electromagnetic Research
RF:	Radio Frequency
RFI	Radio Frequency Interference
SNR	Signal to Noise Ratio
WLAN	Wireless Local Area Network

ABSTRACT

This study is concerned with the analysis of signal strength and loss pattern of IEEE 802.11 wireless LANs. The efforts of which involved Electromagnetic Compatibility (EMC) assessment of the various access points (APs) operating in both 2.4GHz and 5GHz Frequencies from the Ahmadu Bello University Zaria, Wireless Network, at varied locations and times, using Middleton Class A model and MATLAB/SIMULINK model. The result indicate Electromagnetic Interference (EMI) based error of **0.612** and **0.743** at the 2.4GHz and 5GHz Radio Frequency respectively, indicating a better throughput at the side of 2.4GHz Frequency.

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION TO EMC

One major trend in the implementation of networking is the increased adoption of wireless networks, primarily due to the advantages it offers over its wired counterpart. Current generation of wireless networking is considerably slower than conventional wired networks, limited by Shannon's information capacity theorem. More importantly is by the use of wireless signals susceptibility to the electromagnetic propagation in an omnidirectional manner. This gives rise to the characteristics of wireless propagation (e.g. interference and attenuation) and the resulting objects (e.g. metallic objects and other unlicensed 2.4Ghz products) that can hinder or impair wireless network transmissions. This ultimately results in higher loss rates, which reduces the bandwidth available to the end user. Thus understanding wireless characteristics in electromagnetic environment is fundamental for improving transport protocols leading to a reduction in errors and resulting in increased network throughput and determining an optimum position to achieve maximum wireless performance. (Wilson, 1988)

1.1.1 Concept of Electromagnetic Compatibility

Electromagnetic compatibility (EMC) is the branch of electrical sciences which studies propagation and reception of electromagnetic energy with reference to the unwanted effects (Electromagnetic interference, or EMI) that such energy may induce(Loyka, 2002). The goal of EMC is the correct operation, in the same electromagnetic environment, of different equipment which use electromagnetic phenomena, and the avoidance of any interference effects.(Loyka, 1999)

In order to achieve this, EMC pursues two different kinds of issues. Emission issues are related to the unwanted generation of electromagnetic energy by some *source*, and to the countermeasures which should be taken in order to reduce such generation and to avoid the escape of any remaining energies into the external environment. Susceptibility or immunity issues, in contrast, refer to the correct operation of electrical equipment, referred to as the *victim*, in the presence of unplanned electromagnetic disturbance and hence electromagnetic compatibility is achieved primarily by addressing both emission and susceptibility issues, i.e., quieting the sources of interference and hardening the potential victims. The coupling path between source and victim may also be separately addressed to increase its attenuation. (Loyka, 2002)

1.2 TYPES OF INTERFERENCE

Electromagnetic interference divides into several categories according to the source and signal characteristics. The origin of noise can be man-made or natural. (Mordachev and Loyka 1998)

1.2.1 Continuous Interference

Continuous, or Continuous Wave (CW), interference arises where the source regularly emits a given range of frequencies. This type is naturally divided into sub-categories according to frequency range, and as a whole is sometimes referred to as "DC to daylight".

a. Audio Frequency, from very low frequencies up to around 20 kHz. Frequencies up to 100 kHz may sometimes be classified as Audio. Sources include:

i. Mains hum from power supply units, nearby power supply wiring, transmission lines and substations.

ii. Audio processing equipment, such as audio power amplifiers and loudspeakers.

iii. Demodulation of a high-frequency carrier wave such as an FM radio transmission.

b. Radio Frequency Interference, RFI, from 20 kHz to a limit which constantly increases as technology pushes it higher. Sources include:

i. Wireless and Radio Frequency Transmissions

ii. Television and Radio Receivers

iii. Industrial, scientific and medical equipment

iv. High Frequency Circuit Signals (For example microcontroller activity)

c. Broadband noise may be spread across parts of either or both frequency ranges, with no particular frequency accentuated. Sources include:

i. Solar Activity

ii. Continuously operating spark gaps such as arc welders

iii. CDMA mobile telephony

1.2.2 Transient (Pulse) Interference

Electromagnetic Pulse, EMP, also sometimes called Transient disturbance, arises where the source emits a short-duration pulse of energy. The energy is usually broadband by nature, although it often excites a relatively narrow-band damped sine wave response in the victim.

Sources divide broadly into isolated and repetitive events.

a. Sources of isolated EMP events include:

i. Switching action of electrical circuitry, including inductive loads such as relays, solenoids, or electric motors.

ii. Electrostatic Discharge (ESD), as a result of two charged objects coming into close proximity or even contact.

iii. Lightning Electromagnetic Pulse (LEMP)

iv. Nuclear Electromagnetic Pulse (NEMP), as a result of a nuclear explosion.

v. Non-Nuclear Electromagnetic Pulse (NNEMP) weapons.

vi. Power Line Surges/Pulses

b. Sources of repetitive EMP events, sometimes as regular pulse trains, include:

i. Electric Motors

ii. Gasoline engine ignition systems

iii. Continual switching actions of digital electronic circuitry.

1.3 ELEMENTS OF AN EMC PROBLEM

There are three essential elements to an EMC problem as illustrated in Figure 1.1. There must be a source of electromagnetic energy, a receptor (or victim) that cannot function properly due to the electromagnetic energy, and a path between them that couples the energy from the source to the receptor. Each of these three elements must be present although they may not be readily identified in every situation. Electromagnetic compatibility problems are generally solved by identifying at least two of these elements and eliminating (or attenuating) one of them. (Rajendra,2009).

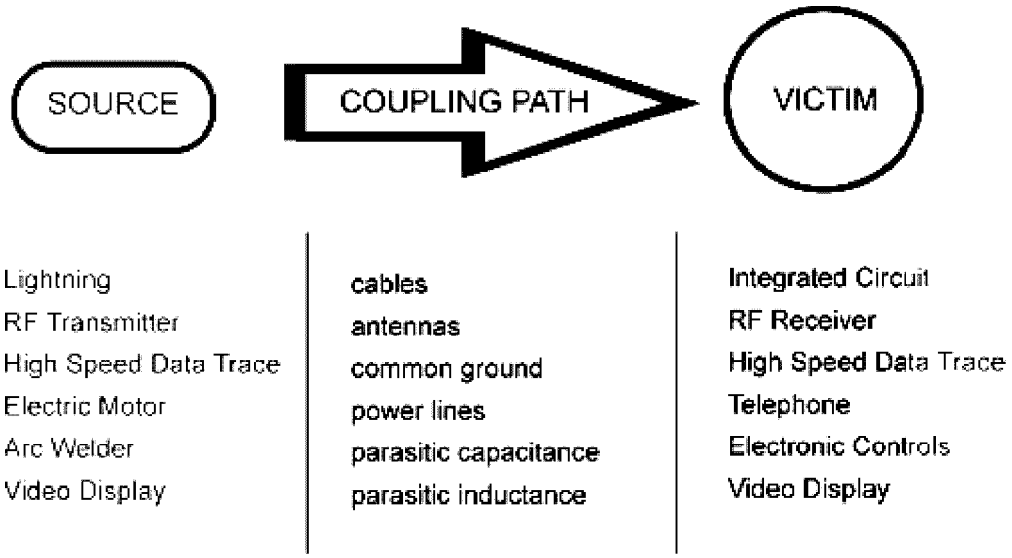


Figure 1.1 The Three Essential Elements of an EMC Problem.

1.4 WIRELESS NETWORKING STANDARDS

Institute of Electrical and Electronics Engineers (IEEE) (WLAN Association, 2002) has specified various WLAN standards. Some important standards in the context of this thesis are summarized in Table 1.1.

Table 1.1 IEEE WLAN Standards

Standard	**Description**	**Approved**
IEEE 802.11	Data rates up to 2Mbps in 2.4-GHz ISM band	July 1997
IEEE 802.11a	Data rates up to 54Mbps in 5-GHz UNII band	Sept 1999. End user product began shipping in early 2002
IEEE 802.11b	Data rates up to 11Mbps in 2.4-GHz ISM band	Sept 1999. End user product began shipping in early 2000

Other standards are the following:

IEEE 802.11g

In 2002 and 2003, WLAN products supporting a newer standard called 802.11g emerged in the market. 802.11g attempts to combine the best of both 802.11a and 802.11b. 802.11g supports bandwidth up to 54 Mbps, and it uses the 2.4 GHZ frequency for greater range. 802.11g is backwards compatible with 802.11b, meaning that 802.11g access points will work with 802.11b wireless network adapters and vice versa. (WLAN Association, 2002)

IEEE 802.11n

The newest IEEE standard in the WiFi category is 802.11n. It was designed to improve on 802.11g in the amount of bandwidth supported by utilizing multiple wireless signals and antennas (called MIMO technology) instead of one. When this standard is finalized, 802.11n connections should support data rates of over 100 Mbps. 802.11n also offers somewhat better range over earlier WiFi standards due to its increased signal intensity. 802.11n equipment will be backward compatible with 802.11g gear. IEEE 802.11n (2009)

1.5 RESEARCH OBJECTIVE

Wireless LAN communication suffers distortions as a result of continuous interference of signal arising from the following: radio transmitters, power lines, electronic circuits, lightning, lamp dimmers, electric motors, arc welders, solar flares and just about anything that utilizes or creates electromagnetic energy. The main objective of this work is to identify EMC issues if any and provide a means by which the Susceptibility or immunity of the wireless network can be enhanced.

1.6 PROBLEM STATEMENT

The primary concern of a wireless local area network (WLAN), like any other communication network, is to ensure that the technology is deployed in a way that preserves the integrity of the information technology infrastructure and delivers an acceptable level of service for the users of that technology. It is a known fact that there are problems associated with most if not all wireless networks. These includes electromagnetic interference, insecure data due to signal spill, ad-hoc unauthorized access points and suppression and degradation of signal due to physical barriers along the line of sight, attenuations, scattering, reflections e t c.

This study will thus seek to assess the electromagnetic compatibility issues that are found within the A B U Zaria 2.4GHz and 5GHz wireless network community, with the intent of exploring and determining a possible remedy.

1.7 THESIS OUTLINE

The thesis is divided into five chapters: Chapter One introduces the research work where the objectives of the research are defined and the concepts under consideration are explained. The reviews of literature of similar research work, with the theoretical background are contained in Chapter Two. Chapter Three discusses the methodology in achieving the thesis aims, while Chapter Four deals with the analysis of the results obtained. Chapter Five explains conclusion and recommendation proffered, while references are provided at the end of the work.

CHAPTER TWO

LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 LITERATURE REVIEW

Several researches have been carried out on wireless LAN environments for different purposes, including EMC/EMI and data driven approaches. This chapter aims at reviewing previous works carried out in relevant and related areas

Wilson (1988) expressed the factors affecting signals in an electromagnetic environment which includes Atmospheric absorption, Noise, Reflection, Diffraction, Scattering and most importantly Interferences. In which case, some ways were proposed for suppressing these impairments. The work however, was not carried out with particular interest to wireless network environment.

Loyka (2002) conducted a research on EMC/EMI analysis in wireless communication networks in which main challenges in EMC/EMI modeling and simulation for wireless communication networks, main differences between EMC/EMI analyses for analog and digital systems were discussed and a computationally efficient approach for system-level simulation of wireless systems at the physical layer was proposed which was efficiently combined with the existing methods of simulation at the signal processing level. Thus, a technique for the simulation of the entire communication link, starting from the source of information and up to the destination point was proposed. The computational efficiency of this approach was expected to be high enough to allow the simulation of real-world systems under real-world conditions in reasonable time and using reasonable computational resources. This contribution was limited to the fact that, only the hardware imperfections were taken into account.

Also Loyka (2000), proposed that Transmission and Reception devices operating at the same frequency, can be a source of many EMC/EMI problems, especially in a complex

electromagnetic environment and the complexity of EMC/EMI analysis in a future wireless network is very large due to the large number of systems in the network and due to the complexity of systems (many Transmission/Reception branches, complex structure of every branch) and of the electromagnetic environment.

Gavan (1995) described main differences between EMC/EMI analyses for analog and digital systems and proposed a computationally efficient approach for system-level simulation of wireless systems at the physical layer. Analytical and semi-empirical methods were extensively used for the analysis of these effect. However, the accuracy of those methods is rather poor. Besides, the analysis of complex systems (present-day digital wireless systems) is rather difficult if not impossible at all to do by the old methods.

Rajendra (2009) focused on power delay profile measurement in an outdoor environment in the 5GHz frequency band. The analysis of wideband channel characteristics that the delay spread parameters (RMS-DS, delay window and CIR*X,dB* duration) increase as the receiver transits into the NLOS region from the LOS region were discussed. Although, the increase in dispersion between these regions, e.g., with a linear or other polynomial fit, can be quantified, results would likely pertain only to certain specific environments.

Zhi (2004) presented a research outcome in which an extensive investigation into the development of a narrow-band radio frequency interference (RFI) mitigation algorithm and performance testing using a software Global Positioning System (GPS) receiver where new interference mitigation methods based on software receivers together with modern digital signal processing techniques was developed and tested.

Peter (2005) carried out a study that analyzed signal strength and loss pattern of a wireless LANs through the extraction and collation of data sets, at the packet level, within IEEE 802.11g wireless LANs using MATLAB. According to him, signal strength has greater effect in establishing the PER (Packet Error Rate) than the physical distance from the router. However, the results indicate that signal strength is of primary importance, and distance comes secondary when determining packet loss.

Axel, *et al.,*(2005)**,** examined the mutual effects of these different communication standards in which the most widespread system in the 2.4 GHz ISM band are IEEE802.11, with IEEE802.15.4 as upcoming standard for short range wireless networks. Measurements are performed with real-life equipment, in order to quantify coexistence issues.

Groubard, *et al.*(2002) discussed the experience of working with wireless systems in the immersive virtual environments refered to as C6 Virtual environment where there is more susceptibility to interferences. This leads to the following wireless system requirements:

i. Provide complete volume coverage, with limited radio frequency (RF) power of the virtual environment.
ii. Provide sufficient bandwidth for user communication with the system.
iii. Minimize interference with other wireless devices.
iv. Low power requirements so that the system can be lightweight and not require frequent recharging or new.

Yang**,** *et al.,* (2007) proposed a standard model for measuring Ultra Wide Band (UWB) indoor channel with an additional knowledge of specific environmental geometry. But they restrict their work on indoor channel modeling.

Ifeanacho (2010) focused on the study of radio wave propagation for outdoor environments using the wireless 2.4GHz network technology with emphasis on loss of signal strength as a result of presence of some obstructions in the line-of-sight between some access points and their corresponding base stations. The study did not however include losses as a result of Interference.

Wang, and Zhang, (2007) in their studies "Wideband cavity-backed patch antenna for PCS/IMT2000/2.4GHz WLAN," stressed the importance of efficient computational techniques for the characterization of propagation in modern wireless communication scenarios but with emphasis only on free space pathloss.

Rappaport (2005) Stated that the factors influencing small scale fading are multipath propagation, the speed of the mobile receiver, the relative speed of surrounding scattering and reflecting objects, and the bandwidth of the transmitted signal. The effects of small scale fading are as follows: Variation in received signal strength over a small distance; delay in multipath causes time dispersion of the signal; Varying Doppler shifts of multipath components leads to random frequency modulation. Although,the emphasis was on small scale fading.

Volker *et al* **(**2009) investigated the performance in an interference-limited environment, and showed that frequency-selective interference knowledge improves the performance by means of optimum combination at the terminal side and yields a more precise estimation of the achievable rates as well. By sharing the same resource among multiple users in a cell, the overall throughput can be enhanced by 68 percent in a cellular 2 × 2 MIMO link compared to the traditional interference whitening approach. This was based on multiple input multiple output antenna system.

David *et al* (2009) suggested that a coverage and interference analysis based on a realistic OFDMA macro/femtocell scenario be provided, as well as some guidelines on how the spectrum allocation and interference mitigation problems can be approached in these networks. Special attention was paid to the use of self-configuration and self-optimization techniques for the avoidance of interference

Sevic, *et al* (1996) in their work suggested that the best likely method for the EMC/EMI analysis of present-day and future wireless systems is a numerical simulation approach.

Shahzad *et al* (2009). Proposed Middleton's three models (class A, B and C) that are statistical physical models which include the non-Gaussian components of natural and man-made noise.These models are canonical in nature i.e. their mathematical form is independent of the physical environment.

The above approaches while good and interesting have limitations as to be fully inplemented in this work. A much more different approach with emphasis on Middleton class A noise model was used on both 2.4GHz and 5GHz frequency bands, using MATLAB and Simulink in this theses.

2.2 RADIO PROPAGATION THEORY

Radio propagation follows well-known laws of physics and refers to the behavior of radio waves when they are transmitted or received. Radio propagation can also be seen as the transfer of energy and is measured in terms of units of power or Watts. This power is measured at the transmitter and the receiver (Ifeanacho, 2010). The signal strength is the total amount of power measured at the receiver. Due to the nature of radio wave propagation, it is usually less than the former because the signal looses power as it moves through the air in form of radio waves.

In free space, all electromagnetic waves (radio, light, X-rays, etc) obeys the inverse square law which states that the power density of an electromagnetic wave is inversely proportional to the square of the distance from the source as shown in equation (2.1)

$$\rho_p \propto \frac{}{} \qquad (2.1)$$

The inverse square law gives rise to what is referred to as Friss transmission formula given by:

$$\frac{}{} = \frac{}{(\quad)} G_{tx} G_{rx} \qquad (2.2)$$

Where P_{tr} is transmitted Power, P_{rx} is received Power, while $\mathbf{G_{tx}}$ and $\mathbf{G_{rx}}$ are transmitter and receiver gain. *L* is the distance between transmitter and receiver,

The free space model provides a measure of path loss as a function of Transmitter-Receiver separation when the transmitter and receiver are within line of sight (LOS) range in free space environment. $\mathbf{PL(d)} = \frac{}{} = \frac{(\quad)}{}$ (2.3)

The above equation is then modified to equation (2.4) which represents the Path Loss as a positive quantity in dB

$$\mathbf{PL(d) = 10Log} \frac{}{} \quad \frac{}{}^{\mathbf{2}} \ \mathbf{dB} \qquad (2.4)$$

Expanding the above equation and considering the fact that for isotropic antenna, $G_{tr} = G_{rx} = 1$ and wave lenght, $= -$, where c is speed of light= 3×10^8 m/s

The above was simplified to yield Path Loss formula;

$$\mathbf{Path\ Loss\ PL\ (dB) = 32.44 + [20 \times log\ f\ (MHz)] + [20 \times log\ R\ (km)]} \qquad (2.5)$$

Where R= distance between transmitter & receiver, f= frequency

2.3 NOISE FLOW

Power levels can sometimes be represented in terms of their signal-to-noise (S/N) ratio. This is important, as many times the ability to receive a signal is not necessarily tied exclusively to the absolute power of the signal at the receive antenna, but the amount of power relative to the noise floor. For instance, if the noise floor in a particular area is particularly high, due to interfering signals or just thermal noise, the S/N ratio will be lower, representing this condition. (Fuschini *e tal*, 2008). With the same amount of power in another area, the noise floor might be much lower, meaning a higher S/N ratio and a better condition to try to receive a signal. These are illustrated in Figure 2.1

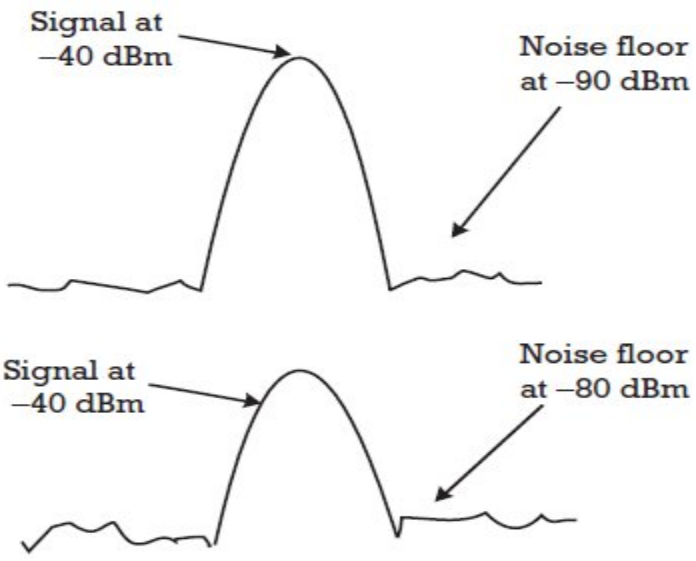


Figure 2.1 Signal and noise floor pattern

Even though the signal levels remain the same, the noise floor rose, and thus the S/N ratio worsened. (Andrew 2003)

2.4 IMPULSIVE NOISE MODELLING

Broadly speaking, man-made interference can be ‘intelligent’ where the interfering signal carries meaningful information or ‘unintelligent’ where the interfering signal carries no (conventional)

information. The latter includes partial discharge (PD), switching transients and combustion engine ignition noise. This deals with 'unintelligent' interference having impulsive characteristics which may dominate close to a source of PD (Middleton, 1983) (Middleton, 1999).

Middleton's three models (class A, B and C) are statistical physical models which include the non-Gaussian components of natural and man-made noise . These models are canonical in nature i.e. their mathematical form is independent of the physical environment. The distinction between the three models is based on the relative bandwidth of noise and receiver. (Shahzad *et al*, 2009)

2.4.1 Middleton Class A Model:

This was adopted in this work becouse it is a tractable analytical model for combined man-made and natural radio noise for the following purposes:

a. It provides a realistic and quantitative description of man-made and natural electromagnetic (EM) interference,

b. It guides experimental protocols for the measurement of such interference,

c. It can be used to identify optimal communication systems and their performance comparison with the sub-optimal systems.

The Middleton Class A Model covers impulsive noise with a spectrum that is narrow compared to the receiver bandwidth and includes all pulses which do not produce transients in the receiver front end . Its probability density function (pdf) is :

$$f_x(x) = e^{-A} \sum_{m=0}^{\infty} \frac{A^m}{m!\sqrt{2\pi\sigma_m^2}} e^{-\frac{x^2}{2\sigma_m^2}} \qquad (2.6)$$

where $\sigma_m^2 = \frac{\frac{m}{A}+\Gamma}{1+\Gamma}$ is the noise variance

Where m is an arbitrary constant $\mathbf{A = v_t T_s}$ is impulse index, $\mathbf{v_t}$ is mean impulse rate and $\mathbf{T_s}$ is mean impulse duration. (Strictly, of course, impulses have a duration that tends to zero and we should really be referring to pulses rather than impulses (Middleton, 1999). The term impulse is used, however, since we are addressing what is universally called impulsive noise. Equation (2.6) is a weighted sum of Gaussian distributions. By increasing impulse index, **A**, the noise can be made arbitrarily close to Gaussian and by decreasing **A** it can be made arbitrarily close to a conventional Poisson process. The model assumes that the individual impulses are Poisson distributed in time. Small values of **A** mean that the probability of pulses overlapping in time is small. Large values of **A** mean that this probability is large (Shahzad *et al,* 2009).

In the latter case the central limit theorem can be invoked resulting in a distribution that tends to Gaussian. The scale factor **Γ** is the ratio of powers in the Gaussian and Poisson (non- Gaussian) components, and is given by:

$$\Gamma = \frac{(X_G^2)}{(X_P^2)} \qquad (2.7)$$

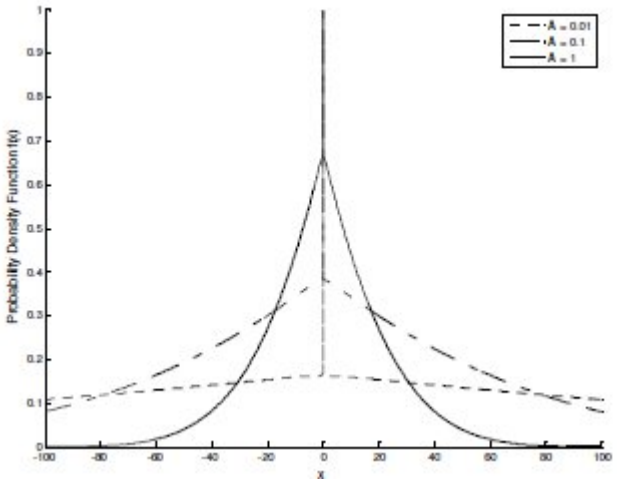


Figure 2.2: Probability density function of the amplitude of Class-A noise for different values of **A** and **Γ**= 0.001

Man-made noise is typically impulsive and therefore not included in the AWGN model. (Shan *et al,* 2008) and (Shahzad *et al,* 2009) reported that transmission systems designed under the AWGN assumption typically suffer from severe performance degradations when exposed to impulsive noise. This shows the need to adapt communication systems to man-made noise.

In (Middleton, 1999),the Class-A, Class-B and Class-C models for man-made noise was introduced. The derivation of the models is based on the mathematical analysis of the physical, noise-generating process. Although the derivation incorporates many simplifications, numerous examples have shown the excellent agreement of the models with measured data from both natural and man-made noise environments.

In this work, the Class-A model is considered. It is distinguished from the Class-B and Class-C models by the assumption that the man-made noise does not cause transients

2.5 AN EMPIRICAL STUDY OF ABU WIRELESS NETWORK

2.5.1 DEFINITION OF TERMS

2.5.2 Base Station

It serves as service or signal provider to either client stations and/or clients (users) that are normally within the remote area (i.e. the network coverage area).

2.5.3 Client Stations

They are wireless devices that receive and transmit signal from the main-base station, to clients within the network coverage area.

2.5.4 Satellite (VSAT)

The term Very Small Aperture Terminal (VSAT) refers to a small fixed earth station. VSATs provide the vital communication link required to set up a satellite based communication network. VSATs can support any communication requirement be it voice, data, or video conferencing.

2.5.5 Modem

It is a device that receives and transmit signal from the satellite to the clients and/or client stations and vice versa.

2.6 IEEE802.11 STANDARDS USED ON THE ABU WLAN

IEEE 802.11 standards used by ABU WLAN are as follows:

2.6.1 IEEE 802.11 a

It is used mainly for digital centers within some faculties in the university. We have 12 of them out of which 10 are deployed in the main campus and the remaining two in the Kongo campus of the university. It has frequency of 5.0 GHz and runs at 54 mbps.(IEEE 802.11a 1999)

2.6.2 IEEE 802.11 b | g

These two standards are used for the one backbone and the three base stations of the network. The same configuration has been used to configure the client stations within each base station of the network. They both have frequency of 2.4 GHz. The major distinction between IEEE 802.11 g and IEEE 802.11 b is that IEEE 802.11 g runs at 54 mbps while IEEE 802.11 b runs at 11 mbps.

2.6.3 IEEE 802.11 b |g versus IEEE 802.11a

IEEE 802.11 g is among the latest WLAN standard in the WiFi category It has a frequency of 2.4GHz as the IEEE 802.11b and it is also backward-compatible with IEEE 802.11b, and not backward compatible with IEEE 802.11a. It covers far distances and it is effective and efficient, only that it has the same data rate with IEEE 802.11a. The major distinction between IEEE 802.11g and IEEE 802.11a is the technology behind them. (KaryGiannis 2002)

2.7 ABU-ZARIA WIRELESS NETWORK LAYOUT

There is one backbone (main base stations) and other 3 base stations for the University wireless LAN deployment, so as to provide effective signal transmission across the campuses as shown in Figure 2.3.

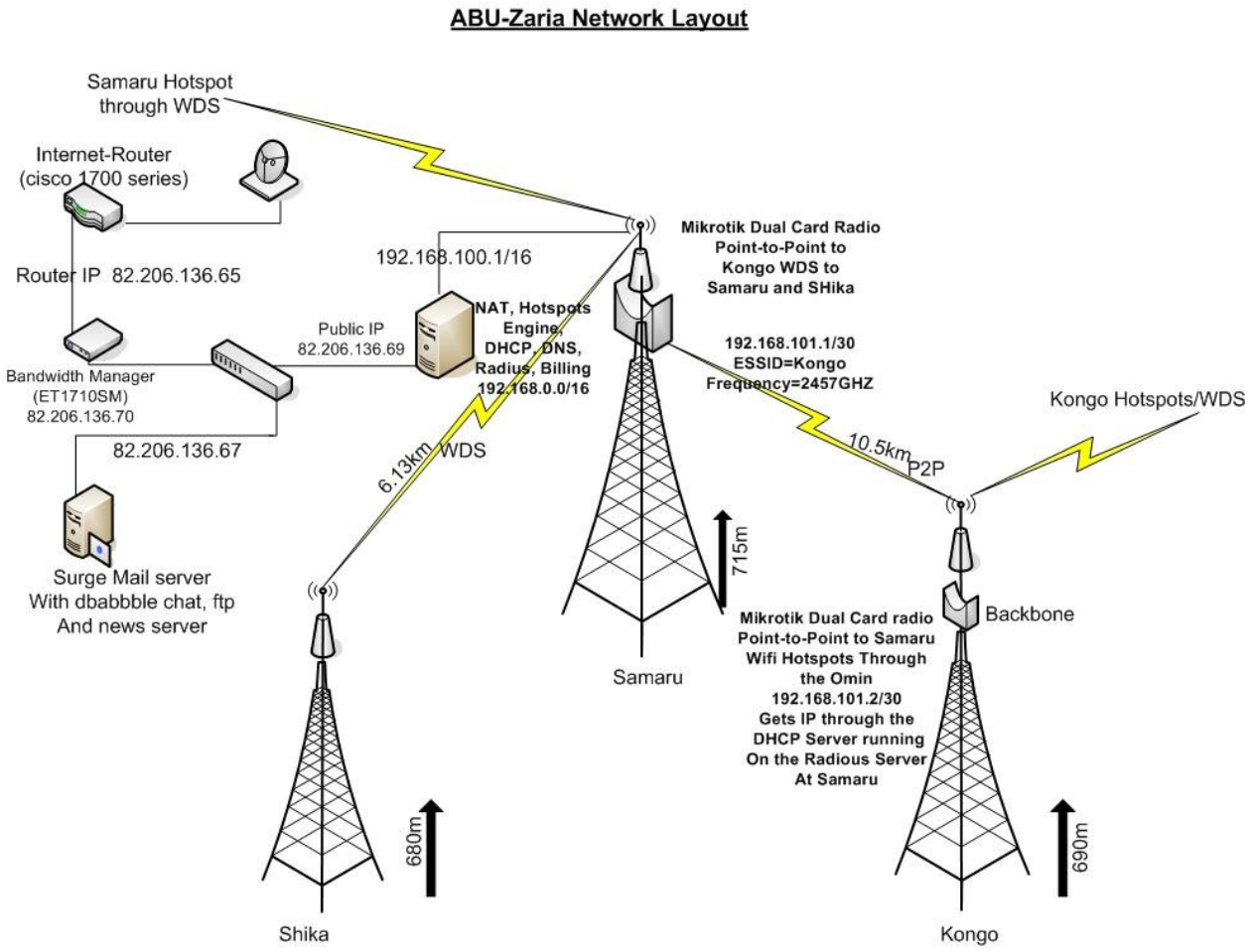


Figure 2.3 ABU Point to Point diagram

Samaru base station (at senate building) is the main backbone or base station via which all the other three base stations are connected as shown in Figure 2.4. This station receives signal from the main service provider's satellite and channelizes it appropriately.

It serves as signal transmitter to the other 3 base stations, which are the Senate WEST base station, Senate EAST base station, and Senate NORTH base station. These base stations connect a number

of client stations across departments and other buildings, which in return connects clients to the network via AP's wirelessly.

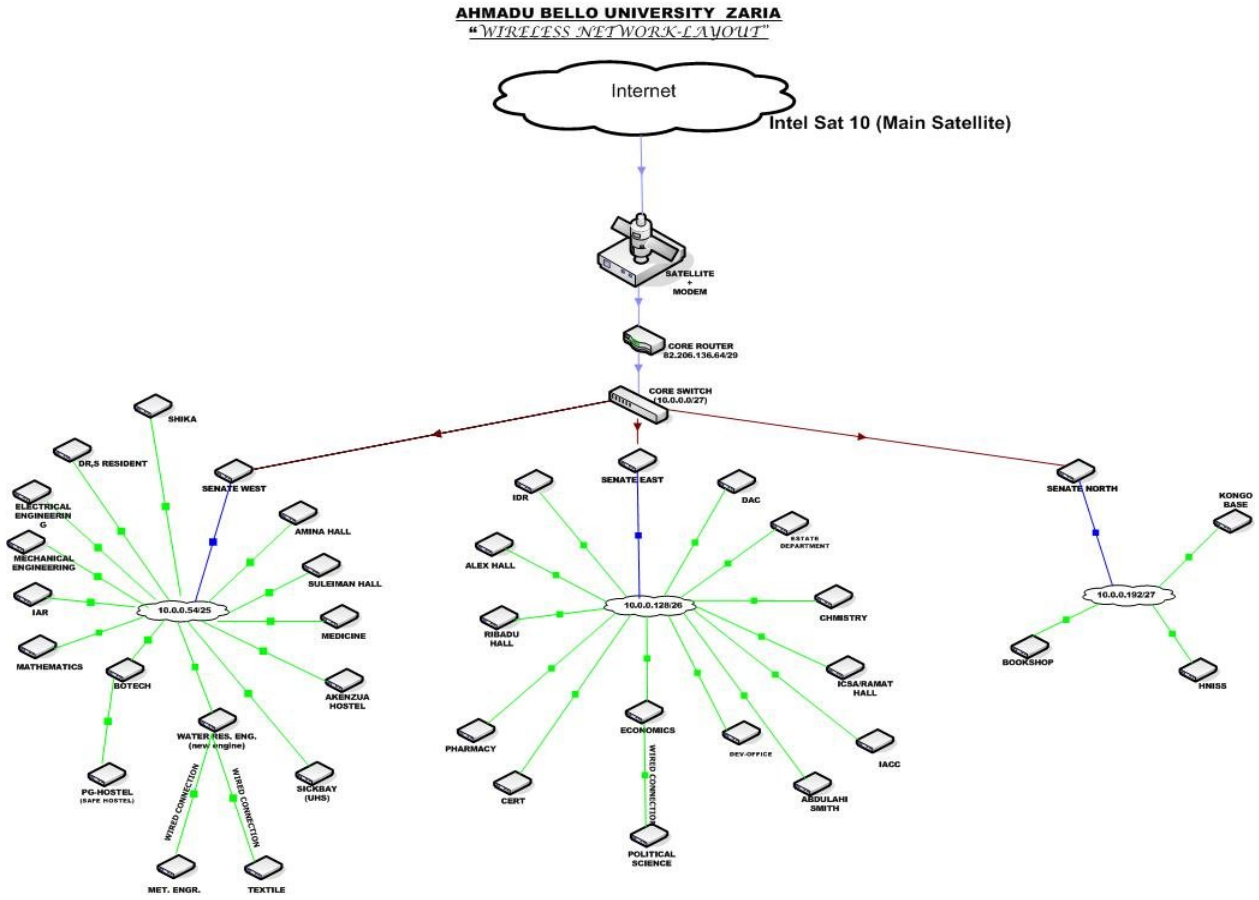


Figure 2.4: General Overview of the Wireless LAN (ABU-WLAN)

2.7.1 Senate West Base Station

This base station connects the following client stations in the campus, which are; Shika, Doctors resident, Mathematics Department, Electrical engineering, Mechanical engineering, IAR, BIOTECH, Wired connection to SAFE HOSTEL, Sickbay(UHS), Akenzua hall, Medicine, Suleiman hall, Amina hall.

Water Resources Engineering (new engineering block) is a newly installed client station that connects Metallurgical Engineering and Textile Science Department using wired connection. The deployment of the Senate WEST base station and its client stations are as shown in Figure 2.5.

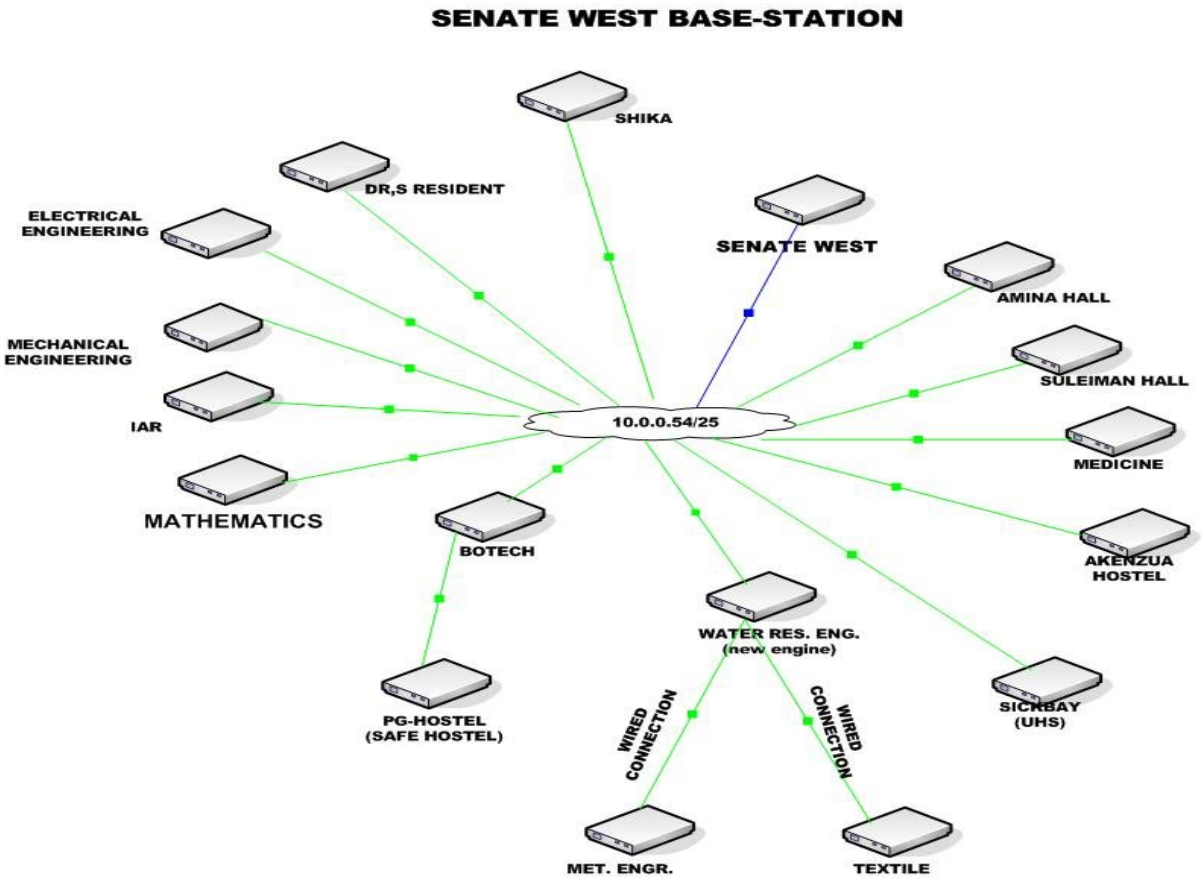


Figure 2.5 Senate West base station

2.7.2 Senate East Base Station

This base station connects the following client stations in the campus, which are; IDR, ALEX hall, RIBADU hall, Pharmacy, CERT, Development Office, Abdullahi Smith, IACC, ICSA/RAMAT, Chemistry, Estate Department, and DAC.

Economics connects Political Science department using wired connection. The deployment of the Senate EAST base station and its client stations are as shown in Figure 2.6.

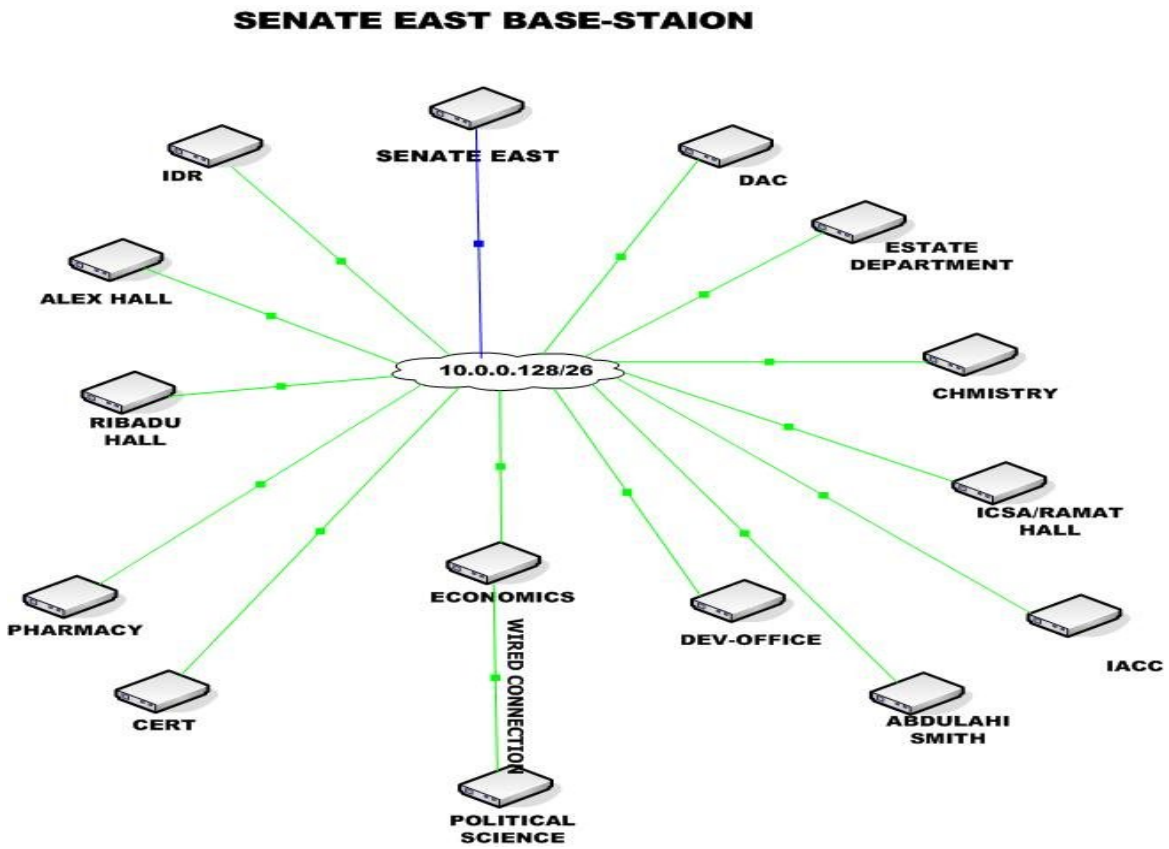


Figure 2.6 Senate East base station

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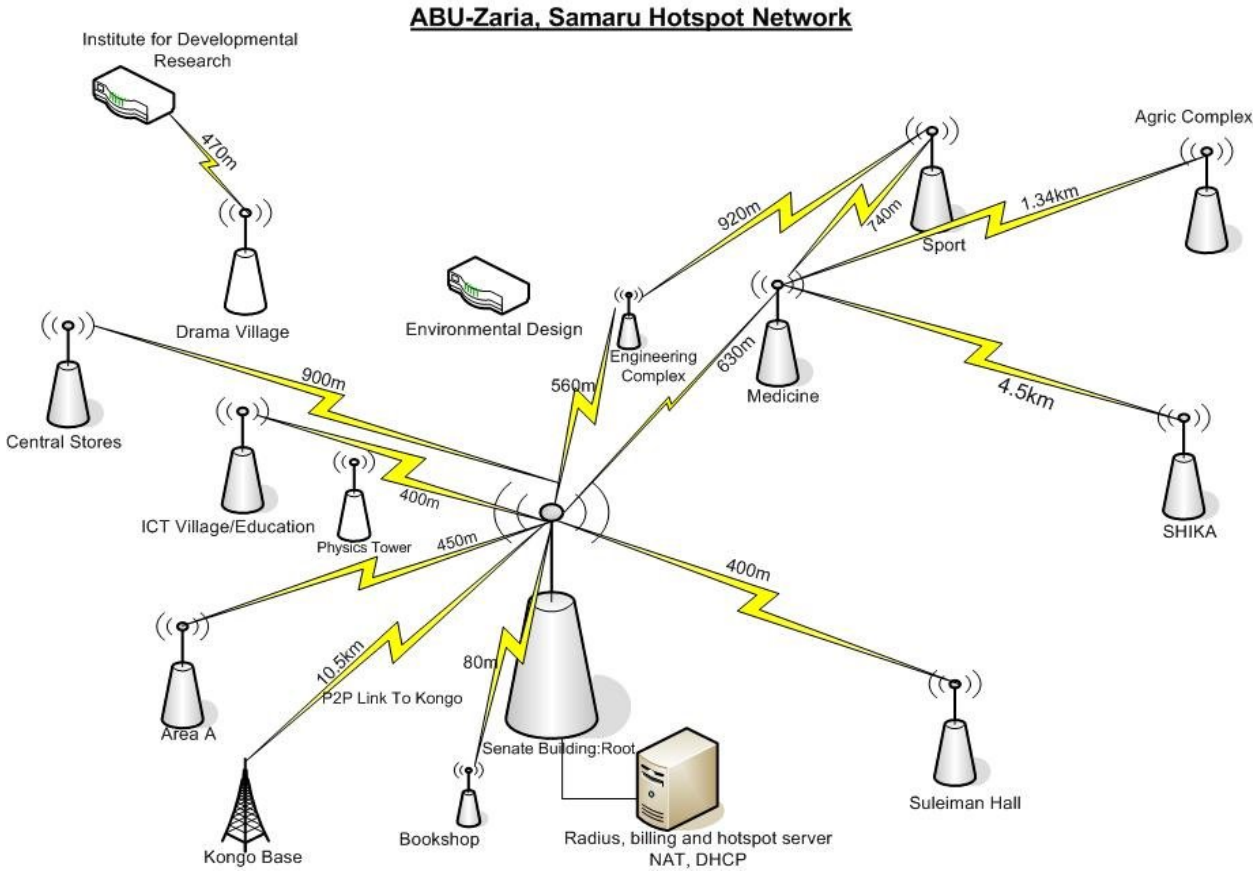


Figure 2.7 ABU Samaru Campus Initial Network Layout

CHAPTER THREE:
METHODOLOGY

3.1 INTRODUCTION

This chapter discussed the methodology adopted in detail in order to fully throw more light on the various approaches towards achieving the set objective of Electromagnetic Compatibility Assessment.

3.2.1 Data Acquisition

This begins with the preparation and collection of data, which includes, signal strength, both transmitted and received rates per day of the various access points present in the two networks, at the 2.4 GHz and 5GHz frequency bands over the period of three months as well as the distances of the various access points to the base stations in the ICT Directorate of Ahmadu Bello University Zaria. The signal strength data is shown in Appendix II.

3.2.2 Procedure of Data Analyses

The data analysis steps covers the following areas;

a. Use of Microsoft Excel® in determining the overall average of the various data for the period of three months.

b. Developing a programme (M-file) using the communication toolbox in MATLAB®. The complete programme is shown in Appendix I (Sevic, *et al,* 1996). This program is designed to carry out the following tasks;

(i) Evaluating the various path loss of the access points and hence generates the various noise floor and determine the signal to noise ratio of these access points that are found within the dual radio network.

(ii) Plotting the bar chat of path loss and signal strength of the various base stations present in the dual network environment.

(iii) Determining system performance using qualitative scatter plots of the network through the plot of pathloss against signal to noise ratio.

(iv) Evaluating the EMI of the various access points using Middleton Class A model and hence producing the Fourier Transform plots of these access points.

c. Development of a Simulink Model using custom built Simulink blocks for both 2.4GHz and 5GHz networks and compare the effects of the signal deterioration with that of EMI plots.**(** Shahzad *et al,* 2009) and (Sebestian 2007)

d. Validation of Simulink Model.

e. The Flow chart of the Matlab programme is given at Figure 3.1 below:

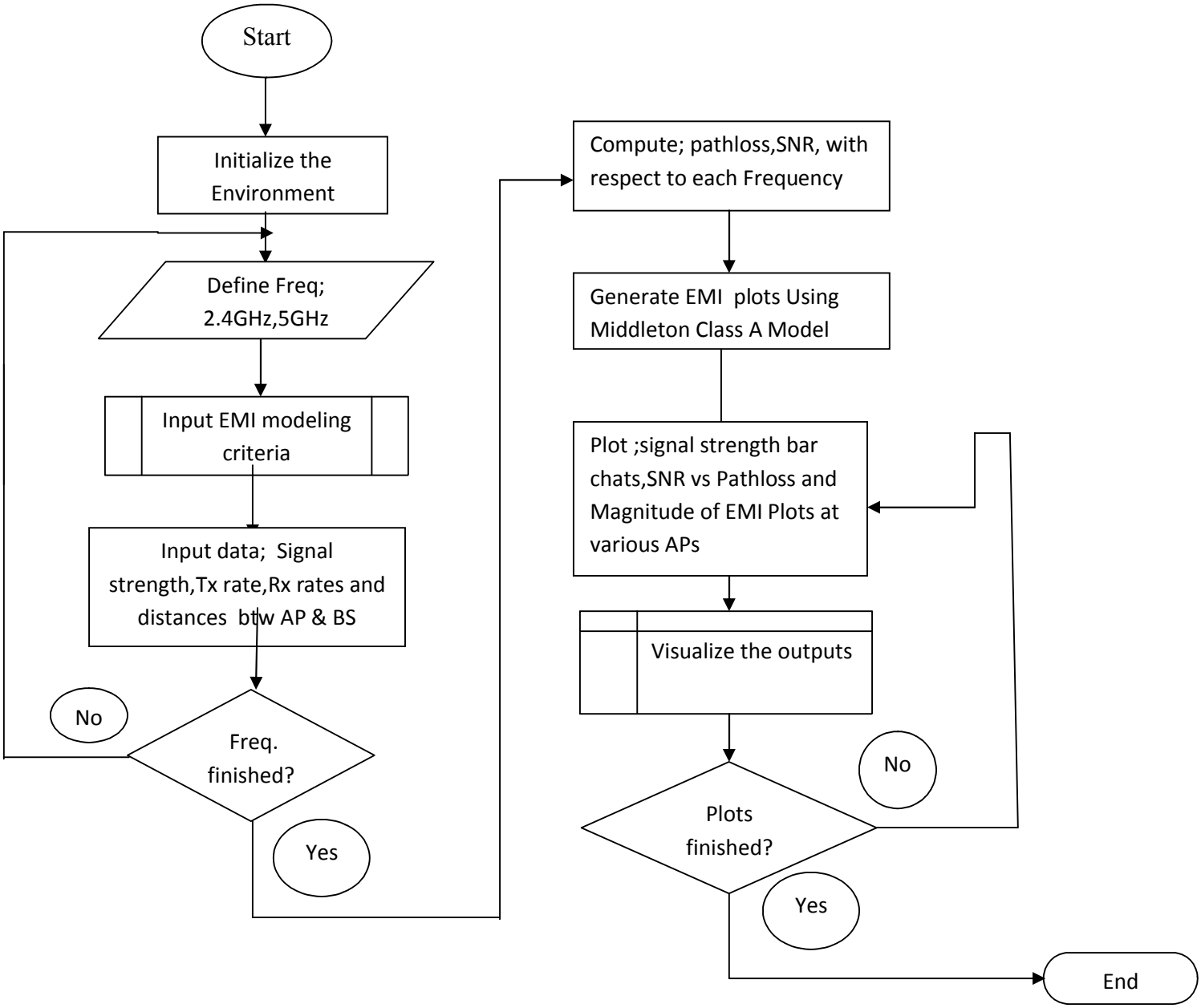


Figure 3.1 Middleton Class A Model Flow Chart

3.3 SIMULINK-BASED MODELLING

Simulink provides a graphical user interface (GUI) for building models as block diagrams, allowing you to draw models as you would with pencil and paper. Simulink also includes a comprehensive block library of sinks, sources, linear and nonlinear components, and connectors. If the existing blocks do not meet the requirements, it is possible to create application-specific blocks. The interactive graphical environment simplifies the modeling process, eliminating the need to formulate differential and difference equations in a language or program.

3.3.1 DEVELOPMENT OF SIMULINK MODEL

Figure 3.2 shows the MATLAB/SIMULINK blocks for the representative model of 2.4 GHz network. Figure 3.3 also shows MATLAB /SIMULINK blocks for the representative model of 5 GHz network.

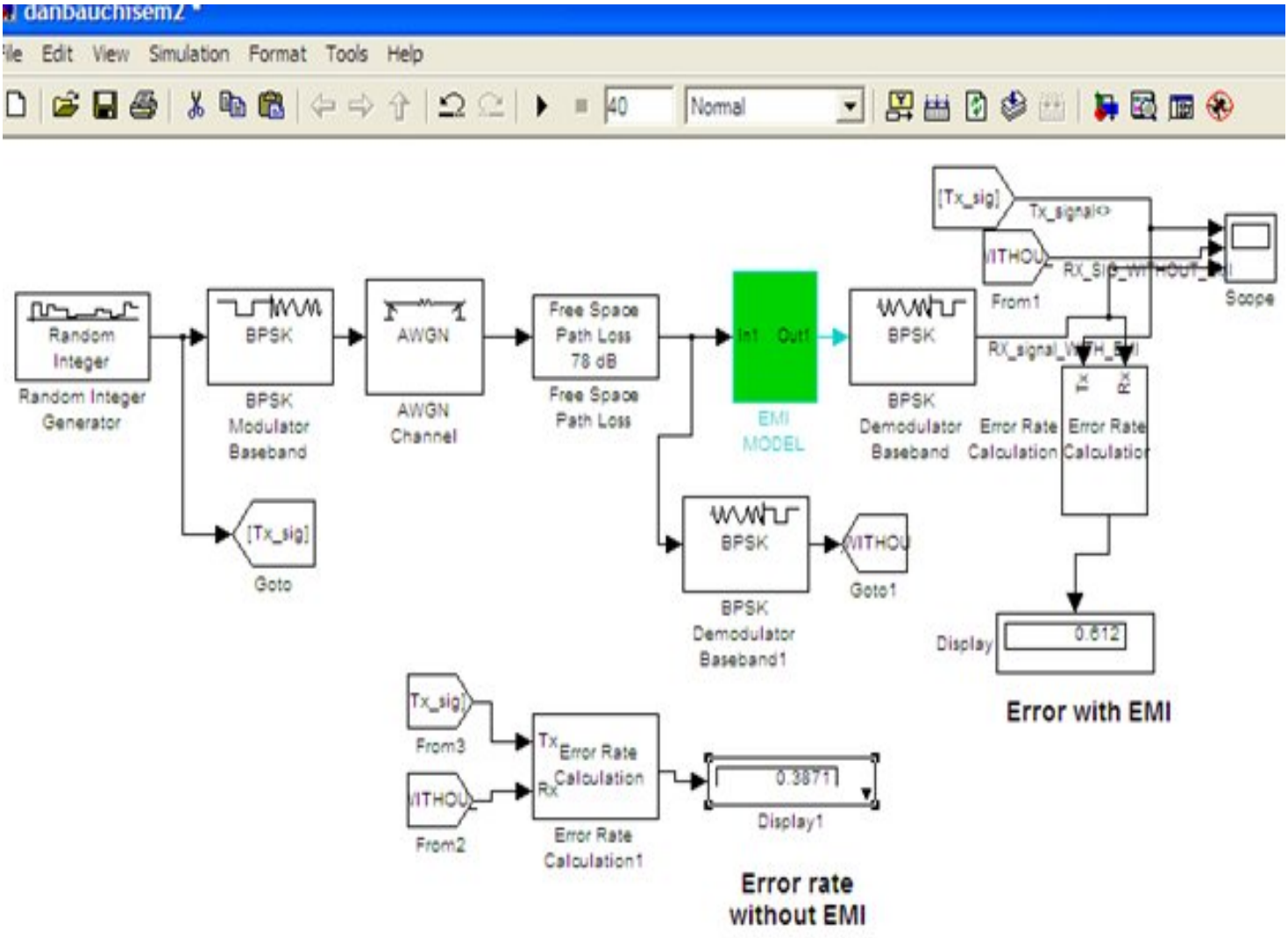


Figure 3.2 MATLAB/SIMULINK blocks for the 2.4 GHz representative model

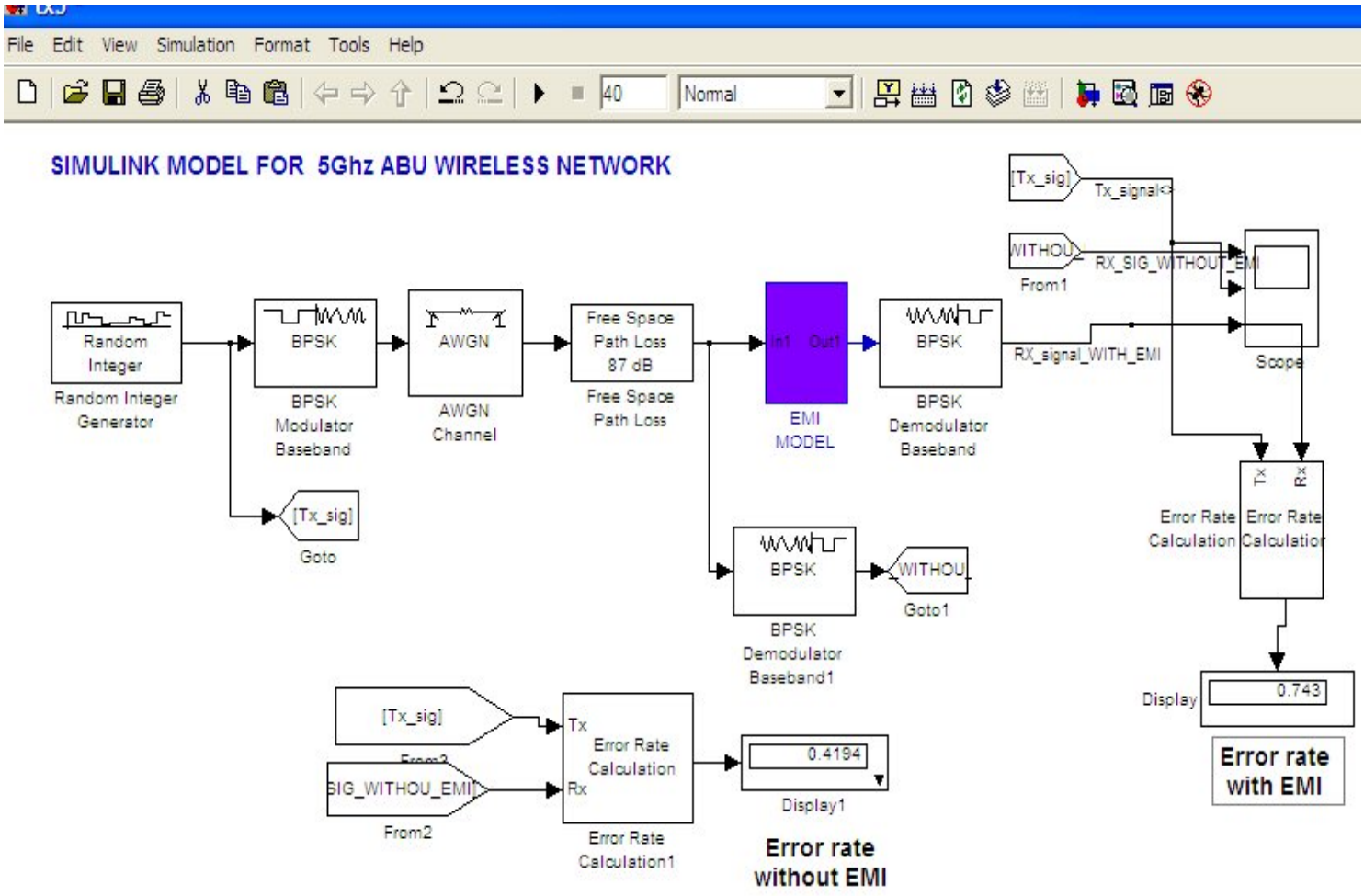


Figure 3.3 MATLAB/SIMULINK blocks for the 5 GHz representative model

3.3.2 Simulink

Simulink® software models were also used in building the model. Simulink® software models simulate, and analyze dynamic systems. With Simulink, one can easily build models from scratch, or modify existing models to meet the set expectations. Simulink supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multirate — having different parts that are sampled or updated at different rates. (Stuat, 2009)

3.3.3 Blocks Used in the Model

(1) Random Integer Generator block

The Random Integer Generator block generates uniformly distributed random integers in the range [0, M-1], where M is the M-ary number defined in the dialog box. The M-ary number can be either a scalar or a vector. If it is a scalar, then all output random variables are independent and identically distributed. If the M-ary number is a vector, then its length must equal the length of the initial seed; in this case each output has its own output range. If the initial seed parameter is a constant, then the resulting noise is repeatable.

(2) BPSK Modulator Baseband block

The BPSK Modulator Baseband block modulates using the binary phase shift keying method. The output is a baseband representation of the modulated signal. For both integer and bit inputs, this block can accept the data types int8, uint8, int16, uint16, int32, uint32, boolean, single, and double.

(3)AWGN Channel block

The AWGN Channel block adds white Gaussian noise to a real or complex input signal. When the input signal is real, this block adds real Gaussian noise and produce a real output signal. When the input signal is complex, this block adds complex Gaussian noise and produces a complex output signal. This block inherits its sample time from the input signal.

(4) Free Space Path Loss block

The Free Space Path Loss block simulates the loss of signal power due to the distance between transmitter and receiver. The block reduces the amplitude of the input signal by an amount that is determined in either of two ways:

By the Distance (km) and Carrier frequency (MHz) parameters, if Distance and Frequency are specified in the Mode field.

By the Loss (dB) parameter, if Decibels is specified in the Mode field

Mode: Method of specifying the amount by which the signal power is reduced. The choices are Decibels and Distance and Frequency.

Loss: The signal loss in decibels. This parameter appears when the Mode is set to Decibels.

Distance: Distance between transmitter and receiver in kilometers. This parameter appears when the Mode is set to Distance and Frequency.

Carrier frequency (MHz): The carrier frequency in megahertz. This parameter appears when the Mode is set to Distance and Frequency.

(5) Error Rate Calculation block

The Error Rate Calculation block compares input data from a transmitter with input data from a receiver. It calculates the error rate as a running statistic, by dividing the total number of unequal pairs of data elements by the total number of input data. This block can be used to compute either symbol or bit error rate, because it does not consider the magnitude of the difference between input data elements. If the inputs are bits, then the block computes the bit error rate.

CHAPTER FOUR

RESULT AND ANALYSIS

4.1 INTRODUCTION

4.1.1 Data Calculations

The calculations were carried out for the determination of the average signal strength of the various access points in both the senate west 2.4 GHz and senate east 2.4 GHz base stations as well as the 5 GHz network, for the period of three months (April to June 2009), the result was tabulated below in Table 4.1

Table 4.1: Average Signal Strength of various access points

S/No	RADIO LOCATION/IDENTITY	DISTANCE FROM BASE TRANSMITTER (m)	AVERAGE SIGNAL STRENGTH (dBm)
SENATE WEST BASE STATION			
1	ENGINEERING	592.0	-53
2	UHS	535.0	-54.41
3	BIOTECH	732.0	-56.47
4	NEW ENGINEERING	641	-52.97
5	AGRIC ENGINEERING	2,457	-71.77
6	IAR	2,462	-47.53
7	AKENZUA	544	-71.10
8	OLD PHARMACY	649	-55.90
9	ESTATE	2,422	-62.83
10	MECHANICAL ENGINEERING	489	-56.27
11	DANFODIO	1,002	-68.90

12	NEW PHARMACY	705	-61.93
13	SAFE HOSTEL	693	-69.00
14	BBC	559	-60.90
SENATE EAST BASE STATION			
1	ECONOMICS	465	-55.24
2	ICSA/RAMAT	505	-60.22
3	ALEXANDRA	163	-50.13
4	RIBADU	163	-54.19
5	IDR	1,151	-52.18
6	DEVELOPMENT OFFICE	136	-45.20
7	CERT	1,341	-52.13
8	IACC	889	-53.17
9	ARCHITECH	375	-48.14
10	MATHS DEPT	58	-47.12
11	ICT PARK	337	-62.13
12	STAFF SCHOOL	444	-45.13
13	ICT DIRECTORATE	78	-50.18
5GHz ACCESS POINTS			
1	ADMIN	10,500	-66.00
2	AGRIC	2,657	-69.00
3	ART	100	-47.00
4	EDUCATION	400	-51.00
5	ENVIRONMENTAL DESIGN	380	-60.00
6	LAW	10,550	-77.00
7	MEDICINE	650	-67.00
8	PHARMACY	700	-64.00
9	SCIENCE	150	-62.00

4.2 RESULTS OBTAINED

The Matlab programme, for the complete EMC assessment of both the 2.4GHz and 5GHz WLAN, was developed and when run produced results as shown in Figures 4.1 to 4.9.These are categorized as follows:

a. Figures 4.1 to 4.3 gave the bar chart (plot) of signal strength of the various access points that are found within the environment.
b. Figures 4.4 to 4.6 gave the scattered plot of signal to noise ratio (SNR) against the path loss of all the access points at various base stations i.e both the 2.4 GHz senate west and east as well as the 5GHz network environment.
c. Figures 4.7 to 4.9 gave the Fourier transform of the electromagnetic interference using the Middleton's class A model .This provides the magnitude of the EMI at various points in the network.

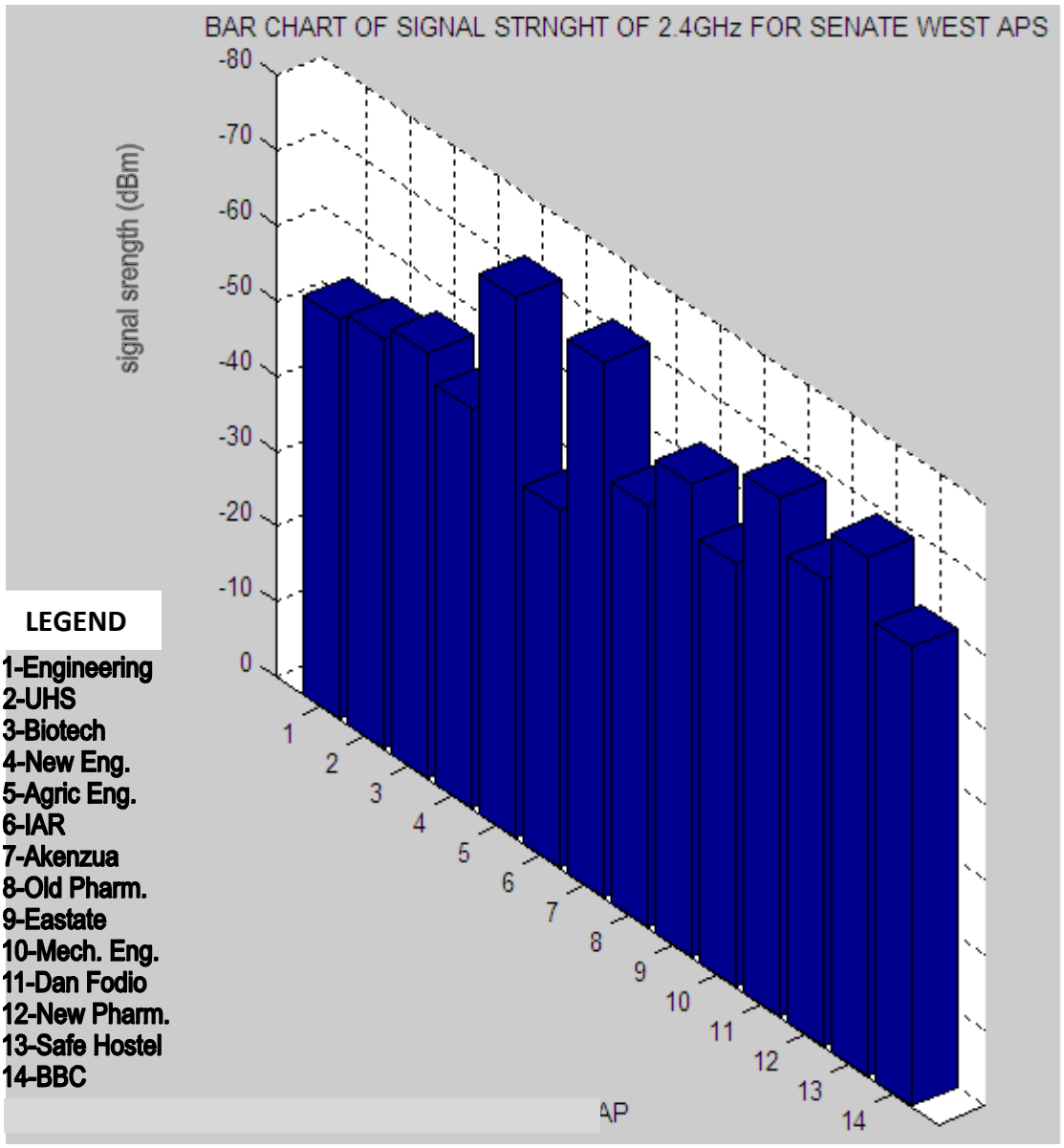


Figure 4.1 Signal Strength Bar chart of Senate-West Access Points

In Figure 4.1, it could be noted that Agric Engineering, Akenzua hostel,Dan Fodio and Safe Hostel are the access points with higher signal strength as compared with Institute of Agricultural Research(IAR) that has the lowest signal strength in the Senate West Base Station.

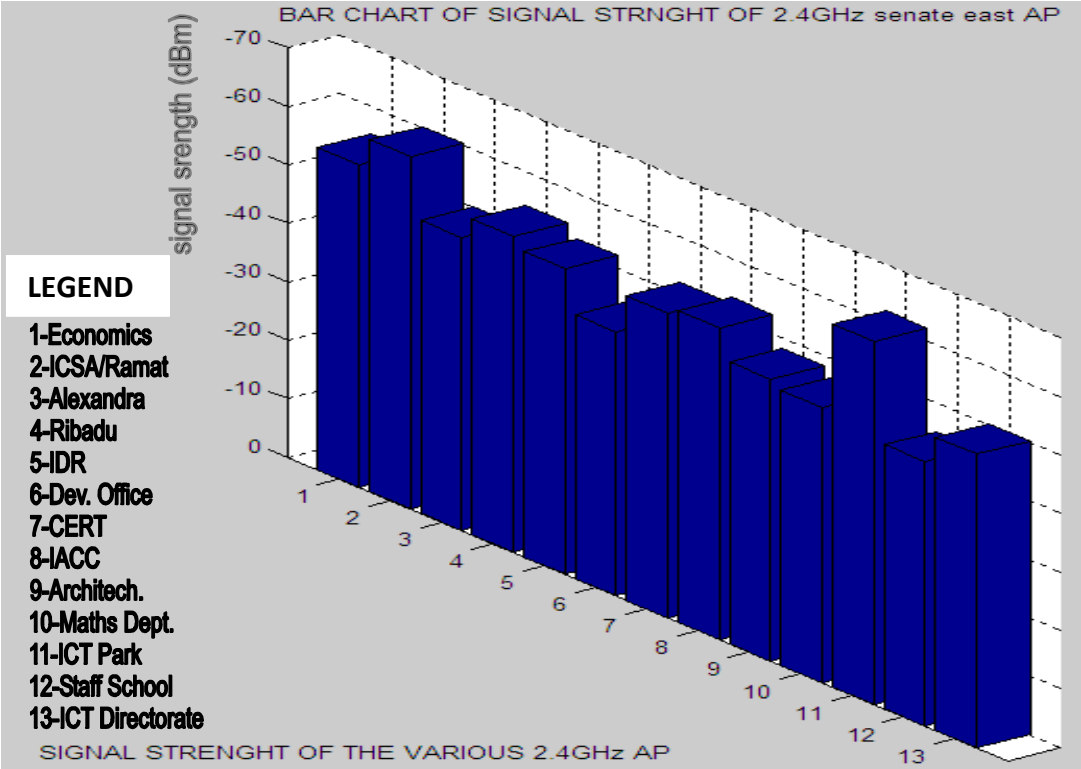


Figure 4.2 Signal Strength Bar chart of Senate-East Access Points

Figure 4.2 indicated that Staff School and Development Office are the Access Points with the lowest signal strength while ICT Park and ICSA/Ramat possessed higher signal strength in the Senate East Base Station.

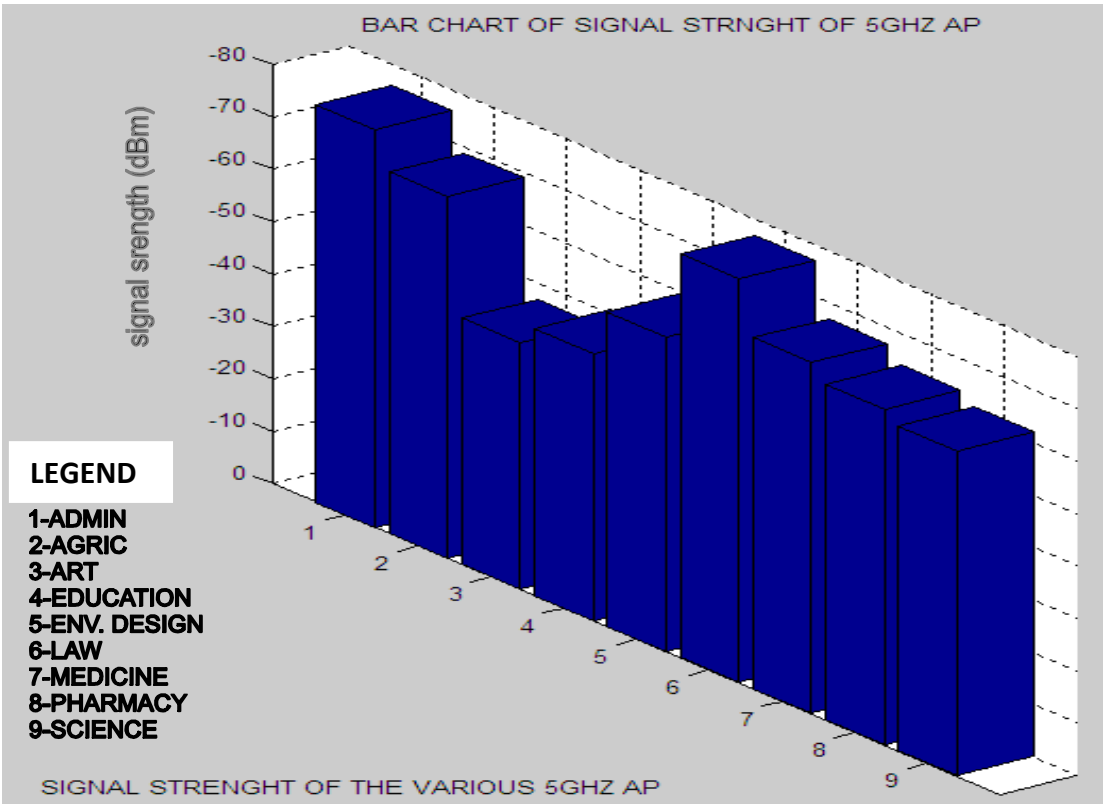


Figure 4.3 Signal Strength Bar chart of 5GHz Access Points

Figure 4.3 illustrated that the Signal Strength is higher in the Fuculty of Art And Faculty of Education while Faculty of Law and Faculty of Administration has the lowest signal strength in the 5GHz network.

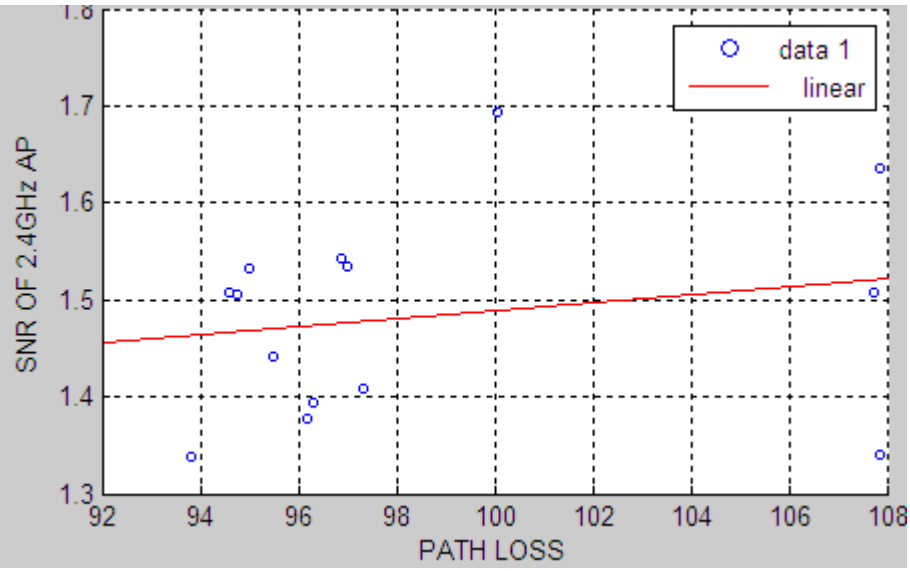


Figure 4.4 Graph of SNR Against Path Loss for Senate-West Aps

Figure 4.4 gives the scatter plots of the Signal to Noise ratio (SNR) against the Path Loss in which Matlab representation of linear plot gives 1.46 as the point with least SNR,that is point of intersection of SNR axis in the 2.4GHz Senate West Base Station.

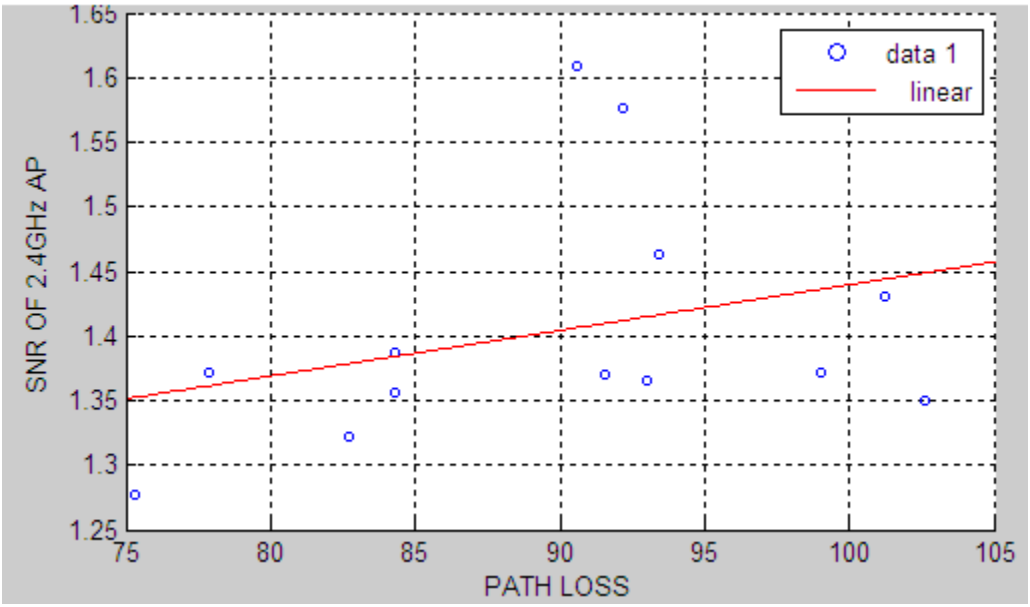


Figure 4.5 Graph of SNR Against Path Loss for Senate-East Aps

Figure 4.5 illustrates the graph scatter plots of the Signal to Noise ratio (SNR) against the Path Loss in which Matlab representation of linear plot gives 1.35 as the point with least SNR, that is point of intersection of SNR axis in the 2.4GHz Senate East Base Station.

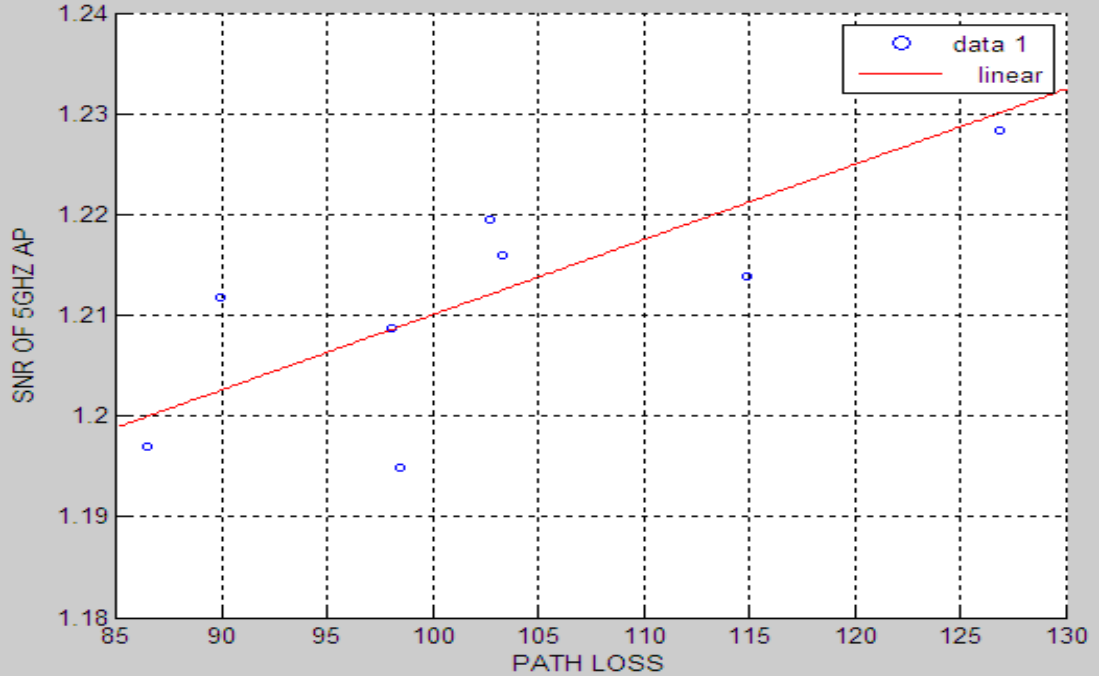


Figure 4.6 Graph of SNR Against Path Loss for 5GHz Aps

Figure 4.6 gives the scatter plots of the Signal to Noise ratio (SNR) against the Path Loss in which Matlab representation of linear plot gives 1.198 as the point with least SNR that is point of intersection of SNR axis in the 5GHz network, indicating lowest SNR.

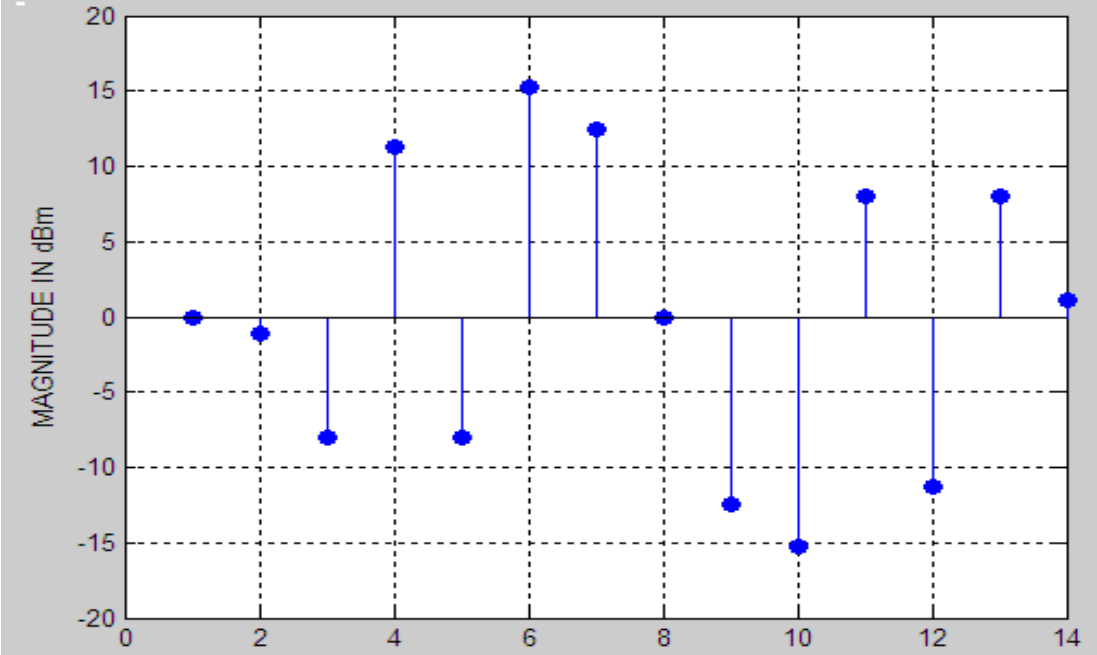


Figure 4.7 EMI Magnitude Plot of Senate-West Access Points

Figure 4.7 Shows magnitude of EMI at the various access points in the 2.4GHz senate west base station indicating that New Engineering, IAR, Akenzua, Danfodio and Safe Hostel as access points with constructive Interferences. While Biotech, Agric Engineering, Estate, Mechanical Engineering and New Pharmacy as access points with destructive Interference. But Engineering,University Health Services (UHS) and BBC studio has no interference.

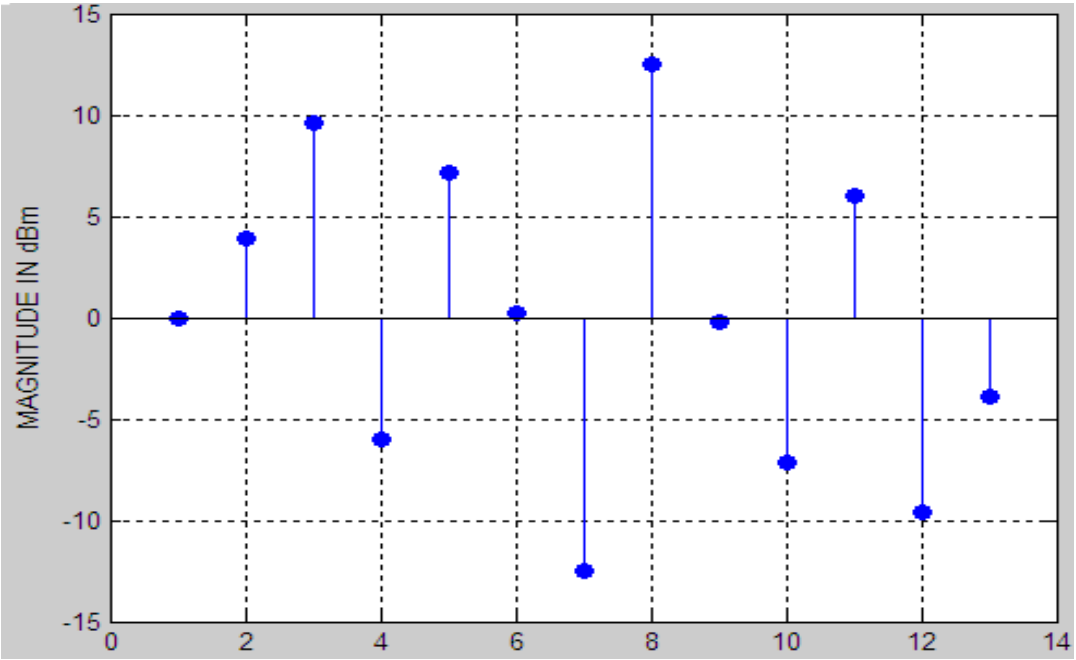


Figure 4.8 EMI Magnitude Plot of Senate-East Access Points

Also,Figure 4.8 Shows magnitude of EMI at the various access points in the 2.4GHz senate east base station indicating that ICSA/Ramat, Alexandra, Institute of Development Research (IDR), Iya Abubakar Computer Center (IACC) and ICT Park as access points with constructive Interferences. While Ribadu, Center for Energy Research and Training (CERT), Maths Department,Staff School and ICT Directorate as access points with destructive Interference. But Economics Department, Development Office and Architechture Department have no interference.

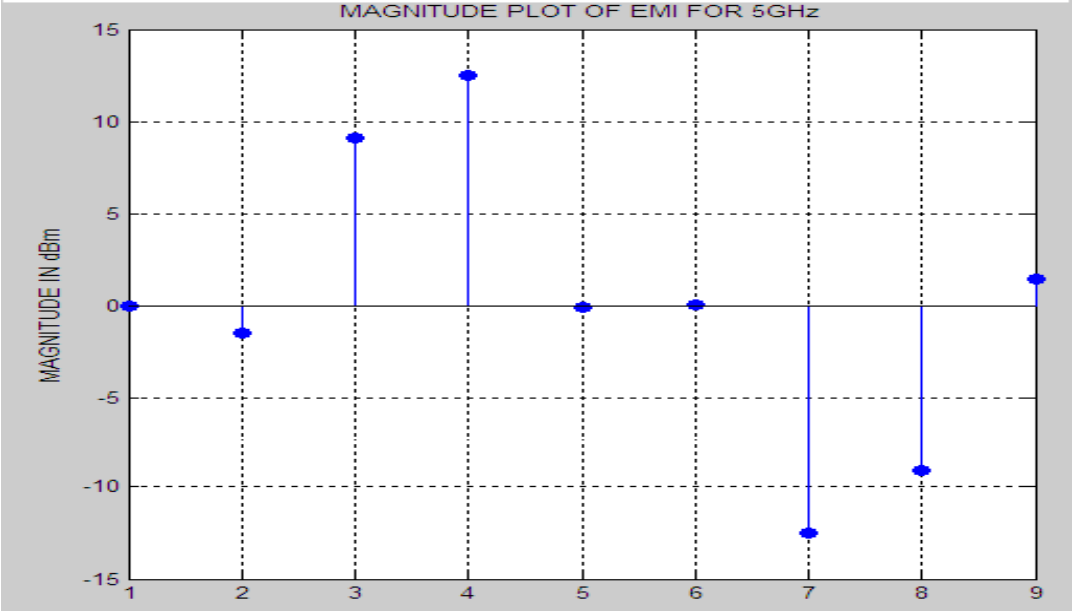


Figure 4.9 EMI Magnitude Plot of 5GHz Access Points

Figure 4.9 Shows magnitude of EMI at the various access points in the 5GHz Network indicating that Faculty of Art and Faculty of Education, as access points with constructive Interferences. While Faculty of Medicine and Faculty Pharmacy are the access points with destructive Interference. But Faculty of Administration, Faculty of Environmental Design and Faculty of Law are access points with no interference.

4.3 RESULT ANALYSIS BASED ON SIMULINK MODEL DISPLAY

Figure 4.10 and Figure 4.11 shows the display of signal deterioration as a result of effect of EMI on both 2.4 GHz and 5 GHz networks respectively.

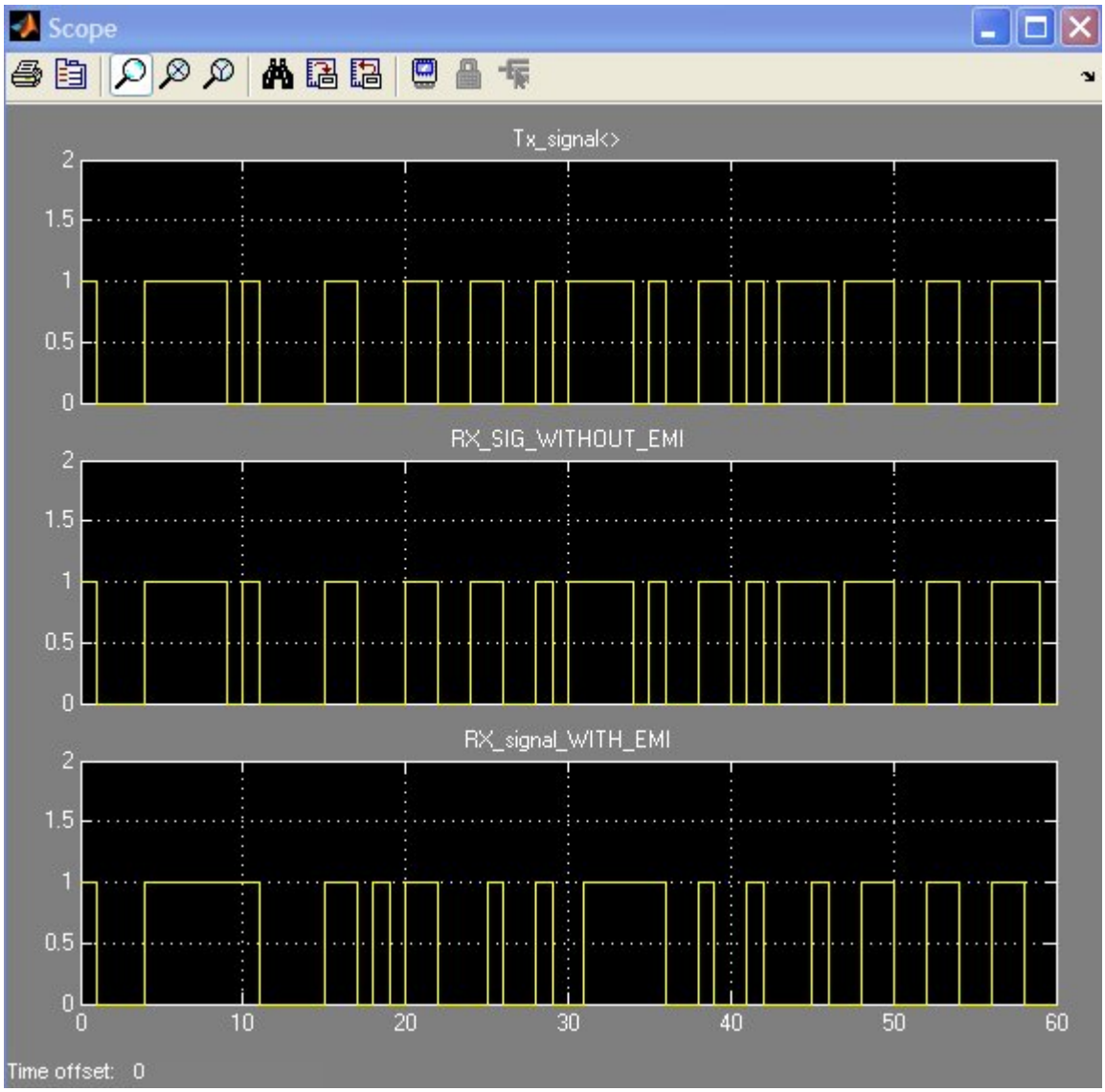


Figure 4.10 EMI Distortion of Signal Display in 2.4 GHz Network

Figure 4.10 shows the Oscilloscopic display of the effects of EMI, based on Littleton Class A Model, on the transmitted signal as can be seen to cause Jitters at points 20,25 and 40 in the 2.4GHz network

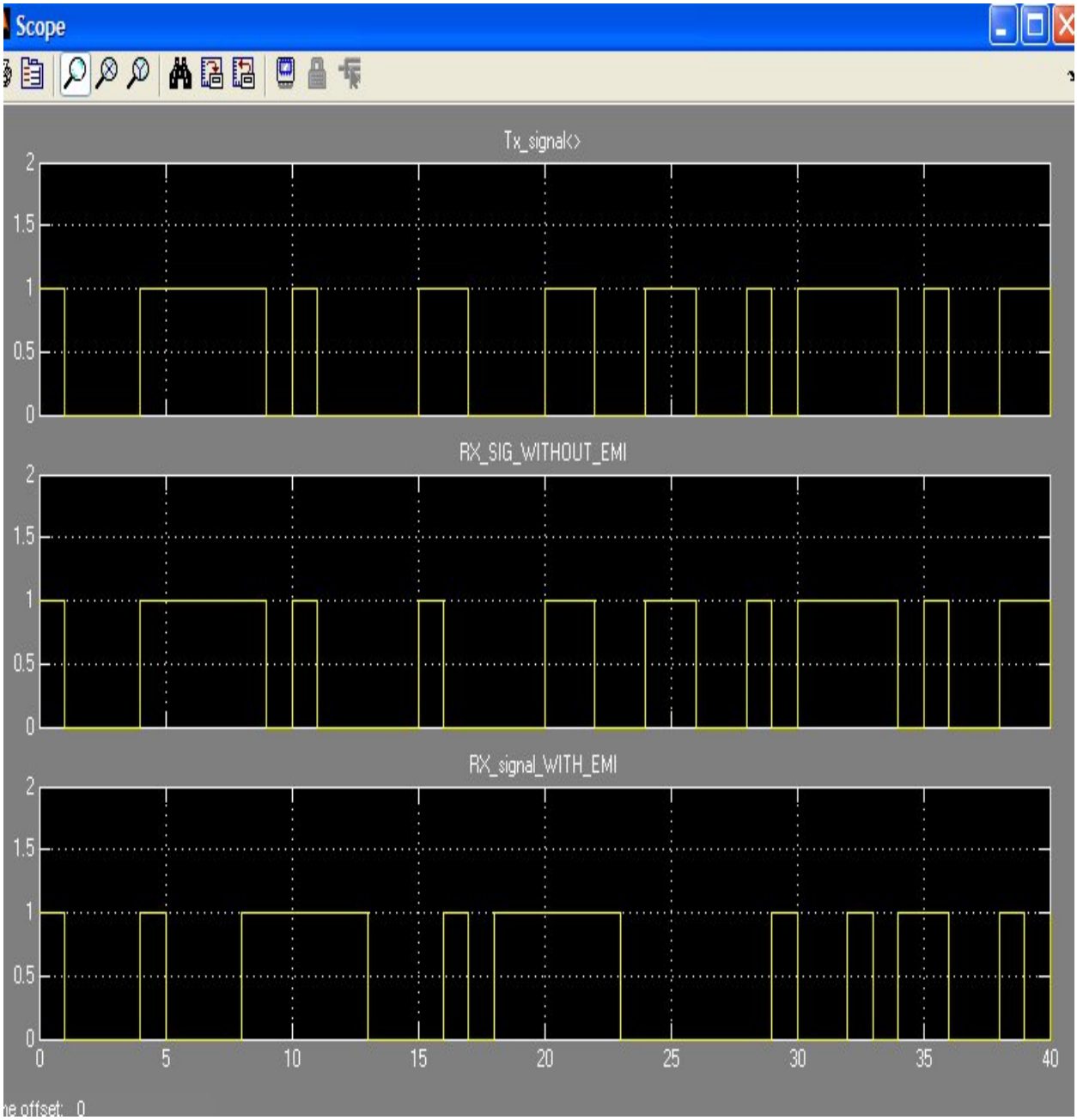


Figure 4.11 EMI Distortion of Signal Display in 5 GHz Network

Figure 4.11 shows the Oscilloscopic display of the effects of EMI, based on Littleton Class A Model, on the transmitted signal as can be seen to cause Jitters at points 10,15, 20, 25,35 and 40 in the 5GHz network

4.4 DISCUSSION OF RESULTS OBTAINED

The signal strength is seen to be dependent on, among other things ,the distance from the base station. The further away the access point is the more likely it is for the signal to deteriorate. As can be seen from Figures 4.1 to 4.3

The results also confirms that while the 5GHz frequency network is better in terms of immunity to EMI, it is more prone to noise than the other 2.4GHz frequency network as can be seen to have the lowest point of intercept on the SNR axis, as illustrated in Figures 4.4 to 4.6

Also, From the plots of Figures 4.7 to 4.9, it can be clearly seen that, the signal distortion or magnitude of destructive EMI as a result of influence of EMI is more evident in the 2.4 GHz networks. While in the case of 5GHz network it shows less fluctuations except for access points 7, 8 and 9 located at Faculties of Medicine, Pharmacy and Sciences respectively which could be attributed to the presence of Medical and Scientific equipment in the environment that induces Doppler shift that causes destructive effect on the magnitudes of EMI.

It could be seen from the models that the Error rate at the **5GHz** Model is higher **0.743** as against that of **2.4GHz** that was only **0.612**.

Furthermore, when comparing the EMI plots with the oscilloscopic outcome of the models developed, it can also be seen from Figure 4.10 that the signal distortion as a result of EMI can be seen at points 10, 30 and 40 indicating Random Jitter. Also at points 18, 25 and 45 the signal got shifted from the phase originally transmitted a situation referred to as Deterministic Jitter which now causes degradation at these particular locations. (Comer and Douglas, 2008).

In addition, from the results displayed by 5GHz signal on Figure 4.11 it could also be noticed that, unlike the transmitted signal at the 2.4 GHz network as shown in Figure 4.10, the signal is affected by the free space loss as can be seen at points 16 and 17. This further confirms the fact that, in a free space propagation, the higher the operating frequency, the greater the attenuation

of the signal caused by Jitters. (Khvilivitzky and Alexander, 2008). The received signal is being shifted by the EMI at points 8, 18, 25 and 35 that induces Random Jitter.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTON

Middleton Class A technique was applied in this research work to develop a EMI model; using M Files and Communication toolbox of MATLAB® V7.9.0.529 (R2009b).

The Middleton Class A-based model handled every Frequency separately, which can be fully identified using the base station values. This implementation is important as it gives the evaluation and extent of EMI at every access point as part of Electromagnetic Compatibility Assessment.

5.2 LIMITATIONS

Electromagnetic Compatibility assessment is concerned with generation, propagation and reception of Interferences with a view to unwanted effect that these Interferences could yield, the Middleton Class A model is a data driven technique. This means that the quality of data is very important to the working of this technique, which essentially means that the quality of the output is highly dependent on the quality of the input data. It is worth mentioning however, that values of signal strength are constantly changing, hence, there is an observable change of ±2dB in which the values fluctuates

Also, in carrying out the Matlab/Simulink model design, average distance of the various access points to base station that are found within each network was adopted.

5.3 SIGNIFICANCE OF WORK DONE

Based on the work done and result obtained, this research has been able to achieve the following:

a. Prove the theory about RF signal propagation which states that signal strength degrades in an outdoor environment as it moves from transmitter to receiver due to

losses experienced from the air and interferences encountered along the way.

b. Shows that the Middleton Class A model of EMC can be used to ascertain the magnitude of EMI in a basic analysis of any wireless LAN

c. Establishes that both Random and Deterministic Jitters are the consequences of Electromagnetic Interference present in both the 5GHz and 2.4GHz network of the ABU wireless LAN.

5.4 CONCLUSION

The study has shown that the 5GHz network is more immune to EMI than the 2.4GHz network based on the EMI magnitude plots at the access points while the SIMULINK/ MATLAB models display of the two networks available in the ABU wireless environment indicated that the signals shifted by the various EMI induced Jitters as well as free space jitters are more pronounced at **5GHz** than at **2.4GHz**., as can be seen from the **Error rate** calculation which gives **0.743** and **0.612** respectively.

5.5 RECOMMENDATIONS FOR FURTHER WORK

The following are suggested as possible means of minimizing the effect of Interference on the ABU wireless network

a. The use of Optic Fiber as a coupling path between the base station and the various access points makes the signal less susceptible to not only interference but also all the losses suffered by the signal as a result of Free Space loss, reflections, absorption, diffraction and scattering at least before it reaches the access point.

b. A further performance analysis can be carried out by accessing the overall network impairments not just interferences alone.

c. Further Electromagnetic Compatibility Analysis can be conducted with the view to uncover the various sources of destructive interference within the University environment.

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APPENDIX I: MATLAB PROGRAM

2.4GHz SENATE WEST MATLAB PROGRAM

```
clc;clear all;close all;

freq_Ghz=2.4;%wireless scheme operating frequency
Tx_power_dB=7; %Rated value of senate-west access point
R_sig_str_dBm=[-53 -54.41 -56.47 -52.97 -71.77 -47.53 -71.10 -55.90 -62.83 -56.27 -68.90 -61.93 -69.00 -60.9];
dist_Fr_Tx=[592 535 732 641 2457 2462 544 649 2422 489 1002 705 693 559];
F_path_loss=32.44+(20*log10(freq_Ghz))+(20*log10(dist_Fr_Tx));

%this segment randomly generates values for the noise floor
noise_floor_dBm=[-33.4 -30.5 -37.9 -38.1 -33.6 -37.3 -40.0 -38.7 -35.2 -44.4 -30.1 -33.3 -36.6 -32.8];
%compute the signal to noise ratio
SNR_dB=R_sig_str_dBm./noise_floor_dBm;
SNR=10.^(SNR_dB/10);
%legend,title,xlabel

%subplot(2,2,1);
figure('Name','BAR CHART PATH LOSS OF 2.4GHz senate west AP','NumberTitle','off');
dat(:,2)=R_sig_str_dBm';
dat(:,1)=F_path_loss';
bar3(dat(:,1),'detached');
%set(gca,'FaceColor',[0.6824 0.4667 0]);
legend('path loss in dB');
grid on;
ylabel('PATH LOSS OF THE VARIOUS 2.4GHz AP');
title 'BAR CHART OF PATH LOSS FOR SENATE WEST BASE STATION';

figure('Name','SIGNAL STRENGTH OF 2.4GHz senate west AP','NumberTitle','off');
bar3(dat(:,2),'detached');
set(gca,'ZDir','reverse');
legend('signal strenght in dB');
grid on;
ylabel('SIGNAL STRENGHT OF THE VARIOUS 2.4GHz AP');
```

```
title 'BAR CHART OF SIGNAL STRNGHT OF 2.4GHz FOR SENATE WEST APS';

figure('Name','SCATTER PLOT OF PATHLOSS VS SNR FOR 2.4GHz senate west AP','NumberTitle','off');
scatter(F_path_loss,SNR,8);
grid on;
ylabel('SNR OF 2.4GHz AP');
Xlabel('PATH LOSS');
title 'SCATTER PLOT OF SNR VS PATHLOSS FOR THE SENATE WEST BASE STATION';

figure('Name','VARIOUS ANALYTICAL PLOTS FOR FOR 2.4GHz senate west AP','NumberTitle','off');
%hold on
%subplot(2,2,2);
%area(R_sig_str_dBm);
%grid;
%ylabel('SIGNAL STRENGHT OF THE VARIOUS 2.4GHz AP');
%title 'AREA PLOT OF SIGNAL STRNGHT OF 2.4GHz AP';



subplot(1,1,1);
scatter(F_path_loss,SNR,8);
grid on;
ylabel('SNR OF 2.4GHz AP');
Xlabel('PATH LOSS');
title 'SCATTER PLOT OF SNR VS PATHLOSS FOR SENATE WEST BASE STATION';



%subplot(2,2,4);
%axis([1 9 -100 0]);
%bar3h(R_sig_str_dBm,1,'detached','r');
grid on;
%ylabel('SIGNAL STRENGHT OF THE VARIOUS 2.4GHz AP');
%title '3d bar OF SIGNAL STRNGHT OF 2.4GHz AP';
%[x,y] = meshgrid(F_path_loss,SNR);
%z=peaks(x,y);
%surfl(x,y,z);
%colormap(copper);
```

```
%plot(R_sig_str_dBm,F_path_loss);

%For example, the command below generates a column vector of length 50
%containing real white Gaussian noise whose power is 2 dBW.
%The function assumes that the load impedance is 1 ohm.
%y1 = wgn(50,1,2);

%To generate complex white Gaussian noise whose power is 2 watts,
%across a load of 60 ohms, use either of the commands below.
%Notice that the ordering of the string inputs does not matter.
%y2 = wgn(50,1,2,60,'complex','linear');
%WGN(ROW,COLUMN,NOISEPOWER_dBm,LOAD IMPEDANCE_OHMS);

%Generate a random sample of 10 pseudo-observations from a
%Poisson distribution with ? = 2.
%lambda = 2;
%random_sample1 = poissrnd(lambda,1,10)
%random_sample1 =
%   1   0   1   2   1   3   4   2   0   0

%TO GENERATE THE EMI USING THE MIDDLETON
%CLASS A MODEL
figure('Name','MAGNITUDE PLOT OF EMI FOR 2.4GHz senate west APs','NumberTitle','off');
POISCOMP=poissrnd(8,1,14);
GAUSSCOMP=wgn(1,14,-4,50);
emi=POISCOMP+GAUSSCOMP;
EMI=fft(emi);
stem(EMI,'fill');
ylabel('MAGNITUDE IN dBm');
title 'MAGNITUDE PLOT OF EMI FOR SENATE WEST ACCESS POINTS';
grid on;
```

2.4 GHz SENATE EAST MATLAB PROGRAMME

```
clc;clear all;close all;

freq_Ghz=2.4;%wireless scheme operating frequency
Tx_power_dB=7; %Rated value of senate east access point
R_sig_str_dBm=[-55.24 -60.22 -50.13 -54.19 -52.18 -45.20 -52.13 -53.17 -48.14 -47.12 -62.13 -45.13 -50.18];
dist_Fr_Tx=[465 405 163 163 1151 136 1341 889 375 58 337 444 78];
F_path_loss=32.44+(20*log10(freq_Ghz))+(20*log10(dist_Fr_Tx));

%this segment randomly generates values for the noise floor
noise_floor_dBm=[-33.4 -30.5 -37.9 -38.1 -33.6 -37.3 -40.0 -38.7 -35.2 -44.4 -30.1 -33.3 -36.6];
%compute the signal to noise ratio
SNR_dB=R_sig_str_dBm./noise_floor_dBm;
SNR=10.^(SNR_dB/10);
%legend,title,xlabel

%subplot(2,2,1);
figure('Name','BAR CHART PATH LOSS OF 2.4GHz AP senate east','NumberTitle','off');
dat(:,2)=R_sig_str_dBm';
dat(:,1)=F_path_loss';
bar3(dat(:,1),'detached');
%set(gca,'FaceColor',[0.6824 0.4667 0]);
legend('path loss in dB');
grid on;
ylabel('PATH LOSS OF THE VARIOUS 2.4GHz senate east AP');
title 'BAR CHART OF PATH LOSS OF S-E BASE';

figure('Name','SIGNAL STRENGTH OF 2.4GHz AP senate east','NumberTitle','off');
bar3(dat(:,2),'detached');
set(gca,'ZDir','reverse');
legend('signal strenght in dB');
grid on;
ylabel('SIGNAL STRENGHT OF THE VARIOUS 2.4GHz AP');
title 'BAR CHART OF SIGNAL STRNGHT OF 2.4GHz senate east AP';
```

```
figure('Name','SCATTER PLOT OF PATHLOSS VS SNR FOR 2.4GHz senate east AP','NumberTitle','off');
scatter(F_path_loss,SNR,8);
grid on;
ylabel('SNR OF 2.4GHz AP');
Xlabel('PATH LOSS');
title 'SCATTER PLOT OF SNR VS PATHLOSS senate east AP ';

figure('Name','VARIOUS ANALYTICAL PLOTS FOR FOR 2.4GHz senate east AP','NumberTitle','off');
%hold on
%subplot(2,2,2);
%area(R_sig_str_dBm);
%grid;
%ylabel('SIGNAL STRENGHT OF THE VARIOUS 2.4GHz AP');
%title 'AREA PLOT OF SIGNAL STRNGHT OF 2.4GHz AP';



subplot(1,1,1);
scatter(F_path_loss,SNR,8);
grid on;
ylabel('SNR OF 2.4GHz AP');
Xlabel('PATH LOSS');
title 'SCATTER PLOT OF SNR VS PATHLOSS  senate east AP';



%subplot(2,2,4);
%axis([1 9 -100 0]);
%bar3h(R_sig_str_dBm,1,'detached','r');
grid on;
%ylabel('SIGNAL STRENGHT OF THE VARIOUS 2.4GHz AP');
%title '3d bar OF SIGNAL STRNGHT OF 2.4GHz AP';
%[x,y] = meshgrid(F_path_loss,SNR);
%z=peaks(x,y);
%surfl(x,y,z);
%colormap(copper);
%plot(R_sig_str_dBm,F_path_loss);
```

```
%For example, the command below generates a column vector of length 50
%containing real white Gaussian noise whose power is 2 dBW.
%The function assumes that the load impedance is 1 ohm.
%y1 = wgn(50,1,2);

%To generate complex white Gaussian noise whose power is 2 watts,
%across a load of 60 ohms, use either of the commands below.
%Notice that the ordering of the string inputs does not matter.
%y2 = wgn(50,1,2,60,'complex','linear');
%WGN(ROW,COLUMN,NOISEPOWER_dBm,LOAD IMPEDANCE_OHMS);

%Generate a random sample of 10 pseudo-observations from a
%Poisson distribution with ? = 2.
%lambda = 2;
%random_sample1 = poissrnd(lambda,1,10)
%random_sample1 =
%   1   0   1   2   1   3   4   2   0   0

%TO GENERATE THE EMI USING THE MIDDLETON
%CLASS A MODEL
figure('Name','MAGNITUDE PLOT OF EMI FOR 2.4GHZ senate east APs','NumberTitle','off');
POISCOMP=poissrnd(8,1,13);
GAUSSCOMP=wgn(1,13,-4,50);
emi=POISCOMP+GAUSSCOMP;
EMI=fft(emi);
stem(EMI,'fill');
ylabel('MAGNITUDE IN dBm');
title 'MAGNITUDE PLOT OF EMI senate east AP';
grid on;
```

5GHz matlab programme

```
clc;clear all;close all;

freq_Ghz=5;%class A operating frequency
Tx_power_dB=7; %Rated value of access point
R_sig_str_dBm=[-76 -69 -47 -51 -60 -77 -67 -64 -62];
dist_Fr_Tx=[10500 2657 100 400 380 10550 650 700 150];
F_path_loss=32.44+(20*log10(freq_Ghz))+(20*log10(dist_Fr_Tx));

%this segment randomly generates values for the noise floor
noise_floor_dBm=[-99.4 -104.5 -93.9 -101.1 -98.6 -94.3 -97.0 -96.7 -98.2 ];
%compute the signal to noise ratio
SNR_dB=(R_sig_str_dBm-120)./(noise_floor_dBm-120);
SNR=10.^(SNR_dB/10);
%legend,title,xlabel

%subplot(2,2,1);
figure('Name','BAR CHART PATH LOSS OF 5GHZ AP','NumberTitle','off');
dat(:,2)=R_sig_str_dBm';
dat(:,1)=F_path_loss';
bar3(dat(:,1),'detached');
%set(gca,'FaceColor',[0.6824 0.4667 0]);
legend('path loss in dB');
grid on;
ylabel('PATH LOSS OF THE VARIOUS 5GHZ AP');
title 'BAR CHART OF PATH LOSS';

figure('Name','SIGNAL STRENGTH OF 5GHZ AP','NumberTitle','off');
bar3(dat(:,2),'detached');
set(gca,'ZDir','reverse');
legend('signal strenght in dB');
grid on;
ylabel('SIGNAL STRENGHT OF THE VARIOUS 5GHZ AP');
title 'BAR CHART OF SIGNAL STRNGHT OF 5GHZ AP';
```

```
figure('Name','SCATTER PLOT OF PATHLOSS VS SNR','NumberTitle','off');
scatter(F_path_loss,SNR,8);
grid on;
ylabel('SNR OF 5GHZ AP');
Xlabel('PATH LOSS');
title 'SCATTER PLOT OF SNR VS PATHLOSS';

figure('Name','BARCHART OF SNR AGAINST DISTANCE TRAVELLED','NumberTitle','off');
data2=[SNR;dist_Fr_Tx];
bar3(dist_Fr_Tx,'detached');
legend('DISTANCE FROM TRANSMITTER');
%area(R_sig_str_dBm);
%grid;
%ylabel('SIGNAL STRENGHT OF THE VARIOUS 5GHZ AP');
%title 'AREA PLOT OF SIGNAL STRNGHT OF 5GHZ AP';

figure('Name',' PLOT OF SNR AGAINST PATHLOSS','NumberTitle','off');
scatter(F_path_loss,SNR,8);
grid on;
ylabel('SNR OF 5GHZ AP');
Xlabel('PATH LOSS');
title 'SCATTER PLOT OF SNR VS PATHLOSS';



%subplot(2,2,4);
%axis([1 9 -100 0]);
%bar3h(R_sig_str_dBm,1,'detached','r');
%ylabel('SIGNAL STRENGHT OF THE VARIOUS 5GHZ AP');
%title '3d bar OF SIGNAL STRNGHT OF 5GHZ AP';
%[x,y] = meshgrid(F_path_loss,SNR);
%z=peaks(x,y);
%surfl(x,y,z);
%colormap(copper);
%plot(R_sig_str_dBm,F_path_loss);
```

```
%For example, the command below generates a column vector of length 50
%containing real white Gaussian noise whose power is 2 dBW.
%The function assumes that the load impedance is 1 ohm.
%y1 = wgn(50,1,2);

%To generate complex white Gaussian noise whose power is 2 watts,
%across a load of 60 ohms, use either of the commands below.
%Notice that the ordering of the string inputs does not matter.
%y2 = wgn(50,1,2,60,'complex','linear');
%WGN(ROW,COLUMN,NOISEPOWER_dBm,LOAD IMPEDANCE_OHMS);

%Generate a random sample of 10 pseudo-observations from a
%Poisson distribution with ? = 2.
%lambda = 2;
%random_sample1 = poissrnd(lambda,1,10)
%random_sample1 =
%   1   0   1   2   1   3   4   2   0   0

%TO GENERATE THE EMI USING THE MIDDLETON CLASS A MODEL.
%CLASS A
figure('Name','fourier transform of emi','NumberTitle','off');
POISCOMP=poissrnd(8,1,9);
GAUSSCOMP=wgn(1,9,-4,50);
emi=POISCOMP+GAUSSCOMP;
EMI=fft(emi);
stem(EMI,'fill');
ylabel('MAGNITUDE IN dBm');
title 'MAGNITUDE PLOT OF EMI FOR 5GHz';
grid on;
```

APPENDIX II: 90 Days Signal Strength Data for ABU Network

S/No	RADIO LOCATION/IDENTITY	SIGNAL STRENGTH [dBm]														
	SENATE west[BASESTATION]	Day1	Day2	Day3	Day4	Day5	Day6	Day7	Day8	Day9	Day10	Day11	Day12	Day13	Day14	Day15
1	ENGINEERING	-55	-52	-53	-50	-51	-52	-53	-55	-53	-54	-53	-52	-53	-52	-53
2	UHS	-54	-52	-51	-52	-55	-53	-54	-56	-54	-56	-53	-53	-52	-56	-55
3	BIOTECH	-57	-58	-57	-56	-56	-57	-56	-56	-57	-57	-51	-56	-57	-56	-56
4	NEW ENGINEERING	-53	-55	-54	-52	-53	-53	-54	-52	-53	-53	-52	-53	-52	-53	-52
5	AGRIC ENGINEERING	-72	-72	-71	-74	-73	-73	-70	-72	-71	-70	-72	-70	-70	-72	-71
6	IAR	-48	-47	-48	-48	-47	-49	-47	-48	-49	-48	-50	-49	-50	-48	-43
7	AKENZUA	-73	-70	-72	-71	-72	-73	-70	-78	-71	-70	-71	-70	-71	-69	-71
8	OLD PHARMACY	-57	-55	-57	-56	-56	-57	-58	-56	-57	-57	-56	-57	-56	-57	-56
9	ESTATE	-63	-63	-64	-61	-62	-63	-64	-63	-63	-63	-63	-63	-61	-63	-62
10	MECHANICAL ENGINEERING	-57	-57	-56	-57	-56	-57	-58	-57	-57	-57	-54	-57	-55	-54	-55
11	DAN FODIO	-70	-71	-70	-71	-69	-70	-71	-70	-70	-70	-70	-70	-69	-70	-69
12	NEW PHARMACY	-53	-60	-65	-65	-58	-65	-66	-61	-54	-56	-65	-65	-63	-65	-64
13	SAFE HOSTEL	-68	-60	-67	-70	-74	-60	-66	-67	-61	-59	-72	-72	-69	-72	-70
14	BBC	-60	-59	-59	-59	-57	-59	-58	-66	-65	-65	-63	-65	-61	-65	-64
	SENATE east[BASESTATION]															
1	ECONOMICS	-56	-56	-54	-55	-55	-56	-56	-53	-54	-55	-55	-56	-55	-56	-56
2	ICSA/RAMAT	-65	-67	-69	-58	-58	-62	-58	-58	-63	-58	-58	-58	-60	-60	-61
3	ALEXANDRA	-50	-49	-48	-50	-51	-49	-48	-50	-47	-45	-47	-51	-49	-50	-48
4	RIBADU	-54	-55	-53	-55	-55	-53	-54	-53	-53	-54	-53	-54	-54	-54	-54
5	IDR	-52	-52	-51	-50	-53	-52	-52	-52	-51	-52	-51	-52	-52	-52	-51
6	DEV OFFICE	-45	-45	-46	-45	-46	-44	-45	-44	-43	-45	-44	-45	-45	-45	-47
7	CERT	-52	-52	-50	-50	-53	-51	-52	-52	-50	-52	-51	-52	-52	-51	-54

8	IACC	-53	-53	-53	-52	-54	-53	-53	-52	-52	-53	-52	-53	-53	-54	-53
9	ARCHITECH	-48	-48	-48	-47	-49	-48	-48	-48	-46	-48	-47	-48	-49	-50	-48
10	MATH DEPARTMENT	-47	-48	-46	-47	-48	-47	-47	-48	-49	-47	-46	-47	-48	-46	-47
11	ICT PARK	-62	-62	-63	-63	-62	-63	-62	-62	-61	-62	-61	-62	-62	-62	-62
12	STAFF SCHOOL	-45	-45	-45	-47	-45	-45	-45	-46	-45	-45	-45	-45	-45	-45	-45
13	ICT DIRECTORATE	-50	-50	-49	-51	-51	-49	-50	-50	-49	-50	-49	-50	-51	-49	-50
5 GHz Network																
1	ADMIN	-66	-65	-66	-66	-67	-65	-66	-66	-65	-66	-66	-65	-66	-66	-65
2	AGRIC	-69	-68	-68	-69	-70	-68	-69	-70	-71	-70	-71	-71	-70	-71	-66
3	ARTS	-47	-47	-46	-47	-48	-46	-47	-47	-46	-47	-46	-47	-48	-49	-48
4	EDUCATION	-51	-51	-52	-51	-50	-50	-51	-51	-51	-50	-51	-52	-51	-50	-51
5	ENV. DESIGN	-65	-64	-66	-65	-67	-66	-64	-67	-64	-63	-65	-66	-65	-68	-66
6	LAW	-77	-78	-79	-77	-78	-76	-77	-77	-79	-77	-78	-77	-76	-78	-77
7	MEDICINE	-67	-68	-67	-67	-68	-66	-67	-67	-67	-68	-66	-67	-65	-67	-67
8	PHARMACY	-64	-65	-65	-64	-65	-63	-64	-64	-64	-62	-64	-63	-66	-63	-63
9	SCIENCES	-62	-61	-60	-62	-63	-61	-62	-61	-63	-61	-62	-60	-60	-63	-60

S/No	RADIO LOCATION/IDENTITY	SIGNAL STRENGTH [dBm]														
	SENATE west[BASESTATION]	Day16	Day17	Day18	Day19	Day20	Day21	Day22	Day23	Day24	Day25	Day26	Day27	Day28	Day29	Day30
1	ENGINEERING	-55	-52	-54	-53	-56	-55	-54	-55	-54	-53	-53	-54	-55	-52	-53
2	UHS	-55	-56	-56	-56	-56	-56	-55	-55	-55	-53	-55	-55	-54	-52	-51
3	BIOTECH	-57	-57	-57	-55	-57	-57	-57	-57	-58	-57	-56	-57	-57	-58	-57
4	NEW ENGINEERING	-53	-53	-53	-54	-53	-53	-54	-53	-51	-53	-54	-52	-53	-55	-54
5	AGRIC ENGINEERING	-71	-72	-72	-72	-72	-73	-72	-73	-73	-73	-72	-70	-72	-72	-71

6	IAR	-47	-44	-48	-48	-46	-49	-50	-47	-48	-45	-46	-47	-48	-47	-48
7	AKENZUA	-72	-68	-72	-71	-71	-70	-69	-69	-72	-70	-72	-72	-73	-70	-72
8	OLD PHARMACY	-57	-57	-57	-58	-50	-57	-56	-53	-56	-52	-56	-53	-57	-55	-57
9	ESTATE	-63	-63	-62	-64	-63	-63	-63	-63	-63	-63	-62	-63	-63	-63	-64
10	MECHANICAL ENGINEERING	-57	-57	-57	-56	-56	-57	-57	-57	-56	-55	-56	-54	-57	-57	-56
11	DAN FODIO	-70	-70	-65	-68	-70	-64	-69	-65	-66	-67	-69	-68	-70	-71	-70
12	NEW PHARMACY	-65	-65	-65	-63	-61	-61	-59	-65	-60	-62	-59	-62	-53	-60	-65
13	SAFE HOSTEL	-73	-72	-72	-70	-72	-72	-72	-70	-72	-74	-68	-69	-68	-60	-67
14	BBC	-66	-65	-65	-63	-58	-57	-56	-57	-58	-57	-58	-59	-60	-59	-59
SENATE east[BASESTATION]																
1	ECONOMICS	-55	-55	-53	-55	-54	-56	-56	-58	-56	-55	-56	-55	-56	-56	-54
2	ICSA/RAMAT	-60	-60	-61	-59	-58	-60	-58	-62	-60	-60	-62	-54	-65	-67	-69
3	ALEXANDRA	-50	-48	-50	-53	-52	-50	-54	-51	-50	-51	-59	-54	-50	-49	-48
4	RIBADU	-54	-54	-55	-54	-55	-54	-55	-55	-56	-54	-55	-54	-54	-55	-53
5	IDR	-52	-52	-53	-52	-54	-52	-55	-52	-53	-52	-54	-53	-52	-52	-51
6	DEV OFFICE	-45	-46	-47	-45	-45	-45	-46	-45	-45	-47	-46	-45	-45	-45	-46
7	CERT	-52	-53	-53	-54	-53	-54	-53	-52	-53	-52	-52	-53	-52	-52	-50
8	IACC	-53	-53	-55	-53	-53	-55	-54	-53	-53	-54	-54	-53	-53	-53	-53
9	ARCHITECH	-49	-48	-47	-48	-49	-48	-49	-48	-49	-48	-48	-49	-48	-48	-48
10	MATH DEPARTMENT	-47	-45	-46	-48	-47	-48	-47	-48	-47	-48	-47	-47	-47	-48	-46
11	ICT PARK	-62	-61	-61	-62	-62	-63	-62	-64	-63	-63	-62	-62	-62	-62	-63
12	STAFF SCHOOL	-44	-44	-45	-44	-45	-45	-46	-47	-46	-45	-45	-45	-45	-45	-45
13	ICT DIRECTORATE	-50	-50	-50	-51	-51	-51	-50	-51	-52	-50	-50	-51	-50	-50	-49
5 GHz Network																
1	ADMIN	-66	-67	-65	-66	-66	-68	-67	-67	-65	-66	-65	-68	-66	-65	-66
2	AGRIC	-71	-67	-69	-67	-69	-69	-68	-69	-69	-68	-68	-68	-69	-68	-68

3	ARTS	-47	-48	-48	-48	-47	-49	-47	-48	-46	-45	-45	-45	-47	-47	-46
4	EDUCATION	-50	-51	-50	-50	-51	-52	-53	-51	-53	-51	-52	-50	-51	-51	-52
5	ENV. DESIGN	-65	-67	-68	-66	-68	-67	-67	-66	-66	-67	-66	-68	-65	-64	-66
6	LAW	-75	-77	-76	-77	-77	-77	-78	-75	-77	-76	-77	-76	-77	-78	-79
7	MEDICINE	-67	-66	-65	-67	-68	-67	-69	-67	-69	-67	-67	-66	-67	-68	-67
8	PHARMACY	-64	-65	-61	-65	-64	-64	-64	-64	-64	-64	-65	-65	-64	-65	-65
9	SCIENCES	-63	-61	-62	-64	-63	-62	-63	-62	-65	-65	-61	-62	-62	-61	-60

S/No	RADIO LOCATION/IDENTITY	SIGNAL STRENGTH [dBm]														
	SENATE west[BASESTATION]	Day31	Day32	Day33	Day34	Day35	Day36	Day37	Day38	Day39	Day40	Day41	Day42	Day43	Day44	Day45
1	ENGINEERING	-50	-51	-52	-53	-55	-53	-54	-53	-52	-53	-52	-53	-55	-52	-54
2	UHS	-52	-55	-53	-54	-56	-54	-56	-53	-53	-52	-56	-55	-55	-56	-56
3	BIOTECH	-56	-56	-57	-56	-56	-57	-57	-51	-56	-57	-56	-56	-57	-57	-57
4	NEW ENGINEERING	-52	-53	-53	-54	-52	-53	-53	-52	-53	-52	-53	-52	-53	-53	-53
5	AGRIC ENGINEERING	-74	-73	-73	-70	-72	-71	-70	-72	-70	-70	-72	-71	-71	-72	-72
6	IAR	-48	-47	-49	-47	-48	-49	-48	-50	-49	-50	-48	-43	-47	-44	-48
7	AKENZUA	-71	-72	-73	-70	-78	-71	-70	-71	-70	-71	-69	-71	-72	-68	-72
8	OLD PHARMACY	-56	-56	-57	-58	-56	-57	-57	-56	-57	-56	-57	-56	-57	-57	-57
9	ESTATE	-61	-62	-63	-64	-63	-63	-63	-63	-63	-61	-63	-62	-63	-63	-62
10	MECHANICAL ENGINEERING	-57	-56	-57	-58	-57	-57	-57	-54	-57	-55	-54	-55	-57	-57	-57
11	DAN FODIO	-71	-69	-70	-71	-70	-70	-70	-70	-70	-69	-70	-69	-70	-70	-65
12	NEW PHARMACY	-65	-58	-65	-66	-61	-54	-56	-65	-65	-63	-65	-64	-65	-65	-65
13	SAFE HOSTEL	-70	-74	-60	-66	-67	-61	-59	-72	-72	-69	-72	-70	-73	-72	-72
14	BBC	-59	-57	-59	-58	-66	-65	-65	-63	-65	-61	-65	-64	-66	-65	-65
	SENATE															

	east[BASESTATION]															
1	ECONOMICS	-55	-55	-56	-56	-53	-54	-55	-55	-56	-55	-56	-56	-55	-55	-53
2	ICSA/RAMAT	-58	-58	-62	-58	-58	-63	-58	-58	-58	-60	-60	-61	-60	-60	-61
3	ALEXANDRA	-50	-51	-49	-48	-50	-47	-45	-47	-51	-49	-50	-48	-50	-48	-50
4	RIBADU	-55	-55	-53	-54	-53	-53	-54	-53	-54	-54	-54	-54	-54	-54	-55
5	IDR	-50	-53	-52	-52	-52	-51	-52	-51	-52	-52	-52	-51	-52	-52	-53
6	DEV OFFICE	-45	-46	-44	-45	-44	-43	-45	-44	-45	-45	-45	-47	-45	-46	-47
7	CERT	-50	-53	-51	-52	-52	-50	-52	-51	-52	-52	-51	-54	-52	-53	-53
8	IACC	-52	-54	-53	-53	-52	-52	-53	-52	-53	-53	-54	-53	-53	-53	-55
9	ARCHITECH	-47	-49	-48	-48	-48	-46	-48	-47	-48	-49	-50	-48	-49	-48	-47
10	MATH DEPARTMENT	-47	-48	-47	-47	-48	-49	-47	-46	-47	-48	-46	-47	-47	-45	-46
11	ICT PARK	-63	-62	-63	-62	-62	-61	-62	-61	-62	-62	-62	-62	-62	-61	-61
12	STAFF SCHOOL	-47	-45	-45	-45	-46	-45	-45	-45	-45	-45	-45	-45	-44	-44	-45
13	ICT DIRECTORATE	-51	-51	-49	-50	-50	-49	-50	-49	-50	-51	-49	-50	-50	-50	-50
5 GHz Network																
1	ADMIN	-66	-67	-65	-66	-66	-65	-66	-66	-65	-66	-66	-65	-66	-67	-65
2	AGRIC	-69	-70	-68	-69	-70	-71	-70	-71	-71	-70	-71	-66	-71	-67	-69
3	ARTS	-47	-48	-46	-47	-47	-46	-47	-46	-47	-48	-49	-48	-47	-48	-48
4	EDUCATION	-51	-50	-50	-51	-51	-51	-50	-51	-52	-51	-50	-51	-50	-51	-50
5	ENV. DESIGN	-65	-67	-66	-64	-67	-64	-63	-65	-66	-65	-68	-66	-65	-67	-68
6	LAW	-77	-78	-76	-77	-77	-79	-77	-78	-77	-76	-78	-77	-75	-77	-76
7	MEDICINE	-67	-68	-66	-67	-67	-67	-68	-66	-67	-65	-67	-67	-67	-66	-65
8	PHARMACY	-64	-65	-63	-64	-64	-64	-62	-64	-63	-66	-63	-63	-64	-65	-61
9	SCIENCES	-62	-63	-61	-62	-61	-63	-61	-62	-60	-60	-63	-60	-63	-61	-62

S/No	RADIO LOCATION/IDENTITY	SIGNAL STRENGTH [dBm]														
	SENATE west[BASESTATION]	Day46	Day47	Day48	Day49	Day50	Day51	Day52	Day53	Day54	Day55	Day56	Day57	Day58	Day59	Day60
1	ENGINEERING	-53	-56	-55	-54	-55	-54	-53	-53	-54	-55	-52	-53	-50	-51	-52
2	UHS	-56	-56	-56	-55	-55	-55	-53	-55	-55	-54	-52	-51	-52	-55	-53
3	BIOTECH	-55	-57	-57	-57	-57	-58	-57	-56	-57	-57	-58	-57	-56	-56	-57
4	NEW ENGINEERING	-54	-53	-53	-54	-53	-51	-53	-54	-52	-53	-55	-54	-52	-53	-53
5	AGRIC ENGINEERING	-72	-72	-73	-72	-73	-73	-73	-72	-70	-72	-72	-71	-74	-73	-73
6	IAR	-48	-46	-49	-50	-47	-48	-45	-46	-47	-48	-47	-48	-48	-47	-49
7	AKENZUA	-71	-71	-70	-69	-69	-72	-70	-72	-72	-73	-70	-72	-71	-72	-73
8	OLD PHARMACY	-58	-50	-57	-56	-53	-56	-52	-56	-53	-57	-55	-57	-56	-56	-57
9	ESTATE	-64	-63	-63	-63	-63	-63	-63	-62	-63	-63	-63	-64	-61	-62	-63
10	MECHANICAL ENGINEERING	-56	-56	-57	-57	-57	-56	-55	-56	-54	-57	-57	-56	-57	-56	-57
11	DAN FODIO	-68	-70	-64	-69	-65	-66	-67	-69	-68	-70	-71	-70	-71	-69	-70
12	NEW PHARMACY	-63	-61	-61	-59	-65	-60	-62	-59	-62	-53	-60	-65	-65	-58	-65
13	SAFE HOSTEL	-70	-72	-72	-72	-70	-72	-74	-68	-69	-68	-60	-67	-70	-74	-60
14	BBC	-63	-58	-57	-56	-57	-58	-57	-58	-59	-60	-59	-59	-59	-57	-59
	SENATE east[BASESTATION]															
1	ECONOMICS	-55	-54	-56	-56	-58	-56	-55	-56	-55	-56	-56	-54	-55	-55	-56
2	ICSA/RAMAT	-59	-58	-60	-58	-62	-60	-60	-62	-54	-65	-67	-69	-58	-58	-62
3	ALEXANDRA	-53	-52	-50	-54	-51	-50	-51	-59	-54	-50	-49	-48	-50	-51	-49
4	RIBADU	-54	-55	-54	-55	-55	-56	-54	-55	-54	-54	-55	-53	-55	-55	-53
5	IDR	-52	-54	-52	-55	-52	-53	-52	-54	-53	-52	-52	-51	-50	-53	-52

6	DEV OFFICE	-45	-45	-45	-46	-45	-45	-47	-46	-45	-45	-45	-46	-45	-46	-44
7	CERT	-54	-53	-54	-53	-52	-53	-52	-52	-53	-52	-52	-50	-50	-53	-51
8	IACC	-53	-53	-55	-54	-53	-53	-54	-54	-53	-53	-53	-53	-52	-54	-53
9	ARCHITECH	-48	-49	-48	-49	-48	-49	-48	-48	-49	-48	-48	-48	-47	-49	-48
10	MATH DEPARTMENT	-48	-47	-48	-47	-48	-47	-48	-47	-47	-47	-48	-46	-47	-48	-47
11	ICT PARK	-62	-62	-63	-62	-64	-63	-63	-62	-62	-62	-62	-63	-63	-62	-63
12	STAFF SCHOOL	-44	-45	-45	-46	-47	-46	-45	-45	-45	-45	-45	-45	-47	-45	-45
13	ICT DIRECTORATE	-51	-51	-51	-50	-51	-52	-50	-50	-51	-50	-50	-49	-51	-51	-49
5 GHz Network																
1	ADMIN	-66	-66	-68	-67	-67	-65	-66	-65	-68	-66	-65	-66	-66	-67	-65
2	AGRIC	-67	-69	-69	-68	-69	-69	-68	-68	-68	-69	-68	-68	-69	-70	-68
3	ARTS	-48	-47	-49	-47	-48	-46	-45	-45	-45	-47	-47	-46	-47	-48	-46
4	EDUCATION	-50	-51	-52	-53	-51	-53	-51	-52	-50	-51	-51	-52	-51	-50	-50
5	ENV. DESIGN	-66	-68	-67	-67	-66	-66	-67	-66	-68	-65	-64	-66	-65	-67	-66
6	LAW	-77	-77	-77	-78	-75	-77	-76	-77	-76	-77	-78	-79	-77	-78	-76
7	MEDICINE	-67	-68	-67	-69	-67	-69	-67	-67	-66	-67	-68	-67	-67	-68	-66
8	PHARMACY	-65	-64	-64	-64	-64	-64	-64	-65	-65	-64	-65	-65	-64	-65	-63
9	SCIENCES	-64	-63	-62	-63	-62	-65	-65	-61	-62	-62	-61	-60	-62	-63	-61

		SIGNAL STRENGTH [dBm]														
S/No	RADIO LOCATION/IDENTITY															
	SENATE west[BASESTATION]	Day61	Day62	Day63	Day64	Day65	Day66	Day67	Day68	Day69	Day70	Day71	Day72	Day73	Day74	Day75
1	ENGINEERING	-53	-55	-53	-54	-53	-52	-53	-52	-54	-53	-53	-54	-53	-55	-52
2	UHS	-54	-56	-54	-56	-53	-53	-52	-56	-55	-53	-55	-55	-55	-55	-56
3	BIOTECH	-56	-56	-57	-57	-51	-56	-57	-56	-58	-57	-56	-57	-56	-57	-57

4	NEW ENGINEERING	-54	-52	-53	-53	-52	-53	-52	-53	-51	-53	-54	-52	-52	-53	-53
5	AGRIC ENGINEERING	-70	-72	-71	-70	-72	-70	-70	-72	-73	-73	-72	-70	-71	-71	-72
6	IAR	-47	-48	-49	-48	-50	-49	-50	-48	-48	-45	-46	-47	-43	-47	-44
7	AKENZUA	-70	-78	-71	-70	-71	-70	-71	-69	-72	-70	-72	-72	-71	-72	-68
8	OLD PHARMACY	-58	-56	-57	-57	-56	-57	-56	-57	-56	-52	-56	-53	-56	-57	-57
9	ESTATE	-64	-63	-63	-63	-63	-63	-61	-63	-63	-63	-62	-63	-62	-63	-63
10	MECHANICAL ENGINEERING	-58	-57	-57	-57	-54	-57	-55	-54	-56	-55	-56	-54	-55	-57	-57
11	DAN FODIO	-71	-70	-70	-70	-70	-70	-69	-70	-66	-67	-69	-68	-69	-70	-70
12	NEW PHARMACY	-66	-61	-54	-56	-65	-65	-63	-65	-60	-62	-59	-62	-64	-65	-65
13	SAFE HOSTEL	-66	-67	-61	-59	-72	-72	-69	-72	-72	-74	-68	-69	-70	-73	-72
14	BBC	-58	-66	-65	-65	-63	-65	-61	-65	-58	-57	-58	-59	-64	-66	-65
SENATE east[BASESTATION]																
1	ECONOMICS	-56	-53	-54	-55	-55	-56	-55	-56	-56	-55	-56	-55	-56	-55	-55
2	ICSA/RAMAT	-58	-58	-63	-58	-58	-58	-60	-60	-60	-60	-62	-54	-61	-60	-60
3	ALEXANDRA	-48	-50	-47	-45	-47	-51	-49	-50	-50	-51	-59	-54	-48	-50	-48
4	RIBADU	-54	-53	-53	-54	-53	-54	-54	-54	-56	-54	-55	-54	-54	-54	-54
5	IDR	-52	-52	-51	-52	-51	-52	-52	-52	-53	-52	-54	-53	-51	-52	-52
6	DEV OFFICE	-45	-44	-43	-45	-44	-45	-45	-45	-45	-47	-46	-45	-47	-45	-46
7	CERT	-52	-52	-50	-52	-51	-52	-52	-51	-53	-52	-52	-53	-54	-52	-53
8	IACC	-53	-52	-52	-53	-52	-53	-53	-54	-53	-54	-54	-53	-53	-53	-53
9	ARCHITECH	-48	-48	-46	-48	-47	-48	-49	-50	-49	-48	-48	-49	-48	-49	-48
10	MATH DEPARTMENT	-47	-48	-49	-47	-46	-47	-48	-46	-47	-48	-47	-47	-47	-47	-45
11	ICT PARK	-62	-62	-61	-62	-61	-62	-62	-62	-63	-63	-62	-62	-62	-62	-61
12	STAFF SCHOOL	-45	-46	-45	-45	-45	-45	-45	-45	-46	-45	-45	-45	-45	-44	-44
13	ICT DIRECTORATE	-50	-50	-49	-50	-49	-50	-51	-49	-52	-50	-50	-51	-50	-50	-50
5 GHz Network																
1	ADMIN	-66	-66	-65	-66	-66	-65	-66	-66	-65	-66	-65	-68	-65	-66	-67

2	AGRIC	-69	-70	-71	-70	-71	-71	-70	-71	-69	-68	-68	-68	-66	-71	-67
3	ARTS	-47	-47	-46	-47	-46	-47	-48	-49	-46	-45	-45	-45	-48	-47	-48
4	EDUCATION	-51	-51	-51	-50	-51	-52	-51	-50	-53	-51	-52	-50	-51	-50	-51
5	ENV. DESIGN	-64	-67	-64	-63	-65	-66	-65	-68	-66	-67	-66	-68	-66	-65	-67
6	LAW	-77	-77	-79	-77	-78	-77	-76	-78	-77	-76	-77	-76	-77	-75	-77
7	MEDICINE	-67	-67	-67	-68	-66	-67	-65	-67	-69	-67	-67	-66	-67	-67	-66
8	PHARMACY	-64	-64	-64	-62	-64	-63	-66	-63	-64	-64	-65	-65	-63	-64	-65
9	SCIENCES	-62	-61	-63	-61	-62	-60	-60	-63	-65	-65	-61	-62	-60	-63	-61

S/No	RADIO LOCATION/IDENTITY	SIGNAL STRENGTH [dBm]															
	SENATE west[BASESTATION]	Day76	Day77	Day78	Day79	Day80	Day81	Day82	Day83	Day84	Day85	Day86	Day87	Day88	Day89	Day90	AVERAGE
1	ENGINEERING	-54	-53	-56	-55	-54	-55	-54	-53	-53	-54	-55	-52	-53	-50	-51	-53.30
2	UHS	-56	-56	-56	-56	-55	-55	-55	-53	-55	-55	-54	-52	-51	-52	-55	-54.41
3	BIOTECH	-57	-55	-57	-57	-57	-57	-58	-57	-56	-57	-57	-58	-57	-56	-56	-56.48
4	NEW ENGINEERING	-53	-54	-53	-53	-54	-53	-51	-53	-54	-52	-53	-55	-54	-52	-53	-52.96
5	AGRIC ENGINEERING	-72	-72	-72	-73	-72	-73	-73	-73	-72	-70	-72	-72	-71	-74	-73	-71.78
6	IAR	-48	-48	-46	-49	-50	-47	-48	-45	-46	-47	-48	-47	-48	-48	-47	-47.56
7	AKENZUA	-72	-71	-71	-70	-69	-69	-72	-70	-72	-72	-73	-70	-72	-71	-72	-71.11
8	OLD PHARMACY	-57	-58	-50	-57	-56	-53	-56	-52	-56	-53	-57	-55	-57	-56	-56	-55.93
9	ESTATE	-62	-64	-63	-63	-63	-63	-63	-63	-62	-63	-63	-63	-64	-61	-62	-62.81
10	MECHANICAL ENGINEERING	-57	-56	-56	-57	-57	-57	-56	-55	-56	-54	-57	-57	-56	-57	-56	-56.26
11	DAN FODIO	-65	-68	-70	-64	-69	-65	-66	-67	-69	-68	-70	-71	-70	-71	-69	-68.93
12	NEW PHARMACY	-65	-63	-61	-61	-59	-65	-60	-62	-59	-62	-53	-60	-65	-65	-58	-61.93
13	SAFE HOSTEL	-72	-70	-72	-72	-72	-70	-72	-74	-68	-69	-68	-60	-67	-70	-74	-69.00

14	BBC	-65	-63	-58	-57	-56	-57	-58	-57	-58	-59	-60	-59	-59	-59	-57	-60.89
	SENATE east[BASESTATION]																
1	ECONOMICS	-53	-55	-54	-56	-56	-58	-56	-55	-56	-55	-56	-56	-54	-55	-55	-55.26
2	ICSA/RAMAT	-61	-59	-58	-60	-58	-62	-60	-60	-62	-54	-65	-67	-69	-58	-58	-60.26
3	ALEXANDRA	-50	-53	-52	-50	-54	-51	-50	-51	-59	-54	-50	-49	-48	-50	-51	-50.15
4	RIBADU	-55	-54	-55	-54	-55	-55	-56	-54	-55	-54	-54	-55	-53	-55	-55	-54.19
5	IDR	-53	-52	-54	-52	-55	-52	-53	-52	-54	-53	-52	-52	-51	-50	-53	-52.19
6	DEV OFFICE	-47	-45	-45	-45	-46	-45	-45	-47	-46	-45	-45	-45	-46	-45	-46	-45.22
7	CERT	-53	-54	-53	-54	-53	-52	-53	-52	-52	-53	-52	-52	-50	-50	-53	-52.15
8	IACC	-55	-53	-53	-55	-54	-53	-53	-54	-54	-53	-53	-53	-53	-52	-54	-53.19
9	ARCHITECH	-47	-48	-49	-48	-49	-48	-49	-48	-48	-49	-48	-48	-48	-47	-49	-48.15
10	MATH DEPARTMENT	-46	-48	-47	-48	-47	-48	-47	-48	-47	-47	-47	-48	-46	-47	-48	-47.15
11	ICT PARK	-61	-62	-62	-63	-62	-64	-63	-63	-62	-62	-62	-62	-63	-63	-62	-62.15
12	STAFF SCHOOL	-45	-44	-45	-45	-46	-47	-46	-45	-45	-45	-45	-45	-45	-47	-45	-45.15
13	ICT DIRECTORATE	-50	-51	-51	-51	-50	-51	-52	-50	-50	-51	-50	-50	-49	-51	-51	-50.19
5 GHz Network																	
1	ADMIN	-65	-66	-66	-68	-67	-67	-65	-66	-65	-68	-66	-65	-66	-66	-67	-66.00
2	AGRIC	-69	-67	-69	-69	-68	-69	-69	-68	-68	-68	-69	-68	-68	-69	-70	-69.00
3	ARTS	-48	-48	-47	-49	-47	-48	-46	-45	-45	-45	-47	-47	-46	-47	-48	-47.00
4	EDUCATION	-50	-50	-51	-52	-53	-51	-53	-51	-52	-50	-51	-51	-52	-51	-50	-51.00
5	ENV. DESIGN	-68	-66	-68	-67	-67	-66	-66	-67	-66	-68	-65	-64	-66	-65	-67	-66.00
6	LAW	-76	-77	-77	-77	-78	-75	-77	-76	-77	-76	-77	-78	-79	-77	-78	-77.00
7	MEDICINE	-65	-67	-68	-67	-69	-67	-69	-67	-67	-66	-67	-68	-67	-67	-68	-67.00
8	PHARMACY	-61	-65	-64	-64	-64	-64	-64	-64	-65	-65	-64	-65	-65	-64	-65	-64.00
9	SCIENCES	-62	-64	-63	-62	-63	-62	-65	-65	-61	-62	-62	-61	-60	-62	-63	-62.00