IMPROVED PROPAGATION MODELS FOR LTE PATH LOSS PREDICTION IN GHANA

By

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DECLARATION

I hereby declare that this study was carried out by me and that to the best of my knowledge and belief, it has not been presented anywhere for the award of a degree and that where use is made of other related work, due acknowledgment is made in the thesis.

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ABSTRACT

Long Term Evolution (LTE) Networks offer significant advancement compared with third-generation (3G) Networks in the areas of capacity, latency, network complexity and quality of service. To maximize these benefits of LTE cellular networks, careful and proper planning is needed. This requires the use of accurate propagation models to quantify the path loss required for base station (BS) deployment. However deployed LTE networks in Ghana mostly do not offer the desired 100Mbps throughput leading to customer dissatisfaction. This stems from the fact that Network operators rely on transmission planning tools designed for generalized environments, having no detailed knowledge of the Ghanaian environment. These transmission planning tools come with already embedded propagation models for path loss prediction suited to other environments. A challenge therefore to Ghanaian Network operators at the planning stage will be choosing a propagation model that best suits the Ghanaian environment for accurate path loss prediction. Therefore an accurate and precise propagation model reflecting the Ghanaian environment is needed. In view of this, this study considers extensive LTE path loss measurements at 800MHz and 2600MHz taken in selected urban(Adum, Sunyani, Techiman) and suburban(Agogo, Afrancho, New Dorma, Berekum) environments in Ghana. The measured path loss is compared with the corresponding results obtained from six(6) commonly used propagation models: Stanford University Interim model (SUI), Electronic Communication Committee model (ECC-33), Hata model, COST 231 model, Free space path loss model , and the Ericson model. The commonly used industry standard propagation models that best fit measurement data in these Ghanaian environments were then selected. The measured results show that the Ericson model predicts best in urban areas at 800MHz, the SUI model predicts best rather in suburban areas at 800MHz and the ECC 33 model best predicts path loss in urban and suburban areas at 2.6GHz.These models were modified and developed to predict more accurately the path loss in these environments.

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LIST OF ABBREVIATIONS

Abbreviation	-	Full Meaning
BS	-	Base Station
COST	-	Co-operative for Scientific and Technical Research
ECC	-	Electronic Communication Committee
FDD	-	Frequency Division Duplexing
FDTD	-	Finite Difference Time domain
FSPL	-	Free Space Path Loss
GHz	-	Giga Hertz
GSM	-	Global System for Mobile Communication
HARQ	-	Hybrid Automatic Repeat Request
IEEE	-	Institute of Electrical & Electronic Engineers
ITU	-	International Telecommunication Union
ITU-R	-	Radio Standardization Sector of ITU
ITU-T	-	Telecommunication Standardization Sector of ITU
Km	-	Kilometer
LOS	-	Line of Sight
LS	-	Least Squares

LTE	-	Long Term Evolution
MATLAB	-	Matrix Laboratory
Mbps	-	Mega Bits per second
MHz	-	Mega Hertz
MIMO	-	Multiple Input Multiple Output
MMDS	-	Multipoint Microwave Distribution System
MOM	-	Method of Moments
MS	-	Mobile Station
NCA	-	National Communication Authority
NLOS	-	Non-Line of Sight
OFDM	-	Orthogonal Frequency Division Multiplexing
OFDMA	-	Orthogonal Frequency Division Multiple Access
PAPR	-	Peak to Average Power Ratio
PL	-	Path Loss
RF	-	Radio Frequency
RMSE	-	Root Mean Square Error
RSL	-	Received Signal Level
RSRP	-	Received Signal Reference Power

SC-FDMA.	-	Single Carrier Frequency Division Multiple Access
SNR	-	Signal to Noise Ratio
SUI	-	Stanford University Interim
TDD	-	Time Division Duplexing
Tx-Rx	-	Transmitter - Receiver distance
UHF	-	Ultra-High Frequency
UMTS	-	Universal Mobile Telecommunications System
USB	-	Universal Serial Bus
VHF	-	Very High Frequency
WiMaX	-	Worldwide Interoperability for Microwave Access
4G	-	Fourth Generation

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CHAPTER 1

1.0 INTRODUCTION

This chapter gives the background and motivation to the study. The research problem, general and specific objectives are also outlined. The significance of the study and methodology used are also presented. The chapter ends with the organization of the study.

1.1 BACKGROUND & MOTIVATION

Cisco's visual networking index, 2017-2022 predicts that the IP traffic recorded annually around the globe is estimated at 4.8 Zb by 2022. This translates to a threefold increase over the next five years. Twenty-eight billion, five hundred million (28.5 billion) networked devices are expected by 2022 as against eighteen (18) billion as of 2017 [1]. Mobile data subscription in Ghana as of July 2018 stood at twenty-nine million, one hundred and eighty-one thousand, eight hundred and sixty-three (**29,181,863)** [2]. For a country with an estimated total population of thirty million [3], it shows the high demand for data and broadband services.

With this growing demand for bandwidth in mobile communication [4] as user numbers keep increasing significantly, mobile networks have evolved from 1G - 4G to meet the demand over the years. In Ghana, Blu telecom, Busy internet, Surfline, MTN, and recently Vodafone have commercially deployed 4G LTE networks for higher throughputs and improved user experience. However, this hasn't been completely achieved since the expected throughput of 100Mbps is barely realized leading to dissatisfaction among customers. This has resulted in a lot of complaints and sanctioning from the National communications authority [5]

Transmitted signals from a base station suffer severe attenuation as they propagate through space leading to degradation in signal strength and quality [6]. This severe attenuation is introduced due to reflection, diffraction, and scattering of the signal as it impinges on obstacles. For subscribers of a network who have varying mobility, it is imperative to design a mobile network so that they have robust signal levels at all locations. To achieve this, conditions for radio propagation need to be well understood and predicted as accurately as possible. Propagation models are instrumental in wireless network planning as they support interference estimates, frequency assignments, and cell coverage assessment and other parameters [7].

Empirical propagation models which are mostly used are however environment specific and are developed based on a specific propagation environment of interest [8]. Any little deviation in characterizing the propagation environment under investigation affects the efficiency of propagation models designed from the area [9],[10]. Therefore, the use of propagation models in settings other than those intended to be used might lead to inaccurate prediction which affects system performance [11],[12].

To investigate these claims, the approach adopted in this project is to take Signal Reference Received Power (RSRP) values from deployed cell sites and compare with predictions from 4 propagation models at 800MHz and 6 models at 2600MHz. This approach will help us develop modified and improved versions of already existing propagation models suited for the Ghanaian environment.

1.2 PROBLEM DEFINITION

With the increased request for higher throughputs, there is enough motivation to start looking at issues confronting LTE networks deployed with the initial intent of offering higher throughput and why they might not be living to expectation. Empirical propagation models that are used in coverage estimation at the planning stage of networks are environment-specific. Therefore, their general use in every environment without modification leads to inaccurate estimation of path loss which eventually leads to a mismatch between predicted parameters and physically deployed parameters.

1.3 GENERAL OBJECTIVE

To improve industry-standard propagation models for a more accurate prediction of path loss at LTE Frequencies (800MHz &2600MHz) in the Ghanaian environment.

1.3.1 SPECIFIC OBJECTIVES

1. To review literature on propagation models with a focus on path loss prediction at LTE band of frequencies and other related works
2. To conduct drive test measurements at different cell sites in selected Ghanaian environments
3. To generate predicted path loss values of the various propagation models using MATLAB
4. To compare predictions of propagation models with measured data
5. To analyze and translate results into improved propagation models suited for the Ghanaian environment.

1.4 SIGNIFICANCE OF PROJECT

This study concentrates on the identification of the propagation model that best predicts the lossy nature of transmitted signals in the different Ghanaian environments under investigation. This will be the foundation for the development of improved and simplified versions of the models that predict with higher precision, the path loss in the studied environment. With little available data on propagation models suited to the Ghanaian environment, this project envisions to set the pace and make available models suited for the Ghanaian environment and also encourage a lot more work in this discipline. This will be very helpful in coverage estimation and facilitating less tedious planning. Frequency allocation and interference analysis are both network planning procedures that this project aims at making easier in the long run. Mobile network operators can leverage this for enhanced services, better signal quality coverage and in the long-run serve customers more satisfactorily and get their loyalty.

1.5 METHODOLOGY

Modifying already existing propagation models for better prediction will require substantial knowledge of how these models work and how they translate into physical cell site deployment. To do this, this project compares the measurement data of physically deployed LTE sites and predicted data from propagation models. Drive tests were conducted to measure RSRP values from physically deployed cell sites and MATLAB simulation tool was used for path loss prediction of the different propagation models. Several pieces of literature from published journals, reports and various research works were reviewed. The technical expertise of engineers of the various LTE Operators was also sought to shape this work.

1.6 ORGANISATION OF THESIS

The rest of this thesis is structured as follows. Chapter two(2) presents a review of existing literature and related works, chapter three(3) introduces and discusses the methodology applied, chapter four(4) presents and discusses the study outcomes and chapter five(5) concludes the thesis with recommendations and further work to be considered.

CHAPTER 2

2.0 INTRODUCTION

This chapter reviews the literature and works related to the subject matter.

2.1 RELATED WORKS

Considering the increased demand placed on mobile communication, higher throughputs and seamless connectivity, designing LTE networks in compliance with the performance metrics it promises is crucial. Numerous studies have gone into finding propagation models that predict accurately the path loss in the USA, Europe, Africa, and Asia to improve network performance for both voice and data communication.

How best current propagation models will perform when used in wireless environments other than those originally intended for frequently deviate from the ideal [7]. Numerous studies around the globe, however, show that many industry-standard path loss models perform effectively when adjusted to measured data from these areas [13].

In [13], path loss measured data at 3.5GHz in Cambridge was compared with the predictions of three empirical propagation models. Results indicated that the SUI and COST-231 models over-estimated path loss in this environment. The closest fit to the measurement data was the ECC-33 model. It was therefore recommended for use in urban environments.

Data from drive tests in the city of Oman are presented in [14] at a GSM band of 890-960MHz.This data was compared with predictions from the empirical Okumura model to verify the applicability of this model in Oman. The contribution made was the use of Artificial Neural Network (ANN) for predicting the data and development of an experimental model. A recommendation was made for the inclusion of environmental information in the model for better prediction.

Path loss measurement results in four suburban areas of Kuala Lumpur were provided in [7]. The results showed that the log-normal model together with the SUI model can **be** used to estimate the path loss in Malaysia's mobile microcells.

Modification of the Okumura-Hata model was achieved in [15] .The Okumura-Hata propagation model was applied in a BS in Salalah City operating at 900MHz to investigate the varying path loss between measured and expected values. The altered model's accuracy was checked by testing it on other cells and calculating the resulting mean square error. This gave acceptable results.

In [16] a comparison was made between path loss predictions of four propagation models(Lee, COST-231, log-normal shadowing, and SUI) with path loss measured at two cell sites in Malaysia. Results showed that predictions by the COST-231 and SUI models deviate by far from the measured data. However, the log-normal shadowing model and Lee model were nearer to the measured data.

The least-square method was used in [17] to optimize the Hata empirical path loss model for accurate prediction suited to a suburban area in Malaysia. Outdoor measurements were taken in Cyberjaya, Malaysia at a frequency range of 400MHz to 1800 MHz . Measurements were then compared with the existing models from which the Hata model showed the best fit. The optimized Hata model was used and validated in the Putrajaya region to detect the relative error to evaluate its efficiency. Smaller mean relative error was recorded hence showing that the optimization was done successfully.

Propagation models are presented in [18] for LTE Advanced Networks. Path loss for varying environments (rural, suburban and dense urban) were computed using the following propagation models, COST-231 Walfisch–Ikegami model, SUI, ECC-33, Okumura extended

Model and COST-231 Hata Model using MATLAB. Three frequencies between 2.3GHz and 3.5 GHz were considered in this work. Results presented indicated the COST-231 Hata model agreed better, giving the least path loss in all the environments compared with the other models. This work, however, did not compare the prediction of empirical models with measured data but only based on the model with least path loss. The conclusion made favoring the cost 231 Hata model by simulation as agreeing best in all environments might be misleading.

The Hata and Okumura model was investigated in [19] for propagation scenarios in the Indian environment. A conclusion was made that the better prediction path loss for the area can be selected and be optimized according to variations in the wireless system.

Studies in [20] proved that harmattan precipitates affect attenuation significantly. This was established from the measurement data of a GSM network in Chad taken over a year. Comparison between measured data and two models (Hata and FSPL) showed that Hata model agreed closely with the data set whiles the FSPL model underestimates the path loss .A valid conclusion cannot be made from this work, choosing the Hata model as the best propagation model suited for that environment since the comparison was made only between the Hata and FSPL model. It is obvious from the theory that the FSPL model will underestimate the path loss due to the assumptions made in developing this model.

In [21] , the reliability of commonly used path loss models for UMTS Networks was tested against simulation data to determine the model suitable for efficient coverage planning. Results showed that the Lee path loss model's coverage performance surpassed the COST-231 and ECC-33 path loss models. A simulator that can be applied to other settings was developed. Measurement data from the environment is however needed to ascertain these facts.

Extensive measurements in[11] taken in Lagos at a frequency of 3.4GHz made comparison with 6 standard propagation models. It was concluded that the COST 231-Hata and Ericson models showed the best performance in urban and suburban areas. Recent works in [22] also compared the efficiencies of empirical, heuristic, and geospatial methods used for signal path loss predictions using data collected in urban Nigerian cities to develop path loss models. The developed models and empirical models were compared with field measured data. All models gave acceptable RMSE values excluding the ECC-33 and Egli models. Empirical models were the simplest and most commonly applied of the three techniques submitted. Their work, therefore, emphasized the further improvement of empirical models for optimum prediction. A hybrid of heuristic and empirical models for prediction was recommended to decrease the errors associated with empirical models.

Other works focused on varying antenna height, compared the effect on various propagation models. In [23] it was concluded that a specific model cannot be chosen for estimating the path loss at different antenna heights in every setting since results from seven propagation models were incongruent on the basis of use of different variables and terrain classification. The SUI model was however chosen because it had reduced path loss values for suburban and rural settings at lower receiver antenna heights relative to the other models reviewed. In [24], the performance of the Lee Model in large-scale propagation Urban, Suburban and Open Areas was compared by altering the Transmitter-Receiver distance, Mobile Station (MS) antenna height, and Base Station (BS) antenna height at a frequency of 900 MHz. Results showed that the Open area had better performance compared with the other areas.

Works have also gone into comparing path loss of urban and suburban areas and to ascertain if a particular propagation model can be used for both settings. [23] showed that propagation models in urban areas experience higher losses compared with suburban areas. For all environments, no single model could be proposed.

Deployed WiMAX networks, failed to meet the optimum service quality requirements for delivering continuous wireless connectivity requests in the sub-Sahara region needed for emerging mobile applications. On this background, [25] investigated the throughput performance of a deployed 4G LTE site to ascertain if LTE meets the bandwidth demand needed for data-centric broadband applications. Field data from a deployed 4G LTE BS in Ghana operating at 2600 MHz recorded a maximum throughput of 29.9 Mbps per sector. Maximum throughput of 62.318 Mbps was recorded at the downlink for customers within 2.5 km of the cell range from the BS. It was concluded that 4G LTE can meet the ever-increasing demand of Ghanaians for broadband. This conclusion was made after comparing these throughputs with the desired throughput required to sustain datacentric broadband applications.

The impact of interference should be catered for so as to, attain maximum capacity, maintain an optimal level of service and improved network performance of newly deployed networks. Results of a recently installed 4G-WiMAX BS in Accra and Tema Municipality, Ghana, have been researched in [26]. The resultant interference in the network was derived through a Monte Carlo simulation.

Works in the Ghanaian environment focusing on WiMAX networks in the 2500-2530 MHz band was presented in [12]. The measurement from a deployed WiMAX site around the University of Ghana, Accra was compared with the prediction of four empirical models. The extended COST-231 model was selected as the model that best fits the measured data because it recorded the least RMSE and a higher correlation coefficient. This model was recommended therefore for efficient radio network planning in Ghana and the sub-region at large. It was also concluded that no particular propagation model can be used to forecast coherent outcomes for all propagation settings. The reason for this was the variations in weather and geography. Recommendations were made to consider varying terrain parameters.

Intensive measurements in separate environments must be conducted to parameterize a model. The parameters of the channel model are then adjusted to suit the measurement outcomes. It is imperative therefore from the works reviewed to evaluate the performance of industry-standard propagation models proposed for 4G LTE networks by considering different Ghanaian environments. With several path loss models performing differently in different environments, it is therefore, essential to determine which of the most frequently used models is best suited for 4G LTE networks in Ghana. Further improving the suited model for more accurate prediction pertinent to the Ghanaian and Sub-Saharan environment will facilitate effective deployment of LTE networks by operators, meeting the promises the standard came with. This, in the end, will afford subscribers the chance to enjoy seamless connectivity leading to customer satisfaction and loyalty.

2.2 MULTIPATH PROPAGATION

Mechanisms that contribute to the propagation of electromagnetic waves are varied and are distinguished by wave reflection, refraction, and diffraction phenomena. These phenomena lead to signal dispersion, fading and shadowing along the signal route. Transmitted signals travel through a complex path and are exposed to a variety of obstructions as they pass through different propagation environments.

These factors cause the signal level to vary, resulting in different signal coverage and quality in the network. From distinct directions, radio waves converge at the mobile receiver having distinct amplitudes, phases, and time delays. Multi-path propagation is then the resulting phenomenon. Contributions from all the different paths are then summed to result in the radio channel. Phenomenon contributing to radio wave propagation in space and multipath propagation are discussed briefly below.

(1) Diffraction

(2) Reflection

(3) Scattering

2.2.1 DIFFRACTION

Electromagnetic wave diffraction happens when a body with sharp edges obstructs the radio route. Diffraction causes waves to bend around the obstruction, even without a line of sight path from the transmitter to the receiver. This describes how radio signals can propagate even without a line of sight route in urban and rural environments.

2.2.2 REFLECTION

Reflection is said to have happened when a traveling electromagnetic wave hits a body having an extremely big dimension compared with the traveling wave's wavelength.Typical examples include the ground surface reflection of waves and reflection of waves from walls, houses, and furniture. When reflection happens, electromagnetic waves can also be partly refracted.

2.2.3 SCATTERING

Scattering of electromagnetic waves happens when the medium by which the wave travels is made up of small-scale objects compared to its wavelength. Scattered waves are generated through rough surfaces, tiny objects, or other channel impairments. Foliage, road signs, lamposts, and stairs in houses can cause dispersion in mobile communications systems in reality.

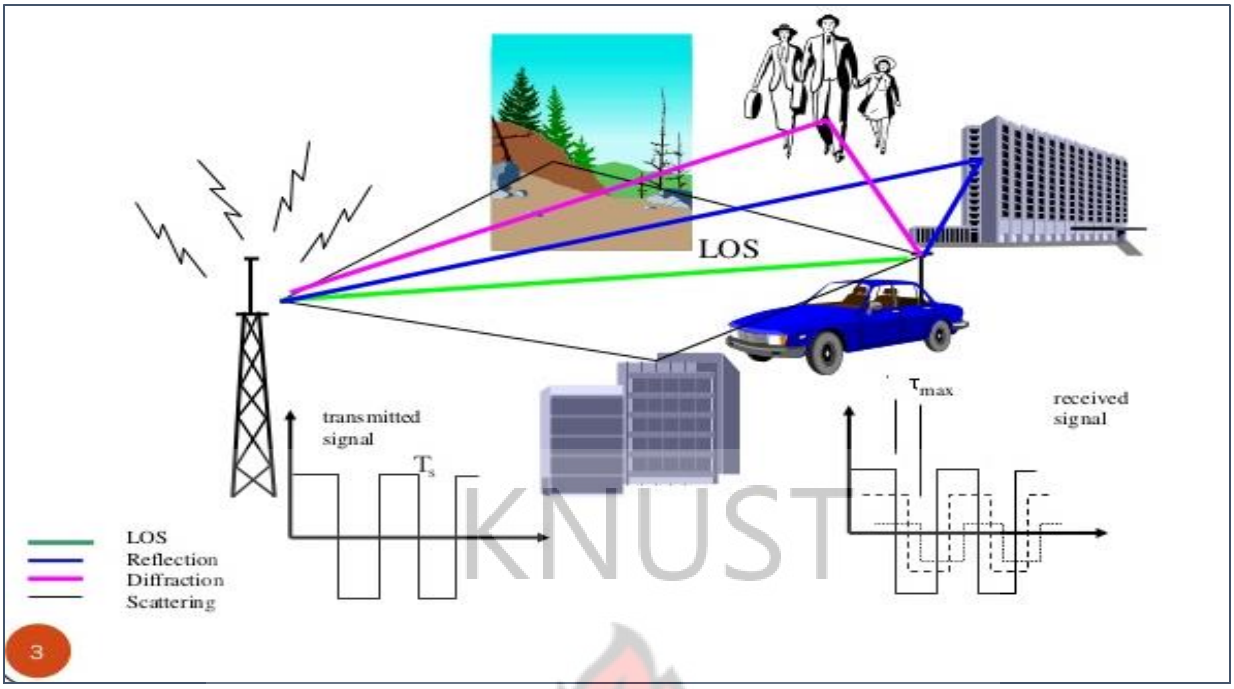

Figure 2.1 Multipath Propagation

2.3 PATH LOSS

Wireless signals as they propagate through space; interact with the environment causing them to lose power from the transmitting end to when they are received. This reduction in signal power as it propagates is what is termed path loss. It is a metric representing the average RF attenuation signals suffer after traversing several wavelengths from the transmitter to the receiver[28]. It is defined mathematically by equation (2.0)

$$PL = \log(\frac{P_t}{P_r}) \quad 2.0$$

Where PLrepresents Path loss, $P_t$and P_r are the transmitted and received power respectively.

Another basic definition of path loss (PL) by J. Milanovic, [29] is the remainder after subtracting the received power from the transmitted power as in (2.1);

$$PL = EIRP + G_T + G_R - L_t - L_r \quad 2.1$$

Where $EIRP$ is the effective isotropic radiated power, G_T and G_R represent gains of the transmitting and the receiving antennas, L_t and L_r are feeder losses, expressed in dB .

2.4 PROPAGATION MODELS

One major concern in wireless communication is identifying fundamental factors affecting the strength and quality of a transmitted signal propagating through space and how best to estimate their strength. In cellular mobile system design, the extent of coverage of the proposed system has to be estimated. The ultimate quality of mobile network coverage is evaluated in terms of location probability. Mobile network coverage is affected mainly by factors including geographical, landscape and subscriber behavior and for that, the conditions for radio propagation for the region under research must be estimated as correctly as possible. propagation models are useful for predicting the cell range and coverage region more accurately. They do so by estimating signal attenuation or path loss, which can be used as a controlling factor for system efficiency or coverage to obtain ideal reception. Propagation models are widely applied in planning networks. This in particular, is so during deployment, to carry out feasibility studies. They come in very helpful when carrying out interference studies and optimization of radio resources [20].

These propagation models are mathematical results of works on wave propagation under varying conditions ; frequency, antenna height, locations, and distance [14]. Propagation models, in general, show that signal power received logarithmically decreases with increased range [14].

2.4.1 CLASSIFICATION OF PROPAGATION MODELS

Propagation models are grouped broadly under three headings. These are empirical, deterministic and stochastic.

1. Empirical models are predominantly based only on observations made and measurement data. They are used primarily to estimate the path loss based on the received signal's statistical characterization. They are simpler to achieve, involve less effort in computing and

are less susceptible to the geometry of the environment [28]. Due to their speed of implementation and their limited dependence on a thorough understanding of the terrain, these propagation models have won favor in both research and industrial societies [13]. Examples of these models are the SUI, Hata, Okumura, and the COST-231 models. These models estimate path loss using different parameters like distance, frequency, the height of antennas, etc.

2. Deterministic propagation models apply the rules of electromagnetic wave propagation to estimate the signal power received at defined locations. These models rely on a detailed map of the environment under study for path loss estimation. The deterministic channel model characterizes the propagation channel in an absolutely deterministic way. They may be based on a strict analysis of Maxwell's equations (Method of Moments(MOM) & Finite Difference Time Domian (FDTD)). Others are also based on asymptotic methods applying the notion of ray tracing. Ray tracing, although computational intensive can simulate much larger environments than MoM or FDTD. In ray tracing , rays are regenerated from the transmitter to the receiver, factoring in reflections and diffractions occurring due to obstructions in the signal's path. Details and properties of obstacles in the signal's path all have to be defined requiring intensive computations. These models require a lot of effort and time since the channel impulse response is not generalized for different scenarios [27]. Though more accurate, these models involve large amounts of information (geometry, terrain profile, building and furnishings places in houses, etc.) and are computational intensive [28].

3. Stochastic models, model a set of random variables in the environment. In terms of accuracy of prediction, they are less accurate compared to the other types. Amongst the propagation model types, stochastic models rely on the least environmental information.

In order to design contemporary mobile cellular networks to have effective and reliable coverage regions, measuring the signal strength should be factored [14]. Empirical propagation models are preferred by both researchers and industry groups due to the speed of implementation and reduced dependence on a thorough understanding of the terrain [13]. They are widely used across the world for cell dimensioning and planning. This work focuses solely therefore on empirical propagation models and how to improve them for more accurate predictions.

2.5 PROPAGATION MODELS UNDER CONSIDERATION

The following propagation models were considered in this work.

I. Free Space Path Loss Model
II. Hata Model
III. COST- 231Model
IV. ECC-33 Model
V. Stanford University Interim (SUI) Model
VI. Ericson Model

2.5.1 FREE SPACE PATH LOSS MODEL

The free-space path loss model is attributed to Friis. The equation given by Friis is used to estimate the power reaching a receiving antenna separated from the transmitting antenna by a distance in free space. This model relates the path loss to frequency and distance with the assumption of an unobstructed line of sight between the transmitter and receiver. Path loss by this model is as given in equation (2.2)

$$Pl = 32.44 + 20\log(d) + 20\log(f) \qquad 2.2$$

Where f refers to frequency and d refers to distance.

Free space is not a suitable medium in realistic mobile radio stations [28]. This is so because a clear line of sight without any obstruction does not occur in reality.

2.5.2 HATA MODEL

The Hata-Okumura model stands as the most important and popular empirical model. Curves presented by Yoshihisa Okumura [30] for path loss estimation were tedious to estimate. The Hata-Okumura model converts these curves into mathematical equations for path loss estimation [30]. The Hata model provides equations on the basis of extrapolations to Okumura's curve measurements [30]. As a definitive formula, Hata provided the loss of urban spread as well as extra correction factors for suburban, and rural areas. The model is applicable for frequencies ranging from 150 MHz to 1500 MHz. Path loss for the Hata model as given in [6] and [31] is given in (2.3).

$$Pl_{urban}(dB) = 69.55 + 26.16\log(f) - 13.82\log(h_t) - ah_r + [44.9 - 6.55\log(h_t)]\log(d) \qquad 2.3$$

In suburban areas path loss is computed as in (2.4)

$$Pl_{suburban}(db) = Pl_{urban} - 2[\log(\frac{f}{28})]^2 - 5.4 \qquad 2.4$$

f =frequency in MHz, d=distance expressed in Km, h_r = height of MS antenna in meters, h_t = BS antenna height in meters and αh_r = correction factor for h_r, affected by coverage area

In small and medium cities,

$$ah_r = (1.1\log(f) - 0.7)h_r - (1.56\log(f) - 0.8) \qquad 2.5$$

In larger cities,

$$ah_r = 3.2[\log(11.75h_r)]^2 - 4.97 \text{ for } f > 300MHz \qquad 2.6$$

$$\alpha h_r = 8.29\left[\log\left(1.54h_r\right)\right]^2 - 1.1 \text{ for f} \le 300\text{MHz} \qquad 2.7$$

2.5.3 COST- 231 MODEL

The COST-231 model was implemented by the European Co-operative for Scientific and Technical Research (COST), which was an expansion of the Hata-Okumura Model for working frequency 1500 - 2000 MHz. This propagation model is obtained from the Hata model and relies on parameters such as frequency, antenna height, distance and base station height for path loss estimation. It can be applied for suburban and urban environments and as such, it is an outdoor propagation model.

The path loss equation for this mode expressed in dB as given in [30] is shown below

$$PL(dB) = 46.3 + 33.9\log(f) - 13.82\log(h_{te}) - a(h_a) + (44.9 - 6.55\log(h_{te}))\log(d) + C_m \quad 2.8$$

where, f is the frequency specified in MHz, d is the distance between the base station and mobile antennas given in km, h_{te} is the base station antenna height above ground level in meters. $h_{re}$is the mobile antenna height in meters, C_m is defined as 0 dB for suburban or open environments and 3 dB for urban environments.

$a(h_a)$is defined for large area as,

$$a(h_a) \text{ dB} = 8.29\left(\log(1.54\, h_{re})\right)^2 - 1.1 \; for\ f \leq 300\ MHz \quad 2.9$$

$$\alpha(h_a)\ dB = 3.2(\log(11.75h_{re}))^2 - 4.97\ for\ f > 300MHz \quad 2.10$$

In medium or small cities,

$$\alpha(h_a)dB = (1.1\log(f) - 0.7)h_r - (1.56\log(f) - 0.8) \quad 2.11$$

2.5.4 ECC-33 PATH LOSS MODEL

Measurement data for Okumura's propagation model was gathered in Tokyo, Japan. Urban cities in Tokyo were segmented into categories of large and medium city and correction factors made available for suburban and open environments. Tokyo which is a highly built-up area has characteristics very much different from typical European suburban areas. This was the reason behind the Electronic communication Committee (ECC) extrapolating the original Okumura measurement data and modifying its postulations so it closely fits wireless systems in Europe. This resulted in the ECC-33 model. The path loss equation for this model is given in [21]

$$PL = A_{fs} + A_{bm} - G_b - G_r \qquad 2.12$$

Where A_{fs} is the free space path loss, A_{bm} is the basic median path loss G_b, is the transmitter antenna height gain factor and G_r is the receiver antenna height gain factor.

Each of these parameters is expressed fully as;

$$Afs = 92.4 + 20log_{10}(d) + 20log_{10}(f) \qquad 2.13$$

$$A_{bm} = 20.41 + 9.83log_{10}(d) + 7.894log_{10}(f) + 9.56[log_{10}(f)]^2 \qquad 2.14$$

$$G_b = log_{10}(hb/200)\left\{13.958 + 5.8[log_{10}(d)]^2\right\} \qquad 2.15$$

When considering medium city environments

$$G_r = \left[42.57 + 13.7log10(f)\right]\left[log10(hr) - 0.585\right] \qquad 2.16$$

For large cities,

$$G_r = 0.759hr - 1.862 \qquad 2.17$$

where f : frequency expressed in GHz , d : distance between the transmitter and receiver in Km , hb : transmitter antenna height in meters, hr : receiver antenna height in meters.

2.5.5 STANFORD UNIVERSITY INTERIM (SUI) MODEL

The IEEE 802.16 Broadband Wireless Access Working Group introduced the Stanford University Interim (SUI) propagation, model. This was derived on the basis of the Hata model. The SUI model categorizes terrains into three types. They are terrains A, B and C. There is no specific reference to a particular environment. Terrain type A is applied for hilly environments having sizeable or very thick vegetation. This terrain type has the highest signal path loss. Terrain type B is defined for hilly regions with mild vegetation or flat terrains with moderate or lots of trees. This terrain is usually modeled for suburban environments. Terrain type C is appropriate for flat terrains. It is mostly applicable to rural environments having light vegetation. The path loss experienced in this terrain type is the minimum.

Path loss for this model is given in (2.18) as presented in [32]

$$PL_{SUI} = A + 10\gamma\log(\frac{d}{d_o}) + s \quad \text{for } f < 2GHz \qquad 2.18$$

$$PL_{SUI} = A + 10\gamma\log(\frac{d}{d_o}) + s + X_{freq} + X_{height} \quad \text{for } f \geq 2GHz \qquad 2.19$$

Where; $8.2dB < s < 10.6dB$, d_o=50m,

$$A = 20\log(\frac{4\pi d_o}{\lambda}) \qquad 2.20$$

$$\gamma = a - bh_b + \frac{c}{h_b} \qquad 2..21$$

$$X_{freq} = 6.0\log_{10}\left(\frac{f}{2000}\right) \qquad 2.22$$

$$X_{height} = -10.8\log_{10}\left(\frac{h_r}{2000}\right) \quad \text{applicable to Terrain type A and B} \qquad 2.23$$

$$X_{height} = -20.0\log_{10}\left(\frac{h_r}{2000}\right) \quad \text{applicable to Terrain type C} \qquad 2.24$$

Where d is the distance between the transmitter and receiver, f is the frequency in MHz

X_{freq} is the frequency correction factor, X_{height} is the Receive antenna height correction factor h_b is the base station antenna height $10m < h_b < 80m$, λ,is the wavelength expressed in meters. h_r is the receiver antenna height in meters

The SUI model predicts extensively the path loss in all environments (rural, suburban and urban)[7].

$a, b, and\ c$ are terrain factors specified in Table 2.1.

Table 2.1 Terrain Parameters

Parameter	Category A	Category B	Category C
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20

2.5.6 ERICSON MODEL

Transmission engineers at the planning stage use a model created by Ericsson Company to predict the loss along the propagation route with comparatively high accuracy. The model is based on the modified Okumura-Hata model by Ericsson and enables model parameters to be changed depending on the propagation setting. The equation specifying path loss for this model as presented by J. Milanovic et al [32] is shown in equation (2.25);

$$Pl_{Ericson} = a0 + a1\log(d) + a2\log(h_b) + a3\log(h_b)\log(d) - 3.2(\log(11.75h_m))^2 + g(f) \quad 2.25$$

$$g(f) = 44.49\log(f) - 4.78(\log(f))^2 a + b + c \quad 2.26$$

The parameters $a0, a1, a2, and\ a3$, given in equation (2.) are constants, that can be tuned to best fit specified propagation conditions. The default values of $a0, a1, a2, and\ a3$ for different environment categories are specified in Table 2.2

Table 2.2 Default Values of $a0, a1, a2$ and $a3$

Category of Area	$a0$	$a1$	$a2$	$a3$
Urban	36.2	30.2	12.0	0.1
Suburban	43.20	68.93	12.0	0.1

2.6 PATH LOSS EXPONENT

The path loss exponent is valuable in describing the path loss of a given area. It measures the rate of increase of path loss against distance [13], [14]. In short, it shows the lossy nature of a particular propagation environment. Path loss exponent values for diverse cellular radio environment types are given in Table 2.3

Table 2.3 Path Loss Exponents for Different Environments

Environment Type	Path Loss exponent
Free space	2
Urban area cellular radio	2.7-3.5
Urban area(shadowed)	3-5
Building(line of sight)	1.6-1.8
Building (Obstructed)	4-6
Factories(obstructed)	2-3

2.7 ROOT MEAN SQUARE ERROR

The RMSE measures the difference between the signal power estimated by a model and the actual measured signal. It serves as a measure of accuracy to compare forecasting errors of different models for a specified dataset. It is defined mathematically by [6]

$$RMSE = \sqrt{\frac{\sum_{k=1}^{k}\left(p_i - \hat{p}_i\right)^2}{k}} \tag{2.27}$$

Where p_i represents the measured power value at a specified distance

$\hat{p}_i$ is the predicted power value at a specified distance

k represents the number of measured samples

2.8 4G LONG TERM EVOLUTION (LTE)

The Third Generation Partnership Project (3GPP) began debates in November 2004 on the creation of a new radio interface to follow High Speed Packet Access' (HSPA's) scheduled improvements [33]. The 3GPP consists of working groups from the telecommunications industry standard bodies. They create test requirements to confirm industrial performance adherence. Several worldwide operators and suppliers recognized that there was a need for common principles and requirements that would meet the performance criteria and would be sufficiently flexible to help the commonly diverse technology migration strategies of operators.

Submissions regarding the requirements of LTE given in [33] include the following :

- Significantly increased peak data rates compared to existing 3G technologies, with an uplink target of 100Mbps and downlink target of over 50Mbps.
- Increased bit rates at the cell edge
- Enhanced spectrum efficiency
- The latency of the radio access network below 10ms
- It requires a scalable bandwidth of 1.25, 2.5, 5, 10, 15 and 20 MHz
- Function in both paired and unpaired spectrum
- increased service provisioning
- Greater coverage by increasing data rates across broader fields and flexibility in the use of current and new frequency bands

To be a worldwide standard, LTE was required to meet the demands of all carriers who would migrate from a distinct point of departure to the technology, distinct technologies, distinct frequencies and varying quantities of coupled and unpaired spectrum resources. The scalable bandwidth requirement was designed to assist providers to more readily move from narrowband systems such as GSM and CDMA2000 to LTE while also acknowledging the need for wider LTE bandwidth deployments to attain the target maximum data rates. Globally, operators have already implemented LTE networks of 1.4, 5, 10,15 and 2MHz. Deployments of 1.4 and 5 MHz happen in the United States and Japan, where operators have a restricted spectrum in a specific frequency band. LTE 10 MHz's wider and larger channel deployments happen in Europe, Asia, and North America with 20MHz deployments predominantly happening at higher frequencies, such as 2600 MHz, where there is more spectrum accessible inherently. Several providers are presently supporting the concurrent use in their networks of distinct LTE channel bandwidths, either separated by frequency band or geography.

Current LTE networks operate on both the standard 2 GHz band and the increased 2.6 GHz band and 900 MHz, bands. As stated above, distinct carrier bandwidths ranging from 1.25 MHz to 20 MHz are feasible for flexible use of the bandwidth. with a subcarrier spacing of 15KHz. LTE's (2.6 GHz) higher frequency band is intended to provide greater throughputs, enabling various users to connect at one moment. It is mostly deployed in towns that are densely populated. However, this frequency is not performing well over lengthy distances [33]. LTE lower frequency band (800MHz) is mainly intended for regions with low populations. Compared to the higher frequencies, their capacity is reduced but they perform well over lengthy distances. It is on this basis that, if an operator prioritizes wider coverage to throughput, lower frequencies are preferred. Frequencies in the middle range (1800 MHz), strike a balance between data capacity and coverage. Mobile Operators tend to blend the three, low-frequency, mid-frequency, and high-frequency LTE services to suit the varying needs of their subscribers. Mobile operators offer their services in different areas, with some focusing more on densely populated cities and others servicing suburban or even rural areas. They, therefore, offer vastly different LTE frequencies and bands.

There are two types of LTE deployments, LTE FDD or LTE TDD. A couple of spectrum bands is required in LTE FDD. One for uplink transmission and the other for downlink transmission the spacing between the top of the reduced band and the bottom of the upper band should be adequate to allow adequate filtration. Transmissions in LTE TDD involve only one band, relegating the need for paired bands. LTE FDD is presently the most popular of both. In LTE TDD and LTE FDD, the Hybrid Automatic Repeat Request (HARQ) is used to handle corrupted data that can not be decoded by the mobile device or eNodeB. Data is retransmitted to manage corrupted bits with extra error correction bits. The 3GPP RAN Working Group 1 set up the downlink for OFDM / OFDMA and the uplink for LTE networks for OFDM / SC-FDMA. SC-FDMA (Single Carrier – Frequency Division Multiple Access) demonstrates to be more effective in uplink considering mobile device constraints and its capacity to mitigate elevated peak to average energy ratios (PAPR) which are an intrinsic feature of OFDMA.

2.9 LTE DEPLOYMENT IN GHANA

In January 2011, the National Communication Authority (NCA), Ghana, released a publication inviting prospective Bandwidth Access (BWA) license buyers to deploy WiMAX and LTE in the 2.5GHz – 2.69GHz band [34]. Since then, the digital migration team has been working to develop spectrum for LTE deployment [34]. This has made it possible to deploy LTE in Ghana. Surfline became the first operator to be licensed to provide LTE in Ghana around the environs of Accra and Tema. Vodafone was the most recent to be awarded a license for LTE operation. Table 2.4 summaries the various LTE operators in Ghana and when they were licensed to roll out their LTE services.

Table 2.4 LTE Operators in Ghana as of July 2019

operator	Frequency(MHz)	Bandwidth(MHz)	Licensed
Blu Telecom	2600	38	Oct. 2014
Busy internet	2300	40	Jan 2016
MTN	800&2600	20	June2016 &Mar 2019
Surfline	2600	7	Aug 2014
Vodafone	800	20	Mar 2019

Figure 2.2 summarizes the market share of the various LTE operators as of December 2018.

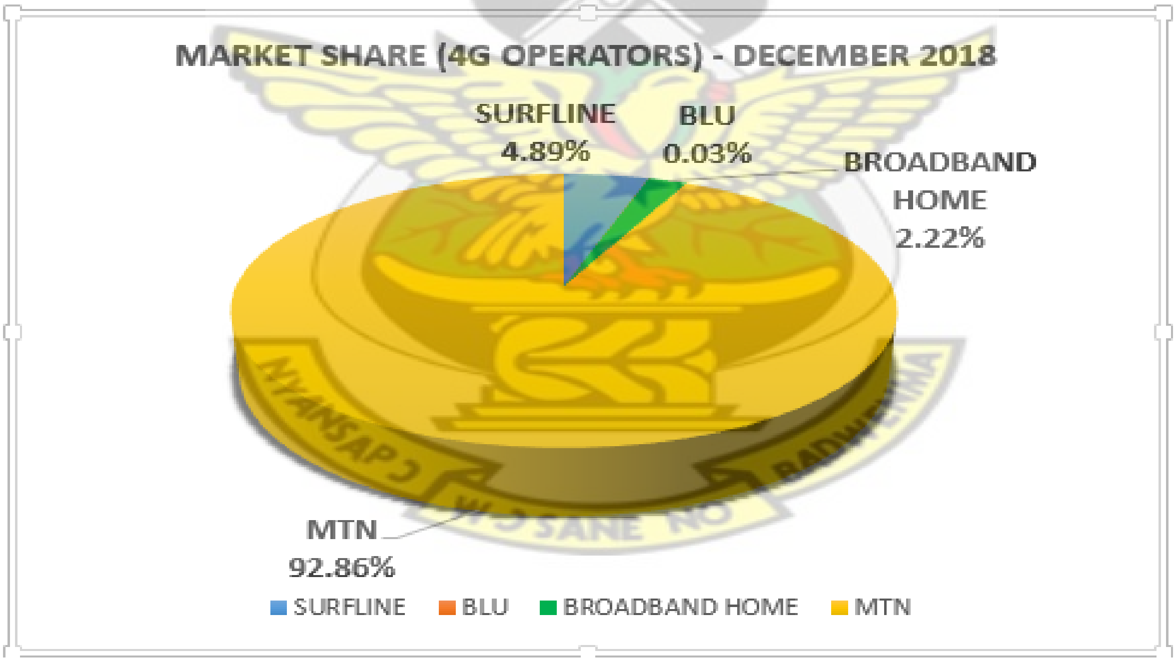

Figure 2.2 4G Market Share in Ghana as of December 2018

(Source: https://www.nca.org.gh/ industry-data-2/market-share-statistics-2/data-3/)

CHAPTER 3

3.0 INTRODUCTION

This chapter gives a vivid description of the investigated environments, the drive test measurement campaign and the theoretical basis to support methods used.

3.1 MEASUREMENT PROCEDURE AND EXPERIMENTAL SETUP

Received signal power values of base stations in environments under investigation were taken by conducting drive tests at each location. The procedure is described below.

Procedure

Received signal reference power (RSRP) values in dBm were taken at a nearly constant height of 1.5 m using a mobile antenna at 10 Base stations in seven selected areas in Ghana with varying environmental conditions. A drive test was conducted using Huawei smart phones connected via the USB port to a computer with LTE software (Genex probe) installed on it. Genex probe serves as a data collection software interface. A GPS was attached for location finding and tracking distance covered. The frequency was set to 800MHz for the first test case at five base stations and 2600MHz for the second test case for the other five base stations. At the various sectors of each LTE site in these environments, RSRP values at a varying distance starting from a reference distance (do) of 50m to 500m with 50m intervals were recorded. Distances considered were in the far field of the radiating base station antennas. The Transmit -Receiver distance was limited to 500m to reduce the impact of interference from neighboring cells and also to cater for obstructions in the way of the drive. A receiver antenna height of 1.5m was maintained throughout the measurement campaign. Measured data is sent via the phones to the computing device which stores the data as recorded log files. Recorded log files for the different areas are shown in figures 3.2-3.11. These recorded log files are then interpreted and analyzed. Field measurements were taken between February and May. This was so, to cater for both the dry and rainy seasons in Ghana. The RSRP in dBm were taken along the LOS and NLOS of the fixed base stations with heights ranging between 16m and 35m.The laptop having GENEX software installed on it, the phone and the GPS were set-up in the drive test vehicle as shown in figure 3.1.

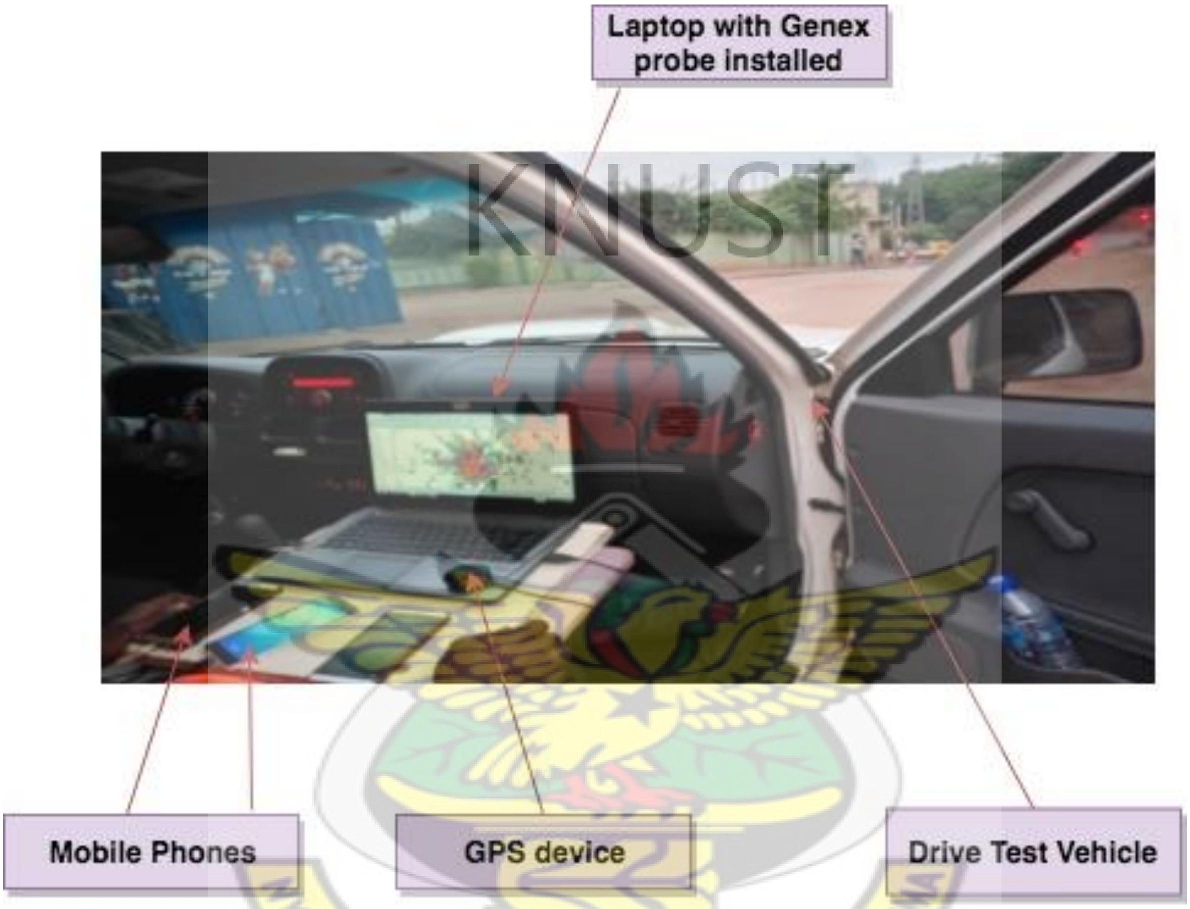

Figure 3.1 Measurement Set Up

RECORDED LOG FILES (800MHZ)

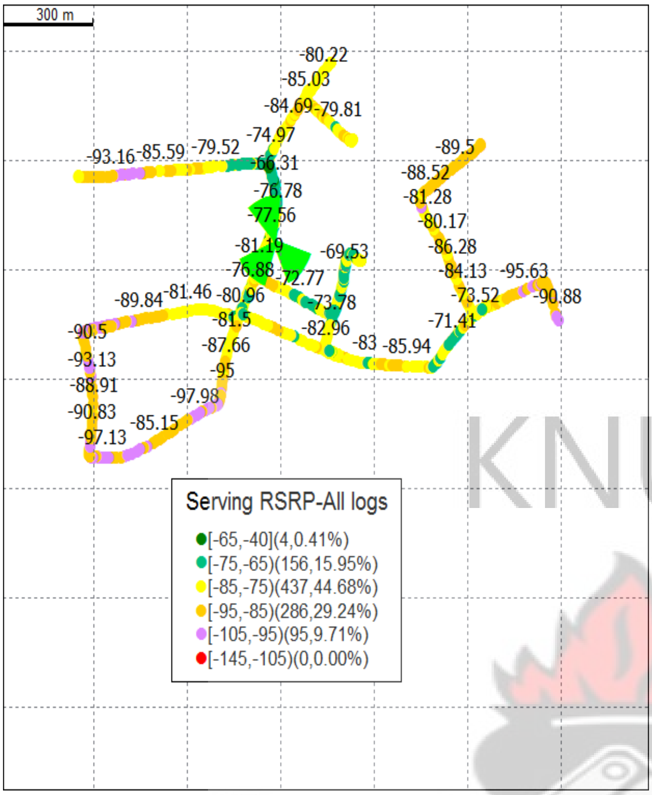

Figure 3.2 Techiman Log File

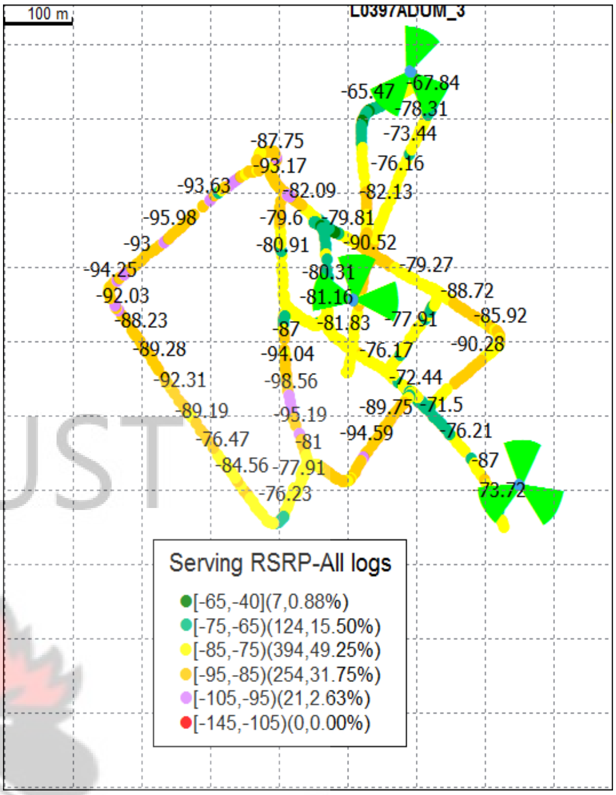

Figure 3.3 Adum Log File

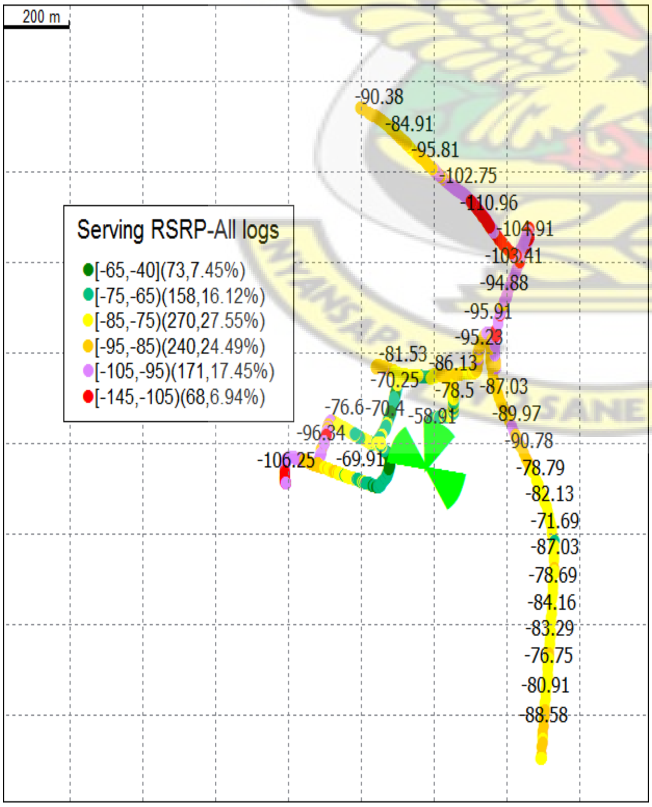

Figure 3.4 Agogo Log File

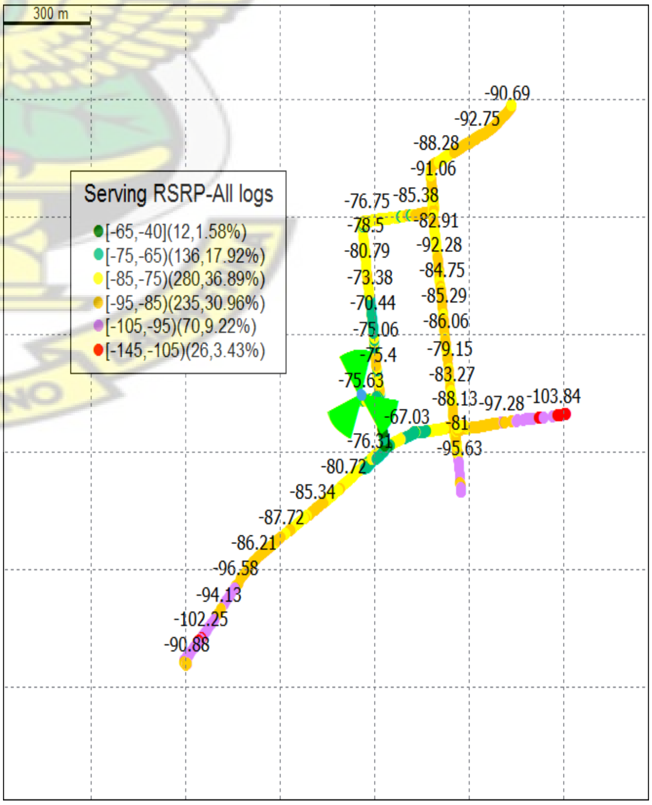

Figure 3.5 Afrancho Log File

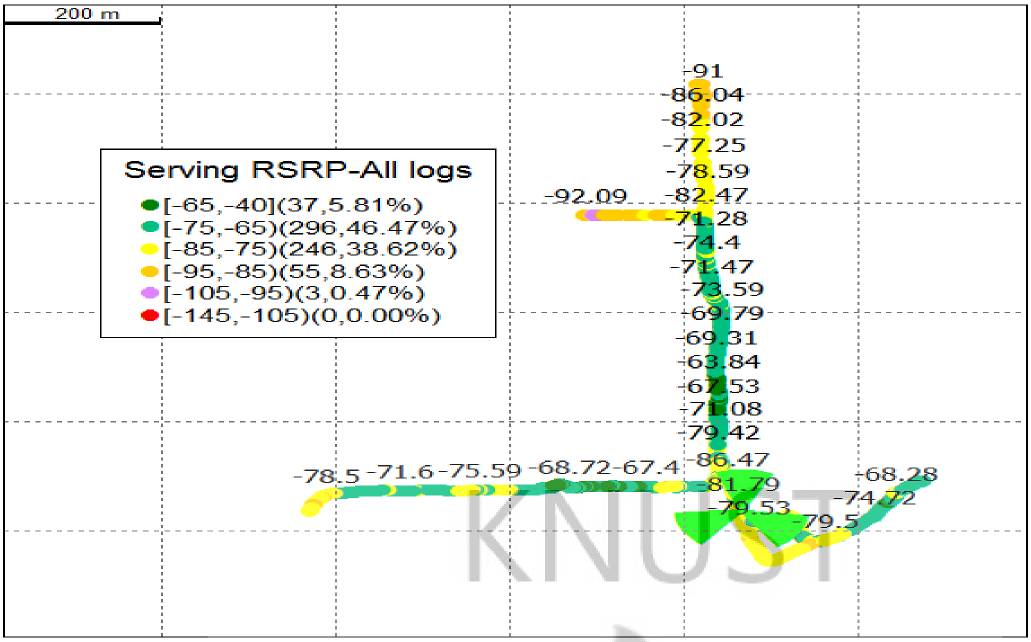

Figure 3.6 New Dorma Log File

RECORDED LOG FILES (2600MHZ)

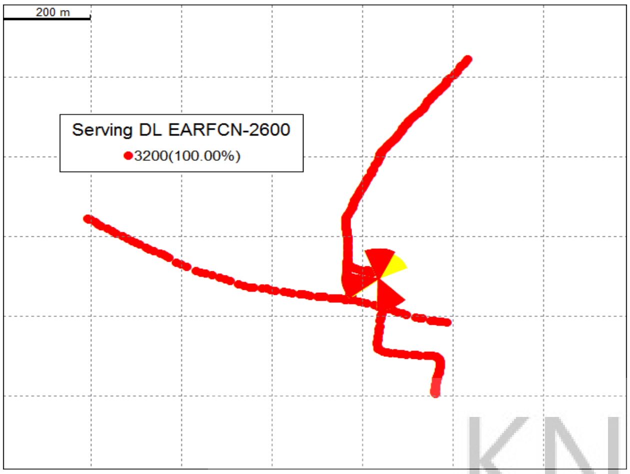

Figure 3.7 Techiman 1 Log File

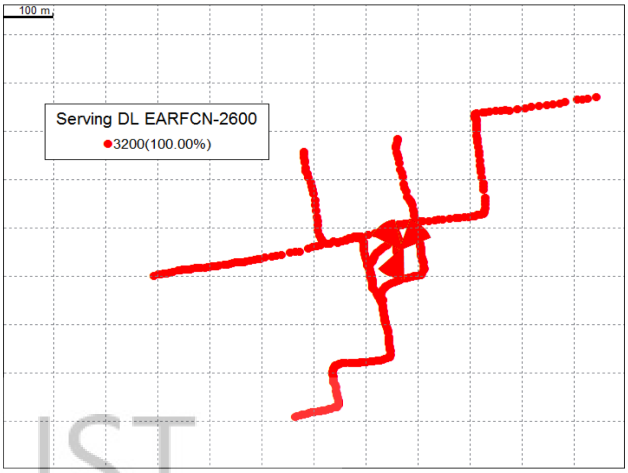

Figure 3.8 Techiman 2 Log File

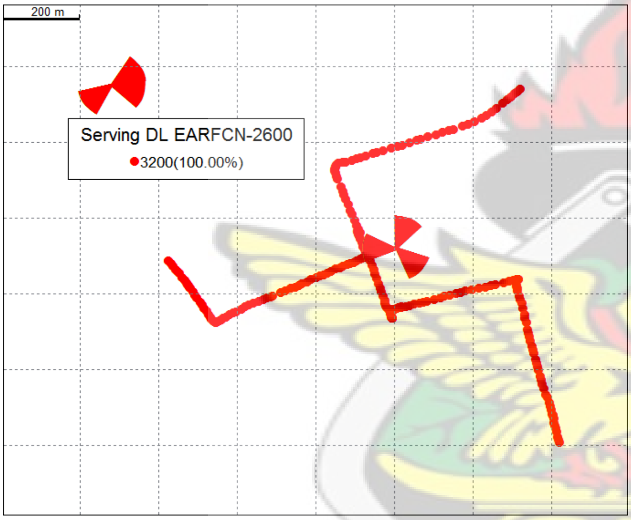

Figure 3.9 Techiman 3 Log File

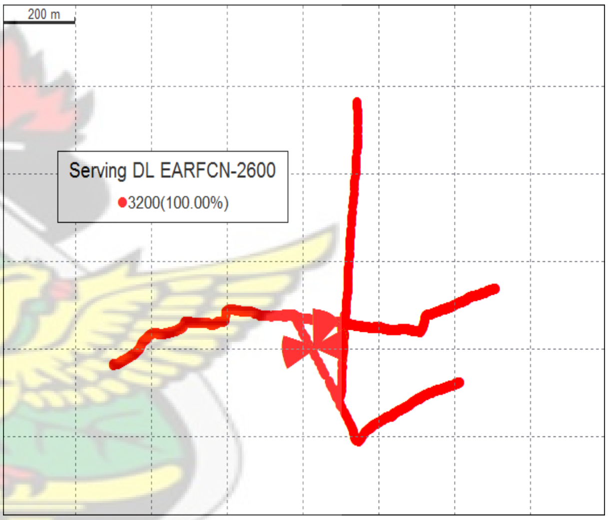

Figure 3.10 Berekum Log File

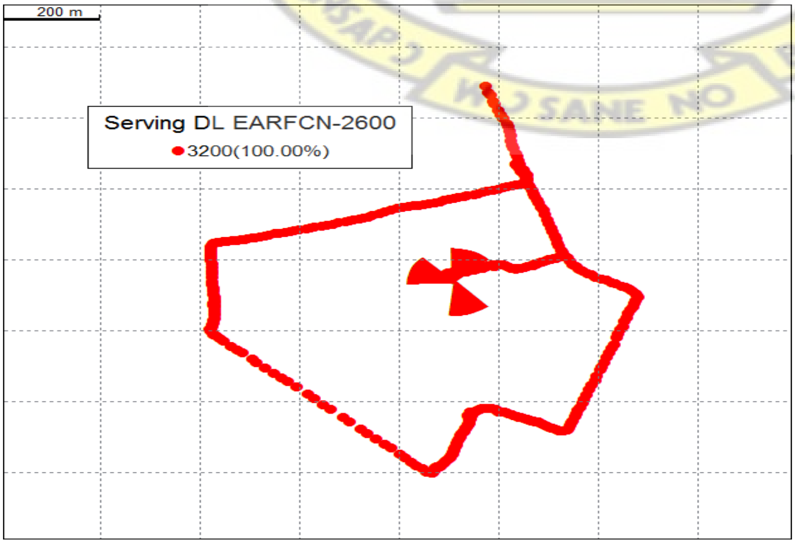

Figure 3.11 Sunyani Log File

3.2 CLASSIFICATION OF ENVIRONMENTS

Different environment types give rise to different attenuation levels [10]. This makes it very important to categorize terrains accurately since the complexity of a propagation model depends on the characteristics of the environment [35]. Propagation models are often based on assumptions that the characteristics of the environment match those where the system is operating, and so it is, therefore, crucial to categorize and choose the terrain type accurately[10] . [36] categorized areas into three. These are;

1. Urban areas
2. Suburban areas
3. Rural areas.

1. Urban areas are characterized by large towns with high rise buildings and closely built houses.

2. Suburban areas can be villages or towns not very congested as urban areas with evenly spaced buildings.

3. Rural areas have relatively large open spaces with the presence of little or no obstacles in the propagation path.

The various definitions given to a category of areas in one country might, however, be different in other countries. An urban area in Tokyo Japan will have a vast difference to an urban area in Ghana. This is so due to different building densities, building heights and town layout. Table 3.1 gives the breakdown of urban and suburban areas considered in this study.

Table 3.1 Classification of Measurement Environments

Frequency(MHz)	Urban	Suburban
800	1.Adum 2.Techiman	3.Agogo 4.Afrancho 5.New Dorma
2600	6.Sunyani 7.Techiman 1 8.Techiman 2 9.Techiman 3	10.Berekum

3.3 DESCRIPTION OF INVESTIGATED ENVIRONMENTS

Site surveys were conducted to choose LTE base stations with varying terrains at different locations. The survey helped to easily classify the various environments as suburban or urban. Drive tests were conducted and measurements were taken in the following Ghanaian environments described below. The locations of investigated environments as on google map is shown in figures 3.12-3.19

1. Adum: This is an urban area located in the central hub of Kumasi, in the Ashanti Region of Ghana with coordinates 6.6919° N, 1.6287° W. It is highly populated and Characterized by a lot of business activity. It also has a lot of high-rise buildings.

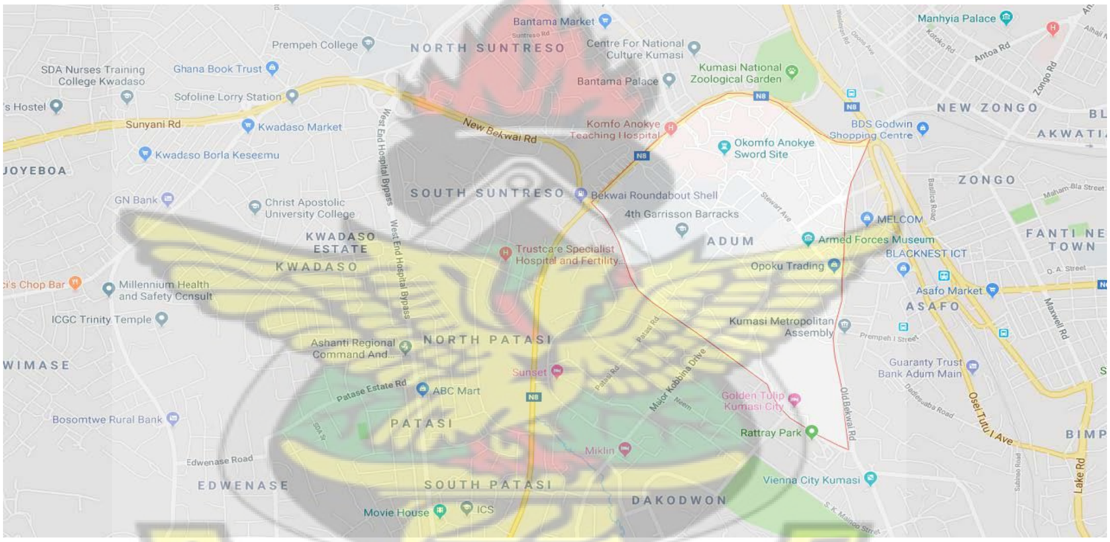

Figure 3.12 Google Map of Adum

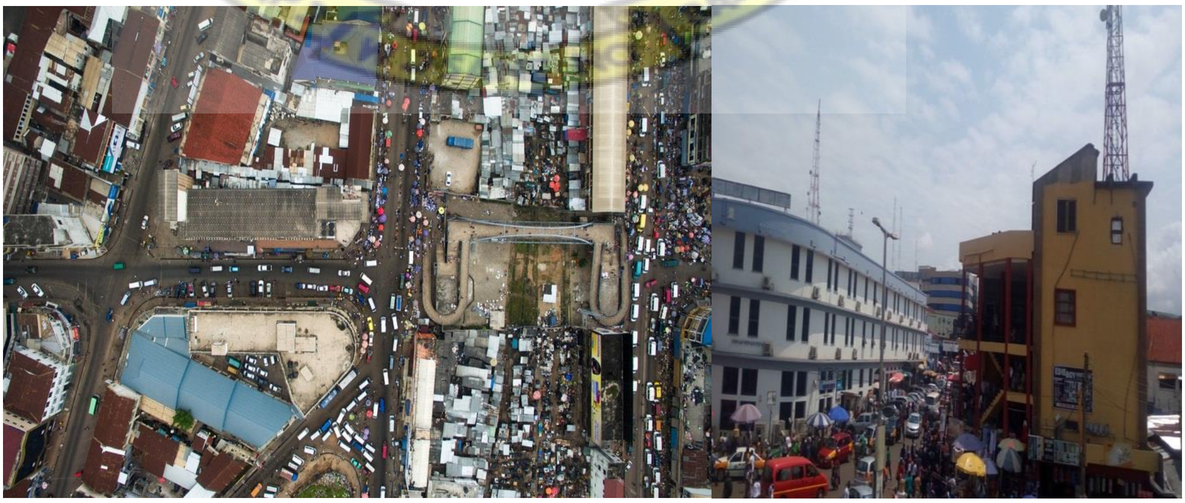

Figure 3.13 Pictorial Views of Adum, Kumasi

2. Techiman: This is an urban area that serves as the capital of the newly created Bono East Region of Ghana with coordinates 7.5909° N, 1.9344° W. It is characterized by quite several high-rise buildings.

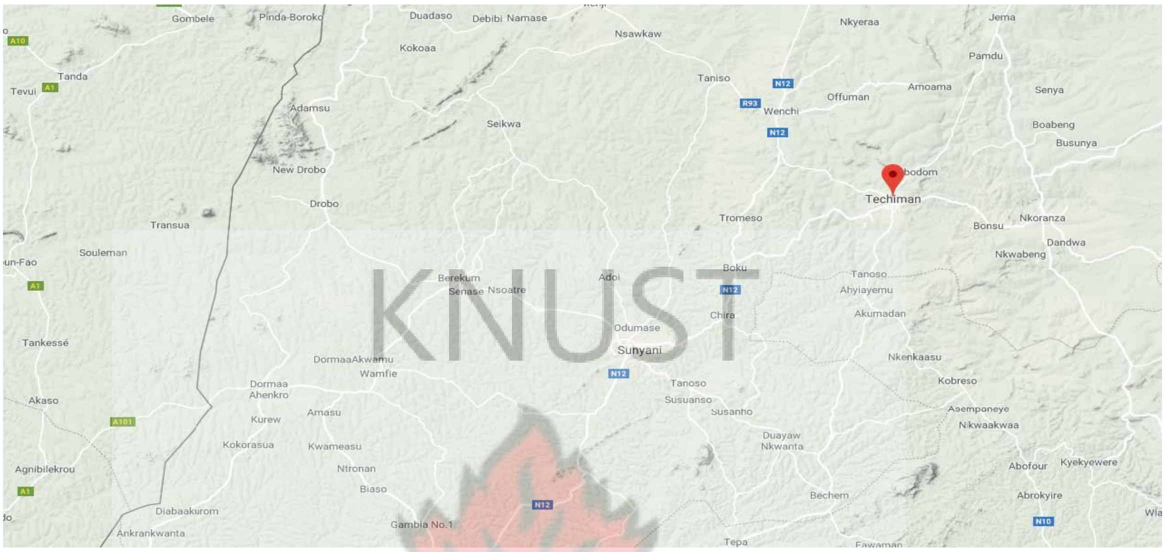

Figure 3.14 Google Map of Techiman

3. Agogo: This is a Suburban area in the Asante Akyem North Municipal District of the Ashanti Region of Ghana with coordinates 6.7991° N, 1.0850° W. Agogo is approximately 80 kilometres east of Kumasi, with moderate population and buildings. Buildings are mostly not high rise and are a little isolated from each other. The terrain is relatively flat.

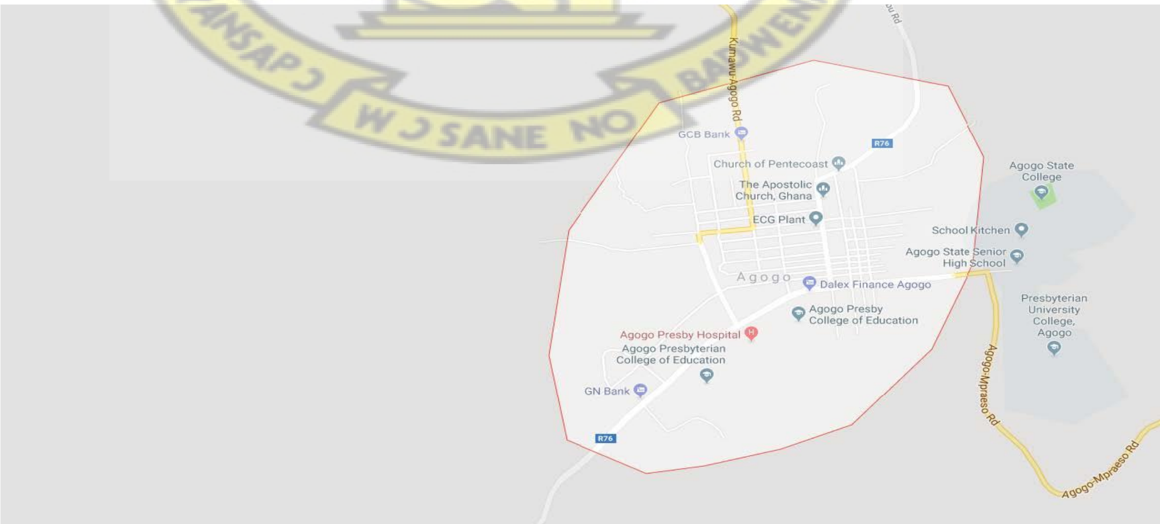

Figure 3.15 Google Map of Agogo

4. Afrancho: It is a populated suburban community in the Kwabre District of the Ashanti region of Ghana with coordinates 6° 33' 0" N,1° 38' 0"W. It is characterized by relatively hilly terrain with the presence of valleys. The road network in this area is quite bad and presented a lot of hindrances during the drive test.

Figure 3.16 Google Map of Afrancho

5. New Dorma: This is a suburban area in the Bono Region of Ghana. It is characterised by flat and hilly terrain with a lot of vegetation. It lies on coordinates 7° 16' 39" N,2° 52' 42"W.

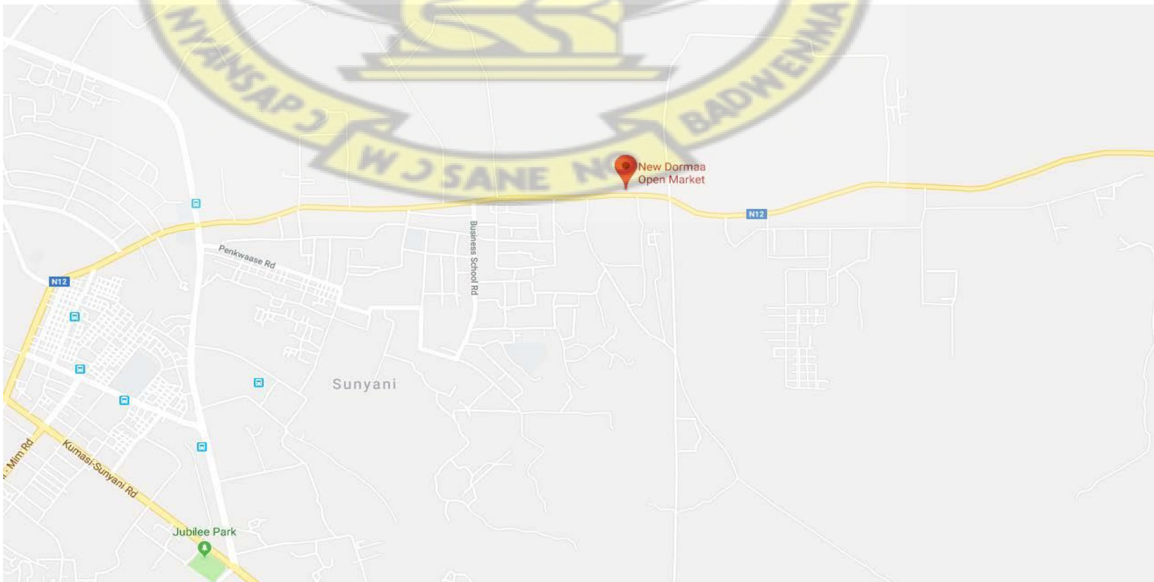

Figure 3.17 Google Map of New Dorma

6. Berekum: This is a Municipal located in the Bono Region of Ghana. It lies on coordinates 7° 27'N,2° 35'W.

Figure 3.18 Google Map of Berekum

7. Sunyani: This is an Urban populated city serving as the capital of the Bono Region of Ghana. Sunyani is surrounded by the forested Southern Ashanti uplands. It lies on coordinates 7° 20'N,2° 20'W.

Figure 3.19 Google Map of Sunyani

3.4 MODELLING PARAMETERS OF PROPAGATION MODELS

The carrier frequencies of propagation models were set to 800MHz for simulation 1 and 2600MHz for simulation 2 in MATLAB. The farthest distance away from the base station considered for RSRP measurement was set to 500m. A reference distance (d_O) of 50m was chosen. Transmitter antenna heights varied in urban and suburban areas between 16m and 35m. To cater for the effect of shadowing, correction factors are given by V. Erceg et al'; 10.6 dB in Urban and 8.2dB in sub-urban areas were used. Simulation parameters used in generating the path loss for the different propagation models are summarized in Table 3.2. Antenna heights presented represent the actual heights of the antennas at the various base stations where measurements were taken. shadowing factor as presented in [10] are used.

Table 3.2 Modeling Parameters

PARAMETERS		**VALUES**
Operating frequency		800 MHz &2600MHz
Transmit power		46dBm
Transmitter Antenna Height	Techiman	35m
	Adum	24m
	Agogo	25m
	Afrancho	32m
	New Dorma	32m
	Berekum	32m
		25m
Shadowing factor	urban	10.6 dB
	suburban	8.2 dB
distance	Sunyani	50 m – 500 m
reference distance (d_O)		50m
Receiver antenna height		1.5m

3.5 MATLAB SIMULATION AND THEORY

Drive test measurement results were analysed as described in section 3.5.1 based on theories also detailed in sections 3.5.2 & 3.5.3

3.5.1 MATLAB SIMULATION

RSRP values at varying distances from the base station were generated from the log files obtained through the drive test and recorded in a Microsoft Excel sheet. This was then imported into MATLAB simulation tool. The RSRP values recorded at different sectors of each base station were averaged. The calculated average power received was then used to estimate the path loss corresponding to each measurement. A comparison was then made between the path loss given by measurement data and the path loss estimated by the propagation models under investigation. The least-squares (LS) regression analysis was used to determine the path loss exponent. This is achieved by minimizing the summed squares of residuals between the measured and the predicted data. To determine the coefficients the summed square of residuals is differentiated with respect to each parameter and equating the result to zero [37]. The mean square error between measured path loss of the different environments and estimated path loss of propagation models was computed in MATLAB using the equation given in (3.10). Propagation models with lower RMSE values were improved and optimized for more accurate prediction. MATLAB codes are given in the Appendix. Results of these measurements and simulation in MATLAB are discussed in Chapter 4

3.5.2 PATH LOSS EXPONENT

The Path loss exponent for each measurement environment was computed, adapting the approach in [37]. The path loss exponent from theory as presented in[37] is derived as follows;

If P_i is the received power at a distance d_o and $\hat{p}_i$ is the estimated signal power, the sum of squared errors between the measured and estimated values $j(n)$ is given as

$$j(n) = \sum_{i=1}^{k} (P_i - \hat{P}_i)^2 \qquad 3.0$$

Standard deviation σ^2 is given as

$$\sigma^2 = \frac{j(n)}{k} \qquad 3.1$$

From the log distance model, the path loss (Pl) at a specified distance d is

$$Pl(d) = Pl(d_o) - 1on\log(\frac{d}{d_o}) \qquad 3.2$$

Making n the subject yields

$$n = \frac{Pl(d_o) - Pl(d)}{10\log(\frac{d}{d_o})} \qquad 3.3$$

By equating the derivative of $j(n)$ to zero, the n value that minimizes the mean square error can be obtained

$$\frac{dj(n)}{dn} = 2\sum_{i=1}^{k} (P_i - \hat{P}_i)\frac{d(P_i - \hat{P}_i)}{dn} = 0 \qquad 3.4$$

The estimated value can be obtained from

$$Pl(d) = Pl(d_o) - 1on\log(\frac{d}{d_o}) \qquad 3.5$$

Substituting this into the previous equation yields

$$\frac{dj(n)}{dn} = 2\sum_{i=1}^{k} (P_i - \hat{P}_i)\frac{d(P_i - Pl(d_o) + 1on\log(\frac{d}{d_o}))}{dn} = 0 \qquad 3.6$$

$$\frac{dj(n)}{dn} = \sum_{i=1}^{k} (P_i - Pd_o) + 1on\log(\frac{d}{d_o}))1o\log(\frac{d}{d_o}) = 0 \qquad 3.7$$

$$\sum_{i=1}^{k} (P_i - Pd_o)1o\log(\frac{d}{d_o}) + n\log(\frac{d}{d_o})^2 = 0 \qquad 3.8$$

n which is the path loss exponent can then be calculated as

$$n = \frac{\sum_{i=1}^{k} (Pd_o - P_i)10\log(\frac{d}{d_o})}{\sum_{i=1}^{k} (1o\log(\frac{d}{d_o}))^2} \qquad 3.9$$

The final expression for n (path loss exponent) was programmed in MATLAB for each of the measurement environments.

3.5.3 ROOT MEAN SQUARE ERROR

The RMSE which measures the difference between the signal power predicted by a model and the actual measured signal was implemented in MATLAB. It served as a measure of accuracy to compare forecasting errors of the different propagation models given the drive test measurement data. It is defined mathematically by equation (3.10)

$$RMSE = \sqrt{\frac{\sum_{k=1}^{k}\left(p_i - \overset{\Lambda}{p_i}\right)^2}{k}} \qquad 3.10$$

Where p_i represents the measured power value at a specified distance, $\overset{\Lambda}{p_i}$ is the predicted power value at a specified distance, k represents the number of measured samples

To calculate the RMSE, the predicted power values for each propagation model is subtracted from the actual measured power at each environment and squared. This result is then divided by the number of measured samples ,10 and the square root taken to arrive at the RMSE. This was implemented in MATLAB to arrive at results later discussed in chapter 4.

CHAPTER 4

4.0 INTRODUCTION

This chapter presents the results, analysis, and discussions from the study. The results presented are in two-fold. The first is at an operating frequency of 800MHz and the second at an operating frequency of 2600MHz.The chapter ends with the Validation of the presented results.

4.1 RESULTS AND DISCUSSIONS AT AN OPERATING FREQUENCY OF 800MHZ

Results presented at this frequency was categorized under urban and suburban scenarios.

4.1.0 RESULTS OF DRIVE TEST MEASUREMENTS

Results of the RSRP in dBm from the investigated environments are shown in Tables 4.1-4.2. Tables 4.1 are results of urban areas and Table 4.2 gives results of suburban areas

Table 4.1 Received Power Values of Urban Areas at 800MHz

DISTANCE(m)	RECEIVED POWER VALUES(dBm)					
	Techiman			Adum		
	S1	S2	S3	S1	S2	S3
50	-84.21	-70.94	-77.88	-89.58	-80.56	-77.59
100	-68.53	-86.41	-86.41	-68.25	-77.54	-82.03
150	-65.53	-77.84	-79.25	-88.25	-91.50	-86.22
200	-68.40	-78.19	-72.33	-92.31	-92.58	-85.31
250	-76.25	-81.44	-77.41	-94.28	-89.71	-81
300	-81.53	-84.06	-79.44	-95.62	-87.70	-86.30
350	-81.72	-81.59	-74.63	-95.89	-90.50	-87.40
400	-85.03	-88.50	-84.03	-91.40	-90.70	-88.60
450	-79.78	-95.40	-73	-98.25	-92.60	-87.20
500	-84.7	-95.59	-85.88	-98.70	-93.68	-89.14

S1, S2, and S3 represent the various sector antennas (sector 1-3) from which RSRP values were recorded. The reference distance of 50m was chosen in the far field of the radiating antennas.

Table 4.2 Received Power Values of Suburban Areas at 800MHz

DISTANCE(m)	RECEIVED POWER VALUES(dBm)								
	Afrancho			New Dorma			Agogo		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
50	-59	-60	-53.56	-80.40	-82.97	-86.71	-81.97	-70.01	-67.88
100	-64.72	-61.66	-61.76	-79.03	-76.69	-79.56	-92.91	-65.54	-59.31
150	-74.15	-67.38	-80.02	-68.97	-64.67	-71.71	-75.06	-66.06	-83.13
200	-90.34	-79.63	-85.65	-65.25	-69.67	-68.92	-70.25	-80.25	-73.38
250	-86.16	-84	-91.03	-66.81	-69.31	-64.41	-72.25	-82.96	-75.06
300	-97.08	-90.23	-82.58	-69.38	-75.59	-65.15	-81.81	-86.63	-82.59
350	-96.92	-97.13	-84.09	-68.28	-72.31	-70.14	-83.97	-82.88	-93.35
400	-96.78	-101.91	-77.08	-72.08	-73.44	-74.54	-81.69	-81.23	-100.1
450	-102.2	-102.20	-82.88	-74.40	-70.59	-76.49	-79.19	-89.50	-97.28
500	-106.7	-104.40	-81.46	71.23	-75.70	-87.24	-92.59	-85.38	-97.81

The average received power was computed for each of the measurement environments by averaging the readings taken at the three different sector antennas of the base stations. Results are shown in Table 4.3

Table 4.3 Mean Received Power Values at 800MHz

DISTANCE	MEAN RECEIVED POWER VALUES(dBm)				
	Techiman	Adum	Agogo	Afrancho	New Dorma
50	-77.68	-82.58	-73.29	-57.52	-83.36
100	-80.45	-75.94	-72.59	-62.71	-78.43
150	-74.21	-88.66	-74.75	-73.85	-68.45
200	-72.97	-90.07	-74.63	-85.21	-67.95
250	-78.37	-88.33	-76.76	-87.06	-66.84
300	-81.68	-89.87	-83.68	-89.96	-70.04
350	-79.31	-91.26	-86.73	-92.71	-70.24
400	-85.85	-90.23	-87.650	-91.92	-73.35
450	-82.73	-92.68	-88.66	-95.76	-73.83
500	-88.72	-93.84	-91.93	-97.50	-78.07

The mean received power for the different environments in Table 4.3 was compared and analyzed by plots against varying distances from the base station using MATLAB. This is shown in figure 4.1. The corresponding MATLAB codes are as given in Appendix A1.

As can be observed from the graph, the received power decreases as distance away from the base station is increased. Deviations from this trend, however, occurred on a few occasions. This was partly as a result of obstacles and contribution from the terrain of those environments.

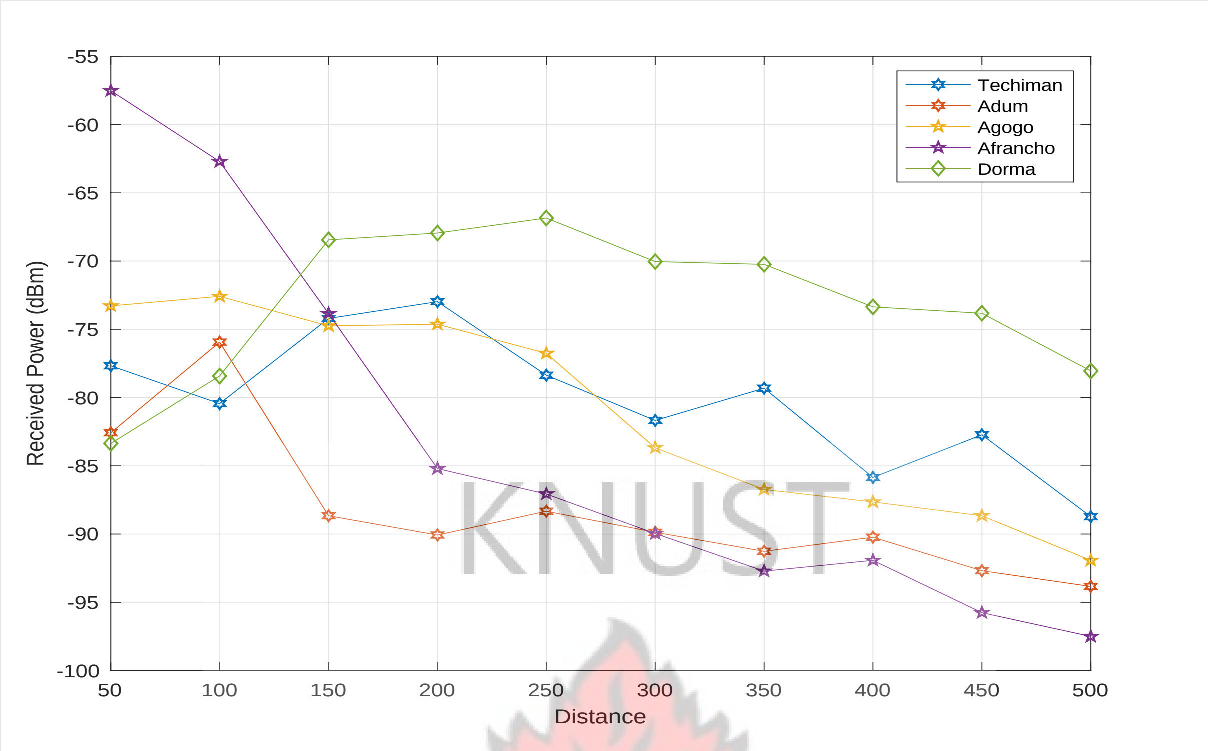

Figure 4.1 Received Power of All Sites at 800MHz

4.1.1 PATH LOSS OF MEASURED DATA

The experienced path loss at each measurement location at a distance $d(m)$ was computed as follows;

$$Pl(dB) = EIRP(dBm) - \mathrm{Pr}(dBm) \tag{4.0}$$

where Pr = Mean received power in dBm, $EIRP$ = Effective isotropic radiated power in dBm.

$EIRP$ is given in (4.1) and (4.2)

$$EIRP = Pt + G - L \tag{4.1}$$

Where G stands for Gains and L for losses

Typical gains considered are the antenna gains at the transmitter

Typical losses are connector, body and combiner loss

Expanding this yield,

$$EIRP = Pt + Gt - Lco - Lcon - Lbo \tag{4.2}$$

Pt = Transmit power (dBm),Gt = Gain of Transmit Antenna (dBi), $Lcon$ = Connector loss (dB), Lbo = Body loss (dB),Lco = Combiner loss(dB).

The values of the stated parameters commonly applied in LTE Networks are given by S. A. Mawjoud [38] as;

$P_t = 40W = 46dBm$, $G_t = 18.15dBi$, $G_{ms} = 0dBi$,$Lbo = 3dB$,

$Lcon = 4.7dB$, $Lco = 3dB$

These parameters are substituted into equation (4.2)

$EIRP = 53.5dBm$

Table 4.4 gives the path loss experienced in the different areas where measurements were taken. The path loss is obtained by substituting the calculated value of EIRP (dBm) and the mean received power Pr (dBm) values given earlier in Table 4.3 into equation (4.0)

Table 4.4 Path Loss Values for Environments at 800MHz

PATH LOSS VALUES(dB) 800MHz					
Distance(m)	Techiman	Adum	Agogo	Afrancho	New Dorma
50	131.13	136.03	126.74	110.97	136.81
100	133.90	129.39	126.04	116.16	131.88
150	127.66	142.11	128.20	127.30	121.90
200	126.42	143.52	128.08	138.66	121.39
250	131.82	141.78	130.21	140.51	120.29
300	135.13	143.32	137.13	143.41	123.49
350	132.76	144.71	140.18	146.16	123.69
400	139.30	143.68	141.10	145.37	126.80
450	136.18	146.13	142.11	149.21	127.28
500	142.17	147.29	145.38	150.95	131.51

The effect of varying distance on path loss for each measurement environment was investigated by plots of path loss versus distance and the graph shown below in figure 4.2 illustrates this. Appendix A2 shows the corresponding code in MATLAB

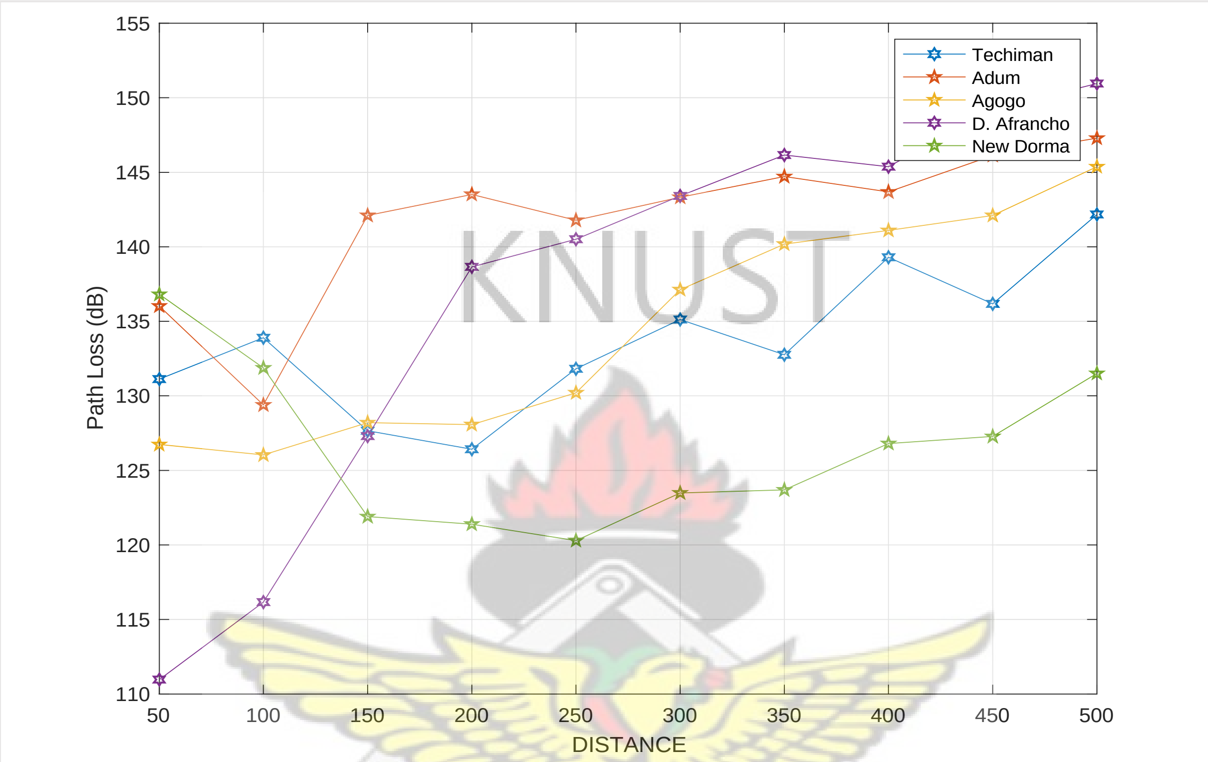

Figure 4.2 Path Loss of All Environments at 800MHz

It can be observed from the graph given in figure 4.2 that path loss increases as the distance from the Base station increases. Comparing the path loss experienced for all the measurement environments, the path loss of Adum and Afrancho is relatively higher compared to the other areas. The hilly nature of Afrancho and the presence of many high-rise buildings in Adum are good reasons to support the high path loss in these areas.

4.1.2 PATH LOSS OF PROPAGATION MODELS

Using parameters specified in Table 3.1 together with path loss equations of four propagation models(FSPL, Hata, SUI, and Ericson), path loss was generated using MATLAB. The path loss was generated for both Urban and Suburban Environments as shown in Tables 4.5 and 4.6 respectively.

Table 4.5 Path Loss Estimations of Propagation Models Typical of Urban Environments at 800 MHz

PATH LOSS(dB) 800MHz				
Distance(m)	FSPL	Hata	SUI	Ericson
50	64.4812	78.6447	72.6830	97.4062
100	70.5018	89.0021	80.4909	106.5394
150	74.0236	95.0608	85.0583	111.8819
200	76.5224	99.3595	88.2989	115.6726
250	78.4606	102.6938	90.8125	118.6128
300	80.0442	105.4182	92.8663	121.0151
350	81.3832	107.7216	94.6027	123.0463
400	82.5430	109.7169	96.1069	124.8057
450	83.5661	111.4769	97.4336	126.3577
500	84.4812	113.0512	98.6205	127.7460

Table 4.6 Path Loss Estimations of Propagation Models Typical of Suburban Environments at 800MHz

PATH LOSS(dB) 800MHz				
Distance	Fspl	Hata	SUI	Ericson
50	64.4812	61.4821	72.6830	55.2899
100	70.5018	71.8395	80.0714	76.0852
150	74.0236	77.8981	84.3933	88.2496
200	76.5224	82.1969	87.4598	96.8805
250	78.4606	85.5312	89.8383	103.5751
300	80.0442	88.2555	91.7817	109.0449
350	81.3832	90.5589	93.4248	113.6697
400	82.5430	92.5542	94.8482	117.6758
450	83.5661	94.3142	96.1037	121.2094
500	84.4812	95.8886	97.2267	124.3704

4.1.3 COMPARISON OF PATH LOSS OF MEASUREMENT RESULTS WITH PROPAGATION MODELS

The path loss of each measurement environment was compared with the path loss estimations of the understudied propagation models at 800MHz

4.1.3.1 COMPARISON FOR URBAN SCENARIOS

The path loss from the propagation models under urban scenarios is compared with the path loss of the two urban areas (Adum and Techiman) to observe which model predicts closely to the measured data. This is shown in fig 4.3 & 4.4. Corresponding MATLAB codes are given in Appendix A3

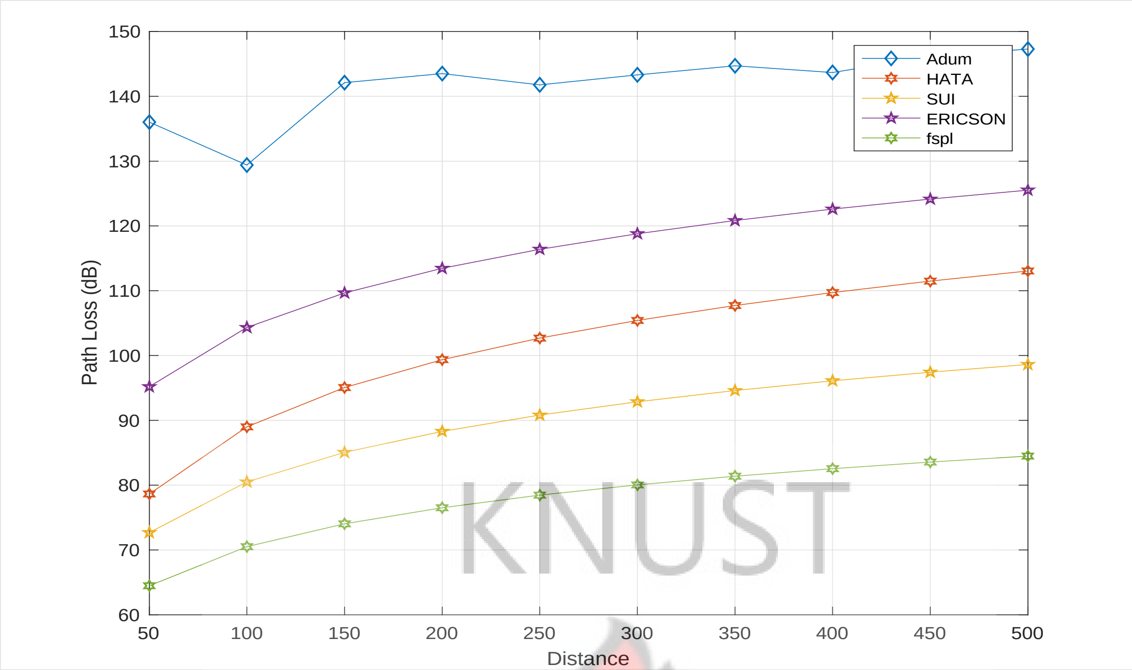

Figure 4.3 Path Loss of Adum Compared With Path Loss of Propagation Models at 800MHz

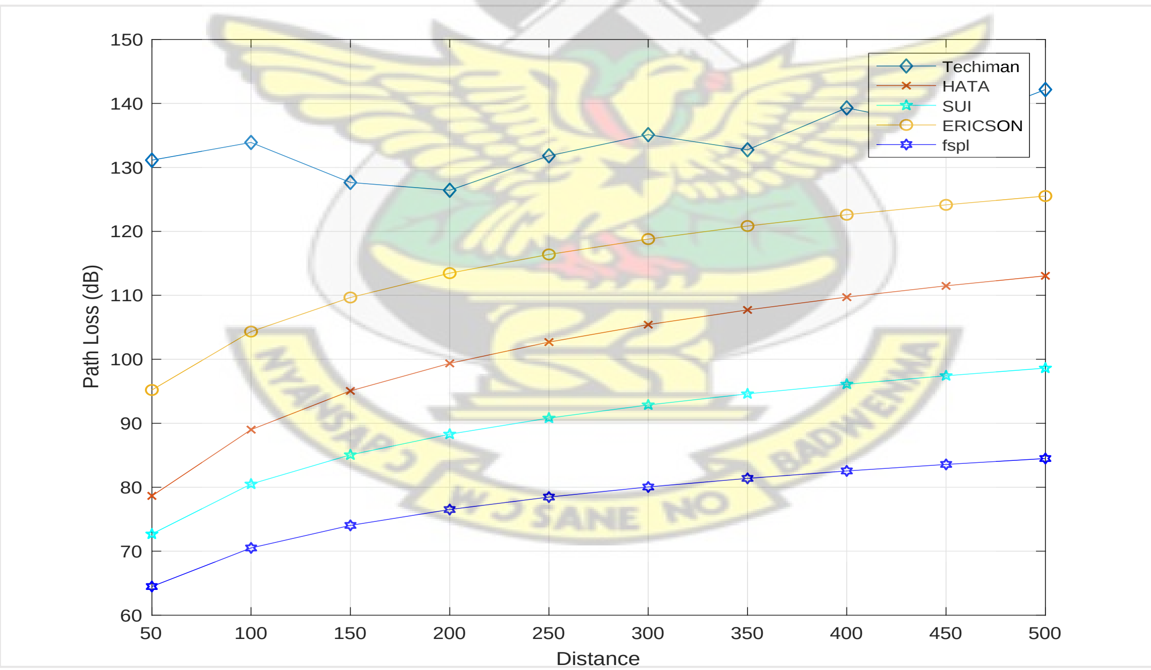

Figure 4.4 Path Loss of Techiman Compared With Path Loss of Propagation Models at 800MHz

The path loss in these urban environments (Adum &Techiman) compared with the Ericsson and Hata model experience smaller deviation compared to the other propagation models.

4.1.3.2 COMPARISON FOR SUBURBAN SCENARIOS

The path loss from the propagation models under suburban scenarios is also compared with the path loss of the three suburban environments (Agogo, Afrancho &Techiman) to observe which model predicts closely to the measured data. This is shown in figures 4.5 - 4.7

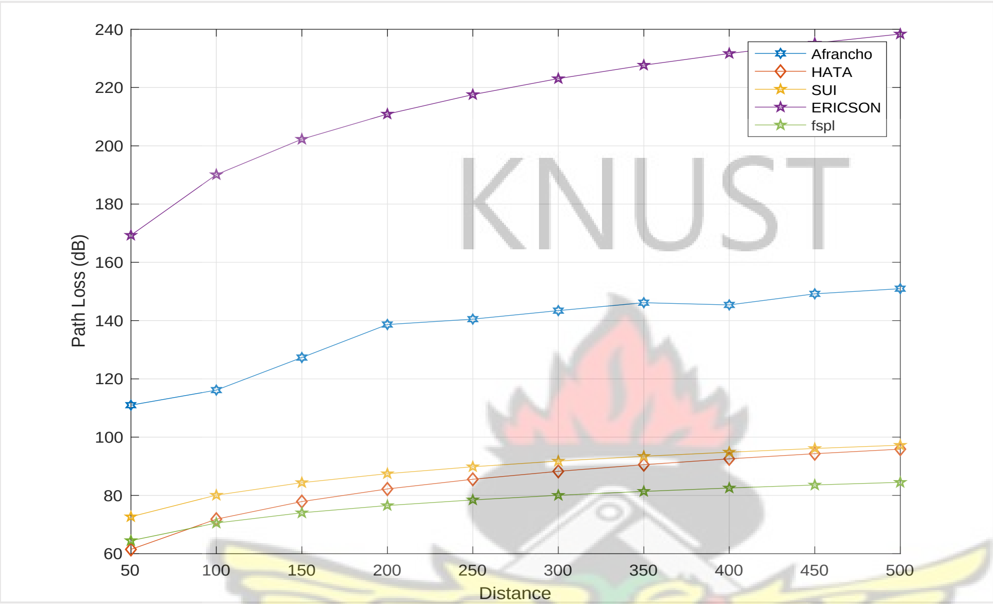

Figure 4.5 Path Loss of Afrancho Compared With Path Loss of Propagation Models at 800MHz

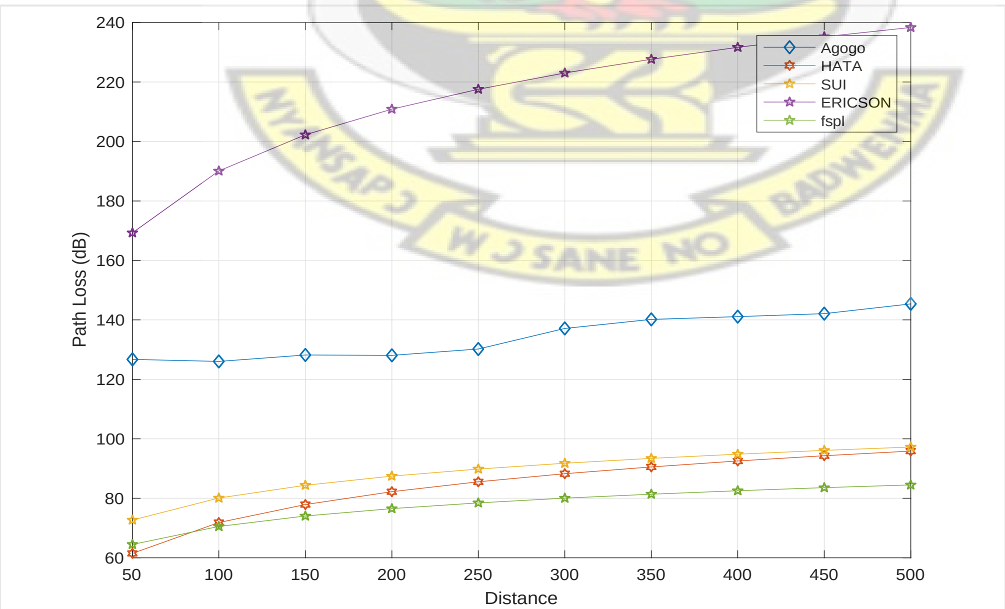

Figure 4.6 Path Loss of Agogo Compared With Path Loss of Propagation Models at 800MHz

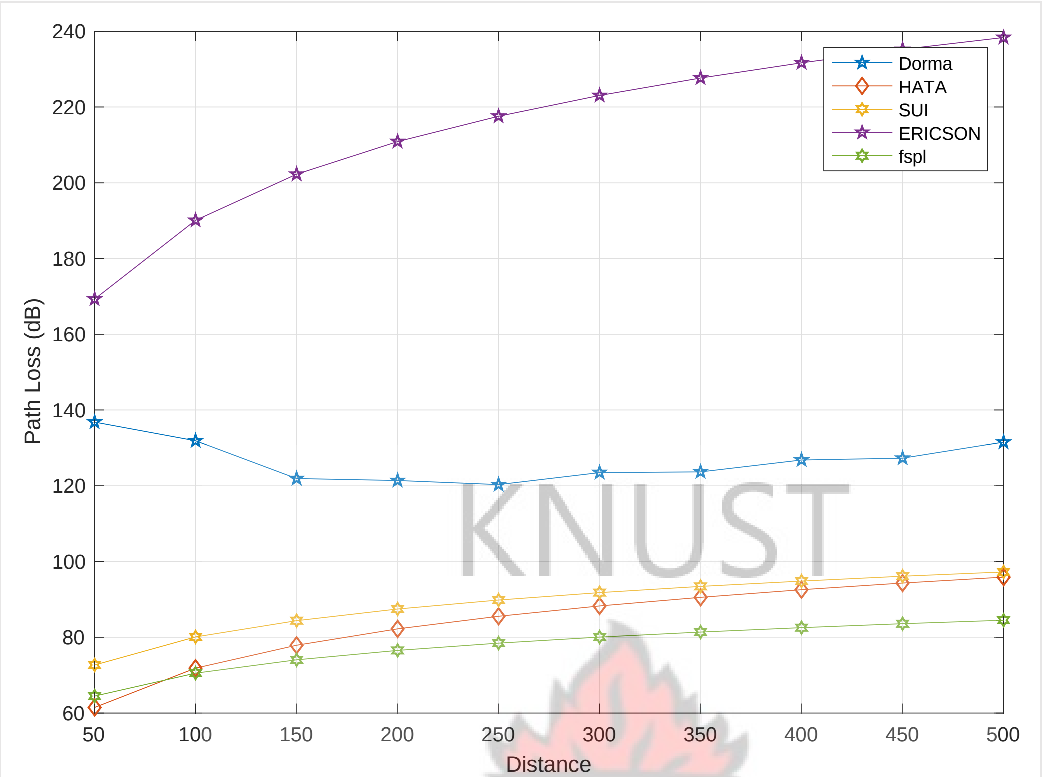

Figure 4.7 Path Loss of New Dorma Compared With Path Loss of Propagation Models at 800MHz

For all the suburban environments, the Ericson model over predicts the Path loss hence will not be a suitable model for consideration. The SUI model fits best to the measured data for all three suburban areas

4.1.4 PATH LOSS EXPONENT

The path loss exponent which shows the lossy nature of a particular propagation environment was computed from the measurement data for each of the areas considered. Appendix A5 goes through the step by step procedure of computing the path loss exponent in MATLAB. The results are shown in Table 4.7.

Table 4.7 Path Loss Exponents at 800MHz

Area	Path loss exponent
Adum	3.02
Techiman	2.79
Agogo	2.55
Afrancho	4.014
New Dorma	2.33

4.1.5 CHOICE OF PROPAGATION MODEL THAT BEST FITS MEASUREMENT DATA

Root Mean square error was used as a quantitative measure of accuracy for choosing the propagation model that best fits the measured data in the Ghanaian environment. The best propagation model was the model that had the least Root Mean squared errors (Least RMSE). The Ericson Model was considered best in predicting path loss in the urban areas because it has the lowest Mean Square Error of 17.98dB but fared badly in the suburban areas with very high RMSE values. The RMSE computed for the measurement areas together with the various propagation models are given in Table 4.8. The FSPL model is left out since the propagation environments considered have no clear line of sight.

Table 4.8 RMSE Values

ROOT MEAN SQUARE ERROR(URBAN)			
Environments	Hata model	SUI model	Ericson model
Techiman	30.66	32.96 44.41	17.98
Adum	40.64	40.39 52.31	25.17
MEAN SQUARE ERROR(SUBURBAN)			
Agogo	50.22	45.88	173.99
Afrancho	52.39	48.48	171.18
New Dorma	44.03	39.21	182.86

The Ericson model had the lowest MSE values in Urban environments as shown in Table 4.8. This model is therefore chosen as the model that predicts best in Urban areas in Ghana and it is further modified and improved for more accurate predictions. In the suburban environments, the SUI model had the lowest RMSE values and hence was chosen as the best model for path loss prediction in suburban cities in Ghana. It is also further modified for a more accurate prediction.

4.1.6 MODIFICATION OF ERICSON MODEL

The Ericson model which best fit measurement in the urban environments was chosen and modified to fit the measured data in urban environments. To modify and further improve the Ericson model the mean square error between the urban environments and the Ericson model was added to the standardized Ericson path loss equation.

$$a0 + a1 * \log(d) + a2 * \log(h_b) + a3 * \log(h_b) * \log(d) - 3.2 * (\log(11.75 * h_r))^2 + g_f + RMSE \qquad 4.3$$

$RMSE$ for Adum =17.98

Adding the *RMSE* yields;

$$a0 + a1 * \log(d) + a2 * \log(h_b) + a3 * \log(h_b) * \log(d) - 3.2 * (\log(11.75 * h_r))^2 + g_f + 17.98 \qquad 4.4$$

This new equation with the $RMSE$ added was plotted with measurement data from Adum together with the initial standardized Ericson model equation and the graph is shown in figure 4.8. It can be clearly observed that adding the *RMSE* to the initial equation improves the accuracy of prediction as the modified Ericson equation fits best to the measured data.

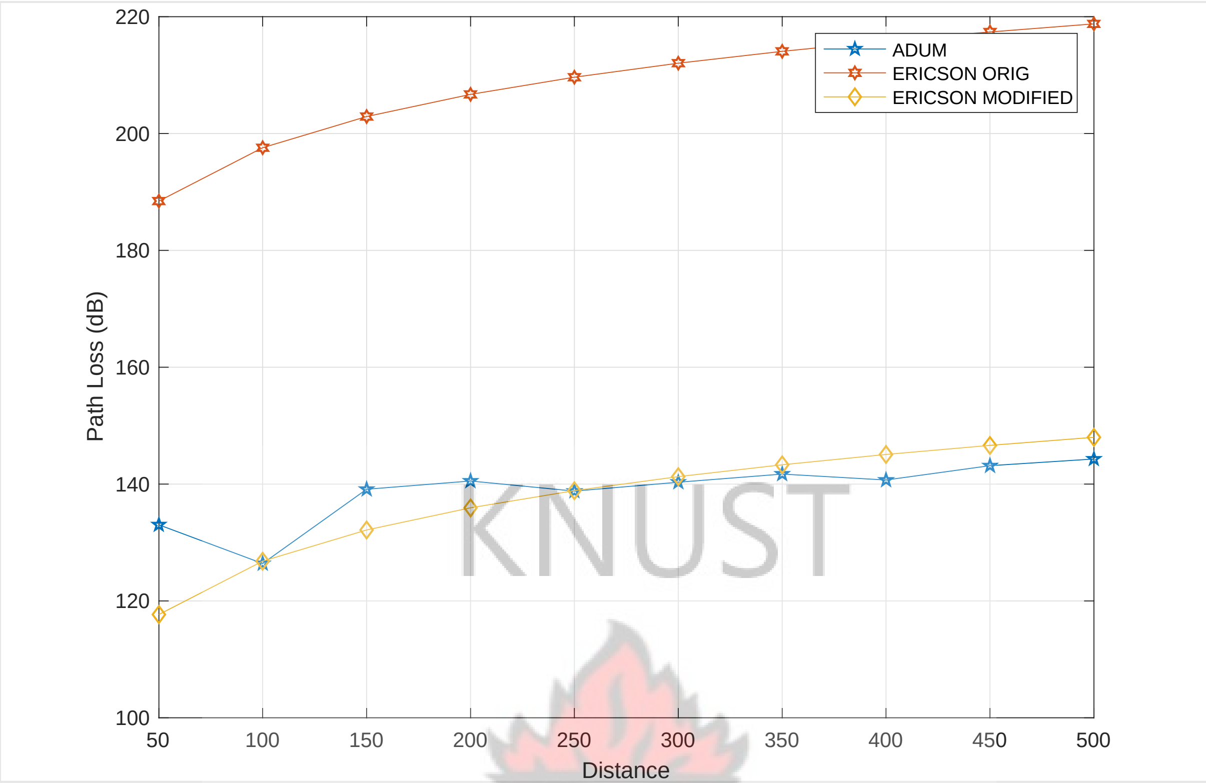

Figure 4.8 Comparison of Modified Model and Original Ericson Model for Adum

The values of various parameters $a0, a1, a2, a3, h_b, h_r$ and g_f in the Ericson model suited for an urban area were substituted into the modified equation and approximated to make the Ericson equation simple and less tedious to use yet not compromising accuracy. The resulting equation is as in equation 4.5

$$Pl_{\text{modified}} = 68.30 + 30.2\log(d) + 0.139\log(d) \qquad 4.5$$

This simplified equation, the original equation, modified equation and measurement data from adum are compared in figure 4.9. The simplified equation developed does not deviate from the modified model hence can be used to predict path loss accurately for the environment under investigation.

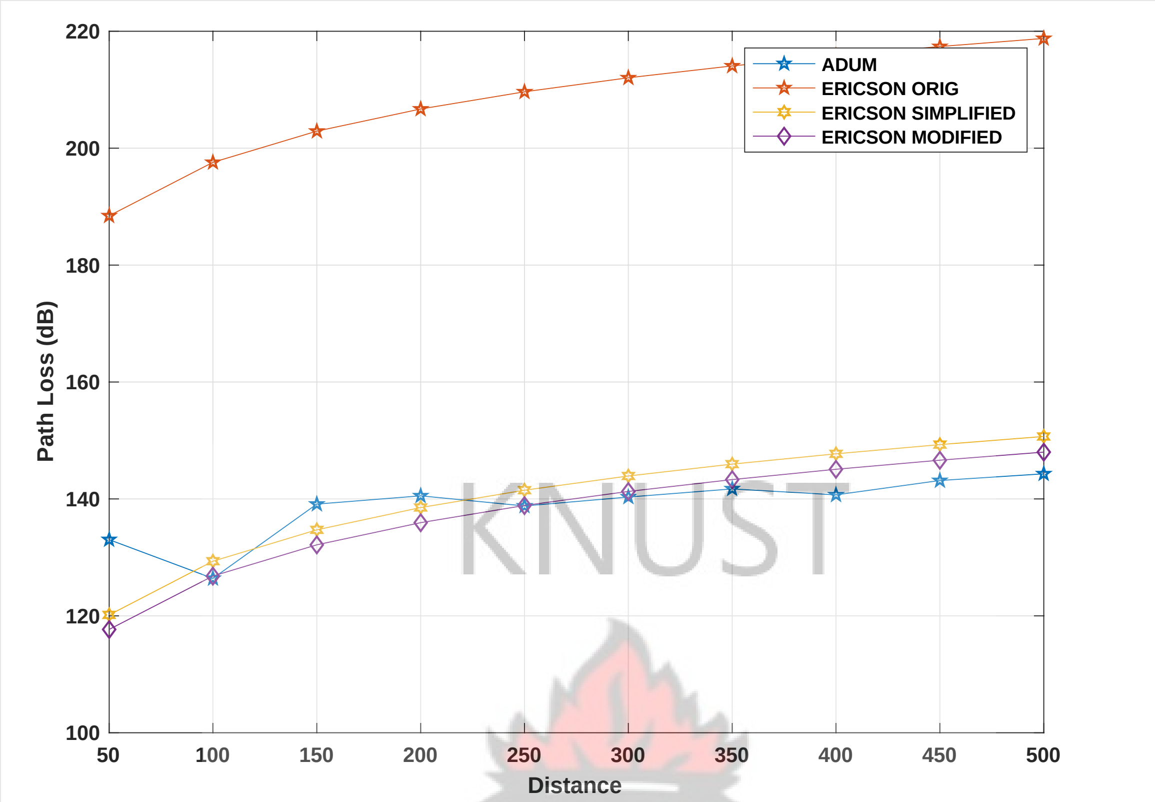

Figure 4.9 Comparison of Simplified,Modified and Original Ericson Path Loss Models for Adum

Measurement data from Techiman followed the Ericson model also and hence the Ericson model was modified and further simplified to better predict path loss in Techiman and also for similar environments to Techiman operating at 800MHz.Figures 4.10 & 4.11 shows the performance of the modified and simplified path loss equations developed compared with the original Ericson path loss equation.

The RMSE for Techiman with the Ericson model was added to the initial Ericson equation in equation (4.6)

$$a0 + a1 * \log(d) + a2 * \log(h_b) + a3 * \log(h_b) * \log(d) - 3.2 * (\log(11.75 * h_r))^2 + g_f + RMSE \quad 4.6$$

$RMSE$ for Techiman =25.17

Adding the $RMSE$ yields;

$$a0 + a1 * \log(d) + a2 * \log(h_b) + a3 * \log(h_b) * \log(d) - 3.2 * (\log(11.75 * h_r))^2 + g_f + 25.17 \quad 4.7$$

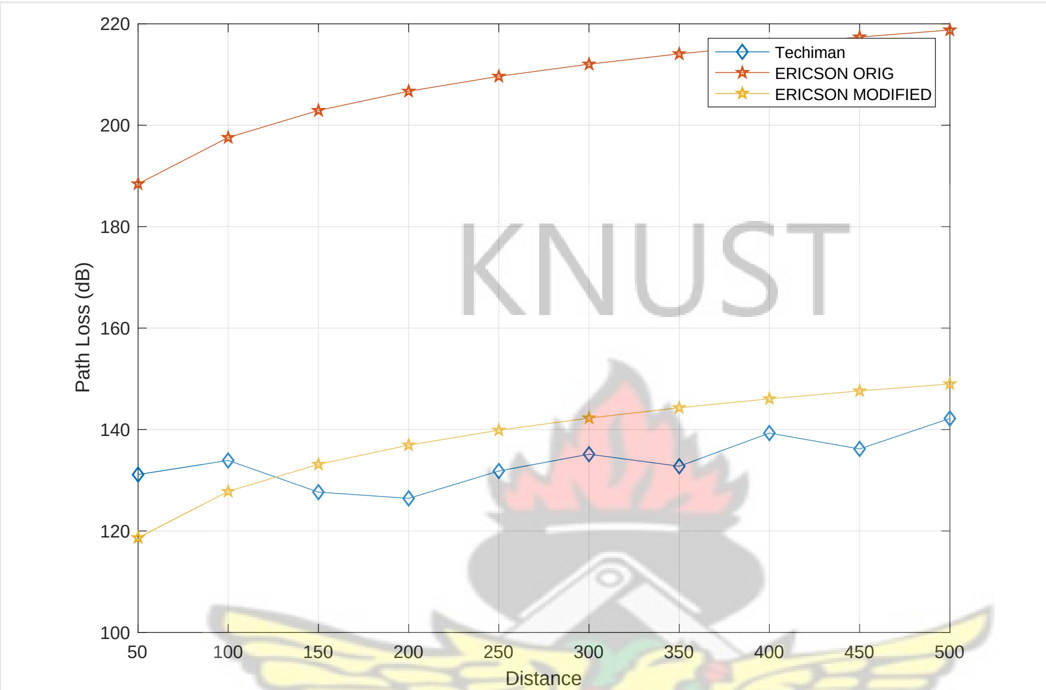

Figure 4.10 Comparison of Modified Model and Original Ericson Model for Techiman

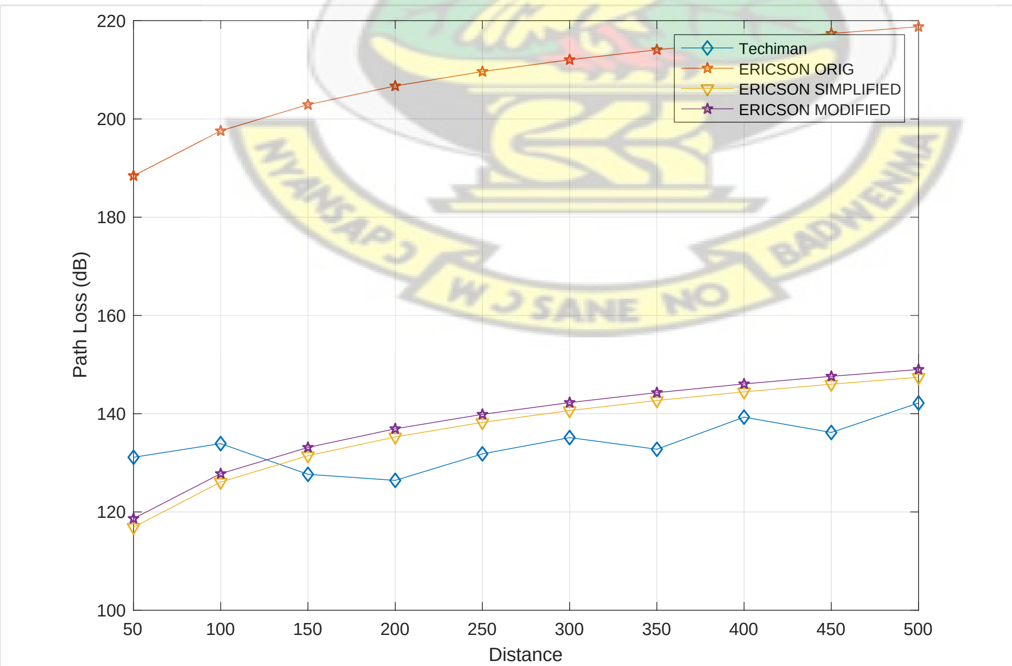

Figure 4.11 Comparison of Simplified, Modified and Original Ericson Path Loss Models for Techiman

4.1.7 MODIFICATION OF SUI MODEL

Results of RMSE for suburban areas favored the SUI model which had the lowest RMSE values. On this basis, the SUI model was chosen as the best-fit propagation model for path loss estimation in suburban areas in Ghana. It was further modified for more accurate predictions in Ghanaian suburban environments. The RMSE each of Agogo, Afrancho and New Dorma were added to the original SUI equations and further simplified in equations 4.8- 4.11

$$PL_{SUI} = A + 10\gamma\log\left(\frac{d}{d_o}\right) + s \pm RMSE \qquad 4.8$$

4.1.7.1 MODIFIED MODEL FOR AGOGO

$$Pl_{sui(simple)} = 72.68 + 24.54\log(\frac{d}{d_0}) + RMSE \qquad 4.9$$

4.1.7.2 MODIFIED MODEL FOR AFRANCHO

$$Pl_{sui(simple)} = 72.68 + 24.54\log(\frac{d}{d_o}) + RMSE \qquad 4.10$$

4.1.7.3 MODIFIED MODEL FOR NEW DORMA

$$Pl_{sui(simple)} = 72.6830 + 47.54\log(\frac{d}{d_o}) + RMSE \qquad 4.11$$

Graphs comparing the performance of the modified models with the original SUI models are shown in figures 4.12 - 4.14.

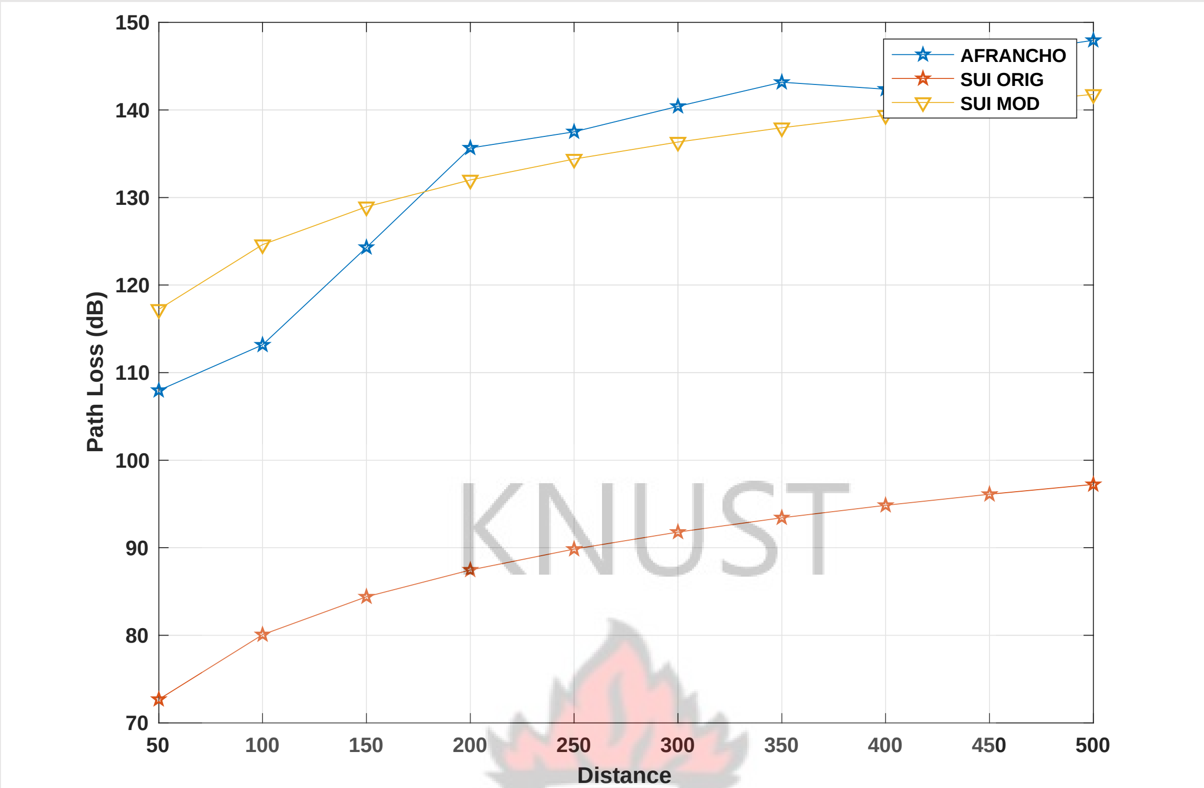

Figure 4.12 Comparison of Modified SUI Model and Original SUI Model for Afrancho

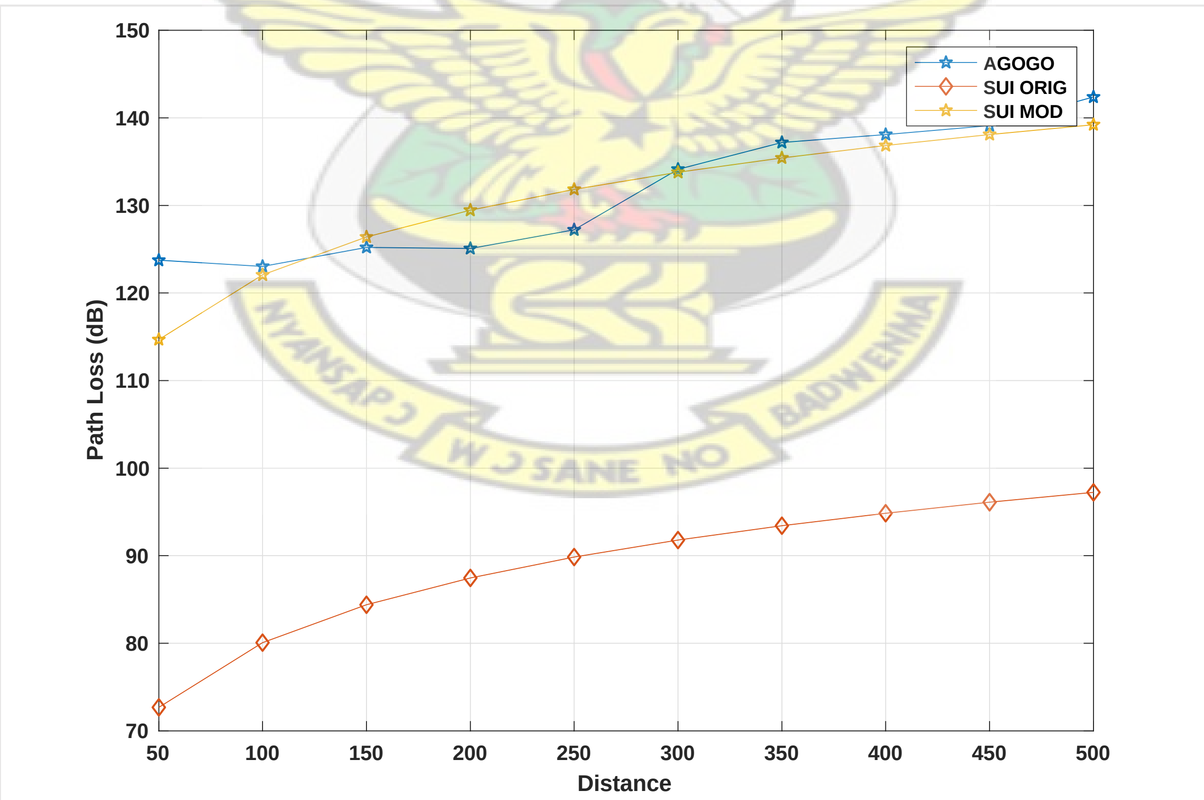

Figure 4.13 Comparison of Modified SUI Model and Original SUI Model for Agogo

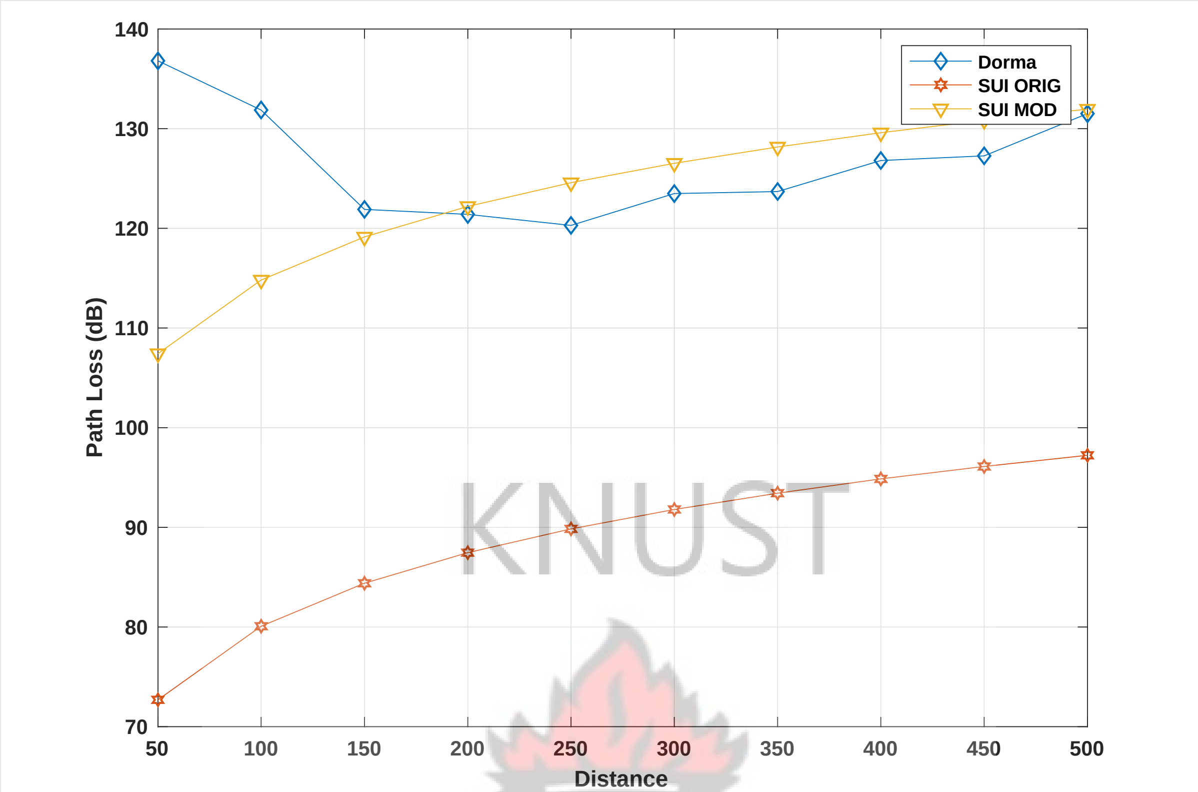

Figure 4.14 Comparison of Modified SUI Model and Original SUI Model for New Dorma

4.2 RESULTS AND DISCUSSIONS AT AN OPERATING FREQUENCY OF 2600MHZ

Results at a carrier frequency of 2600MHz are presented and discussed for both urban and suburban environments.

4.2.0 RESULTS OF DRIVE TEST MEASUREMENTS

Investigated environments at this frequency are renamed according to table 4.7. Results of the RSRP in dBm from the investigated environments at an operating frequency of 2600MHz are shown in Tables 4.10. The environments where measurements were taken are renamed in Table 4.9

Table 4.9 Renaming of Measurement Environments at 2600MHz

Measurement Environments at 2600MHz	Names used in MATLAB Simulation
Techiman 2	Site1
Techiman 3	Site 2
Berekum	Site 3
Techiman 1	Site 4
Sunyani	Site 5

Table 4.10 RSRP Values at 2600MHz

RSRP VALUES(dBm) 2600MHz									
Distance (m)	SITE 1 (Techiman 2)			SITE 2 (Techiman 3)			SITE 3 (Berekum)		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
50	-81.94	-87.75	-87.31	-85.20	-90.20	-85.20	-75.25	-89.00	-94.38
100	-80.44	-77.88	-86.19	-93.31	-103.13	-89.94	-96.00	-88.88	-95.38
150	-88.75	-68.81	-76.31	-87.19	-91.75	-81.25	-10.63	-93.75	-100.63
200	-88.44	-67.81	-72.63	-96.69	-91.31	-76.00	-86.28	-77.50	-83.69
250	-89.38	-85.56	-76.63	-94.63	-86.31	-74.06	-89.88	-75.44	-88.25
300	-89.19	-93.13	-85	-98.81	-93.13	-78.13	-76.75	-83.44	-76.75
350	-98.63	-99.31	-88.88	-82.25	-95.25	-76.88	-90.06	-77.44	-89.81
400	-99.81	-113.88	-87.25	-90.75	-101.06	-78.00	-89.81	-68.81	-89.81
450	-92.31	-114	-88.63	-99.31	-88.81	-78.81	-90.13	-79.19	-79.00
500	-93.20	-115.20	-89.20	-96.13	-96.81	-101.19	-92.56	-94.69	-89.00

Table 4.10 RSRP Values at 2600MHz

RSRP VALUES(dBm) 2600MHz						
Distance(m)	SITE 4(Techiman 1)			SITE 5 (Sunyani)		
	S1	S2	S3	S1	S2	S3
50	-90.06	-80.38	-83.56	-80.94	-85.56	-80.94
100	-89.94	-98.13	-82.50	-82.13	-88.44	-85.88
150	-101.94	-85.94	-82.00	-88.44	-94.69	-88.44
200	-99.19	-97.00	-94.50	-97.02	-71.00	-97.02
250	-94.00	-91.25	-91.19	-96.56	-86.06	-110.31
300	-87.88	-97.50	-94.44	-92.56	-79.06	-100.31
350	-90.44	-81.56	-97.38	-79.69	-79.5	-104.69
400	-94.25	-86.30	-96.25	-91.38	-85.13	-86.38
450	-95.44	-89.20	-100.19	-79.38	-94.44	-97.50
500	-87.50	-90.45	-92.56	-90.44	-96.69	-93.69

The average received power was computed for each of the measurement environments by averaging the RSRP readings taken at the three different sector antennas of the base stations. Results are shown in Table 4.11

Table 4.11 Mean RSRP Values at 2600MHz

MEAN RSRP VALUES(dBm) 2600MHz					
Distance(m)	Site 1	Site 2	Site3	Site4	Site5
50	-85.66	-86.87	-86.21	-84.67	-82.48
100	-81.50	-95.46	-93.42	-90.19	-85.48
150	-77.95	-86.73	-68.33	-89.96	-90.52
200	-76.29	-88.00	-82.490	-96.89	-88.35
250	-83.86	-85.00	-84.52	-92.15	-97.64
300	-89.11	-90.02	-78.98	-93.27	-90.64
350	-95.61	-84.79	-85.77	-89.79	-87.96
400	-100.31	-89.94	-82.81	-92.26	-87.63
450	-98.31	-88.98	-82.77	-94.94	-90.44
500	-99.20	-98.04	-92.08	-90.17	-93.61

The mean received power of all five measurement environments were compared against distance in figure 4.15

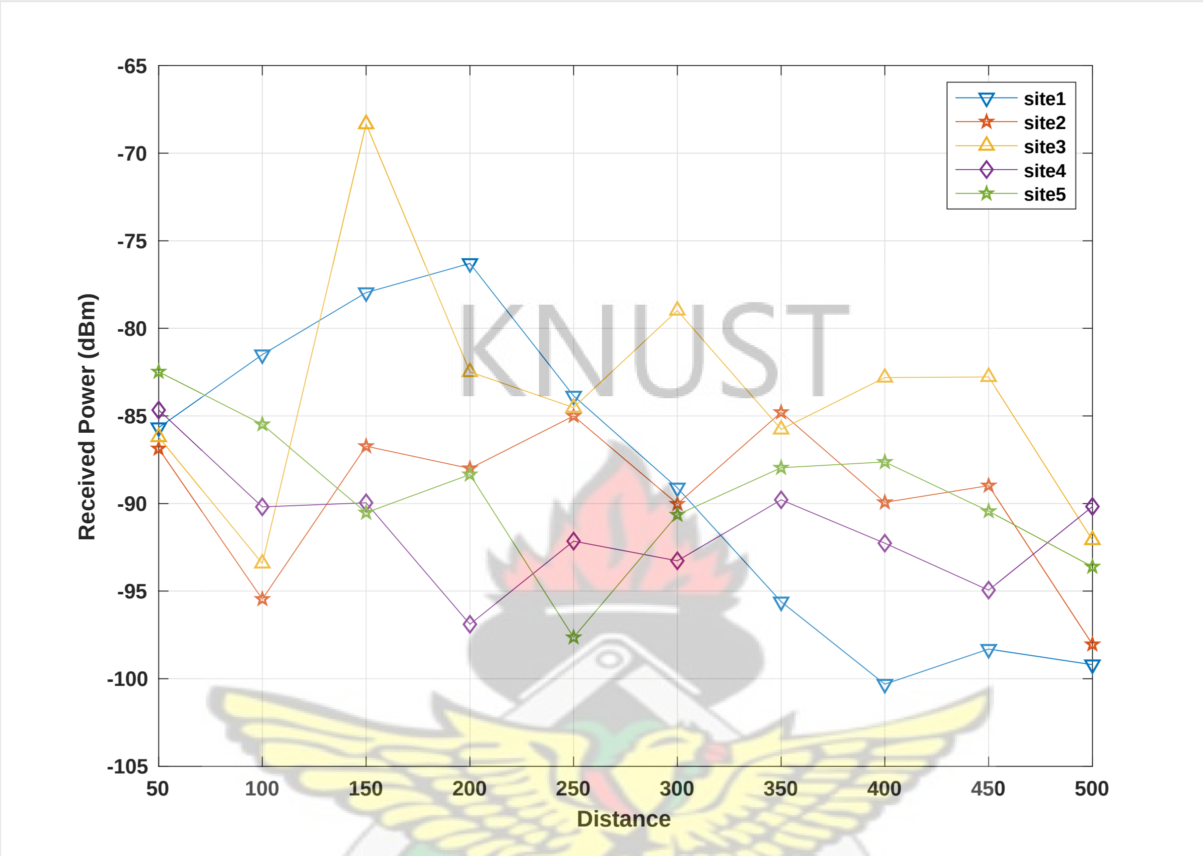

Figure 4.15 Received Power of All Environments

4.2.1 PATH LOSS OF MEASURED DATA

As shown already in the analysis at an operating frequency of 800MHz, the path loss is obtained by substituting the calculated value of EIRP (dBm) and the mean received power Pr (dBm) values also at 2600MHz given in Table 4.11 into equation (4.0)

Table 4.12 gives the path loss experienced at the different environments where measurements were taken from and figure 4.16 compares path loss at each measurement environment with distance.

Table 4.12 Path Loss Values for Environments at 2600MHz

PATH LOSS (dB) 2600MHz					
Distance(m)	Site1	Site2	Site 3	Site 4	Site 5
50	136.12	137.32	136.66	135.12	132.93
100	131.95	145.91	143.87	140.64	135.93
150	128.41	137.18	118.79	140.41	140.97
200	126.74	138.45	132.94	147.35	138.79
250	134.31	135.45	134.97	142.59	148.09
300	139.56	140.47	129.43	143.72	141.09
350	146.06	135.24	136.22	140.24	138.41
400	150.76	140.39	133.26	142.72	138.08
450	148.76	139.43	133.22	145.39	140.89
500	149.65	148.49	142.53	140.62	144.05

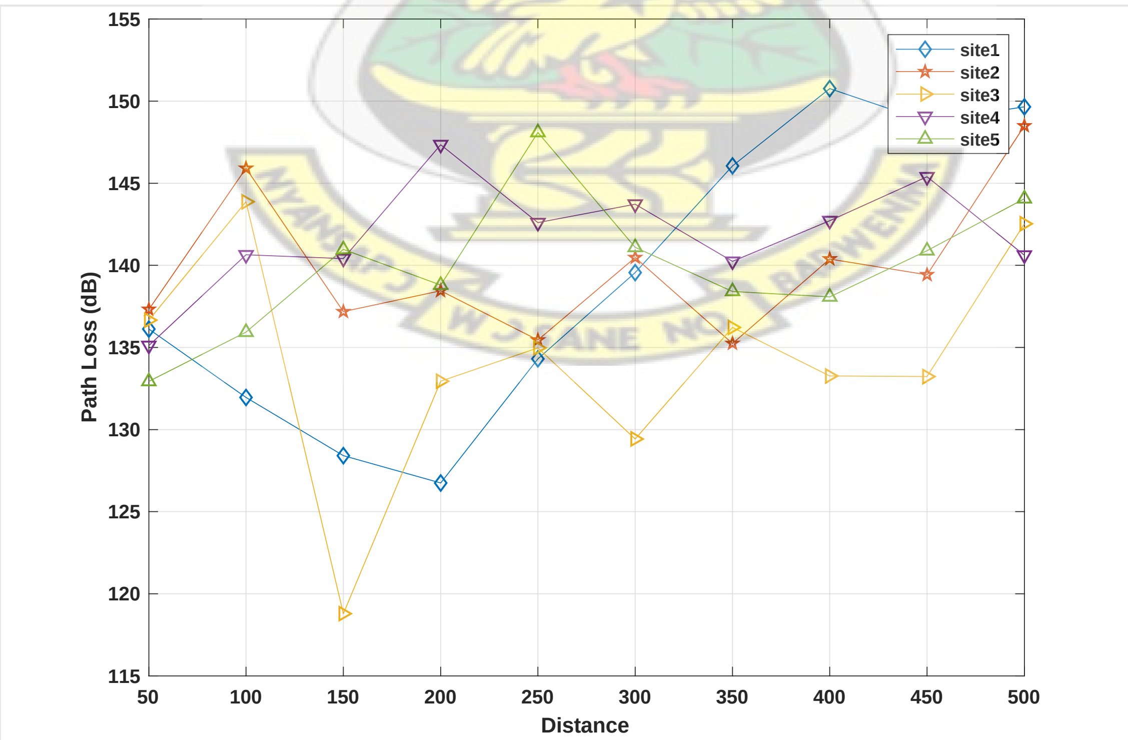

Figure 4.16 Path Loss of All Environments at 2600MHz

4.2.2 PATH LOSS OF PROPAGATION MODELS

Five propagation models were considered at 2600MHz. These are FSPL,SUI,COST231,ECC-33 and Ericson model. Their path loss was calculated using parameters specified in Table 3.1. Resulting path loss is given in table 4.13

Table 4.13 Path Loss of Propagation Models Typical of Urban Areas

PATH LOSS (dB)					
distance	FSPL	Cost 231	SUI	ECC-33	ERICSON
50	74.72	201.44	85.32	107.93	195.74
100	80.74	211.79	93.13	113.28	204.87
150	84.26	217.85	97.69	116.85	210.22
200	86.76	222.15	100.94	119.58	214.01
250	88.70	225.49	103.45	121.82	216.95
300	90.28	228.21	105.50	123.71	219.35
350	91.62	230.51	107.24	125.36	221.38
400	92.78	232.51	108.74	126.84	223.14
450	93.80	234.27	110.07	128.16	224.69
500	94.72	235.84	111.26	129.37	226.08

4.2.3 COMPARISON OF PATH LOSS OF MEASURED DATA WITH PROPAGATION MODELS

The path loss of each measurement environment was compared with the path loss estimations of the understudied propagation models at 2600MHz

4.2.3.1 COMPARISON FOR URBAN SCENARIOS

Path loss of the urban environments (site1, 2, 4 & 5) is compared with path loss predictions from the propagation models under study. Graphs are shown in Figures 4.17 - 4.20

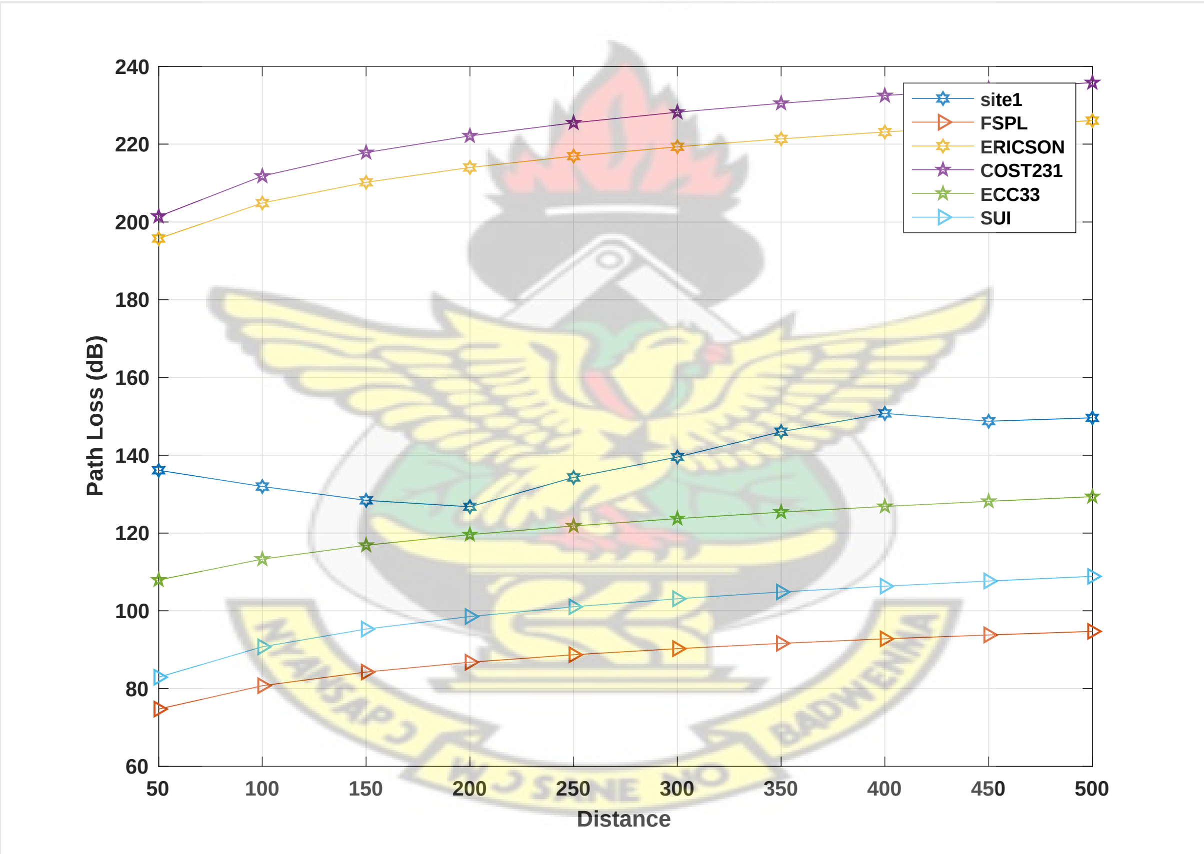

Figure 4.17 Comparison of Path Loss of Site 1 With Propagation models

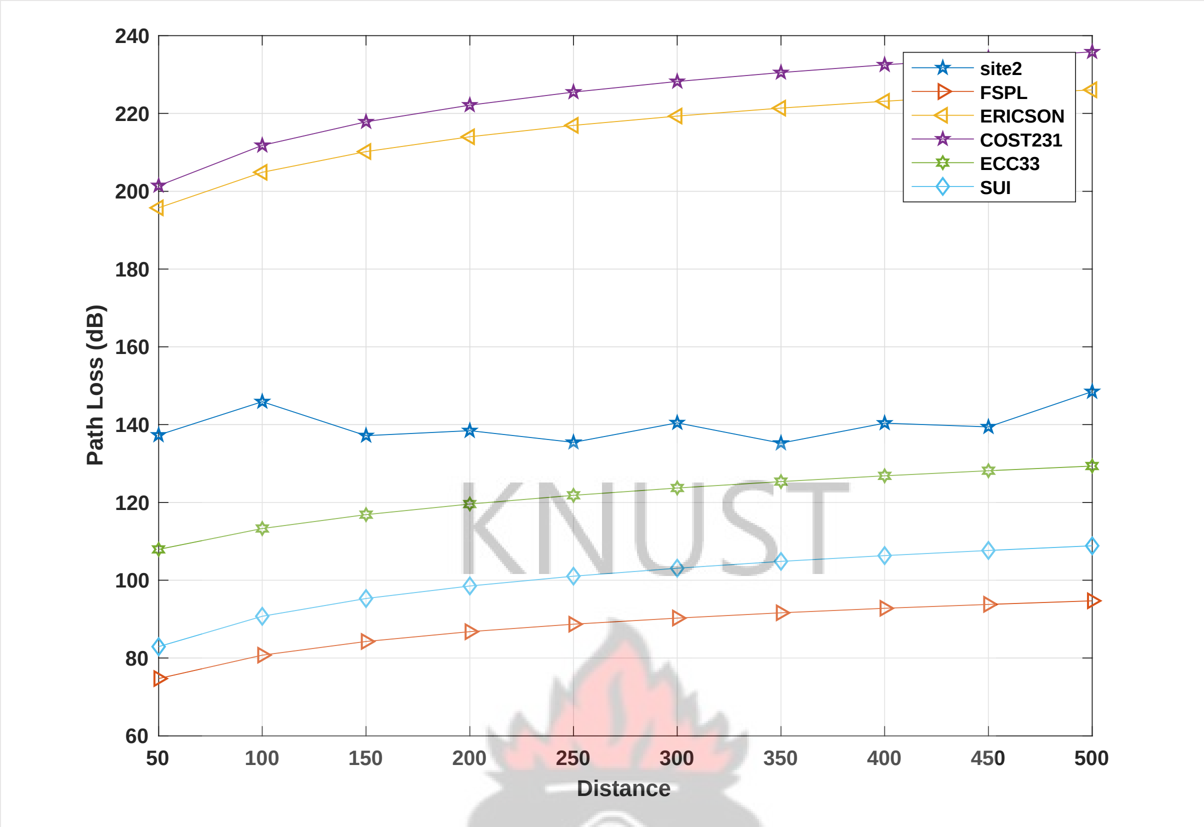

Figure 4.18 Comparison of Path Loss of Site 2 With Propagation Models

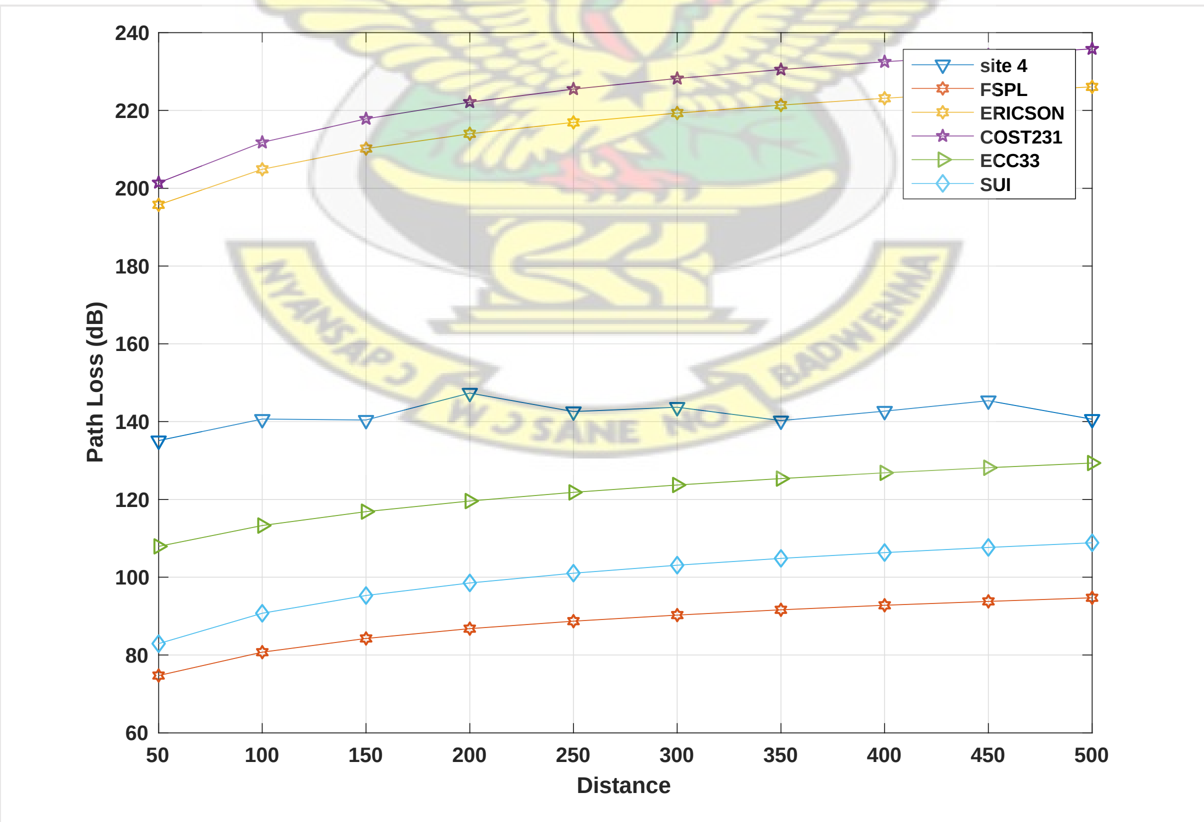

Figure 4.19 Comparison of Path Loss of Site 4 With Propagation Models

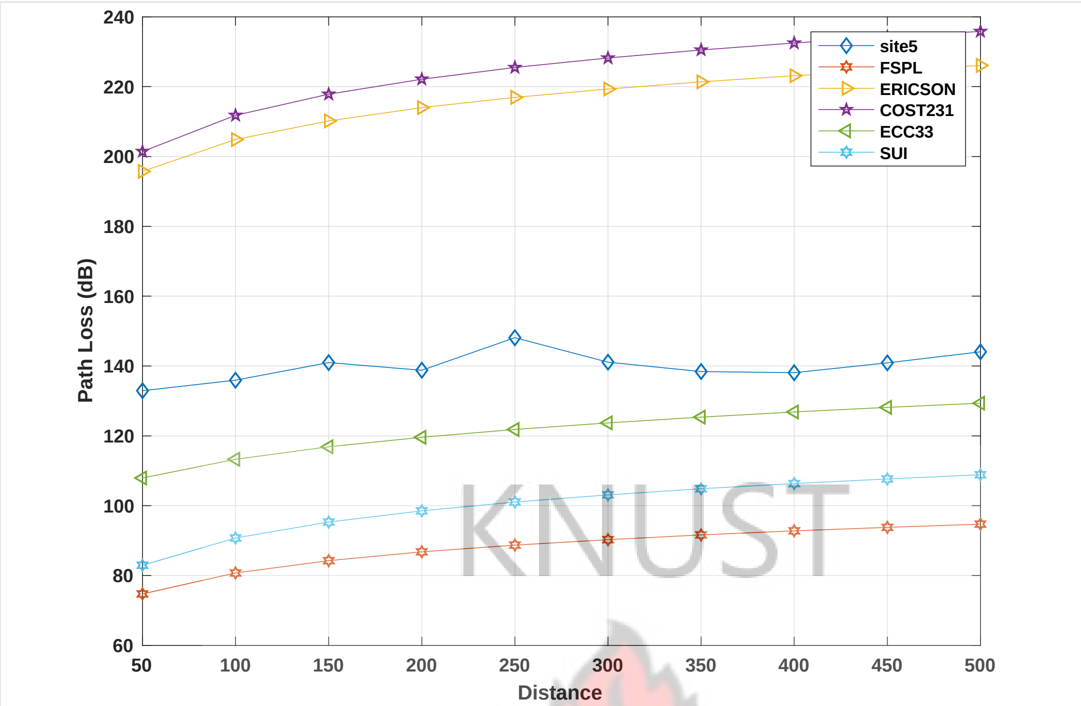

Figure 4.20 Comparison of Path Loss of Site 5 With Propagation Models

4.2.3.2 COMPARISON FOR URBAN SCENARIOS

Path loss estimations of the propagation models under suburban scenarios were also compared with path loss of the suburban area under consideration (Site 3) in figure 4.21

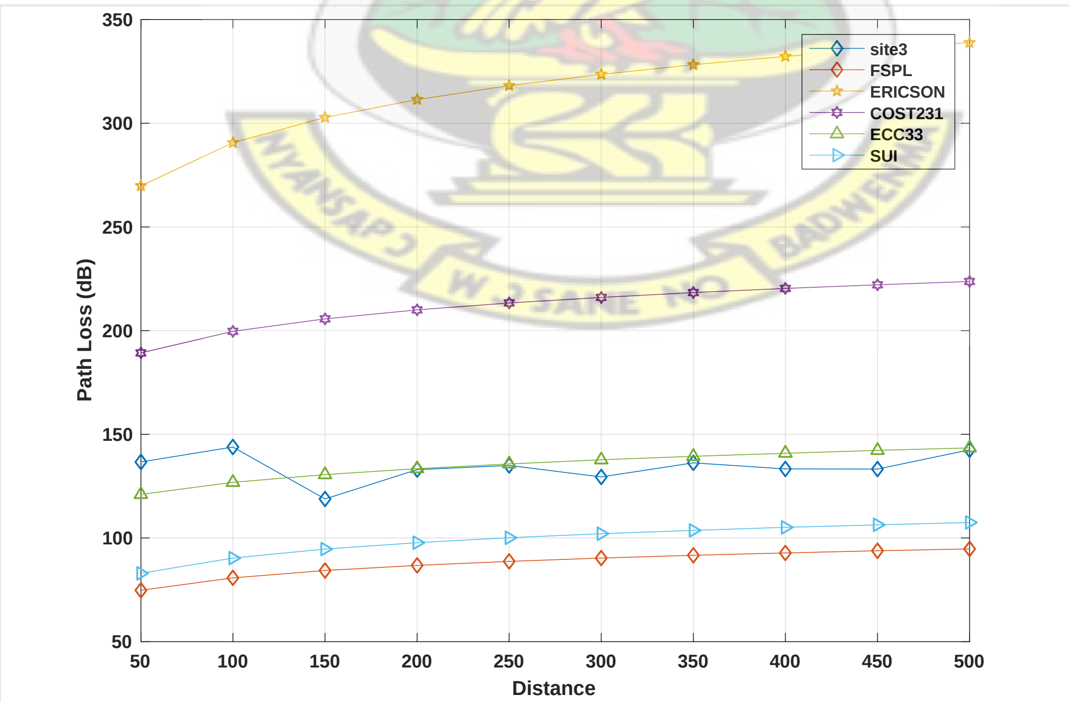

Figure 4.21 Comparison of Path Loss of Site 3 With Propagation Models

Observing the projected path loss of propagation models relative to measurement data in both urban and suburban environments, the ECC-33 model fits best in all cases. The Ericson and Cost 231 models predict the path loss at this frequency with a degree of error in all studied settings.

4.2.4 PATH LOSS EXPONENT AT 2600MHZ

The path loss exponent was computed for each measurement environment and results are given in Table 4.14 it is observed that the values of path loss exponents presented in Table 4.14 agree closely with values obtained in other sub-Saharan regions [10],[11]. The slight variations of a few may be due to differences in factors such as building heights, town layout, street orientation and many more. This goes to explain that the environment has its effects on radio waves propagation.

Table 4.14 Path Loss Exponents at 2600MHz

site	Path loss exponent
1	3.19
2	3.07
3	2.70
4	2.88
5	3.06

4.2.5 CHOICE OF PROPAGATION MODEL THAT BEST FITS MEASUREMENT DATA AT 2600MHZ

Among all the propagation models considered, the ECC-33 model gave lower mean square error values in the urban and suburban environments. Therefore, it was selected as the best model for predicting path loss in both urban and suburban environments in Ghana at

2600MHz LTE frequency. The RMSE is computed for all propagation models in MATLAB and shown in Table 4.15.

Table 4.15 RMSE Values for All Environments at 2600MHz

Site	SUI	Cost 231	ECC-33	Ericson
1	40.8896	67.8700	32.4744	69.4633
2	42.3062	67.6438	35.0937	69.1363
3	37.5333	63.1565	19.4977	175.0325
4	43.8650	65.3834	36.8359	66.8967
5	41.8744	67.2759	34.8757	68.8053

4.2.6 MODIFICATION OF ECC-33 MODEL

Results of *RMSE* for both urban and suburban areas at 2600 MHz favored the ECC-33 model which had the lowest *RMSE* values. On this basis, this model was chosen as the best-fit propagation model for path loss estimation in urban and suburban areas in Ghana at an operating frequency of 2600MHz. A further modification was carried out on it for more accurate predictions in Ghanaian environments. The RMSE each of the five environments were added to the original ECC-33 model equation and further simplified, resulting in equation 4.12

$$Pl = A + B - G_b - G_r \tag{4.12}$$

$$A = 100.6995 + 20\log(d) \tag{4.13}$$

$$B = 25.3321 + 9.83\log(d) \tag{4.14}$$

$$G_b = (\log_{10}(\frac{h_b}{200})\{13.958 + 5.8(\log_{10}(d))^2\} \tag{4.15}$$

$$G_r = -19.7315$$

$substituting\ A, B\ \&G_r\ into\ Pl\ equation\ yields;$

$$Pl_{\text{mod}} = 145.7630 + 20\log_{10}(d) + 9.83\log_{10}(d) - G_b \pm RMSE \qquad 4.16$$

The modified ECC-33 model for one urban environment (Site 1) and the only suburban environment (Site 3) are plotted with the original ECC-33 model to compare their accuracy in predicting close to the measured data. Graphs are shown in figures 4.22&4.23

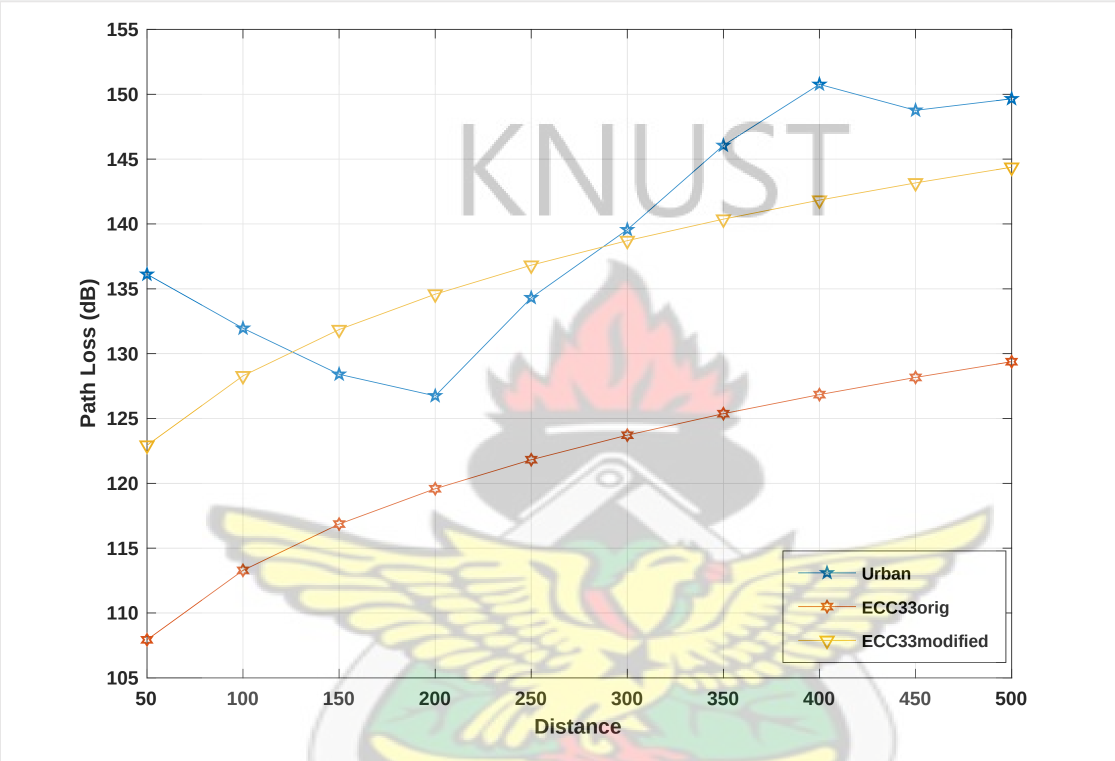

Figure 4.22 Comparison of Modified ECC-33 Model and Original ECC-33 Model for Urban Environments

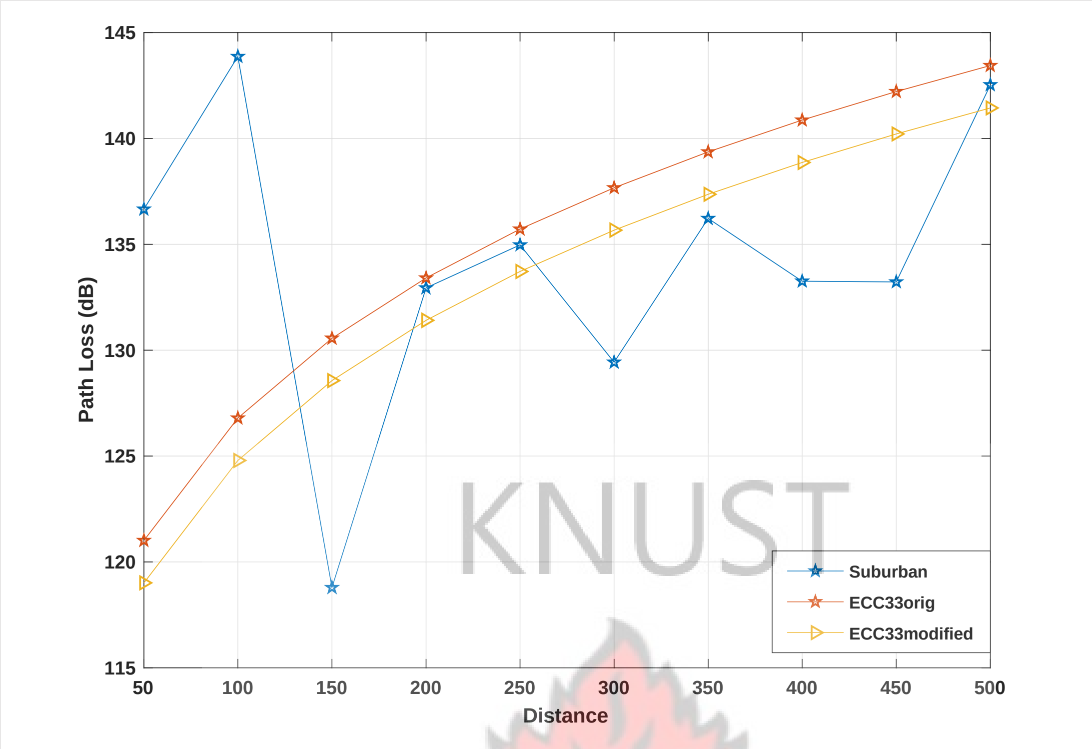

Figure 4.23 Comparison of Modified ECC-33 Model and Original ECC-33 Model for Suburban Environments

The modified equations of the ECC-33 model predicts more accurately as it fits best to data from the measurement environments as can be seen in figures 4.22&4.23.The big difference in path loss noticed every 50m in the suburban area is due the changing terrain around the BS where measurements were taken (presence of hills and valleys).

4.3 VALIDATION

Two approaches were used to validate the modified path loss equations presented in this thesis. The two approaches are described below.

4.3.1 VALIDATION USING RMSE

This approach focused on calculating the error between the measured and estimated path loss for the various measurement environments using the modified equations presented. This is achieved by using equation(3.10) programmed in MATLAB. The values of RMSE closer to zero indicate a better fit [39][12]. Thus, the developed models are described as valid and suitable for the tested environments since the RMSE between the measured and the predicted path loss values are closer to zero than the initial RMSE values. Table 4.16 & 4.17 show the RMSE generated using the developed models in this thesis at 800MHz and 2600MHz respectively.

Table 4.16 RMSE Values Using Developed Models at 800MHz

ROOT MEAN SQUARE ERROR VALUES OF DEVELOPED MODELS AT 800MHz	
Measurement Environment	Root Mean Square Error
adum	11.8494
Techiman	9.6717
agogo	5.2510
Afrancho	7.1129
New Dorma	29.8491

Table 4.17 RMSE Values Using Developed Models at 2600MHz

ROOT MEAN SQUARE ERROR VALUES OF DEVELOPED MODELS AT 2600MHz	
Measurement Environment	Root Mean square Error
Site 1	9.1408
Site 2	13.3313
Site 3	16.8445
Site 4	15.2780
Site 5	11.9498

4.3.2 VALIDATION USING A SIMULATOR BUILT ON TRUE MEASURED DATA

This approach focused on Testing the developed models against the path loss simulated by the use of a simulator called NYUSIM. NYUSIM is a simulation tool developed by the New York University (NYU) wireless team and T.S Rappaport, an authority in the wireless domain. The simulator has been tested widely and found very reliable. It places emphasis more on a physical basis and was built relying on huge amounts of true measured data at mm-wave frequencies in New York[40]. The propagation model the NYUSIM is based on is the close-in free space reference distance (CI) path loss model[41]. Operating frequency in the NYUSIM channel model simulator spans between 0.5GHz -100GHz and hence covers the range of frequencies used in this thesis. Path loss of the CI model at 800MHz and 2600MHz are extracted from the NYUSIM tool as shown in Table 4.18 and are compared with the developed models in this thesis in figures 4.26 & 4.27.

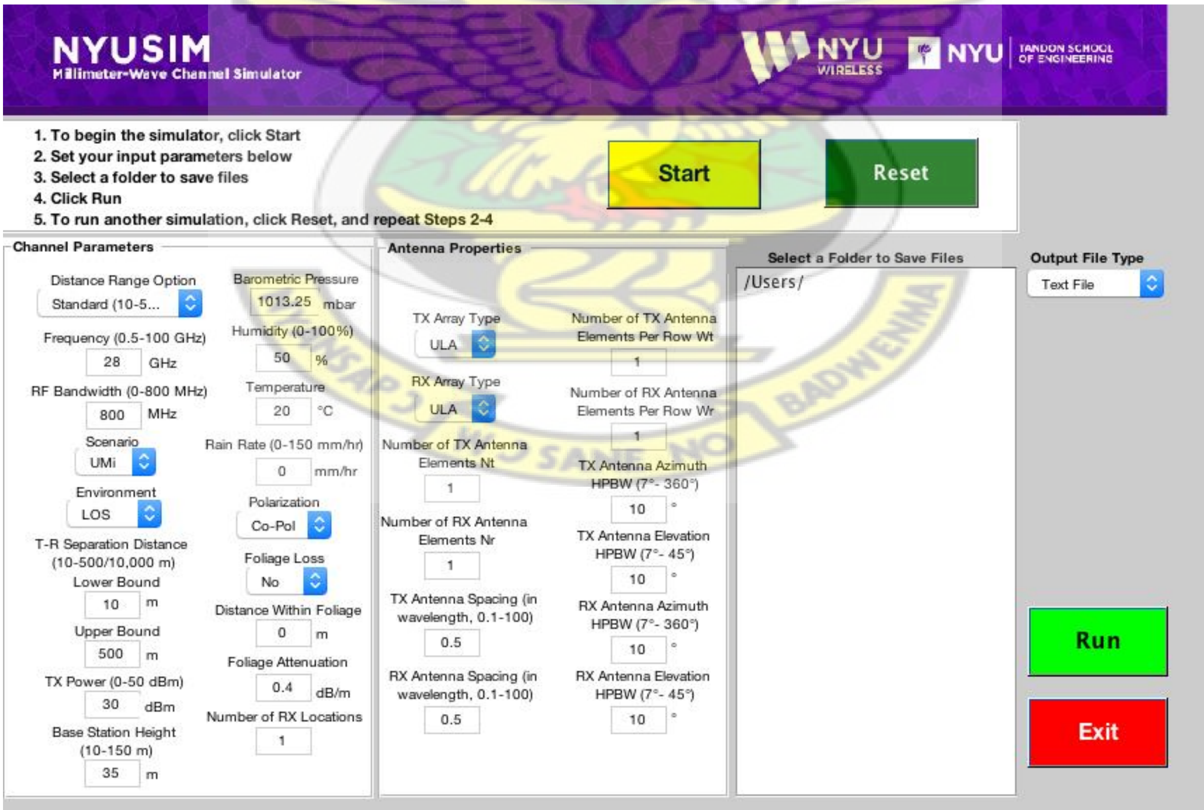

Figure 4.24 Gui of NYUSIM

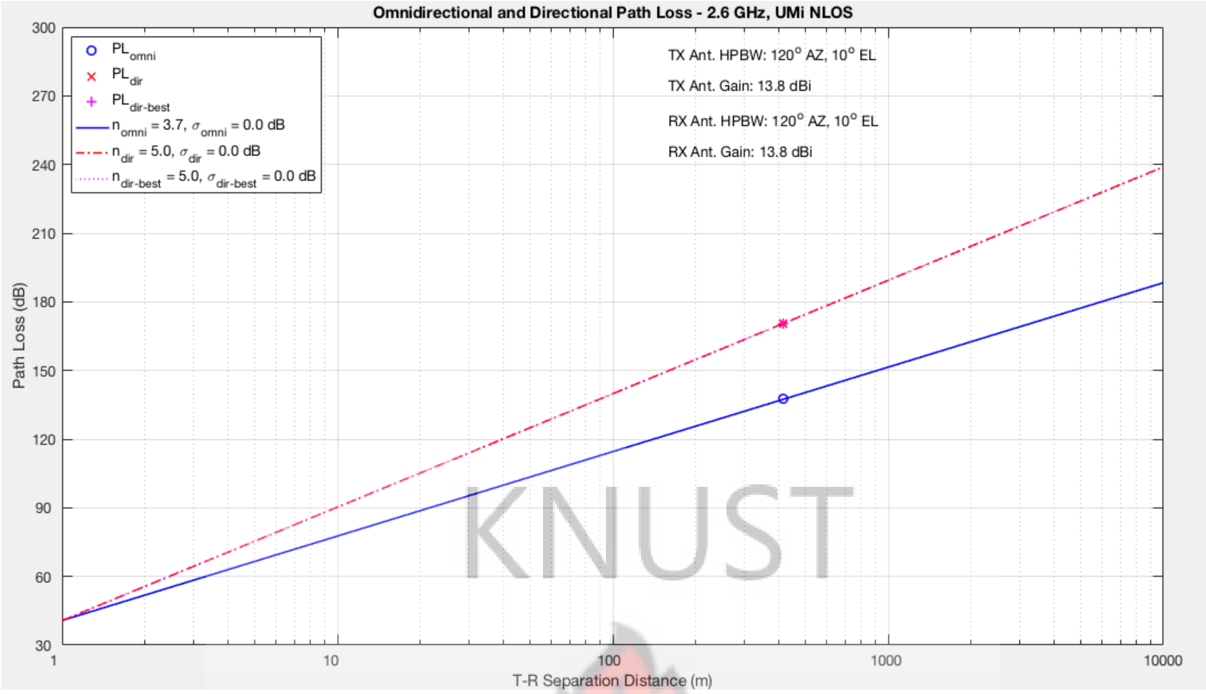

Figure 4.25 Simulation of Path Loss in NYUSIM

Table 4.18 Extracted Path Loss Values From NYUSIM

PATH LOSS VALUES(dB) OF NYUSIM AT 800 &2600 MHz		
distance	800MHz	2600MHz
50	88.21	125.1
100	97.94	140.3
150	103.5	149.5
200	108.3	155
250	111.9	159
300	114.3	164.1
350	116.5	167.3
400	118.1	169.9
450	120.1	177.5
500	121.7	174.5

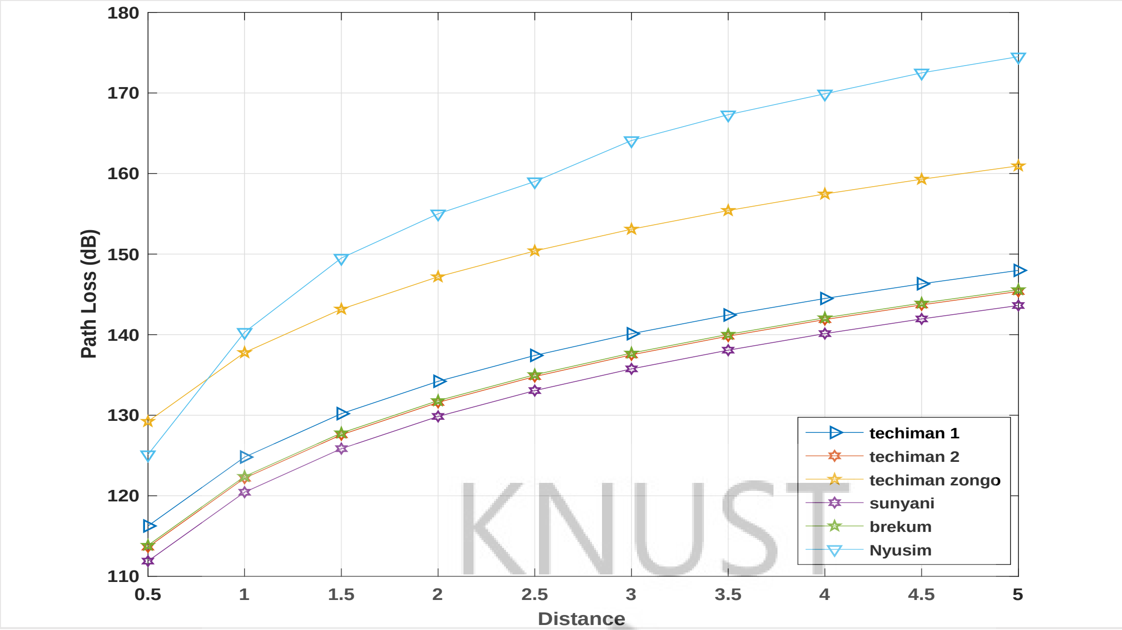

Figure 4.26Comparison of Performance of Developed Models against NYUSIM at 2600MHz

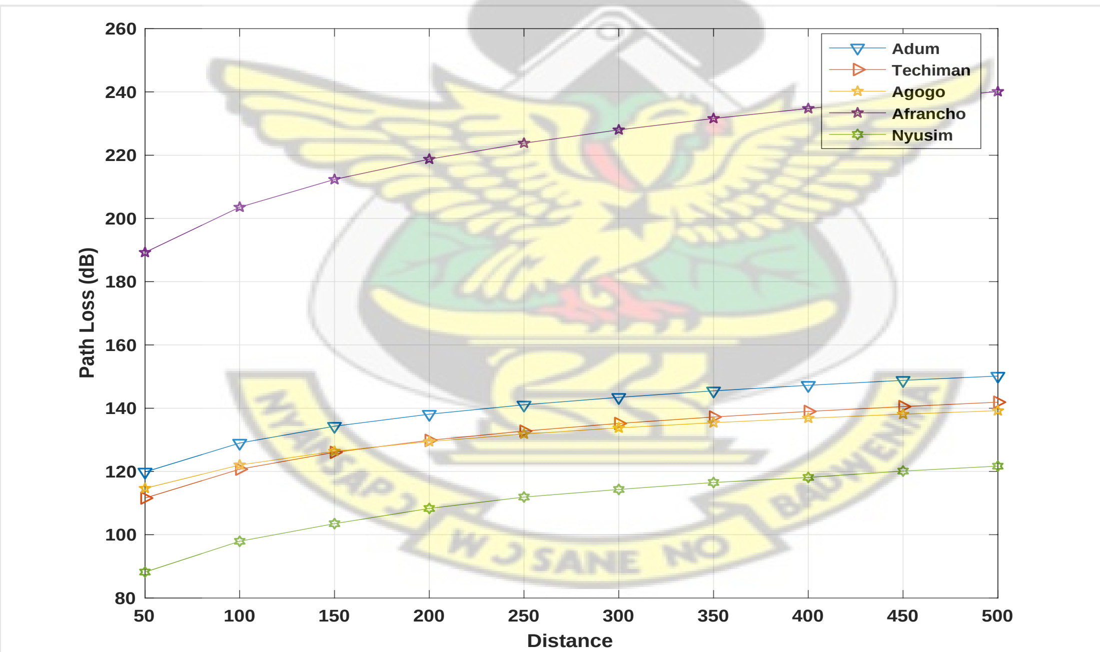

Figure 4.27 Comparison of Performance of Developed Models against NYUSIM at 800MHz

Developed models show consistent prediction behavior compared with the NYU simulator's path loss and hence can be considered valid models for use in the Ghanaian environment with similar environmental features as the measurement environments.

CHAPTER 5

5.0 CONCLUSION

This study was focused on developing improved versions of industry-standard propagation models suited for LTE path loss prediction in the Ghanaian environment. Path loss of four propagation models was compared with Path loss of propagation measurements taken from five LTE 800MHz base stations located in the urban and suburban areas of Ghana using MATLAB. Results confirmed the initial assumption of the study, that propagation models predict far from the ideal. The Ericson model showed satisfactory performance in the urban environments at 800MHz. This model however over predicted the path loss in the suburban environments. The SUI model outperformed the other models in predicting close to the propagation measurement in suburban areas at 800MHz.The Ericson and SUI models were further improved for a more accurate prediction of LTE path loss in urban and suburban Ghanaian environments at 800MHz.

For similar studies at an LTE frequency of 2600MHz, the Path loss of five propagation models was compared with the Path loss of propagation measurements taken at five base stations located in the urban and suburban areas of Ghana. The ECC-33 model best fit propagation measurements both in the urban and suburban environments and hence it was developed further for use in LTE path loss estimation at 2600MHz.

5.1 CONTRIBUTION

The major contribution of this study is the improvement of industry-standard propagation models for a more accurate prediction of path loss in the Ghanaian setting at two LTE frequencies. The improvement of these models is very important because these models were developed using propagation measurements from environments having different geographical characteristics from the Ghanaian environment. To apply these propagation models efficiently to the Ghanaian environment, modification and improvement of these models become very necessary. Extensive drive test data from 10 different Base stations in Ghana have been readily made available through this study.

5.2 USEFULNESS OF WORK

The improved path loss models developed in this study can be used to improve the quality of radio coverage in Ghana. Improved quality of the signal will translate into higher throughputs for mobile users resulting in customer satisfaction. These developed models will come in handy for radio network planning, deployment, and optimization processes. Vendors of Planning tools can take advantage of incorporating these models in their tools for more accurate predictions at these LTE frequencies.

5.3 RECOMMENDATION

This study focused on propagation measurements mainly from two regions in Ghana. A comparison of measurement data from other environments in the different regions of Ghana having similar geographical characteristics with improved models in this study will further enhance the reliability of the models presented. Future work can also focus on varying parameters in the propagation models to predict consistent results with measured data instead of simply factoring in the margin of error (RMSE).

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APPENDICES

A1 COMPUTATION AND PLOT OF MEAN RECEIVED POWER

```
%{
 Received power plots
 Date: 20th June, 2019
 Author: Stephen Nuagah
%}
% Loading data
clc; clear; close all;
load('drivelow')
Gt = 18.15;
L = 10.7;
Pt=46;
techiman = drivelow(1:10, 1:3);
adum = drivelow(14:23, 2:4);
agogo = drivelow(27:36, 2:4);
afrancho = drivelow(51:60, 2:4);
dorma = drivelow(68:77, 2:4);
%% Calculating average of received power (column 4)
for k=1:10
   techiman(k, 4) =  mean(techiman(k, 1:3));
   adum(k, 4) = mean(adum(k, 1:3));
   agogo(k, 4) = mean(agogo(k, 1:3));
   afrancho(k, 4) = mean(afrancho(k, 1:3));
   dorma(k, 4) = mean(dorma(k, 1:3));
end
```

```
%% Calculating EIRP (column 5)
for k=1:10
   techiman(k, 5) =  EIRP(Pt, Gt, L);
   adum(k, 5) = EIRP(Pt, Gt, L);
   agogo(k, 5) = EIRP(Pt, Gt, L);
   afrancho(k, 5) = EIRP(Pt, Gt, L);
   dorma(k, 5) = EIRP(Pt, Gt, L);
end
 x = 50:50:500;
figure(2)
plot(x, techiman(1:10, 4),...
    x, adum(1:10, 4),...
    x, agogo(1:10, 4),...
    x, afrancho(1:10, 4),...
    x, dorma(1:10, 4)) ;

xlabel('Distance'), ylabel('Received Power (dBm)');
title('RECEIVED POWER FOR CELL SITES ');
legend('Techiman', 'Adum','Agogo','Afrancho','Dorma');
grid('on');
```

A2 COMPUTATION AND PLOTS OF PATH LOSS

```
clc; clear; close all;
load('drivelow')
Gt = 18.15;
L = 10.7;
Pt=46;
techiman = drivelow(1:10, 1:3);
adum = drivelow(14:23, 2:4);
agogo = drivelow(27:36, 2:4);
afrancho = drivelow(51:60, 2:4);
dorma = drivelow(68:77, 2:4);

%% Calculating average of received power (column 4)
for k=1:10
  techiman(k, 4) =  mean(techiman(k, 1:3));
  adum(k, 4) = mean(adum(k, 1:3));
  agogo(k, 4) = mean(agogo(k, 1:3));
  afrancho(k, 4) = mean(afrancho(k, 1:3));
  dorma(k, 4) = mean(dorma(k, 1:3));
end
for k=1:10
  techiman(k, 5) =  EIRP(Pt, Gt, L);
  adum(k, 5) = EIRP(Pt, Gt, L);
  agogo(k, 5) = EIRP(Pt, Gt, L);
  afrancho(k, 5) = EIRP(Pt, Gt, L);
  dorma(k, 5) = EIRP(Pt, Gt, L);
end
```

```
 %% Calculating Path Loss (Column 6)
for k = 1:10
   techiman(k, 6) =  PL(techiman(k,5), techiman(k, 4));
   adum(k, 6) = PL(adum(k,5), adum(k, 4));
   agogo(k, 6) = PL(agogo(k,5), agogo(k, 4));
   afrancho(k, 6) = PL(afrancho(k,5), afrancho(k, 4));
   dorma(k, 6) = PL(dorma(k,5), dorma(k, 4));
end
%% Plotting Path Loss / Distance
x = 50:50:500;
% single graphs
figure(1)
plot(x, techiman(1:10, 6));
xlabel('DISTANCE'), ylabel('Path Loss (dB)');
title('Path Loss (Techiman)');
grid('on');
figure(2)
plot(x, adum(1:10, 6));
xlabel('DISTANCE'), ylabel('Path Loss (dB)');
title('Path Loss (Adum)');
grid('on')
figure(3)
plot(x, agogo(1:10, 6));
xlabel('DISTANCE'), ylabel('Path Loss (dB)');
title('Path Loss (Agogo)');
grid('on')
figure(4)
```

```
plot(x, afrancho(1:10, 6));

xlabel('DISTANCE'), ylabel('Path Loss (dB)');

title('Path Loss (D. Afrancho)');

grid('on')

figure(5)

plot(x, dorma(1:10, 6));

xlabel('DISTANCE'), ylabel('Path Loss (dB)');

title('Path Loss (New Dorma)');

grid('on')

 % all areas

figure(6)

plot(x, techiman(1:10, 6),...

        x, adum(1:10, 6),...

        x, agogo(1:10, 6),...

        x, afrancho(1:10, 6),...

        x, dorma(1:10, 6));

xlabel('DISTANCE'), ylabel('Path Loss (dB)');

title('Path Loss');

legend('Techiman', 'Adum', 'Agogo', 'D. Afrancho', 'New Dorma');

grid('on');
```

A3 PATH LOSS OF PROPAGATION MODELS

PATH LOSS (ERICSON MODEL)

```
%defining variables
f=0.8
d=50:50:500
hr=1.5
% write an if statement to distinguish values of a0 a1 a2 a3 and a4
% divisions are into 1. urban 2.suburban 3.rural
env=input('input ericson environment type 1.urban 2.suburban 3. rural')
if env==1
   a0=36.20; a1=30.20; a2=12.0; a3=0.1 ;hb=25;
elseif env ==2
   a0=43.20; a1=68.93; a2=12.0; a3=0.1; hb=32;
else
   a0=45.95; a1=100.6; a2=12.0; a3=0.1; hb=35;
end
%path loss equation
gf=44.49*log10(f)-4.78*(log10(f))^2
Pl=a0 +a1*log10(d)+a2*log10(hb)+a3*log10(hb)*log10(d)-3.2*(log10(11.75*hr))^2+gf
```

PATH LOSS (HATA MODEL)

```
city1=input('which hata city type are you planning for 1 for small 2 for medium 3 for large')
suborurb=input('keyin   hata area type, 1for urban 2 for suburban, 3 for open area')
pathLossData1 = [];
```

```
for k = 1 : length(distance)

 %cost231 general eqn for path loss

plurban= 69.55+26.16*log10(frequency) - 13.82*log10(hte) + (44.9 - 6.55*log10(hte))*log10(distance(k))

%based on users initial choice of city type calculate @hr


%computing @hr for small and medium city

if city <=2

    alphahrsmallandmed1=(1.1*log10(frequency)-0.7)*hre + (1.56*log10(frequency)-0.8);

    plcostm1=plurban-alphahrsmallandmed1

    % computing @hr for large cities

else

  alphahrlarge1=3.2*(log10(11.57*hre))^2-4.97

  plcostm1=plurban-alphahrlarge1

end


%based on city type whether urban or suburban or open area

if suborurb ==1

   plhatafinal = plcostm1 + 0

elseif suborurb==2

       plhatafinal=plcostm1-2*(log10(frequency/28))^2-5.4  %path loss for suburban area

   else

    plhatafinal= plcostm-4.78*(log10*frequency)^2+18.33*log10(frequency)-40.94 %path loss for an open area

end

 pathLossData1(k) = plhatafinal;


end
```

PATH LOSS (COST231 MODEL)

```
% at beginning of code user should specify type of city

%choices user has are 1.small city 2.medium city 3.large city

%store choice of city type in a variable called City


city=input('which COST231 city type are you planning for 1.SMALL 2.MEDIUM 3.LARGE')

frequency = 800

hte=40

hre=1.5

%cm has a value of 0 or 3. small and medium city =0 metropolitan =3

Cm=input('keyin the value of cm 0 FOR SMALL &MED 3 FOR LARGE')

pathLossData = [];

distance=0.05:0.05:0.5

%d=50:50:500

  for k = 1 : length(distance)

     %cost231 general eqn for path loss

    plcost= 46.30 + 33.90*log10(frequency) - 13.82*log10(hte) + (44.9 - 6.55*log10(hte))*log10(distance(k))

    %based on users initial choice of city type we calculate @hr


    %computing @hr for small and medium city

    if city <=2

    alphahrsmallandmed=(1.1*log10(frequency)-0.7)*hre + (1.56*log10(frequency)-0.8);

    plcostm=plcost-alphahrsmallandmed

    % computing @hr for large cities

    else
```

```
alphahrlarge=3.2*(log10(11.57*hre))^2-4.97
 plcostm=plcost-alphahrlarge
end

%based on city type Cm =0 for small and medium and Cm =3 for
%large/metropolitan areas

if Cm <=2
   plcostfinal = plcostm + 0;

else
    plcostfinal = plcostm + 3;
end

 pathLossData(k) = plcostfinal;

end
```

PATH LOSS (FREES SPACE MODEL)

```
free space path loss
fc=800;
k1=0.05:0.05:0.5;

ploss=32.44 +20*log10(fc)+20*log10(k1)
```

PATH LOSS (ECC-33 MODEL)

```
hre=1.892

f1=0.8

D=0.05:0.05:0.5;

%x=50:50:500;

Grpara=input('input ECC-33 environment type 1.MEDIUM 2.LARGE ')

if Grpara==1

   Gr=(42.57+13.7*log10(f1))*(log10(hre)-0.585);

   hbb=32

else

   Gr=0.759;

    hbb=25

end

A=92.4+20*log10(D)+20*log10(f1)

B=20.41+9.83*log10(D)+7.89*log10(f1)+9.56*(log10(f1).^2)

C=(log10(hbb/200))*(13.958+(5.8*log10(D).^2))

att=A+B-C-Gr
```

PATH LOSS (SUI MODEL)

```
ENV=input('which SUI environment type are you planning 1.HILLY VEG 2.MODERATE 3.FLAT')

if ENV ==1

   a=4.6;

   b=0.075 ;

   c=12.6;
```

```
elseif ENV==2
   a=4 ;
   b=0.065 ;
   c=17.1;


else
   a=3.6
   b=0.005
   c=20
end
%path loss equation for SUI model
do=50
dis=50:50:500
he=32
%shadoWing factor is given between 8.2 and 10.6
S=8.2
%compute wavelenght from the operating frequency OF 800MHz
wavelength=0.375
for k=1:length(dis)
A=20*log10((4*pi*do)/wavelength)
gamma=a-b*he +c/he


Loss=A+10*gamma*log10(dis/do)+S
end
```

A4 COMPARIOSON OF PATH LOSS OF AN ENVIRONMENT WITH PROPAGATION MODELS

```
%% Loading data
clc; clear; close all;
load('drivetest2')

Gt = 18.15;
L = 10.7;
Pt = 46;
site1 = drivetest2(2:11, 1:3);
site2 = drivetest2(14:23, 1:3);
site3 = drivetest2(27:36, 1:3);
site4 = drivetest2(39:48, 1:3);
site5 = drivetest2(53:62, 1:3);

%% Calculating average of received power (column 4)
for k=1:10
   site1(k, 4) =  mean(site1(k, 1:3));
   site2(k, 4) = mean(site2(k, 1:3));
   site3(k, 4) = mean(site3(k, 1:3));
   site4(k, 4) = mean(site4(k, 1:3));
   site5(k, 4) = mean(site5(k, 1:3));
end

%% Calculating EIRP (column 5)
for k=1:10
```

```
  site1(k, 5) =  EIRP(Pt, Gt, L);
  site2(k, 5) = EIRP(Pt, Gt, L);
  site3(k, 5) = EIRP(Pt, Gt, L);
  site4(k, 5) = EIRP(Pt, Gt, L);
  site5(k, 5) = EIRP(Pt, Gt, L);
end

%% Calculating Path Loss (Column 6)
for k = 1:10
  site1(k, 6) =  PL(site1(k,5), site1(k, 4));
  site2(k, 6) = PL(site2(k,5), site2(k, 4));
  site3(k, 6) = PL(site3(k,5), site3(k, 4));
  site4(k, 6) = PL(site4(k,5), site4(k, 4));
  site5(k, 6) = PL(site5(k,5), site5(k, 4));
end

%PREDICTED PATH LOSS OF COST231

city=input('which city type are you planning for 1.small 2.medium 3.large')
frequency = 2600
hte=40
hre=1.5
%cm has a value of 0 or 3. small and medium city =0 metropolitan =3
Cm=input('keyin the value of cm')
pathLossData = [];
distance=50:50:500
  for k = 1 : length(distance)
```

```
%cost231 general eqn for path loss

plcost= 46.30 + 33.90*log10(frequency) - 13.82*log10(hte) + (44.9 - 6.55*log10(hte))*log10(distance(k))

%based on users initial choice of city type we calculate @hr


%computing @hr for small and medium city

if city <=2

alphahrsmallandmed=(1.1*log10(frequency)-0.7)*hre + (1.56*log10(frequency)-0.8);

plcostm=plcost-alphahrsmallandmed

% computing @hr for large cities

else

alphahrlarge=3.2*(log10(11.57*hre))^2-4.97

 plcostm=plcost-alphahrlarge

end


%based on city type Cm =0 for small and medium and Cm =3 for

%large/metropolitan areas


if Cm <=2

   plcostfinal = plcostm + 0;


else

    plcostfinal = plcostm + 3;

end


 pathLossData(k) = plcostfinal;
```

```
  end

 %sui model

 %PROMPT USER FOR ENV TYPE AND THAT WILL DETERMINE VALUES OF a,b AND C


ENV=input('which environment type are you planning 1.hilly,moderate 2.hilly rare veg 3.flat')

if ENV ==1

   a=4.6;

   b=0.075 ;

   c=12.6;


elseif ENV==2

   a=4 ;

   b=0.065 ;

   c=17.1;


else

   a=3.6

   b=0.005

   c=20


end

%path loss equation for SUI model

do=50

d=50:50:500

he=32

%shadoWing factor is given between 8.2 and 10.6
```

```
S=8.2
%compute wavelenght from the operating frequency OF 2600MHz
wavelength=0.1154
for k=1:length(d)
A=20*log10((4*pi*do)/wavelength)
gamma=a-b*he +c/he

Loss=A+10*gamma*log10(d/do)+S

end
%Ecc33
% ECC-33 MODEL
%write an if statement to distinguish values of Gr
% divisions are into 1. large 2.medium
clc; close all;
hr=1.892
f1=2.6
D=0.05:0.05:0.5;
x=50:50:500;
Grpara=input('input ECC-33 environment type 1.MEDIUM 2.LARGE ')
if Grpara==1
   Gr=(42.57+13.7*log10(f1))*(log10(hr)-0.585);
   hbb=32
else
   Gr=0.759;
    hbb=25
end
A1=92.4+20*log10(D)+20*log10(f1)
```

```
B1=20.41+9.83*log10(D)+7.89*log10(f1)+9.56*(log10(f1).^2)

C1=(log10(hbb/200))*(13.958+(5.8*log10(D).^2))

att=A1+B1-C1-Gr

%Ericson model

%defining variables

f=2600

d=50:50:500

hr=1.5

% write an if statement to distinguish values of a0 a1 a2 a3 and a4

% divisions are into 1. urban 2.suburban 3.rural

env=input('input environment type 1.urban 2.suburban 3. rural')

if env==1

   a0=36.20; a1=30.20; a2=12.0; a3=0.1 ;hb=25;

elseif env ==2

   a0=43.20; a1=68.93; a2=12.0; a3=0.1; hb=32;

else

   a0=45.95; a1=100.6; a2=12.0; a3=0.1; hb=35;

end

%path loss equation

gf=44.49*log10(f)-4.78*(log10(f))^2

Pl=a0 +a1*log10(d)+a2*log10(hb)+a3*log10(hb)*log10(d)-3.2*(log10(11.75*hr))^2+gf

%free space model

fc=2600;

d=0.05:0.05:0.5;
```

```
ploss=32.44 +20*log10(fc)+20*log10(d)


plot(x, site1(1:10, 6),...
    x,ploss,...%fspl
    x,Pl,...%ericson
    x,pathLossData,...%cost231
    x,att,... %ecc33
    x,Loss); %sui


 xlabel('Distance'), ylabel('Path Loss (dB)');
title('Path Loss (SITE 1 & PROP MODELS)');
legend('site1', 'FSPL','ERICSON','COST231','ECC33','SUI');
grid('on');
```

A5.PATH LOSS EXPONENT

```
clc; clear; close all;
load('drivetest2')
Gt = 18.15;
L = 10.7;
Pt = 43;
site1 = drivetest2(2:11, 1:3);
site2 = drivetest2(14:23, 1:3);
site3 = drivetest2(27:36, 1:3);
site4 = drivetest2(39:48, 1:3);
site5 = drivetest2(53:62, 1:3);

%% Calculating average of received power (column 4)
for k=1:10
  site1(k, 4) =  mean(site1(k, 1:3));
  site2(k, 4) = mean(site2(k, 1:3));
  site3(k, 4) = mean(site3(k, 1:3));
  site4(k, 4) = mean(site4(k, 1:3));
  site5(k, 4) = mean(site5(k, 1:3));
end
d=50:50:500;
  Xo =50 ;
%% Calculating Pl measured - pl ref distance (Column 7)

  site1(:, 7) = ( site1(1,4)-site1(:,4)).*(10*log10(d/Xo))' ;
  site2(:, 7) = (site2(1,4)-site2(:,4)).*(10*log10(d/Xo))' ;
  site3(:, 7) = (site3(1,4)- site3(:,4)).*(10*log10(d/Xo))';
```

```
site4(:, 7) = (site4(1,4)-site4(:,4)).*(10*log10(d/Xo))';

site5(:, 7) = (site5(1,4)- site5(:,4)) .*(10*log10(d/Xo))';

% calculating 10logd/do COLUMN 8

%choos do of 50m and call it XO and my d will be my do


A=(10*log10(d/Xo)).^2;

site1(:, 8) =  A;

site2(:, 8) = A;

site3(:, 8) = A;

site4(:, 8) = A;

site5(:, 8) = A;

%finally to get path loss exponent we take sum of pl meas - pl at do

%divided by 10log10(d/do)


%PLEadum=sum(adum(:,7)) / sum(adum(:,8))

PLEsite1=sum(site1(:,7)) / sum(site2(:,8))

PLEsite2=sum(site2(:,7)) / sum(site2(:,8))

PLEsite3=sum(site3(:,7)) / sum(site3(:,8))

PLEsite4=sum(site4(:,7)) / sum(site4(:,8))

PLEsite5=sum(site5(:,7)) / sum(site5(:,8))
```

A6 ROOT MEAN SQUARE ERROR

```
clc; clear; close all;
load('drivetest2')
Gt = 18.15;
L = 10.7;
Pt = 46;
site1 = drivetest2(2:11, 1:3);
site2 = drivetest2(14:23, 1:3);
site3 = drivetest2(27:36, 1:3);
site4 = drivetest2(39:48, 1:3);
site5 = drivetest2(53:62, 1:3);

%% Calculating average of received power (column 4)
for k=1:10
  site1(k, 4) =  mean(site1(k, 1:3));
  site2(k, 4) = mean(site2(k, 1:3));
  site3(k, 4) = mean(site3(k, 1:3));
  site4(k, 4) = mean(site4(k, 1:3));
  site5(k, 4) = mean(site5(k, 1:3));
end
%% Calculating EIRP (column 5)
for k=1:10
  site1(k, 5) =  EIRP(Pt, Gt, L);
  site2(k, 5) = EIRP(Pt, Gt, L);
  site3(k, 5) = EIRP(Pt, Gt, L);
  site4(k, 5) = EIRP(Pt, Gt, L);
  site5(k, 5) = EIRP(Pt, Gt, L);
```

```
end
%% Calculating Path Loss (Column 6)
for k = 1:10
  site1(k, 6) =  PL(site1(k,5), site1(k, 4));
  site2(k, 6) = PL(site2(k,5), site2(k, 4));
  site3(k, 6) = PL(site3(k,5), site3(k, 4));
  site4(k, 6) = PL(site4(k,5), site4(k, 4));
  site5(k, 6) = PL(site5(k,5), site5(k, 4));
end
%defining variables
f=800
d=50:50:500
hr=1.5
% write an if statement to distinguish values of a0 a1 a2 a3 and a4
% divisions are into 1. urban 2.suburban 3.rural
env=input('input environment type 1.urban 2.suburban 3. rural')
if env==1
   a0=36.20; a1=30.20; a2=12.0; a3=0.1 ;hb=25;
elseif env ==2
   a0=43.20; a1=68.93; a2=12.0; a3=0.1; hb=32;
else
   a0=45.95; a1=100.6; a2=12.0; a3=0.1; hb=35;
end
%path loss equation
gf=44.49*log10(f)-4.78*(log10(f))^2
Pl=a0 +a1*log10(d)+a2*log10(hb)+a3*log10(hb)*log10(d)-3.2*(log10(11.75*hr))^2+gf
 %MSE FOR SUI TECHIMAN
```

```
%difference of measured and predicted losses
m1=site1(:,6)-(Pl)';
%taking square of the difference divided by the number of data points
%=10
sa1=m1.^2 /10;

% FINDING MSE
MSE1=sqrt(sum(sa1))
%MSE FOR SUI ADUM
m2=site2(:,6)-(Pl)';
sa2=m2.^2 /10;
MSE2=sqrt(sum(sa2))
%MSE FOR SUI AGOGO
m3=site3(:,6)-(Pl)';
sa3=m3.^2 /10;
MSE3=sqrt(sum(sa3))
%MSE FOR SUI AFRANCHO
m4=site4(:,6)-(Pl)';
sa4=m4.^2 /10;
MSE4=sqrt(sum(sa4))
%MSE FOR COST231 DORMA
m5=site5(:,6)-(Pl)';
sa5=m5.^2 /10;
MSE5=sqrt(sum(sa5))
```