ألآيـــــــــــــه

قال تعالى :

بسم الله الرحمن الرحيم

﴿ ....وَمَا أُوتِيتُمْ مِنْ الْعِلْمِ إِلاَّ قَلِيلاً ﴾

صدق الله العظيم

سورة الاسراء الاية 85

DEDICATION

I have a great pleasure, to dedicate this work to my parents, who has been giving me more than what I needed and deserved, for their love, support, and sacrifices.

ACKNOWLEDGMENT

In the name of ALLAH, the Beneficent, the Merciful. All praises to Allah who created me and granted me everything and give me the ability to complete this task. I would like to express my deepest gratitude to my supervisors **Dr Elsadig Saeid Gebreel Hamed** for his support, valuable advice and guidance throughout my thesis work. Also I have to thank all the engineers' managers at the telecommunication directorate of the Sudanese Electricity transmission company for their valuable help and assistance during the measurement collection phase of the thesis. Furthermore, special gratitude also goes to staff, colleagues and students of the School of electronic engineering of course Sudan University of Science and technology for providing me all the facilities and for being a part of such wonderful environment.

I cannot forget to mention my parents, brothers and sisters for their love and support that always kept me motivated throughout my thesis work.

Finally, I express my deep appreciation to my friends, for their concern, guidance and moral support.

Mussaab Ibrahim Mohammed

Khartoum, June. 2015

المستخلص

يستخدم التنبؤ بفقد المسار في العديد من أنظمة الإتصالات الاسلكية لمعرفة مستوي الإشارة الواصلة إلي المستقبل. وكذلك ليُمكِن المصممين من معرفة خصائص البيئة، من أهم قضايا هذه الأطروحة هو قلة الأبحاث في الخرطوم في مجال توصيف القناة عند التردد 415 ميغاهيرتز. إضافة إلي ذلك ما تم ذكره في إتفاقية جنيفا 2006 عن " الحصة الرقمية ". والتي من المحتمل أن تستخدم في المستقبل القريب من قبل مزودي خدمة الهاتف الجوال لذا ليتم التحقيق في هاتان القضيتان تم اختيار وتطوير معاملات النموذج المبسط لكي يصف هذه البيئة في التردد المختار.

تم تجميع عينة قراءات لمستوي الإشارة من منطقة وسط مدينة الخرطوم، في التردد 415 ميغاهيرتز ومن ثم تم تحليلها وحساب معاملات النموذج (فقد المسار، الظل) إحصائياَحيث وجد أن فقد المسار الأ ُسي للنموذج المبسط هو $\gamma = 4.9$ والتي تصف منطقة مدن ذات توهين عالٍ. ومن ثّم وجد أن الانحراف المعياري للظل أو متوسط مربعات الأخطاء لكل نموذج علي النحو التالي (نموذج أوكامورا-هاتا 6.74 ديسبل، نموذج التعاون التقني والعلمي المشروع 231 بـ 9.33 ديسبل و النموذج المبسط بــ 5.00 ديسبل). عليه فإن أقرب نموذج لتخمين فقد المسار للقراءات العملية هو النموزج المبسط المطور من القراءات.

ABSTRACT

Path loss prediction is used in many wireless communication systems in order to know the signal level at the receiver and to enables the designer to know the environment characteristics. One of the important issues of this thesis are the lack of research in Khartoum in channel characterisation at 415 MHz. Moreover, what has been mentioned in Geneva 2006 agreement about “digital dividend” that this low UHF band is more likely to be used in near future by mobile service provider. In order to investigate these issues a simplified path loss model framework had been chosen and developed to characterize this environment at this frequency band.

Measurement of the received signal level is collected from a sampled area at the operating frequency of 415 MHz. Consequently the model parameter (Path loss exponent, Shadowing) is calculated statistically. The path loss exponent of simplified path loss models were found $\gamma = 4.9$ that describe an urban environment with high attenuation. Then the shadowing standard deviation or Minimum Mean-Squared Error (MMSE) for each model also found as follows (6.74 dB for Okumura-Hata model, 9.33 dB for Collaboration in Science and Technology, project 231 (COST231) Model and 5.00 dB for the developed Simplified Path loss Model), Thus the nearest model in path loss prediction to real measurement is the developed simplified path loss model.

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ABBREVIATIONS

BTS	Base Transceiver Station
CDMA	Code Division Multiple Access
COST231	Collaboration in Science and Technology, project 231
DW	Double Wall reflected
EM	Electromagnetic
FCC	Federal Communications Commission
FSPL	Free Space Path Loss
Gen06	Geneva 2006
GPS	Global Positioning System
GR	Ground Reflected
GW	Ground Wall reflected
LOS	Line of Sight
lsline	Least squares line
MATLAB	Matrix Laboratory
MMSE	Minimum Mean-Squared Error
R.F	Radio Frequency
RRC06	Regional Radio Communication Conference 2006
STDV	Standard Deviation
SW	Single Wall reflected
TV	Television
TW	Triple Wall reflected
UHF	Ultra High Frequency
USA	United State of America
VHF	Very High Frequency
WG	Wall ground reflected

CHAPTER ONE
INTRODUCTION

1.1 Preface:

In 1864 J. Clark Maxwell developed his dynamical theory of the electromagnetic field. He perceived theoretically the electromagnetic disturbance propagate in free space with speed of light, then he anticipated that the light is a transverse of electromagnetic wave [1]. Although the idea of electromagnetic wave is hidden into the set of proposed equations by Maxwell's, he didn't say anything about the electromagnetic (E.M) wave propagation. Even more he didn’t propose any clue about electromagnetism of waves. So it took around a quarter of decade before Heinirch Hertz (1857 – 1894) discovered E. M. with his brilliant experiments that proved the Maxwell’s theory. Hertz discovered the E. M. waves around 1888. This discovery made Maxwell’s theory acceptable to the general public. Consequently, Maxwell’s equations were expanded, modified and made understandable by the efforts of Hertz, George Francis FitzGerald, Oliver lodge and Oliver Heaviside. Thus the last three scientist were called the Maxwellians [1].

Marconi (1874 – 1937) formulates and puts E. M. waves that discovered by Hertz in practical use. He starting by setting up successful wireless telegraph in Italy, then he find out the great importance of aerial-earth system, which he made electromagnetic communication over great distance achievable. In fact In December 1901, he succeeded to send the letter “S” by pressing three dots in Morse code from Cornwell in England to the Newfoundland (North America) [2]. This achievement is marked as the starting of wireless communication era.

Accordingly in 1948, Claude Shannon published his famous paper titled “A mathematical theory of communication” in Bell System Technical Journal. Next he used a tool in probability theory developed by his teacher Norbert Wiener (1894 – 1964) to be applied in communication theory. Thus the great contribution in communication for Claude Shannon is that he found the theoretical upper limit or the maximum data rate (Channel Capacity). He stated that the maximum data rate of information depend upon bandwidth and signal to noise ratio [3].

In 1947 the two engineers Douglas H. Ring and W. Rae Young at Bell Lab proposes the hexagonal cellular concept for mobile phones communications [4]. After around twenty year or so, Richard H. Frenkiel, Joel S. Engel and Philip T. Porter expand the cellular idea to a detail planning procedure. In fact, the first cellular system developed in seventies of the last century made use of cellular idea (Hexagonal cell & frequency reuse). Eventually the developing pace(in the cellular concepts) increase dramatically until nowadays cellular system.

The main and central factor in cellular system design and optimization is the characterization of the propagation channel. Modeling and channel characterization started at the early time of cellular communications. This thesis focus on propagation channel model parameter prediction for the city centre of Khartoum. Path loss prediction “Propagation channel prediction” is one of the planning pillars in various wireless networks represented by cellular networks and as proven via experiments the power loss in such networks is related to distance among transmitter, receiver and, the Base antenna height. Researchers tried hard to formulate a model that helps the system designers in accurate planning. Thus, prediction models used to reduce the expense of planning. These prediction models whether they are developed in the USA, Europe or East Asia they specifically characterize the respective environment and making use of them in other areas such as Khartoum is expected to have their output predicted values differ from the actual measurement, these deviations between the predicted value and measuring value is due to the difference between the model development area and model application area (Khartoum). Furthermore the overpopulation that appears clearly in the recent years in the capital of Sudan axiomatically it will affect the construction characteristic compared with that one before many years or even in the future. Thus this thesis is going to develop a reference model that can help the cellular system designer to optimize their network.

1.2 Motivation:

In addition to the lack of channel characterisation at 415 MHz. there are additional reasons motivate us to carry on channel characterisation at city center of Khartoum: namely developing a reference model for the system designer and providing Benchmark study to the global research at the divided frequency range of Geneva 06 agreement.

1.3 Objectives:

The objectives of this thesis are as follows:

a. Deeply study and research the empirical path loss prediction models (Okumura Model, Okumura-Hata Model, COST231 Extension to Hata Model and Simplified Path Loss Model).

b. To collect real data “Received measurement” from the city center of Khartoum, develop the simplified path loss model parameters and compare the developed model with empirical models.
c. Weighting the best path loss prediction model in term of MMSE between measured and predicted values, by looking for the model that has nearest predicted received power values to the measured one.

1.4 Scope of the work:

a. Collecting real data from the field.
b. The area under consideration is an urban environment.
c. We are going to develop large scale fading parameters for simplified path loss model (path loss exponent that characterize the environment, shadowing that describe the building).
d. We are going to assume the city center of Khartoum (AL Riayadh, Arkaweet, Al-Ma’mora, Al-Mujahedeen and Al-Taif).
e. Compare the developed model with other models in the literature.

1.5 Methodology:

In this research, the measured data of the received signal level were collected at random position around the BTS and the focus was on the main beam of the BTS. Each sector is 120°, two test phone; GPS receiver; laptop equipped (Drive Test Tools) were used.

The GPS receiver was fixed on the top of the car to record the longitude and latitude of each measurement point. The test phone held around one meter from the ground to record the received signal level. Transmitted power is sent at height of 30 meter antenna. Sufficient statistic measurements (45) are recorded from two base sites and the simplified path loss parameter are calculated. Finally the developed model parameters are compared with Okumura-Hata and COST231 model in term of MMSE.

1.6 Thesis Outlines:

In Chapter Two we review the four path loss prediction models ordered historically starting from Okumura Model, followed by Okumura-Hata Model then COST231 Extension to Hata Model and finally Simplified Path Loss Model. The major merits and shortages of any model were mentioned. The methodology of data collections, propagation model parameter development, and result analysis are explained in Chapter Three. Results and discussions were layered in chapter four. Chapter Five, concludes the thesis with solid reasoning on the achieved results and recommendation for future studies.

CHAPTER TWO
LITERATURE REVIEW

2.1 Preface:

Path loss “is a measure of average radio frequency (R. F) power attenuation suffered by a transmitted signal when it arrives at receiver” [5]. It is clear from the definition that the need for path loss calculation is to know the amount of loss due to the channel attenuation, and to know the nature of the propagation environment.

Path loss prediction is used in many wireless communication systems planning , in order to know the signal level at the receiver. It helps in the designing and optimization of wireless communication network and enables the designer to know the environment characteristics before and after installing a new system. In general path loss models can be classified into deterministic methods and empirical method. Deterministic models are based on physical laws of wave propagation. Like Maxwellians Free Space Path Loss (FSPL) and it is not realistic or practical since it assumes a channel with clear LOS propagation path between the transmitter and receiver, other example of deterministic models are ray tracing models (Two rays and multiple rays). To use these models we need to know the details of the object in the propagation environment to know the reflection coefficient, which is difficult to be applied practically.

In this chapter we are going to review a set of empirical path loss propagation models namely, Okumra-Hata, COST231 and simplified path loss model. These models were developed based on methodology relying upon extensive measurement collection from a test site and statistically developing the corresponding model parameters.

Figure 2.1 shows a chart of propagation channel prediction where simplified path loss model that developed is under empirical models.

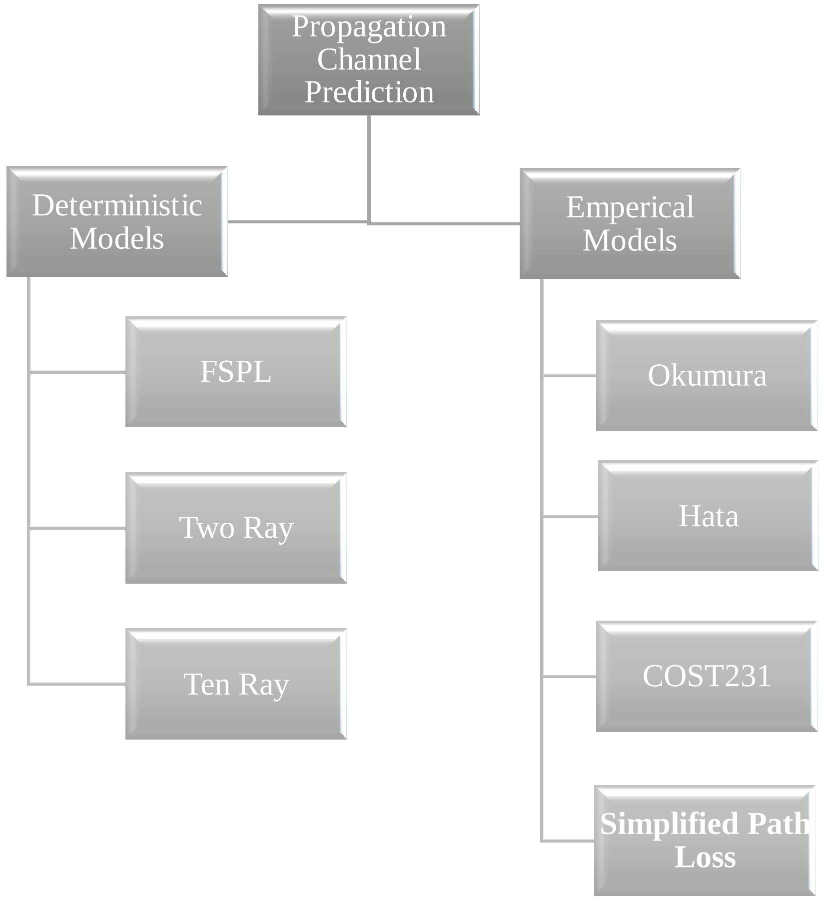

Figure 2-1: Propagation channel prediction chart

2.2 Free Space Path Loss Model:

This type of path loss model is called deterministic model and it is mainly based on theory of electromagnetic-wave propagation that we mentioned in Chapter One. Unlike statistical models, this model is not based on comprehensive filed measurements of power in order to find the path loss. It could be computed directly via solving Maxwell's equations. It has been applied to simple propagation environment [5].

The free space path loss is defined as the loss in the received signal level due to the signal propagation in the LOS. With assumption that no obstacles between transmitter and receiver, thus it is rarely used alone, but as a part of Harald T. Frris and the linear relation of the free space path loss factor is given by:

$$FSPL = \left(\frac{4\pi d}{\lambda}\right)^2 \qquad 2.1$$

Where:

D	The distance from Transmitter
λ	Wave length

From equation 2.1, It can be seen that the path loss value is directly proportion to the distance and reversely proportion to the wave length.

2.3 Ray Tracing:

Ray tracing models are based on a geometrical optics (G.O.) ((describes light propagation in terms of rays)), which is an approximation method for estimating the level of light frequency electromagnetic fields [5]. It can be classified as two ray model and ten ray models.

2.3.1 Two Ray Model:

Free space path loss model is not realistic because it assumes clear path between the transmitter and receiver. In fact in long distance communication set up, then receiver may receive many signal reflected component, in addition to direct LOS.

As shown in Figure 2.2, two ray models assume two received signal components, the direct line-of-sight path signal component and the ground reflected signal component [6].

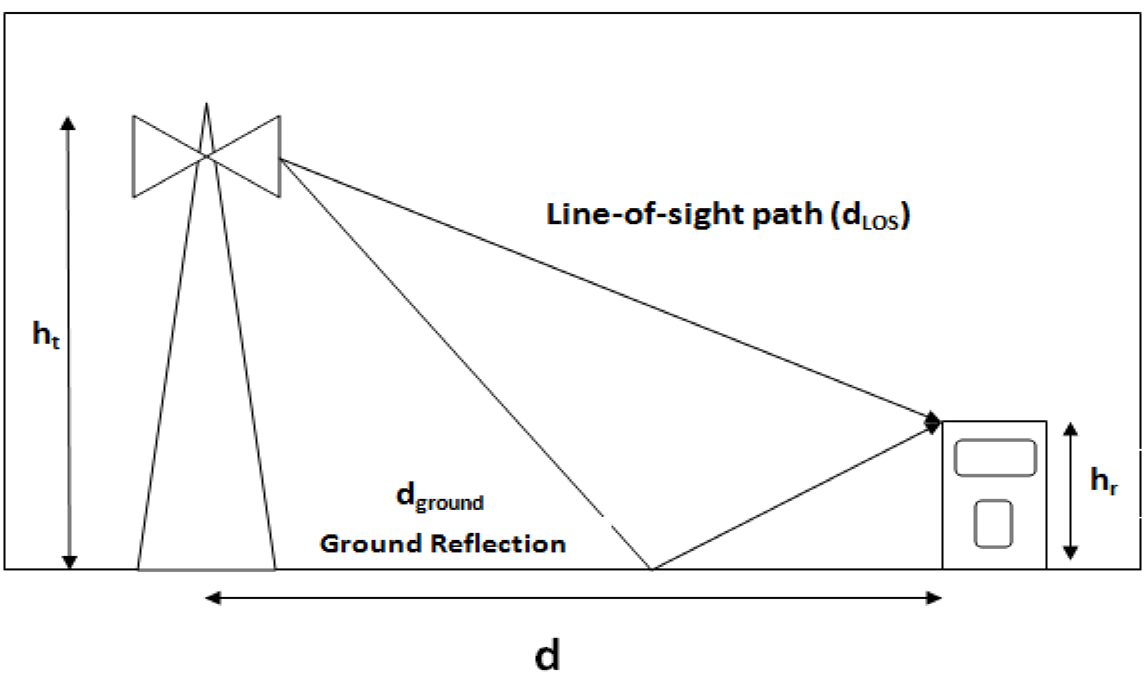

Figure 2-2: Two ray model with LOS and Ground reflected from [6]

And the base antenna height and receive antenna height both assumed to be at elevations above the ground [6].

The relationship among Transmitter and Receiver power shown linearly by Equ.2.2 and Equ. 2.3 [7]:

$$E_{TOT} = E_{LOS} + E_{GROUND} \qquad 2.2$$

$$E_{TOT} = \frac{E_0 d_0}{d_{Los}} Cos\left(\omega_c\left(t - \frac{d_{Los}}{c}\right)\right) + R_{ground}\frac{E_0 d_0}{d_{ground}} Cos\left(\omega_c\left(t - \frac{d_{ground}}{c}\right)\right) \qquad 2.3$$

Where:

E_{GROUND}	E-field for ground-reflected ray
R_{ground}	Ground reflection coefficient
d_{ground}	$\sqrt{(h_t + h_r)^2 + d^2}$
h_t, h_r	Height of Transmitter and Receiver respectively
E_{TOT}	Total E-field
d_{Los}	Line-of-sight distance
E_{LOS}	Line-of-sight E-field
ω_c	Angular frequency $2\pi f$
c	Speed of light
t	Time at which E-field is evaluated
E_0	E-field at reference distance d_0 in the antenna far field

2.3.2 Ten Ray Model:

Moreover, to two rays model also not sufficient to represent the real environment with only LOS and ground reflected. Mr. N. Amity in 1991 come up with ten ray model or it called (Dielectric canyon) (canyon like a deep gorge, typically one with a river flowing through it) [8]. His model assume rectangular and linear street with buildings along with sides. Theoretically an infinite number of rays can be generated between transmitter and receiver even some of rays can reflected back. But this is not considered in this model and the experiment shows that ten ray model closely approximate signal propagation. Inside the dielectric canyon or similar street, where, there is one LOS ray and (one, two and three) reflected ray could happen until signal reach the receiver. This model is sound to give fair prediction results as illustrated in Figure 2.3 [8]:

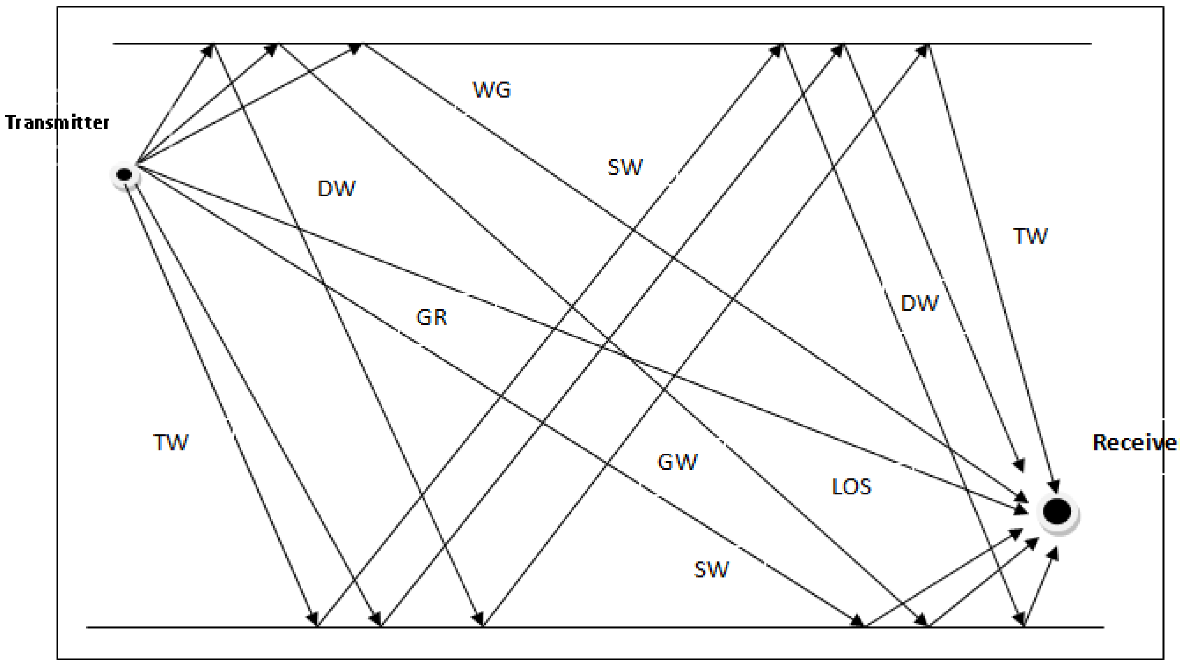

Figure 2-3: Over head view of Ten Ray Model from Andrea [8]

Then the received signal expressed as [8]:

$$r_{10ray}(t) = R\left\{\frac{\lambda}{4\pi}\left[\frac{\sqrt{G_l}u(t)e^{-j2\pi l/\lambda}}{l} + \sum_{i=1}^{9}\frac{R_i\sqrt{G_{xi}}u(t-\tau_i)e^{-j2\pi x_i/\lambda}}{x_i}\right]e^{j2\pi f_c t}\right\} \qquad 2.4$$

Where:

x_i	Path loss of the Ith reflected ray
τ_i	$= \frac{x_i - l}{c}$ time delay
$\sqrt{G_{xi}}$	Is the product the transmitter and receiver antenna gain
R_i	Is signal reflection coefficient
l	distance between the transmitter and receiver
	$l = \sqrt{d^2 + (h_t - h_r)^2}$

λ	Signal wave length
f_c	Carrier frequency
t	Time
G_l	Is the product the transmitter and receiver antenna field radiation pattern in LOS direction.
r_{10ray}	The received signal for 10 ray model

2.4 Empirical Path Loss Models:

Empirical model are those classes of models that developed statistically from large collected data "measurements" from specific area. Practical empirical models are best fit the reality than the deterministic models, because most communication systems operate in complex propagation environment that cannot accurately modeled by deterministic models [8]. In this section we are going to review Okumura model in section (2.4.1). Then Okumura-Hata model in section (2.4.2) and what had been added to previous model, followed by COST231 Extension to Hata model in section (2.4.3). Then Simplified path loss model at section (2.4.4), finally we conclude the chapter.

2.4.1 Okumura Model:

In 1968 Okumura et al. have done an abundant field data collection in Japanese capital Tokyo for field strength. After that they developed their graphical model [8]. It became widely used model because of it is best fit to a lot of practical situations.

They construct the path loss formula which is valid in frequency range (150 – 1920 MHz) and base station antenna heights (30 – 100 m) and separation distance amidst BS and mobile (1 – 100 km) and the formula are [9]:

$$P_L(d)\ dB = L(f_c, d) + A_{mu}(f_c, d) - G(h_t) - G(h_r) - G_{Area} \qquad 2.5$$

Where:

$L(f_c, d)$	Free space path loss at distance d and frequency f_c.
$A_{mu}(f_c, d)$	Median attenuation relative to free space over all environments.
$G(h_t), G(h_r)$	Are the gain factors for BTS and mobile heights respectively.
G_{Area}	The gain of environment type.

P_L Path loss in dB

The $A_{mu}(f_c, d)$ and G_{Area} values are obtained from Okumura graphs [5, 8, 9]. Which made the obtaining of them not comfortable to make use of it, thus Hata obtain them from simple formula [10].

Also Okumura & et al. drive prediction equation for $G(h_t), G(h_r)$ [8]:

$$G(h_t) = 20\log_{10}({}^{h_t}/_{200}) \qquad 30m < h_t < 1000m \qquad 2.6$$

$$G(h_r) = \begin{cases} 10\log_{10}{}^{h_r}/_{3} & h_r \le 3m \\ 20\log_{10}{}^{h_r}/_{3} & 3m < h_r < 10m \end{cases} \rightarrow (3) \qquad 2.7$$

Okumura's model has standard deviation of (10 – 14 dB) between field measurements and that had been predicted by the model [8]. Many researchers stated that this model has slow response to rapid change in terrain. Finally, it is fairly good in urban and sub-urban, but not good in rural environment [9] because it originally developed from dense urban data.

2.4.2 Okumura-Hata Model:

M. HATA in 1980 conveys the figurative data given by Okumura in 1968 by an enumeration formula. This formula simplify the process of wireless system planning, Hata formula is [11]:

$$P_L\,(Urban) = 69.55 + 26.16\log_{10} f_c - 13.82\log_{10} h_b - a(h_m) + (44.9 - 6.55\log_{10} h_b)\log_{10} R \;\; dB \qquad 2.8$$

In this formula path loss P_L can be calculated via knowledge of four parameters, f_c (frequency range) (100 – 1500 MHz) h_b (Base Station Height) (30 – 200m), $h_m$vehicle height (1 – 10m). And the distance between base station and vehicle R (1 – 20 km) as well he forms a correction factor to the vehicle height if it changes from 1.5 meter and that according to the city size [11].

Medium – small city:

$$a(h_m) = (1.1 \log_{10} f_c - 0.7)h_m - (1.56 \log_{10} f_c - 0.8)\ dB \qquad 2.9$$

Large city:

$$a(h_m) = 8.29(\log_{10} 1.54\, h_m)^2 - 1.1 \quad , \qquad f_c \le 200 \quad MHz \qquad 2.10$$

$$a(h_m) = 3.2(\log_{10} 11.75\, h_m)^2 - 4.79 \quad , \qquad f_c \ge 400 \quad MHz \qquad 2.11$$

As his model includes the alteration in the region of coverage area such as sub-urban & open area [5]:

$$P_{LS}(Suburban) = P_L[Urban\ area] - 2[\log_{10}({f_c}/{28})]^2 - 5.4\ dB \qquad 2.12$$

$$P_{LO}(Open\ area) = P_L[Urban\ area] - 4.78 \log_{10}(f_c)^2 + 18.33 \log_{10} f_c - 40.98\ dB \qquad 2.13$$

A group of researcher agrees that HATA model suites a macro-cells system and no doubt that they will suite 1st generation. Thus axiomatically for current cellular technology that depend upon micro-cells and high frequency, this model will not work in a good manner [9, 10, 12, 13].

2.4.3 COST231 Extension to HATA Model:

In 1981, the European cooperative for Scientific and technical research COST231 extend Okumura-Hata model, which was done in 1980 to frequency up to 2 GHz and that enables the subsequent generation after 1st G to make use of path loss prediction results. Then according to it is simplicity and dense usage it’s better to extrapolate this model [8, 10, 14, 15].

The standard equation for path loss is:

$$PL(Urban) = 46.3 + 33.9 \log_{10} f_c - 13.82 \log_{10} h_t - a(h_r) + (44.9 - 6.55 \log_{10} h_t) \log_{10} d + C_m \quad dB \qquad 2.14$$

Where: $C_m = 0\ dB$ For medium city & suburban

$C_m = 3\ dB$ For urban (metropolitan)

And the model restricted by the following parameters:

$$1.5 < f < 2\ GHz, 30 < h_t < 200m, 1 < d < 20\ km \text{ and } 1 < h_r < 10m$$

As well there is a correction factor for receiver height [9]:

For urban:

$$a(h_r) = (1.1 \log_{10} f_c - 0.7)h_r - (1.56 \log_{10} f_c - 0.8)\ dB \qquad 2.15$$

For suburban & rural:

$$a(h_r) = 3.2(\log_{10} 11.75\, h_r)^2 - 4.79 \quad , \qquad f_c \geq 400\ MHz \qquad 2.16$$

COST231 – Hata model were designed to medium and large macro-cells i.e. (antennas height at the level of base station antenna height at the rooftop) [10].

The prediction path loss exponent that developed by COST231 is given by [13, 15]:

$$n_{cost} = (44.9 - 6.55 \log_{10} h_t)/10 \qquad 2.17$$

2.4.4 Simplified Path Loss Model:

Undoubtedly according to various environments and wider frequency range that communication system work on it, it's not easy to find one model that characterize the wave propagation. Thus sometimes it's better to use what is called a simple model that characterize the channel [8, 13].

In 1999 V. Ereg and et al. made a wiping to large geographical area in the USA then they had reached to a formula that enables system designer or planner to predict the path loss in distinct terrain according to their classification, and the formula:

$$PL = A + 10\gamma \log_{10} \left({d}/{d_0} \right) + S\ dB \qquad 2.18$$

A	Fixed Intercept or free space loss
γ	Path loss exponent
d	Distance between transmitter and receiver

d_0 Reference distance

S Gauss-distributed random variable with mean zero and variance $\sigma^2 \ dB$

Where A is fixed intercept value that given by free space formula:

$$A = 20\log_{10}\frac{4\pi d_0}{\lambda} \quad dB \qquad 2.19$$

They also had used 1.9 GHz frequency, and d_0 is the reference distance from the base station, which is determined depending upon the environment (1 – 10 m) for indoor and (10 – 100 m) [8, 13] for outdoor. But it’s valid only for $d > d_0$. For γ $(path\ loss\ exponent)$ it mainly depends upon propagation environment and the base station antenna height. For example the environment near to free space $\gamma\ lay$ between (2 – 4) and it increases for more complex environments.

This, as V. Ereg et al. explain in their graph γ decrease when base station height increase, is not surprising according to its approach to LOS, furthermore it explains that for light tree dense environment then γ diminish compared with the other environment [12].

Also the path loss for higher frequencies likely to be higher [8]. It is likely that the simplified path loss model gives near values to the measured one because there is flexibility to use this model for wider range of frequencies. Where V. Ereg et al. develop the model at 1.9 GHz, also M. Hasna et al. [16] tested the model in 3.5 GHz.

2.5 The Frequency Issue:

In early 19th century, bands in VHF and UHF were assigned for analog TV terrestrial broadcasting, but with the appearance of A/D and D/A conversion technique and it started with satellite TV broadcast a huge compression can achieved, practically, today up to 20 digital TV channel can be accommodated in the conventional 6 – 8 MHz analog TV channel bandwidth [17].

A conference was done under the title “Final Acts of the regional radio communication conference for planning of the digital terrestrial broadcasting service in parts of regions 1 and 3 in the frequency bands (174 – 230 MHz) and (470 – 862 MHz) RRC06” [18]. With knowledge that the conference is about digital broadcasting in the explained frequency bands or UHF and VHF, also one of the issue is how to plan and assign this band in future. And, evacuate the TV broadcaster that broadcast in this band because of it is large bandwidth that been and still utilized. And, broadcasting with analog systems and it is known to what extended the consumption of this rare coin (i.e. spectrum).

The cut-off date for the rights to use analog transmission for the 119 member countries of the GE06 agreement in 17 June 2015, with extension to 17 June 2020 for developing countries, thus, will be a large part of spectrum free or it called digital dividend that may defined as “the amount of spectrum made available by the transmission of terrestrial TV broadcasting from analog to digital” [17].

And, with digital developing it is possible to find terrestrial station with digital system that lead us to utilize it is band in another technology like smart grid or cellular systems, with knowledge that Sudan have 224 analog terrestrial TV channel according to what have been stated in the agreement and it lay in region 1 and 2 as appears in the map of figure 2.4 [18]:

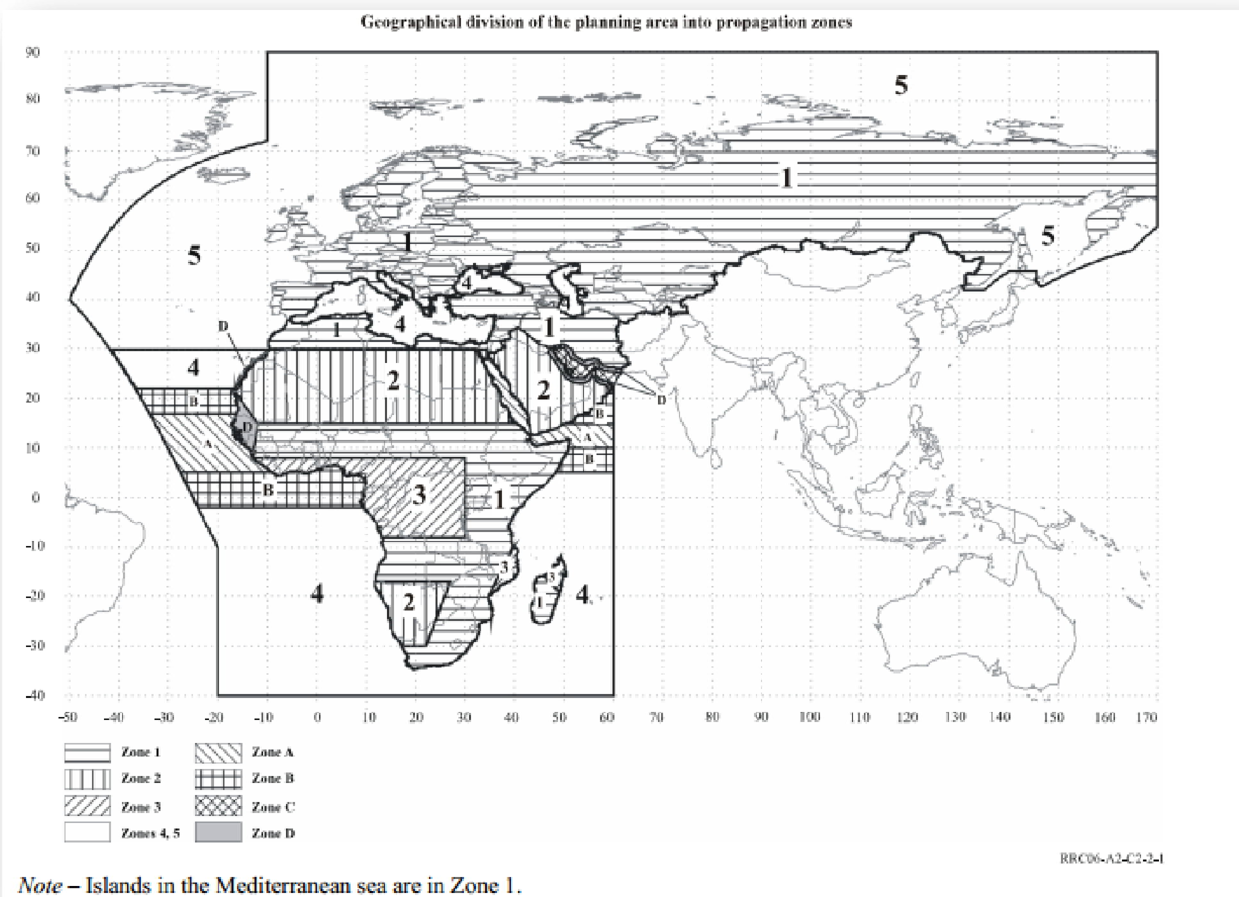

Figure 2-4: Geographical division of the planning area into propagation zones from Gen06 [18].

Since 2006, many countries start to plan for the digital dividend for example (the USA, Netherland, Norway, Australia … etc). That was one of the important reasons that motivate us to carry on channel characterization on the 415 MHz frequency range.

In the next chapter we will describe our methodology to achieve our thesis goals by describing the steps for and data collection and analysis. The city of Khartoum was chosen because it represents one of the largest cities in Sudan, in term of geographical area and population. Since it is urban area buildings and the environment expected to affect the path loss which is our concern.

Again we emphasize an important question. Why this frequency 415 MHz had been chosen? We can say according to what Geneva 06 agreement provided, the evacuation and repacking of UHF and VHF bands, especially the bands that exploited by analog terrestrial TV broadcasting. Then there are no such channel characterizations so far for this center frequency.

Table 2.1 and Table 2.2 explain each model with classifications.

Table 2.1: Deterministic models:

No	**Model**	**Suitable for**	**Limitations**
1	FSPL	LOS	Not realistic
2	Two Ray	LOS + NLOS	Knowledge of details of objects in propagation environment "reflection coefficient".
3	Ten Ray	Streets or dielectric canyon	

Table 2.2: Empirical Models:

No	**Model**	**Suitable for**	**Frequency Range**
1	Okumura 1968	Urban and Suburban	150 – 1920 MHz
2	Hata 1980	1st generation cellular system (Large cell mobile systems)	150 – 1500 MHz
3	COST231 1991	1st and 2nd	1.5 – 2 GHz

		generation cellular system	
4	Simplified Path Loss	Many terrain categories	Done around 1.9 GHz

CHAPTER THREE

METHODOLOGY AND ANALYSIS OF MODELS

3.1 Preface:

This chapter will introduce the selected area for measurement collection and describes the data collection methodology. Furthermore, it describes the analysis, methodology and how the results will be represented in the following chapter. In section 3.2 detailed description of the selected area for measurements collection is given. The steps of the data collection are explained in section 3.3 and the analysis of the developed simplified path loss parameters given in section 3.4, finally, the conclusion of this chapter given in section 3.5.

3.2 The Selected Area for Measurement Collection:

A territory of AL Riayadh, Arkaweet, Al-Ma'mora, Al-Mujahedeen and Al-Taif had been chosen to be the area of this research. It is approximately 16 Km^2 although their sensible similarity in the building to a large extend, and the height of their buildings around 15 meter. Moreover, these territories characterized by not higher building compared to chosen base station. Also it has moderate trees with a flat land. Furthermore, small cars were seen across the streets.

Since these areas are residential, there are no factories or institution that exploits a vast area which could make an obstruction to collect the received power. So the digging in the channel characteristic represented by the models that will applied it is vital, proportion to the relationship of the environment directly with channel characteristic.

3.3 Data Collection Method:

For the mentioned selected area two base antenna heights of 30 meter and approximate cell radius of 2 Km each, with center frequency 415 MHz .

Each cell consist of three sectors each sector 120°, the number of taken readings is around (1 – 11) readings. And the overall points are about 45. Random places were chosen to pick up the received signal power. GPS receiver placed at the top of the car to record the longitude and latitude that given in appendix tables (1 to 13), two test phones were used. One to establish calls and the second to receive calls where the second phone connected to a laptop via U.S.B cable held around one meter above the ground, then a drive test software is installed into the laptop with Windows XP also two DC to AC power converter where used and connected to the car. The location of measured points is illustrated in Figure 3.1 and Figure 3.2 for both BTS.

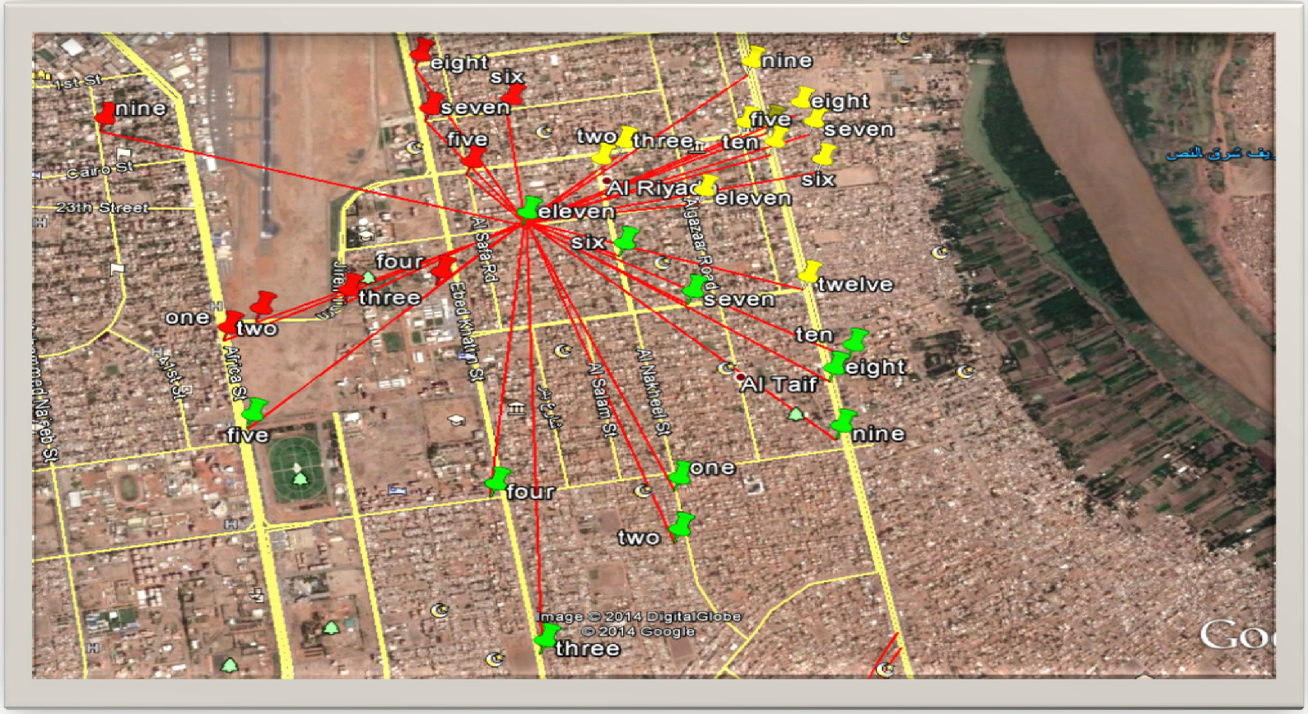

Figure 3-1: Al-Riyadh BTS East-South of Khartoum Air port, with three Sector Labeled by different color. (Yellow for sector 0, Green for sector 1 and Red for sector 2)

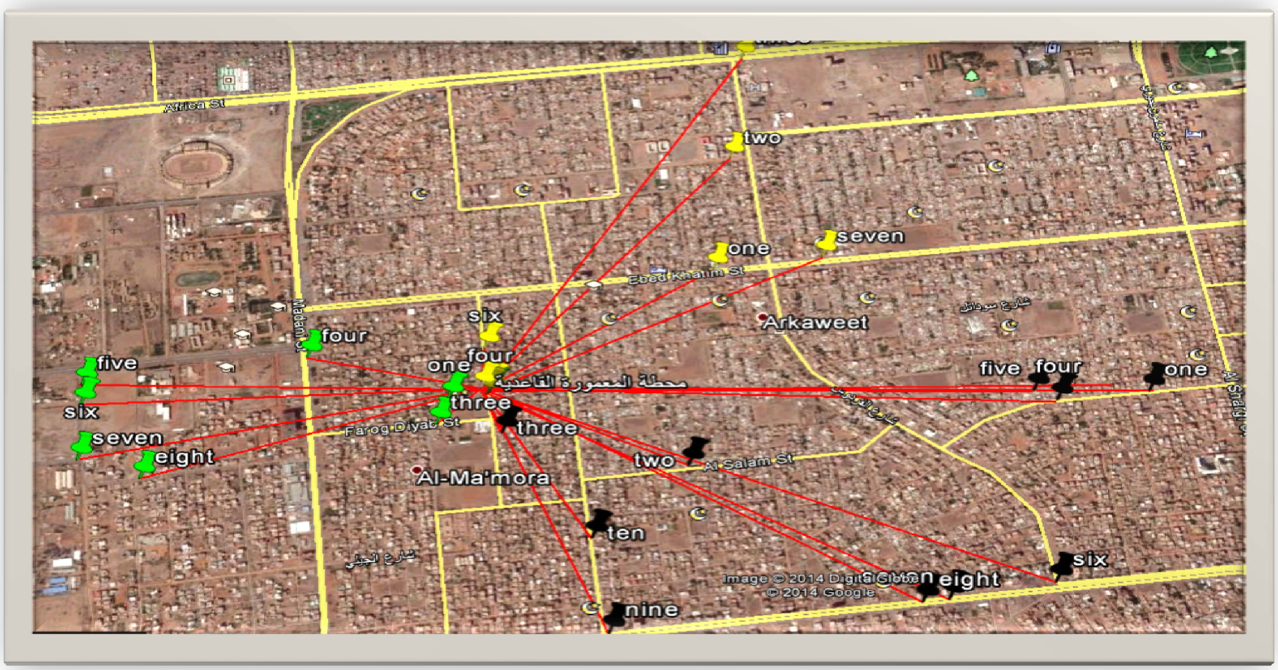

Figure 3-2: Al-Ma'mora BTS East-South of Khartoum Air port with three Sector Labeled with different color. (Black for sector 0, Green for sector 1 and Yellow for sector 2)

The collected measurements are summarized in tables (1 to 13) in the appendix-A. These tables also summarized the locations of the measured data in term of longitude and latitude position parameters.

3.4 Analysis and Simplified Path Loss Model Parameters Development:

In this section we are going to summarize the steps of collected data analysis and propagation model development.

3.4.1 Distance between Transmitter and Receiver Calculation:

The accurate distance between BTS and each point were calculated using Spherical law of Cosines the formula are for calculations on the basis of a spherical earth as follows [19]:

$$d = acos(sin\varphi_1 sin\varphi_2 + cos\varphi_1 cos\varphi_2 cos\Delta\beta) * R \qquad 3.1$$

Where:

D	The distance in Km
φ_1	Latitude 1 (after conversion to radian)
φ_2	Latitude 2 (after conversion to radian)
$\Delta\beta$	The difference between Longitude 2 and Longitude 1 (~)
R	6367 Km earth radius
acos	Arc cosine

The first analysis of distance as an example, for 1st BTS:

Latitude1(φ_1)=	15.539468*pi/180	= 0.2719	Rad
Longitude1 =	32.571691*pi/180	= 0.5684	Rad
Latitude2(φ_2)=	15.56015 *pi/180	= 0.2716	Rad
Longitude2 =	32.57126 *pi/180	= 0.5685	Rad

$\Delta\beta$ = = 0.5685 - 0.5684 = 0.1136*10^-3

R = 6.367*10^6 m

$d =$

$aCos$(sin (0.2719)sin (0.2716) + cos (0.2719)cos (0.2716)cos (0.1136 $*$ 10^−3) $*$6.367$*$10^6

$$d = 1.9789\ Km$$

Which mean the distance between the first BTS and first position is 1.9789 Km. The rest of calculation given in Appendix-A in table (1-13)

3.4.2 Path loss exponent calculation:

The calculation of simplified path loss with (f = 415 MHz), the reference distance (d_0=100 m) and (d) represent the distance between base antenna height and mobile and since it's a matrix vector with length 45, thus the explanation as follows:

$$PL = A + 10\gamma \log_{10}\left({}^{d}/_{d_0}\right) + S\ dB \qquad 3.2$$

First, we neglect shadow fading Gaussian random variable S and let us calculate A (fixed Intercept)

$$A = 20 \log_{10} \frac{4\pi d_0}{\lambda}\ dB$$

$$A = 20 \log_{10} \frac{4\pi * (100) * (415 * 10^6)}{2.99792458 * 10^8}\ dB$$

$$A = 64.8087\ dB$$

Then the path loss as a function in distance will be:

$$PL = 64.8087 + 10\gamma \log_{10}\left({}^{d}/_{100}\right) dB$$

Table 15 in Appendix-A summarize the path loss as a function in path loss exponent after substituting the reference distance, the distance between base antenna height and the receive antenna height.

So to find the path loss exponent by using the following equation:

$$F(\gamma) = \sum_{i=1}^{45} [P_{measured}(d_i) - P_{predicted}(d_i)]^2 \qquad 3.3$$

$P_{measured}(d_i)$ Represent measured path loss as shown in appendix-A tables

$P_{predicted}(d_i)$ Path loss of the measured values as a function in γ

Where N= 45 is the total number of readings for both BTS,

$$F(\gamma) = (P_m(d_1) - P_r(d_1))^2 + (P_m(d_2) - P_r(d_2))^2 + \cdots + (P_m(d_{45}) - P_r(d_{45}))^2$$

$$F(\gamma) = (5571.0\gamma^2 - 54597.13\gamma + 137073.09)$$

Then by differentiating $F(\gamma)$ relative to γ and equate the result with zero[8]:

$$\frac{\partial F(\gamma)}{\partial \gamma} = 11142\gamma - 54597.13 = 0$$

$$\gamma = 4.9$$

And accordance to [8] this path loss exponent describe an **Urban Macrocell environment** , followed by substation of γ in appendix-A Table 15 we got Predicted Path Loss via Simplified Path loss model.

3.4.3 Shadow Calculation:

After that let us find shadow fading STDV by the formula 3.5:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[P_{measured}(d_i) - P_{predicted}(d_i)]^2} \qquad 3.5$$

Where N represents the number of readings

The following explanation it is for Simplified Path loss model:

$$\sigma^2 = \frac{1}{N}([P_{measured}1 - P_{predicted}1]^2 + [P_{measured}2 - P_{predicted}2]^2 + \cdots + [P_{measured}45 - P_{predicted}45]^2)$$

$$\sigma^2 = \frac{1}{45}([125.80 - 121.99]^2 + [108.75 - 118.63]^2 + \cdots + [114.41 - 121.32]^2)$$

$$\sigma = 5.00\ dB$$

Then for Okumura-Hata:

$$\sigma^2 = \frac{1}{45}([125.80 - 132.5510]^2 + [108.75 - 116.6928]^2 + \cdots + [114.41 - 131.3267]^2)$$

$$\sigma = 6.74\ dB$$

For COST231 model:

$$\sigma^2 = \frac{1}{45}([125.08 - 129.564]^2 + [108.75 - 113.7065]^2 + \cdots + [114.41 - 128.3404]^2)$$

$$\sigma = 9.33\ dB$$

In tables (3,5,7,10,12,14) at appendix-A given the path loss for all measured values, also in tables (2,4,6,9,11,13) in appendix-A summarize the path loss for predicted values for all three models.

3.5 Summary:

In the next chapter we are going to layout three types of results. As shown in figure 3.3, firstly scatter plot of the received signal verses the developed line, secondly the developed simplified path loss model compared with the other empirical models. Finally, the square of error between predicted and measured values for three models will be also compared to recommend the best practical Model.

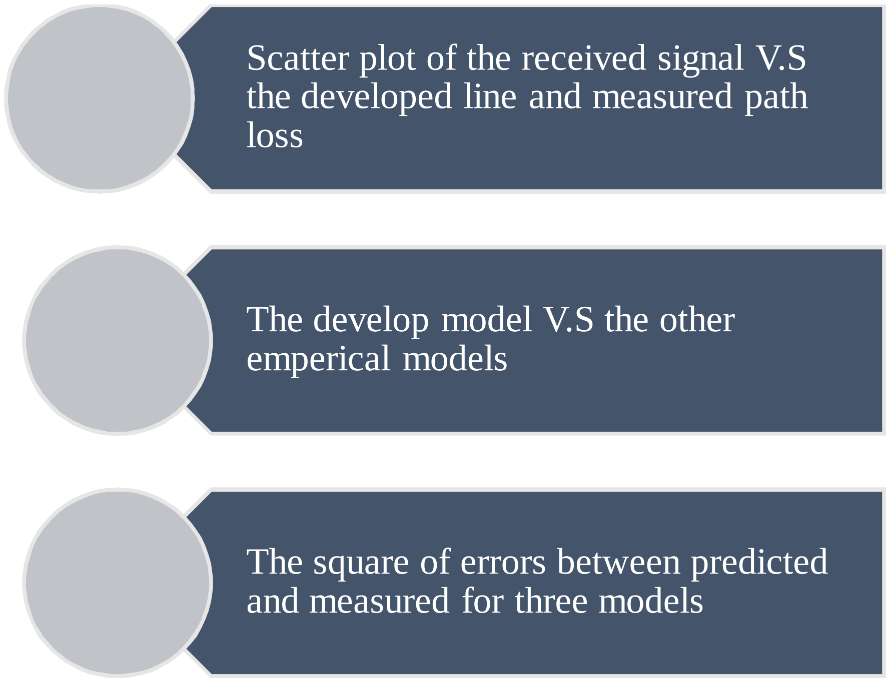

Figure 3-3: General view for the results

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Preface:

The analysis of simplified path loss parameters mentioned in chapter three will take palce here. Initially we are going to substitute our propagation environment in the three models discussed in the literature review. Our goal in this step is to be able to compare these models with the developed path loss model.

Starting from Okumura-Hata model, COST231 Extension to Hata Model and Simplified path loss model then obtaining the general relation between the distances along with the received power and knowing what we can observe from it.

4.2 Results:

4.2.1 Okumura-Hata Model:

We will start by explaining how to obtain the path loss mathematically for this model, accordingly the chosen territory is neither open area nor sub-urban. So the path loss equation for urban is:

$$L_p\,(Urban) = 69.55 + 26.16\log_{10} f_c - 13.82\log_{10} h_b - a(h_m) + (44.9 - 6.55\log_{10} h_b)\log_{10} R \;\; dB$$

f_c Carrier frequency = 415 MHz

h_b Base station antenna height = 30 meter.

R The separation distance amidst BTS and mobile user, since its variable and given in Appendix tables around 45 value in our explanation let us take R = 0.8152 Km from table 2 (No. 2).

$a(h_m)$ The correction factor to vehicle height which is one meter, we will choose Medium-Small city:

$$a(h_m) = (1.1\log_{10} f_c - 0.7)h_m - (1.56\log_{10} f_c - 0.8)\; dB$$

$$a(h_m) = (1.1\log_{10}(415) - 0.7) * (0.5) - (1.56\log_{10}(415) - 0.8)\; dB$$

$a(h_m) = -2.1942\ dB$

$$L_p\ (Urban) = 69.55 + 26.16 \log_{10}(415) - 13.82 \log_{10}(30) - (-2.1942) + (44.9 - 6.55 \log_{10}(30)) \log_{10}(0.8152\ )\ dB$$

$L_p\ (Urban) = 115.6029\ dB$

And so on the rest of values which found in Appendix-A tables had been calculated.

4.2.2 COST231 Extension to HATA:

As shown in chapter two that the European group COST231 is just extend the work done by Hata thus the same previous steps can be followed with the same mobile correction factor as follows:

$a(h_r) = -2.1942\ dB$

$$PL(Urban) = 46.3 + 33.9 \log_{10}(415) - 13.82 \log_{10}(30) - (-2.1942) + (44.9 - 6.55 \log_{10}(30)) \log_{10}(0.8152\ ) + 0\ \ dB$$

$PL(Urban) = 112.6166\text{dB}$

4.2.3 Distance Vs Measured Path loss:

Figure 4.1 shows the relationship between the scattered plot of the measured path loss and the best fit regression line. This graph clearly had shows the direct proportion of the path loss with distance and these agree with equations (2.4), (2.14) and (2.18). It is appears the maximum path loss is approximately 127 dB at distance around 3 km, the data given in appendix-A tables (2, 4, 6, 9, 11, 13). Also it is appear different path loss values around the same distance from BTS and that due to shadowing effect which related to the building size.

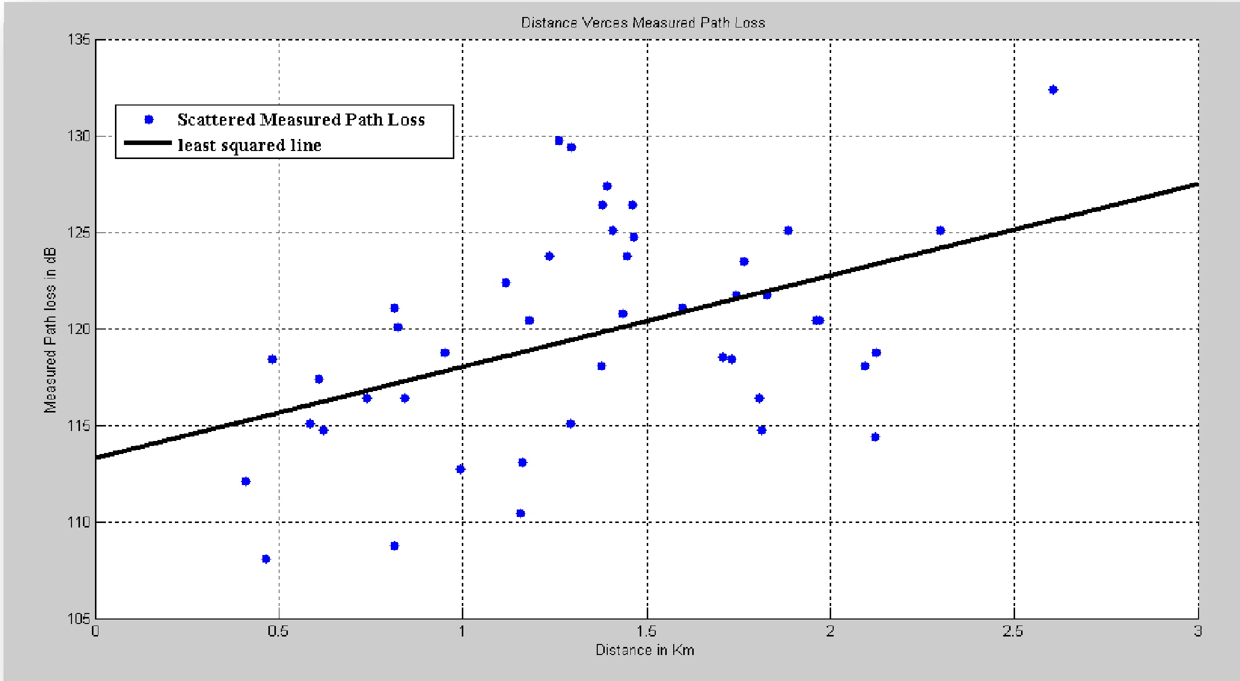

Figure 4-1: Scatter plot for the relationship between Distance (Km) and measured Path loss (dB)

4.2.4 Distance between Base antenna height and Receive antenna height Vs Received Power:

Figure 4.2; illustrate the relationship between the scattered plot of the received signal level in dB and the best fit regression line it is clearly shown that the average received signal decreased linearly with distance.

Also the median of higher signal power received is -75 dB which mean to an expert user "very good" signal, that is usually appeared in many drive test software with blue color as an indicator for signal quality. And, it respect as lower "very good" signal, where the upper "very good" signal lay between (-75 and -65) dBm as we will explain in the Table 4.1:

Table 4.1 : Received Signal Power Ranges and Indications:

Received Signal Range dBm	**Indication**
$-65 \leq P_r \leq Max$	Excellent
$-75 \leq P_r \leq -65$	**Very good**
$-85 \leq P_r \leq -75$	Good
$-95 \leq P_r \leq -85$	**Fair**

$-105 \leq P_r \leq -95$	Poor
$Min \leq P_r \leq -105$	Extremely Poor

Moreover it is observed from figure 4.2 that the worst average received signal power according to regression line below -90 dBm which can be approximated by -89 dBm which in turn respect as “Fair” signal.

The scattered values showed that the worst signal that been received at receive antenna height in this test was -94 dB at distance of 2.6 Km. Far from base antenna height and this value also lay in “Fair” range with a an existence probability of more worst signal power can be received. But we should keep in mind that, whenever we move away from given distance, there is a probability of entering a neighbor cell via what is called Hand-off. Especially when there is not accurate cellular planning from beginning, and around this distance up to $\leq 3\,Km$ we can describe the cell by Microcell.

In another point of view where the slope of the line given by:

$$Slope = \frac{y_2 - y_1}{x_2 - x_1} = \frac{-80 + 85}{2.166 - 1.108} = 4.725 \qquad 4.1$$

Since the slope it is not very high, thus the relationship between the received power and the distance it is linear and direct proportion.

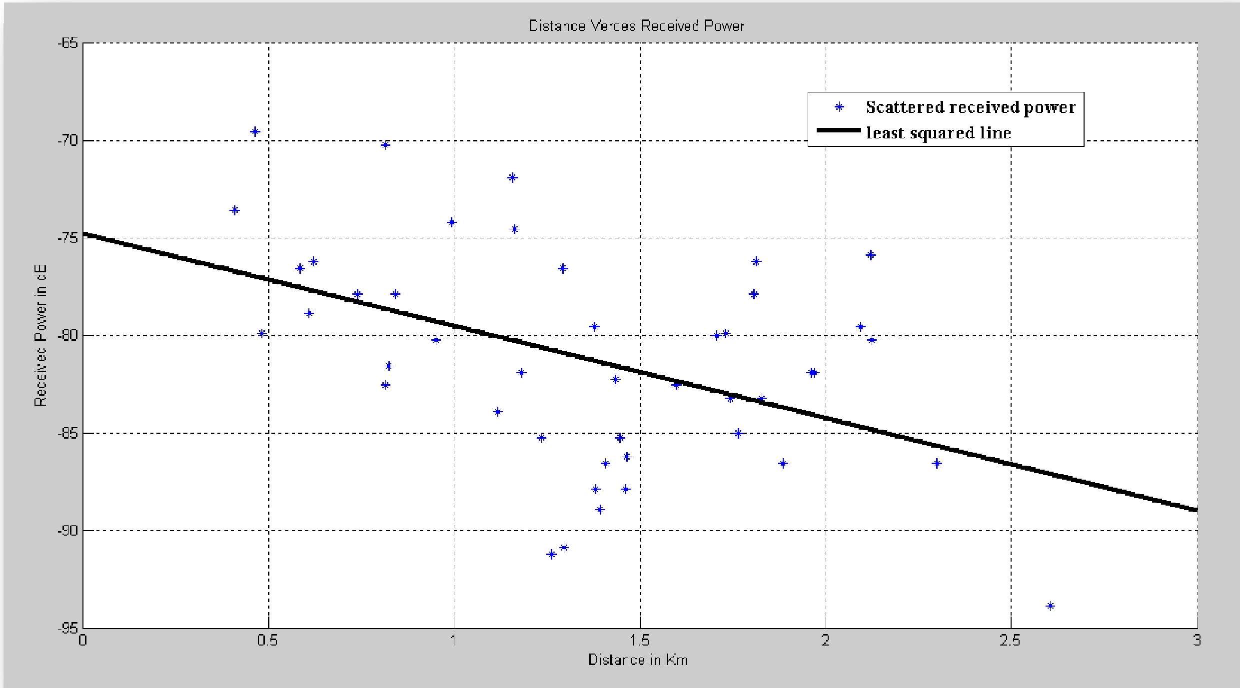

Figure 4-2: Comparison between the distances in Km verses the received power in dBm

4.2.5 Simplified Path loss Model Vs Okumura-Hata:

Figure 4.3 represents a linear plot with least squares for both models path loss values. The three lines in general show an incremental relationship in path loss verses distance. Okumura-Hata model shows an over prediction compared to Simplified path loss model and measured data for distance greater than 1.2 kilometers approximately. And, it shows under prediction for the distance less than that. Also in near and far distance to BTS there is divergence in path loss prediction. Because Okumura-Hata model basically made in Tokyo for different building compared to ours in Khartoum. That led to this large difference compared to measured and simplified path loss model.

In addition, if we compare between these two models in term of MMSE or STDV that had been calculated via equation 3.5, 5.0 dB for Simplified path loss model & 6.74 dB for Okumura-Hata model, which means the developed simplified path loss model shows better path loss prediction compared to Okumura-Hata model.

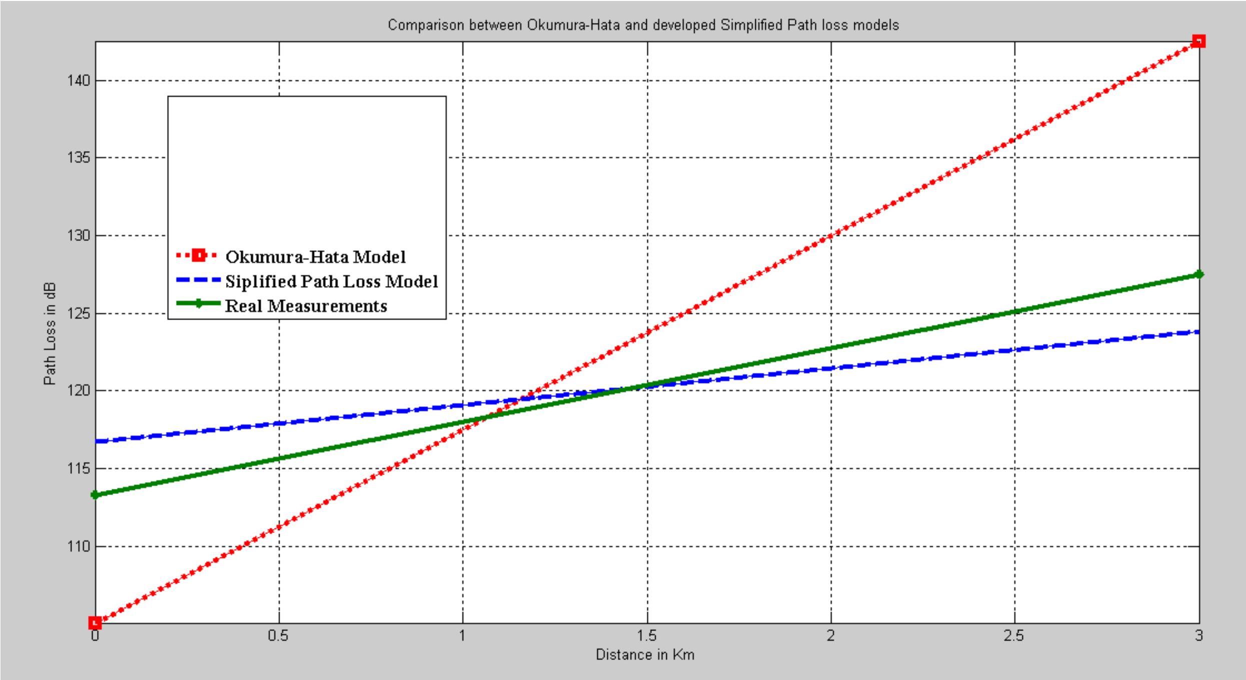

Figure 4-3: Illustrate the path loss in dB Vs distance for Simplified path loss Model and Okumura-Hata Model with respect to measured values

4.2.6 Simplified Path loss Model Vs COST231 Extension to Hata:

Figure 4.4 explains that in general the two models shows incremental in path loss with distance which means when the distance between transmitter and receiver increase the probability of losses in signal increase. On other point of view, simplified path loss models predicted values vary between 115 dB to 125 dB or 10 dB difference. But COST231 predicted values vary between 100 dB up to 140 dB or 40 dB which is quite large compared to developed simplified path loss model. And, that also return to the same reason mentioned in Figure 4.3 since COST231 model as mentioned in Chapter Two it is just an extension to Hata model.

So there is big difference between two models in prediction for the same area and that appears clearly when we compare in term of MMSE or STDV, Simplified path loss model gives 5.0 dB when COST231 Extension to Hata gives 9.33 dB which is quite large than simplified and Okumura-Hata i.e. “it has a large difference between the predicted vales and the measured data”. So in this case the developed simplified path loss model is better.

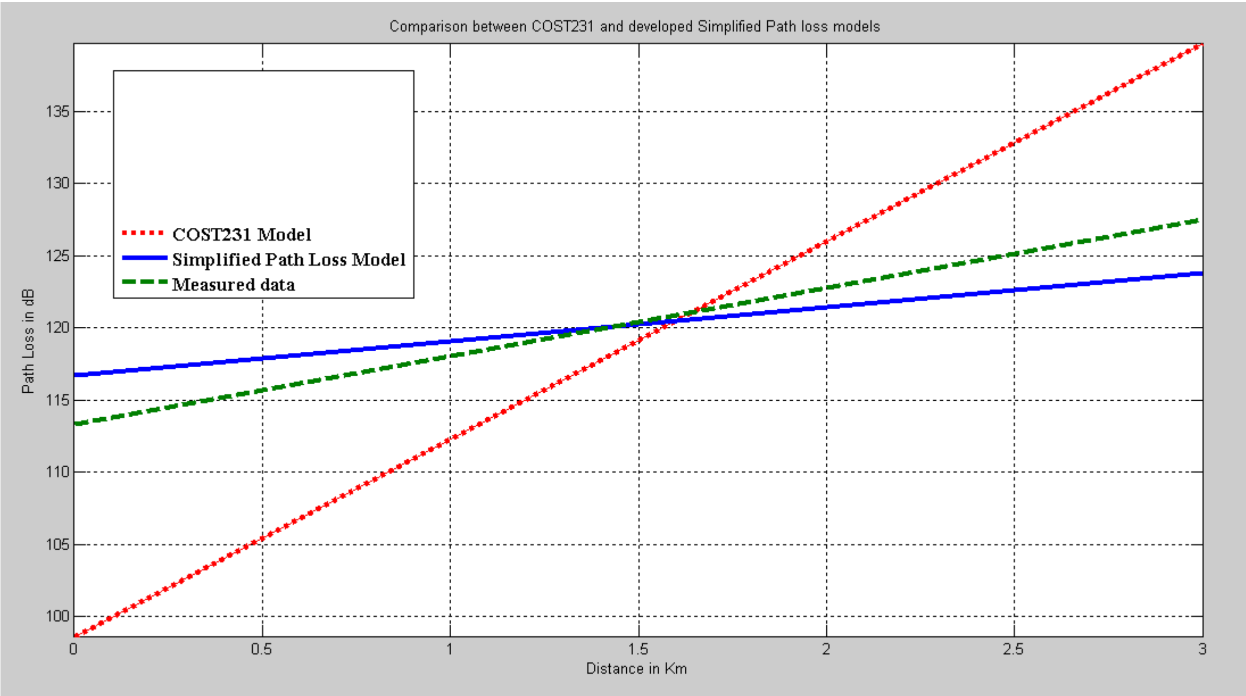

Figure 4-4: Illustrate the path loss in dB Vs distance for COST231 extension to Hata and simplified path loss models with respect to measured values

4.2.7 The square of errors between Predicted and Measured values for three models:

Figure 4.5 show square of errors between the predicted path loss and the measured, which is shown in the Y axis verses distance. It show when distance increase the squares of error increase thus, Okumura-Hata model have a good prediction around the BTS. And, the maximum error around the cell edge which is less than 100.

Also the simplified path loss model shows a constant relationship between the distance and the square of errors around 25 dB. Which means that the developed model. Predict near values to measured one. Moreover, the obtained STDV = 5 dB that it's squared equal the average value of the square distance between the predicted path loss and measured path loss.

The for COST231 model, Also show maximum error achieved compared to the two other model which is around 150 at distance less than 500 meters. Then minimum error about 15 at the cell edge, this model showed good prediction or less error at distances far for BTS center.

This model represent the worst case in prediction, and the result of STDV or MMSE that been mentioned confirm this fact. Because COST231 best fit open area.

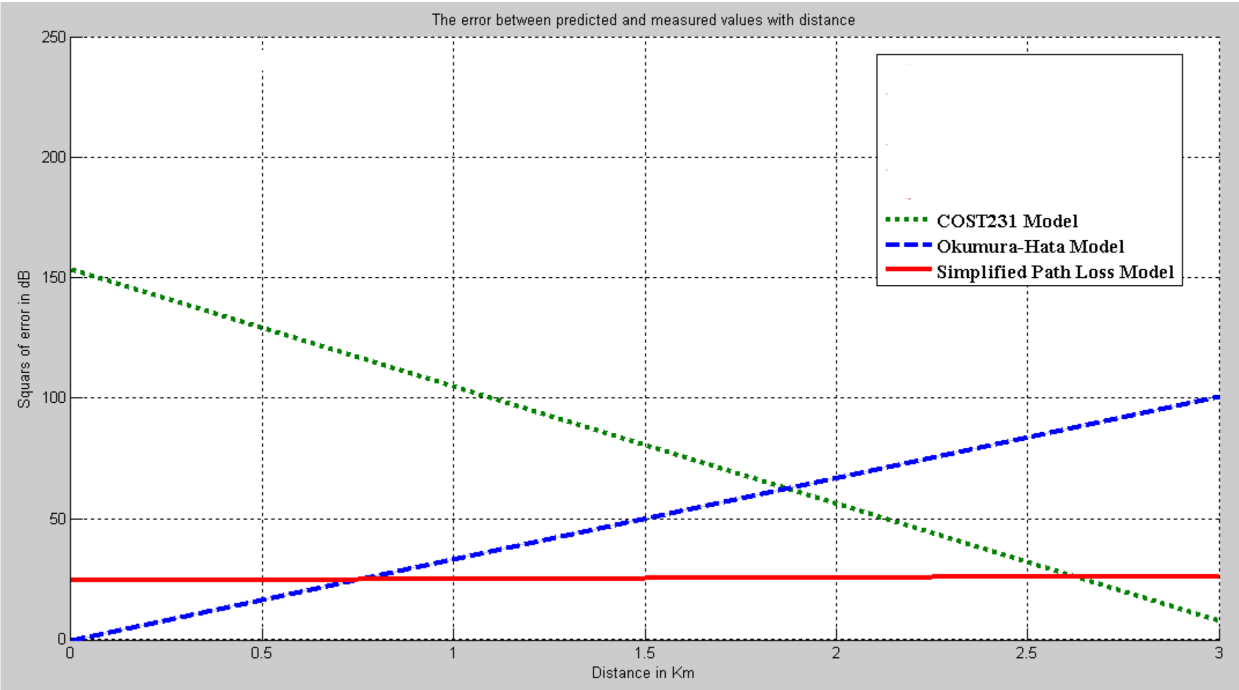

Figure 4-5: Representation of square of errors for three models

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

4.3 Conclusion

In this thesis propagation channel prediction model they have been deeply studied. And, the comparison between them have done, the three models are Okumura-Hata model, COST231 extension to Hata model and simplified path loss model.

The measurement collection of the received signal level also achieved, at the assumed areas (AL Riayadh, Arkaweet, Al-Ma'mora, Al-Mujahedeen and Al-Taif). Then the simplified path loss parameters have been developed. Firstly, the path loss exponent and it is achieved value is $\gamma = 4.9$ that describe and Urban environment with higher attenuation where this results agree with the assumption. Secondly, the shadowing parameter and it is achieved via finding the Gaussian-distributed random variable with zero mean and variance which is square of STDV. That has been generated randomly, and it was 47.8005 dB.

Then the developed simplified path loss model has been compared with firstly, Okumura-Hata model, where it is found that the Okumura-Hata model gave over-prediction in a distance greater than 1.2 km. And, under-prediction in a distance less than that. That means the prediction path loss of developed model it is near to the real measured rather than Okumura-Hata prediction.

Secondly, when the comparison has been made between the developed model and the COST231 model, a similar to previous result achieved, where COST231 shows an over-prediction at a distance greater than the half of cell radius. In addition under prediction in a distance less than that, which means the developed model also near to the measured real data than COST231 model.

Eventually, when a comparison had done in term of MMSE the Okumura-Hata and COST231 extension to Hata model gives 6.74 dB and 9.33 dB respectively. This respected as large values compared to the developed simplified path loss model that give lesser value 5.0 dB, which is less than acceptable value 6 dB according to [13].

Therefore, the developed simplified path loss model it is the better, and nearer to real measurements followed by Okumura-Hata model.

4.4 Recommendations:

From the results of this thesis we can draw out the following outcomes as recommendation for future studies:

1. Further studies can be carried in small scale fading, where one of its effects is the rapid change in signal strength or Doppler shift due to moving objects, which exist in any city.
2. City center of Khartoum has been chosen as a sample, but other cities inside Sudan haven’t been covered yet. That can be characterized as Sub-urban or rural area. Especially at that frequency band.
3. We strongly recommend the mobile service provider to use this thesis results in guessing the path loss at different distances. Via the developed simplified path loss model.

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Appendix-A

COLLECTED AND CALCULATED MEASUREMENT

Table 1: Transmitter one location data

Base Station One	Al-Ma'mora
Transmitter Power	38.5 dBm
BTS Latitude	15.539468 (N 15 35,22,86)
BTS longitude	32.571691 (E 32,34,18,87)
BTS height	30 m
BS Antenna Type	Directional

Table 2: sector zero distance and measured path loss

No	Longitude	Latitude	Distance Km	$PL_{measured}$ (dBm)
1	32.57126	15.56015	2.2986	125.0800
2	32.57499	15.54608	0.8152	108.7500
3	32.57166	15.55713	1.9626	120.4100
4	32.57135	15.55642	1.8841	125.0800
5	32.57960	15.55699	2.1232	118.7500
6	32.58027	15.55368	1.8269	121.7500
7	32.58027	15.55348	1.8077	116.4100
8	32.58145	15.54395	1.1574	110.4100
9	32.57823	15.54366	0.8409	116.4100

Table 3: sector zero models predicted path loss with received power

No	Okumura-HATA Model (dBm)	COST231 Model (dBm)	Simplified Path Loss Model (dBm)	Received Power (dBm)
1	132.5510	129.5647	121.99	- 86.58

2	116.6928	113.7065	118.63	-70.25
3	130.1335	127.1472	121.32	-81.91
4	129.5090	126.5227	121.32	-86.58
5	131.3368	128.3505	121.32	-80.25
6	129.0374	126.0511	121.32	-83.25
7	128.8758	125.8895	121.32	-77.91
8	122.0547	119.0684	119.97	-71.91
9	117.1677	114.1814	118.63	-77.91

Table 4: Sector one distance and measured path loss

No	Longitude	Latitude	Distance Km	$PL_{measured}$ (dBm)
10	32.57047	15.53411	0.6096	117.4000
11	32.57242	15.52784	1.2945	129.4100
12	32.57258	15.52707	1.3809	126.4100
13	32.57530	15.52742	1.3934	127.4100
14	32.57594	15.52984	1.1626	113.0800

Table 5: Sector one models predicted path loss with received power

No	Okumura-HATA Model (dBm)	COST231 Model (dBm)	Simplified Path Loss Model (dBm)	Received Power (dBm)
10	112.2468	93.4929	117.96	-78.9
11	123.7673	105.0134	119.97	-90.91
12	124.7557	106.0018	119.97	-87.91
13	124.8936	106.1397	119.97	-88.91
14	122.1233	103.3694	119.97	-74.58

Table 6: Sector two distance and measured path loss

No	Longitude	Latitude	Distance Km	$PL_{measured}$ (dBm)
15	32.56561	15.54951	1.2919	115.0800

Table 7: Sector two models predicted path loss with received power

No	Okumura-HATA Model (dBm)	COST231 Model (dBm)	Simplified Path Loss Model (dBm)	Received Power (dBm)
15	123	120	119.97	-76.58

Table 8: Transmitter two location data

Base Station One	Al-Riyadh
Transmitter Power	38.5 dBm
BTS Latitude	N 15,34,36,547(15.576819)
BTS longitude	E 32,33,53,116 (32.564754)
BTS height	30 m
BS Antenna Type	Directional

Table 9: Sector zero distance and measured path loss

No	Longitude	Latitude	Distance Km	$PL_{measured}$ (dBm)
16	32.56796	15.57964	0.4648	108.0800
17	32.56893	15.58070	0.6211	114.7500
18	32.57542	15.58167	1.2625	129.7500
19	32.57560	15.58065	1.2365	123.7500
20	32.57766	15.57932	1.4091	125.0800
21	32.57749	15.58164	1.4647	124.7500
22	32.57688	15.58288	1.4623	126.4100
23	32.57483	15.58533	1.4344	120.7500
24	32.57458	15.58164	1.1803	120.4100
25	32.57238	15.57774	0.8227	120.0800
26	32.57687	15.57263	1.3779	118.0800

Table 10: Sector zero models predicted path loss with received power

No	Okumura-HATA Model (dBm)	COST231 Model (dBm)	Simplified Path Loss Model (dBm)	Received Power (dBm)
16	107	104	117.29	-69.58
17	111	108	117.96	-76.25
18	122	119	119.97	-91.25
19	122	119	119.97	-85.25
20	124	121	119.97	-86.58
21	125	122	120.65	-86.25
22	125	122	120.65	-87.91
23	124	121	120.65	-82.25
24	121	118	119.97	-81.91
25	116	113	118.63	-81.58
26	124	121	119.97	-79.58

Table 11: Sector one distance and measured path loss

No	Longitude	Latitude	Distance Km	$PL_{measured}$ (dBm)
27	32.57075	15.56203	1.7642	123.5000
28	32.57087	15.55891	2.0950	118.0800
29	32.56523	15.55338	2.6050	132.4000
30	32.56354	15.5615	1.7072	118.5100
31	32.55264	15.56541	1.8135	114.7500
32	32.56868	15.57469	0.4823	118.4100
33	32.57197	15.57183	0.9508	118.7500
34	32.57774	15.56751	1.7327	118.4100
35	32.578	15.56449	1.9716	120.4100
36	32.57869	15.56871	1.7427	121.7500

Table 12: Sector one models predicted path loss with received power

No	Okumura-HATA Model (dBm)	COST231 Model (dBm)	Simplified Path Loss Model (dBm)	Received Power (dBm)
27	128.5032	125.5169	120.65	-85
28	131.1322	128.1459	121.32	-79.58
29	134.4653	131.4790	121.99	-93.9
30	128.0007	125.0144	120.65	-80.01
31	128.9248	125.9385	121.32	-76.25
32	108.6634	105.6771	117.29	-79.91
33	119.0467	116.0604	119.30	-80.25
34	128.2275	125.2412	120.65	-79.91
35	130.2035	127.2172	121.32	-81.91
36	128.3156	125.3293	120.65	-83.25

Table 13: Sector two distance and measured path loss

No	Longitude	Latitude	Distance Km	$PL_{measured}$ (dBm)
37	32.55143	15.57031	1.5991	121.0800
38	32.5525	15.57130	1.4480	123.7500
39	32.55673	15.57230	0.9949	112.7500
40	32.56082	15.57316	0.5853	115.0800
41	32.56213	15.57949	0.4086	112.0800
41	32.563968	15.58343	0.7394	116.4100
43	32.56038	15.58281	0.8139	121.0800
44	32.55973	15.58562	1.1161	122.4100
45	32.5458	15.58241	2.1218	114.4100

Table 14: Sector two models predicted path loss with received power

No	Okumura-HATA Model (dBm)	COST231 Model (dBm)	Simplified Path Loss Model (dBm)	Received Power (dBm)
37	127.0000	124.0137	120.65	-82.58
38	125.4816	122.4953	120.65	-85.25
39	119.7403	116.7540	119.30	-74.25
40	111.6245	108.6382	117.96	-76.58
41	106.1266	103.1403	116.62	-73.58
42	115.1998	112.2135	118.63	-77.91
43	116.6684	113.6821	118.63	-82.58
44	121.4989	118.5126	119.30	-83.91
45	131.3267	128.3404	121.32	-75.91

Table 15: path loss as a function in ($\boldsymbol{\gamma}$):

No.	Distance in Km	$PL_{predicted}$ (dB)	$PL_{measured}$ (dB)
1	2.2986	14.0*gma + 64.808	125.0800
2	0.8152	9.0*gma + 64.8087	108.7500
3	1.9626	13.0*gma + 64.8087	120.4100
4	1.8841	13.0*gma + 64.8087	125.0800
5	2.1232	13.0*gma + 64.8087	118.7500
6	1.8269	13.0*gma + 64.8087	121.7500
7	1.8077	13.0*gma + 64.8087	116.4100
8	1.1574	11.0*gma + 64.8087	110.4100
9	0.8409	9.0*gma + 64.8087	116.4100
10	0.6096	8.0*gma + 64.8087	117.4000
11	1.2945	11.0*gma + 64.8087	129.4100
12	1.3809	11.0*gma + 64.8087	126.4100
13	1.3934	11.0*gma + 64.8087	127.4100
14	1.1626	11.0*gma + 64.8087	113.0800
15	1.2919	11.0*gma + 64.8087	115.0800

16	0.4648	7.0*gma + 64.8087	108.0800
17	0.6211	8.0*gma + 64.8087	114.7500
18	1.2625	11.0*gma + 64.8087	129.7500
19	1.2365	11.0*gma + 64.8087	123.7500
20	1.4091	11.0*gma + 64.8087	125.0800
21	1.4647	12.0*gma + 64.8087	124.7500
22	1.4623	12.0*gma + 64.8087	126.4100
23	1.4344	12.0*gma + 64.8087	120.7500
24	1.1803	11.0*gma + 64.8087	120.4100
25	0.8227	9.0*gma + 64.8087	120.0800
26	1.3779	11.0*gma + 64.8087	118.0800
27	1.7642	12.0*gma + 64.8087	123.5000
28	2.0950	13.0*gma + 64.8087	118.0800
29	2.6050	14.0*gma + 64.8087	132.4000
30	1.7072	12.0*gma + 64.8087	118.5100
31	1.8135	13.0*gma + 64.8087	114.7500
32	0.4823	7.0*gma + 64.8087	118.4100
33	0.9508	10.0*gma + 64.8087	118.7500
34	1.7327	12.0*gma + 64.8087	118.4100
35	1.9716	13.0*gma + 64.8087	120.4100
36	1.7427	12.0*gma + 64.8087	121.7500
37	1.5991	12.0*gma + 64.8087	121.0800
38	1.4480	12.0*gma + 64.8087	123.7500
39	0.9949	10.0*gma + 64.8087	112.7500
40	0.5853	8.0*gma + 64.8087	115.0800
41	0.4086	6.0*gma + 64.8087	112.0800
42	0.7394	9.0*gma + 64.8087	116.4100
43	0.8139	9.0*gma + 64.8087	121.0800
44	1.1161	10.0*gma + 64.8087	122.4100
45	2.1218	13.0*gma + 64.8087	114.4100

Appendix-B

Matlab Code

1. The function that calculated the measured path loss from collected power**:**

```
function [plossm,prep]= measuredPL()

pre  = [- 86.58,-70.25,-81.91,-86.58,-80.25,-83.25,-77.91,-71.91,-77.91];
pre2 = [-78.9,-90.91,-87.91,-88.91,-74.58];
pre3 = [-76.58];
pre00= [-69.58,-76.25,-91.25,-85.25,-86.58,-86.25,-87.91,-82.25,-81.91,-
81.58,-79.58];
pre11= [-85,-79.58,-93.9,-80.01,-76.25,-79.91,-80.25,-79.91,-81.91,-83.25];
pre22= [-82.58,-85.25,-74.25,-76.58,-73.58,-77.91,-82.58,-83.91,-75.91];
prep = [pre,pre2,pre3,pre00,pre11,pre22]

for i = 1:9
    ploss(i) = 38.5 - pre(i)
end
for j = 1:5
    ploss2(j) = 38.5 - pre2(j)
end
for k = 1:1
    ploss3(k) = 38.5 - pre3(k)
end
for l = 1:11
    ploss4(l) = 38.5 - pre00(l)
end
for m = 1:10
    ploss5(m) = 38.5 - pre11(m)
end
for n = 1:9
    ploss6(n) = 38.5 - pre22(n)
end

plossm=[ploss,ploss2,ploss3,ploss4,ploss5,ploss6]
plossm1=[ploss,ploss2,ploss3]
plossm2=[ploss4,ploss5,ploss6]
end
```

2. The function for Okumura-Hata Model:

```
function [hh]=hata()
[plossm]= measuredPL()
[p,AA,plme,dist]= simplified()
ahm  =((1.1*log10(415)-0.7)*1-(1.56*log10(415)-0.8))
d1d0 =[2.2986,0.8152,1.9626,1.8841,2.1232,1.8269,1.8077,1.1574,0.8409];
d1d1 =[0.6096,1.2945,1.3809,1.3934,1.1626];
d1d2 =[1.2919];
dist =[d1d0,d1d1,d1d2]

%****************************** for the Second BTS ****************
d2d0  = [0.4648    ,0.6211    ,1.2625    ,1.2365    ,1.4091    ,1.4647
,1.4623    ,1.4344    ,1.1803    ,0.8227  ,1.3779];
d2d1  = [1.7642    ,2.0950    ,2.6050    ,1.7072    ,1.8135    ,0.4823
,0.9508    ,1.7327    ,1.9716    ,1.7427 ];
d2d2  = [1.5991    ,1.4480    ,0.9949    ,0.5853    ,0.4086    ,0.7394
,0.8139    ,1.1161    ,2.1218];
dist2 = [d2d0,d2d1,d2d2]
dist  = [d1d0,d1d1,d1d2,d2d0,d2d1,d2d2]

for d=1:9
    x=d1d0(d);
      h1(d)= 69.55+26.16*log10(415)-13.82*log10(30)-ahm+(44.9-
6.55*log10(30))*log10(x)
end
for i=1:5
    y=d1d1(i);
    h2(i)= 69.55+26.16*log10(415)-13.82*log10(30)-ahm+(44.9-
6.55*log10(30))*log10(y)
end
for j=1:1
    z=d1d2(j);
    h3(j)= 69.55+26.16*log10(415)-13.82*log10(30)-ahm+(44.9-
6.55*log10(30))*log10(z)
end
for k=1:11
    a=d2d0(k);
    h4(k)= 69.55+26.16*log10(415)-13.82*log10(30)-ahm+(44.9-
6.55*log10(30))*log10(a)
end
for l=1:10
    b=d2d1(l);
    h5(l)= 69.55+26.16*log10(415)-13.82*log10(30)-ahm+(44.9-
6.55*log10(30))*log10(b)
end
for m=1:9
    c=d2d2(m);
    h6(m)= 69.55+26.16*log10(415)-13.82*log10(30)-ahm+(44.9-
6.55*log10(30))*log10(c)
end
ht=zeros(1,45);
ht=[h1,h2,h3,h4,h5,h6]
```

```
hh=round(vpa(ht))  % Variable Precision Arithmetic Vpa symbolic tool convert
to decimal rather than rational
%{
figure('Name','Figure2','NumberTitle','off')
scatter(dist,plossm,'filled')
lsline
hold on
grid on
scatter(dist,hh,'Og')
lsline
xlabel('BTS Mobile Distance in Km')
ylabel('Measured Path loss in dB')
title('Okumura-Hata Model Compared with Theoretical Values')
%}
end
```

3. The function for COST231 Extension to Hata:

```
function [cc]= extendedhatacost()
[p,AA,plme,dist]= simplified()
% COST231 extended to hata model
[prep]= measuredPL();

ahm=((1.1*log10(415)-0.7)*(1)-(1.56*log10(415)-0.8));

d1d0 =[2.2986,0.8152,1.9626,1.8841,2.1232,1.8269,1.8077,1.1574,0.8409];
d1d1=[0.6096,1.2945,1.3809,1.3934,1.1626];
d1d2=[1.2919];
dist=[d1d0,d1d1,d1d2]

%**************************** for the Second BTS *******************
d2d0 = [0.4648    ,0.6211    ,1.2625    ,1.2365    ,1.4091    ,1.4647
,1.4623    ,1.4344    ,1.1803    ,0.8227  ,1.3779];
d2d1 = [1.7642    ,2.0950    ,2.6050    ,1.7072    ,1.8135    ,0.4823
,0.9508    ,1.7327    ,1.9716    ,1.7427 ];
d2d2 = [1.5991    , 1.4480    ,0.9949    ,0.5853    ,0.4086    ,0.7394
,0.8139    ,1.1161    ,2.1218];
dist2 = [d2d0, d2d1, d2d2]

dist0=[d1d0,d1d1,d1d2,d2d0,d2d1,d2d2]

for d=1:9
    x=d1d0(d);
      c1(d)= 46.3+33.9*log10(415)-13.82*log10(30)-ahm+(44.9-
6.55*log10(30))*log10(x)+0
end
for i=1:5
    y=d1d1(i);
    c2(i)= 46.3+33.9*log10(415)-13.82*log10(415)-ahm+(44.9-
6.55*log10(30))*log10(y)+0
end
for j=1:1
    z=d1d2(j);
```

```
    c3(j)= 46.3+33.9*log10(415)-13.82*log10(30)-ahm+(44.9-
6.55*log10(30))*log10(z)+0
end
for k=1:11
    a=d2d0(k);
    c4(k)= 46.3+33.9*log10(415)-13.82*log10(30)-ahm+(44.9-
6.55*log10(30))*log10(a)+0
end
for l=1:10
    b=d2d1(l);
    c5(l)= 46.3+33.9*log10(415)-13.82*log10(30)-ahm+(44.9-
6.55*log10(30))*log10(b)+0
end
for m=1:9
    c=d2d2(m);
    c6(m)= 46.3+33.9*log10(415)-13.82*log10(30)-ahm+(44.9-
6.55*log10(30))*log10(c)+0
end


ct = zeros(1,45);
ct = [c1,c2,c3,c4,c5,c6]
cc = round(vpa(ct))  % Variable Precision Arithmetic Vpa symbolic tool
convert to decimal rather than rational

figure('Name','Figure3','NumberTitle','off')
scatter(dist0,plossm,'filled')
lsline
hold on
scatter(dist0,cc,'*y')
lsline
xlabel('BTS Mobile Distance in Km')
ylabel('Measured Path loss in dB')
title('COST231 Extended Hata Model')
grid on
figure('Name','Figure4','NumberTitle','off')
scatter(dist0,prep,'filled')
lsline
xlabel('BTS Mobile Distance in Km')
ylabel('Received Power in dBm')
title('Distance verces Received Power')
grid on
end
```

4. Simplified path loss function :

```
function [p,AA,dist0]=simplified()
% gma it is path loss exponent which characterize the environment
clear
clc
syms gma;
aa=20*log10((4*pi*100*415*10^6)/(2.99792458*10.^8));
a=aa + 47.8005; % 47.8005 its Gaussian random variable or shadowing
d1d0 =[2.2986,0.8152,1.9626,1.8841,2.1232,1.8269,1.8077,1.1574,0.8409];
d1d1=[0.6096,1.2945,1.3809,1.3934,1.1626];
```

```
d1d2=[1.2919];
dist=[d1d0,d1d1,d1d2] %

%*********************** for the Second BTS *********************
d2d0 = [0.4648    ,0.6211    ,1.2625    ,1.2365    ,1.4091    ,1.4647
,1.4623    ,1.4344    ,1.1803    ,0.8227  ,1.3779];
d2d1 = [1.7642    ,2.0950    ,2.6050    ,1.7072    ,1.8135    ,0.4823
,0.9508    ,1.7327    ,1.9716    ,1.7427 ];
d2d2 = [1.5991    ,1.4480    ,0.9949    ,0.5853    ,0.4086    ,0.7394
,0.8139    ,1.1161    ,2.1218];
dist2 =[d2d0,d2d1,d2d2]
dist0=[d1d0,d1d1,d1d2,d2d0,d2d1,d2d2]
for d=1:45
    x=dist0(d);
       A1(d)= a + gma.*round(10.*log10((x.*1000)/(100))) % the is simplified
path loss fourmula
end
%At=zeros(1,45);
At= A1
AA=vpa(At)  % Variable Precision Arithmetic Vpa symbolic tool convert to
decimal rather than rational
[plossm,prep]=measuredPL()
for fg= 1:45
   nfg(fg)= (plossm(fg)-AA(fg))^2
end
u=expand(nfg)   % expand the full sqares and add them together
B = sum(u)   % sum the elements of matrix together in one 2nd order equation
o=diff(B)    % deffrentiation the gama fuction
p=solve(o, gma) % find the path loss exponent by solving the 1st order
equation
need=AA
end
```

5. The Test function that we can call several other functions:

```
function []  = test(p,AA,dist0)
[p,AA,dist0] = simplified()
[hh]         = hata()
[cc]         = extendedhatacost()
[plossm,prep]= measuredPL()
gma=p       % path loss exponent
H=AA
syms gma
iii=(subs(H, gma, p)) % subustitute gama value to find the predicted path
loss
plot(dist0,iii,'*b')
lsline
hold on
grid on
xlabel('Distance in Km')
ylabel('Path Loss in dB')
title('Comparison between Okumura-Hata and developed Simplified Path loss
models ')
plot(dist0,hh,'*r')
lsline
```

```
grid on
hold on
plot(dist0,hh,'Og')
lsline
hold on
plot(dist0,cc,'Ob')
lsline
hold on
%scatter(dist0,plossm,'b')
%lsline
[plossm,plossm1,plossm2]= measuredPL();
figure('Name','Figure1','NumberTitle','off')
scatter(dist0,plossm,'filled')
lsline
title('Simplified Path Loss Model Compared with Theoratical Values')
xlabel('BTS Mobile Distance in Km')
ylabel('Measured Path loss in dB')
%title('Scatter Plot of Measured Data')
grid on
hold on
%subplot(2,2,2)
scatter(dist0,iii,'*r')
lsline
%xlabel('BTS Mobile Distance in Km')
%ylabel('Measured Path loss in dB')
%subplot(2,2,3)
%set(gcf,'Color',[1,0.4,0.6])
%}
% to calculate the variance of shadow fading
for k= 1:45
   nfg(k)= (plossm(k)-iii(k))^2
end

for l= 1:45
   nfghh(l)= (plossm(l)-hh(l))^2
end

for m= 1:45
   nfgcc(m)= (plossm(m)-cc(m))^2
end

scatter(dist0,nfgcc,'Ob','fill')
lsline
grid on
xlabel('Distance in Km')
ylabel('squars of error')
title('The error between predicted and measured values with distance')
%hold on
%{
scatter(dist0,nfghh,'Og','fill')
lsline
hold on
scatter(dist0,nfgcc,'Or','fill')
lsline
hold on
grid on
%}
```

```
sigmasim = sqrt(0.0222.*sum(vpa((nfg)))) % standard deviation  0.0189 it is
1\53
sigmahh = sqrt(0.0222.*sum(vpa((nfghh)))) % standard deviation 0.0667 it is
1\15
sigmacost = sqrt(0.0222.*sum(vpa((nfgcc)))) % standard deviation 0.0667 it is
1\15

end
```

6. Distance Calculation code:

```
% Program to calculate surface distance between two points
% on Earth given the latitude and longitude
% Almamora lat1 and lon1
%lat1 = 15.539468;
%lon1 = 32.571691 ;
% Alreiad lat1 and lon1
lat1= 15.576819;
lon1= 32.564754;
% the following lat and lon for Almamora PN 0 (136)
%lat2=
[15.56015,15.54608,15.54030,15.55713,15.55642,15.55699,15.55368,15.55348,15.5
4395,15.54366];
%lon2=
[32.57126,32.57499,32.5736,32.57166,32.57135,32.57960,32.58027,32.58027,32.58
145,32.57823];
% the following lat and lon for Almamora PN 1 (304) , last two repeated
%lat2=[15.53872,15.53973,15.53828,15.53411,15.52784,15.52707,15.52742,15.5298
4,15.52984,15.52984];
%lon2=[32.57241,32.57196,32.57347,32.57047,32.57242,32.57258,32.57530,32.5759
4,32.57594,32.57594];
% the following lat and lon for Almamora PN 2 (472) last three repeated
%lat2=[15.54658,15.54643,15.54733,15.53979,15.53976,15.53943,15.54951,15.5495
1,15.54951,15.54951];
%lon2=[32.56618,32.56100,32.55549,32.57192,32.57192,32.5698,32.56561,32.56561
,32.56561,32.56561];

% the following lat and lon for Alreiad PN 0 (112) here is 12 values you
% need to add two
%lat2=[15.557713,15.57964,15.58070,15.58167,15.58065,15.57932,15.58164,15.582
88,15.58533,15.58164,15.57774,15.57263];
%lon2=[32.56490,32.56796,32.56893,32.57542,32.57560,32.57766,32.57749,32.5768
8,32.57483,32.57458,32.57238,32.57687];
% the following lat and lon for Alreiad PN 1 (280)  this is 11 values
%lat2=[15.56203,15.55891,15.55338,15.5615,15.56541,15.57469,15.57183,15.56751
,15.56449,15.56871,15.57661];
%lon2=[32.57075,32.57087,32.56523,32.56354,32.55264,32.56868,32.57197,32.5777
4,32.578,32.57869,32.56478];
% the following lat and lon for Alreiad PN 2 (448)  this is 11 values two
% appended
lat2=[15.57031,15.57130,15.57230,15.57316,15.57949,15.58343,15.58281,15.58562
,15.58241,15.58241,15.58241];
lon2=[32.55143,32.5525,32.55673,32.56082,32.56213,32.563968,32.56038,32.55973
,32.5458,32.5458,32.5458];
%Convert to radians
latrad1 = lat1*pi/180;
```

```
lonrad1 = lon1*pi/180;

latrad2=zeros(1,11);
lonrad2=zeros(1,11);

for i=1:11
    latrad2(i)=lat2(i)*pi/180
    lonrad2(i)=lon2(i)*pi/180
end

londif=zeros(1,11);
for j=1:11
londif(j) = abs(lonrad2(j)-lonrad1);
end
raddis=zeros(1,11);
nautdis=zeros(1,11);
stdism=zeros(1,11);

for k=1:11
raddis(k) =
acos(sin(latrad2(k))*sin(latrad1)+cos(latrad2(k))*cos(latrad1)*cos(londif(k))
);
nautdis(k) = raddis(k) * 3437.74677;
stdism(k) = nautdis(k) * 1.852*1000
end
```

7. The function that generated the shadowing:

```
samples =  0 + 8.56^2.*randn(10, 1)

%where the 8.56 db it is STDV for simplified path loss model before
%developing and 8.56^2 it is variance 10 it is the number of randomization to
%be generated abs it is absolute value for the random numbers ‘cos there is
%negative but it is not important where 0 it is the mean
```