PERSPECTIVES ON MACROCELL PROPAGATION MODELS AND ANALYSIS
(A Case Study of Celtel Network, Kano)

By

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REG.NO: MSc/ENG/50498/2005-06

A Thesis submitted to the Department of Electrical Engineering, Ahmadu Bello University, Zaria, in partial fulfillment of the requirement for the award of a Master of Science (MSc.) degree in Electrical Engineering

March 2008

DECLARATION

I hereby declare that all the work carried out in this thesis is entirely my work and to the best of my knowledge, no such has been submitted to any institution.

______________________ ________________

Ogundapo Olusegun **Date**

CERTIFICATION

This is to certify that the thesis titled "Perspectives on Macro-cell Propagation Models and Analysis": A Case Study of Celtel Network, Kano, has met the requirement for the award of a Master of Science (MSc.) degree in Electrical Engineering of Ahmadu Bello University, Zaria.

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DEDICATION

This thesis is dedicated to the Almighty God, the owner and giver of life without which nothing can be done.

ACKNOWLEDGEMENT

My profound gratitude goes to the Almighty God for His guidance and protection throughout this course of study. I express my thanks to my major supervisor: Dr. D.D. Dajab and minor supervisor: Dr. J.Y. Oricha for their support and contribution that made the thesis work a success. I am also grateful to Prof. B.G. Bajoga and other lecturers in the department who in one way or the other contributed to the success of this work. This acknowledgement will not be complete without commending the efforts of Mr. O. Ajayi and Mr. U. Aliyu of Celtel Network for their assistance in the data collection. I also appreciate the effort of Engr. A. Alex of NITEL for his moral and spiritual support.

I wish to express my sincere appreciation to my father Mr. T. Ogundapo, my Late Mother Mrs. M. Mojibola and my step mother Mrs. E. Ogundapo for their care and financial support. I also acknowledge the tireless efforts of my typists: Mr. J. Amos and Mr. K. Mathew who endured the technical nature of the work.

Finally, my thanks go to friends and course mates who are a source of encouragement to me. Worthy of mentioning are Mr. Parfait, Mr. Bartineh, Mr. Philip and Mr. Kazeem.

ABSTRACT

This research studies the propagation prediction variations of three models over a Nigerian urban environment and the development of a suitable propagation prediction model for the environment. The measurements of the received signal strength at various distances for nine base stations were conducted at Celtel,Kano. The measurement equipment used consists of a Test Mobile System (TEMS) connected to GPS and radio antennas. The TEMS was mounted inside a car that was driven along an open route for each of the sectors selected from the nine base stations. Three macro cell propagation models: COST-231 Hata, Lee and COST-231 Walfisch-Ikegami models were examined with respect to nine base stations of Celtel, Kano. The results gave mean prediction error values of –0.7dB,-4.2dB and 8.9dB for COST-231 Hata, Lee and COST-231Walfisch-Ikegami models respectively. The analysis show that the COST-231 Hata and Lee models underestimate the path loss for this environment, while the COST-231 Walfisch-Ikegami model over predict the environment. The new propagation prediction model was developed from the three modified propagation models.

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LIST OF ABBREVIATIONS

GSM	-	Global System for Mobile Communications
TEMS	-	Test Mobile System
COST	-	Committee for Science and Technology
NS	-	Network Subsystem
BSC	-	Base Station Subsystem
MSC	-	Mobile Services Switching Centre
MS	-	Mobile Station
BTS	-	Base Transceiver Station
PSTN	-	Public Switched Telephone Network
ISDN	-	Integrated Services Digital Network
HLR	-	Home Location Register
VLR	-	Visitor Location Register
ME	-	Mobile Equipment
SIM	-	Subscriber Identity Module
EIR	-	Equipment Identity Register
AUC	-	Authentication Center
IMEI	-	International Mobile Equipment Identity
BSS	-	Base Station Subsystem
TDMA	-	Time Division Multiple Access
$a(h_m)$	-	Correction factor for mobile antenna height
FDMA	-	Frequency Division Multiple Access
G_r	-	Gain of the receiver
G_t	-	Gain of the transmitter
F_c	-	Area type correction factor
h_m	-	Height of mobile station
h_{bs}	-	Height of base station
f_c	-	Carrier frequency
EIRP	-	Effective Isotropic Radiated Power
L_p	-	Path Loss
S_R	-	Received Signal Strength
BSG_A	-	Base Station Antenna Gain
L_{rts}	-	Rooftop-to-street diffraction loss
L_{msd}	-	Multiscreen diffraction loss
L_{ori}	-	Path loss due to orientation angle
h_{roof}	-	Height of roof
b	-	Buildings Separation
w	-	Width of road
L_{bsh}	-	Path loss due to shadowing effect
K_f	-	Constant due to frequency effect
K_d	-	Constant due to transmitter-receiver distance

dB_m	-	Decibel mill watt
km	-	Kilometer
Δh_{bs}	-	Difference between base station and average buildings height
L_p	-	Path Loss
ϕ	-	Orientation angle
dBi	-	Decibel with respect to isotropic antenna
L_o	-	Free space path loss
GPS	-	Global Positioning System

CHAPTER ONE
GENERAL INTRODUCTION

1.1 INTRODUCTION

Propagation models have become an inevitable tool for network coverage prediction and planning. This is even more paramount for macro cells since they accommodate majority of the subscribers due to the large area they are expected to cover. However, research has shown that the problems faced by most network operators are the lack of a fast and suitable propagation prediction model for network coverage prediction and planning especially in urban areas.[8]

Propagation models are based on measurements and observations over a particular environment. There is the need to examine the propagation prediction variation of these models over the environment. The analysis of these propagation models will aid the provision of a fast and suitable propagation prediction model for the urban environment under consideration.

This research work involves the collection of the received signal strength at various locations for nine base stations of Celtel; Kano. The measurement equipment used by the radio frequency personnel of the network operator consists of a Test Mobile System (TEMS) connected to GPS and radio antennas. The TEMS was mounted inside a car that was driven along open routes for each of the sectors selected from the nine base stations. The result of this analysis was used to provide propagation prediction models that can be used for fast network coverage prediction and optimization of radio resources in this environment.

1.2 MOTIVATION

Standardized propagation models are based on measurements carried out over a particular environment. There is the need to examine the propagation prediction variations of these models over a Nigerian urban environment. The results of this analysis will aid the provision of a fast and suitable means of predicting the network coverage for the environment.

1.3 PROBLEM DEFINITION AND METHODOLOGY

The performance of any cellular mobile network depends to a large extent on the availability of fast and suitable network coverage prediction tool. This is even more paramount in macro cells where the area intended to cover is large .The ability to predict the network coverage between the transmitter and receiver is a very important aspect of any cellular network planning and optimization.

The methodology adopted involves the collection of the received signal strength data at various locations for nine base stations of Celtel Network conducted by the radio frequency personnel through drive tests using the Test Mobile System (TEMS).These data were analyzed using other base station parameters and compared with the predictions from the three models considered: COST-231 Hata, Lee and COST-231 Walfisch-Ikegami models. The results of this analysis were used to obtain modified coverage prediction models.

1.4 THESIS OUTLINE

The whole work is divided into five chapters. Chapter One contains the introduction to the thesis. Chapter Two explains the theoretical background of the cellular mobile system, radio propagation characteristics and models for macro cells. In chapter Three, the methodology adopted in carrying out the research is discussed. Chapter Four presents the analysis of the data collected and the results. Chapter Five contains the problems encountered, limitations, applications, recommendation for further work and conclusion.

CHAPTER TWO
THEORETICAL BACKGROUND

2.0 INTRODUCTION

This chapter provides the theoretical backgrounds of the components of the thesis work. It presents the description of the cellular system, the GSM network architecture, radio propagation characteristics and macro cell propagation models.

2.1 LITERATURE REVIEW

The desire to have suitable means of predicting the path losses of cellular mobile networks led to the different propagation models. In macro cells, since the base station antenna height is above the average roof top and the area covered is large: empirical and semi empirical models are the most commonly used.

The most popular propagation model for macro cell is an empirical model first described by Okumura in 1968[5]. Hata in 1980 modified this model which led to the restriction that only regions with less than 20Km distance to the transmitter can be predicted [9].The model now known as the Hata – Okumura model is used to predict the path loss of land mobile radio operating at a frequency of 150 to 1000MHz.The model was later modified by the European Committee for Science and Technology (COST-231) project to include frequency up to 2000MHz[1][6].

The other empirical model used in predicting the path loss for macro cells is the Lee model which was originally meant for an operating frequency of 900MHz, base station antenna height of 30.4m and mobile station antenna height of 3m.This was later modified to accommodate higher frequencies and different parameters [6][10].

Another model commonly used for macro cells which is a combination of empirical and semi deterministic models is the COST- 231 Walfisch –Ikeganmi model. It can be used to predict the path loss of macro cells in urban environments at a distance of 20m to 5000m between the transmitter and the receiver. The model consists of inputs from publications made by Walfisch et.al. [2] which provided for the estimation of the multiscreen diffraction loss and Ikeganmi et.al[8] that considered an approximation for the roof top to street diffraction loss. The model was later modified by the European Committee for Science and Technology (COST- 231) project to include antenna height below rooftop [6].

Adisa Shittu [4] also in 2005 conducted a research work on cellular mobile propagation characteristics for three base stations using the Hata- Okumura model for open areas and the two ray model.

2.2 THE CELLULAR SYSTEM

The cellular system uses a network of base stations and antennas to cover a large area. The area a base station covers is known as a cell, while the spot where the base station and antennas are located is called a cell site. The cell provides access for the mobile handset to network the resources. The cellular system was created due to limited radio spectrum. In order to use the radio spectrum efficiently, the same frequencies are reused in non adjacent cells. A geographical region is divided up into cells .The cells overlap at the edges to prevent holes in coverage. The power transmitted is chosen to be large enough to communicate with the mobile stations located near the edges of the cell. An illustration of the cellular system is shown in Figure 2.1. [10]

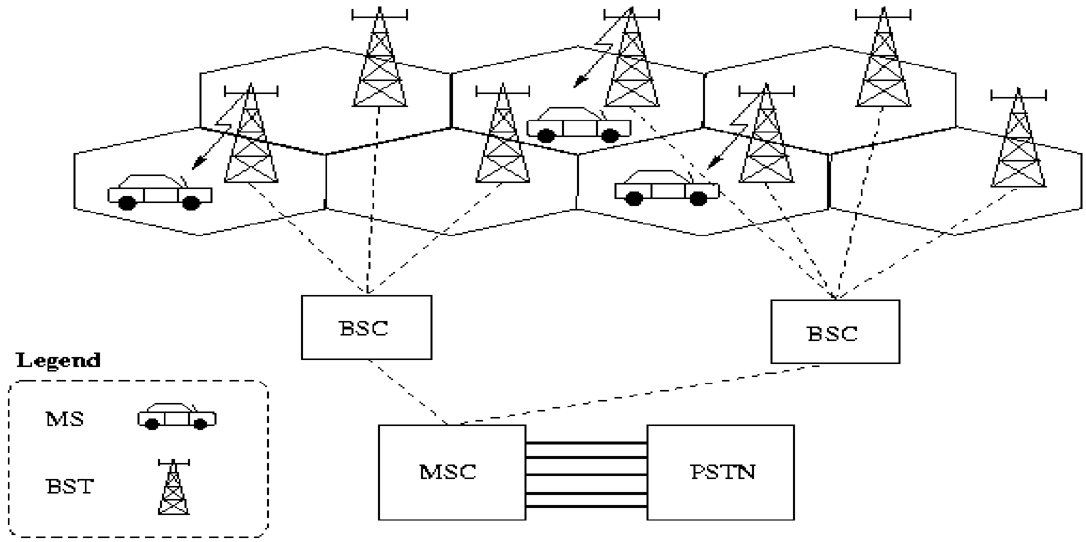


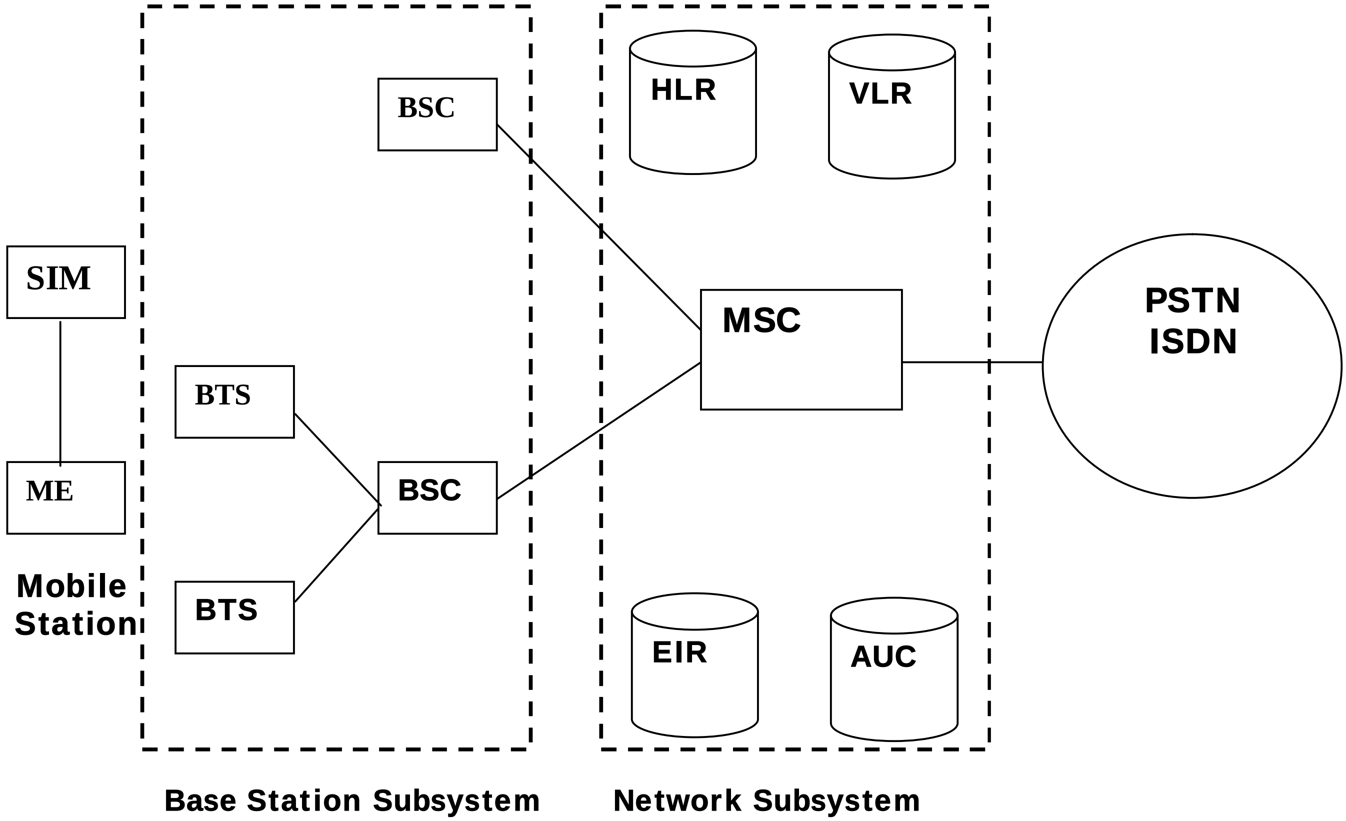
Figure 2.1: The Cellular System

2.2.1 Macro cell

A macro cell provides the main coverage in a mobile network. The base station antenna height is built above the average roof-tops of the surrounding buildings. A macro cell is often is often built first to provide coverage and smaller cells built to provide capacity. As the antenna height is above the average roof-top level, the area that can be covered is wide. A macro cell can vary from a couple of kilometers to 30 km, the distance depending on the type of terrain and the propagation conditions. In urban areas, microcellular antennas usually have more gain. Several sectored directional antennas are often combined around a tower to provide full 360 degree coverage[4][13].

2.3 THE GSM NETWORK ARCHITECTURE

The Global System for Mobile Communications (GSM) network can be divided into three main units: the Mobile Station (MS), the Base Station Subsystem (BSS) and the Network Subsystem (NS).The GSM network architecture is shown in Figure 2.2[11].



SIM – Subscriber Identity Module
ME – Mobile Equipment
BTS – Base Transceiver Station
MSC – Mobile Services Switching Center
AUC – Authentication Center
PSTN- Public Switched Telephone Network
BSC – Base Station Controller
HLR – Home Location Register
VLR – Visitor Location Register
EIR – Equipment Identity Register
ISDN-Integrated Services Digital Network

Figure 2.2: **The GSM Network Architecture**

2.3.1 The Mobile Station(MS)

The mobile station consist of two units: the mobile equipment (terminal) and a smart card called the Subscriber Identity Module (SIM).The mobile equipment is used to communicate between the user and the network. The SIM card provides personal mobility by allowing access to subscribed services irrespective of terminal. The mobile equipment is identified by the International Mobile Equipment Identity

(IMEI).Each mobile equipment has a code number that is used to identify and distinguish it from others.[11]

2.3.2 The Base Station Subsystem(BSS)

The Base Station Subsystem (BSS) is the section that facilitates wireless mobile communications between the mobile station and the network. It consists of two units: the Base Station Controller (BSC) and the Base Transceiver Station (BTS).

2.3.2.1 Base Station Controller(BSC)

The Base Station Controller (BSC) is the central point of the base station subsystem. The BSC can manage the entire radio network and performs the following functions: handling of the mobile station and handover, radio network management, transcoding and rate adaptation, transmission management of the BTSs e.t.c.

2.3.2.2 Base Transceiver Station (BTS)

The Base Transceiver Station (BTS) controls the interface to the mobile station. It consists of radio transceivers that define a cell and connected to antennas that serve each cell in the network. Each BTS operates at one or several pairs of frequencies. One frequency of each pair is used to transmit signals to the mobile station and the other is used to receive signals from the mobile station.

2.3.2.3 The Network Subsystem

The main components of this subsystem are outlined below as follows:

(A) Message Switching Center (MSC)

This is heart of the cellular network which sets up and maintains calls made over the network. It provides the connection to the fixed networks such as the Public Switched Telephone Network (PSTN) and the Integrated Services Digital Network (ISDN).

(B) Home Location Register (HLR)

The home location register is a centralized database that stores and transmits mobile subscriptions belonging to each subscriber. It stores information such as subscribers' location, authentication, identity and other supplementary services. These data are stored permanently in the database until when that subscription is cancelled.

(C) Visitor Location Register (VLR)

The visitor location register temporarily stores subscriptions information so that the MSC can access it when services are to be provided to subscribers within the MSC area .When a subscriber enters a new MSC area, the VLR connected to that MSC requests information about the subscriber from the HLR. The HLR sends a copy of the information to the VLR and updates its own location information.

(D) Authentication Center (AuC)

The authentication center is a protected database that stores soft copy of the secret code in each subscribers SIM card which is used for authentication and to protect the network against unauthorized users.

(E) Equipment Identity Register (EIR)

The equipment identity register is a database that contains a list of all valid mobile equipment on the network. Each mobile station is identified by an International Mobile Equipment Identity (IMEI) code number that is used to block calls from mobile equipments that have been reported stolen or lost, unauthorized or defective mobile stations from accessing the network [11].

2.3.3 GSM Frequency Management

The GSM frequency management makes use of the Time Division Multiple Access (TDMA) and the Frequency Division Multiple Access (TDMA) to facilitate the efficient use of frequency. The FDMA is used to divide the allocated frequency up into smaller frequency bands .These bands are called carrier frequencies and the two 25MHz bands (forward and reverse links) are each divided up into 124 such carrier frequencies. Carrier frequencies are allocated to base stations making sure that interference does not occur by the same frequencies being allocated to base stations in close proximity to one another.

The TDMA is used to divide each of the carrier frequencies into communication channels .Each carrier frequency is divided into up into eight communication channels by means of the TDMA [11].

2.4 RADIO PROPAGATION CHARACTERISTICS

The signal that is transmitted from the mobile station travels a small and complex path. The signal is exposed to a variety of manmade structures, passes through different types of terrain and is affected by the combination of propagation environments .Several factors contribute to variation in signal coverage and quality in the network. The major effects on signal behavior and path loss are outlined below.

2.4.1 Free Space Loss

The signal transmitted by an antenna will suffer attenuation during its propagation in free space .The amount of power received at any given point in space will be inversely proportional to the distance covered by the signal. In free space, the power radiated by an isotropic antenna is spread uniformly in all directions. Here an isotropic antenna is a hypothetical entity. As the power is radiated uniformly it can be assumed that a sphere is formed. The surface area of this power is:

$$A = 4\pi R^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (2.1)$$

The power density S at any point at a distance R from the antenna can be expressed as:

$$S = \frac{P_t G_t}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2.2)$$

Where,

P_t is the power transmitted by the antenna and G is the antenna gain.

Thus, the received power P_r at a distance R is:

$$P_r = \frac{PG_t G_r \lambda^2}{(4\pi R)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots ..(2.3)$$

Where, G_t and G_r are the gain of the transmitting and receiving antennas respectively, λ is the wavelength of the radio wave receiver and R is the distance from the transmitter to the receiver. In the urban environments, where there are different obstacles such as buildings, trees, vehicles, poles e.t.c, the free space loss is almost invalid for the prediction of signal strength .However it can be applied if there is a direct line of sight, usually a few meters, between the transmitter and receiver[1][3].

2.4.2 Diffraction

This is a phenomenon that takes place when the radio path between the transmitter and the receiver is obstructed by a surface usually with sharp edges. The radio wave changes it direction of propagation owing to the inability of the surface to absorb it thereby creating an artificial line of sight between the transmitter and receiver [1][3].

2.4.3 Scattering

This occurs when the radio wave travels through a medium consisting of objects with dimensions that are small compared to the wavelength. In such a case the numbers of such particles per unit volume are usually very large. Scattered waves arise when radio wave meets rough surfaces or small objects between the transmitter and the receiver.

2.4.4 Fading

Fading is the reduction in signal strength as a wave propagates from the transmitting antenna to the receiving antenna. There are two major types of fading: multipath fading and shadowing[1].

2.4.4.1 Multipath Fading

Mulipath fading is due to the arrival of the same signal from different paths at different times and its combination at the receiver. It can cause fast fluctuations in signal level[1].

2.4.4.2 Shadowing

This is the loss of field signal strength in an area. The most common causes are tunnels, valleys, mountains, hills e.t.c[1].

2.5 MACROCELL PROPAGATION MODELS

Macro cells are generally large, providing coverage range on the order of kilometers and used for outdoor communications. The base station antenna height is also usually above the average rooftops. Empirical and semi empirical propagation models are therefore most commonly used for macro cells in urban environments because it is practically impossible to model radio propagation everywhere.

Propagation models are a set of mathematical expressions, equations, diagrams obtained from a series of measurements and analysis. They are used to aid radio network system design, planning and prediction coverage design[1][3].

2.5.1 The COST- 231 Hata Model

This model was first described by Okumura through extensive studies and field campaigns. It is used for the prediction of path loss of land mobile radios. The model provided estimations for urban, suburban and open environment. Modifications later made by Hata led to restrictions that only a distance of not more than 20Km between the transmitter and the receiver can be predicted at an operating frequency not more than 1000MHz.The European Committee for Science and Technology (COST- 231) later extended it to include estimations of path loss for frequencies up to 2000MHz and a correction factor for urban areas. The conditions for which the model can be applied are:

Carrier frequency: $500MHz \leq f_c \leq 2000MHz$

Base station height: $30m \leq h_b \leq 200m$

Mobile Station height: $1m \leq h_m \leq 10m$

Distance between mobile station and base stations: $1km \leq d \leq 20km$

The path loss for urban area is given by the expression [6] [13]:

$$L_P = A + B\log(d) + C \qquad (2.4)$$

Where ,

$$A = 46.3 + 33.9\log(f_c) - 13.82\log(h_{bs}) - a(h_m) \qquad (2.5)$$

$$B = 44.9 - 6.55\log(h_b) \qquad (2.6)$$

C is the area type correction factor and is given as 3dB for urban environments.

$a(h_m) = 3.2[\log(11.75h_m)]^2 - 4.97$ for $f_c \geq 400MHz$ ……………………....(2.7)

The eceived signal strength can be predicted using the expression: [1]

$S_R = EIRP - L_P$ ……………………………………………. ………..(2.8)

2.5.2 The Lee Model

The Lee path loss model also provided a means of predicting the path loss of macro cells through a series of empirical data. The empirical data set by this model are [14][15]:

d_o (Distance between transmitter and receiver) $= 1.6km$.

Base station antenna height $= 30.48m$

Mobile station antenna height: $1m \leq h_m \leq 3m$

Base station transmit power $= 10W$

$f_o(frequency) = 900MHz$

However, if the actual conditions differ from the nominal ones, correction factors were included in the prediction of the path loss to ensure accuracy. The equation for the prediction of path loss in urban areas is given as [14] [15]:

$$L_P = 124 + 30.51\log\left(\frac{d}{1.6km}\right) + 10n\log\left(\frac{f_c}{900MH_Z}\right) - \alpha_o \text{ ………………...... (2.9)}$$

Where,

d is the actual distance between the transmitter and the receiver (km)

f_c is the actual carrier frequency (MHz)

n is 3 for f_c >450MHz and in urban areas

α_o is the correction factor and is given as :

$\alpha_o = \alpha_1\alpha_2\alpha_3\alpha_4\alpha_5$ …………………………………………………….....(2.10)

$$\alpha_1 = \left[\frac{NewH_{BS}(m)}{30.48m}\right]^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.11)}$$

$$\alpha_2 = \left[\frac{NewH_{MS}(m)}{3m}\right]^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{....(2.12)}$$

$$\alpha_3 = \left[\frac{NewTransmitterPower(W)}{10W}\right]^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.13)}$$

$$\alpha_4 = \left[\frac{NewBSG_A}{4}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.14)}$$

where ,

H_{BS} is the height of the base station, H_{MS} is the height of the mobile station, BSG_A is the base station antenna gain.

$\alpha_5 =$ New mobile station antenna gain……………………. ...(2.15)

The received signal strength can now be predicted using equation (2.8.).

2.5.3 The COST- 231 Walfisch Ikegami Model

This model is used to estimate the path loss of mobile cellular networks in urban environment. It is a combination of empirical and semi deterministic models. The model combines both line of sight and none line of sight situations. The conditions for which this model is valid are [3] [6]:

Carrier frequency: $800MHz \le f_c \le 2000MHz$

Height of base station: $4m \le h_b \le 50m$

Mobile station antenna height: $1m \le h_m \le 3m$

Distance between transmitter and receiver: $0.02km \le d \le 5km$

The expression for the path loss is:

$$L_P = L_o + L_{rts} + L_{msd} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.16)}$$

where,

L_P is the path loss , L_o is the free space path loss , L_{rts} is the roof top-to-street diffraction and scatter loss, L_{msd} is the multiscreen diffraction loss

$$L_o = 32.44 + 20\log\left(\frac{f_c}{MHz}\right) + 20\log\left(\frac{d}{Km}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.17)}$$

$$L_{rts} = -16.9 - 10\log\left(\frac{w}{m}\right) + 10\log\left(\frac{f_c}{MHz}\right) + 20\log\left(\frac{h_{roof-}h_m}{m}\right) + L_{ori} \ldots\ldots \text{(2.18)}$$

w is the average width of the street (m), f_c is the carrier frequency

$$\text{w} = \frac{b}{2}, \text{where b is the buildings separation} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.19)}$$

$$h_{roof} = 3m \text{ (number of floors) + roof} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.20)}$$

$$roof = 3m \text{ for pitched} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.21)}$$

$$L_{ori} = -10 + 0.354\frac{\varphi}{\deg} \quad \text{for } 0^0 \le \varphi < 35^0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.22)}$$

$$= 2.5 + 0.075\left(\frac{\varphi}{\deg} - 35\right) \quad \text{for } 35^0 \le \varphi < 55^0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.23)}$$

$$= 4.0 - 0.114\left(\frac{\varphi}{\deg} - 35\right) \quad \text{for } 55^0 \le \varphi \le 90^0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.24)}$$

L_{ori} is the path loss due to the orientation angle

$$L_{msd} = L_{bsh} + K_a + K_d \log\left(\frac{d}{Km}\right) + K_f \log\left(\frac{f_c}{MHz}\right) - 9\log\left(\frac{b}{m}\right) \ldots\ldots\ldots\ldots \text{(2.25)}$$

L_{bsh} is the loss due to shadowing effect given by:

$$L_{bsh} = -18\log(1 + \Delta h_{bs}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.26)}$$

$$\Delta h_{bs} = h_{bs} - h_{roof} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.27)}$$

$K_a = 54$

$K_d = 18$

$$K_f = -4 + 1.5\left(\frac{f_c}{925} - 1\right) \text{ for urban } \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.28)$$

The received signal strength can now be predicted using equation (2.8).

CHAPTER THREE
METHODOLOGY

3.0 INTRODUCTION

The study of the propagation prediction variations of three standardized models over a Nigerian urban environment and the provision of a new modified prediction model for the area requires the conduct of propagation measurements from base stations. However, due to the restrictions on the part of the network operators, the propagation measurements were conducted by the radio frequency (RF) personnel of the network operator as part of their maintenance schedule. This reluctance for cooperation also limited the number of samples obtained.

3.1 MEASUREMENT TECHNIQUE

The measurement equipment used by the radio frequency personnel consists of a Test Mobile System (TEMS) connected to a radio signal receiving antenna and a GPS (Global Positioning System) antenna. The TEMS is mounted inside a car. The base stations consist of sectorized cells designed to gain capacity in this urban environment. In conducting the signal strength measurements, a sector is selected from each of the nine base stations and the test car driven along an open route from it. The GPS antenna helps in tracking the distance of the receiver from the transmitter. The received signal strength data is then extracted from a laptop connected to the TEMS. This was achieved with the aid of software (Nirview) already installed on the laptop. It helps to process the propagation measurements at the various locations. The data when taken the second time using this software did not differ significantly from the first one. An equal interval of propagation measurements was considered for each of the nine base stations to enhance the accuracy of the propagation predictions and model to be provided. However, cases of minor lapses (errors) on the part of the GPS and radio wave receivers were observed.

3.2 MEASUREMENT ENVIRONMENT

The detailed topography of the environment in which the propagation measurements was conducted could not be ascertained and therefore could not be categorically provided. The propagation measurements were carried out by the RF personnel and the large areas covered by the nine base stations were not abstracted. This problem limited the research work to empirical and semi empirical propagation models that do not require detailed environmental data. However, the environment consists mainly of residential, public and business buildings. The average height of the highest buildings in the area is about nine floors.

3.3 BASE STATION PARAMETERS

The parameters collected from the operations and radio frequency departments were those of the base station height, antenna gain and the effective isotropic radiated power (EIRP) for each of the nine sectors selected. The mobile station antenna height is about 1.5m as it was mounted on the top of a car. The antenna gain is 1.8dB.These parameters with their sectors code numbers are as follows:

(A) Kan 032

Base station antenna height =34m

Antenna gain =17dBi

EIRP =57dBm

(B) Kan 027

Base station antenna height =34m

Antenna gain =15dBi

EIRP = 55dBm

(C) Kan 021

Base station antenna height =34m

Antenna gain =18dBi

EIRP=58dBm

(D) Kan 011

Base station antenna height =32m

Antenna gain =17dBi

EIRP=57dBm

(E) Kan 052

Base station antenna height =32m

Antenna gain =17.5dBi

EIRP=57.5dBm

(F) Kan 044

Base station antenna height =32m

Antenna gain=15dBi

E IRP= 55dBm

(G) Kan 017

Base station antenna height =32m

Antenna gain=15dBi

EIRP=55dBm

(H) Kan 056

Base station antenna height =32m

Antenna gain =15dBi

EIRP=55dBm

(I) Kan 026

Base station antenna height =34m

Antenna gain =17.5dBi

EIRP=57.5dBm

3.4 DATA PRESENTATION

The data collected are as shown in Table (3.1) to Table (3.9).The path loss was obtained using equation (2.8).

Table 3.1: Measured Received Signal Strength and Path Loss versus Distance for Base Station 1 (Kan 032).

Distance (km)	Received Signal Strength(dBm)	Path Loss (dB)
0.5	-72.0	129.0
1.0	-84.1	141.1
1.5	-75.8	132.8
2.0	-82.5	139.5
2.5	-85.2	142.2
3.0	-110.0	167.0
3.5	-102.7	159.7

Table 3.2: Measured Received Signal Strength and Path Loss versus Distance for Base Station 2 (Kan027).

Distance (km)	Received Signal Strength(dBm)	Path Loss (dB)
0.5	-73.8	128.8
1.0	-82.3	137.3
1.5	-77.0	132.0
2.0	-84.1	139.1
2.5	-86.4	141.4

Table 3.3: Measured Received Signal Strength and Path Loss versus Distance for Base Station 3 (Kan021).

Distance (km)	Received Signal Strength(dBm)	Path Loss (dB)
0.5	-74.5	132.5
1.0	-77.7	135.7
1.5	-76.4	134.4
2.0	-75.8	133.8
2.5	-79.5	137.5
3.0	-88.4	146.4
3.5	-81.1	139.1
4.0	-92.0	150.0

Table 3.4: Measured Received Signal Strength and Path Loss versus Distance for Base Station 4 (Kan 011).

Distance (km)	Received Signal Strength(dBm)	Path Loss (dB)
0.5	-54.0	111.0
1.0	-58.9	115.9
1.5	-57.2	114.2
2.0	-61.1	118.1
2.5	-74.5	131.5
3.0	-82.2	139.2

Table 3.5: Measured Received Signal Strength and Path Loss versus Distance for Base Station 5 (Kan 052).

Distance (km)	Received Signal Strength(dBm)	Path Loss (dB)
0.5	-77.6	135.1
1.0	-79.3	136.8
1.5	-78.8	136.3
2.0	-84.0	141.5
2.5	-81.2	138.7
3.0	-91.0	148.5
3.5	-85.1	142.6

Table 3.6: Measured Received Signal Strength and Path Loss versus Distance for Base Station 6 (Kan044).

Distance (km)	Received Signal Strength(dBm)	Path Loss (dB)
0.5	-76.6	136.1
1.0	-77.1	132.1
1.5	-78.7	133.7
2.0	-85.2	140.2
2.5	-89.5	144.5

Table 3.7: Measured Received Signal Strength and Path Loss versus Distance for Base Station 7(Kan017).

Distance (km)	Received Signal Strength(dBm)	Path Loss (dB)
0.5	-82.5	137.5
1.0	-75.1	130.1
1.5	-71.0	126.0
2.0	-76.8	131.8
2.5	-78.7	133.7

Table 3.8: Measured Received Signal Strength and Path Loss versus Distance for Base Station 8(Kan056).

Distance (km)	Received Signal Strength(dBm)	Path Loss (dB)
0.5	-55.7	110.7
1.0	-60.1	115.1
1.5	-72.3	127.3
2.0	-77.5	132.5

Table 3.9: Measured Received Signal Strength and Path Loss versus Distance for Base Station 9 (Kan 026).

Distance (km)	Received Signal Strength(dBm)	Path Loss (dB)
0.5	-76.5	134.0
1.0	-83.0	140.5
1.5	-84.1	141.6
2.0	-83.6	141.1
2.5	-95.1	152.6
3.0	-97.2	154.7

CHAPTER FOUR
ANALYSIS AND RESULTS

4.0 INTRODUCTION

This chapter deals with the analysis of the data collected and the results obtained. The path loss from measurements will be compared with that obtained using the COST- 231 Hata, Lee and COST-231 Walfisch Ikegami models. The results will serve as a basis for the provision of modified propagation models that can be used to aid network coverage prediction and planning.

4.1 ANALYSIS OF THE COST- 231 HATA MODEL

The COST- 231 Hata path loss model for urban areas from equation (2.4) is:

$$L_P = A + B\log(d) + C \quad \text{..(4.1)}$$

$$A = 46.3 + 33.9\log(f_c) - 13.82\log(h_b) - a(h_m) \quad \text{.(4.2)}$$

$$B = 44.9 - 6.55\log(h_b) \quad \text{...(4.3)}$$

$$a(h_m) = 3.2[\log(11.75h_m)]^2 - 4.97 \quad \text{..(4.4)}$$

$C = 3dB$, $f_c = 900MHz$, $h_m = 1.5m$

Substituting the above parameters into equation (4.1) to have:

$$L_P = 46.3 + 33.9\log(900) - 13.82\log(h_b) - \left[3.2(\log 17.63)^2 - 4.97\right] + \left[44.9 - 6.55\log(h_b)\right]\log d + 3$$

$$= 149.45 - 13.82\log(h_b) + \left[44.9 - 6.55\log(h_b)\right]\log d \quad \text{(4.5)}$$

For base stations of height 32m, substituting $h_b = 32m$ into equations (4.5):

$$L_P = 149.45 - 13.82\log(32) + \left[44.9 - 6.55\log(32)\right]\log d \quad \text{.(4.6)}$$

$$= 128.65 + 35.05\log d \quad \text{(4.7)}$$

For base stations of height 34m, substituting the value of $h_b = 34m$ into equation (4.5):

$$L_P = 149.45 - 13.82\log(34) + [44.9 - 6.55\log(34)]\log d \text{ ....(4.8)}$$

$$= 128.28 + 34.87\log d \quad \text{..(4.9)}$$

The average of equations (4.7) and (4.9) is:

$$= 128.5 + 35\log d \text{ ....(4.10)}$$

The received signal strength was predicted using equations (2.8) and (4.5).

4.2 ANALYSIS OF THE LEE MODEL

The Lee path loss model for urban areas from equation (2.9) is:

$$p_L = 124 + 30.51\log\left(\frac{d}{1.6km}\right) + 10n\log\left(\frac{f_c}{900MH_Z}\right) - \alpha_o \text{ (4.11)}$$

$$f_c = 900MHz, n = 3$$

$$\alpha_o = \alpha_1\alpha_2\alpha_3\alpha_4\alpha_5 \text{ ....(4.12)}$$

$$\alpha_1 = \left[\frac{NewH_{BS}(m)}{30.48m}\right]^2 \text{ ....(4.13)}$$

$$\alpha_2 = \left[\frac{NewH_{MS}(m)}{3m}\right]^3 \text{ ....(4.14)}$$

$$\alpha_3 = \left[\frac{NewTransmitterPower(W)}{10W}\right]^2 \text{ ....(4.15)}$$

$$\alpha_4 = \left[\frac{NewBSG_A}{4}\right] \text{ ....(4.16)}$$

$$\alpha_5 = \text{New mobile station gain} \text{ ....(4.17)}$$

New height of mobile station is 1.5m

$$\alpha_2 = \left(\frac{1.5}{3}\right)^3 = 0.125$$

$$\alpha_3 = \left(\frac{50}{10}\right)^2 = 25$$

$$\alpha_5 = -0.34$$

Substituting the above parameter into equation (4.11) yields :

$$L_P = 117.77 + 30.51\log(d) - \alpha_o \qquad (4.18)$$

Where,

$$\alpha_o = \left[\left(\frac{NewH_{BS}}{30.48}\right)^2 \left(\frac{NewH_{BS}}{4}\right)(-1.0625)\right] \qquad (4.19)$$

Finally, substituting equation (4.19) into equation (4.18):

$$L_P = 117.77 + 30.51\log d - \left[\left(\frac{NewH_{BS}}{30.48}\right)^2 \left(\frac{NewBSG_A}{4}\right)(-1.0625)\right] \qquad (4.20)$$

Applying equation (4.20) to find the expressions for the path loss for the following base station parameters collected in section (3.1): using the antenna gain of 15dBi and height of base station of 32m,results in:

$$L_P = 122.18 + 30.51\log d \qquad (4.21)$$

Antenna gain of 15dBi, height of base station of 34m:

$$L_P = 122.66 + 30.51\log d \qquad (4.22)$$

Antenna gain of 17dBi, height of base station of 32m:

$$L_P = 122.77 + 30.51\log d \qquad (4.23)$$

Antenna gain of 17dBi, height of base station of 34m:

$$L_P = 122.32 + 30.51\log d \qquad (4.24)$$

Antenna gain of 17.5dBi, height of base station of 32m:

$$L_P = 122.92 + 30.51\log d \quad \text{……………………………………………. ….(4.25)}$$

Antenna gain of 17.5dBi, height of base station of 34m:

$$L_P = 123.5 + 30.51\log d \quad \text{……………………………………………….(4.26)}$$

Antenna gain of 18dBi, height of base station of 32m:

$$L_P = 123.06 + 30.51\log d \quad \text{……………………………………………….(4.27)}$$

Antenna gain of 18dBi, height of base station of 34m:

$$L_P = 123.66 + 30.51\log d \quad \text{……………………………………………….(4.28)}$$

Taking the average of equations (4.21) to (4.28)

$$L_P = 123 + 30.51\log d \quad \text{……………………………………………….(4.29)}$$

The received signal strength was predicted using equation (2.8) and (4.20).

4.3 ANALYSIS OF THE COST-231 WALFISCH IKEGAMI MODEL

The COST-231 Walfisch Ikegami Model for urban areas from equation (2.16) is:

$$L_P = L_o + L_{rts} + L_{msd} \quad \text{……………….…………………………. (4.30)}$$

$$L_o = 32.44 + 20\log\left(\frac{f_c}{MHz}\right) + 20\log\left(\frac{d}{Km}\right) \text{………………………. (4.31)}$$

Substituting $f_c = 900MHz$ into equation (4.32):

$$L_o = 91.52 + 20\log(d) \quad \text{…………………………………….. ….(4.32)}$$

Similarly, from equation (2.18):

$$L_{rts} = -16.9 - 10\log\left(\frac{w}{m}\right) + 10\log\left(\frac{f_c}{MHz}\right) + 20\log\left(\frac{h_{roof-}h_m}{m}\right) + L_{ori} \text{…….(4.33)}$$

The average width of the road (w) for the area under consideration is taken as 20m, from equation (2.19): $w=\frac{b}{2}$, $b=2w$, $b=40m$.

The h_{roof} which is the height of buildings just below the base station antenna was determined from equations (2.20) and (2.21):

$h_{roof}=3m(9)+3m=30m$.

The L_{ori} which is the path loss due to the orientation angle will be determined for angles 0^o to 90^o using the equations(2.22),(2.23) and (2.24).This is to obtain an average path loss due to orientation angle. The results obtained are shown in Table (4.1).

Table 4.1: Orientation Angles and Computed Path Loss

θ^o	10	20	30	40	50	60	70	80	90
$L_{Ori}(dB)$	-6.46	-2.92	0.62	2.87	3.62	3.43	2.29	1.15	0.01

Average Path Loss $=\frac{4.62}{9}=0.51dB$

Substituting the parameters f_c, w, h_{roof} and h_m into the equation (4.33):

$L_{rts}=26.23dB$ ……………………………………………….. ………(4.34)

Similarly, from equation (2.26):

$L_{msd}=L_{bsh}+K_a+K_d\log\left(\frac{d}{Km}\right)+K_f\log\left(\frac{f_c}{MHz}\right)-9\log\left(\frac{b}{m}\right)$ ………. …..(4.35)

Substituting the parameters for L_{bsh} in equation (2.26), K_f in equation (2.28), $K_a=54$, $K_d=18$, $f_c=900MHz$ and $b=40m$ into equation(4.35):

$$L_{msd} = -18\log\Delta h_{bs} + 18\log(d) + 27.64 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4.36)$$

Finally, substituting equations (4.32), (4.34) and (4.36) into equation (4.30):

$$L_P = 145.39 + 38\log(d) - 18\log\Delta h_{bs} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.37)$$

For base stations of height 32m, substituting $h_b = 32m$ into equation (4.37), where Δh_{bs} is 2m:

$$L_P = 139.97 + 38\log d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.38)$$

For base stations of height 34m, substituting $h_b = 34m$ into equation (4.37), where Δh_{bs} is 4m:

$$L_P = 134.55 + 38\log d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.39)$$

Taking the average of equations (4.38) and (4.39):

$$L_P = 134.55 + 38\log d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.40)$$

The received signal strength was predicted using the equations (2.8) and (4.37).

4.4 PROPAGATION LOSS MODELS PREDICTIONS

The three macro cell propagation models analyzed in the last section will be used to compute the path loss and received signal strength for each of the nine base stations. This is to obtain the received signal strength and path loss for each of the nine base stations at the various distances.

4.4.1 Results obtained using the COST- 231 Hata Model

The equations (2.8) and (4.5) were used respectively to compute the received signal strength and path loss at an interval of 0.5km using the base station parameters provided in section(3.3).The results obtained are shown in Tables(4.4) to (4.7) of appendix A.

4.4.2 Results obtained using the Lee Model

Similarly, the equation (2.8) and (4.20) were used to compute respectively the received signal strength and path loss at an interval of 0.5km using the base station parameters in section (3.3).The results obtained are presented in Tables (4.8) to (4.11) of appendix B.

4.4.3 Results obtained using the COST- 231 Walfisch Ikegami Model

Similarly, the equation (2.8) and (4.37) were used to compute the received signal strength and path loss respectively at an interval of 0.5km using the base station parameters in section (3.3).The results obtained are shown in Tables (4.12) to (4.15) of appendix C.

4.5 COMPARISON OF MEASURED AND PREDICTED RESULTS

This section deals with the comparison between the received signal strength and path loss from measured results in section (3.4) with that obtained using the Hata, Lee and Walfisch-Ikegami models in section (4.4) for each of the nine base stations. The results obtained are presented in Tables (4.16) to (4.24) of appendix D and Tables (4.25) to (4.33) of appendix E for the received signal strength and path loss respectively. The graphical illustrations are shown in Figures (4.1) to (4.9).

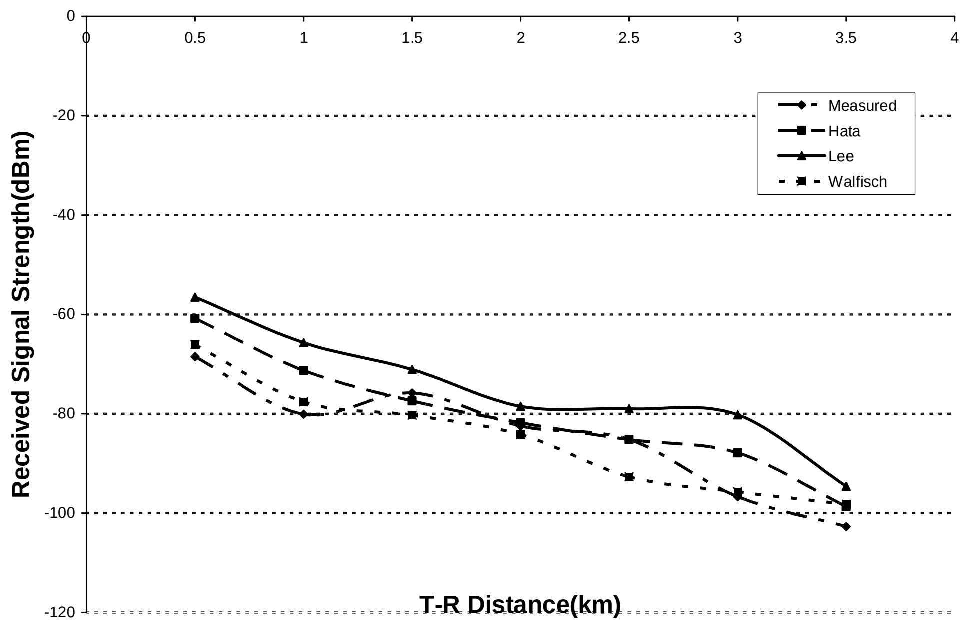


Figure 4.1 (a): Received Signal Strength for Base Station 1(Kan032)

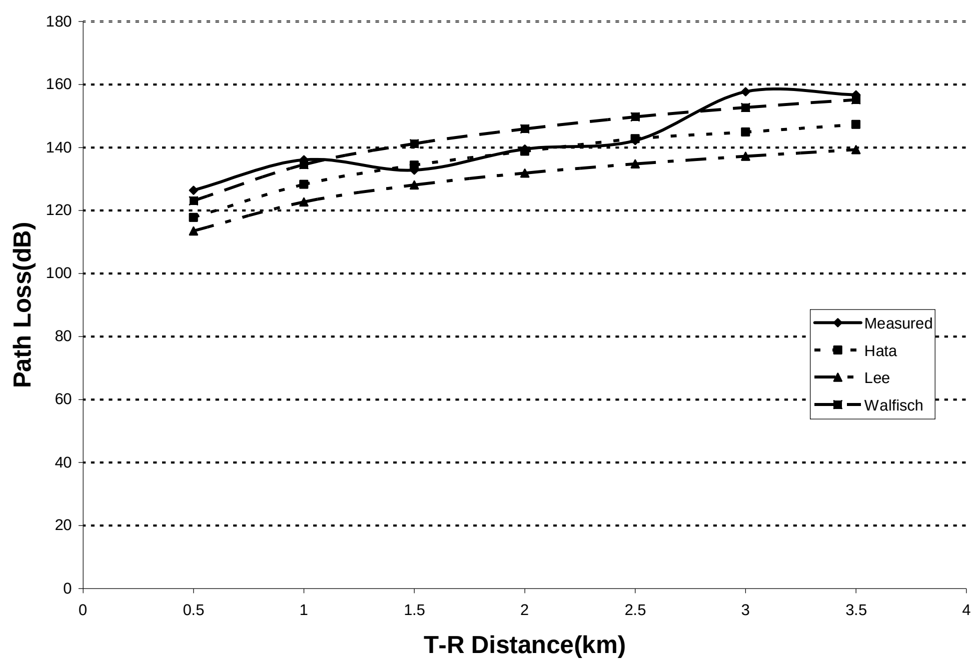


Figure 4.1(b): Path Loss for Base Station 1 (Kan032)

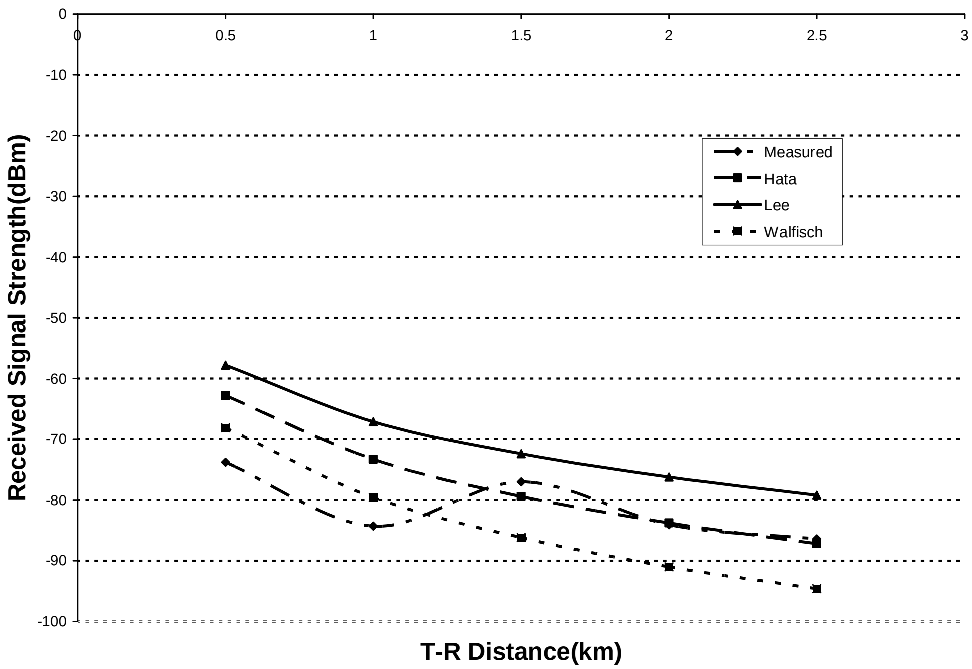


Figure 4.2(a): Received Signal Strength for Base Station 2 (Kan027)

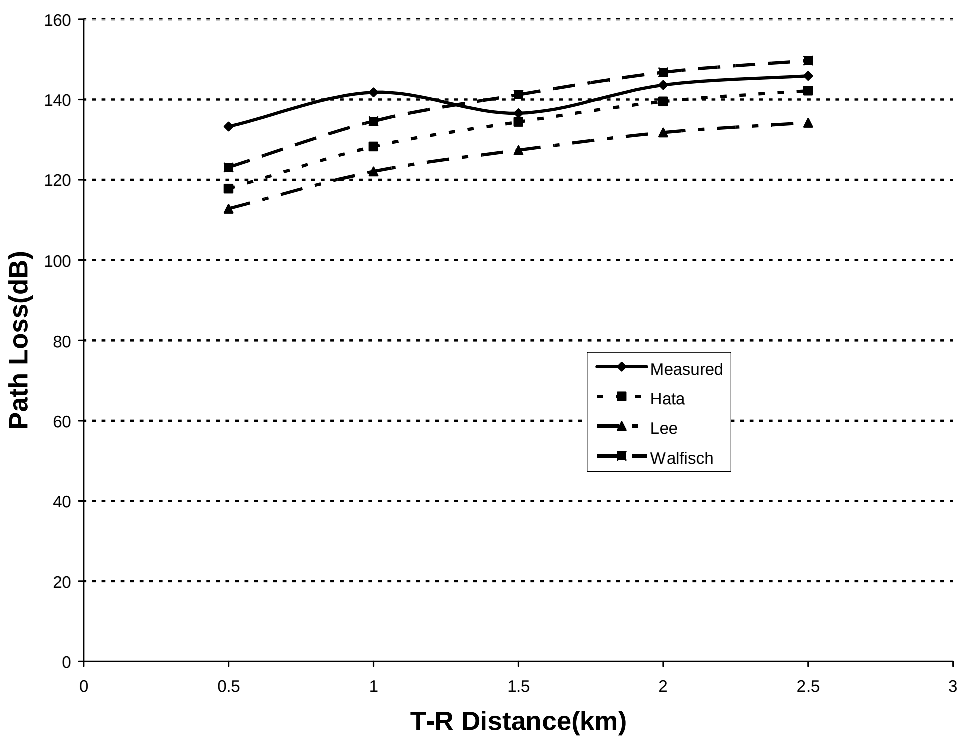


Figure 4.2(b): Path Loss for Base Station 2 (Kan027)

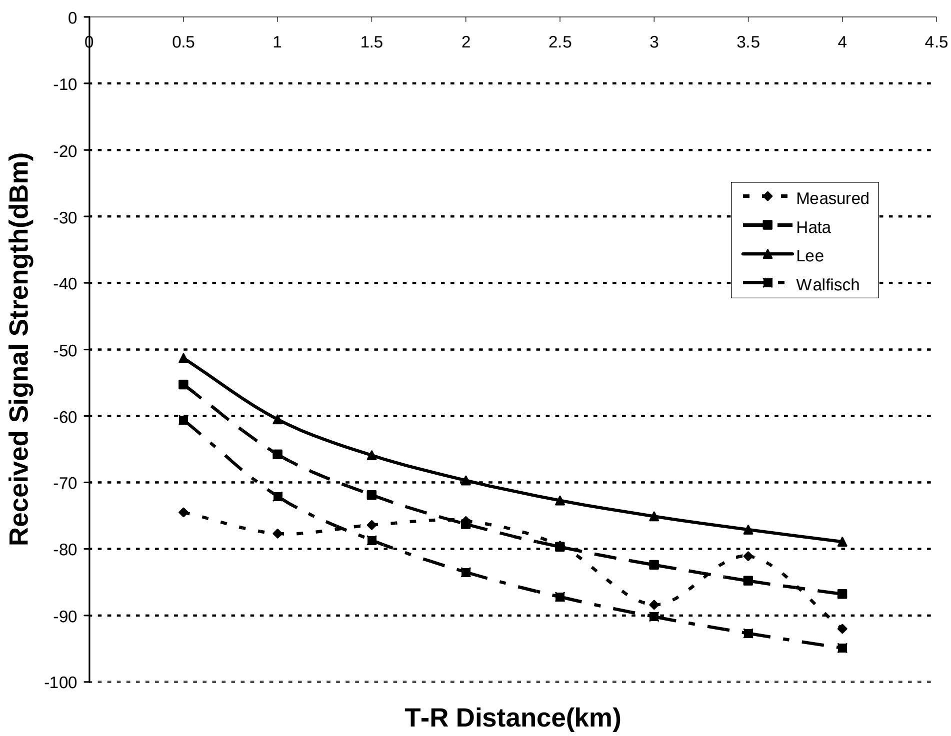


Figure 4.3(a): Received Signal Strength for Base Station 3 (Kan021)

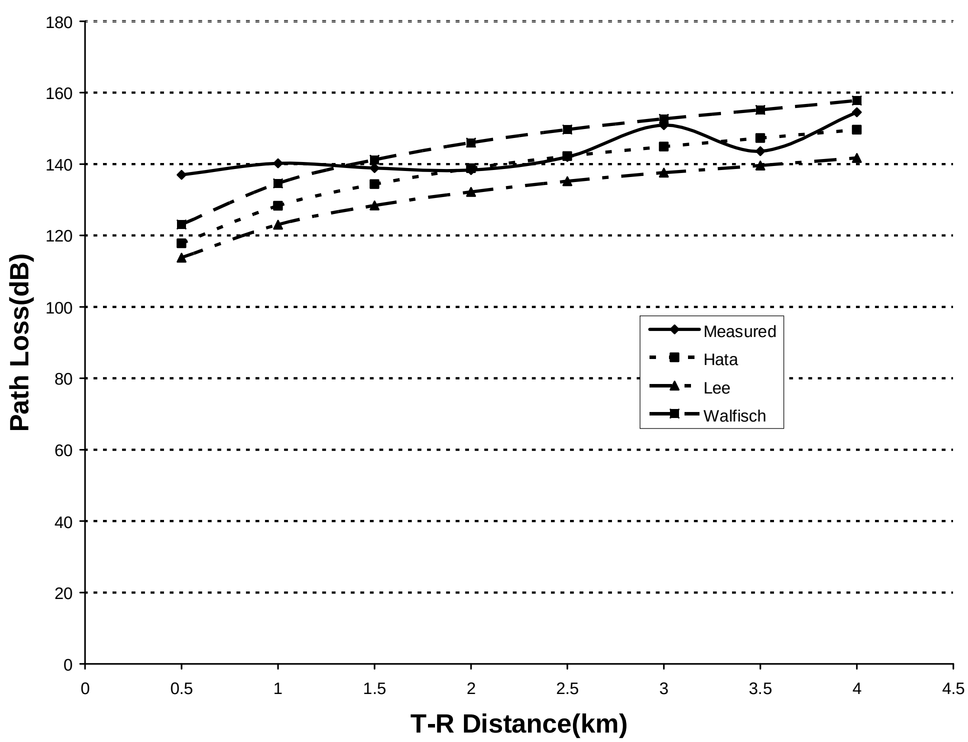


Figure 4.3(b): Path Loss for Base Station 3 (Kan021)

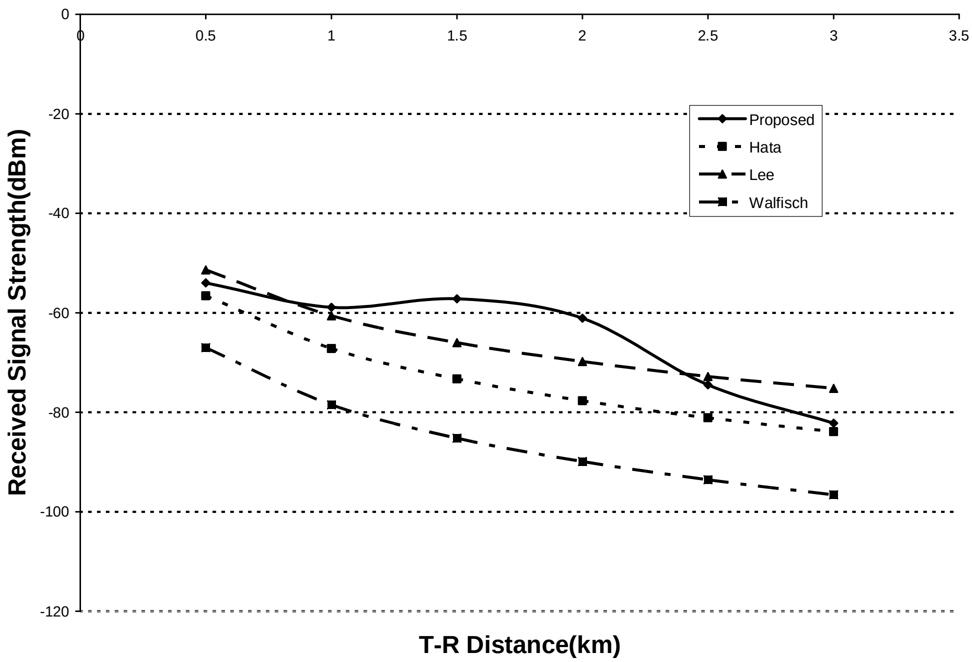


Figure 4.4 (a): Received Signal Strength for Base Station 4 (Kan011)

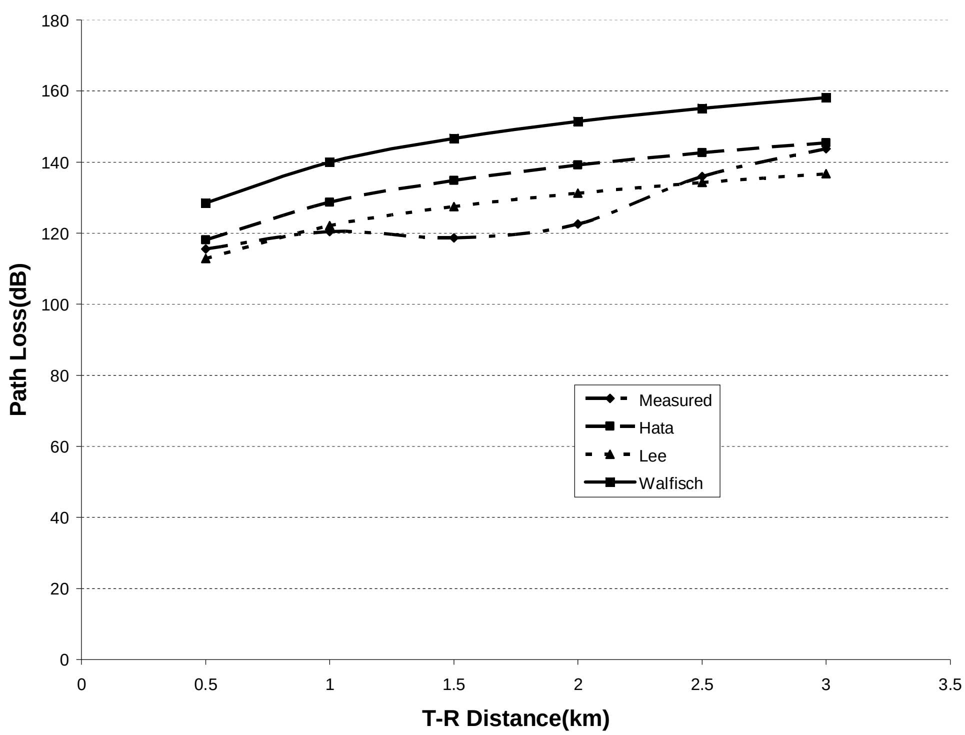


Figure 4.4(b): Path Loss for Base Station 4 (Kan011)

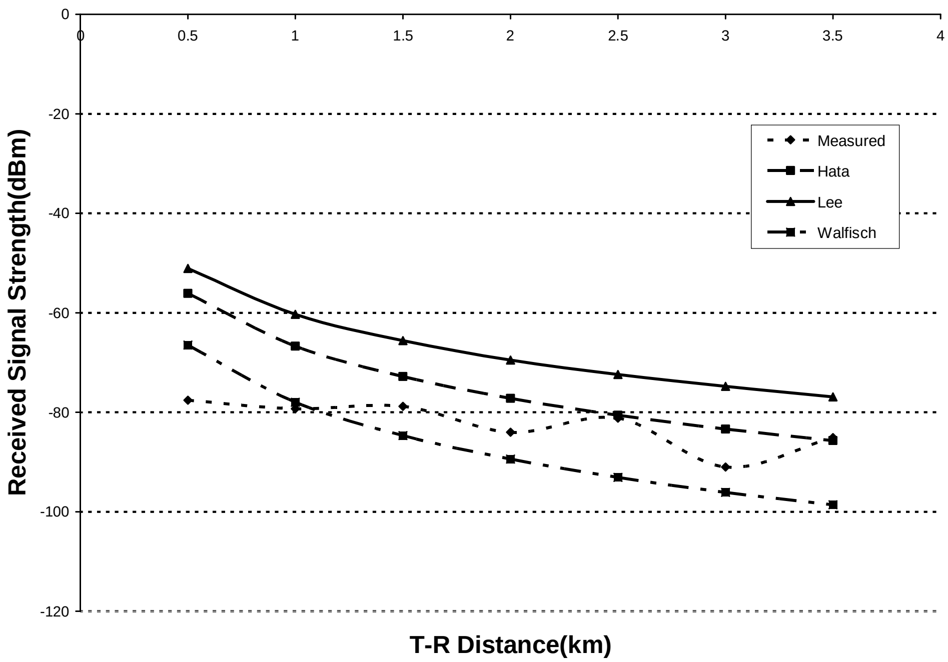


Figure 4.5(a): Received Signal Strength for Base Station 5 (Kan052)

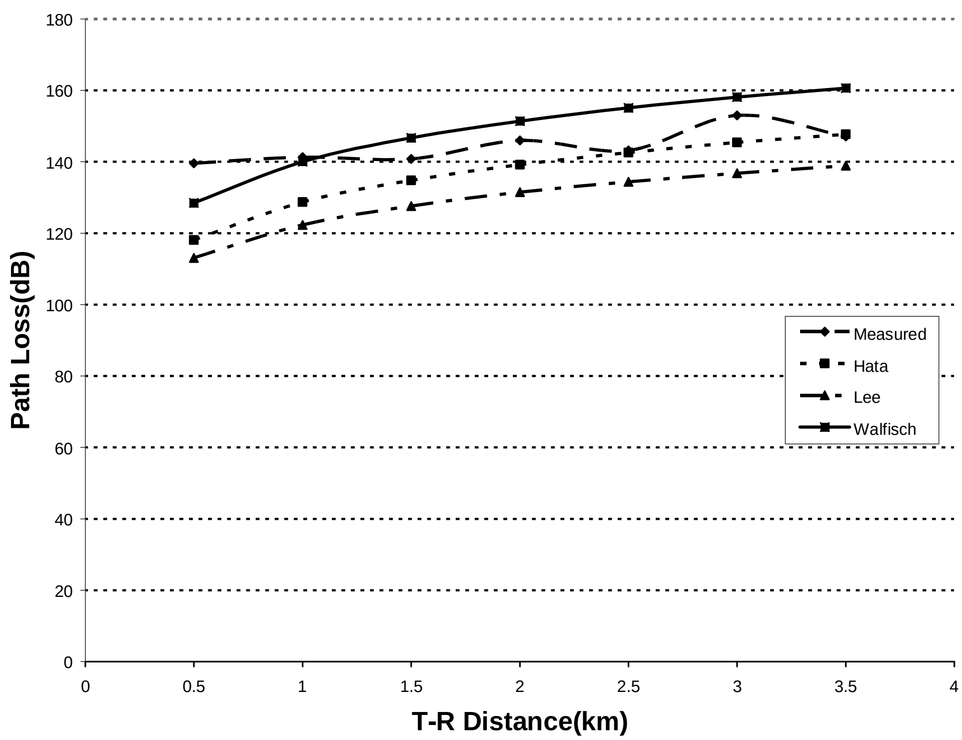


Figure 4.5(b): Path Loss for Base Station 5 (Kan052)

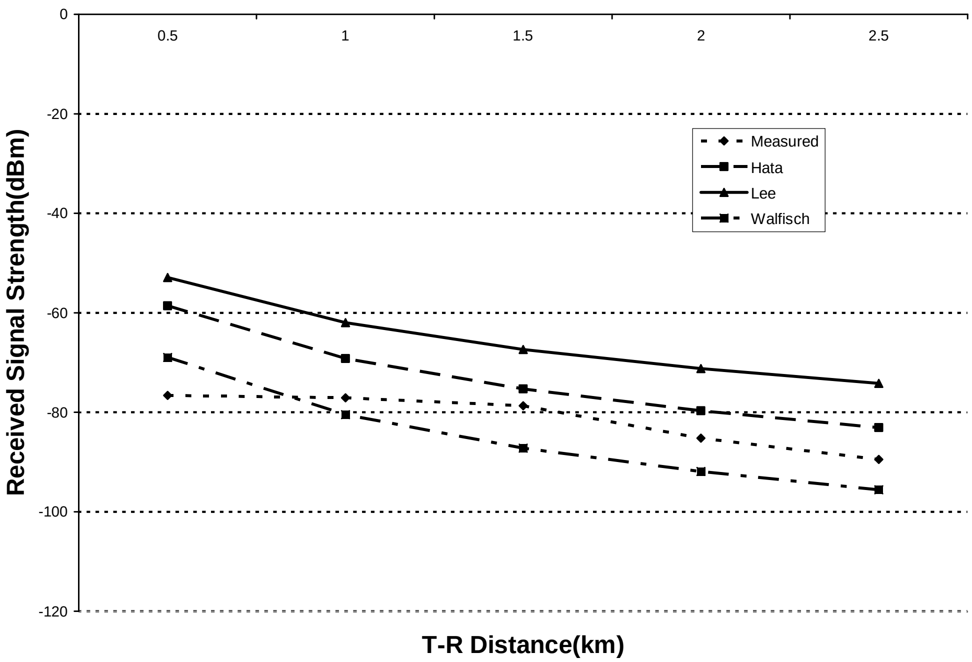


Figure 4.6(a): Received Signal Strength for Base Station 6 (Kan044)

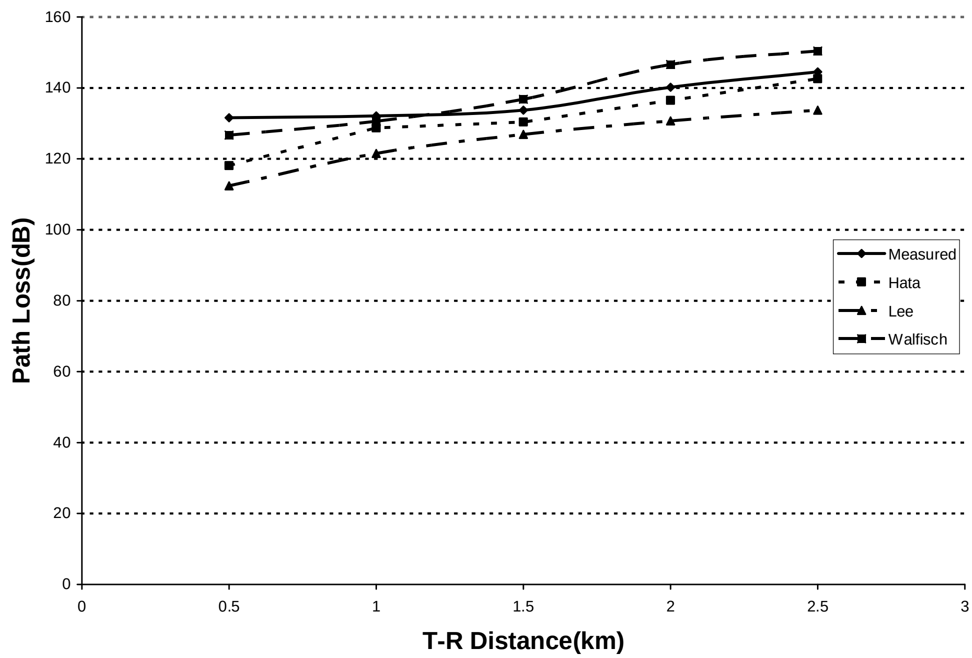


Figure 4.6(b): Path Loss for Base Station 6 (Kan044)

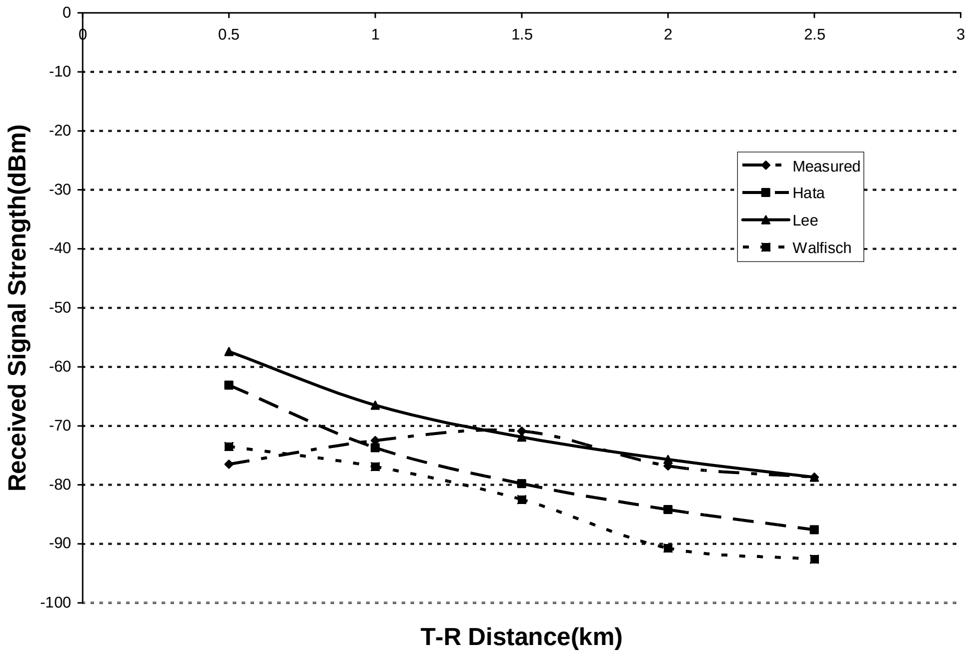


Figure 4.7(a): Received Signal Strength for Base Station 7 (Kan017)

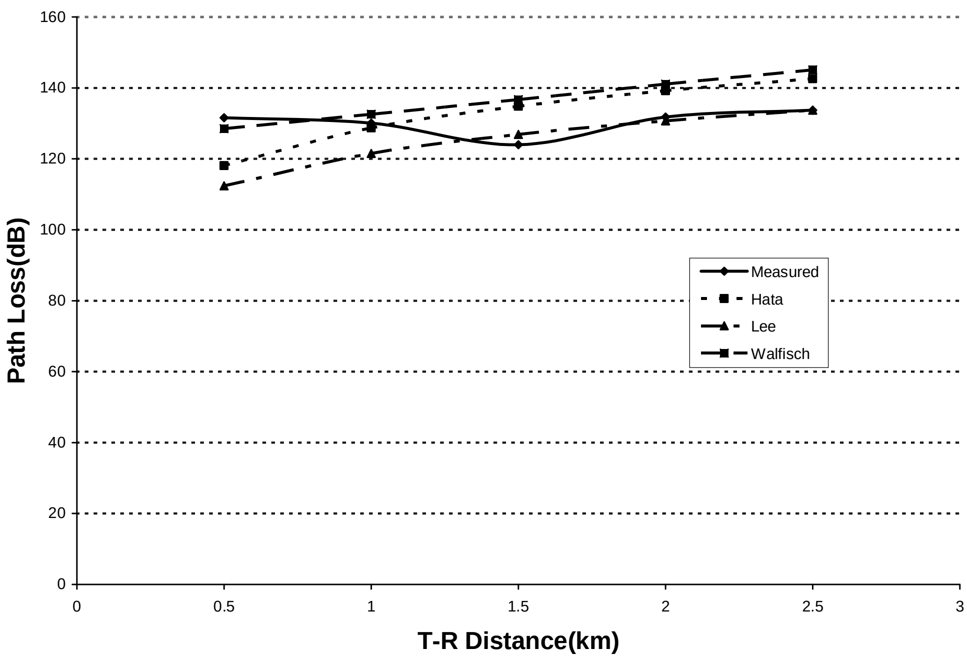


Figure 4.7(b): Path Loss for Base Station 7 (Kan017)

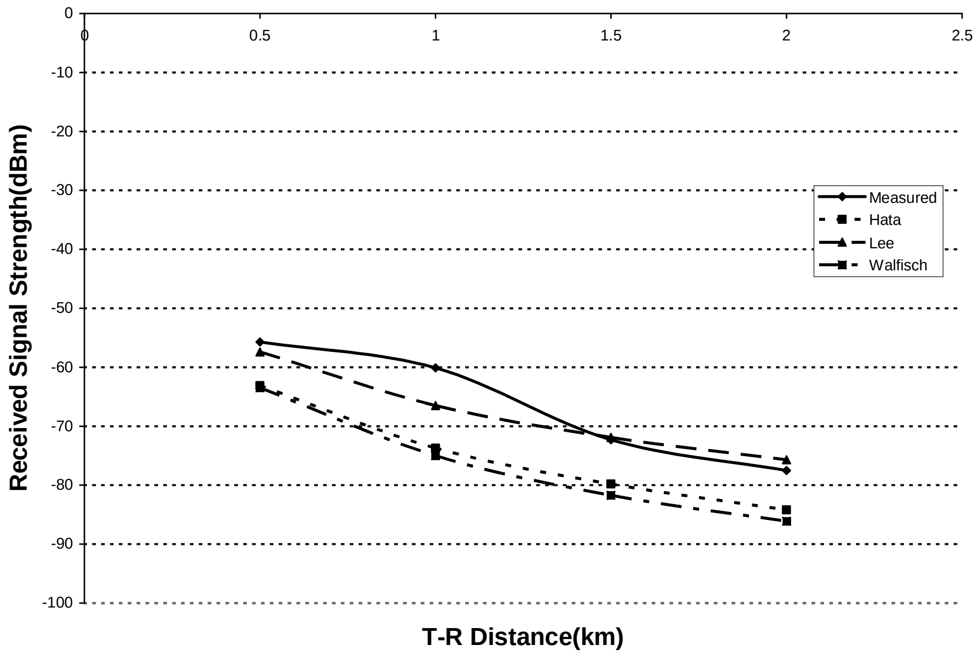


Figure 4.8(a): Received Signal Strength for Base Station 8 (Kan056)

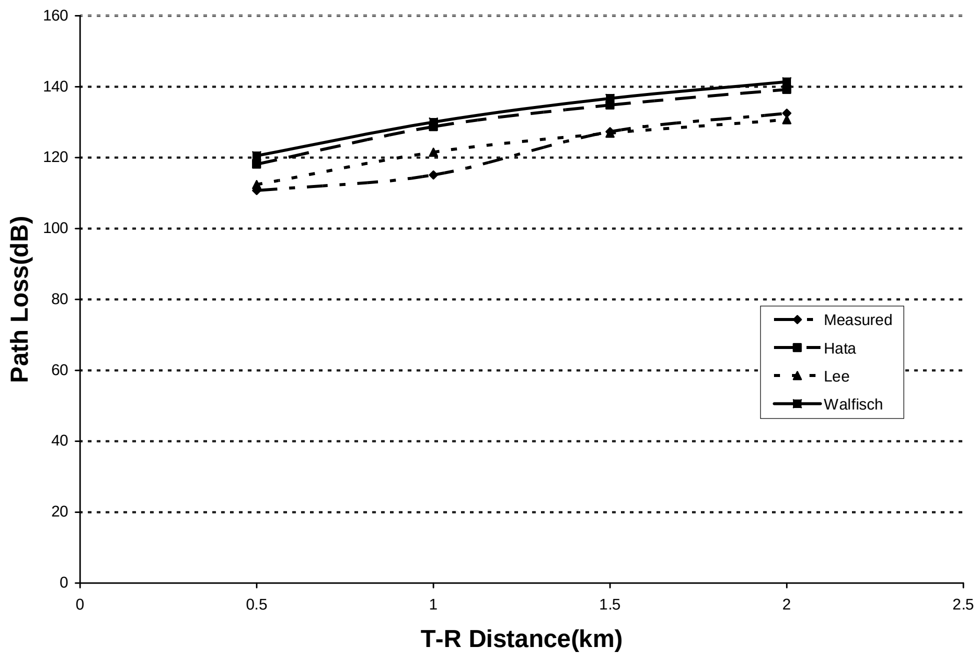


Figure 4.8(b): Path Loss for Base Station 8 (Kan056)

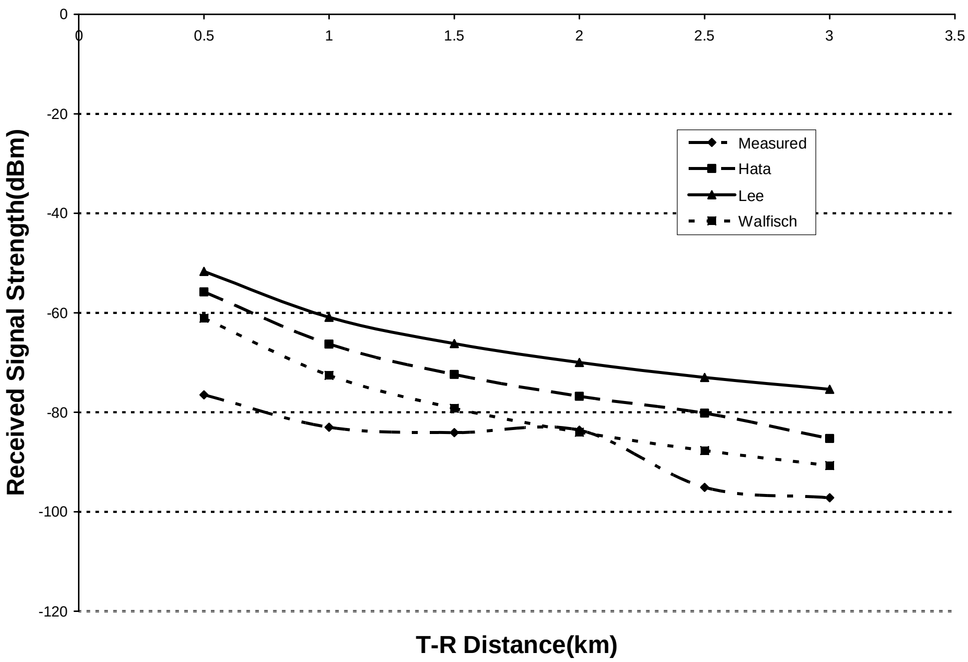


Figure 4.9 (a): Received Signal Strength for Base Station 9 (Kan026)

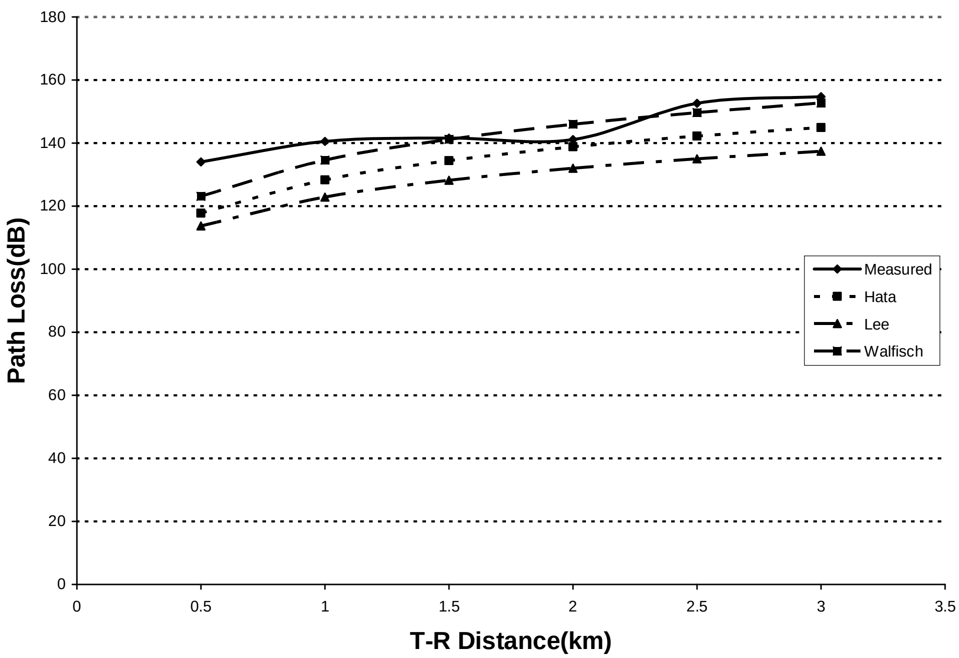


Figure 4.9(b): Path Loss for Base Station 9 (Kan026)

4.6 DIFFERENCES BETWEEN THE MEASURED AND PREDICTED RESULTS

The differences in path loss values between the measured and predicted results for the three path loss models were determined at an interval of 0.5km using the expression:

$$Difference = (\text{Pr}\,edicted) - (Measurement) \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.41)$$

The average of the differences in path losses for each base station was obtained from the expression:

$$Average = \frac{\sum Differences}{N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.42)$$

Where, N is the number of propagation measurements collected. The total average of the path losses for each model was obtained from the expression:

$$Total\ \ Average = \frac{\sum Averages}{9} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.43)$$

The results obtained are shown in Tables (4.34) to (4.60) of appendix F for base station one to nine. The average path loss from the differences between measured results and the Hata model is -0.7 dB. Similarly, the average path loss for the Lee model is -4.2 dB. Finally, the average path loss for the Walfisch-Ikegami model is 8.9dB.

4.7 PROPAGATION LOSS PREDICTION STATISTICS

This section deals with the use of statistical analysis to determine the propagation prediction variations of the three propagation models under study over this urban environment. The propagation loss prediction statistics consists of the mean prediction error (μ_e) and the standard deviation of the mean prediction error (σ_e) for each base station. The mean prediction (μ_e) was determined from the expression in equation (4.42).The standard deviation of the mean prediction error (σ_e) was determined using the expression: [12]

$$\text{Standard deviation} = \sqrt{\frac{\sum d^2}{n-1}} \quad \text{...} (4.44)$$

Where, d is the difference between predicted and measured results, n is the number of propagation measurements collected. The results obtained are shown in Table (4.2).

Table 4.2: Propagation Loss Prediction Statistics

Base Station	**COST-231 Hata Model**		**Lee Model**		**COST-231 Walfisch-Ikegami Model**	
	(μ_e)	(σ_e)	(μ_e)	(σ_e)	(μ_e)	(σ_e)
1	-8.2	12.5	-14.8	18.3	-1.3	8.9
2	8.3	7.2	-10.2	12.5	3.2	7.7
3	7.1	7.4	-7.3	10.0	6.3	10.6
4	13.2	15.8	5.8	9.0	25.0	28.2
5	-3.3	8.3	-10.7	13.2	8.7	12.6
6	-3.7	7.1	-11.4	13.5	7.9	10.9
7	0.9	12.1	-6.8	13.3	12.5	19.0
8	8.8	10.7	1.5	4.0	20.3	23.6
9	-9.7	11.6	15.9	17.9	-2.9	6.2
Ave.	-0.7	10.3	-4.2	12.4	8.9	14.2

4.8 PROPOSED PROPAGATION PREDICTION MODELS

The result of the path loss analysis of the three path loss models in section (4.6) will be used to obtain the modified path loss models:

The COST- 231 Hata Model:

From equation (4.10):

$$L_P = 128.5 + 35\log d \quad \text{...} (4.45)$$

Applying the correction factor F_C:

$$L_p = 128.5 + 35\log(d) - F_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.46)}$$

where, F_c: the correction factor is -0.7dB

$$L_p = 128.5 + 35\log(d) + 0.7$$

$$= 129.2 + 35\log(d) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.47)}$$

The Lee Model:

Similarly, from equation (4.29):

$$L_p = 123 + 30.5\log(d) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.48)}$$

Applying the correction factor F_C:

$$L_p = 123 + 30.5\log(d) - F_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.49)}$$

Where, F_c: the correction factor is -4.2dB

$$L_p = 123 + 30.5\log(d) + 4.2$$

$$= 127.2 + 30.5\log(d) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.50)}$$

The COST- 231 Walfisch Ikegami Model:

Finally from equation (4.40):

$$L_P = 137.3 + 38\log(d) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.51)}$$

Applying the correction factor F_C:

$$L_p = 137.3 + 38\log(d) - F_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.52)}$$

Where, F_c: the correction factor is 8.9dB

$$L_p = 137.3 + 38\log(d) - 8.9$$

$$= 128.4 + 38\log(d) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.53)}$$

The mean value of equations (4.47), (4.50) and (4.53) is:

$L_P = 128.3 + 34.5\log(d)$ ………………………………………………… (4.54)

The equation (4.54) is the proposed modified path loss model.

The received signal strength can now be predicted using the equation (2.8): $S_R = EIRP - L_P$ .EIRP is the average Effective Isotropic Radiated Power of the nine base stations given by 56.3dBm and $L_P = 128.3 + 34.5\log(d)$ from equation (4.54). Substituting the values of EIRP and L_P is into equation (2.8):

$S_R = 56.3 - 128.3 - 34.5\log(d)$

$= 72 - 34.5\log(d)$ ……………………………………………………….(4.55)

The received signal strength is presented in Table 4.3.

Table 4.3: Computed Signal Strength for the New Propagation Prediction Model

Distance(km)	Signal Strength $S_R(dBm)$
0.5	-61.6
1.0	-72.0
1.5	-78.1
2.0	-82.4
2.5	-85.7
3.0	-88.5
3.5	-90.8
4.0	-92.8

4.9 COMPARISON OF THE PROPOSED PREDICTION MODEL WITH MEASURED RESULTS

The section deals with the comparison of the received signal strength using the proposed prediction model in equation (4.55) with measured results obtained from the nine base stations. The plots are shown in Figures (4.10) to (4.18).

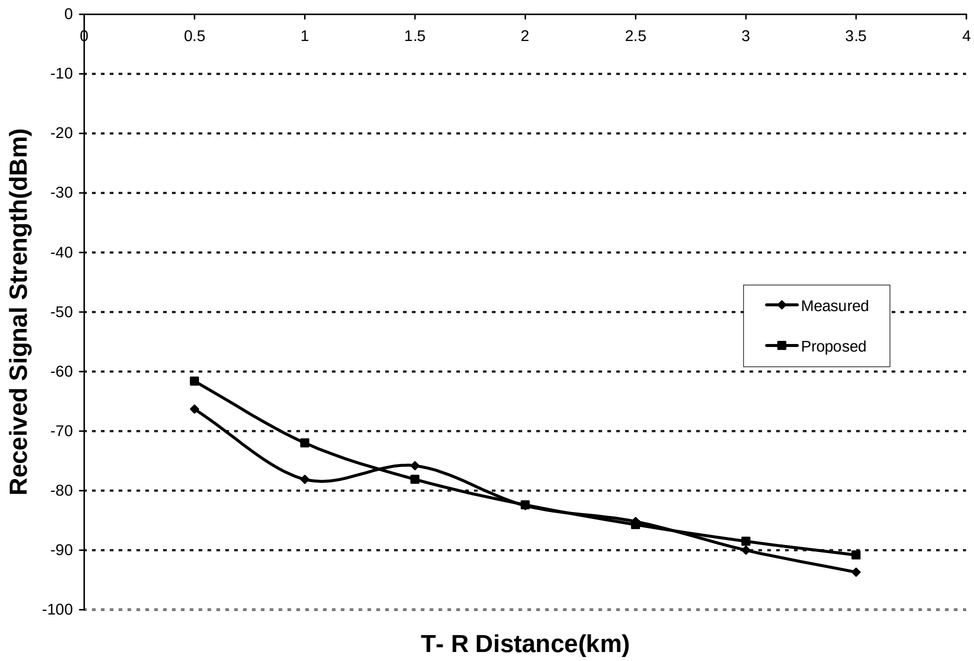


Figure 4.10:Comparison of Proposed Model and Measurement for Base Station 1(Kan032)

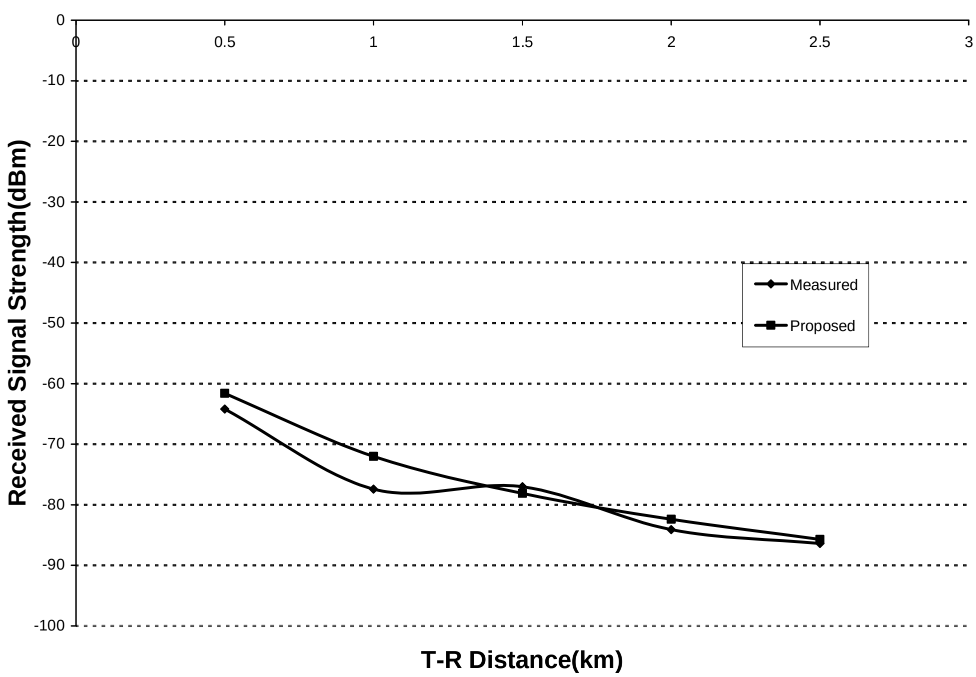


Figure 4.11: Comparison of Proposed Model and Measurement for Base Station 2(Kan027)

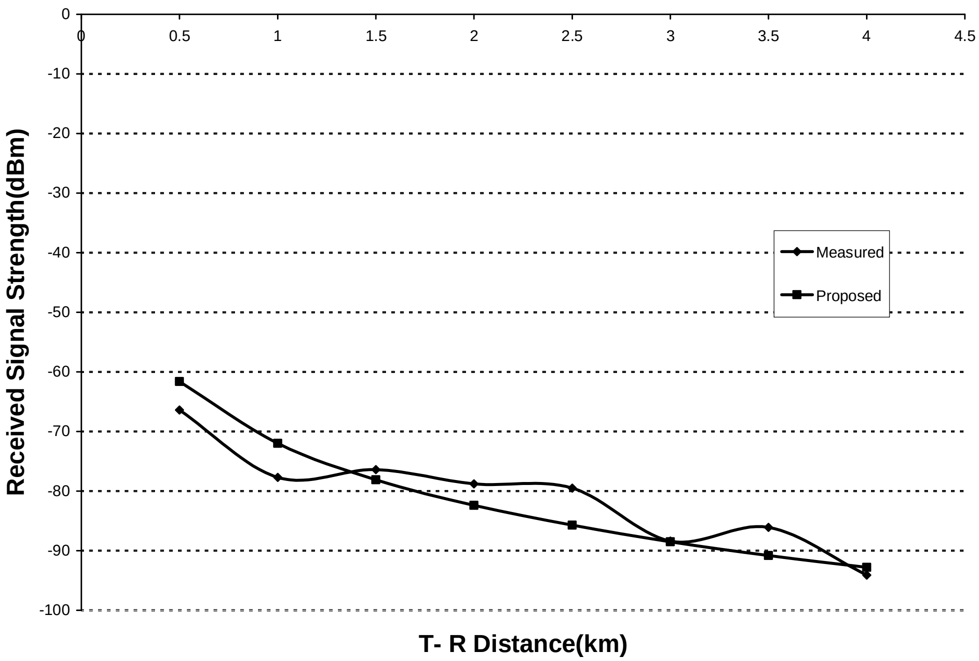


Figure 4.12: Comparison of Proposed Model and Measurement for Base Station 3(Kan021)

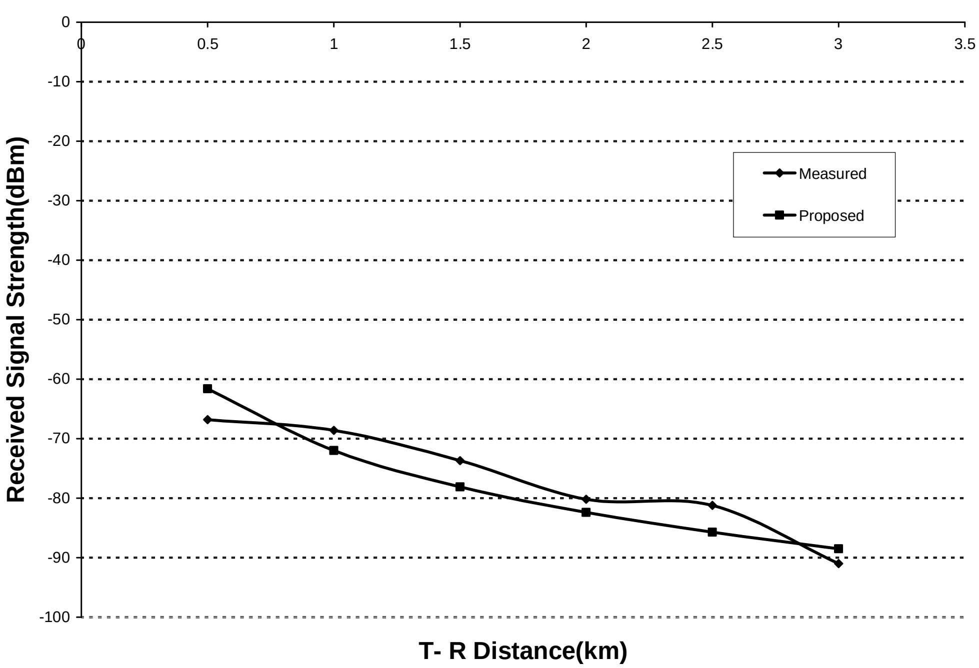


Figure 4.13: Comparison of Proposed Model and Measurement for Base Station 4(Kan011)

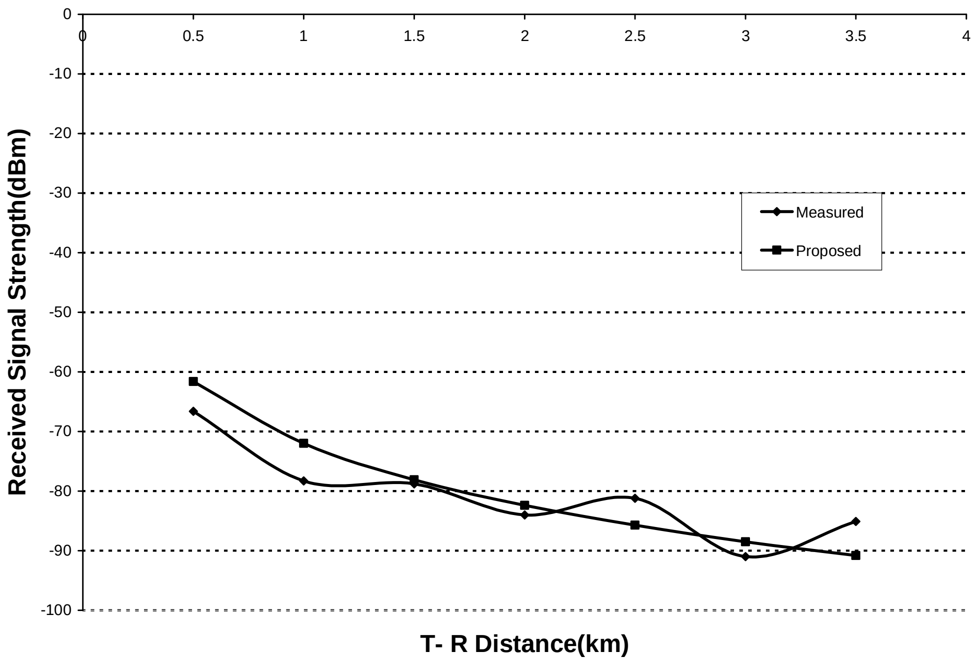


Figure 4.14: Comparison of Proposed Model and Measurement for Base Station 5(Kan052)

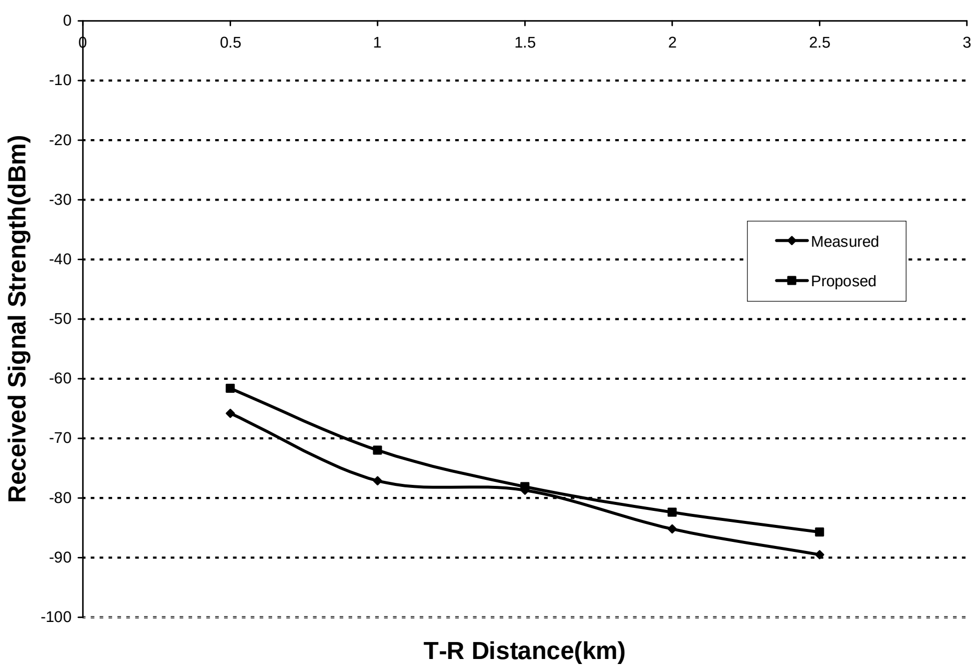


Figure 4.15: Comparison of Proposed Model and Measurement for Base Station 6(Kan044)

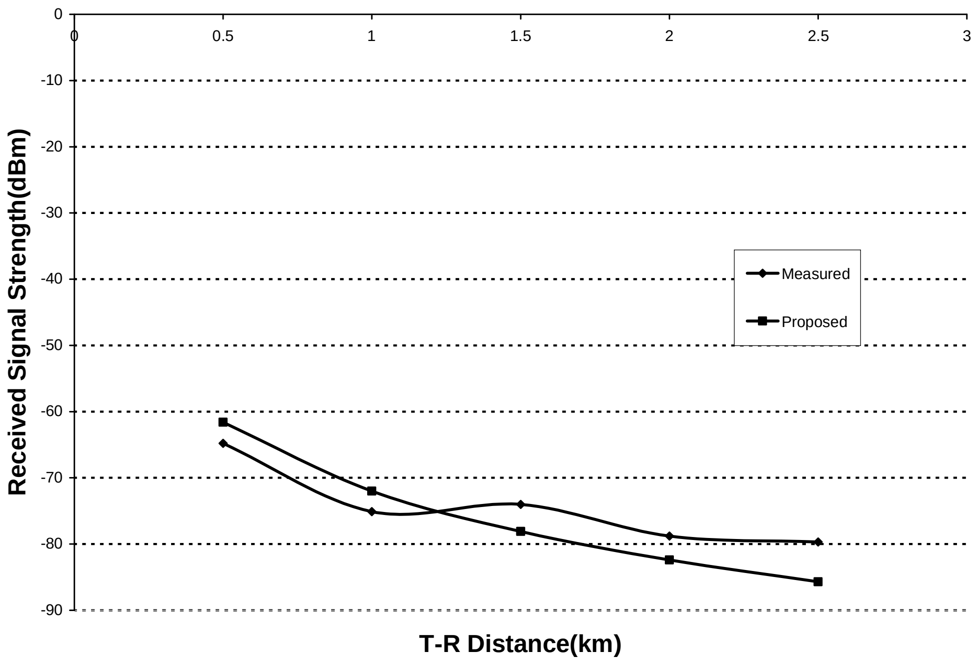


Figure 4.16: Comparison of Proposed Model and Measurement for Base Station 7(Kan017)

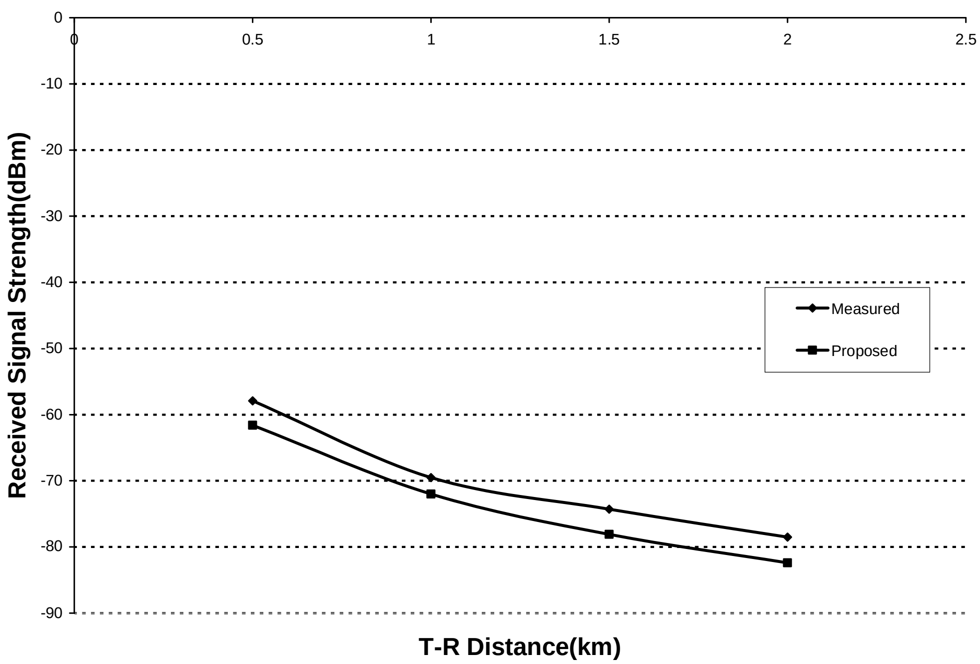


Figure 4.17: Comparison of Proposed Model and Measurement for Base Station 8(Kan056)

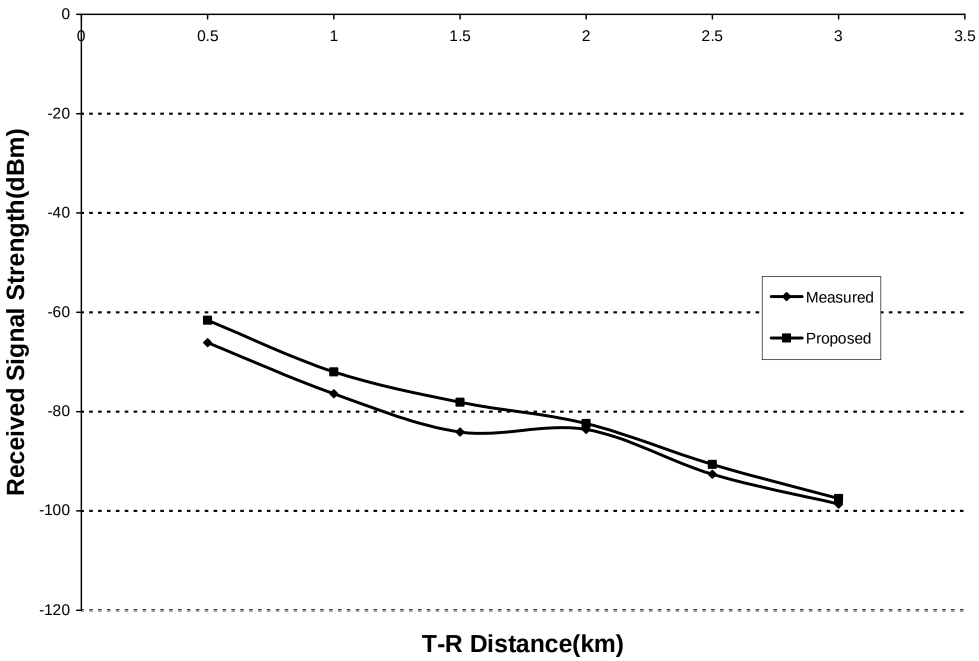


Figure 4.18: Comparison of Proposed Model and Measurement for Base Station 9(Kan026).

4.10 DISCUSSION AND INTERPRETATION OF RESULTS

The graphs in Figures (4.1) to (4.9) show the variation of the received signal strength and path loss computed using the propagation models and that obtained from measured results at various distances. The graphs show that the propagation models overestimate the path loss and received signal strength at some distances, while underestimating them at some other locations. The propagation predictions also differ from one base station to the other. These can be attributed to the differences in physical impairments such as buildings, trees, poles, walls e.t.c between the areas under consideration and that used for the development of these standardized models. The analysis of the three propagation models provided mean prediction error values of -0.7dB,-4.2dB and 8.9dB for Hata, Lee and Walfisch –Ikegami Models respectively. These data show that the COST-231 Hata and Lee models underestimate the path loss for this environment, while the COST-231 Walfisch-Ikegami model over-predict the environment. The prediction of the COST-231 Walfisch-Ikegami model can be attributed to the fact that the model considers some radio wave propagation impairments like roof top to street diffraction loss, multiscreen diffraction loss, shadowing e.t.c which made computation difficult.

The statistical analysis in section (4.7) provides the prediction variations of the three propagation models for each of the nine base stations. It shows the mean prediction errors between measured and predicted results for each base station. The deviation between the three models is also indicated by the standard deviation of the mean prediction errors. The standard deviations of 10.3dB, 12.4dB and 14.2dB were obtained for the COST-231 Hata, Lee and COST-231Walfisch-Ikegami models respectively over the environment. It shows that the COST-231Hata model provided a closer prediction of the environment to the Lee model when compared to the COST-231 Walfisch-Ikegami model. However, the Lee model provided a closer prediction of the environment to the COST-231 Walfisch-Ikegami model. It also indicates that the path loss predictions of the three models do not differ substantially. The mean prediction error values obtained were used as correction factors to modify the three models examined for the area. The new prediction model was developed from the three modified models. It provides ease of predicting the network coverage for the environment as it eliminates the many parameters requirement and difficulties encountered in computation.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.0 INTRODUCTION

This chapter deals with the summary of the results obtained, significance and applications. It also includes the research limitations, problems encountered, conclusions and recommendation for further work.

5.1 SUMMARY OF RESULTS

The results of the research work shows that on the average, the propagation models provide a slightly higher prediction of the path loss and received signal strength at some instances and lower at other locations when compared to that obtained from measured results. These are due to the differences in environmental clutters used in developing these models and that of the area under study. The mean prediction error values of –0.7dB, –4.2dB and 8.9 dB obtained for the Hata, Lee and Walfisch–Ikegami models respectively constituted correction factors for modifying the three models examined. The new path loss model developed from the three modified models is:

$$L_P = 128.3 + 34.5\log(d) \quad \text{.....(5.1)}$$

The received signal strength can now be predicted using the expression:

$$S_R = -72 - 34.5\log(d) \quad \text{..(5.2)}$$

5.2 SIGNIFICANCE OF RESULTS AND APPLICATIONS

The significance of the results is that it shows the propagation prediction variations of the models over the Nigerian Urban environment. The results gave mean prediction errors of –0.7dB, –4.2 dB and 8.9 dB for Hata,Lee and Walfisch-Ikegami models respectively. This indicates that the COST-231 Walfisch-Ikegami model provided a closer prediction of the environment than the COST-231 Hata and Lee models. The simplicity and ease of computation using the new propagation prediction models enables fast network coverage prediction and planning. These are unlike the standardized models that requires a lot of parameters with the difficulty encountered in it computation. The new prediction models were developed by using the environment for which it is be to be adopted. They are therefore suitable for radio network coverage prediction and planning for this area.

The new prediction models can be used for propagation predictions for the Nigerian mobile GSM network environment whose average buildings height is not more than nine floors. The base stations height can be from 30m upwards with antenna gains from15dBi to 18dBi.These were the parameters considered for the study.

5.3 PROBLEMS ENCOUNTERED AND LIMITATIONS

The major problem encountered at the start of research work is the reluctance on the part of the network operators for cooperation on the collection of data. This problem accounted for the delay in the completion of the research work due to loss of valuable time and expenses in consultations for cooperation. It also accounted for the limited number of propagation measurements obtained.

The limitations were mostly lack of sophisticated equipment for direct measurement of base stations and terrain data. Thus, the reliance on the parameters given by the radio frequency and operations department’s staffs.

5.4 CONCLUSION

The aim of the thesis to provide a fast and suitable network coverage prediction model for this Nigerian urban environment has been achieved. The simplicity and ease of predicting the path loss as well as the received signal strength using the models developed makes it a viable tool for radio network planning. The research also provided the propagation prediction variations of three standard propagation models over a Nigerian urban environment. It showed the effects of the differences in environmental clutters used in developing the model and that of the area under consideration. These are evident from the differences in propagation predictions from the three models examined and that from the base stations in the area studied. However, the new model developed can aid radio network planning and maximize radio network resources for the area.

5.5 RECOMMENDATIONS FOR FURTHER WORK

The management of the network operators should encourage periodic propagation measurements of their base stations to ascertain the quality of service provided and expand their network where necessary. This is very important in urban areas due to increasing number of structures and human migration. These measures will help to improve the performance of the network and enable future network planning. Depending on the availability of sophisticated measurement equipment and terrain data, the research can be expanded to include other models not treated.

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APPENDIX A

Table 4.4: Computed Signal Strength and Path Loss using the COST- 231 Hata Model

	$H_{BS} = 32m$ $f_c = 900MHz, EIRP = 55dBm$		$H_{BS} = 34m$ $f_c = 900MHz, EIRP = 55dBm$	
Distance(km)	$S_R(dBm)$	$L_P(dB)$	$S_R(dBm)$	$L_P(dB)$
0.5	-63.1	118.1	-62.8	117.8
1.0	-73.7	128.7	-73.3	128.3
1.5	-79.8	134.8	-79.4	134.4
2.0	-84.2	139.2	-83.8	138.8
2.5	-87.6	142.6	-87.2	142.2
3.0	-90.4	145.4	-89.9	144.9
3.5	-92.7	147.7	-92.3	147.3
4.0	-94.8	149.8	-94.3	149.3

Table 4.5: Computed Signal Strength and Path Loss using the COST- 231 Hata Model

	$H_{BS} = 32m$ $f_c = 900MHz, EIRP = 57dBm$		$H_{BS} = 34m$ $f_c = 900MHz, EIRP = 57dBm$	
Distance(km)	$S_R(dBm)$	$L_P(dB)$	$S_R(dBm)$	$L_P(dB)$
0.5	-61.1	118.1	-60.8	117.8
1.0	-71.7	128.7	-71.3	128.3
1.5	-77.8	134.8	-77.4	134.4
2.0	-82.2	139.2	-81.8	138.8
2.5	-85.6	142.6	-85.2	142.2
3.0	-88.4	145.4	-87.9	144.9
3.5	-90.7	147.7	-90.3	147.3
4.0	-92.8	149.8	-92.3	149.3

Table 4.6: Computed Signal Strength and Path Loss using the COST- 231 Hata Model

	$H_{BS} = 32m$ $f_c = 900MHz, EIRP = 57.5dBm$		$H_{BS} = 34m$ $f_c = 900MHz, EIRP = 57.5dBm$	
Distance(km)	$S_R(dBm)$	$L_P(dB)$	$S_R(dBm)$	$L_P(dB)$
0.5	-60.6	118.1	-60.3	117.8
1.0	-71.2	128.7	-70.8	128.3
1.5	-77.3	134.8	-76.9	134.4
2.0	-81.7	139.2	-81.3	138.8
2.5	-85.1	142.6	-84.7	142.2
3.0	-87.9	145.4	-87.4	144.9
3.5	-90.2	147.7	-89.8	147.3
4.0	-92.3	149.8	-91.8	149.3

Table 4.7: Computed Signal Strength and Path Loss using the COST-231 Hata Model

	$H_{BS} = 32m$ $f_c = 900MHz, EIRP = 58dBm$		$H_{BS} = 34m$ $f_c = 900MHz, EIRP = 58dBm$	
Distance(km)	$S_R(dBm)$	$L_P(dB)$	$S_R(dBm)$	$L_P(dB)$
0.5	-60.1	118.1	-59.8	117.8
1.0	-70.7	128.7	-70.3	128.3
1.5	-76.8	134.8	-76.4	134.4
2.0	-81.2	139.2	-80.8	138.8
2.5	-84.6	142.6	-84.2	142.2
3.0	-87.4	145.4	-86.9	144.9
3.5	-89.7	147.7	-89.3	147.3
4.0	-91.8	149.8	-91.3	149.3

APPENDIX B

Table 4.8: Computed Signal Strength and Path Loss using the Lee Model

	$H_{BS} = 32m$ $f_c = 900MHz, EIRP = 55dBm$, $G_A = 15dBi$		$H_{BS} = 34m$ $f_c = 900MHz, EIRP = 55dBm$ $G_A = 15dBi$	
Distance(km)	$S_R(dBm)$	$L_P(dB)$	$S_R(dBm)$	$L_P(dB)$
0.5	-57.4	112.4	-57.8	112.8
1.0	-66.5	121.5	-67.1	122.1
1.5	-71.9	126.9	-72.4	127.4
2.0	-75.7	130.7	-76.2	131.2
2.5	-78.7	133.7	-79.2	134.2
3.0	-81.1	136.1	-81.6	136.6
3.5	-83.1	138.1	-83.6	138.6
4.0	-84.9	139.9	-85.4	140.4

Table 4.9: Computed Signal Strength and Path Loss using the Lee Model

	$H_{BS} = 32m$ $f_c = 900MHz, EIRP = 57dBm$, $G_A = 17dBi$		$H_{BS} = 34m$ $f_c = 900MHz, EIRP = 57dBm$ $G_A = 17dBi$	
Distance(km)	$S_R(dBm)$	$L_P(dB)$	$S_R(dBm)$	$L_P(dB)$
0.5	-55.9	112.9	-56.5	113.5
1.0	-65.1	122.1	-65.7	122.7
1.5	-70.4	127.4	-71.1	128.1
2.0	-74.3	131.3	-74.9	131.9
2.5	-77.3	134.3	-77.8	134.8
3.0	-79.7	136.7	-80.2	137.2
3.5	-81.7	138.7	-82.3	139.3
4.0	-83.5	140.5	-84.1	141.1

Table 4.10: Computed Signal Strength and Path Loss using the Lee Model

	$H_{BS} = 32m$ $f_c = 900MHz, EIRP = 57.5dBm$, $G_A = 17.5dBi$		$H_{BS} = 34m$ $f_c = 900MHz, EIRP = 57.5dBm$ $G_A = 17.5dBi$	
Distance(km)	$S_R(dBm)$	$L_P(dB)$	$S_R(dBm)$	$L_P(dB)$
0.5	-55.6	113.1	-56.2	113.7
1.0	-64.8	122.3	-65.4	122.9
1.5	-70.1	127.6	-70.7	128.2
2.0	-74.0	131.5	-74.5	132.0
2.5	-76.9	134.4	-77.5	135.0
3.0	-79.3	136.8	-79.9	137.4
3.5	-81.4	138.9	-82.0	139.5
4.0	-83.1	140.6	-83.7	141.2

Table 4.11: Computed Signal Strength and Path Loss using the Lee Model

	$H_{BS} = 32m$ $f_c = 900MHz, EIRP = 58dBm$, $G_A = 18dBi$		$H_{BS} = 34m$ $f_c = 900MHz, EIRP = 58dBm$ $G_A = 18dBi$	
Distance(km)	$S_R(dBm)$	$L_P(dB)$	$S_R(dBm)$	$L_P(dB)$
0.5	-55.2	113.2	-55.8	113.8
1.0	-64.4	122.4	-65.0	123.0
1.5	-69.8	127.8	-70.4	128.4
2.0	-73.6	131.6	-74.2	132.2
2.5	-76.6	134.6	-77.2	135.2
3.0	-79.0	137.0	-79.6	137.6
3.5	-81.0	139.0	-81.6	139.6
4.0	-82.8	140.8	-83.4	141.4

APPENDIX C

Table 4.12: Computed Signal Strength and Path Loss using the COST-231 Walfisch Ikegami Model

	$H_{BS} = 32m$ $f_c = 900MHz, EIRP = 55dBm$,		$H_{BS} = 34m$ $f_c = 900MHz, EIRP = 55dBm$	
Distance(km)	$S_R(dBm)$	$L_P(dB)$	$S_R(dBm)$	$L_P(dB)$
0.5	-73.5	128.5	-68.1	123.1
1.0	-85.0	140.0	-79.6	134.6
1.5	-91.7	146.7	-86.2	141.2
2.0	-96.1	151.1	-91.0	146.0
2.5	-100.0	155.0	-94.6	149.6
3.0	-103.1	158.1	-97.6	152.6
3.5	-105.6	160.6	-100.2	155.2
4.0	-107.8	162.8	-102.4	157.4
4.5	-109.7	164.7	-104.3	159.3

Table 4.13: Computed Signal Strength and Path Loss using the COST-231 Walfisch Ikegami Model

	$H_{BS} = 32m$ $f_c = 900MHz, EIRP = 57dBm$,		$H_{BS} = 34m$ $f_c = 900MHz, EIRP = 57dBm$	
Distance(km)	$S_R(dBm)$	$L_P(dB)$	$S_R(dBm)$	$L_P(dB)$
0.5	-71.5	128.5	-66.1	123.1
1.0	-83.0	140.0	-77.6	134.6
1.5	-89.7	146.7	-84.2	141.2
2.0	-94.4	151.4	-89.0	146.0
2.5	-98.1	155.1	-92.7	149.7
3.0	-101.1	158.1	-95.7	152.7
3.5	-103.6	160.6	-98.2	155.2
4.0	-105.8	162.8	-100.4	157.4
4.5	-107.7	164.7	-102.3	159.3

Table 4.14: Computed Signal Strength and Path Loss using the COST-231 Walfisch Ikegami Model

	$H_{BS} = 32m$ $f_c = 900MHz, EIRP = 57.5dBm$,		$H_{BS} = 34m$ $f_c = 900MHz, EIRP = 57.5dBm$	
Distance(km)	$S_R(dBm)$	$L_P(dB)$	$S_R(dBm)$	$L_P(dB)$
0.5	-71.0	128.5	-65.6	123.1
1.0	-82.5	140.0	-77.1	134.6
1.5	-89.2	146.7	-83.7	141.2
2.0	-93.9	151.4	-88.5	146.0
2.5	-97.6	155.1	-92.2	149.7
3.0	-100.6	158.1	-95.2	152.7
3.5	-103.1	160.6	-97.7	155.2
4.0	-105.3	162.8	-99.9	157.4
4.5	-107.2	164.7	-101.3	159.3

Table 4.15: Computed Signal Strength and Path Loss using the COST-231 Walfisch Ikegami Model

	$H_{BS} = 32m$ $f_c = 900MHz, EIRP = 58dBm$,		$H_{BS} = 34m$ $f_c = 900MHz, EIRP = 58dBm$	
Distance(km)	$S_R(dBm)$	$L_P(dB)$	$S_R(dBm)$	$L_P(dB)$
0.5	-70.5	128.5	-65.1	123.1
1.0	-82.0	140.0	-76.6	134.6
1.5	-88.7	146.7	-83.2	141.2
2.0	-93.4	151.4	-88.0	146.0
2.5	-97.1	155.1	-91.7	149.7
3.0	-100.1	158.1	-94.7	152.7
3.5	-102.6	160.6	-97.2	155.2
4.0	-104.8	162.8	-99.4	157.4
4.5	-106.7	164.7	-101.3	159.3

APPENDIX D

Table 4.16: Received Signal Strength for Base Station 1(Kan032)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	-72.0	-60.8	-56.5	-66.1
1.0	-84.1	-71.3	-65.7	-77.6
1.5	-75.8	-77.4	-71.1	-84.2
2.0	-82.5	-81.8	-74.9	-89.0
2.5	-85.2	-85.2	-77.8	-92.7
3.0	-110.0	-87.9	-80.2	-95.7
3.5	-102.7	-90.3	-82.3	-98.2

Table 4.17: Received Signal Strength for Base Station 2(Kan027)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	-73.8	-62.8	-57.8	-68.1
1.0	-82.3	-73.3	-67.1	-79.6
1.5	-77.0	-79.4	-72.4	-86.2
2.0	-84.1	-83.8	-76.2	-91.0
2.5	-86.4	-87.2	-79.2	-94.6

Table 4.18: Received Signal Strength for Base Station 3(Kan021)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	-74.5	-59.8	-55.8	-65.1
1.0	-77.7	-70.3	-65.0	-76.6
1.5	-76.4	-76.4	-70.4	-83.2
2.0	-75.8	-80.8	-74.2	-88.0
2.5	-79.5	-84.2	-77.2	-91.7
3.0	-88.4	-86.9.	-79.6	-94.7
3.5	-81.1	-89.3	-81.6	-97.2
4.0	-92.0	-91.3	-83.4	-99.4

Table 4.19: Received Signal Strength for Base Station 4(Kan011)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	-54.0	-61.1	-55.9	-71.5
1.0	-58.9	-71.7	-65.1	-83.0
1.5	-57.2	-77.8	-70.4	-89.7
2.0	-61.1	-82.2	-74.3	-94.4
2.5	-74.5	-85.6	-77.3	-98.1
3.0	-82.2	-88.4	-79.7	-101.1

Table 4.20: Received Signal Strength for Base Station 5(Kan052)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	-77.6	-60.6	-55.6	-71.0
1.0	-79.3	-71.2	-64.8	-82.5
1.5	-78.8	-77.3	-70.1	-89.2
2.0	-84.0	-81.7	-74.0	-93.9
2.5	-81.2	-85.1	-76.9	-97.6
3.0	-91.0	-87.9	-79.3	-100.6
3.5	-85.1	-90.2	-81.4	-103.1

Table 4.21: Received Signal Strength for Base Station 6(Kan044)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	-76.6	-63.1	-57.4	-73.5
1.0	-77.1	-73.7	-66.5	-85.0
1.5	-78.7	-79.8	-71.9	-91.7
2.0	-85.2	-84.2	-75.7	-96.1
2.5	-89.5	-87.6	-78.7	-100.0

Table 4.22: Received Signal Strength for Base Station 7(Kan017)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	-82.5	-63.1	-57.4	-73.5
1.0	-75.1	-73.7	-66.5	-85.0
1.5	-71.0	-79.8	-71.9	-91.7
2.0	-76.8	-84.2	-75.7	-96.1
2.5	-78.7	-87.6	-78.7	-100.0

Table 4.23: Received Signal Strength for Base Station 8(Kan056)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	-55.7	-63.1	-57.4	-73.5
1.0	-60.1	-73.7	-66.5	-85.0
1.5	-72.3	-79.8	-71.9	-91.7
2.0	-77.5	-84.2	-75.7	-96.1

Table 4.24: Received Signal Strength for Base Station 9(Kan026)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	-76.5	-60.3	-56.2	-65.6
1.0	-83.0	-70.8	-65.4	-77.1
1.5	-84.1	-76.9	-70.7	-83.7
2.0	-83.6	-81.3	-74.5	-88.5
2.5	-95.1	-84.7	-77.5	-92.2
3.0	-97.2	-87.4	-79.9	-95.2

APPENDIX E

Table 4.25: Path Loss for Base Station 1(Kan032)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	129.0	117.8	113.5	123.1
1.0	141.1	128.3	122.7	134.6
1.5	132.8	134.4	128.1	141.2
2.0	139.5	138.8	131.9	145.9
2.5	142.2	142.2	134.8	149.7
3.0	167.0	144.9	137.2	152.7
3.5	159.7	147.3	139.3	155.2

Table 4.26: Path Loss for Base Station 2(Kan027)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	128.8	117.8	112.8	123.1
1.0	137.3	128.3	122.1	134.6
1.5	132.0	134.4	127.4	141.2
2.0	139.1	138.8	131.2	145.9
2.5	141.4	142.2	134.2	149.7

Table 4.27: Path Loss for Base Station 3(Kan021)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	132.5	117.8	113.8	123.1
1.0	135.7	128.3	123.0	134.6
1.5	134.4	134.4	128.4	141.2
2.0	133.8	138.8	132.2	146.0
2.5	137.5	142.2	135.2	149.7
3.0	146.4	144.9	137.6	152.7
3.5	139.1	147.3	139.6	155.2
4.0	150.0	149.3	141.4	157.4

Table 4.28: Path Loss for Base Station 4(Kan011)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	111.0	118.1	112.9	128.5
1.0	115.9	128.7	122.1	140.0
1.5	114.2	134.8	127.5	146.7
2.0	118.1	139.2	131.3	151.4
2.5	131.5	142.6	134.3	155.1
3.0	139.2	145.4	136.7	158.1

Table 4.29: Path Loss for Base Station 5(Kan052)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	135.1	118.1	113.1	128.5
1.0	136.8	128.7	122.3	140.0
1.5	136.3	134.8	127.6	146.7
2.0	141.5	139.2	131.5	151.4
2.5	138.7	142.6	134.4	155.1
3.0	148.5	145.4	136.8	158.1
3.5	142.6	147.7	138.9	160.6

Table 4.30: Path Loss for Base Station 6(Kan044)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	131.6	118.1	112.4	128.5
1.0	132.1	128.7	121.5	140.0
1.5	133.7	134.8	126.9	146.7
2.0	140.2	139.2	130.7	151.4
2.5	144.5	142.6	133.7	155.1

Table 4.31: Path Loss for Base Station 7(Kan017)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	137.5	118.1	112.4	128.5
1.0	130.1	128.7	121.5	140.0
1.5	126.0	134.8	126.9	146.7
2.0	131.8	139.2	130.7	151.4
2.5	133.7	142.6	133.7	155.1

Table 4.32: Path Loss for Base Station 8(Kan056)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	110.7	118.1	112.4	128.5
1.0	115.1	128.7	121.5	140.0
1.5	127.3	134.8	126.9	146.7
2.0	132.5	139.2	130.7	151.4

Table 4.33: Path Loss for Base Station 9(Kan026)

Distance(km)	Measurement	Hata	Lee	Walfisch
0.5	134.0	117.8	113.7	123.1
1.0	140.5	128.3	122.9	134.6
1.5	141.6	134.4	128.2	141.2
2.0	141.1	138.8	132.0	146.0
2.5	152.6	142.2	135.0	149.7
3.0	154.7	144.9	137.4	152.7

APPENDIX F

Table 4.34: Differences between Measurements and Predictions using the Hata Model for Base Station 1(kan032).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	117.8	129.0	-11.2
1.0	128.3	141.1	-12.8
1.5	134.4	132.8	1.6
2.0	138.8	139.5	-0.7
2.5	142.2	142.2	-5.0
3.0	144.9	167.0	-22.1
3.5	147.3	159.7	-12.4

Table 4.35: Differences between Measurements and Predictions using the Lee Model for Base Station 1(kan032).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	113.5	129.0	-15.5
1.0	122.7	141.1	-18..4
1.5	128.1	132.8	-4.7
2.0	131.8	139.5	-7.7
2.5	134.8	142.2	-7.4
3.0	137.2	167.0	-29.8
3.5	139.3	159.7	-20.4

Table 4.36: Differences between Measurements and Predictions using the Walfisch-Ikegami Model for Base Station 1(kan032).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	123.1	129.0	-5.9
1.0	134.6	146.1	-6.5
1.5	141.2	132.8	8.4
2.0	146.0	139.5	6.5
2.5	149.7	142.2	7.5
3.0	152.7	167.0	-14.3
3.5	155.2	159.7	-4.5

Table 4.37: Differences between Measurements and Predictions using the Hata Model for Base Station 2(kan027).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	117.8	128.8	-11.0
1.0	128.3	137.3	-9.0
1.5	134.4	132.0	2.4
2.0	138.8	139.1	-0.3
2.5	142.2	141.4	0.8

Table 4.38: Differences between Measurements and Predictions using the Lee Model for Base Station 2(kan027).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	112.8	128.8	-16.0
1.0	122.1	137.3	-15.2
1.5	127.4	132.0	-4.6
2.0	131.2	139.1	-7.9
2.5	134.2	141.4	-7.2

Table 4.39: Differences between Measurements and Predictions using the Walfisch- Ikegami Model for Base Station 2(kan027).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	123.1	128.8	-5.7
1.0	134.6	137.3	-2.7
1.5	141.2	132.0	9.2
2.0	145.9	139.1	6.8
2.5	149.7	141.4	8.3

Table 4.40: Differences between Measurements and Predictions using Hata Model for Base Station 3(kan021).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	117.8	132.5	-14.7
1.0	128.3	135.7	-7.4
1.5	134.4	134.4	0
2.0	138.8	133.8	5.0
2.5	142.2	137.5	4.7
3.0	144.9	146.4	-1.5
3.5	147.3	139.1	8.2
4.0	149.3	150.0	-0.7

Table 4.41: Differences between Measurements and Predictions using Lee Model for Base Station 3(kan021).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	113.8	132.5	-18.7
1.0	123.0	135.7	-12.7
1.5	128.4	134.4	-6.0
2.0	132.2	133.8	-1.6
2.5	135.2	137.5	-2.3
3.0	137.6	146.4	-8.8
3.5	139.6	139.1	-0.5
4.0	141.4	150.0	-8.6

Table 4.42: Differences between Measurements and Predictions using the Walfisch-Ikegami Model for Base Station 3(kan021).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	123.1	132.5	-9.4
1.0	134.6	135.7	-1.1
1.5	141.2	134.4	6.8
2.0	146.0	133.8	12.2
2.5	149.7	137.5	12.2
3.0	152.7	146.4	6.3
3.5	155.2	139.1	16.1
4.0	157.4	150.0	7.4

Table 4.43: Differences between Measurements and Predictions using the Hata Model for Base Station 4(kan011).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	118.1	111.0	7.1
1.0	128.7	115.9	12.8
1.5	134.8	114.2	20.6
2.0	139.2	118.1	21.1
2.5	142.6	131.5	11.1
3.0	145.4	139.2	6.2

Table 4.44: Differences between Measurements and Predictions using the Lee Model for Base Station 4(kan011).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	112.9	111.0	1.9
1.0	122.1	115.9	6.2
1.5	127.5	114.2	13.3
2.0	131.3	118.1	13.2
2.5	134.3	131.5	2.8
3.0	136.7	139.2	-2.5

Table 4.45: Differences between Measurements and Predictions using the Walfisch–Ikegami Model for Base Station 4(kan011).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	128.5	111.0	17.5
1.0	140.0	115.9	24.1
1.5	146.7	114.2	32.5
2.0	151.4	118.1	33.3
2.5	155.1	131.5	23.6
3.0	158.1	139.2	18.9

Table 4.46: Differences between Measurements and Predictions using the Hata Model for Base Station 5(kan052).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	118.1	135.1	-17.0
1.0	128.7	136.8	-8.1
1.5	134.8	136.3	-1.5
2.0	139.2	141.5	-2.3
2.5	142.6	138.7	3.9
3.0	145.4	148.5	-3.1
3.5	147.7	142.6	5.1

Table 4.47: Differences between Measurements and Predictions using the Lee Model for Base Station 5(kan052).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	113.1	135.1	-22
1.0	122.3	136.8	-14.5
1.5	127.6	136.3	-8.7
2.0	131.5	141.5	-10.0
2.5	134.4	138.7	-4.3
3.0	136.8	148.5	-11.7
3.5	138.9	142.6	-3.7

Table 4.48: Differences between Measurements and Predictions using the Walfisch-Ikegami Model for Base Station 5(kan052).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	128.5	135.1	-6.6
1.0	140.0	136.8	3.2
1.5	146.7	136.3	10.4
2.0	151.4	141.5	9.9
2.5	155.1	138.7	16.4
3.0	158.1	148.5	9.8
3.5	160.6	142.6	18

Table 4.49: Differences between Measurements and Predictions using the Hata Model for Base Station 6(kan044).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	118.1	131.6	-13.5
1.0	128.7	132.1	-3.4
1.5	134.8	133.7	1.1
2.0	139.2	140.2	-1.0
2.5	142.6	144.5	-1.9

Table 4.50: Differences between Measurements and Predictions using the Lee Model for Base Station 6(kan044).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	112.4	131.6	-19.2
1.0	121.5	132.1	-10.6
1.5	126.9	133.7	-6.8
2.0	130.7	140.2	-9.5
2.5	133.7	144.5	-10.8

Table 4.51: Differences between Measurements and Predictions using the Walfisch-Ikegami Model for Base Station 6(kan044).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	128.5	131.6	-3.1
1.0	140.0	132.1	7.9
1.5	146.7	133.7	13
2.0	151.4	140.2	11.2
2.5	155.1	144.5	10.6

Table 4.52: Differences between Measurements and Predictions using the Hata Model for Base Station 7(kan017).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	118.1	137.5	-19.4
1.0	128.7	130.1	-1.4
1.5	134.8	126.0	8.8
2.0	139.2	131.8	7.4
2.5	142.6	133.7	8.9

Table 4.53: Differences between Measurements and Predictions using the Lee Model for Base Station 7(kan017).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	112.4	137.5	-25.1
1.0	121.5	130.1	-8.6
1.5	126.9	126.0	0.9
2.0	130.7	131.8	-1.1
2.5	133.7	133.7	0

Table 4.54: Differences between Measurements and Predictions using the Walfisch-Ikegami Model for Base Station 7(kan017).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	128.5	137.5	-9.0
1.0	140.0	130.1	9.9
1.5	146.7	126.0	20.7
2.0	151.4	131.8	19.6
2.5	155.1	133.7	21.4

Table 4.55: Differences between Measurements and Predictions using the Hata Model for Base Station 8(kan056).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	118.1	110.7	7.4
1.0	128.7	115.1	13.6
1.5	134.8	127.3	7.5
2.0	139.2	132.5	6.7

Table 4.56: Differences between Measurements and Predictions using the Lee Model for Base Station 8(kan056).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	112.4	110.7	1.7
1.0	121.5	115.1	6.4
1.5	126.9	127.3	-0.4
2.0	130.7	132.5	-1.8

Table 4.57: Differences between Measurements and Predictions using the Walfisch-Ikegami Model for Base Station 8(kan056).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	128.5	110.7	17.8
1.0	140.0	115.1	24.9
1.5	146.7	127.3	19.4
2.0	151.4	132.5	18.9

Table 4.58: Differences between Measurements and Predictions using the Hata Model for Base Station 9(kan026).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	117.8	134.0	-16.2
1.0	128.3	140.0	-12.2
1.5	134.4	141.6	-7.2
2.0	138.8	141.1	-2.3
2.5	142.2	152.6	-10.4
3.0	144.9	154.7	-9.8

Table 4.59: Differences between Measurements and Predictions using the Lee Model for Base Station 9(kan026).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	113.7	134.0	-20.3
1.0	122.9	140.0	-17.6
1.5	128.2	141.6	-13.4
2.0	132.0	141.1	-9.1
2.5	135.0	152.6	-17.6
3.0	137.4	154.7	-17.3

Table 4.60: Differences between Measurements and Predictions using the Lee Model for Base Station 9(kan026).

Distance(km)	Predicted $L_P(dB)$	Measured $L_P(dB)$	Difference $L_P(dB)$
0.5	123.1	134.0	-10.9
1.0	134.6	140.0	-5.9
1.5	141.2	141.6	-0.4
2.0	146.0	141.1	4.9
2.5	149.7	152.6	-2.9
3.0	152.7	154.7	-2.0