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SCHOOL OF GRADUATE STUDIES
FACULTY OF ELECTRICAL & COMPUTER ENGINEERING
DEPARTMENT OF TELECOMMUNICATIONS ENGINEERING

SENSITIVITY OF RECEIVED POWER IN ANTENNA DOWN-TILT IN CLUTTERED MOBILE ENVIRONMENTS

A CASE STUDY OF WEST AFRICA TELECOM INDUSTRY

BY

KOFFI AGBEBLEWU, DOTCHE

OCTOBER, 2010

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By

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DECLARATION

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

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ABSTRACT

In Code Division Multiple Access (CDMA) mobile environment, transmitter and receiver signals are heavily influenced by the effect of clutter surrounding both the transmitter and the receiver. Therefore the ability to optimize a CDMA system is dependent on the initial system configuration at the deployment stage. This includes the site location, antenna type, orientation, down-tilt and the choice of propagation model which contributes greedily to a better optimization of the network. It is a very important function in cellular radio system design. For the prior optimization of the network, the propagation parameters should be optimized. The parameters that influence the received signal such the terrain topology with regard to the mechanical down-tilt are presented. In incorrect coordinate of the BTS cell site, a poor coverage was also observed. Furthermore, the measurement of the received power from CDMA pilot carried out during the drive-test in Greater Accra was used to evaluate the excess path loss. This excess path loss in value was obtained from the comparison between Hata-Okumura Models and the measured path loss. The prediction response was not satisfactory in the study area therefore the prediction model was then tuned by the use of the least square algorithm.

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ABBREVIATION LIST

3-D: Three Dimensions

BS: Base Station

BTS: Base Transceiver Station

CDMA: Code Division Multiple Access

CDMA2000: Multi-carrier CDMA

CAEDT: Continuously Adjustable Electrical Down-Tilt

CDF: Cumulative Distribution Function

CINR: Carrier to-Interference-plus-Noise Ratio

CIR: Carrier to Interference Ratio

CNP: Communication Network Planning

CNT: Communication Network Terminal /Tool

ECC: Electronic Communication Committee

EDT: Electrical Down-tilt

EV-DV: Evolution-Data/Voice

EV-DO: Evolution Data Optimized

ERP: Effective Radiated Power

FET: Fixed Electrical Tilt

FCC: Federal Communication Commission

FDMA: Frequency Division Multiple Access

GPS: Global Positioning System receiver set

GSM: Groupe Spéciale Mobile / Global System for Mobile communication

IMT-2000: International Mobile Telecommunication - 2000

IS: Integrated Standard / Interim Standard-95

ITU: International Telecommunication Union

KPI: Key Performance Indicator

LOS: Line of Sight

MDT: Mechanical Down-Tilt

MS: Mobile Station

NLOS: Non-Line-of-Sight

PN: Pseudo-Noise code

PSMM: Pilot Strength Measurement Message

QoS: Quality of Service

Rev A: Revision A

Rev B: Revision B

RET: Remote Electrical Tilt

RF: Radio Frequency

RSSI: Received Signal Strength Indicator

SLA: Service Level Agreement

SNR: Signal to Noise Ratio

TDMA: Time Division Multiple Access

UE: User-Equipment (Terminal)

UHF: Ultra High frequency

UMTS: Universal Mobile Telecommunication System, a high speed 3G mobile phone technology

VET: Variable Electrical Tilt

VHF: Very High Frequency

WCDMA: Wideband CDMA

Eb/No is the energy per bit divided by the noise power spectral density

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CHAPTER ONE

INTRODUCTION

1.0. Introduction

A mobile radio propagation channel is the air interface between the Mobile Station (MS) and the Base Station (BS or BTS). It takes into account buildings, trees, streets, hills, water; and all kinds of obstructions in addition to the extent of the terrain's roughness, etc., as illustrated in **Figure: 1.1.** In this cluttered environment, the signal is heavily influenced by reflections from buildings surrounding both the transmitter (BS) and receiver (MS). Due to this cluttered environment, the radio signal received at MS, varies randomly. This variation in received signal is also explained by the effect of shadowing or fading in signal.

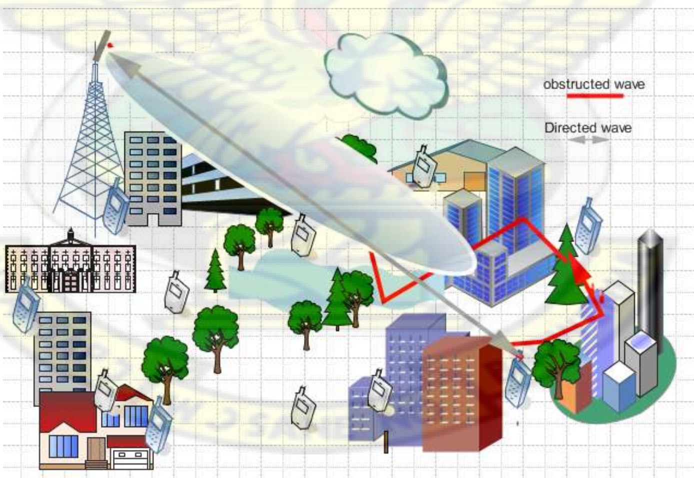

Figure 1.1: Mobile cluttered environment

The fading manifests itself in two ways: over small distance (known as Small Scale Fading: SSF) or over a long distance (known as Large Scale Fading: LSF). The large-scale fading is related to diffraction and reflection effects that the multipath components undergo on their way between the transmitter and the receiver. The small-scale fading is rapid changes observed in received signal. On the other hand, another general phenomenon, which is a source of signal attenuation, is multipath propagation.

Multipath propagation has several stochastic models (Parsons, 1992) such as:

- Rayleigh fading model (when all multipath signals reach receiver with same levels),
- Rician fading model: when one multipath signal is stronger than the rest.

These fading models have been generalized in the Nakagami fading model.

Fading occurs when a radio wave propagated through the air medium (radio channel), is forced to deviate, reflect, bounce, refract or scatter. These phenomena give birth to several copies of the same signal which may arrive at the receiver's end with different delays, in time or in phase (Parsons, 1992). In mobile communication, the receiver antenna is a moving user with a handset. Due to the relative low height of the user, the mobile antenna receives a large number of reflected and scattered waves.

In order to reduce the air medium attenuation and multipath effects on radio signal, the transmitter beam-width is directed towards the ground in a specific area. This technique is known as antenna down/up-tilt or beam-tilt. The main idea behind antenna down-tilt is to reduce the radio frequency energy refracted by the ground-based layers and also the multipath fading (Jarno et al., 2005). It is used to provide effective coverage in interference-limited environments as in Code Division Multiple Access (CDMA) cellular networks air interface.

The concept of antenna down-tilt also aims at reducing co-channel interference between cells in noise-limited environments as in Global System for Mobile (GSM) communication (Jöerg, 1998) which in turn improves the soft or softer handover effect in CDMA network.

The benefit of this is that mobiles operating at the edge of a cell can be supported by neighbouring cells or served by adjacent sectors. There are basically two ways to down-tilting antenna, which are: Mechanical Down-Tilt (MDT), and Electrical Down-tilt (EDT). In MDT, the antenna element is physically directed towards the ground. Naturally, the areas near the base station experience stronger signal. An EDT is carried out by adjusting the relative phase of the antenna elements in an antenna array in such a way that the radiation pattern can be down-tilted uniformly in all horizontal directions (Jarno et al., 2005). An electrical beam-tilt can be adjusted in the field by changing external phasing cables (Forkel et al., 2001). Many antenna down-tilt schemes exist including purely fixed mechanical tilt, fixed electrical tilt, variable electrical tilt (VET), remote electrical tilt (RET), and continuously adjustable electrical down-tilt (CAEDT) (Kathrein, 2009). These latest techniques highly remove the need of site visit.

1.1. Motivation

In CDMA systems cell overlapping technique is used to attain a high capacity thus its performance (Yang, 1998). Cell overlapping can be obtained by Pseudo Noise (PN) code assignment (Yang, 1998) to the Base Transceiver Station (BTS) sector also called Base Station (BS) and BTS antenna down-tilt. However, the selection of the optimum down-tilt angle for an antenna for practical macro-cell coverage is quite difficult within its environment.

Antenna down-tilt has been studied to be a useful tool for radio resource management and Radio Frequency (RF) planning engineers. In down-tilting, a less co-channel interference is observed for far-end users. This contributes to remarkable increase in system capacity at the cost of decreased cell service radius (Wu et al., 1998). When the down-tilt angle increases, the cell radius decreases therefore the soft-handoff probability also decreases (Jarno et al., 2005) then the received power also decreases. The questions of concern now are: what are the design parameters that should be optimized such that the interference area is minimized by mitigating the following: the cell radius, the received power and the coverage, and what are the parameters that contribute to the optimum down-tilt angle in cellular network coverage?

1.2. Objective

In this thesis, the main aim is to measure the sensitivity of received power to variation in antenna down-tilting situations in cluttered mobile environments in CDMA2000 cellular network by using a drive-test system based on GPS receiver antenna. The results obtained from the variation in received signal will be compared with that predicted by macro-cell 3D propagation algorithm.

1.3. Conclusion

Minimizing signal attenuation between the transmitter (BTS) and the receiver (MS) in mobile communication is very vital for the reliability of any communication link design. For this reason the transmitter antenna is down or up tilted. The use of down-tilt technique and directional antennae in CDMA mobile cellular network contribute to combat Rayleigh channel impairment. In addition predicting a BTS cell-coverage area is a very complicated problem which involves an in-depth knowledge of the frequency of operation, the nature of the terrain, the extent of urbanization, the height of the antenna and several other factors. It is also challenging to pursue an exact deterministic analysis of the environment except if current terrain and environmental databases are available. With regard to this demanding aspect, RF cellular coverage design parameters are a priori optimized.

The layout of this thesis is as follows. The first chapter is devoted to the introduction and objectives. Chapter two tackles the previous related works on antenna down-tilt, the received power theory. In chapter three, RF drive-testing measurement procedure is presented. Chapter four presents the analysis of measurement of various environments and comparative results to that predicted by 3-D propagation algorithm. Chapter five presents a conclusion and exhibits eventual recommendation which can lead to further research.

CHAPTER TWO

LITERATURE REVIEW

2.0. Introduction

Sensitivity is the ability to respond to slight changes observed in a measured quantity influenced by the design parameters. Sensitivity study aims to optimize the design parameters. CDMA mobile system design, one important factor is the carrier to noise and interference ratio (CINR) or $\boldsymbol{C/(N+I)}$. This parameter indicates the power level at receiver end compared to the total available noise over the channel. It is a function of the allowable path loss $\boldsymbol{PL_{al}}$ (medium attenuation of the signal strength), the Effective Radiated Power (ERP) from the transmitter and the overall noise (Thermal noise $\boldsymbol{N_{thermal}}$ plus that of neighbouring cell interference often modelled as a Gaussian Noise $\boldsymbol{\eta}$) given as in **Equation 2.1.a**, also called link equation. It can then be used as a figure of merit (Yang, 1998).

$$\boldsymbol{C/(N+I)} = \frac{\boldsymbol{erp * g_{Rx} * PL_{al}}}{\boldsymbol{\eta + N_{thermal}}} \qquad 2.1.a$$

where $\boldsymbol{erp(w)} \Longrightarrow ERP(dBW) = P_{T_x} + G_{Tx} - C_{loss}$ 2.1.b

$\boldsymbol{C_{loss}}$ takes into account connectors loss and cable loss, $\boldsymbol{P_{T_x}}$ is the power at the output of the transmitter amplifier, $\boldsymbol{G_{Tx}}$ transmitter antenna gain and $\boldsymbol{g_{Rx}}$ is the receiving antenna gain.

$\boldsymbol{N_{thermal}} = k * TB_{dB}$

$k = 1.38 * 10^{-23}\,\mathrm{W/Hz/K}$ or $-228.6\ \mathrm{dBW/Hz/K}$ is the Boltzmann constant,
B is the channel bandwidth,

T is the temperature in the environment in °Kelvin.

There are two parameters involved in the link equation which are not under the control (can only be optimized) of the RF system design engineer. These are $\boldsymbol{\eta}$ cumulative power in inter-cell and intra-cell interference and $\boldsymbol{PL_{al}}$. The inter-cell and intra-cell are system dependent, while $\boldsymbol{PL_{al}}$ depends on the environment. Throughout this thesis, the capital letters are used to express values in dBm or dB.

2.1. Antenna down-tilt

Antenna down-tilt technique has been employed for traffic congestion relief in hot-spot (Wu et al., 1998) and in (J. Wu and D. Yuan, 1996) where the issue of the defining the optimum down-tilt angle for a practical macro-cell was addressed first. However, the analysis of the optimum down-tilt angle empirical formula of Base Station sector of macro-cell was carried out in (Jarno et al., 2005).

An optimum down-tilt angle has been observed to depend on the geometrical factor (ϴgeo) and on antenna vertical beamwidth (ϴVerB) (also expressed as θ_{-3dB}) - either for MDT or EDT. A mechanical down-tilt is illustrated in **Figure: 2.1.**

A macro-cell down-tilt θ is related to the above quantities as in **Equation 2.2** (J. Wu and D. Yuan, 1996).

$$\theta = \theta_{geo} + \frac{\theta_{-3dB}}{2} \qquad 2.2.$$

In **Figure: 2.1**, θ_{geo} is calculated as $\theta_{geo} = \arctan(\frac{\mathrm{H-h_{MS}}}{d})$, where the distance between the transmitter (BTS) of a height H and the Mobile Station (MS) of a height h_{MS} is

$$\boldsymbol{d} = \frac{\Delta \boldsymbol{h}}{\mathbf{tan}(\Theta_{\boldsymbol{geo}})} \qquad \text{with:} \quad \Delta h = H - h_{MS}$$

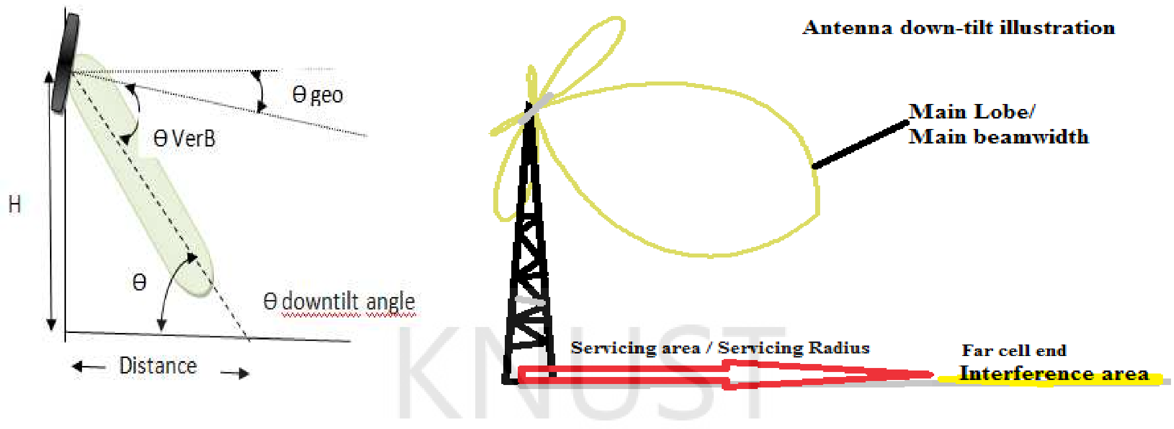

Figure 2. 1: Mechanical down-tilt

Due to the fact that performing a down-tilt angle selection with the expression provided in **Equation 2.2**, as in (J. Wu and D. Yuan, 1996); it overestimates or underestimates the Base Station Sector down-tilt angle which was argued in (Jarno et al., 2005). But then in (Jarno et al., 2005), while from simulation work using Monte Carlo approach, an empirical equation for an optimum down-tilt angle selection was derived with a standard deviation error of 0.5 corresponding to 1 to 3 degrees (J. Lampiainen and M. Mannien Eds, 2003) given as in **Equation 2.3**. This value was found to be in the range of 3.5 degrees to 10.5 degrees.

$$\Theta_{\mathrm{opt}} = 3\,[\ln(h_{BTS}) - d^{0.8}]\,.\log_{10}(\theta_{-3dB}) \qquad 2.3$$

For commodity in the following line of this thesis, $\boldsymbol{h_{BTS}}$ is the effective height of the Base Station (BS) in m is used, $\boldsymbol{d}$ is the cell radius in km and $\boldsymbol{\theta_{-3dB}}$ is the antenna half beam Power in dB. This formula is quite simple and fast in computing, but does not give information about the cell interference area and also not enough information relative to the cluttered environment since one knows that an immediate physical effect of antenna down-tilt is to reduce the cell radius.

Several studies have been conducted on antenna down-tilt in the literature (Karner et al., 2006; WICON'06, 2006; Wilson,1992; Prasad et al., 2005; Baltzis, 2008). In (Jarno et al., 2005; J. Lampiainen and M. Mannien Eds, 2003), it has been proposed that in coverage-limited environments (e.g., in rural areas), mechanical tilting was more useful while in capacity-limited environments (e.g., in a city centre), minimization of the interference was more vital and hence electrical down-tilt could provide better performance. It has also been reported in (I. Forkel et al., 2001) that electrical tilt performed better than mechanical tilt in variation of the target Carrier to noise Interference Ratio (CIR). The network performance was evaluated under different load in antenna down-tilting situation in Universal for Mobile Telecommunication Systems (UMTS) where Hata-Okumura model (Hata, 1980; Okumura et al., 1968) of propagation was applied. However a lower CIR value was observed at distances close to BS. Because of the fact, that the antenna was emitting its power more to the cell boundary.

Fading is also known as attenuation in signal strength. This was observed by Okumura (Okumura et al., 1968) in cluttered environment during a vast drive-test measurement. Okumura (Okumura et al.,1968) therefore claimed that the decreased rate in signal strength with distance was greater than that predicted by Free Space loss (FSL). Okumura then developed some curves for "median" path loss prediction in 1968 (Okumura et al., 1968). Some of the papers reported that the model showed accuracy for median path loss prediction in cluttered environment but argued that the model did not provide any analytical explanation.

2.2. Received power in mobile communication environment

The received power at an MS end varies randomly because of the presence of the cluttered environment. This unfortunately constitutes the air-interface between the MS and the BTS. In the following lines, the impairment of this medium is described by the path loss as stated in above lines. The theories of received power at MS end being a function of the path loss and down-tilt angle are addressed.

2.2.1. Propagation model in mobile communication

A propagation model basically predicts what will happen to the transmitted signal while in transit to the receiver (Rahnema, 2008). It is important in the design of mobile cellular systems. It is used to evaluate the link budget, to determine the cell size, to estimate the fade margin and for frequency reuse planning in GSM cellular network. There are deterministic and stochastic propagation models used in designing, optimization, and performance evaluation of cellular mobile radio systems (Rahnema, 2008). Deterministic models are based on electromagnetic simulations (utilizing ray tracing together with geometrical optics and uniform theory of diffraction, finite difference time domain method, and so forth) making use of information of the specific physical environment or on measurements. Stochastic models, also called local mean propagation models, describe the propagation phenomena on average terrain of the fading distributions). For industry need though local mean models present agreement problems but they are most preferable to estimate the signal strength at a user end.

In cellular macro-cell application (Rahnema, 2008), it is admitted that at a relative close distance $\boldsymbol{d}$ of 20m value far away from BTS, the signal strength attenuation is assumed to follow free space loss prediction. The free space is environment said to be exempt of any impairments. The wave propagation is in line of sight. The free space loss prediction p_{FSL} is known as the Friis Equation (Parsons 1998, Rahnema, 2008) and given as in **Equation 2.4a**:

$$p_{FSL} = g_{Tx} * g_{Rx} * \left(\frac{\lambda}{4\pi d}\right)^2 \qquad 2.4.a$$

$$\Rightarrow P_{FSL}[dB] = -G_{Tx}[dB] - G_{Rx}[dB] + 20log\left(\frac{\lambda}{4\pi d}\right)\ [dB]$$

$$p_{FSL_i} = \left(\frac{\lambda}{4\pi d}\right)^2 \Rightarrow P_{FSL_i}(dB) = 32.4 + 20 * log10(f[MHZ]) + 20log10(d[km])$$

p_{FSL_i} is the relative free space equation between two isotropic antennae. $\lambda = c/f$ is the wavelength, f is the carrier frequency and c is the speed of light in vacuum,

g_{Tx} is the transmitting antenna Tx (BTS or BS) gain in watt and g_{Rx} is the receiving antenna Rx (MS) gain in watt. G_{Tx} , Tx gain in dB, G_{Rx} Rx gain in dB, d in km.

A propagation taken place over plane earth surface is described by the plane earth propagation path loss model (Parsons, 1992). The relative loss p_{Earth} is given as in **Equation 2.4.b**.

$$p_{Earth} = g_{T_X} * g_{R_X}\left(\frac{h_{BTS} * h_{MS}}{d^2}\right)^2 \qquad 2.4.b$$

By contrast, experimental research at mobile telephone frequencies showed that, the received power is overestimated when the receiving antenna height is less than 30m. A new model modifies the exponent of mobile station (MS) height h_{MS} as in (Fujimoto et al., 2001).

The modified model is given as in **Equation 2.4.c.**

$$p_{Earth} = g_{T_X} * g_{R_X}\left(\frac{h_{BTS}^2 * h_{MS}^k}{d^4}\right) \qquad 2.4.c$$

If the height of an MS is below 10m, then $k = 1$ and varies linearly between 10 to 30m an expression of k is as follows:

$$k = \frac{h_{MS}}{20} + \frac{1}{2}$$

Referring to user mobility within an environment and terrain surface roughness, the signal strength at receiver end will vary randomly around the local mean. This variation is known as the fading in signal strength. The fading over large distance is called large scale fading and over short distance this is called small scale fading. The path loss can then be modelled as being a function of **Large Scale Fading** LSF, **Small Scale Fading** SSF (Parsons, 1992; Rahnema, 2008) and the **distance** between the Transmitter (Tx) and the Receiver (Rx) given as follows:

$$PL_{al} = LSF + SSF + D(h_{BTS}, \theta))$$

where, the distance $D(h_{BTS}, \theta)$ can also be expressed as a function of base station antenna height and down-tilt.

$$D(h_{BTS}, \theta) = 10 * \log(d(h_{BTS}, \theta)) \qquad d(h_{BTS}, \theta) = \frac{h_{BTS}}{\tan(\theta)}$$

In industry, the local mean signal strength is the most in concern to estimate the signal strength at a user's particular location. The local mean path loss $P_{L_{al}}(d, X_\sigma)$ between two isotropic antennae in any communication system accounting for the effect of shadowing is expressed by the general empirical model formula in (Wu et al., 1998) given as in **Equation: 2.4.d.**

$$P_{L_{al}}(d, X_\sigma) = loss(d, X_\sigma) = d^{-n}(h_{BTS}, \theta) * 10^{\frac{X_\sigma}{10}} \qquad 2.4.d$$

The discussed path loss expression is a function of three main variables such as the path loss exponent $\boldsymbol{n}$ which describes the environment, the distance separation $\boldsymbol{d}$ between a BS and an MS as a function of the antenna down-tilt angle $\boldsymbol{\theta}$, and $\boldsymbol{X_\sigma}$ shadowing value which typically is modeled as a lognormal random variable. $\boldsymbol{X_\sigma}$ is often found based on measurement over a wide range of locations, with respect to distance between transmitter-receiver. An average value of 8 dB for $\boldsymbol{\sigma}$ is often used giving $\boldsymbol{X_\sigma}$ as 10.5 dB its probability density function, $P(\boldsymbol{X_\sigma})$, of a random normal distribution is given as follows:

$$P(\boldsymbol{X_\sigma}) = \frac{1}{\sigma\sqrt{2\pi}} * e^{-x^2/(2\sigma^2)}$$

The power-law model given as in **Equation: 2.4.e,** estimates the path loss, with regard to a reference distance $\boldsymbol{d_0}$ taking in the near field of transmitting antenna. The propagation within this area is mostly assumed to be taking place in free space having a path loss exponent in a value equals to 2 ($\boldsymbol{n = 2}$), with a reference loss $\boldsymbol{P_0}$ (Rahnema, 2008) the reference loss $\boldsymbol{P_0}$ is as follows:

$$P_0 = -G_{Tx}[dB] - G_{Rx}[dB] + 20log\left(\frac{\lambda}{4\pi d_0}\right)\ [dB]$$

$$P_{L_{al}}(d, X_\sigma) = P_0 + X_\sigma + 10nlog\left(\frac{\boldsymbol{d}(h_{BTS},\theta)}{\boldsymbol{d_0}}\right) \qquad 2.4.e$$

In mobile environment, the MS is assumed to be roaming in the wireless network and be changing N different areas. From **Equation 2.4.c-d**, it shows out that the mean path loss $\boldsymbol{P_{Lmean}}$ for a path length d which runs over N different areas having N different path loss slopes n_i and $i = 0, \dots, N-1$ is obtained as in **Equation: 2.4.f** (Karim and M. Sarrah, 2002), accounting for different shadowing attenuation at various locations the allowable path loss $\boldsymbol{PL_{al}}$ shields **Equation 2.4.g:**

$$PL_{mean} = \left(\frac{4\pi d_0}{\lambda}\right)^{-n_0} \left(\frac{d_1}{d_0}\right)^{-n_1} \left(\frac{d_2}{d_1}\right)^{-n_2} \dots \left(\frac{d}{d_{N-1}}\right)^{-n_{N-1}} \qquad 2.4.f$$

In logarithmic form, it comes as follows:

$$PL_{mean} = 10n_0 log\left(\frac{\lambda}{4\pi d_0}\right) + 10n_1 log\left(\frac{d_0}{d_1}\right) + 10n_2 log\left(\frac{d_1}{d_2}\right) + \cdots + 10n_{N-1} \log\left(\frac{d_{N-1}}{d}\right)$$

$d_{N-1} \leq d \leq d_N$, with $d_i = d(h_{BTS}, \theta_i)$ and thus

$$PL_{al} = 10n_0 log\left(\frac{\lambda}{4\pi d_0}\right) + 10n_1 log\left(\frac{d_0}{d_1}\right) + 10n_2 log\left(\frac{d_1}{d_2}\right) + \cdots + 10n_{N-1} log\left(\frac{d_{N-1}}{d}\right) + X_{\sigma_{n_0}} + \cdots + X_{\sigma_{n_{N-1}}} \qquad 2.4.g$$

$$X_{\sigma}(dB) = X_{\sigma_{n_0}} + X_{\sigma_{n_1}} + \cdots + X_{\sigma_{n_{N-1}}}$$

Admitting the difficulties of modelling different characteristics of various locations and lack of available clutter databases, statistical model analysis of the radio signal measurement, shows that the observed path loss $\boldsymbol{PL_{al}}$ at any separation distance **d** between BS and MS to be followed a normal distribution around the mean path loss $\boldsymbol{P_{Lmean}}$. This is given as in **Equation 2.4.h:**

$$P_{L_{al}}(dB) = P_{Lmean}(dB) + X_{\sigma}(dB) \qquad 2.4.h$$

In solving these problems Hata (Hata, 1980) derived a mathematical model for path loss prediction in urban environment which was approximated to Okumura (Okumura et al., 1968) curve developed in 1968. He considered an urban area as basis for his model and supplied corrections to fit Suburban and Rural area. The modified model of Okumura (Okumura et al., 1968) by Hata is often called Hata-Okumura model. The model has found its application in land and mobile communication environment. It is also knows as macro-cell 3-D propagation algorithm. Hata-Okumura (Hata, 1980; Okumura et al., 1968) model is widely used to describe the path loss prediction in cluttered environment (Rahnema, 2008).

The model makes use of four (4) input parameters such as the carrier frequency (**f**) in **MHz,** BTS antenna height ($\boldsymbol{h_{BTS}}$) in **m,** MS antenna height ($\mathbf{h_{Ms}}$) in **m** and distance of separation between the BTS and the MS (**d**) in **km**. The basic form of Hata-Okumura (Yang, 1998; Hata, 1980; Rahnema, 2008) model applied in urban to the allowable path loss is given as in **Equation 2.5**, for a valid frequency range from 150 to 1500MHz:

$$PL_{al}(dB) = 69.55 + 26.16 * log(\mathrm{f}) - 13.82 * \log(h_{BTS}) + \big(44.9 - 6.55 * log(h_{BTS})\big) * \log\big(d(h_{BTS}, \theta)\big) - a(\mathrm{h_{Ms}}) - K \qquad 2.5$$

where $a(h_{MS})$ is MS antenna height correction factor that depends on the type of environment. K is environment and frequency dependent parameter. Hata model (Hata, 1980) is recalled in the **Appendix A**.

From the above study, the path loss equation may be written as in the form shown in **Equation 2.6:**

$$PL_{al}(\theta, X_{\sigma}) = A + Blog\big(d(h_{BTS}, \theta)\big) + X_{\sigma} \qquad 2.6$$

where, A is the intercept of the straight line equal to P_0, B is the slope different from free space path loss exponent value and X_{σ} is shadowing attenuation.

It has been observed that there is some disagreement between the strict use of empirical model (statistical model) and actual measured data for a specific area. This mismatching problem is explained by the difference in value observed between the measured path loss and the predicted loss for the given area. This difference is called as excess path loss in (Prasad et al., 2005). As an approach to reduce the excess path loss, a tuning process is often used. The goal of tuning process is to refine the model to measurement condition (Lempiäinen et al., 2003; Rahnema, 2008). The recursive algorithm or least square algorithm could be used. The latter is proposed for a large sample of measurements. The least square algorithm method is given in the **Appendix B**.

2.2.2. Received Power in down-tilt situations

Technically, the mobile handset (MS) sends continuous pulse measurement information to the BTSs in the form of the pilot strength measurement message (PSMM) (Yang, 1998). Based on this, a CDMA handset (MS) therefore makes use of the active pilot that has the best or the strongest signal strength to access network resource. For an MS at a location $\boldsymbol{\alpha}$ relative to the sector main antenna lobe beam-width, the received power at MS from a channel pilot signal of a BS sector is dependent on the transmit power strength P_{T_X}, the BS sector antenna gain $g_{T_x}(\alpha, \emptyset, \theta)$ (Wu et al., 1998) in beam-orientation, the handset antenna gain $g_{R_x}$and the allowable path loss can be expressed as in **Equation 2.7.a**:

$$P_{R_x}(\theta, X_\sigma) = p_{T_X} * g_{Tx}(\alpha, \emptyset, \theta) * g_{Rx} * loss(d, X_\sigma) \qquad 2.7.a$$

This can be re-written as in **Equation 2.7.b**:

$$P_{R_x}(\theta, X_\sigma) = p_{T_x} * g_{Tx}(\alpha, \emptyset, \theta) * g_{Rx} * \left(\frac{c}{4\pi}\right)^n * \left(\frac{1}{d}\right)^n * \left(\frac{1}{f}\right)^n * X_\sigma \qquad 2.7.b$$

Using **Equation 2.7.b**; substituting **Equation: 2.4.g** into **Equation: 2.7a**, the received power is given as in **Equation: 2.7.c**.

$$p_{R_x}(\theta, X_\sigma) = p_{T_x} * g_{Tx}(\alpha, \emptyset, \theta) * g_{Rx} \left(\frac{4\pi d_1}{\lambda}\right)^{-n_1} \left(\frac{d_2}{d_1}\right)^{-n_2} \left(\frac{d_3}{d_2}\right)^{-n_3} \dots \left(\frac{d}{d_{N-1}}\right)^{-\gamma_N} X_\sigma \quad 2.7c$$

$d_{N-1} \leq d \leq d_N$ let $d_{N-1},\ d,\ d_N$ assume to follow a geometrical regression $d_2 = kd_1$ then

$d_N = k^{n-1} d_1$ and $\theta_i = \tan^{-1}(\frac{h_{BTS}}{d}) + \theta_0$,

$\theta_{N-1} \geq \theta \geq \theta_N$ $\theta_0 = HP/2$ with HP $the\ half\ beamdwidth\ power$

In (Prasad et al., 2005), the received power as a function of the down-tilt angle θ was given as in **Equation: 2.7.d.**

$$p_{R_x}(\theta, X_\sigma) = m * g_{Tx} * g_{Rx} * \left[\tan^{-1}(\frac{h_{BTS}}{d}) - \theta)\right] * d^{-n} \quad 2.7.d$$

where m is a constant expressed as: $m = p_{T_x}(h_{BTS} * h_{MS})^n * \left(\frac{c}{4*\pi}\right)^n * \left(\frac{1}{f}\right)^n * X_\sigma$

It can be underlined that the expression of received power and the path loss discussed so far don't quantify the diffraction loss explicitly. However, these formulae consider that the diffraction effect is less intense. This effect is embedding in shadowing loss. The generalized received power of Hata prediction model (Lempiäinen et al., Rahnema, 2008) accounting the diffraction effect is given as in **Equation: 2.7.e**:

$$P_{Rx} = P_{Tx} + K_1 + K_2 \log(d) + K_3 \log(h_{BTS}) + K_4 D_{diff} + K_5 \log(\mathrm{h_{BTS}}) \log(d) + K_6 \log(h_{MS}) + K_{clutter} \quad 2.7.e$$

where K_1, K_2, K_3, K_5, and K_6, are the original coefficients in Hata model, K_4 is the diffraction correction factor and D_{diff} is for diffraction loss evaluated by using diffraction theory model (Parsons, 1992) with the help of available clutter database. $K_{clutter}$ is the environment loss (shadowing) in dB. By then the measured received signal power at an MS end in a practical mobile cellular environment is written as in **Equation 2.7.f**:

$$P_{Rx}\ (dBm) = ERP + G_{Rx} - P_{L_{Meas.al}}(dB) \quad 2.7.f$$

In industry, operators are much interested in local mean signal strength at a user end. This value is obtained in (Fujimoto et al., 2001) which is the mean value of the received signal strength over 40 times the wavelength approximately corresponding to 15m in the near field of the BTS cell site. This could be calculated as in (Xuan Liming and Yang Dacheng, 2003) and given as in **Equation: 2.8.**

$$\overline{P_{R_x}}(dBm) = \left(\frac{1}{N}\right) \sum_{i=1}^{N} P_{Rx \to i} \quad 2.8$$

N is the number of the measurement of received power considered within the area.

2.2.3. Near-far problem and power control

Consider two users (mobile stations MSs) as illustrated in **Figure: 2.2**, and recalling the simplest form of path loss model without the effect of shadowing, as in **Equation 2.9**:

$$\frac{\boldsymbol{P_R}}{\boldsymbol{P_T}} = \boldsymbol{P_0} * \left(\frac{\boldsymbol{d}}{\boldsymbol{d_0}}\right)^{\boldsymbol{n}} \quad 2.9$$

Figure 2.2: Illustration of near and far problem

Referring to the path loss formula in **Equation: 2.9**, an MS closer to a BTS has a least path loss, than one far away from the BTS. Consider two users with equal transmitting power, the closer transmitter experiences stronger received power, therefore will jam the farther transmitter hence the latter will be below detection (Yang,1998; Lempiäinen et al., 2003, Gordon, 2002). Thus the farther MS will experience a worse reception. To avoid this phenomenon in CDMA cellular system, where each user is a source of interference for others sharing the same bandwidth in addition to the BTS transmitting antennae, the users are also potentially interfered; a power control technique (Yang, 1998) is therefore employed. Because of the power control issue, coverage dimension in CDMA is of a serious concern. However, it is also underlined in (Prasad et al., 2005) that the power control mechanism does not overcome the fast fluctuation of signal and attenuation occurred by interference from neighbouring cells.

2.3. Coverage analysis parameters

Coverage analysis at pre-planning involves the knowledge of the required signal threshold to be received which determines the outage probability (Yang, 1998; Lempiäinen et al., 2003, Manoj, 1999, Daniel Wong et al., 1997). The outage probability is used for coverage verification (Lempiäinen et al., 2003, Manoj, 1999). The threshold helps contribute to estimate the system fade margin in cellular network (Daniel Wong et al., 1997). Another parameter used for coverage verification is the Service Area Boundary (SAB) (Yang, 1998). SAB for a CDMA system takes into account both forward pilot channel and the reverse traffic channel. SAB is the area where the signal strength falls below the threshold then below detection.

This value is defined by the Federal Communication Commission (FCC). The FCC considers cellular service to be provided in all areas between the BS and the locus of points where the predicted or measured median field strength decreases to **-109dBm** (32dBμV/m).

At post-planning, one is interested in the actual value on the network: the link quality. In a CDMA system, the link quality is what limits the capacity (Daniel Wong et al., 1997). This generally explains the fact that the CDMA system is interference limited, but not noise-limited. The link quality analysis will be oriented on forward link coverage, pilot signal strength ($\boldsymbol{E_c/I_0}$), the frame error rate (FER) and pilot pollution.

Forward-link pilot coverage is a significant factor for link performance analysis. At a given point **i**, forward-link coverage can be estimated from the dominant-server signal-to-interference ratio ($\mathbf{SIR_i}$) as in **Equation: 2.10** (Yang, 1998, Lempiäinen et al., 2003).

$$\mathbf{SIR_i} = \mathbf{max}_{\mathbf{i \le b \le k}} \left(\frac{P_{T_{ik}}}{f_m\,\eta - \alpha_k P_{T_{ik}} + \sum_{j=1}^{n} \beta_j P_{R_x}(\theta, X_\sigma)_{ji}} \right) \qquad 2.10.$$

where n is the number of sectors, $\boldsymbol{\alpha_k}$ is voice activity factor and $\boldsymbol{\beta_j}$ is intercell interference, $\boldsymbol{P_{T_{ik}}}$, power transmit, $\boldsymbol{P_{R_x}(\theta, X_\sigma)_{ji}}$ is the power received from the pilot **j** at received point **i**, $\boldsymbol{\eta}$ is an overall noise term (which can be assumed to that of neighboured cells $\boldsymbol{E_c/I_0}$ contributing), and $\boldsymbol{f_m}$, may represent an additional fade margin (often 1-3dB). Thus point **i,** is covered if $\mathbf{SIR_i}$, is above a certain required threshold $\mathrm{SIR}_{\mathrm{thr}_\mathbf{0}}$(Yang, 1998; Daniel Wong, 1997).

The pilot strength ($\boldsymbol{E_c/I_0}$) is the received chip energy relative to the total power spectral density obtained before signal de-spreading whereas **Eb/No** is after signal de-spreading. It is used as a measure of link performance indicator. It reveals problems in cellular coverage (in GSM as well as CDMA network) areas in down-link analysis.

An MS requires sufficient $\boldsymbol{E_c/I_0}$ to lock on or to remain on the system and is given as in **Equation: 2.11** (Yang, 1998).

$$\frac{E_c}{I_0} = \frac{\alpha_0 P_{T_X} G_{T_X}(\alpha, \emptyset, \theta) G_{R_X}.loss(d, X_\sigma)}{P_{R_X}(\theta, X_\sigma) + \eta + N_{thermal}} \qquad 2.11.$$

where $\boldsymbol{\eta}$ is the total interference from neighbouring cells;

$N_{thermal}$ is thermal noise in the environment and

α_0 is voice activity factor.

Alike the **Ec/Io**, Frame Error Rate (**FER**) is another measure that indicates problem areas in CDMA cellular network coverage. Because FER translates directly into perceived voice quality, the system must be optimized so that there is minimal and acceptable FER on both forward and reverse links (Yang, 1998). As a consequence, a high FER and a low received power, may lead to severe call dropping, resulting in poor forward link coverage. A high FER and a high received power may also lead to a severe interference.

2.4. Quality of Service (QoS) and RF drive-test measurement

The received power strength in cellular mobile system is one of the Key Performance Indicators (KPIs) or parameters of Radio Frequency network coverage. Operators can evaluate the performance of their network in terms of QoS by using Radio Frequency (RF) drive-test system measurement.

2.4.1. Quality of Service (QoS)

In telecommunication, QoS refers to the usability and the reliability of the network and its services (S. Kaiser, 2003). QoS is a measure of the Key Performance Indicators (KPIs). Whereas the coverage is perceived by users as one factor of QoS (Andrews et al., 2007), a network location is covered, if received signal strength indicator (RSSI) is greater than receiver sensitivity, and received signal carrier-to-interference-plus-noise ratio (CINR) exceeds the CINR requirement.

In commercial network, the QoS value is defined based on an international standard value known as Service Level Agreement (SLA) (Yang, 1998). In this policy, some operators define their own level of QoS in agreement with the KPIs which are given as follows:

- Call Setup Ratio % should be greater than (>) 95% (call success),
- Call Drop Ratio % should be less than (<) 2%,
- Traffic Channel congestion per sector ratio % should be less than (<) 2%.

In industry, the analysis of the QoS of the network coverage is often done per cell or sector. The cell coverage is defined by the geographical region around the base station where the received pilot strength $\boldsymbol{E_c/I_0}$ is above the receiver sensitivity. One approach of obtaining a good QoS is the beam-tilt technique. The dependence between received $\boldsymbol{E_c/I_0}$ for a single cell and antenna tilt angle is observed to be a restricted concave function in a range of antenna down-tilt angle which varies from 0° to 9° in dynamic control of coverage (WICON'06, www.antesky.com, 2010). Most of cellular network operators give contracts to "RF drive-test solution" providers such as Huawei, ZTE telecom, Alcatel lucent in Africa and Agilent solution (Agilent Technology, www.agilent.com , 2010), to evaluate their RF coverage link-performance.

2.4.2. RF drive-test measurement procedure

In a RF drive-test system, Global Position System (GPS) receiver antenna is used, often placed on roof-top of the car because GPS receivers require a line of sight to the satellite system in order to obtain a signal representative of the true distance (Corvallis Micro-Technology, www.cmtinc.com, 2010). Therefore, any object in the path of the signal has the potential to interfere with the reception of that signal. Objects which can block a GPS signal include tree canopy, buildings and terrain features. It is an aid to obtain the distance of separation between BS and MS.

Three types of drive testing system could be identified. They are:

- **Market Survey testing**

This is used in the pre-planning stage. Often an omni-directional antenna is used in order to cover the entire cluttered environment which aids in making a good decision on site selection. Usually a communication network planning tool (CNT) is used. It is also used to investigate the RF spectrum, in order to define the carrier frequency.

- **Calibration testing**

A calibration testing is a mini optimization test, when a few base stations are selected. It is part of a-priori planning used to adjust the coverage prediction to measurement. It helps, to identify some of dead-zone and to make a necessary adjustment. In this situation, a communication network terminal or tester (CNT) is used.

- **Optimization test**

It is a-posterior planning process. It is also known as a continuous optimization of network performance. In this case, a CNT or RF spectrum analyzer can also be used or combination of both. The post processing can be done by the help of a communication network analyzer (CAN) or with a help of Microsoft Office Excel spreadsheets.

2.5. Conclusion

In this chapter, theoretical issues concerning network coverage design have been discussed such as the path loss models and the importance of the usage of antenna down-tilt in interference limited environment mainly in capacity limited environment. The design of the

RF coverage involves knowledge of site-survey, a choice of the appropriate model of propagation for coverage prediction. After the site-survey, the next step is site-location selection, this could be done by a help of Network Planning simulator or Communication Network Planner (CNP) software. It would follow by the selection of antennas' types, the orientation of sectors and antenna down-tilt. A great emphasis on characteristics of received power at a user end is also made.

Furthermore, a drive test system used by network operators to investigate the link quality or the signal strength in uplink and down-link is highlighted. Tools in used today are CNT, RF scanners, Master Site or Cell Master (www.tek.com/Measurement, 2010). However, in a practical CDMA mobile telecommunications industry, the required **Eb/No** of the CDMA system is about 7dB for a bit-error rate less than 10E 3. In order to decrease the outage probability, the threshold value is defined as 7.4 dB (www.tek.com/Measurement, 2010), which is slightly higher than 7dB (Yang, 1998).

CHAPTER THREE

METHODOLOGY OF MEASURING THE RECEIVED POWER

3.0. Introduction

Sensitivity study has been carried out in diverse ways. The study of sensitivity is to optimize the design system parameters. Many researchers have also addressed this issue on antenna down-tilt effect in theory. All of these theories were based on assumptions, because of the cost effectiveness and time consumption issues to conduct experiments particularly on commercial cellular networks. Simulation results have been plausible and very interesting. Nevertheless, investigating the parameters that affect the sensitivity of the received power at an MS end in antenna optimum down-tilt angle on real field will be quite difficult. With regard to these difficulties, not much research has been done in this area. Factors that influence the sensitivity of received power had not yet been clearly identified. In addition, most of the researches have been conducted in advanced countries, in which the weather conditions are totally different from that experienced in Africa particularly West Africa. In previous chapters, the issues involved in implementing any mobile cellular communication system have been discussed. This chapter presents the procedures of measuring the received signal strength at an MS location by the usage of the drive-test system as tools of evaluation.

3.1. Research problem

This study aims to quantify the variation of the received signal in antenna down-tilt situation in mobile cluttered environment by conducting some measurements. The transmitted and the received signal strength in both the down-link and the uplink coverage are influenced by reflection from buildings, the nature of the terrain, and so on. The work will compare the received signal to that predicted by macro-cell 3-D propagation algorithm.

3.2. Drive-test setup procedures

The measurement procedure was based on the use of a drive test system. A drive test simply means drive and test while roaming in the wireless network in a car. The drive-test system provides the insight to the performance of a network particularly in terms of RF coverage. It consists of investigating the RF coverage by looking at the key performance indicators such as pilot power strength (**Ec/Io**), the forward transmit power (**Tx**), the down-link transmit (**Rx**) and the Frame Error Rate (**FER**) while roaming in the wireless network. In drive-test evaluation, the BSs must be identified prior and then the route to be followed traced. This is very important in order to conduct a successful drive-test in time. Tools used are as follows:

- A Global Positioning System (GPS) Receiver antenna,
- Two CDMA Handsets (M_1 and M_2),
- A drive – test software,
- A communication network analyser software or excel spread sheet
- A laptop,
- Map info software.
- Inverter
- Extension board
- GPS 76 software version 2

The setup of the measurement procedure is illustrated in **Figure 3.1**.

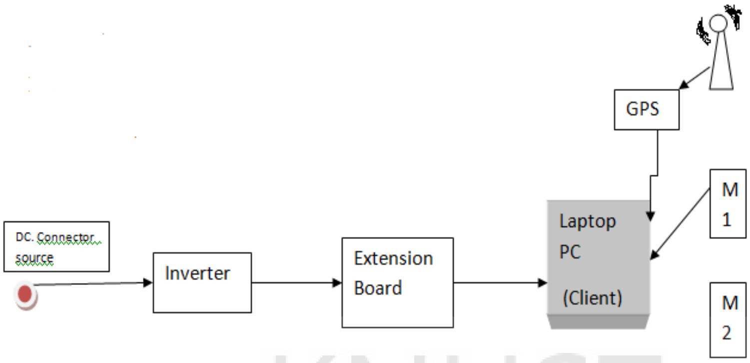

Figure 3. 1: Drive-test system setup

Two modes of configurations for the handsets were used from the monitored software during this drive-test. These were:

- The continuous call mode (Long communication mode)

  In this mode, the handset makes a continuous call without the user having to redial when the call reception fails.

- The redial call mode (Idle mode)

  In redial mode, the handset tries to redial the call accordingly to the redial number and when the ongoing call dropped.

3.2. Site selection and data collection

Drive test system was used for data collection. It is an aid to investigate the network air-interface parameters. When roaming in the wireless network, the drive-test software records or collects the signals at various locations. In the following lines selected cell-sites for this investigating are addressed.

3.2.1. Site selection

The site selection was based on Hata-Okumura environments (Okumura et al., 1968). It is a highlight on data conditions and environment of study during the measurement (Shadowing or cluttered environment). It must be noted that, the considered networks are unloaded.

The data collection was from May - June, 2009 in Hedzranawoe (Lome) and August to September 2009, in Greater Accra.

Lome is a small town and measurements were conducted on Togotelecom network at deployment stage. The mobile environment is made up of hot-spots area and suburban area.

Greater Accra is one of the ten regions in Ghana, such that Central Accra is considered as urban, Nungua Animal Farm and Tema as Rural / Open area, and University of Ghana which is a typical shadowed Urban, as a Suburban area. The description is presented in **Table: 3.1**. It gives details of the environment of study; the measurements were carried out during a rainy season and RF parameters are shown in **Table: 3.2**.

Table 3.1: Description of site of study

Sites	Time period	Characteristics of service area
University of Ghana	11H -15H	Leafy, with scarce buildings: it's assimilated to a suburban
Nungua Animal Farm	15H30-16H30	Motor Highway
Tema	16H30 -17H30	Open area
Osu	12H15-15H45	Urban area with tall buildings
Dansoman	18H15-18H30	Down-City with tall buildings
Exhibition (Accra-Central)	18H45-19H30	Urban area with tall buildings

Table 3. 2: RF parameters for signal variability study

RF parameters	
Antenna type	MB800-90-17D
Operating frequency	800 MHz
RF Power Tx	20 dBm
Tx Antenna Gain	17 dBi
Handset Gain	0 dBi
Antenna Height	32 m
MS Height	1.7 m
Antenna down-tilt	4°

3.2.2. Data collection

Drive tests were performed in different CDMA networks for data collection.

The first one was on Togo-Telecom network of the EVDO 1x revision A. This drive test was performed by using a Communication Network Terminal (CNT) connected to a laptop, monitored by Huawei Airbridge software in live test. The CNT is Huawei wireless modem 56Kbps.

The second one was conducted with ZK tool made by Celltest in 450MHz and 850MHz operating frequencies with initial radius of 1km for voice activity in continuous call mode. Two different types of mobile were used: Huawei C5320 and Kyocera Kx5.

Both the first and the second were conducted in Lomé. This network (Togotelecom CDMA network) was in deployment stage. But then, the focus was on an effect of antenna down-tilt angle in sensitivity of received signal.

The third drive test was conducted on Kasapa Telecom network in an operating frequency of 800MHz. In this measurement, a CNT was used. The CNT was connected to a laptop monitored by a drive test software ZXPOS CNT CDMA V5 91.11.0619A1 which was a planning and optimization software.

These software are network optimization software. They provide real time information of the network.

3.2.3. Data sampling sizes and processing

Data capturing size was carried out by the drive-test software. It takes 115 measurement points in 1 minute. Data processing was done in three stages. Data collected was sent to communication network analyzer (CNA) software as the first step. In the second stage, this was processed in Excel spread sheet and then thirdly with Matlab software.

Signals from the strongest active pilots have been considered in order to alleviate signals correlation from the transmitters. The considered value of received power level for the filtering stage was related to coverage analysis thresholds used in Service Level Agreement (SLA) by operators and in agreement with the Service Area Boundary's (SAB) value defined by Federal Communication Commission (Yang, 1998). The considered boundaries are:

- downlink coverage: Received Power Poor < - 95 dBm
- uplink coverage: Transmit Power Poor ≥ 10 dBm

Then for interference analysis, these thresholds were considered.

- Received Power level, good > -85dBm
- Transmit Power level Poor > 15dBm
- And Aggregate Ec/Io level poor < -12dB

3.3. Conclusion

This chapter explains the method of investigating the received power and the characteristics of the environments. It also underlines the research problem. The drive test system as tool of measurement was also presented.

CHAPTER FOUR

RESULTS AND ANALYSIS

4.0. Introduction

The analysis of sensitivity of received power at a mobile station is a great concern of the network operator. This measure as one of the KPIs depends on planning and design parameters such as the antenna down-tilt angle, site location, beamwidth orientation, height, etc., and also on environmental conditions (shadowing). All these influence the received signal strength at MS end. Some measurements on voice activity have been conducted in live test on existing CDMA cellular networks in Greater Accra and in Lome.

This chapter presents the signal variability to the design parameters such as antenna down-tilt angle, site location coordinates and path loss model. Mainly, it draws a close comparison between Friis Equation, Hata-Okumura path loss prediction and the measurement plots in Greater Accra environment of study.

4.1. Presentation of the drive testing results

A survey on signal sensitivity of drive test results are been discussed in this section.

4.1.1. In Greater Accra

In **Figure: 4.1**, a drive-test route (day one) of measurement is shown.

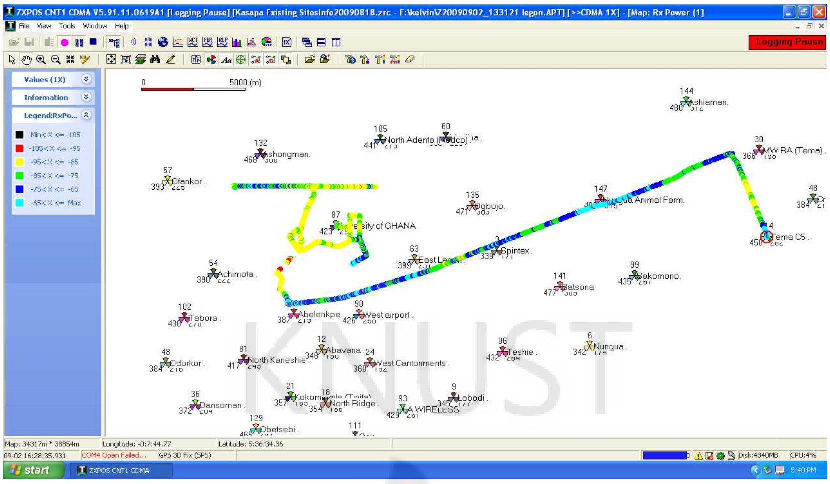

Figure 4.1: Drive test route (day 1)

For various measurement locations the received power level observed in colored is as illustrated in **Figure: 4.1**, is then given in **Table: 4.1** by the code of color.

Table 4. 1: Code of colors

Received Power Level (dBm)					
-65≤x≤max	**-75≤x≤-65**	**-85≤x≤-75**	**-95≤x≤-85**	**-105≤x≤-95**	**Min ≤x≤-105**
Excellent	**Very-good**	**Good**	**Fair**	**Poor**	**extremely poor**

In **Figure: 4.1** the cyan color sections represent excellent signal coverage (strongest signal), the blue color shows a very good coverage and the green color section indicates a good coverage level. The yellow color is the interference area; the red color shows a higher interference area where a severe call drop could be experienced. For the research purposes, the study will be limited to a good received power level throughout this thesis.

4.1.2. Analysis with regard to user mobility

In **Figure: 4.2**, it is shown that users close to the BTS experience better signal than those farther away from the BTS because the antenna has less path gain at the far end [8, 14]. With regard to **Equation 2.9** (Yang, 1998), this explains the need for power control in cellular network, the yellow path represents the interference area. It was observed that the served area was reduced; this is displayed by the Green color limit. The Green color path is the received good signal with less interference.

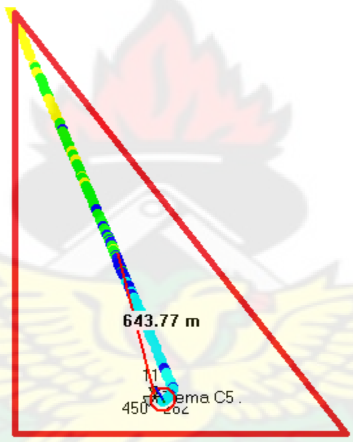

Figure 4. 2: Signal variation due to user location

On the other hand, at the cell boundary, the neighbouring cells support the ongoing call. This support is known as the soft-handoff. Neighbouring cells therefore do not appear as a source of interference but rather as a source of signal strength. The statistical mean received power was -99dBm and the mean signal strength **Eb/No** was 6.79dB. However the required for CDMA system is about 7dB for a bit-error rate (**BER**) less than 10E+3. In order to decrease the outage probability, the threshold value is defined as 7.4dB, which is larger than 7 dB (Yang, 1998; www. tek.com/ Measurement, 2010). Another advantage is that a CDMA handset can work efficiently with a small signal to noise ratio (SNR) in noisy environment (Yang, 1998; Lempiäinen et al., 2003, Daniel Wong et al., 1997) the handset was still in the system as a benefit of the fast power-control used by the BTS (Yang, 1998). At cell boundary, a high value of FER was eventually observed around a mean value of 4. Naturally a higher value of FER greater than 2 may not be good enough for the link quality in reception. And moreover this may lead to a low received signal power at a mobile station (Agilent Technology, 2010).

4.2. Signal variation due to design parameters

This section focuses on analysis of received power with respect to design parameters such as site location, antenna down-tilt and effect of cell site coverage.

4.2.1. Site location coordinate

A wrong coordinate given to a BTS site location was also observed to lead to poor cell coverage. This is illustrated in **Figure: 4.3.**

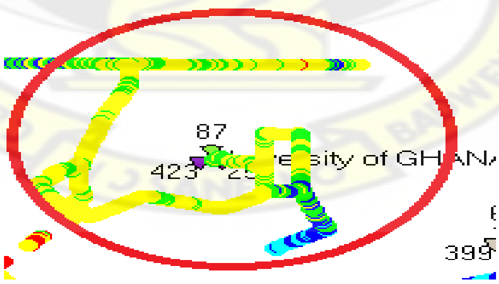

Figure 4. 3: Case of wrong coordinate

The received power level observed in near field of the BTS was not satisfactory (yellow color). At a relative far field, an excellent received power level was observed (cyan color). This increases the interference zone with neighbouring cell sites. In that situation, it was very difficult for a BTS to work efficiently in terms of power resource allocation because in CDMA2000, BTSs use absolute reference for timing synchronisation (Yang, 1998). For a technical explanation, with regard to **Equation: 2.9**, the BTS would have a problem in assessing the distance between users within its cell and would not apply the power control mechanism. Moreover the pilot channel cannot also direct the mobile station. Therefore, the handset would be transmitting a high power and be generating an unnecessary interference. At the BTS end, an unnecessary soft handover would happen. This phenomenon would be a source of ping pong effect in the coverage area (Agilent Technology, 2009). Thus severe call drops would be experienced.

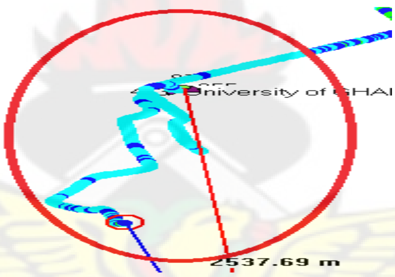

Figure 4. 4: Case of correct coordinate

With a correct cell site coordinate, a strong power signal was observed (**Figure: 4.4)** when one was close to the BTS, and the observed average FER in uplink was 1. This means good cell coverage. Site location coordinate could be solved by a help of GPS set (Freeman, 2005).

4.2.2. Signal variation in down-tilt situation: effect of terrain topology

In **Table: 4.2**, the analysis of the measurements in terms of the distance and the received power level is summarized.

Table 4. 2: Down-tilt angle comparison: effect of clutter

Cell Site	Distance Measured (Km)	Distance Theoretical (Km)	BTS Height (m)	Theoret. Down-tilt Θ_{vopt} (Degree)	Fixed tilt (Degree)	Servicing area
Site 1	1.75	2.208285192	32	4.81	4	Open/Rural
Site 2	1.572	2.340302731	35	5.37	4	Residential
Site 3	2.555	2.939940922	35	3.99	3	Quasi-open
Site 4	1.58	2.801626659	32	5.13	3	Urban
Site 5	1.3	2.208285192	32	5.66	4	Urban
Site 6	1.0	1.119097976	32	6.25	6	Urban
Site 7	1.5	2.208285192	32	5.27	4	Suburban

The optimum predicted down-tilt Θvopt angle was computed and compared to the existing one. The result compares favorably with that obtained for optimum down-tilt formula prediction (Jarno et al., 2005) in relation to intended cell coverage radius.

The empirical formula in **Equation: 2.3**, was used to compute the Θvopt (the theoretical down-tilt angle) and is as given in **Equation: 4.1**.

$$\Theta_{\mathrm{vopt}} = 2.53\ [\ln(h_{BTS}) - d^{0.8}] \qquad (4.1)$$

where $\theta_{-3dB} = 7\mathrm{dB}$, h_{BTS}: height of BTS in m and d is the distance in km.

- **In rural area with mechanical down-tilt situation**

The BTS-sector coverage as shown in **Figure: 4.4**, is the cell site (Site3) serving a motor high-way of Tema-Accra area which can be assumed to a quasi-open area.

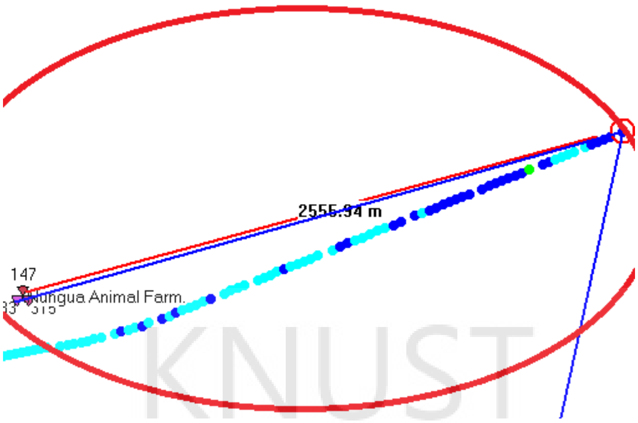

Figure 4. 5: Received signal in open area (Motor highway Accra-Tema)

In **Table: 4.2**, the measured radius was 2.555km where a good signal level was observed for the cell Site3. The intended cell radius was set to 2km. A down-tilt of 3° (three degree) was applied. Using the empirical formula of down-tilt angle selection, the measured cell radius required 4° (four degree) antenna down-tilt.

It may state that the effect observed in antenna down-tilt situation is a reduction of cell site radius. In this situation the measured cell-site radius on Tema-Accra highway did not appear to be reduced. This could also be explained by the relative less intense effect of the clutter and the flat nature of terrain in this area favorable for the signal propagation. The area is a quasi-open area with sparse buildings.

But it could be claimed that with a relative high transmitting power of the site, the same observation would be achieved. As a consequence the direct opposite site (adjacent site) is affected therefore the neighboring cell radius may be observed to be markedly reduced.

For the cell Site 2 in **Table 4.2**, a good signal level of received power (with minimum interference) was observed at a distance close to 1572 m from the BTS. Accordingly to the empirical formula down-tilt angle (Θvopt), 4° (four degree) down-tilt is required to provide a coverage radius of 2km. The measurement shows that, at a down-tilt of 4° (Θf Actual), the received signal level was only fair at a distance close to 2km which indicates some presence of the interference. This deviation may be explained by the effect of the environment. The same results were observed for the cell Site1**,** where a good received power level was observed at 1750 m.

- **In urban area**

For the cell site 4 in **Table 4.2**, where a 3° (three degree) mechanical down-tilt, was used and the received good signal level was observed to be 1.58 km away from the transmitter (BTS). This indicates that the cell coverage is good with a mean distance around 500 m to the direct neighbouring cell at a high interference. For the cell site of 6° (six degree) down-tilt angle, the servicing area radius observed was around 1km which means a reduction in cell radius of 1km. This explains unfavourable terrain nature on one hand. The BS site **4** is in a dense cluttered environment but located on a slightly hilly area.

The cell Site 6 in **Table 4.2** is located in a down-town in a valley. A mechanical down-tilt angle of 6° (six degree) was used. The measurement result shows that a received good signal level of power was around a distance close to 1000m. This could be explained by the effect of the terrain topology.

If the empirical formula for down-tilt angle selection is considered the selected cell radius should be 1km. This corresponds to a theoretical mechanical down-tilt angle in value of 6.25°. For the cell site 5, a 4° (four degree) mechanical down-tilt angle was used in dense cluttered area. At a close distance around 1.3km, the received signal level observed was good. A reduction of the cell-site radius in value of 700 m was found which corresponds to interference zone. The increased excess radius is explained by the buildings, and the cell load.

The cell site 7 in **Table 4.2,** is servicing a suburban area, a mechanical down-tilt in value of 4° (four degree) was fixed. The received good power level observed was at a distance close to 1500.12m far away from the BTS. The overlapping area or interference area of 500m is acceptable in the industry with regard to the predefined cell radius of 2km.

The excess cell-site radius compared to the received power at mobile station end could be explained by many factors such as the presence of buildings, the geomorphology of the propagation land, the load in terms of the number of users within the cell.

4.2.3. Signal variabilityin a poor down-tilt situation

The survey results of drive-test conducted in Lome are presented in **Figure: 4.6** and **Figure: 4.7**.

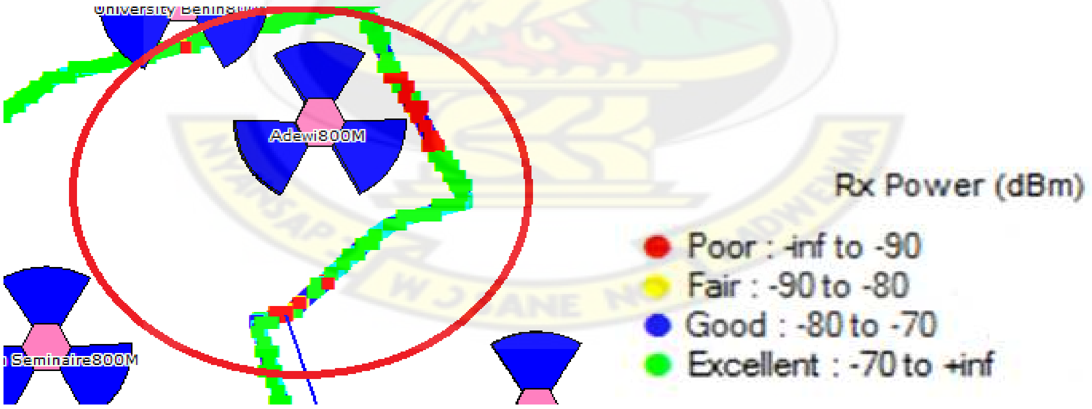

Figure 4.6: Interference due to a poor down-tilt: poor coverage in near field

The illustration in **Figure: 4.6** shows a received poor signal level in the near field. The red colour section indicates a poor signal observed at a distance close to the BTS. As a result, users are being served by the farther sectors. This phenomenon could be a source of an unnecessary interferences and unnecessary soft-handoff in the network which results from a poor orientation of antenna down-tilt. A poor antenna orientation was also observed which may have caused additional inter-cell interference (WICON'06, 2006). This may be explained by call failures even in the area relatively close to the base station.

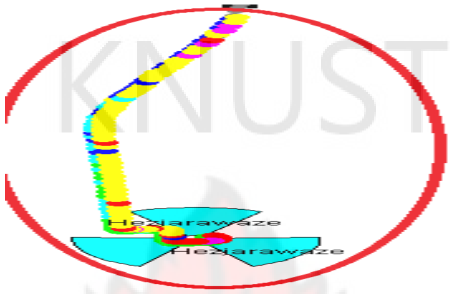

Figure 4. 7: Interference in near field: poor antenna down-tilt

The inter-cell interference effect could also be revealed by a poor received signal at a very short distance of separation between an MS and the BTS. An illustration is given in **Figure: 4.7**. The poor received power is shown by the red colour (Red section) at a close distance to the BTS. For a technical explanation, the mini-cut offs (in red section) observed could result from the time synchronization of the BTS. This can also be explained by the Modulation Impulse Code from the BTS or may be due interference from neighbouring cells. The disconnections of the GPS set could also give a poor snapshot. This explanation shows that several parameters influence the sample of the received power.

In summary, at cell edge a high FER and low received power were observed; this exposed users at cell boundary to inter-cell interference. The effect of down-tilt antenna is to minimize the path loss attenuation at cell edge so that interferences from neighboring cells are mitigated (Daniel, 1997).

4.3. Signal variability studies

The sensitivity of received power is influenced by design parameters. The signal variability at user end also depends on clutter and on propagation model. The performance of a propagation model is observed by the difference in value expressed in decibels (dB) scale between the prediction model and the measurement plot. This difference in value is called the excess path loss (Prasad et al., 2005). A study of signals received from transmitters is carried out in three different clutters in order to quantify the received power and also to estimate the excess path loss. Lack of available clutter database, the effect of diffraction will not be quantified.

4.3.1. Signal variability in different clutter

Signal strength measurement shows that the received signal level depends on a user position (distance) from a transmitter (Jarno et al., 2005; Yang, 1998). Signal variability depends on the environment and also on the transmitter behaviour.

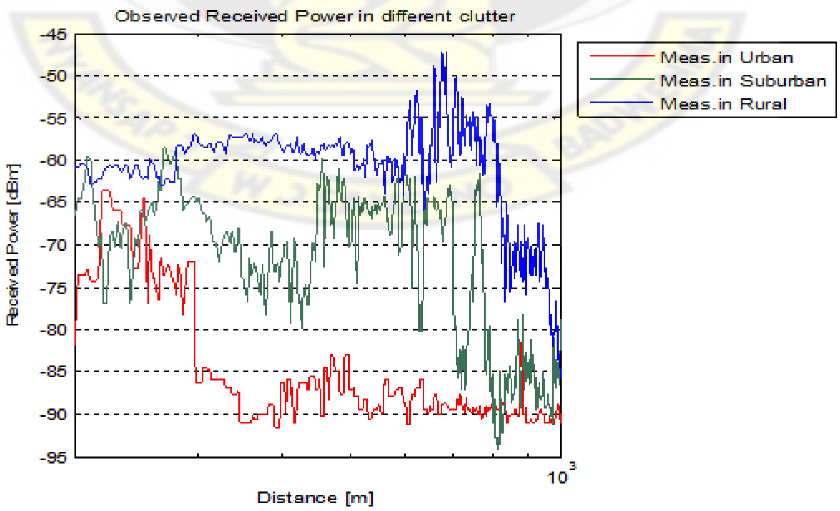

Figure 4. 8: Received signal level (dBm) in different clutter

In **Figure: 4.8**, the received power level for three different clutters is plotted against the distance. It was observed that attenuation of the received signal in urban areas was much more severe compared to the other clutter (Parsons, 1992).

The variation in received signal may be explained by reflection from buildings, human made noise and presence of people. The highest value of received power level was observed in rural area whereas the signal received in suburban lies between the urban and rural. The attenuation observed in the signal in suburban area is explained by the presence of trees (foliage attenuation) and buildings. Because of the unfavourable nature of the land (hilly) the observed attenuation does not follow the normal decreasing trend against the distance. This explains the benefit of the diffraction.

4.3.2. Comparison between the theoretical and the measured path loss

In **Figure: 4.9,** the measured path loss is shown by a scatter plot and the prediction plot by a straight line plot.

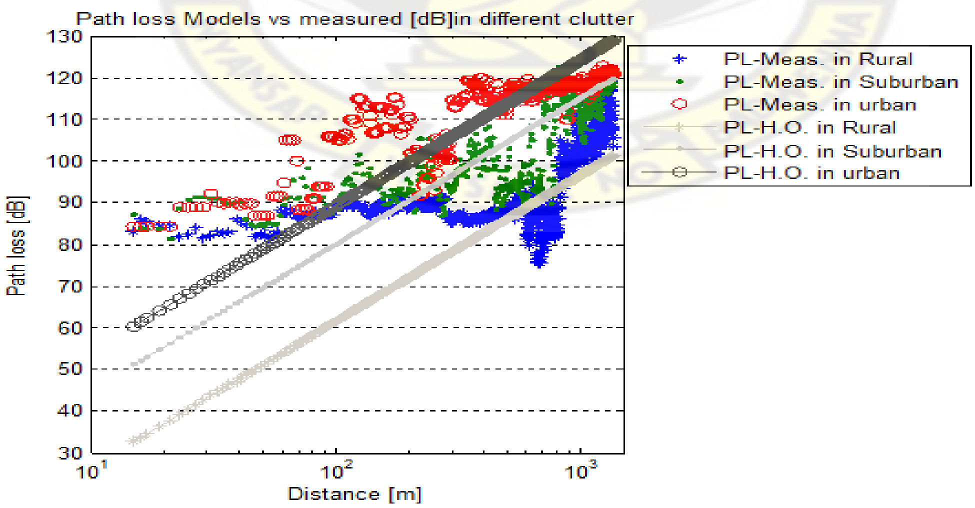

Figure 4. 9: Theoretical model compared to measured data

Okumura-Hata model and the parameters used for the evaluation (**Figure: 4.9**) are as follows:

Operating frequency f=800MHz, BS's antenna height=32m and MS's antenna height=1.7m,

In Urban area:

$$PL_{HO(Ur)}[dB] = 124.246 + 35.041 * logd[km] \quad 4.2$$

In Suburban area:

$$PL_{HO(Sub)}[dB] = 115.0505 + 35.041 * logd[km] \quad 4.3$$

In Rural (open) area:

$$PL_{HO(Ur)}[dB] = 96.611 + 35.041 * logd[km] \quad 4.4.$$

Using **Equation 2.7.f**, the measured path loss is given as in **Equation 4.5:**

$$PL_{meas}\ [dB] = ERP - P_{Rx(meas.)}$$

$$PL_{meas}\ [dB] = 33 - P_{Rx(meas.)} \quad 4.5$$

ERP was calculated using **Equation: 2.1.b,** and by substituting the following parameters: the handset gain $G_{Rx}[dBi] = 0$; the transmitter antenna gain is 17dBi and the transmitting power is 20 dBm. All cable loss, connector loss and duplexers' loss are assumed 4dB.

The analysis in **Figure: 4.9**, shows that the excess path loss was more important in antenna near field than in the far field. It could be said that the coverage issue is met because the three measurements crossover in the far field. This may be explained by the fact that network operators show more concern in network coverage at deployment stage. The excess path loss observed could be explained by the antenna mechanical down-tilt technique used.

The antenna radiated much power at cell boundary however the excellent signal level received in the near field is explained by the fact that there are fewer obstacles in the first 50 to 100m at a distance of separation between the transmitter (BTS) and the receiver point (MS).

The observation in **Figure: 4.9** shows that, when the distance is in logarithmic scale, the theoretical plots of path loss tend to increase linearly. These plots do not give much information to draw a good comparison between Hata-Okumura model predictions (Okumura et al., 1968) and the measured data. In view of this analysis, a linear Least Square method was selected to determine the best fit of the received power measurement as a function of the distance using a curve fitting tool in Matlab software. The observed path loss was plotted by using a least square curve fitting method. These plots are given in **Figure: 4.10.**

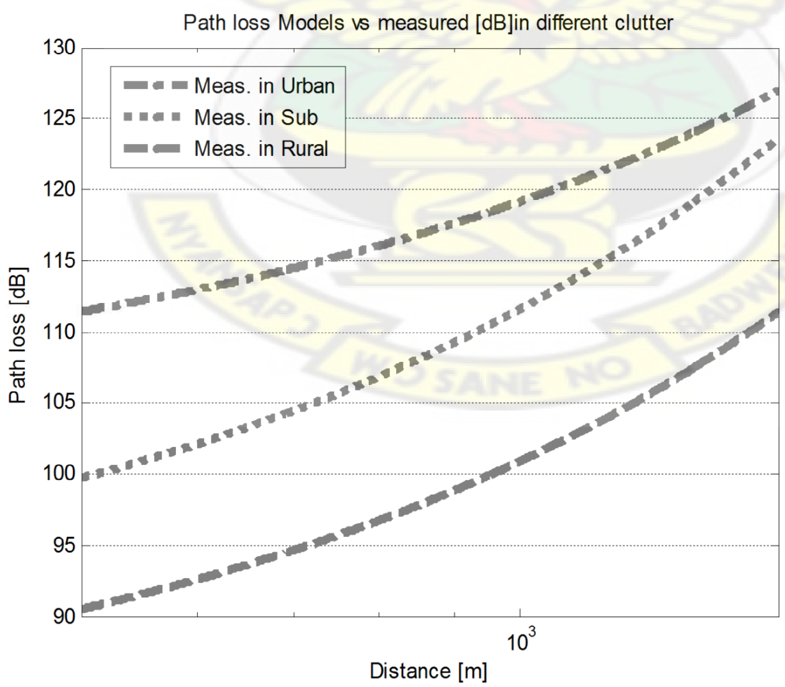

Figure 4. 10: Measured path loss plots (least square fitting)

From **Figure: 4.10**, all the fitted curves obtained from measurement plots are then illustrated. It could be observed that these plots do not exhibit a linear straight line shape because the distance is in logarithmic scale. The fitted curves would be in linear form if the distance is expressed in linear scale form. These curves are given in **Appendix A**.

4.3.2.1. Friis model compared to measurement result

The theoretical Friis model and the measurement result are been compared in this sub-section. The Free space path loss (Friis Equation) was evaluated as in **Equation 4.6**:

$$P_{FSL}[dB] = -G_{Tx}[dB] - G_{Rx}[dB] + 20log\left(\frac{\lambda}{4\pi d}\right)\ [dB]$$

$$P_{FSL}[dB] = 90.512 + 20\log d[km] \qquad 4.6$$

And the measured path loss was evaluated as in **Equation 4.5** given as follows:

$$PL_{meas}\ [dB] = 33 - P_{Rx(meas.)}(dBm)$$

A. Near Field Analysis: Free space study

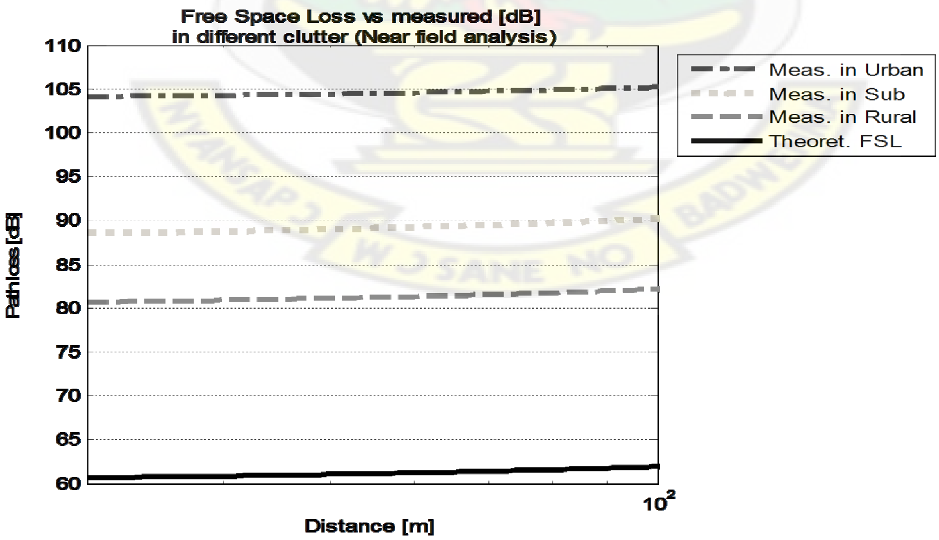

Figure 4. 11: Path loss comparison (Site selection)

Analysis of free space loss (FSL) prediction is carried out in order to quantify the measured received power with regard to site selection. The measurement plots in **Figure 4.11** are being compared to the free space prediction (the plot in red) over 100m from the BTS.

Analysis from **Figure: 4.11**, shows that in urban areas, there is a significant difference around a value of 45dB between FSL prediction and the measurement. This is due to the fact that the BS is located on buildings' roof but the MS is often located in between tall buildings or in streets. Therefore, the received signal at the MS end may be influenced by the effect of reflection, scattering and diffraction. All these phenomena are the result of the attenuation in the signal strength. This explains the increased attenuation in path loss observed in the near field signal measurement as compared to that of Free Space loss prediction (Friis Equation).

In rural areas, the signal strength measurement shows a relative small loss compared to the Friis' Equation prediction loss (Parsons, 1992). This value is explained by buildings' obstruction in the vicinity of BS and MS (a few obstacles). The difference between signal strength predicted and the measurement result in the range up to 100 m was about 20 dB in value which is the least compared to other clutter loss. Moreover the choice of BS antenna site location is not a great concern in rural areas. In suburban areas a relative loss around 7dB greater than that of a rural area loss was observed. This loss can be explained by the presence of some few buildings around the BS, in addition to a significant presence of leafy trees. In urban, a 15dB in value higher than that of loss in suburban is observed. This may be explained by the fact that BTS site location choice was difficult to obtain because of the space shortage in order to find adequate cell site. Most often, BTS site antenna would be located on a building's rooftop. Also, due to MS relative low height, the MS in urban area is mostly surrounded by obstacles (Parsons, 1992) and thus experiences a higher attenuation in signal reception.

B. Far Field analysis: Free space study

In **Figure: 4.12**, FSL prediction in far field was still observed to be lower than the measured data in rural area.

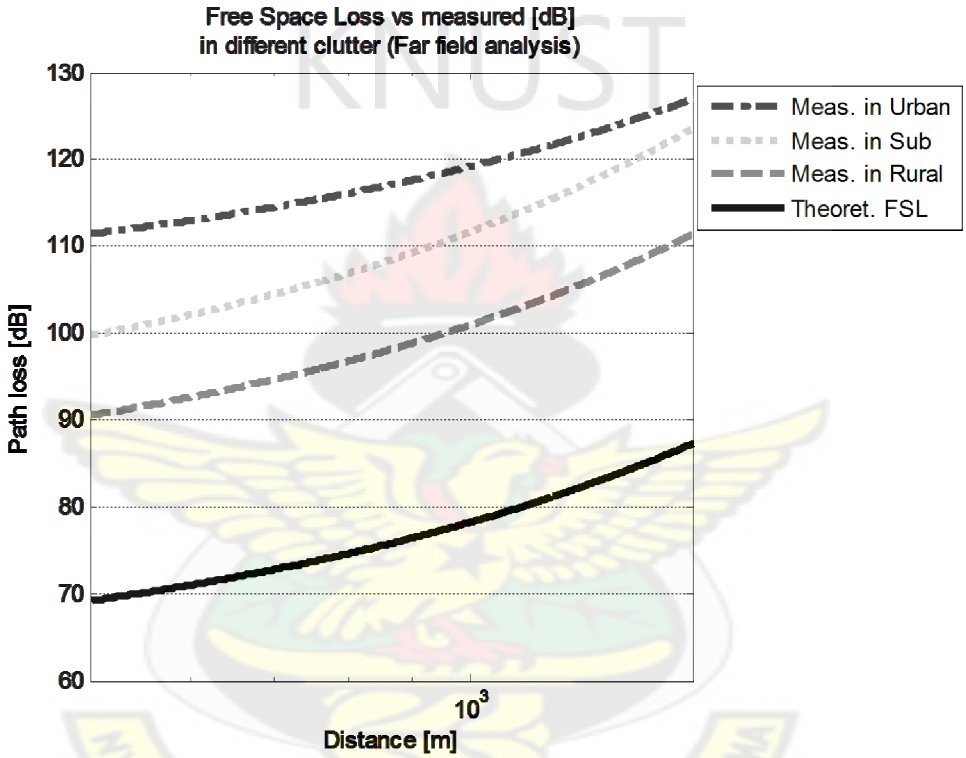

Figure 4. 12: Far field comparison: Friis Equation, Fit Data

This excess path loss increases with a slight higher value than that of 20dB in the selected study area, a rural clutter type.

The excess path loss increases because of the user (MS) mobility (Parsons 1992, Yang, 1998) getting farther from the transmitter (BS). The variation in value of the excess path loss (Prasad et al., 2005) against the distance would depend on the type of clutter. As one moves away from the transmitter, one encounters more and more obstacles. But though, these obstacles are relatively less extensive compared to the clutters of suburban and urban area, the attenuation in signal strength still increases with a relative higher value than that of 20dB/decade. Therefore, the signal prediction in mobile communication environment even in rural area cluttered environment cannot be predicted by the free space loss formula as it was observed earlier by Okumura (Okumura et al., 1968).

4.3.2.2. Hata model compared to measurement result

In this section, the modified Okumura model by Hata (Hata, 1980) will be investigated with measured data**. Figures: 4.13-4.15** depict the comparison between Hata-Okumura (H.O) prediction and signal measurement (scatter plot) for three different types of clutter. The Hata-Okumura model is presented in details in **Appendix B.**

In order to compare the measurement data, a linear Hata model was obtained using a least square method. Fitting parameters for the path loss comparison are obtained using a curve fitting tool "cftool" function in Matlab software.

The curve fitting toolbox uses the linear least squares method to fit a linear model to data (Draper, 1998; Robinson, 1992). A linear model is defined as an equation that is linear in the coefficients. The measurement data have been fitted to a linear equation y. The linear equation y is as follows:

$$y = p_1 x + p_2$$

where the unknown parameters to be solved are p_1 and $p_{2,}$

The linear least square parameters (p_1 and p_2) are found for the measurement and the theoretical Hata Model. The distance is in a linear scale form. If the distance is in a logarithmic scale, H.O. models exhibit a linear shape whilst the scattered plots tend to a bent curve.

In Urban area: H.O. formula used for evaluation is as follows:

$$PL_{HO(Ur)}[dB] = 124.246 + 35.041 * logd[km]$$

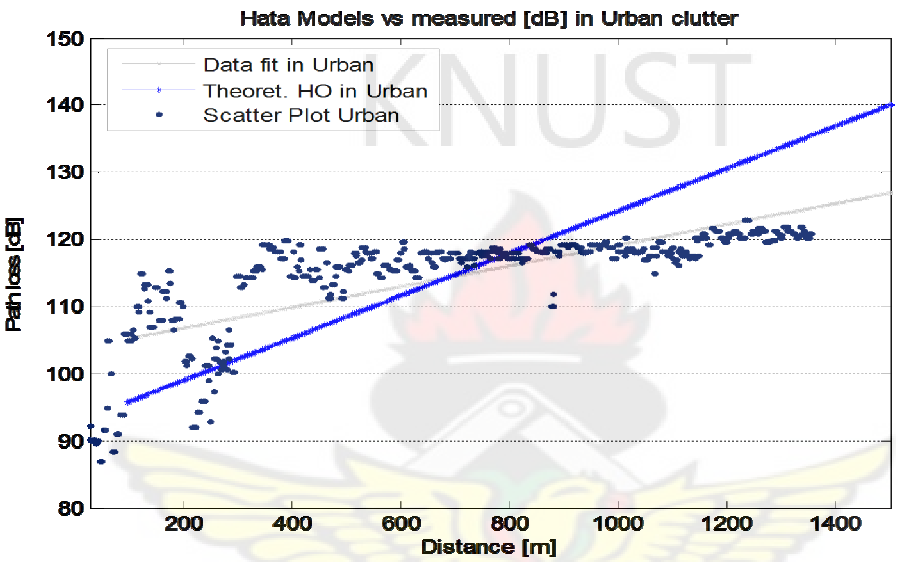

Figure 4. 13: Path loss comparison in urban area

Analysis of **Figure: 4.13** describes that measurement result shows more attenuation around the near field (distance of 250m). Wherever, at a distance above 800m it shows less attenuation in comparison with the theory. Around the near field this is explained by the BTS location and the MS position. The MS was in the street (position during the measurement).

Above 800m the observed lower attenuation may be attributable to less tall buildings which may not be as dense as the theory predicts. Thus attenuation in signal strength results from buildings' reflection and multipath-effect was less.

Furthermore in **Figure: 4.13** at a distance below 800m, a maximum difference of 10dB is observed between the Hata prediction and the measurement data. The plot indicates that there is a little agreement with the theoretical. A difference in a value greater than 5dB is observed. This value tends to increase faster from the point of 1km where Hata-Okumura model is valid. The excess path loss is much increased as the distance of separation between the BTS and the MS also increases therefore it may be concluded that the study environment could not be classified as Hata urban area.

In Suburban area: the H.O. formula used for evaluation is as in **Equation 4.3** which is given as follows:

$$PL_{HO(Sub)}[dB] = 115.0505 + 35.041 * logd[km]$$

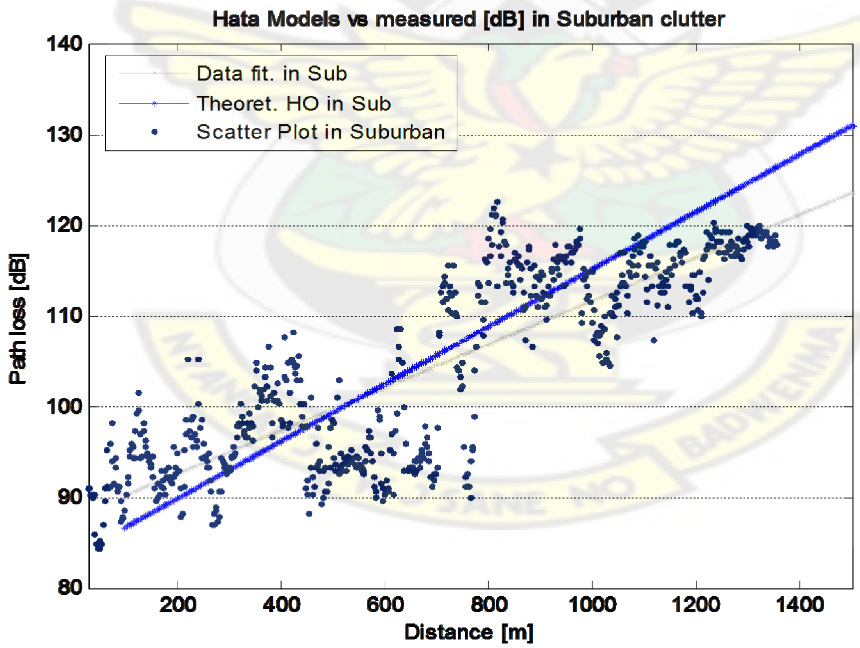

Figure 4. 14: Path loss comparison in suburban area

The measurement result and the Hata-Okumura prediction for suburban show an excess path loss around 2.5dB below a distance of 250 m, (**Figure: 4.14)**. The best agreement is achieved around 300m and 700m. This deviation increases as one moves far away from the transmitting antenna beyond a distance of 700m. The maximum excess path loss in value could be estimated around a mean value of 7.5dB. With regard to mobile communication application, the issue is to mitigate the path loss at far field. Therefore the model may be accepted to have a good response in the study environment. The deviation could be explained by the difference in the propagation model slope. The study environment can be classified as Hata suburban area.

In Rural (open) area, H.O. formula used for evaluation is as follows:

$$PL_{HO(Ur)}[dB] = 96.611 + 35.041 * logd[km]$$

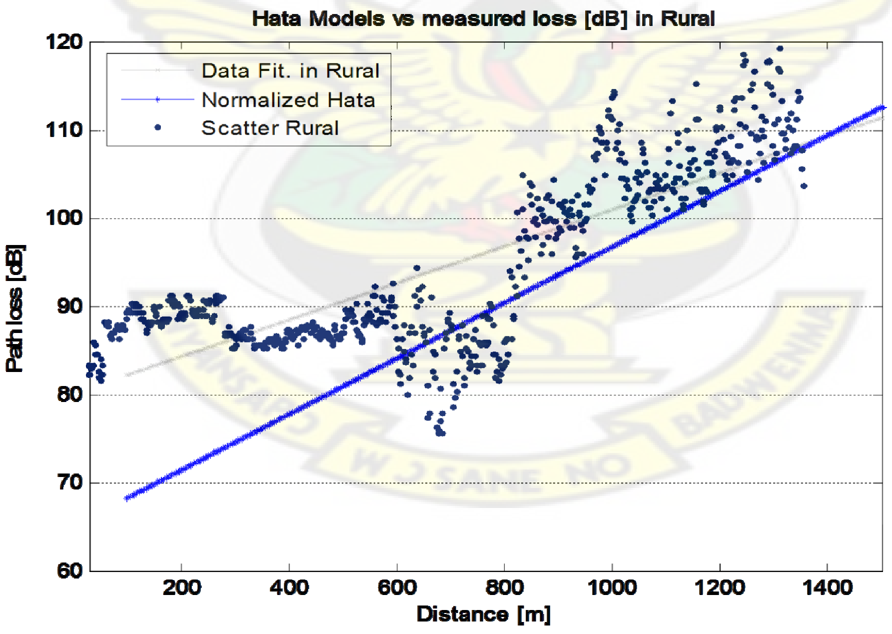

Figure 4.15: Path loss comparison in rural area

Figure 4.15 shows the comparison between Hata-Okumura model for open area and the measurement result in rural area. A difference of 2.5dB to 15dB is observed at a distance below 1km where Hata model is not valid. Beyond the distance of 1km the maximum excess path loss is also around 15dB. This is the most reported deviation observed between the Okumura model and the measured data in open area. It may say that the model response show a little agreement.

Hata-Okumura model could not be used in this area to mitigate far field inter-cell interference, but though most of the users could be out of the transmitting antenna main lobe and experience a poor received signal. This could also lead to a ping-pong effect in the network coverage. The model may not be appropriate for the study environment.

In **Figure: 4.16** is shown the presentation of measurement results of all the three study areas and the prediction from the theory.

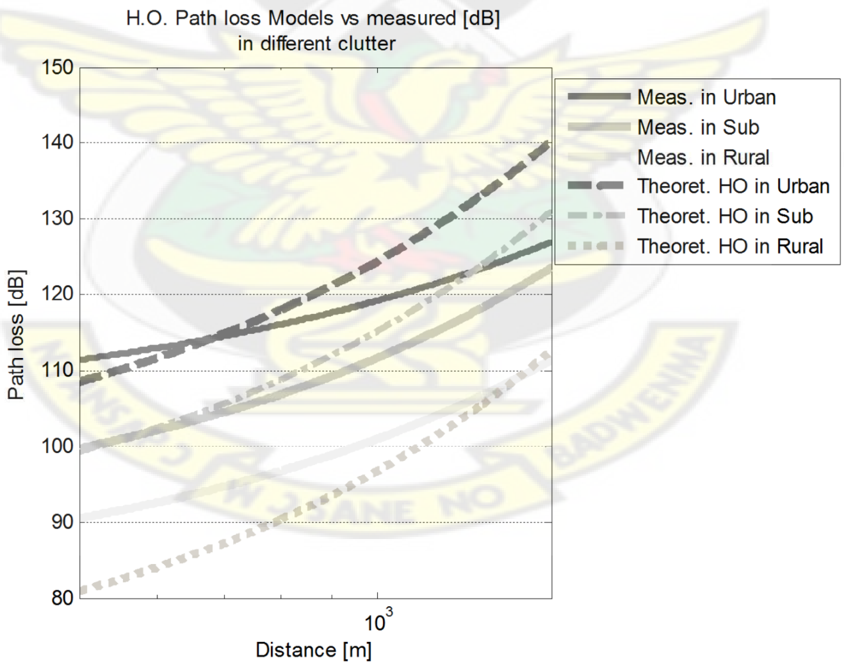

Figure 4. 16: Far field comparison: Hata model, Fit Data

The prediction and measurement plots seem to have the same shape with little agreement. The model could be used to reduce the interference from other cells (BTSs) at cell edge in rural and suburban but users near the base station could not be in the antenna main beamwidth.

The results obtained in urban and rural areas show that the model response has a little agreement. The study area could not be classified as Hata Urban clutter because there are not many tall buildings and not congested as compared to Tokyo city in 1968 (Okumura eta l. 1968; Freeman, 2005) in addition to the land morphology as well, where the measurements were collected to develop the Hata theory (Hata, 1980) of fitting Okumura curves. The rural study area contains probably more edifices and buildings than Hata Open clutter.

4.3.2.3. Hata and Friis models compared to measurement result

A. Near Field Analysis

From **Figure: 4.17**, a comparison between Hata Okumura model, Friis equation and the measurement over a distance up to 100m in near field transmitting analysis is illustrated.

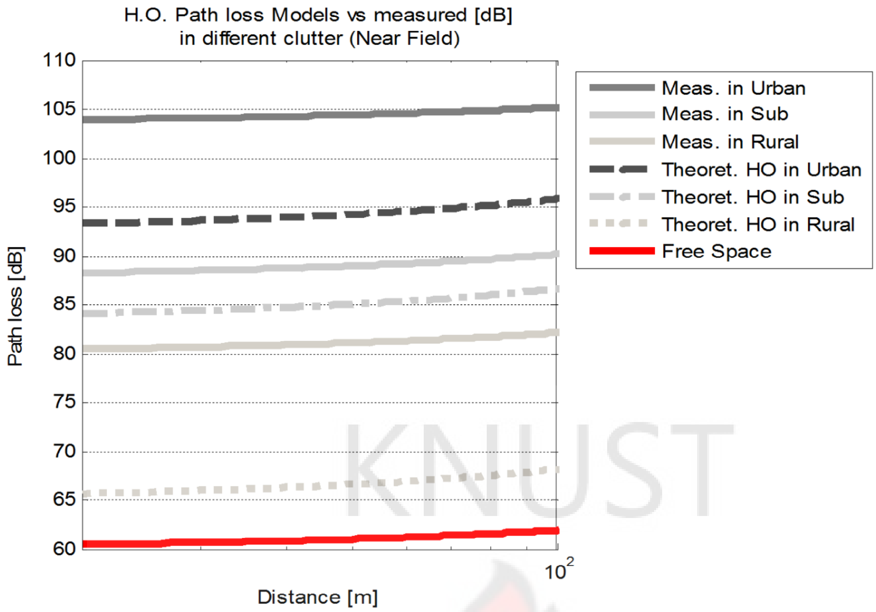

Figure 4. 17: Near field comparison: Hata Model, Friis equation and Fit Data

From **Figure 4.17**, the plot of measurement and H.O theory illustrates that the measurement results are higher than the theoretical values. The theories give a little agreement with the measurement. It could argue that H.O models give a less prediction over short distance as in (Adit Kurniawan, 1997). But it must note that Okumura assumed that the BTS antenna should be located on a hill (Okumura et al., 1968). Therefore, it is likely that the MS experiences better received signal strength. The use of directional antennas and the technique of antenna down-tilt applied, the fading in signal strength at a close distance separation of the BTS, could have less effect on the received signal level. Thus the received power at MS end could be above the prediction value.

It shows that there is a difference of value less than 2.5dB in urban, around 5 dB in suburban area between the prediction and the measurement results. But in Open area the model shows a little agreement. A difference of 7dB was observed.

B. Far Field Analysis

Far field analysis is being considered in the **Figure: 4.18**, the comparison focuses on Hata prediction and the measurement result within a mobile communication range of 500m to 1.5km.

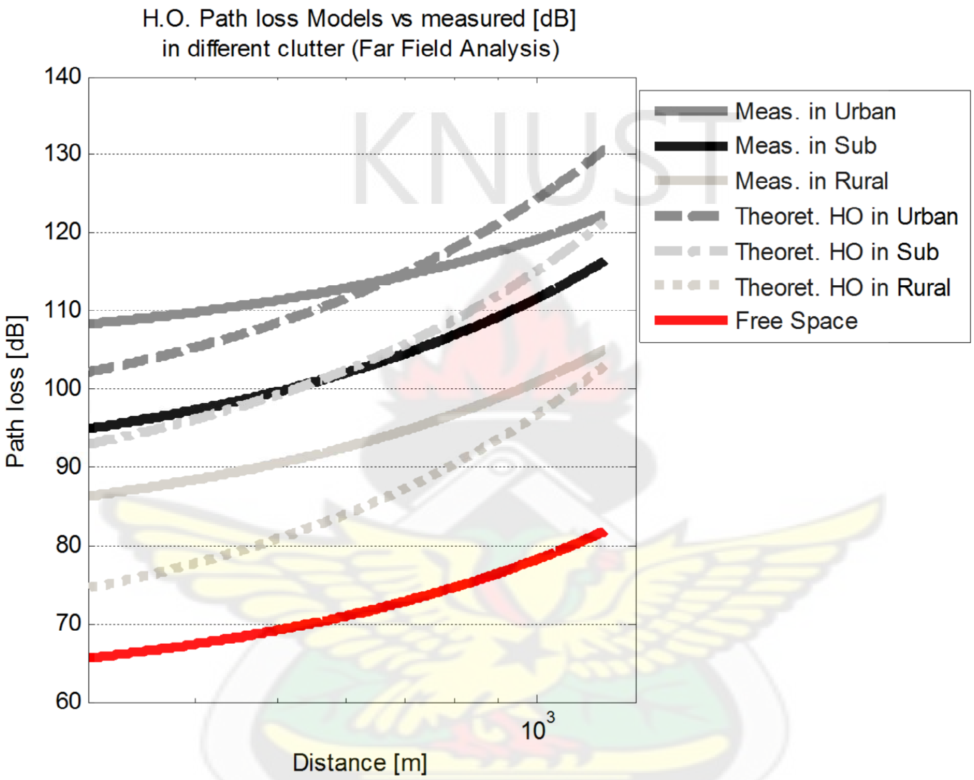

Figure 4. 18: Far field comparison: Hata model, Friis equation, Fit Data

The analysis shows that a difference of 10 dB is observed between the urban prediction and a higher value in measurement. Whereas in suburban a 6dB mean is observed. In rural area, the deviation is much better with a mean value around 2.5dB to 5dB over long distance (far field observation).

In the case of the suburban area, the graphs (theoretical plot and the measurement plot) have a same shape with a difference of 3dB. This seems to be in good agreement between measurement and theory. The little difference may be due to the land nature (hilly) but though the BTS was above the buildings' roof and height of trees, the BTS site location may be problematic.

The plot of measurement and theory in the case of urban presents a minimum difference of 10dB above 1km. The higher value of the prediction than that of the measurement may be attributed to the area of study which may not be a type of Hata urban environment.

The prediction loss (H.O model) is below the measurement result in the case rural area. There is a vast difference in dB between the measurement and the other two theoretical models (Friis Equation and Hata-Okumura for rural prediction). This disagreement may be due to the area which is a small industry area with a few houses though the land is plane surface but still could not be classified as Hata rural area. The model response is not satisfactory in overall observation. This may indicate a new model for West African clutter.

The comparative study also shows that, when the distance is in a logarithmic scale, Hata prediction increases linearly and the data fit curve tends to increases exponentially. If the distance is in linear scale, the Hata prediction increases as a normal logarithmic function but the fitted data curve increases linearly. However, the value of excess path loss observed between the measurement result and the prediction is in the difference of slope graphs.

On the other hand, Hata-Okumura model gives a less prediction values of path loss for smaller distance especially in antenna near field. As a consequence the vertical pattern effect of the transmitting antenna, users in the near field could not be in the main-beamwidth and therefore could experience a poor signal power, if they are at a relative short distance close to the transmitting antenna.

4.3.3. Comparative study parameters

The conducted study so far was focused on quantifying the received power in mobile cluttered environment in order to identify the parameters that influenced the received power. This section proposes the optimizing of H.O. propagation model parameters. The goal is to have the best agreement between the model and the measurement.

4.3.3.1. Fitting parameters for comparison

In **Table 4.3** the comparative parameters obtained from least square fitting method are presented.

Table 4. 3: Fitting parameters for comparison

Data Comparison Fitting Table						
	Urban Area (Osu)		Suburban Area (University of Ghana)		Rural Area(Tema)	
	Hata Model	Meas.	Hata Model	Meas.	Hata Model	Meas.
p1 (slope)	0.02303	0.006171	0.02303	0.02372	0.02303	0.2084
p2 (offset)	100.7	112.7	91.52	88.01	73.08	80.08
RMSE dB	2.34	1.729	2.34	5.871	2.34	5.886
Mean Path loss dB	114.3135	114.2651	105.1177	104.0920	94.3312	86.6779

The results in **Table 4.3** indicate that the obtained excess path loss in the comparative study between Hata model and measurement results is observed to be dependent on the slope of H.O. path loss propagation model. The analysis shows that the theoretical Hata-Okumura

[Hata, 1980; Okumura et al., 1968] models for the study environment could be refined. The least square method would therefore be used to refine the model, because this could give the slope of the plots.

4.3.3.2. Hata-Okumura model refined

Hata-Okumura model (Hata, 1980) for medium city is then selected. The modeling is presented in **Appendix B** and the tuning model is then given as:

$$P_{loss} = b_1 + b_2 logh_{BTS} + b_3 logd + b_4 logh_{MS} + b_5 logd * logh_{BTS} + b_6\, Diff + K_{clutter}$$

$\boldsymbol{b_1 = B_1}$ and $\boldsymbol{b_3 = B_2}$ are coefficients to be optimized.

$\boldsymbol{b_2}$, $\boldsymbol{b_4}$, $\boldsymbol{b_5}$, $\boldsymbol{b_6}$, are the coefficients in Hata-Okumura model and $K_{clutter}$ is the environmental factor (standard deviation of shadowing) its default value is 0 (zero) dB.

The adjusting on the model carried out for the three environments of the study could be observed in **Figure: 4.19** to **4.21**. A very good agreement between the model plot and the measurement plot is achieved in urban (**Figure: 19**), a good agreement in suburban area (**Figure: 20**) and an acceptable agreement in rural area (**Figure: 21**). The adjusted model parameters are compared to Hata model in **Table 4.4.**

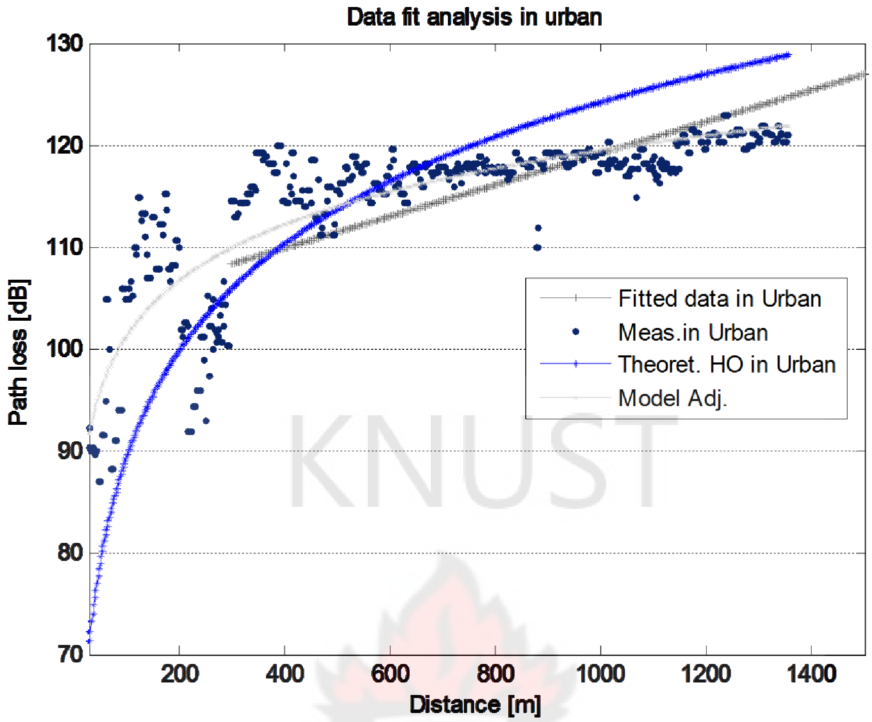

Figure 4. 19: Model adjusted in urban

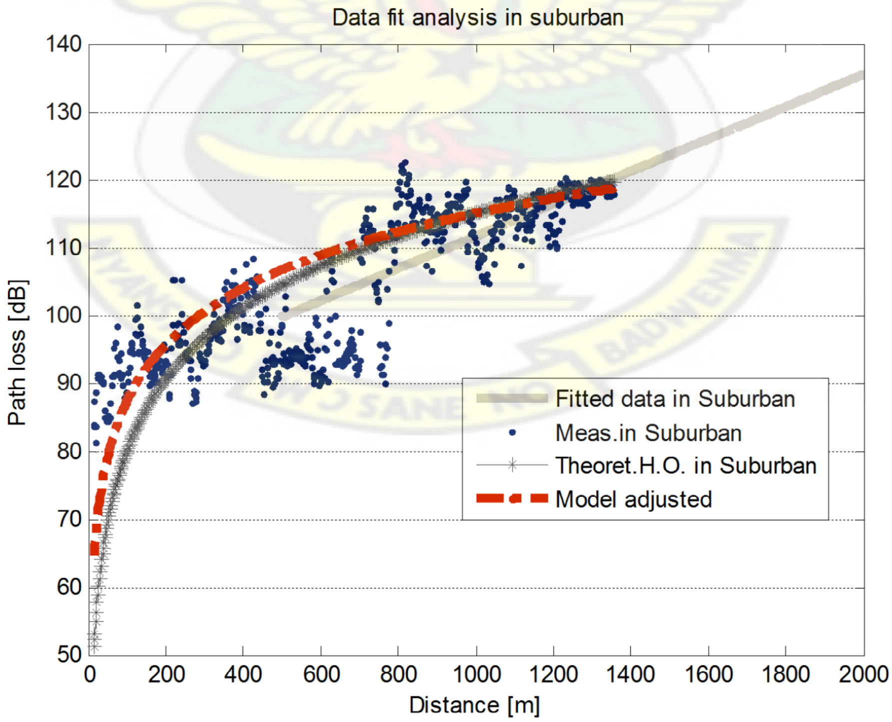

Figure 4. 20: Adjusted model in suburban area

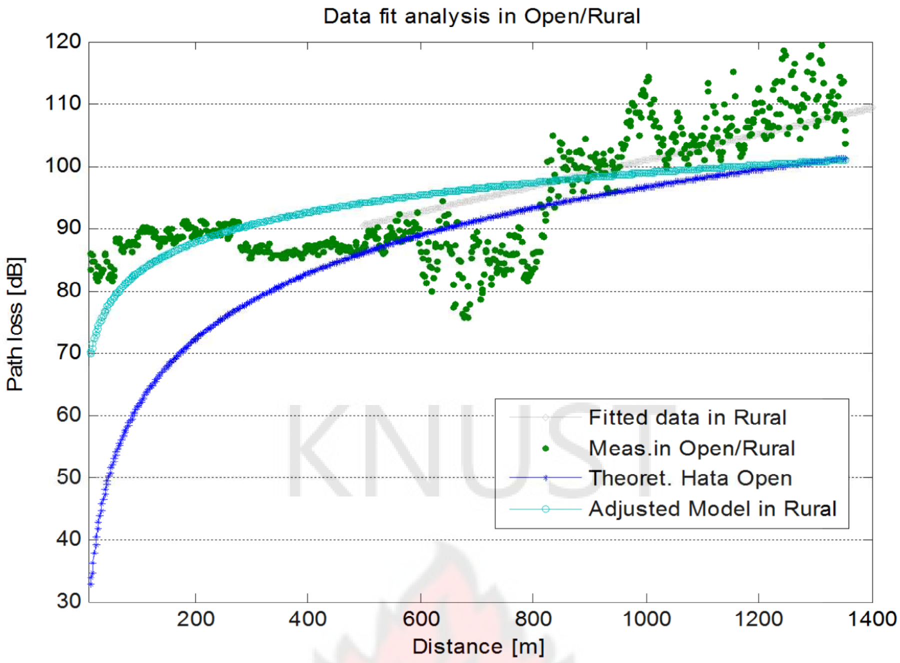

Figure 4. 21: Model adjusted in rural

4.3.3.3. Comparative parameters on adjusted and HO models

In **Table: 4.4** fitting parameters and the propagation parameters optimized are presented.

Table 4. 4: Fitting parameters statistics for Greater Accra

	Urban Area (Osu)		Suburban Area (University of Ghana)		Open Area (Tema)	
	Data Fit	H.O.	Data Fit	H.O.	Data Fit	H.O.
Path loss slope dB/decade	24.89	35.041	27.68	35.01	22.4863	35.041
Offset value (dB)	148.05	145.49	125.5182	145.49	95.8428	145.89
Shadow. std. (dB)	8.2429		10.847		10.003	
RMSE (dB)	4.16	7.69	7.099	8.97	7.8593	13.23
Goodness of fit (dB)	0.7452	0.13	0.57	0.32	0.38	-0.10

In **Table: 4.4,** it is observed that the path loss exponent is high in suburban compared to the other clutter. This could be explained by the effect of foliage. The mean value is about 2.8. The path loss exponent, in open area and residential is 2.25. This value is relatively close to that of free space path loss decay. In urban area, the path loss exponent has a value of about 2.50. All these values are obtained from the path loss slopes. A difference value around 3dB could be observed from shadowing standard deviation in urban area to that of suburban area.

It is also observed that, the “Goodness-of-fit” values of Hata-Okumura model show a little agreement. The value of “Goodness-of-fit” is in the range of 0 and 1. A close value of 1(one) indicates the best fit. Therefore, it could be seen that the area selected as open rural is not Hata open area thus the Goodness-of-fit value is even out of the scope. In Urban area, the value of Goodness-of-fit is also poor. It shows a value of 32% in suburban area which indicates that the study area could be considered as Hata suburban. The adjusted model shows a very good agreement in urban area. It is also good in suburban but the least square algorithm fitting may not be the right algorithm to be used. But though, a dual slope tuning algorithm (Lampiäinien et al., 2003) could have been used to obtain a better tuned model because of the observed distribution in study area of rural.

4.4. Conclusion

The parameters that contribute to CDMA network performance and deployment were investigated in terms of variability of received signal power such as antenna down-tilt, site location, and propagation models. A comparison between Friis equation and measurement can help to make a good decision on cell-site selection. It may recall that Fresnel (Parsons, 1992) first zone is normally used in cell-site appreciation. The signal received in macro-cell down-tilt situation was discussed. It was also observed that a small down-tilt angle not greater than 5° (five degree) provides large coverage in suburban area and rural area (the larger the down-tilt, the smaller the radius). In capacity-limited environment as in urban area, a large antenna downtilt angle greater than 5° (five degree) may be used to provide effective coverage.

The drive-test results in Lome presented a highlight of direct effects of a poor down-tilt on received signal at MS end. A comparison was also carried out between the theoretical model (Hata-Okumura) prediction and the measured path loss (scatter plot). The analysis particularly showed that the applied Hata model for open/rural area give a little agreement in the study area of open clutter (case of Tema in Greater Accra) as well as in the study area of urban clutter (Osu).

The Hata model of medium city was selected as a basis model. A least square method was also used to optimize the propagation parameters.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

The proposed study provides an insight to operators on the sensitivity of received power to variations in antenna down-tilt. The investigation was conducted in a series of drive-tests. The communication network terminal method was used because it responds exactly to what users experience while roaming in the network. The measurement result obtained from the drive test, shows that the down-tilt angle is affected by several parameters such as transmitting power, the environment, etc. The analysis of the result on received power level obtained against the distance on cell site 1, cell site 2 and cell site3 indicates that in a rural area or on open area with a relative flat terrain surface, a small mechanical down-tilt angle less than 4° degree could provide a larger coverage (Prasad et al., 2005). The study also presented a comparison between Hata-Okumura model (Hata, 1980) and the measurement result. Hata-Okumura model (Hata, 1980) and Friis Equation (Parsons, 1992; Rahnema) are compared to the calculated path loss using the received power obtained from Base station in a CDMA cellular network in Ghana. The predicted values using H.O model was less in near field but higher in the far field compared to that of the measurement. The study also shows that the path loss characteristic in the study environment as urban (Osu, Central Accra) could not be described by Hata urban area classification but rather as Hata sub-urban area. The University of Ghana area can be classified as suburban area if approximate fitting parameters are used in the model. Tema (Community 5) area, considered as Hata rural area or open area is not best described by the open area classification.

The path loss prediction in mobile cluttered environment may not follow free space loss as observed by Okumura (Okumura et al., 1968); nonetheless if optimum techniques are met in the design of the air-interface. The definition of cluttered environment is also a relative issue. An area assumed to be a rural or suburban or urban area may vary from one community to another in addition to the extent of land topology. The analysis also shows that Hata-Okumura prediction for suburban area response achieved is closer to the measurement plot. The prediction models applied to urban and rural areas for the selected area show a little agreement. Thus a propagation tuning was then applied to best reduce the excess path loss. Hata model for medium city was adjusted to fit measurement carried out in Greater Accra with the least square algorithm. The model tuned agrees with the measurement very well in urban area and good in suburban area. In rural area, the adjusted model matches better than the Hata model. It indicates that the Hata model for open/rural area may give a little agreement. The least square tuning algorithm was reported in most papers for its inconstancy but it is easy to compute. However, a recursive least square algorithm, iterative least algorithm or multiple slopes tuning algorithm could be used for better improvement of the model refining.

The technical limitation of this project is that it has not been extended to electrical down-tilt because of the difficulty to conduct this experiment on commercial network and in addition to the time and resources allocated to the project. For future works should be addressed on the automatic propagation tuning process and what could be the relative measurement sample to consider for a BTS coverage prediction in cellular mobile and in cell site selection. The investigation of the sensitivity of received power in antenna down-tilt to RF resource allocation (Viterbi et al., 1991) could also be considered. Furthermore, a modified Hata model appropriate for west-African environment could also be undertaken.

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Appendix A: Hata Model

Hata considers urban as a basis of his model and provides correction factors for other clutter (suburban or rural/open areas). Hata's model has four input parameters which are transmitting frequency fc is between 150MHz to 1500MHz, the height of transmitting antenna is in the range of 30-200m the receiving antenna height is between 1 to 10 m and the relevant distance is valid from 1km up to 10km (Parsons, 1992; Yang, 1998; Hata, 1980; Rahnema, 2008, Freeman, 2005; Seybold, 2005).

Hata clutter description such as urban areas, suburban areas and open areas are as follows:

- Urban area: built-up city or large town with large buildings and houses with two or more storeys, or larger villages with closely built houses and tall, thickly grown trees
- Suburban area: village or highway scattered with trees and houses, some obstacles being near the mobile, but assumed to not be very congested;
- Open area: open space, no tall trees or buildings in path, plot of land cleared for 300 – 400 m ahead, e.g. farmland, rice fields, open fields

Urban areas $L_{dB} = A + B\log_{10} R - E$ A-1

Suburban areas: $L_{dB} = A + B\log_{10} R - C$ A-2

Open Area: $L_{dB} = A + B\log_{10} R - D$ A-3

$A = 69.55 + 26.16\log_{10} f_c - 13.82\log_{10} h_b$

$B = (44.9 - 6.55)\log_{10} h_{BTS}$

$C = 2(\log_{10}\left(\frac{f_c}{28}\right))^2 \quad + 5.4$

$D = 4.78(\log_{10} f_c)^2 + 18.33\log_{10} f_c \ + 40.94$

For large cities $f_c \geq 400\text{MHz}$ $E = 3.2(\log_{10}(11.7554 h_{MS}))^2 - 4.97$

For large cities $f_c \leq 200\text{MHz}$ $E = 8.29(\log_{10}(1.54 h_{MS}))^2 - 1.1$

For medium to small cities $E = (1.1\log_{10} f_c - 0.7)h_{MS} - (1.56\log_{10} f_c - 0.8)$

R is the distance between the BTS and the MS.

Other known models: Lee model and Egli model

Lee model (Yang, 1998) is an area-to-area communication link. It is also used in mobile cellular networks design such the personal computers (PCs) network design. The basic Lee model can be written as in Equation A-4:

$$L = 1.14 * 10^{-13} * (\frac{h_{BTS}{}^{2}}{d^{3.84}})$$

$$L[dB] = 129.45 + 38.4 * logd - 20 * logh_{BTS} \quad \text{A-4}$$

The complete form of Lee model is as follows (Adel et al., 2008):

$$L_{50} = L_0 + \gamma \log(d) - 10\log(F_0) \quad \text{A-5}$$

Where L_0 is the median path loss at a reference point taken in the near field.

γ is the slope of the path loss curve in dB/decade. F_0 is a correction factor that depends on MS antenna height, BTS antenna height, MS antenna gain, BTS antenna gain and frequency. It is given as:

$F_0 = f_{cor} * f_{h_{MS}} * f_{h_{BTS}} * f_{G_{T_x}} * f_{G_{Rx}}$, Where

$$f_{cor} = \left(\frac{f_c}{900}\right)^{-n} \qquad f_{h_{MS}} = h_{MS} \quad f_{h_{BTS}} = \left(\frac{h_{BTS}}{30.48}\right)^2 \qquad f_{G_{T_x}} = \frac{G_{Tx}}{4}$$

when MS antenna height in m > 3 , $f_{G_{Rx}} = \frac{h_{MS}}{3}$

when MS antenna height in m < 3 , $f_{G_{Rx}} = h_{MS}$

and**, Egli Model** (Mardeni and Kwan, 2010) is used for point to point communication link (microwave' link).
For receiving antenna (MS) height **h≤10**

$$P_{loss} = 76.3 + 20logf + 40logd - 20logh_{BTS} - 10logh_{MS} \quad \text{A-6}$$

For receiving antenna (MS) height **h ≥ 10**

$$P_{loss} = 85.9 + 20logf + 40logd - 20logh_{BTS} - 10logh_{MS}$$

List of additional Figures

The data fit curves are given in **Fig. A:1 - A:3.** The measured data are the scattered points and the fitting curve is shown in straight line. These curves are obtained using fitting curve function "cftool" in Matlab software. It could be observed that these plots do not exhibit a linear straight line shape when the distance is in logarithmic scale. The fitted curves would be in linear form if the distance is expressed in linear scale form.

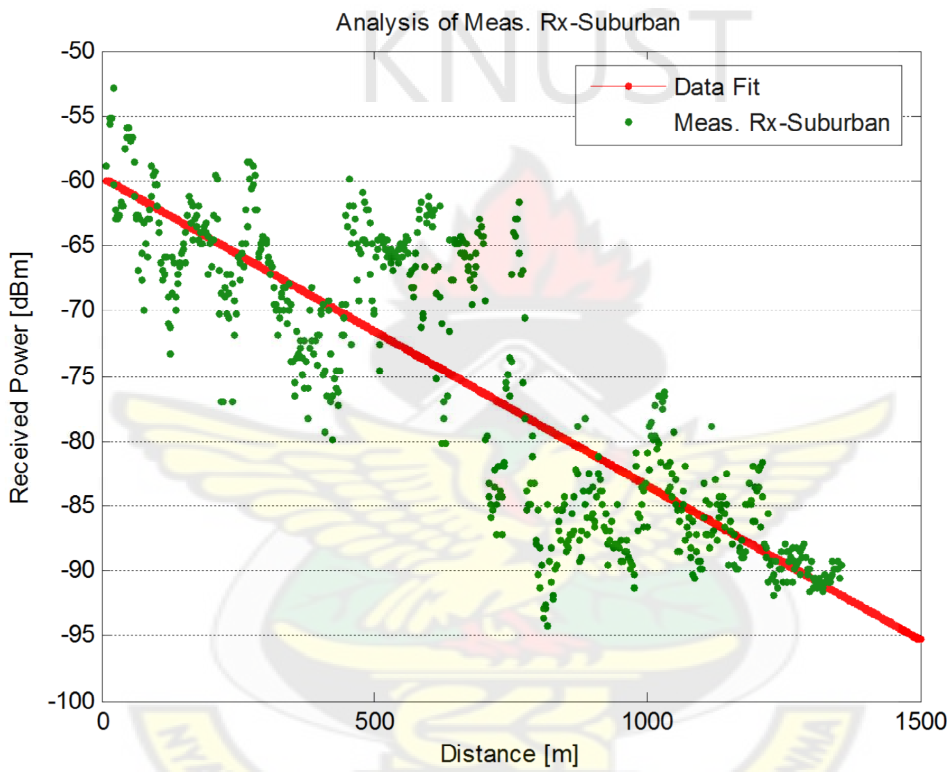

Fig. A. 1: Data fit in suburban (University of Ghana)

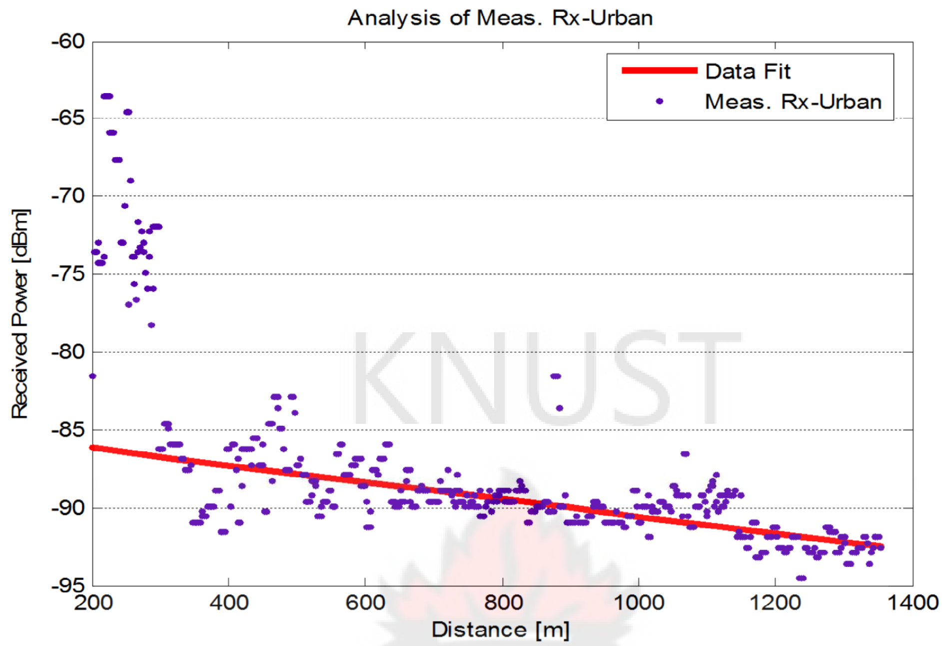

Fig. A. 2: Data fit in urban (Osu)

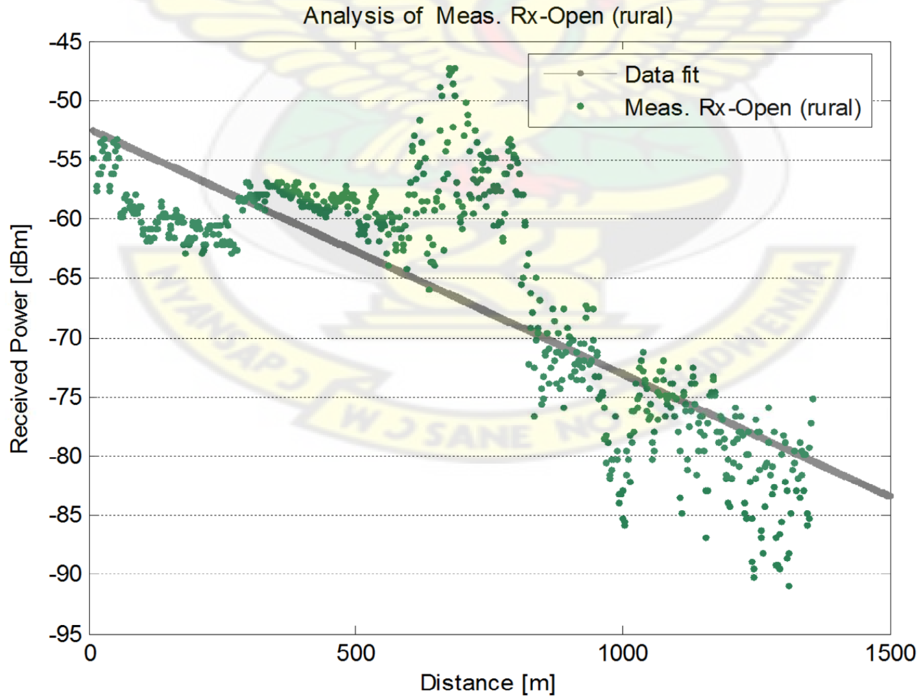

Fig. A. 3: Data fit in rural (Tema C5)

In **Fig. A. 4-Fig. A.7**, are illustrated the shape of the fitting plot and theoretical H.O model against the distance (expressed in linear form, in logarithm scale).

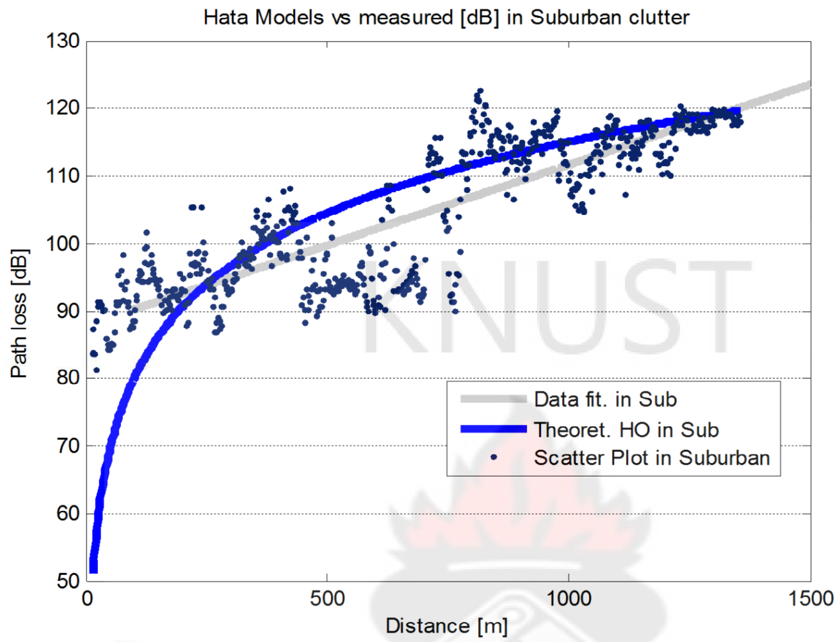

Fig. A. 4: Suburban path loss comparison (distance in linear scale)

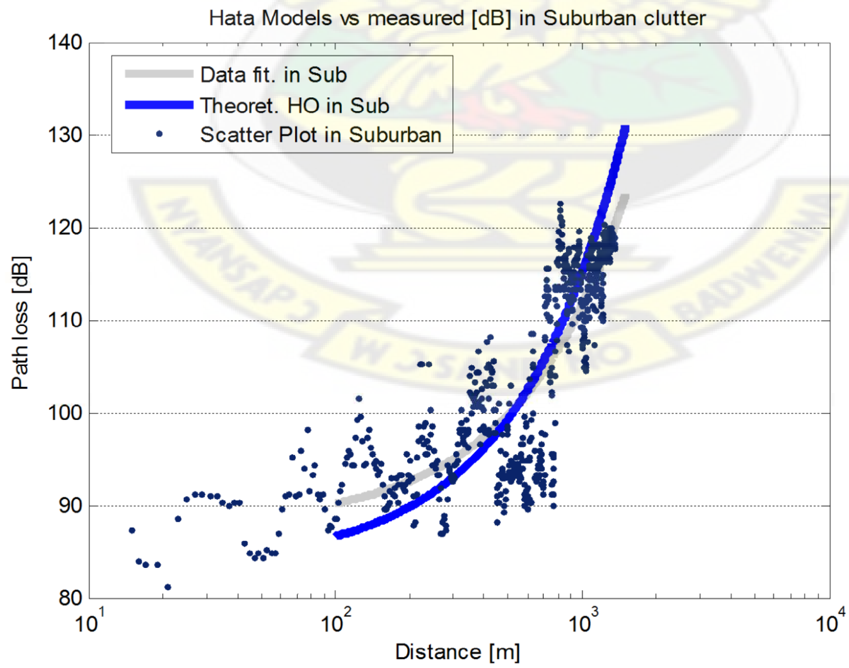

Fig. A. 5: Suburban path loss comparison (distance in logarithmic scale)

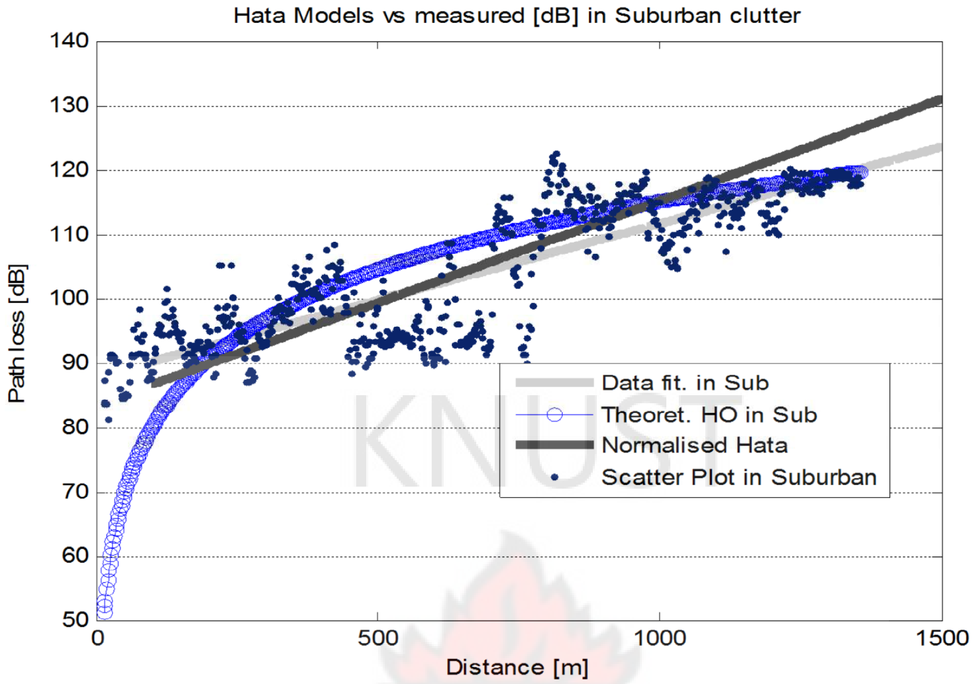

Fig. A. 6: Path loss comparison

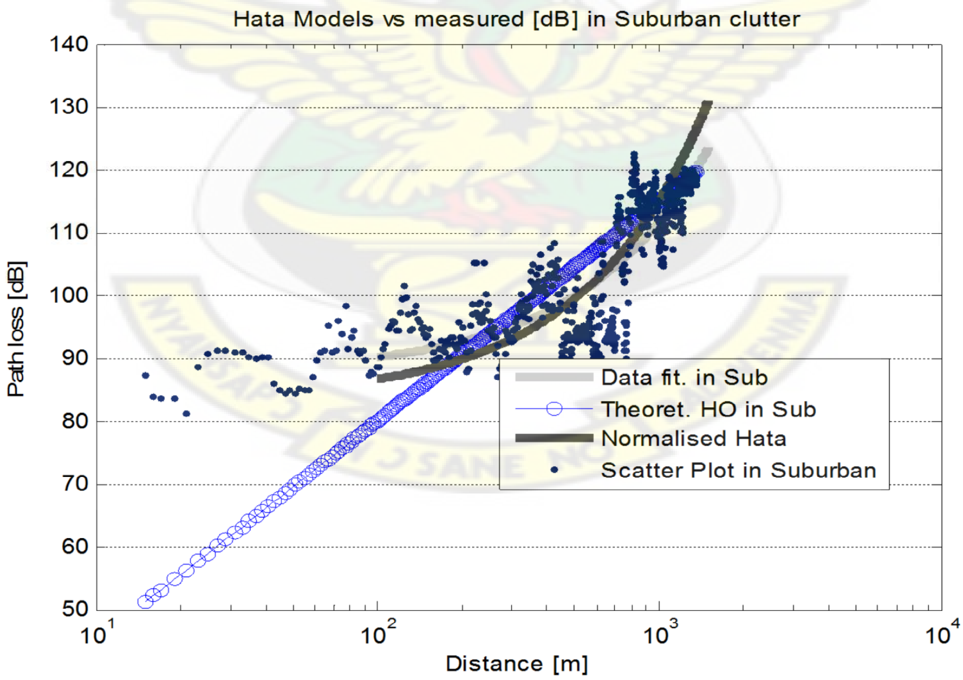

Fig. A. 7: Path loss comparison (distance in logarithmic scale)

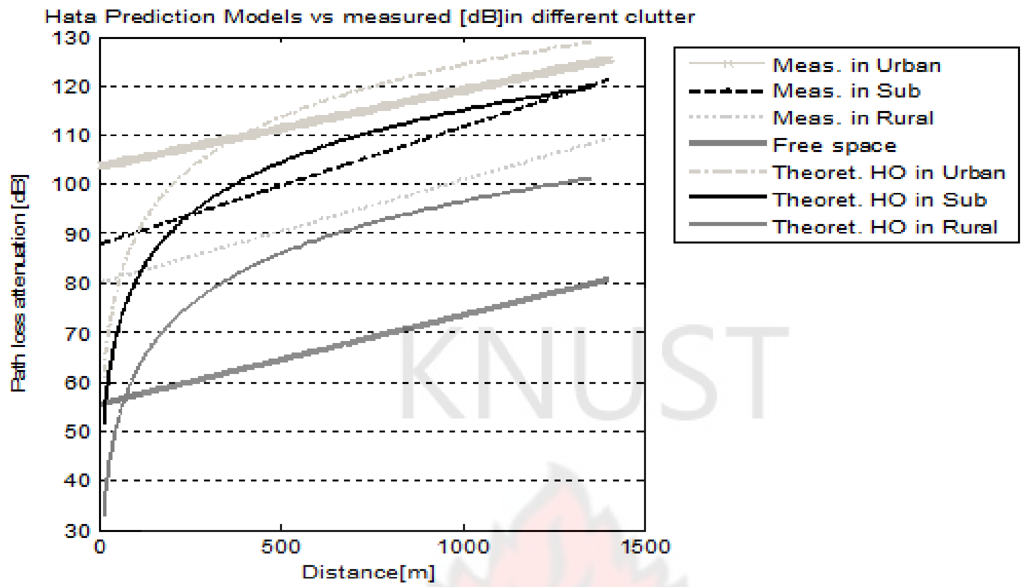

Fig. A. 8: Path loss comparison (distance in linear scale)

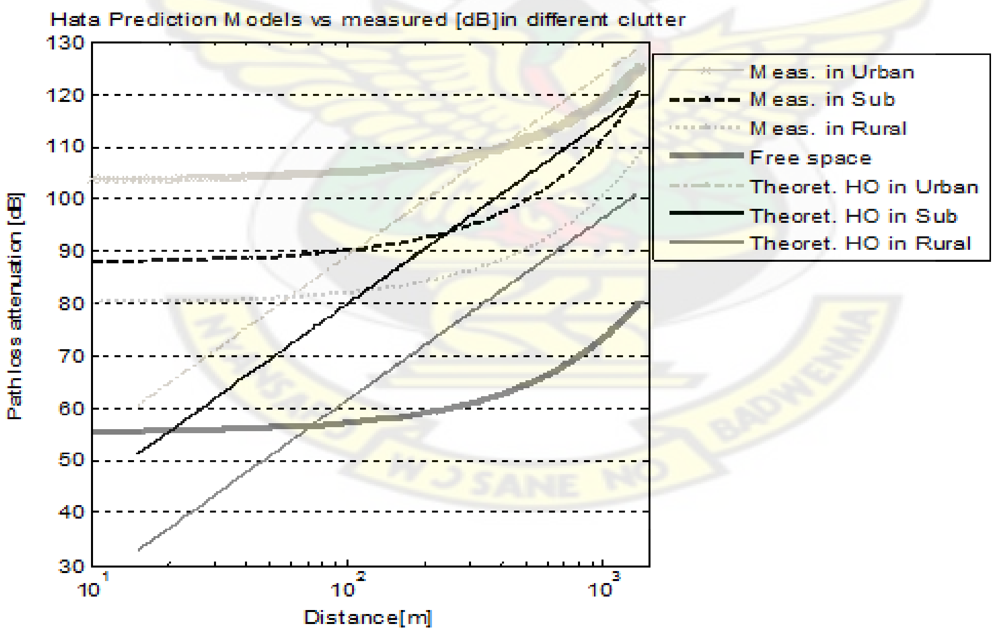

Fig. A. 9: Path loss comparison (distance in logarithmic scale)

Cell coverage in case of BTS site coordination

The bar chart in **Fig. A.10** illustrates the cell servicing coverage in percentage of the received power level measured for the BTS site location in a wrong coordinates and in a correct coordinate. The analysis shows that a fair received power signal level of 42% was observed in near field and the excellent signal level was 24% farther away from the BTS.

In addition, the statistical analysis shows that at cell edge and in case of incorrect site location coordination, the FER was high and an unexpected value of 75 was observed. In terms of good received power level analysis the cell servicing area was 50% covered. This is below the coverage standard of 95% for a cell-site to be said to be fully covered. In **Fig. A.10** the observed received signal in case of correct coordination is shown compared to the received signal in incorrect coordinates of the BTS.

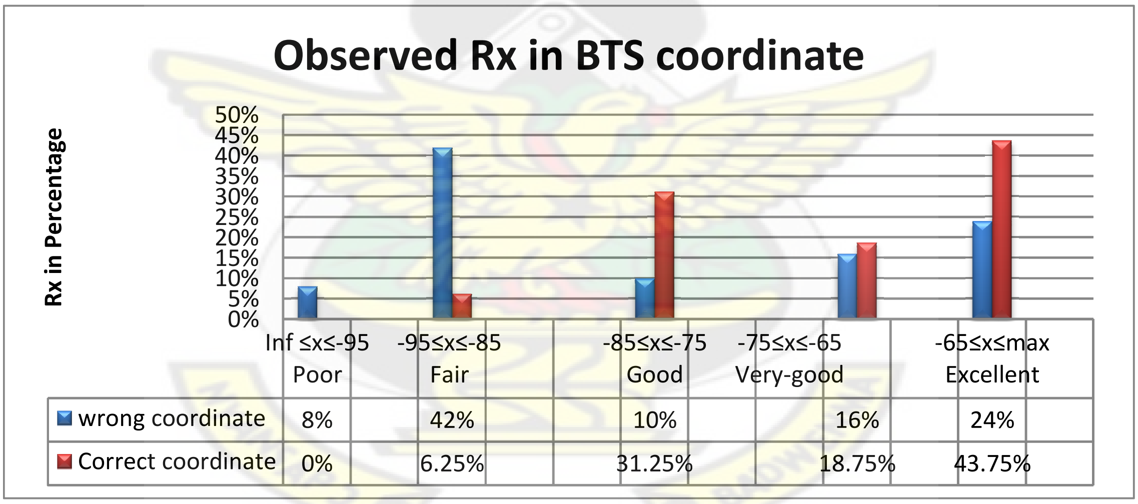

Fig. A. 10: Cell site coverage analysis: case study of BTS site coordinate

Signal sample size issue

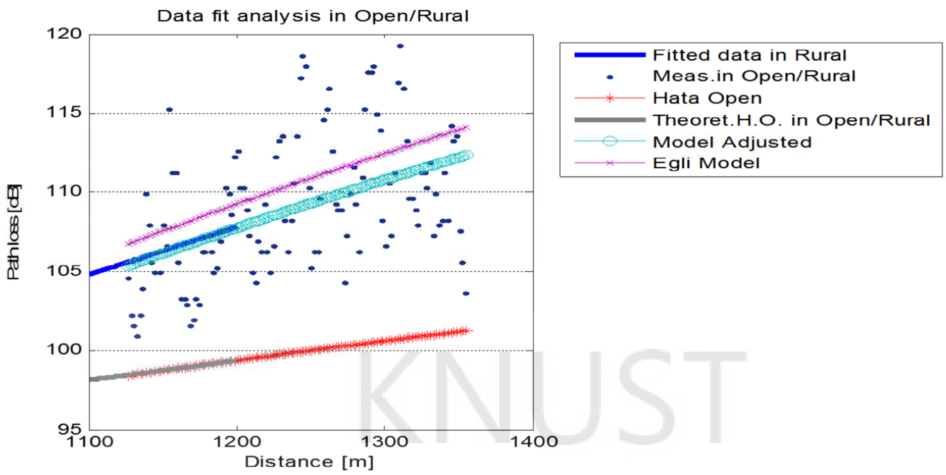

Fig. A. 11: Small sample prediction

In **Fig. A.11**, a sample of the received power in far field in rural area is considered. The measurement, data was compared to Hata Okumura model. The theoretical model (H.O.) adjusted shows very good agreement for a small sample but when a large sample was considered the adjusted model showed a fair agreement. This raises the question of signal measurement sample to be considered for macro-cell coverage prediction or on cell site selection.

Appendix B: The least square method

The measured path loss is expressed as in Equation B-1,

$$y_i = P_{Tx} + G_{Tx} - C_{loss} - P_{R_{x_i}} \qquad \text{B-1}$$

Hata prediction for medium cities to small cities is re-written

$$P_{\ loss} = 69.55 + 26.16 \log_{10} f_c - 13.82 \log_{10} h_b + \left((44.9 - 6.55) \log_{10} h_{BTS}\right) logR + (1.1 \log_{10} f_c - 0.7) h_{MS} - (1.56 \log_{10} f_c - 0.8) \qquad \text{B-2.a}$$

This can be modeling as in Equation B-2.b as follows:

$$P_{loss} = C_1 + C_2 logf + C_3 logh_{BTS} + C_4 logd + C_5 logh_{MS} + C_6 logd * logh_{BTS} + C_7\ Diff + K_{clutter} \qquad \text{B-2.b}$$

In changing variables, this is written as follows:

$B_1 = C_1 + C_2 logf$

$B_2 = C_4$

$x = logd$

$K_a = C_3 logh_{BTS} + C_5 logh_{MS} + C_6 logd * logh_{BTS} + C_7\ Diff + K_{clutter}$

In Suburban area:

$K_a = C_3 logh_{BTS} + C_5 logh_{MS} + C_6 logd * logh_{BTS} + C_7\ Diff + K_{clutter} + C$

In rural area

$K_a = C_3 logh_{BTS} + C_5 logh_{MS} + C_6 logd * logh_{BTS} + C_7\ Diff + K_{clutter} + D$

C and D are Hata correction defined for Suburban and rural given in Appendix A

Then it comes as in Equation B-3

$$P_{loss \to i}(d) = B_1 + B_2 xi + K_a \qquad \text{B-3}$$

The objective of tuning process is to minimize the residual error root mean square function between the predicted value and the measured one. The error function is given as:

$$E(d) = yi - P_{loss \to i}(d) \qquad \text{B-4}$$

The root mean square function is given as in Equation B-5

$$E(B_1, B_2) = \sqrt{\left(\frac{1}{N}\right) \sum_{i=1}^{N} [y_i - P_{loss \to i}]^2} \qquad \text{B-5}$$

Where y_i is the measured value, N is the number of the measurement sample set. To fulfill the least square (Daper, 1998, Robinson, 1992) condition that optimizes the B_1 and B_2, all the partial derivatives of the $E(A, B)$ function must equal to zero. This yields N equations which are given as follows:

$$\begin{cases} i = 1 & \Rightarrow yi - [B_1 + B_2 x_1 + K_{a_1}] \\ i = 2 & \Rightarrow y_2 - [B_1 + B_2 x_2 + K_{a_2}] \\ & \quad . \\ & \quad . \\ & \quad . \\ i = N & \Rightarrow y_N - [B_1 + B_2 x_N + K_{a_N}] \end{cases} \qquad \text{B-6}$$

$$\begin{cases} \frac{\partial E}{\partial B_1} = 0 \\ \\ \frac{\partial E}{\partial B_2} = 0 \\ \\ \frac{\partial err}{\partial K_a} = 0 \end{cases} \qquad \text{B-7}$$

This can be put in square matrix,

$$\begin{bmatrix} x_1 & 1 \\ x_2 & 1 \\ & \\ & \\ & \\ x_N & 1 \end{bmatrix} \times \begin{bmatrix} B_1 \\ \\ B_2 \end{bmatrix} = \begin{bmatrix} y_1 - K_{a_1} \\ y_2 - K_{a_2} \\ . \\ . \\ . \\ y_N - K_{a_N} \end{bmatrix}$$

This can be written as

$$W \times \bar{B} = Y \qquad \text{B-8}$$

The Equation B-8 is over-determined system.

The vector $\bar{B} = [B_1 \quad B_2]^T$

The optimal correction coefficients B_1 and B_2 verifying the least squares condition are obtained from the least-squares solution of the matrix equation given as.

$$\bar{B}_{LS} = [W^T W]^{-1} W^T Y \qquad \text{B-9}$$