A Model for Optimized RF Propagation Path Loss Measurements in Mega Cities: A Case for Lagos Metropolis

Imhomoh E. Linus MNSE\(^1\), John Paul Iloh MNSE, PhD\(^2\), Akaneme S. A MNSE, PhD\(^3\), Kikanme Ronald\(^4\)
Department of Electrical/Electronic Engineering
Federal Polytechnic Nekede, Owerri Imo State, Nigeria\(^1,4\)
Chukwuemeka Odumegwu Ojukwu University Uli, Anambra State, Nigeria\(^2,3\)

Abstract:
This study focuses on developing a model that will best predict the path loss of the received signal power from global system for mobile communication (GSM) base stations located in the Lagos metropolis using a comparative approach. A site survey was carried out and the areas classified as rural, suburban and urban. Propagation measurements were taken at 1800MHz with a BK Precision Spectrum Analyzer, personal computer and a GPS unit to accurately track the location of mobile equipment from the fixed base station. The test locations were within a propagation distance of 2km, starting from a reference distance (do) of 100m. On the average, over 1200 measurement results were taken at about 120 measurement locations from six GSM base station sites. Average power received was calculated to estimate the path loss corresponding to each measurement. Least squares (LS) regression analysis was used to determine the path loss exponent. The modification was done by subtracting the calculated mean square error (MSE) between the measured and the predicted path loss for each location. The developed model was found to predict the measured path loss with acceptable MSEs of 2.30dB in rural (Ifoako), 3.64dB in suburban (Oshodi, Gbagada) and 5.25dB in urban (Saks Tinubu, Osborne in Ikoyi and Victoria Island) area of Lagos. The overall results show a significant reduction in the acceptable standard of 6.0dB. The MSE error reduction translates to improved signal power.

Keywords: Mean Square Error (MSE), 1800MHz Frequency, Path loss, Propagation Measurement.

I. INTRODUCTION
There are different misfortune proliferations of path loss models that exist for radio signal blurring execution forecast in a multipath situation. These propagation models are fundamental instruments for remote system arranging, obstruction examination, and recurrence task and cell parameters assessment [1]. When appropriately comprehended, the system gives uncommon inclusion to remote interchanges. It would then be able to be said that path-loss propagation models are studied to appropriately anticipate the signal propagation conduct of a particular spot. Such arrange model forecast is valuable in organization wanting to ensure productive system execution with great Quality of Service (QoS). However, a portion of these models need investigative portrayal of the measured data from a domain of interest for productive performance yet it is regularly hard to sum up these models for a particular region. The test-apparatuses for organize grouping and parameterization of a region utilizing any chosen path-loss proliferation model are well-characterized by the nature of the quality of service and execution records that the specialist co-ops look to accomplish. In spite of the fact that this innovation has changed the face of mobile communication in Lagos however the shoppers’ fulfillment in certain territories of the state is exceptionally in dismay. A great deal of reactions, for example, reverberation during call trade, normal call drops, and poor interconnectivity to and from other authorized systems, low quality of administration, organize sticking and bends, among others are upsetting issues that should be fixed. A greater amount of these issues are conceived particularly since the state is experiencing some basic and ecological changes as far as development of high rising structures to accept the status of a uber city which will have some effect on its signal propagation paths. So as to beat these efforts, the parameters of certain experimental models can be altered, created and advanced with reference to the focused environment. [2]

PROPAGATION MODELS
Propagation models are numerical apparatuses utilized by architects and researchers to plan and streamline remote system frameworks. These models are utilized generally in organize arranging, prevalently for leading attainability considers and during starting organization. They are likewise helpful for performing impedance thinks about as the arrangement continues [1]. These models can be extensively classified into three kinds; empirical, deterministic and stochastic.

![Figure 1. Block diagram showing classification of propagated model](http://ijesc.org/)

PROPAGATION PATH LOSS
During propagation between the transmitting and the receiving antenna, radio waves interact with the environment, causing path loss. Basically, path loss (PL) is defined as the difference
between the transmitted and the received power given by [3] as:

\[ P_L = EIRP + G_e - G_r - L_{f} - L_{r} \]  \quad (1) [3]

Where EIRP and \( P_r \) are the effective isotropic radiated power and the received power, \( G_e \) and \( G_r \) are gains of the transmitting and the receiving antennas and \( L_f \) and \( L_r \) are feeder losses, all in a dB. The path loss at a given distance is more in open urban environments than in suburban environments. Higher path loss is expected to be experienced by a mobile station that is far away from the BS. The signal experiences more multipath fading as it propagates further away from the transmitter [3]. Higher path loss is also expected in open urban conditions because the clutter of the buildings will cause multipath fading and signal strength deterioration when compared with suburban environments in which as LOS between transmitter and receiver may exist and allow the signal to propagate without suffering from diffractions, reflection, absorption and scattering.

II. METHODOLOGY

The experimental setup is as shown in Figure [2]

![Figure 2: The block diagram showing the experimental setup][2]

At 1800MHz frequency, propagation measurements were taken using a BK Precision Spectrum Analyzer and a GPS unit to correctly create measurement location. The test locations measured, were within a propagation distance of 2km, starting from a locus distance (do) of 100m. In all, an average of 1200 measurement results were taken in 120 measurement locations from six GSM base station sites located in the Lagos environment. Field measurements were taken in December 2016 to April, 2017, a period which properly covers the two major climatic seasons in Lagos when this study was carried out. Each location measurement is an average of 10 readings taken at an interval of 60 seconds of several parameters as well as the received signal power in dB. Measured data were collected at a close constant mobile antenna height of 1.5m along the LOS and NLOS of the fixed base stations with heights ranging from 25-30m [4], due to the presence of obstacles like fly-over bridges and high rise buildings in the areas under study. The determined average power received was used to calculate the path loss corresponding to each measurement and the least squares (LS) regression analysis was used to determine the path loss exponent. This is realised by reducing the summed squares of residuals between the measured and the predicted data. The coefficients determined by differentiating the summed square of residuals with respect to each parameter and equating the result to zero [5]. To improve on the statistical meaning of the path loss exponent, measured data from base stations situated in environments having related morphological and physical features have been prudently combined. Therefore, measurements from two of the base stations located at Ifaiko village an interior in Shomulu, Lagos are combined to give measurements typical of a rural area. In the same way, measured path loss from two of the base stations located in Gbagada, Lagos are combined to give measurements typical of a suburban area and measurements taken at Ikoyi/Osholede and Victoria Island/Lekki have been combined to give measurements typical of urban area. The simulation parameters are as shown in Table I [6].

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUES</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance between Tx – Rx</td>
<td>2</td>
<td>Km</td>
</tr>
<tr>
<td>BaseStation Transmitter power</td>
<td>40</td>
<td>Watts</td>
</tr>
<tr>
<td>Receiver antenna height</td>
<td>1.5</td>
<td>M</td>
</tr>
<tr>
<td>Building to building distance</td>
<td>20</td>
<td>M</td>
</tr>
<tr>
<td>Average building height</td>
<td>15</td>
<td>M</td>
</tr>
<tr>
<td>Street width</td>
<td>25</td>
<td>M</td>
</tr>
<tr>
<td>Operating Frequency</td>
<td>1800</td>
<td>MHz for all environments</td>
</tr>
<tr>
<td>Transmitter antenna height in Urban and Sub-urban areas</td>
<td>30</td>
<td>M</td>
</tr>
<tr>
<td>Transmitter antenna height in Rural</td>
<td>40</td>
<td>M</td>
</tr>
<tr>
<td>Body loss</td>
<td>3</td>
<td>dB</td>
</tr>
<tr>
<td>Cable loss</td>
<td>3</td>
<td>dB</td>
</tr>
<tr>
<td>Transmitter Antenna Gain</td>
<td>18.15</td>
<td>dBi</td>
</tr>
<tr>
<td>Isolator + Combiner + filter loss</td>
<td>4.7</td>
<td>dB</td>
</tr>
<tr>
<td>Street orientation angle in Urban, Sub-urban and Rural areas</td>
<td>90°</td>
<td></td>
</tr>
<tr>
<td>Correction for shadowing effects Sub-urban and Rural areas</td>
<td>8.2</td>
<td>dB</td>
</tr>
<tr>
<td>Correction for shadowing effects in Urban</td>
<td>10.6</td>
<td>dB</td>
</tr>
</tbody>
</table>

PATH LOSS MODELLING EQUATIONS USED FOR COMPARISON

FREE SPACE PROPAGATION MODEL

In free space, ideal propagation implies equal radiation in all directions from the radiating source and propagation to the receiver located at a specified distance with no degradation. This scenario is not realistic in real life situations. Assuming that the radiating source radiates energy at 3.6KW with a fixed power forming an ever increasing sphere, the power flux at the transmitter is given as [7]:

\[ P_d = \frac{4\pi d^2}{L^2} \]  \quad (2) [7]

Basically, the effective area \( A_e \) of an isotropic antenna is:

\[ A_e = \frac{4\pi L^2}{d^2} \]  \quad (3)

While power received is:

\[ P_r = P_t \times A_e = \frac{(4\pi d^2)}{L^2} \]  \quad (4)

Where \( P_t \) is known as the transmitted power (W/m²) and \( P_r \) is the power at a distance \( d \) from the antenna. Having known the power flux density at any point of a given distance from the transmitting antenna, if a receiver antenna is placed at...
At this point, the power received by the antenna can be calculated. The formula for calculating the effective antenna aperture and received power are as shown in (3) and (4). The amount of power “captured” by the antenna at the required distance \(d\) depends upon the “effective aperture” of the antenna and the power flux density at the receiving element. Actual power received by the antenna depends on the following:

i. The aperture of receiving antenna \(A_a\)

ii. The wavelength of the received signal \(\lambda\)

iii. The power flux density at receiving antenna \(P_d\).

The path loss can be calculated as:

\[
P_L = P_r - P_t + 10 \log_2 \left( \frac{\lambda^2}{4\pi d^2} \right)
\]

Expressing (6) in decibels gives:

\[
P_L (dB) = 20 \log_{10}(\frac{4\pi d}{\lambda}) + 20 \log_{10}(\frac{\lambda}{\lambda})(7)
\]

Substituting \([\lambda \text{ in km}] = 0.3\text{f \text{in MHz}}\) in (7) gives the free space propagation loss formula:

\[
P_L (dB) = 32.45 + 20 \log_{10}(d) + 20 \log_{10}(f)
\]

Where, \(f = \text{frequency in MHz}\)

\(d = \text{distance in km}\).

This equation shows the relationship between the path loss, the frequency and distance of the transmission medium.

**COST-231 HATA MODEL**

A model that is widely used for predicting path loss in mobile wireless systems is the COST-231 Hata model [8]. Given the limitation of the Hata model to 1.5GHz and below, as well as the interest in personal communications systems operating near 1.9GHz, this model was devised as an extension to the Hata-Okumura model. The COST-231 Hata model is designed to be used in the frequency band from 500MHz to 2000MHz. It also contains corrections for urban, suburban and rural (flat) environments. Apart from availability of correction factors for the categories of environments under investigation, the COST-231 Hata model is very simple and easy to use for path loss prediction. The basic equation for the path loss in dB predicted by this model is:

\[
P_L = P_{0,H} - 10 \log_{10}(d^2) - 20 \log_{10}(\frac{\lambda}{\lambda}) - 20 \log_{10}(\frac{\lambda}{\lambda})(10)
\]

And for suburban or rural environments:

\[
P_L = P_{0,H} - 10 \log_{10}(d^2) - 20 \log_{10}(\frac{\lambda}{\lambda}) - 20 \log_{10}(\frac{\lambda}{\lambda})(11)
\]

Where, \(P_{0,H}\) is the mobile station antenna height above ground level in meters. 

\(\lambda = \text{wavelength of the received signal}\)

\(d = \text{distance between transmitter and receiver in km}\)

\(f = \text{frequency of transmission in MHz}\)

\(C = \{0 \text{dB for rural and suburban areas, 3dB for urban areas}\}\)

\(\sigma = 44.9\)

\(\delta = 0.7\)

The basic equation for the path loss in dB predicted by this model is:

\[
P_L = P_{0,H} - 10 \log_{10}(d^2) - 20 \log_{10}(\frac{\lambda}{\lambda}) - 20 \log_{10}(\frac{\lambda}{\lambda})(12)
\]

\[
P_L = P_{0,H} - 10 \log_{10}(d^2) - 20 \log_{10}(\frac{\lambda}{\lambda}) - 20 \log_{10}(\frac{\lambda}{\lambda})(13)
\]

Figure 3. Mean power received in rural, suburban and urban areas.

**MODIFICATION OF COST 231 HATA MODEL FOR THE INVESTIGATED ENVIRONMENT**

**Table 1. Mean square error (mse) estimates**

<table>
<thead>
<tr>
<th>Path Loss Model</th>
<th>Rural Areas</th>
<th>Suburban Areas</th>
<th>Urban Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free Space</td>
<td>31.46</td>
<td>34.33</td>
<td>40.22</td>
</tr>
<tr>
<td>Egil</td>
<td>28.25</td>
<td>23.73</td>
<td>29.25</td>
</tr>
<tr>
<td>COST-231 Hata</td>
<td>5.22</td>
<td>4.80</td>
<td>4.41</td>
</tr>
<tr>
<td>Ericsson</td>
<td>22.78</td>
<td>14.77</td>
<td>15.90</td>
</tr>
<tr>
<td>ECC -33</td>
<td>3.96</td>
<td>31.18</td>
<td>48.07</td>
</tr>
<tr>
<td>SUI</td>
<td>59.83</td>
<td>8.36</td>
<td>3.44</td>
</tr>
</tbody>
</table>

Where \(P_L = \text{Median path loss in decibel (dB)}\)

\(f = \text{Frequency of transmission in MHz}\)

\(h_b = \text{Base station antenna height in meters (m)}\)

\(CH = \text{Mobile station antenna height correction factor}\)

\(L_0 = 46.3\)

\(\sigma = 44.9\)

\(C = \{0 \text{dB for rural and suburban areas, 3dB for urban areas}\}\)
From the mean square error calculated in Table III, it was observed that among the existing empirical propagation models compared against propagation measurements taken at 1800KHz in the Lagos environment, the Stanford University Interim (SUI) model and COST 231 W-I showed a satisfactory performance in the rural and Urban area with an MSE of 3.96dB and 3.44dB as shown in Table III. However, these models obviously over predicted the path loss in the rural, suburban and urban areas with MSEs of 59.83dB, 8.36dB, 31.18dB and 48.07dB respectively. As a result of these over predictions, they were not selected as the best models. Likewise, the Egli, Ericsson, and ECC-33 models generally over predicted the path loss in the tested areas with MSEs higher than the acceptable range of up to 6dB as stated by [2]. Hence, they were not also selected as most suitable for the investigated environments. In all, the COST 231 Hata model showed the best performance in the rural, suburban and urban areas with MSEs of 5.22dB, 4.80dB and 4.41dB respectively. The model was selected for modification for better signal prediction with lower values of MSEs on the average.

The path loss predicted by the COST 231 Hata model as stated (9) is:

\[ \text{PL}_{\text{COST}} = 46.3 + 33.9 \log_{10}(f) - 13.82 \log_{10}(h_b) - ah_m + [44.9 - 6.55 \log_{10}(b_b)] \log_{10}d + C_m \]

Where, \( f \) = frequency in MHz
\( d \) = distance between transmitter and receiver in km,
\( b_b \) = Base station antenna height above ground level in meters.
The parameter \( C_m \) is defined as 0dB for suburban and rural environments and 3dB for urban environments. Similarly, the parameter \( ah_m \) is defined for urban environments as;
\[ ah_m = 3.20 [\log_{10}(11.75h_r)]^2 - 4.97 \quad \text{for} \quad f > 400MHz. \]
For suburban or rural environments,
\[ ah_m = (1.1\log_{10}f - 0.7)h_r - (1.56 \log_{10}f - 0.8) \]
Where, \( h_r \) is the mobile antenna height above ground level in meters.

The modification of (9) was done by subtracting the calculated MSE between the measured and the predicted path loss for each environment as stated in Table III from the COST 231 Hata model. Therefore equation (9) becomes;

\[ \text{PL}_{\text{COST Modified}} = 46.3 + 33.9 \log_{10}(f) - 13.82 \log_{10}(h_b) - ah_m + [44.9 - 6.55 \log_{10}(b_b)] \log_{10}d + C_m - \text{MSE} \]

III. RESULT

DEVELOPMENT OF THE NEW MODEL USING MODIFIED COST 231 HATA MODEL

The modified models are developed based on the available network statistics such as operating frequency of 1800MHz, mobile antenna height of 1.5m and base station antenna heights of 40m for rural areas and 30m for suburban and urban areas. The COST 231 Hata model expressed in (9) can be grouped into the three basic elements of any empirical model as stated by [10]; the initial offset parameter \( P_o \), the initial system design parameter \( D_{sys} \) and the slope of the model curve \( M_{slope} \) defined by;

\[ P_o = 46.3 - ah_m + C_m \quad (14) \]
\[ D_{sys} = 33.9 \log_{10}(f) - 13.82 \log_{10}(h_b) \quad (15) \]
\[ M_{slope} = [44.9 - 6.55 \log_{10}(b_b)] \log_{10}d \quad (16) \]

The total path loss is given by;

\[ \text{PL} (\text{dB}) = P_o + rD_{sys} + M_{slope} \quad (17) \]

The least square algorithm in conjunction with the basic fitting function of the computing tool in MATLAB to fit linear models to the logarithmic curves provided by the COST 231 Hata, measured path loss and the modified COST 231 Hata models for rural, suburban and urban region.

Mainly, the linear models fitted to the modified COST 231 Hata models are of the form;

\[ \text{PL} (\text{dB}) = a \ast d + b \quad (18) \]

Where,
\( a \) = Gradient of the Linear Model
\( b \) = Intercept of the Linear Model in dB on the Vertical Axis.
\( d \) = Distance in km along the horizontal axis.
From (14), the value of \( P_o \) equals (46.3- \( ah_m + C_m \)) for all areas. By comparing (18) with the equations of the linear models fitted to the modified COST Hata model, the values of
b are obtained as; \(b = 104.66\) for rural area, \(b = 107.96\) for suburban area and \(b = 111.26\) for urban area. Also, (15) can be used to calculate the system design parameter \(D_{sys}\) for each area as shown. At the operating frequency \(f = 1800\) MHz and base station antenna height \(h_b = 40m\) for rural area and \(h_b = 30m\) for suburban and urban areas;

\[
D_{sys} = 33.9 \log_{10}(1800) - 33.8 \log_{10}(40) = 88.21 \text{ for rural area.}
\]

\[
D_{sys} = 33.9 \log_{10}(1800) - 33.82 \log_{10}(30) = 89.94 \text{ for suburban area.}
\]

\[
D_{sys} = 33.9 \log_{10}(1800) - 33.82 \log_{10}(30) = 89.94 \text{ for urban area.}
\]

Also, (15) can be used to calculate the system design parameter for each area as shown. At the operating frequency \(f = 1800\) MHz and base station antenna height \(h_b = 40m\) for rural area and \(h_b = 30m\) for suburban and urban areas;

\[
\text{New } P_o = 46.3 - \text{ah}_m + C_m \pm \text{MSE} \quad (19)
\]

Where, MSE= Mean Square Error in dB.

From Table III, the MSEs on the basis of the COST 231 Hata model are; 5.22dB, 4.80dB and 4.41dB for rural, suburban and urban areas respectively. By substituting these MSE values into Equation (19), the new \(P_o\) values are obtained as;

\[
\text{New } P_o = 46.3 - 5.22 - \text{ah}_m + C_m = 41.08 - \text{ah}_m + C_m \text{ for rural area.}
\]

\[
\text{New } P_o = 46.3 - 4.80 - \text{ah}_m + C_m = 41.50 - \text{ah}_m + C_m \text{ for suburban area.}
\]

\[
\text{New } P_o = 46.3 - 4.41 - \text{ah}_m + C_m = 41.89 - \text{ah}_m + C_m \text{ for urban area.}
\]

These results are presented in Table IV as;

Thus, the path loss equations developed for the modified models can be stated in the form of (17) as;

\[
\text{PL (dB)} = \text{New } P_o + D_{sys} + M_{slope} \quad (20)
\]

Table 4. Initial offset parameters for modified cost 231 hata model [4]

<table>
<thead>
<tr>
<th>Area</th>
<th>(P_o)</th>
<th>(D_{sys})</th>
<th>New (P_o) = 46.3 - \text{ah}_m + C_m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>46.3 - \text{ah}_m + C_m</td>
<td>104.66 6</td>
<td>88.2 1 41.08 - \text{ah}_m + C_m</td>
</tr>
<tr>
<td>Suburban</td>
<td>46.3 - \text{ah}_m + C_m</td>
<td>107.97 6</td>
<td>89.9 4 41.50 - \text{ah}_m + C_m</td>
</tr>
<tr>
<td>Urban</td>
<td>46.3 - \text{ah}_m + C_m</td>
<td>111.22 6</td>
<td>89.9 4 41.89 - \text{ah}_m + C_m</td>
</tr>
</tbody>
</table>

By substituting (15), (16) and the values of New \(P_o\) for rural, suburban and urban areas in Table IV into (19), the path loss models obtained as shown in (21), (22) and (23) are hereby referred to as the developed models for rural, suburban and urban areas respectively.

\[
\text{PL (dB)} = 41.08 + 33.9 \log_{10}(f) - 13.82 \log_{10}(h_b) - \text{ah}_m + [44.9 - 6.55 \log_{10}(h_b)] \log_{10}(d) + C_m \quad (21)
\]

\[
\text{PL (dB)} = 41.50 + 33.9 \log_{10}(f) - 13.82 \log_{10}(h_b) - \text{ah}_m + [44.9 - 6.55 \log_{10}(h_b)] \log_{10}(d) + C_m \quad (22)
\]

\[
\text{PL (dB)} = 41.89 + 33.9 \log_{10}(f) - 13.82 \log_{10}(h_b) - \text{ah}_m + [44.9 - 6.55 \log_{10}(h_b)] \log_{10}(d) + C_m \quad (23)
\]

Where, \(f = \) Frequency in MHz

\(d = \) Distance between transmitter and receiver in km,

\((h_b) = \) Base station antenna height above ground level in meters.

The parameter \(C_m\) is defined as 0dB for suburban and rural environments and 3dB for urban environments. Similarly, the parameter \(\text{ah}_m\) defined for urban environments as;
The mean square error is given as:

$$\text{MSE} = \frac{1}{k} \sum_{i=1}^{k} (\text{PL}_m - \text{PL}_r)^2$$

Where PL$_m$ = Measured Path Loss (dB)
PL$_r$ = Predicted Path Loss (dB) on the basis of the developed model for rural, suburban and urban areas.

k = Number of Measured Data Points = 20.

From Table 4.18 for a rural area,

$$\text{MSE} = \frac{\sum_{i=1}^{20} (\text{PL}_m - \text{PL}_r)^2}{20} = 2.30$$

From Table 4.19 for a suburban area,

$$\text{MSE} = \frac{\sum_{i=1}^{20} (\text{PL}_m - \text{PL}_r)^2}{20} = 3.64$$

From Table 4.20 for an urban area,

$$\text{MSE} = \frac{\sum_{i=1}^{20} (\text{PL}_m - \text{PL}_r)^2}{20} = 5.25$$

The calculated MSEs on the basis of the developed model for rural, suburban and urban areas are presented in Table VIII. Also, these MSEs are compared with the MSEs obtained on the basis of the COST 231 Hata model as shown in Table IX.

<table>
<thead>
<tr>
<th>Area</th>
<th>Developed Model MSE (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>2.30</td>
</tr>
<tr>
<td>Suburban</td>
<td>3.64</td>
</tr>
<tr>
<td>Urban</td>
<td>5.25</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

The path loss models developed can be used to characterize the quality of radio coverage in the tested areas. For radio network planning, deployment and optimization processes, these models will provide a platform for improved performance. These models are also very useful for predicting various coverage areas, interference analysis, frequency assignments and cell parameters which are the fundamental elements for network planning processes in mobile radio systems. This would pose great benefits for the Nigerian telecommunication providers; GLO, Airtel, Etisalat, MTN etc., to further improve their services in serving high signaled quality coverage for mobile users’ satisfaction while improving coverage in rural areas and increasing capacity in suburban and urban areas in Lagos, Nigeria.

V. RECOMMENDATIONS

In this research, analysis of propagation models for mobile radio reception at 1800MHz is considered. The impact of different frequency bands on the proposed models need to be analyzed. Also, a near constant mobile antenna height of 1.5m was used for propagation measurements. Future studies can compare the results of this study with field tests using other
acceptable mobile antenna heights. Future research could also be directed towards optimizing the parameters of the SUI model to accommodate suburban and urban environments and finding more suitable parameters for the Ericsson and the COST -231 Wallisch-Ikegami models in rural areas. Finally, a comparative analysis of the measured data with test results from other environments having similar geographical characteristics with the investigated areas will further strengthen the reliability of the stated models.

VI. REFERENCE


