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Path Loss Measurement and Model Analysis of 1.8GHz Wireless Network in Benin City, Nigeria.

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Abstract

The frequencies of GSM service in Nigeria are 900 and 1800 MH_Z and like all radio frequencies they are susceptible to path loss. In this work, field strength data was collected in Benin City, Nigeria and was used to calculate the path loss suffered by the wireless network signals. The measured path loss is compared with the theoretical path loss values estimated by the COST-231 Hata model, the ECC 33 and the LEE model. Also simple Hata-like models for urban environment were derived based on path loss measurements in the 1800 MH_Z band. The optimized model is validated using standard deviation error analysis, and the results show that the new optimized model predicts path loss in urban environment with a root mean square error of less than 3dB, standard normal deviation of less than ± 8dB, mean prediction error of less than ± 2.27dB and had a path loss exponent of 3.91. The model developed can be used in network planning, radio network optimization and can also help telecommunication providers to improve their service.

Keywords: Path loss Models, Path loss Exponent, Model Optimization.

1.0 Introduction

Efficient path loss prediction is important for proper design of wireless network. Path loss is essentially the reduction in power density of an electromagnetic wave or signal as it propagates through the environment in which it is traveling [1]. Radio propagation path loss model is an important tool that characterizes the quality of mobile communication, determines effective radio coverage, as well as network optimization. The path loss models also predict to a high level of accuracy the true signal strength reliability of the network and the quality of coverage [2, 3, 4]. With appropriate propagation path loss models, the coverage area of mobile communication system, the signal-to-noise ratio as well as the carrier-to-interference ratio can be determined easily [5,6].

The signal path loss can often be determined mathematically and these calculations are often undertaken when preparing coverage or system design activities. This depends on knowledge of the signal propagation properties. Path loss calculations are wireless survey tools used for determining signal strength at various locations.

However, it is a known fact that the quality of radio coverage of any wireless network depends on the accuracy of propagation model on which the network was built. An accurate path loss model can be predicted from real-time measurement that is exhaustively taken from the service area in which the network designed will be deployed. The true signal strength reliability of a radio network depends on the accuracy of the radio propagation model employed.

Signal propagation models are used extensively in network planning particularly for conducting feasibility studies and doing initial development [7]. The planning of cellular networks requires understanding of basic concepts concerning the use of radio signals. The path travelled by the signal from one point to another through or along a medium is called PROPAGATION PATH [8]. In cellular networks, a signal propagated from base station to mobile users gets weaker with the distance resulting in the received power being significantly less than the original transmitted power. This is referred to as propagation loss.

Non-line of sight (NLOS) between a transmitter and receiver in a wireless link will introduce multipath whereby reflected signal will reach the recover via a number of different paths which will decrease the signal strength and introduce a subsequent increase in the receiver Bit Error Rate (BER). The path loss may differ depending on the terrain e.g. hills which obstruct the path will considerably alternate the signals often making reception impossible. To increase the effectiveness of

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the transmitted information, engineers need to estimate the path loss introduced by a terrain over which the signal will propagate to sufficiently compensate for the power lost during signal propagation. Existing path loss models may be used to estimate this path loss, but it is ideal to develop an optimized model to use over a certain terrain in a particular band for faster transmitter power estimation.

Two sites were chosen for this investigation: Uwasota and University of Benin, both in Benin City, Edo State, Nigeria described as site 1 and site 2 respectively. Site 1 is an area with terrain features such as sparse vegetation and numerous buildings. These buildings, along with a multitude of roads, car parks, and pedestrian pavements, have given rise to an environment which is slightly more than suburban.

Site 2 is a university center also has sparse vegetation and numerous buildings that are widely spaced and few high rise buildings along with several roads, car parks and pedestrian pavements, given rise to a suburban environment.

In this work, three optimized models which are COST-231 Hata model, ECC 33 and the LEE model were used to predict path loss. The mean of the three models were also used to compare with the measured results and was taken as our model. These models were chosen because the performances in estimating the path loss in the 900 - 1800 MH_Z band in suburban environments are validated using standard deviation errors analysis.

2. DATA COLLECTION AND FIELD SETUP

The base stations in Uwasota and University of Benin are described as site 1 and site 2 respectively. Site 1 has a base station refer to as operator A and has a height of about 30m above the sea level. Site 2 has two base stations referred to as operator B and operator C with both having heights of 34m and 35m respectively. Each has a transceiver sectorized antenna which transmits in vertical polarization. An approximate height of 1.5m was used as mobile receiver height in both sites. The field strength was observed using a handset programmed to the net monitor mode which is calibrated in power terms. At each test point, 20 calls were made and measured data of received signal were recorded at each 100m marked point. Each call lasted for a period of 3 months in both sites, from March 2010 to May 2010 and a minimum of 1200 calls were initiated. The values of the signal strength level measured were converted into path losses using the expression [8].

$$P_L = (P_t - P_r)\ \text{dB} \quad (1)$$

The field testing was conducted within a 1km radius, which is the estimated coverage of the base stations. The field strength was collected along the line of sight and non-line of sight (NLOS) as a result of the characteristics features of the environments which include sparse vegetation and numerous buildings. At each measurement location, a global positioning system GPS was used to establish its location, test points were measured at 100m intervals with the BTS as the source point. Operator A lies within latitude $06^0 23' 419''$ N and longitude $005^0 36' 500''$ E, while operator B lies within $06^0\ 24'\ 06.7''$ N and longitude $005^0 36' 34.0''$ E and operator C has a latitude $06^0 24' 048''$ N and longitude $005^0 36' 903''$ E.

3. PATH LOSS MODELS

3.1 COST – 231 HATA MODEL

The Hata model is an analytical formulation based on the path loss measurement data collected by Okumura in 1968 in Japan. The Hata model is one of the most widely used models for estimating median path loss in macro cellular systems. The Hata model is widely used for cellular networks in $800MH_z$ / $900MH_z$ band. As PCS deployments begin in the $1800MH_z/1900MH_Z$ band, the Hata model was modified by the European COST (Cooperation in the field of scientific and Research) group, and the extended path loss model is often referred to as the COST – 231 Hata model. This model is valid for the following range of parameter [9], $150MH_z \le f \le 200MH_z$, $30m \le h_b \le 200m$, $1m \le h_m \le 10m$ and $1km \le d \le 20km$

The median path loss for the COST – 231 Hata model is given by

$$P_L = 46.3 + 33.9\log_{10} f - 13.82\log_{10} h_b + (44.9 - 6.55h_b)\log_{10} d - a(h_m) + C_p \quad (2)$$

The MS antenna – correction factor, a (h_m) is given by

$$a(h_m) = (1.11 \log_{10} f - 0.7)h_m - (1.56\log_{10} f - 0.8) \quad (3)$$

In these parameters, PL is the path loss in decibel (dB), f is the carrier frequency in MH_z, h_B is the base station (BS) antenna height in meters, h_m is the mobile station (MS) antenna height in meters, and d is the distance between the BS and the MS in km [10].

For urban and suburban areas, the correction factor C_F is 3dB and 0dB respectively. The WIMAX forum recommends using this COST-231 Hata model for system simulations and network planning of macro cellular systems in both urban and suburban areas for mobility applications.

3.2. The Lee Model

The lee model has been widely used in the prediction of path loss in macro cell applications, particularly for systems operating near $900MH_Z$ and for ranges greater than 1.6km. The Lee model specifies distinct parameters for varying region types. Lee model should not be expected to be accurate outside a relatively narrow range of frequencies near $900MH_Z$ [5].

$$L = L_0 + \delta \log d - 10 \log F_A \quad (4)$$

where

L = the median path loss in decimal (dB)

L_o = the reference path loss along 1km in (dB)

δ = the slope of the path loss curve in dB
d = the distance on which the path loss is to be calculated in meter (m)
F_A = the adjustment factor
In a given location, the L_o and δ parameters should be determined empirically through a set of measurements.

3.3. ECC–33 MODEL.

The Electronic Communication Committee (ECC) extrapolated the original measurements by Okumura and modified its assumptions. The path loss equation for ECC–33 model is defined as [11];

$$L = A_{fs} + A_{bm} - G_b - G_r \qquad (5)$$

Where A_{bm}, G_b and G_r are the free space attenuation, the basic median path loss, the BS height gain factor and the terminal (CPE) height gain factor. They are individually defined as

$$A_{fs} = 92.4 + 20log_{10}\,(\mathrm{d}) + 20\log_{10}\,(f) \qquad (6)$$

$$A_{bm} = 20.41 + 9.83log_{10} + 7.894log_{10}\,(f) + 9.56[log_{10}\,(f)]^{2} \qquad (7)$$

$$G_b = log_{10}\,(h_b/200)\{13.958 + 5.8\,[log_{10}(d)]^2\} \qquad (8)$$

For medium city environment,

$$G_r = [42.57 + 13.7log_{10}\,(f)]\,[log_{10}\,(h_r) - 0.585] \qquad (9)$$

where
f is the frequency in GHz
d is the distance between AP and CPE in km
h_b is the BS antenna height in meters
h_r is the CPE antenna height in meters.

4.0 Measured Path Loss Determination

The path loss exponent indicates the rate of propagation path loss with respect to distance. It has a strong impact on the quality of transmission links and therefore needs to be accurately estimated for the efficient design and operation of systems. If the path loss exponent value is 2, then the environment propagation characteristics is close to free space propagation [12] or one that has less clutter. A path loss of 2-4 indicates an environment that is urban [13].

The path loss exponent was determined using equation (10), [8]

$$P_L\,(\mathrm{dB}) = 10\mathrm{n}\log_{10}\mathrm{d} \qquad (10)$$

Where d is the distance from the transmitter and n is the path loss exponent, P_Ld is the mean path loss value; P_{Ldo} is a measured or predicted reference path loss at distance d_o.

$$P_{Ldo}\,(\mathrm{dB}) = P_{Ldo\,+}\,10\mathrm{n}\log_{10}\,(\mathrm{d}/\mathrm{d}_o) \qquad (11)$$

For this analysis, reference distance d_o=0.1km, Transmitter –Receiver separation was 1km and we got a path loss exponent of 3.91.

The measured path loss (dB) was then plotted against the distance and the slope was calculated to determine the path loss exponent, the path loss was also calculated for the other models against the distance (km).

Discussion of Results

Measured data of signal strength in (dBm) against their corresponding receive – transmit separation distance over the period of investigation

Table 1: **Standard parameters used in designing this model**

PARAMETERS	STANDARD CONDITION
Transmit power (dBm)	45
Height of transmitting antenna (m)	30 for site 1, 34 and 35 for site 2
Height of receiving antenna (m)	1.5
Reference distance (m)	100

5.0 Data Analysis

The logarithmic regression plot of the path loss models for the different operators investigated is shown in Figure 1.

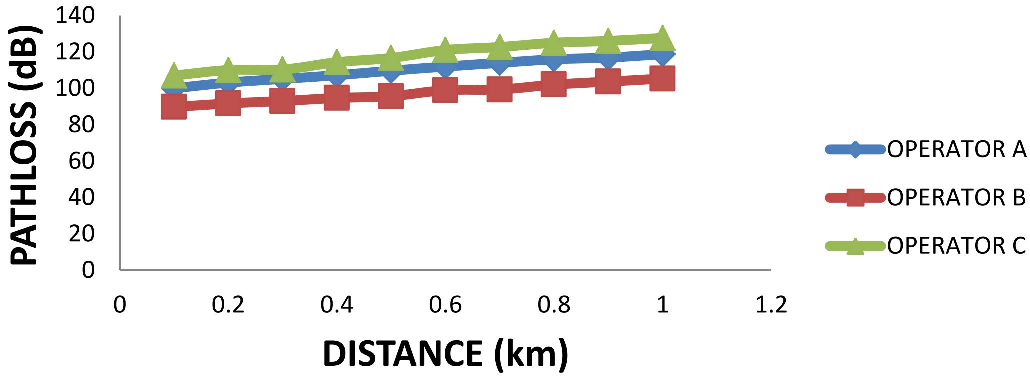

Figure 1: Logarithmic regression plot for operators A, B and C.

Path loss model based on field data increases logarithmically as a function of distance. This is expressed mathematically as [12]

$$P_L = P_L(d_o) + 10n\log D \qquad (12)$$

Where P_L is the mean path loss relative to reference distance in (dB)
P_L (do) is the propagation intercept (dB) (free space loss)
D is the transmit- receive separation distance in meters (m)
n is the propagation exponent

Based on Equation (12), a logarithmic regression propagation path loss model was developed for the different operators.

For operator A,

$$P_L\,(\text{dB}) = 8.326\ln(x) + 97.60 \qquad (13)$$

For operator B,

$$P_L\,(\text{dB}) = 6.770\ln(x) + 87.10 \qquad (14)$$

For operator C,

$$P_L\,(\text{dB}) = 9.6440\ln(x) + 103.4 \qquad (15)$$

The plot of the mean prediction error parameters and the behaviour of the signal in terms of its standard deviation error for the different operators investigated in both sites are shown in Figure 2 and Figure 3 respectively.

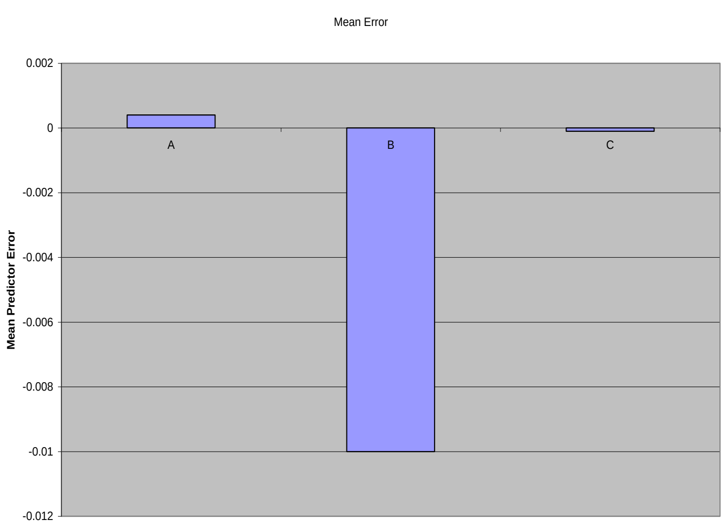

Figure 2: The Mean Prediction Error Parameters for the Different Operators.

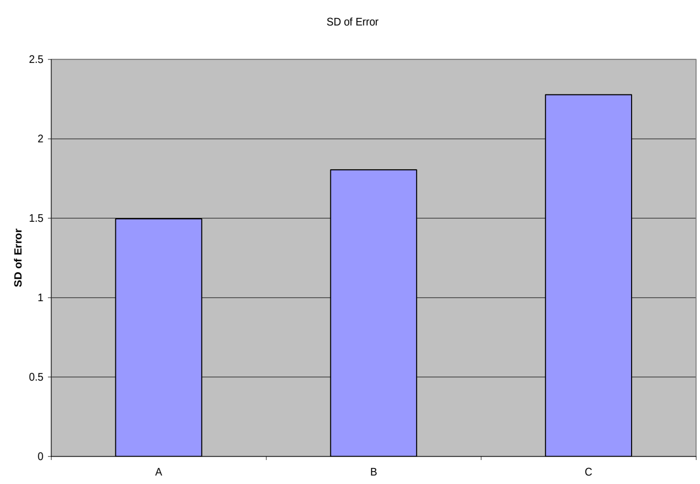

Figure 3: The Behaviour of Signal in Terms of its Standard deviation Error.

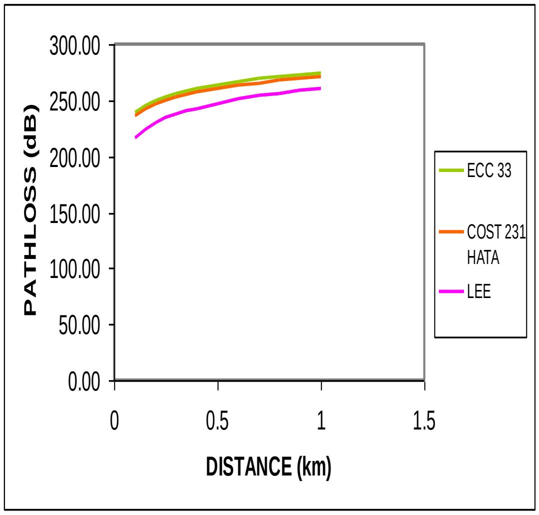

Figure 4: Plots of path loss against distance for ECC-33, the LEE and COST-231 Hata model.

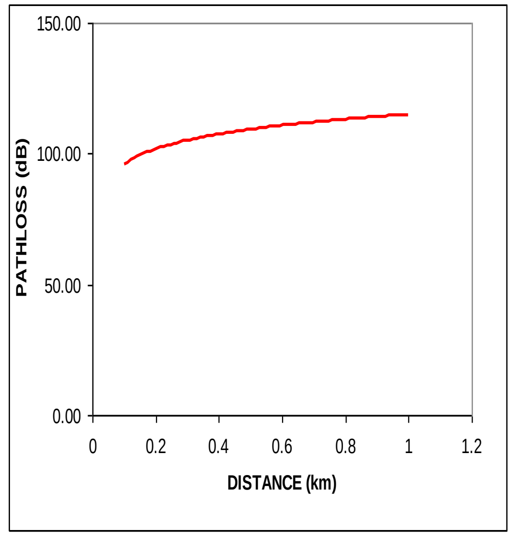

Figure 5: Plot of mean values of path loss against distance for Operator A, B and C.

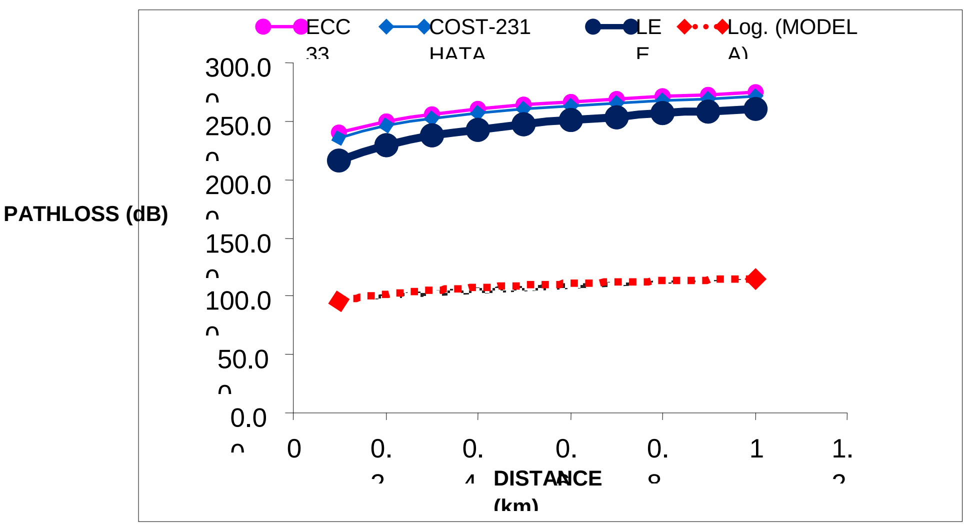

Figure 6: Plot of path loss against distance for model A, ECC 33, COST 231 and the LEE model.

5.1. Comparison Of Model A With ECC 33, COST 231 HATA And The LEE Model.

From Figure 6, ECC 33, COST 231 HATA and the LEE path loss model increases logarithmically at a faster rate as compared to model A, the difference is due to environmental factors. This means that ECC 33, COST 231 HATA and the LEE models cannot be deployed to the environment in which this study was carried out. This is in line with the fact that the efficiency of path loss models suffer when they are deployed to areas other than that which they are designed for.

6.0 Conclusion.

This paper shows how a model was developed for the prediction of path loss for GSM macro cellular networks at 1.8GHz band on measured field strength in Benin City, Nigeria. After comparison with measured path loss against theoretical path loss values was carried out, the model developed best fits the terrain in question, with a very low mean prediction error(less than $\pm$0.004dB), standard deviation error (less than $\pm$2.27dB), root mean square error (less than $\pm$3dB) and standard normal deviation (less than $\pm$8dB). Hence this model validates the measured field strength and was found to predict path loss in this band with higher accuracy than the cost-231 Hata model, ECC-33, and the LEE model for this terrain.

The result mentioned above agrees with the result in [12] that path loss models increases logarithmically with distance, but there was a sharp contrast with the other existing models where they increased at a faster rate. This shows that path loss models suffer when they are used in environment other than that which they have been designed for.

This model will definitely help in network planning, particularly for conducting feasibility studies, characterizing the quality of radio coverage, and also can be applied to any macro cellular environment which has similar terrain features with the sites investigated.

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