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Empirical Path Loss Models for GSM Network Deployment in Makurdi, Nigeria

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Abstract:- Radio propagation prediction is one of the fundamentals of radio network planning. It is therefore vital that the propagation prediction models are as accurate as possible; taking into account the practical limitations that characterized the propagation environment. In this paper, the performance of Okumura – Hata Model, COST 231 – Hata Model, Standard Propagation Model and Stanford University Interim Model were evaluated. A drive test was conducted to obtain the field measured data with which the models were appraised. This was done to determine the most suitable model for GSM network deployment in Makurdi, Nigeria. The analysis of the results showed that Okumura – Hata Model, COST 231 – Hata Model, Standard Propagation Model and Stanford University Interim Model gave Root Mean Square Error values of 11.39 dB, 11.59 dB, 8.11 dB and 18.48 dB respectively for GSM900; and 10.75 dB, 9.78 dB, 12.39 dB and 16.99 dB respectively for GSM 1800. Therefore, it was concluded that Standard Propagation Model and COST 231 – Hata Model would be more suitable for GSM 900 and GSM 1800 network planning and deployment respectively in Makurdi City, Nigeria.

Keywords:- Drive test, Network planning, Path loss, Received signal strength, Root Mean Square Error

I. INTRODUCTION

The efficiency of radio network planning to produce a cost-effective deployment of GSM network for optimal network coverage largely depend on the degree of accuracy of the propagation prediction model employed in characterizing the unique features of the propagation environment where the network is to be deployed. Thus, the choice of an adaptable radio propagation path loss model plays a pivotal role in obtaining an optimal network performance. The analysis of radio propagation in suburban and urban terrains became highly imperative owing to the fact that the environment is composed of different obstructions such as high-rise buildings, towers and bill boards situated on a grid-like pattern of streets. These obstructions are beyond the knowledge and control of the site engineers. It is therefore necessary to develop general principles upon which efficient feasibility studies and optimized network planning can be done based on the theories of physics and mathematics that may be applied.

Radio propagation model is a mathematical formulation for the characterization of radio wave propagation as a function of frequency of transmission, distance and other conditions that influence the behaviour of the radio channel in a given propagation environment [1]. Models are usually developed to predict the behaviour of propagation for all similar links under similar constraints. It provides a platform of simulating the behavioural characteristics of the radio channel before the proper deployment of the cellular mobile network. This is necessary because the mobile communication systems are expensive to deploy and any deficiency in the network planning can lead to an unnecessary cost expenses as a corrective measure. Path loss models are useful planning tools which allow the radio network designer to reach network optimal levels for the base station deployment and configuration while meeting the expected service level requirement. In order to explore the capacity of transmission in a wireless environment and also to develop suitable algorithms, there is a need to understand the concept of mathematical model of the environment. Propagation models are used in the design and development of wireless communication networks.

Path loss is the reduction in power density of an electromagnetic wave as it propagates through space. This is influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height and location of antennas. Path loss is a major component in the analysis and design of the link budget of a telecommunication system [2]. Propagation models have been developed as suitable, low cost and convenient system design alternatives since site measurements are costly. Channel modeling is required to predict path loss associated with the design of cellular network base stations, as this informs the design engineers how much power a transmitter need to radiate so as to service a given cell site. A typical network consists of a transmitter, a receiver and the surrounding environment. A model can be used for a certain frequency band to predict, to a high degree of accuracy, the behaviour of radio signal in a particular environment/terrain. The performance of a communication system depends on design parameters whose values can be selected by the system designer and environmental parameters over which the designer has no control [3].

Empirical models are those based on observations and measurements alone. These models are mainly used to predict the path loss, but models that predict rain-fade and multipath have also been proposed [4]. The deterministic models make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. Deterministic models often require a complete 3-D map of the propagation environment. An example of a deterministic model is a ray tracing model [3]. Stochastic models, on the other hand, model the environment as a series of random variables. These models are the least accurate but require the least information about the environment and use much less processing power to generate predictions. The empirical models account in principle, for all the major mechanisms which are encountered in macro-cell prediction. However, to use such models would require detailed knowledge of the location, dimension and constitutive parameters of every tree, building and terrain feature in the area to be covered. This is too complex and would anyway yield an unnecessary amount of detail.

1.1 Empirical Propagation Path Loss Models

1.1.1 Okumura – Hata Path Loss Model

Hata (1980) developed a model which is an empirical formulation of the graphical path loss data provided by Okumura [5]; and is valid from 150MHz to 1500MHz. Here, the urban area propagation path loss is presented as a standard formula and correction equations are provided for application to other situations [5]. The standard formula for median path loss in urban areas is given by:

$$PL_{urban}(dB) = 69.55 + 26.16\log(f_c) - 13.82\log(h_t) - a(h_r) + [44.9 - 6.55\log(h_t)]\log(d) \quad (1)$$

where f_c = Frequency (in MHz) from 150MHz to 1500MHz
h_t = Effective transmitter antenna height (in metres): 30m to 200m
h_r = Effective receiver antenna height (in metres): 1m to 10m
d = $T_x - R_x$ separation distance (in km): 1km to 20km
$a(h_r)$ = Correction factor for effective mobile antenna height

For a small to medium-sized city,

$$a(h_r) = [1.1\log(f_c) - 0.7]h_r - [1.56\log(f_c) - 0.8] \quad (2)$$

For a large city,

$$a(h_r) = 8.29\,[\log(1.54h_r)]^2 - 1.1 \quad \text{for} \quad f_c \le 300\text{MHz} \quad (3)$$

$$a(h_r) = 3.2\,[\log(11.75h_r)]^2 - 4.97 \quad \text{for} \quad f_c \ge 300\text{MHz} \quad (4)$$

For a suburban area,

$$PL_{suburban} = PL_{urban}(dB) - 2[\log(\tfrac{f_c}{28})]^2 - 5.4 \quad (5)$$

For an open rural area,

$$PL_{rural} = PL_{urban}(dB) - 4.78[\log(f_c)]^2 - 18.33\log(f_c) - 40.98 \quad (6)$$

1.1.2 COST 231 – Hata Model

Committee 231 of the European Cooperation in the field of Scientific and Technical Research (EURO-COST) extends the Hata model for scientific frequencies of interest (900MHz & 1800MHz). The model, which was renamed COST – Hata model, is applicable for only cases in which the antenna heights are above the rooftops of the surrounding buildings. COST 231 has extended Hata's model to the frequency band of 1500MHz $\le f_c \le$ 2000MHz by analyzing Okumura's propagation curves in the upper frequency band [6]. The proposed model for path loss is given as:

$$PL(dB) = 46.3 + 33.9\log(f_c) - 13.82\log(h_t) - a(h_r) + [44.9 - 6.55\log(h_t)]\log(d) + C_m \quad (7)$$

For small to medium-sized city,

$$a(h_r) = [1.1\log(f_c) - 0.7]h_r - [1.56\log(f_c) - 0.8] \quad (8)$$

For a large city,

$$a(h_r) = 8.29\,[\log(1.54h_r)]^2 - 1.1 \quad \text{for} \quad f_c \le 300\text{MHz} \quad (9)$$

$$a(h_r) = 3.2\,[\log(11.75h_r)]^2 - 4.97 \quad \text{for} \quad f_c \ge 300\text{MHz} \quad (10)$$

$$C_m = \begin{cases} 0\text{ dB} & \text{for medium - sized city and suburban areas} \\ 3\text{ dB} & \text{for metropolitan areas} \end{cases}$$

Range of parameters
f : 1500 - 2000MHz
h_t : 30 – 200m
h_r : 1 – 10m

1.1.3 Standard Propagation Model

Standard Propagation Model (SPM) is based on the Hata formulas and is suitable for predictions in the 150 – 3500 MHz frequency band over long distances ranging from 1 – 20 Km. It is best suited to GSM 900 and GSM 180, UMTS, CDMA 2000, WiMAX and LTE radio technologies [7].

The model is based on the formula:

$$P_r = P_t - \{K_1 + K_2 \log(d) + K_3 \log(h_t) + K_4.Diffraction\ Loss + K_5\, log(d).log(h_t) + K_6.h_r + K_7 \log(h_r) + K_{clutter}.f_{clutter} + K_{hill}\} \quad (11)$$

Where,

P_r	=	Received power in dBm
P_t	=	Transmitted power (EIRP) in dBm
K_1	=	Constant offset in dB
K_2	=	Multiplying factor for $\log(d)$
d	=	Distance between the receiver and the transmitter in metres
K_3	=	multiplying factor for $\log(h_t)$
h_t	=	Effective transmitter antenna height in metres
K_4	=	Multiplying factor for diffraction calculation
K_5	=	Multiplying factor for $log(d).log(h_t)$
K_6	=	Multiplying factor for h_r
K_7	=	Multiplying factor for $\log(h_r)$
h_r	=	Effective mobile receiver antenna height in metres
$K_{clutter}$	=	Multiplying factor for $f_{clutter}$
$f_{clutter}$	=	Average of the weighted losses due to clutter
K_{hill}	=	Corrective factor for hilly region

The SPM formula is derived from the basic Hata formula:

$$PL\ (dB) = A_1 + A_2 log(f) + A_3 log(h_t) + [B_1 + B_2 log(h_t) + B_3.h_t][log(d)] - a(h_r) - C_{clutter} \quad (12)$$

Where,

$A_1 \ldots B_3$	:	Hata parameters
f	:	Frequency in MHz
h_t	:	Effective transmitter antenna height in metres
d	:	Distance in Km
$a(h_r)$	:	Mobile receiver antenna height in metres
$C_{clutter}$	:	Clutter correction function

It was observed that the distance in Hata formula is in Km as opposed to the SPM, where the distance is given in metres. The typical values of the Hata parameters are:

$$A_1 = \begin{cases} 69.55 & for\ 900\ MHz \\ 46.30 & for\ 1800\ MHz \end{cases}$$

$$A_2 = \begin{cases} 26.16 & for\ 900\ MHz \\ 33.90 & for\ 1800\ MHz \end{cases}$$

$$A_3 = -13.82$$

$$B_1 = 44.90$$

$$B_2 = -6.55$$

$$B_3 = 0$$

Thus, for GSM 900,

$$PL\ (dB) = 69.55 + 26.16\, log(f) - 13.82\, log(h_t) + [44.9 - 6.55\, log(h_t)][log(d)] - a(h_r) - C_{clutter} \quad (13)$$

For GSM 1800,

$$PL\ (dB) = 46.3 + 33.9\, log(f) - 13.82\, log(h_t) + [44.9 - 6.55\, log(h_t)][log(d)] - a(h_r) - C_{clutter} \quad (14)$$

Therefore, the SPM formula for GSM 900 is:

$$PL\ (dB) = 12.5 + 44.9\, log(d) + 5.83\, log(h_t) - [6.55\, log(d).log(h_t)] \quad (15)$$

Also, for GSM 1800,

$$PL\ (dB) = 22 + 44.9\, log(d) + 5.83\, log(h_t) - [6.55\, log(d).log(h_t)] \quad (16)$$

1.1.4 Stanford University Interim (SUI) Model

IEEE 802.16 Broadband Wireless Access working group proposed the standards for the frequency band below 11GHz containing the channel model developed by Stanford University namely SUI Model [8], [9]. This prediction model comes from the extension of Hata model with frequency larger than 1900MHz. The correction parameters are allowed to extend this model up to 3.5GHz band. In the USA, this model is defined for the Multipoint Microwave Distribution System (MMDS) for the frequency band from 2.5GHz to 2.7GHz [8].

The following are the range of parameters involved:

Base Station (transmitter) antenna height : 10 – 80m
Mobile Station (receiver) antenna height : 2 – 10m
Cell radius : 0.1 – 8km

The SUI model describes three types of terrain, they are terrain A, B and C. there is no declaration about any particular environment. The basic path loss expression is given as:

$$PL(dB) = A + 10\gamma \log\left(\frac{d}{d_o}\right) + X_f + X_h + S \quad \text{for } d > d_o \tag{17}$$

where
- d : distance between T_x and R_x antennas in metres
- d_o : 100m
- λ : wavelength in metres
- X_f : correction factor for frequency above 2GHz (in MHz)
- X_h : correction factor for receiver antenna height in metres
- S : correction factor for shadowing (dB)
- γ : path loss exponent

$$A = 20 \log\left(\frac{4\pi d_o}{\lambda}\right) \tag{18}$$

$$\gamma = a - bh_r + \left(\frac{c}{h_r}\right) \tag{19}$$

The parameter h_r is the receiving antenna height in metres which is between 10m and 80m. The constants *a*, *b* and *c* depend on the type of terrain.

Note that, $\gamma = 2$ for free space propagation
$3 < \gamma < 5$ for Urban NLOS
$\gamma > 5$ for indoor propagation

Table 1: Stanford University Interim (SUI) Model Parameters

Model Parameter	Terrain A	Terrain B	Terrain C
A	4.6	4.0	3.6
b (m^{-1})	0.0075	0.0065	0.005
C (m)	12.6	17.1	20

$$X_f = 6.0 \log\left(\frac{f}{2000}\right)$$

$$X_h = \begin{cases} -10.8 \log\left(\frac{h_r}{2000}\right) & \text{for terrain } A \,\&\, B \\ -20 \log\left(\frac{h_r}{2000}\right) & \text{for terrain } C \end{cases}$$

Where *f* is the frequency of operation in MHz

1.2 Literature Review of Related Works

Over the years, various propagation path loss models have been developed for the assessment of the performance of wireless communication systems for high quality of service delivery. Various research studies have been carried out by different researchers on the behaviour of radio wave within different environments under diverse environmental and geographical conditions. The models derived are specific for the respective environment.

Shoewu (2011) validated that some empirical path loss models with field measurements carried out at different locations within Epe town and its environs [10]. The data were collected from live radio base stations transmitting at 900 MHz and 1800 MHz. The respective path loss values were estimated and compared with the results of he existing models. The results indicated an appreciable consistency with these models except for rural areas. The work showed that the Okumura – Hata model is very effective for radio wave propagation path loss prediction in suburban and urban areas in the western part of Nigeria.

In view of finding an adaptable and suitable propagation path loss models for the cities of Port Harcourt and Enugu, two empirical propagation models were considered by Ogbulezie (2013) [11]. Two sites were selected for each of the city under study and drive test measurements were conducted along the major routes. These measurements were compared with the prediction results obtained by Okumura – Hata and COST 231 – Hata models. The average path loss values for the routes ranged from 135.01 dB to 138.48 dB at 900 MHz and 142.26 dB to 147.30 dB at 1800 MHz. The standard deviations varied from 2.71 dB to 15.94 dB for the Okumura – Hata model at 900 MHz whereas for COST – Hata model it was from 1.91 dB to 15.04 dB. Similarly, the mean square errors ranged from 0.8 dB to 5.04 dB for Okumura – Hata model at 900 MHz. for COST – Hata model at 900 MHz, it was from 0.6 dB to 4.76 dB. The mean square error at 1800 MHz varied from 0.11 dB to 5.40 dB.

Similarly, Sharma (2010) concluded that propagation path loss models may give different results if they are used in different environment other than in which they were designed [12]. Different path loss models were compared with measured field data. The field measurement data were obtained in the urban, suburban and rural environments in India at 900 MHz and 1800 MHz frequency bands with the help of spectrum analyzer. The analysis showed that EEC – 33 and SUI models gave the best results in urban areas. In suburban areas, ECC – 33, SUI and COST 231 – Hata models were of good performance. Okumura – Hata and Log – distance models have better performance in rural areas.

Ogundapo (2011) emphasized the need to examine the prediction error variations of the path loss models over other environment in order to be useful in such areas. COST 231 – Hata, Lee and COST 231 Walfisch – Ikegami models were used as basis to analyze coverage predictions using signal strength measurement obtained from a GSM network in Kano, Nigeria [13]. The results gave mean prediction error values of -5.2 dB, -12.3 dB and 4.3 dB for COST 231 – Hata, Lee and COST 231 Walfisch – Ikegami models respectively. This showed that the COST 231 – Hata and Lee models under-predicted the path loss while the COST 231 Walfisch – Ikegami model over-predicted the path loss but provided the best results for this urban environment. With the help of practical data taken in the urban area of India (high density region of Kosli) and the rural area (a village near to Kosli, named Jonawas) using spectrum analyzer, Okumura – Hata model is best in urban areas while COST 231 – Hata is most suitable for rural areas [14].

Chebil (2013) reported the measurement results of the propagation path loss in four locations in the suburban area of Kuala Lumpur. The measured path loss at each location was extracted from the data and compared with corresponding results obtained from the six models under study: Log – normal shadowing, Lee, SUI, COST 231 – Hata, Egli and ECC – 33 models. The analysis showed that SUI and Log – normal models gave, in general, better prediction and can be used to estimate path loss for prediction of mobile coverage in a macro cell in Malaysia [15].

II. MATERIALS AND METHODS

Figure 1 explains the step-by-step approach of the method employed in this research.

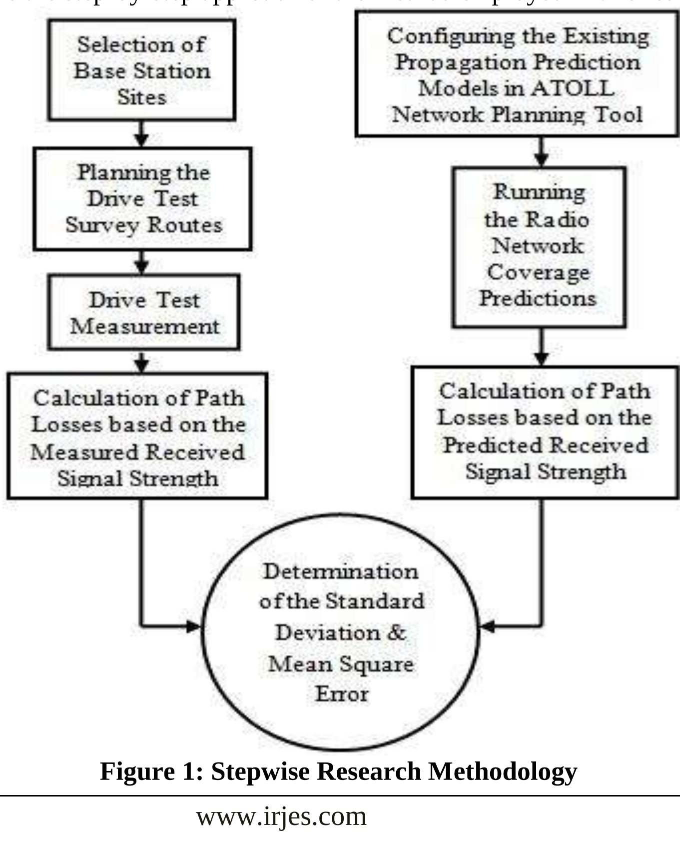

Figure 1: Stepwise Research Methodology

A drive test was conducted within the city of Makurdi, Nigeria with a vehicle driven along predefined routes. The drive test survey routes were carefully planned in such a way that the distance is long enough to allow the noise floor of the receiver to be reached. Typically, a distance of approximately 2 km was considered appropriate. Transmission Evaluation and Monitoring System (TEMS) Investigation software was used on a laptop with a Global Positioning System (GPS) and a TEMS Mobile Station (Sony Ericsson K800i) connected through Universal Serial Board (USB) ports. The personal computer serves as the communication hub for all the equipments in the system. The GPS operates with global positioning satellites to provide the location tracking for the system during data collection. This enables the system to determine the position of the Mobile Station on a global map which is already installed on the laptop. The Mobile Station was used to initiate calls during data collection process. While driving was going on, the handset was configured to automatically make calls to a fixed destination number. Each call lasted for 30 seconds hold time and the call was dropped. The phone remained idle for some period of time then another call was made.

2.1 Description of the Propagation Environment

The measurements were conducted on two different BTS sites in Makurdi, the Capital of Benue State, Nigeria. The city is located in central Nigeria along the Benue River. Makurdi is situated at 7.74°N Latitude, 8.51°E Longitude and 104 metres elevation above the sea level. Figure 2 shows the aerial view of Makurdi city with the clusters of buildings and other scatterers of radio waves. Table presents the clutter classes covered, the average heights of the buildings and obstructions present in each terrain and the percentage of measurement points obtained in each clutter class.

Figure 2: Aerial View of Makurdi City, Nigeria

Table 2: Clutter Class Distribution of Measurement Area

CLUTTER CLASS	AVERAGE CLUTTER HEIGHT (m)	AREA COVERED (%)
Barren	**4**	**21.43**
Rangeland	**6**	**21.43**
Suburban	**10**	**28.57**
Dense Suburban	**11**	**17.86**
Urban	**12**	**10.71**

2.2 Measurement Data Collection

The data collection was carried out starting from the foot of the Base Transceiver Station (BTS) and the vehicle moves along the direction of the main lobes of each of the directional antennas away from the BTS. The TEMS Investigation software provides relevant information such as Base Station Identity Code (BSIC), Received Signal Strength Level (dBm), Longitude, Latitude, Timing Advance, MS Transmit Power etc. The following site data were used during the computation of respective path losses at different distances:

Table 3: GSM Network Equipment Parameters

PARAMETER	VALUE
BTS Transmitter Power (P_t)	43 dBm
BTS Antenna Height (h_t)	30m
MS Antenna Height (h_r)	1.5m
Connector Loss (P_c)	2.5 dB
Feeder Loss (P_f)	3 dB
Duplexer Loss (P_d)	4 dB
BTS Antenna Gain (G_t)	14dBi
MS Antenna Gain (G_r)	18 dBi

The log files obtained from the data collection process were converted into text file format (.txt). This text format data were sorted accordingly in Microsoft Excel and then imported into the ATOLL radio network planning tool. The radio coverage predictions were done in the ATOLL radio network planning tool having the commonly used empirical models embedded in it. The performance of Okumura – Hata, COST 231 – Hata, SPM and SUI models were evaluated with the field measured data. The accuracy of the prediction is enhanced by the availability of Digital Terrain Map (DTM), clutter class information and vector map showing all the major roads and streets with the average height of each clutter class.

III. RESULTS

Figure 3 shows that the field measured data on GSM 900 has mean received signal strength of -76.92 dBm. Okumura – Hata, COST – Hata, SPM and SUI models over-predicted the received signal strength with mean received signal strengths of -66.83 dBm, -66.83 dBm, -71.68 dBm and -60 dBm respectively.

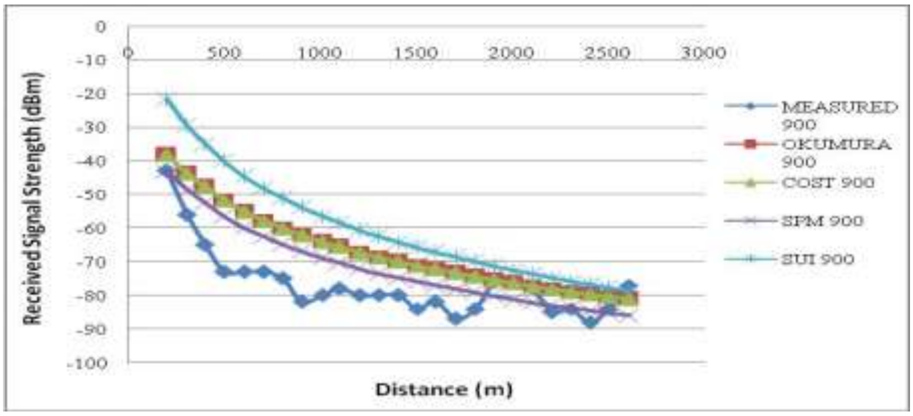

Figure 3: Received Signal Strength Characteristics for GSM 900 in Makurdi

Figure 4 shows that the field measured data on GSM 1800 has mean received signal strength of -82.75 dBm. Okumura – Hata, COST – Hata, SPM and SUI models over predicted the received signal strength with mean received signal strengths of -75.55 dBm, -77.503 dBm, -72.95 dBm and -68.53 dBm respectively.

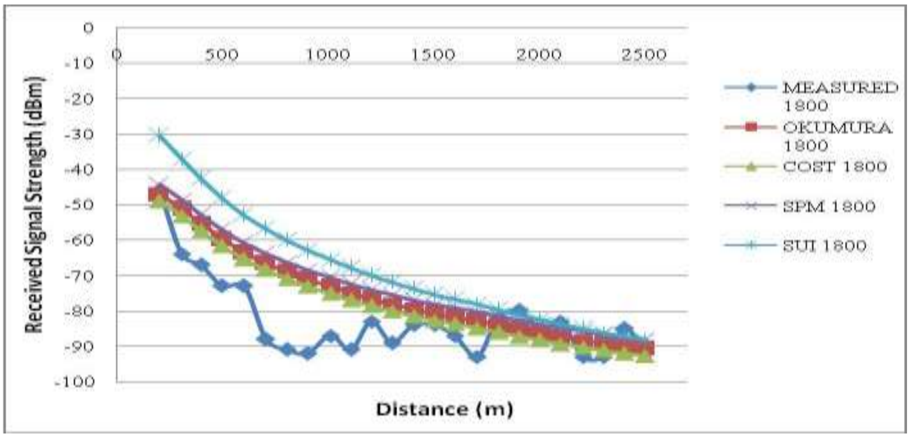

Figure 4: Received Signal Strength Characteristics for GSM 1800 in Markurdi

Figure 5 shows that the field measured data on GSM 900 has mean path loss of 143.071 dB. All the four empirical models under predicted the propagation path loss. Okumura – Hata, COST – Hata, SPM and SUI models gave the path losses of 133.843 dB, 133.843 dB, 138.694 dB and 127.541dB respectively.

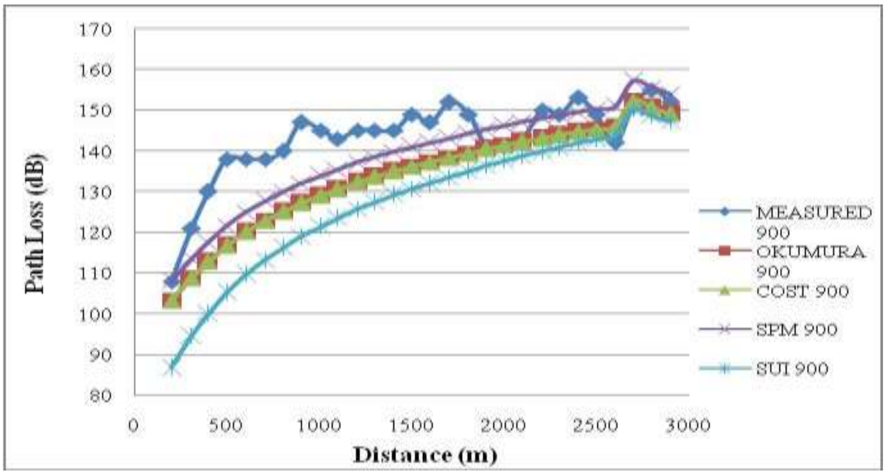

Figure 5: Signal Fading Characteristics for GSM 900 in Makurdi

Figure 6 shows that the field measured data on GSM 1800 has mean path loss of 147.75 dB. All the four empirical models under predicted the propagation path loss. Okumura – Hata, COST – Hata, SPM and SUI models gave the path losses of 140.548 dB, 142.503 dB, 137.952 dB and 133.523 dB respectively.

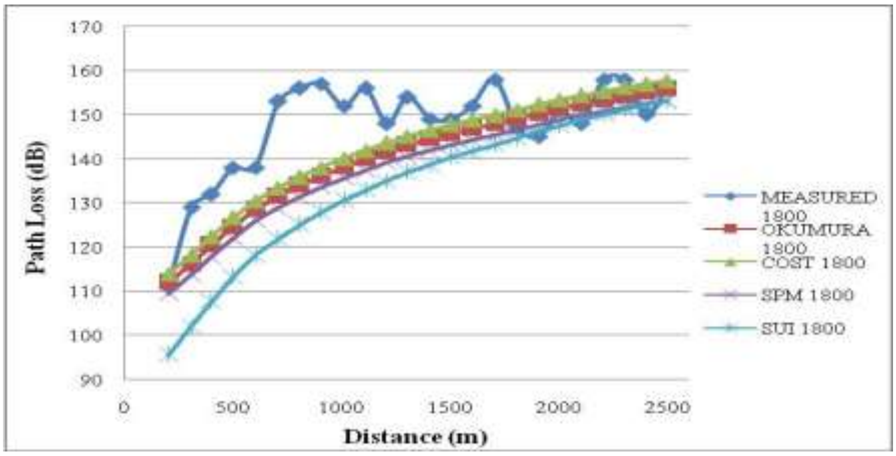

Figure 6: Signal Fading Characteristics for GSM 1800 in Makurdi

Figure 7 shows that the received signal strength decreases with distance as the frequency increases from 900 MHz to 1800 MHz.

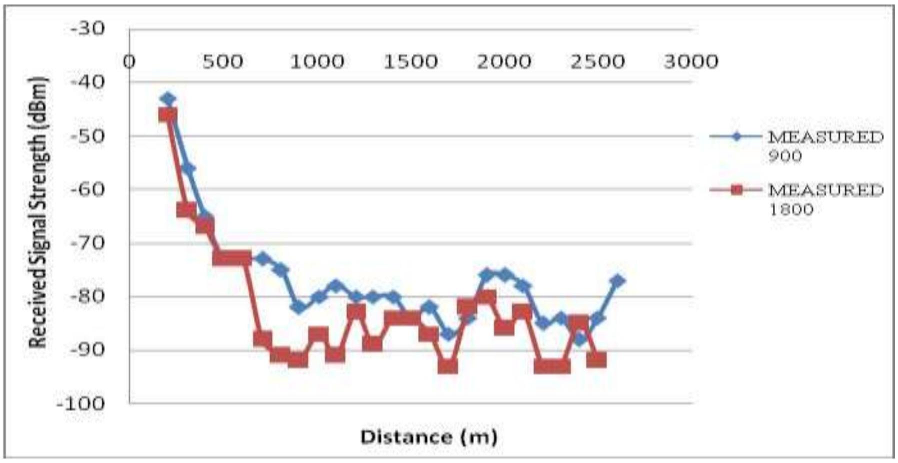

Figure 7: Field Measured Received Signal Strengths for GSM 900 and 1800 in Makurdi

In Figure 8, there is a general trend of path loss increasing with distance as the frequency of transmission moves from 900 MHz to 1800 MHz.

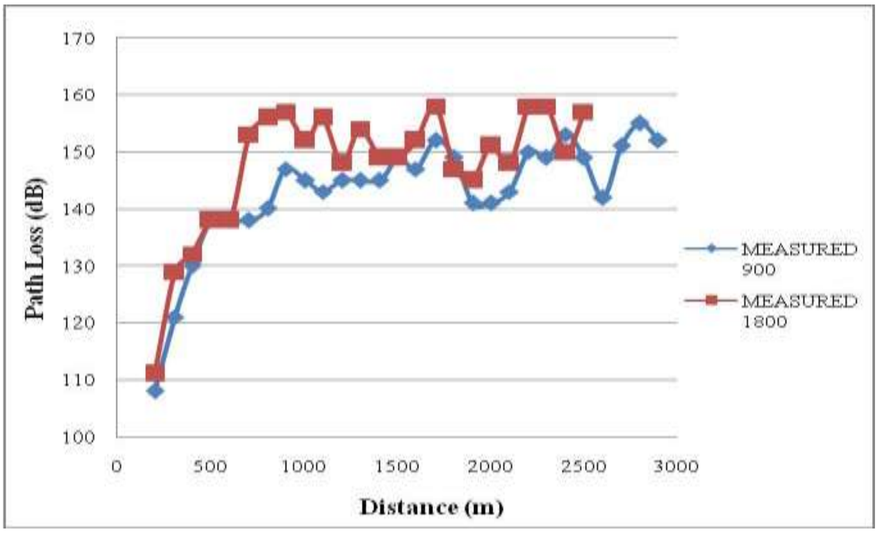

Figure 8: Field Measured Path Loss for GSM 900 and 1800 in Makurdi

IV. DISCUSSIONS

Mean error, standard deviation, root mean square and product-moment correlation coefficient of the models from the actual field measured data were parameters used to appraise the performance of the models as quantitative measures of accuracy. In this research, all the models have fairly good correlation with the actual data obtained by measurement. Nevertheless, Standard Propagation Model has the lowest Root Mean Square Error of 8.11 dB for GSM 900 while COST 231 – Hata model gave the lowest Root Mean Square Error of 9.78 dB for GSM 1800.

The prediction errors were presented in terms of mean error, standard deviation, root mean square and product-moment correlation coefficient as shown in Figure 9.

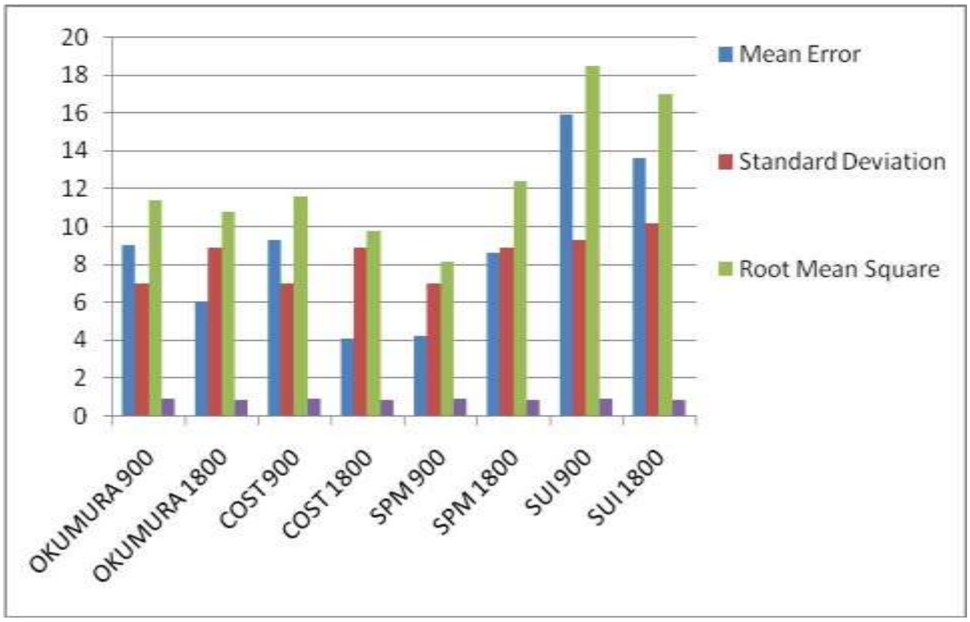

Figure 9: Statistical Model Evaluation Measures

V. CONCLUSION

The result of this investigation shows that there is no single model that consistently provides a good fit for the actual field measured data for all propagation environments. It was also established that the adaptability of radio propagation models also varies as the frequency of transmission increases. Findings proved that Standard Propagation Model and COST 231 – Hata Model are the most suitable radio propagation models for

GSM network deployment in Makurdi, Nigeria at 900MHz and 1800 MHz respectively. This will help radio network planners and engineers to accurately design GSM network with optimal network performance and better quality of service for the large populace of Makurdi city.

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