Performance Evaluation of Radio Propagation Models on GSM Network in Urban Area of Lagos, Nigeria

Segun Isaiah Popoola, Olasunkanmi Fatai Oseni

Abstract—The analysis of radio propagation in urban terrains became highly imperative owing to the fact that the environment is composed of different physical obstructions such as high-rise buildings, towers and bill boards situated on a grid-like pattern of streets. Radio propagation characteristics, to a large extent, vary from one type of environment to the other. In this paper, the suitability of three of the available empirical propagation models- Okumura – Hata model; COST 231 – Hata model and Standard Propagation Model- for radio coverage predictions in the dense suburban and dense urban clutter classes of Lagos metropolis was investigated. A drive test was conducted to obtain the actual field data on the GSM 1800 network deployed in the area under study. All prediction calculations were carried out in the ATOLL network planning tool. From the field measured data, mean path loss values of 137.53 dB and 142.49 dB were recorded in the dense suburban and dense urban areas respectively. COST 231 – Hata model prediction results had the greatest proximity to what was obtained on the live network with a root mean square error value of 12.28 dB and a standard deviation of 6.42 dB for the dense suburban clutter. In the dense urban area, the model also yielded the minimum root mean square error and standard deviation values of 11.82 dB and 7.88 dB respectively. Therefore, COST 231 – Hata model was found most suitable for GSM 1800 network planning and deployment in the urban environment of Lagos, Nigeria.

Index Terms— Clutter, Prediction, Standard Propagation Model, Base Station

1 INTRODUCTION

The tremendous growth of wireless communication systems necessitated that the radio propagation models that are mostly used for radio coverage predictions during the radio network planning should be good enough to provide accurate results for the propagation environment where the mobile network is to be deployed. It is very important to understand the behaviour of the wireless channel so as to use the most suitable propagation models. This is due to the peculiarity of the propagation environment of different terrains which contribute greatly to the complexity and randomness of the wireless communication channel.

Propagation environments are characterized with the complexity they present for the radio propagation. Unlike wired channels that are stationary and predictable, wireless communication channels are extremely random and do not offer easy analysis. This complexity is as a result of many high rise buildings and objects in the streets which produce reflection, diffraction and shadowing of the transmitted signals.

Path loss estimation is a major component of the link budget of a wireless communication system. 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.

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.

2 RADIO PROPAGATION MODELS

2.1 Okumura – Hata Model

Hata, Masahara developed a model which is an empirical formulation of the graphical path loss data provided by Okumura [1]; 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 [1]. The standard formula for median path loss in urban areas is given by:

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

Where

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

- *Segun Isaiah Popoola is currently pursuing a B.Tech degree in Electronic and Electrical Engineering, Ladoke Akintola University of Technology, P.M.B 4000, Ogbomoso, Oyo State, Nigeria. E-mail: sipopoola94@student.lautech.edu.ng*
- *Olasunkanmi Fatai Oseni is a lecturer in the department of Electronic and Electrical Engineering, Ladoke AkintolaUniversity of Technology, P.M.B 4000, Ogbomoso, Oyo State, Nigeria. E-mail: oseni12002@yahoo.co.uk*

For a small to medium-sized city,

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

For a large city,

$$a(h_r) = 8.29\,[\log(1.54h_r)]^2 - 1.1 \quad \text{for} \quad f_c \le 300\text{MHz}$$
$$a(h_r) = 3.2\,[\log(11.75h_r)]^2 - 4.97 \quad \text{for} \quad f_c \ge 300\text{MHz}$$

For a suburban area,

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

For an open rural area,

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

2.2 COST 231 – Hata Model

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 [2]. The proposed model for path loss is given as:

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

For small to medium-sized city,

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

For a large city,

$$a(h_r) = 8.29\,[\log(1.54h_r)]^2 - 1.1 \quad \text{for} \quad f_c \le 300\text{MHz}$$
$$a(h_r) = 3.2\,[\log(11.75h_r)]^2 - 4.97 \quad \text{for} \quad f_c \ge 300\text{MHz}$$

and,

$$C_m = \begin{cases} 0\text{ dB} & \text{for suburban areas} \\ 3\text{ dB} & \text{for metropolitan areas} \end{cases}$$

Range of parameters

f	:	1500 - 2000MHz
h_t	:	30 – 200m
h_r	:	1 – 10m
d	:	1km – 20km

2.3 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 [3].

The model is based on the formula:

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

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 receiver and 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:

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

Where,

A_1 ... 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,

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

For GSM 1800,

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

3 Review of Related Works

The field of wireless communication has been explored through a surge of research activities. 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 [4]. Shoewu (2011) validated some empirical path loss models with field measurements carried out at different locations within Epe town and its environs [5]. 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

IJSER

basis to analyze coverage predictions using signal strength measurement obtained from a GSM network in Kano, Nigeria [6]. 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) [7]. 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 [8].

4 Research Methodology

4.1 Description of Propagation Environment

Lagos metropolitan city is situated in the South Western region of Nigeria within Latitude 6°27′11" N and Longitude 3°23′45" E. The total land mass of the city stretches over 3.345 km with an estimated population of about 15 million. 40% of the total land area is covered by water and wetlands. Lagos is currently ranked as the fifth largest city in terms of population. The Metropolis has emerged as one of the fastest urbanizing cities in the West African Sub-region.

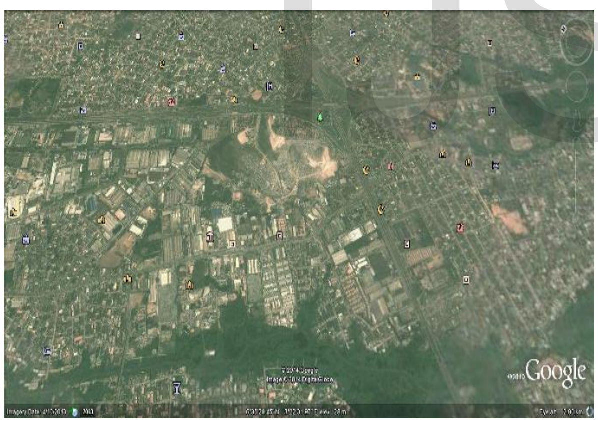

Figure 1: Ariel View of the Investigated Area

This research work studied the behaviour of radio wave propagation in the dense suburban and dense urban clutter classes of Lagos metropolis, Nigeria.

4.2 Base Station Identification and Selection

The base stations that are located on the dense suburban and dense urban clutters of Lagos metropolis were identified within the clusters of cells of GSM 1800 network in the area. The sites were ensured to have a good RF clearance such that they are not in any way obstructed. The antennas on the sites represent the full variation of antenna heights in the area covered by the survey. The terrain within a relevant radius around each selected base station was ensured to be a true representative of the entire area.

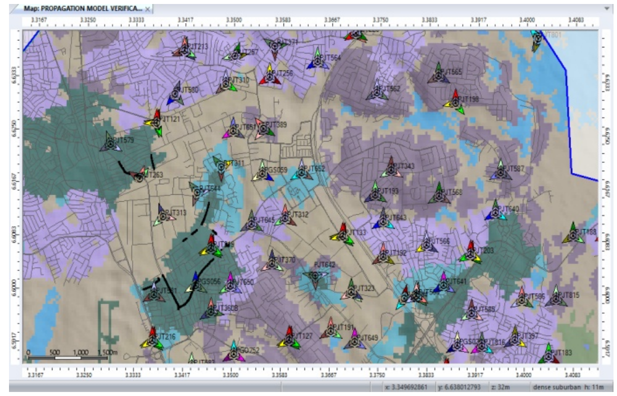

Figure 2: Base Station Configuration in ATOLL

4.3 Data Collection Process

A drive test was conducted to obtain the actual field measurement data which was later used in appraising the accuracy of the empirical path loss models under study. The drive test equipment set up consists of a laptop (having Transmission Evaluation and Monitoring System (TEMS) investigation software installed on it), a power supply unit, TEMS Mobile Station, Global Positioning System (GPS) and a vehicle. TEMS Investigation software offered the capabilities of data collection, real-time analysis and post-processing, all in one [9].

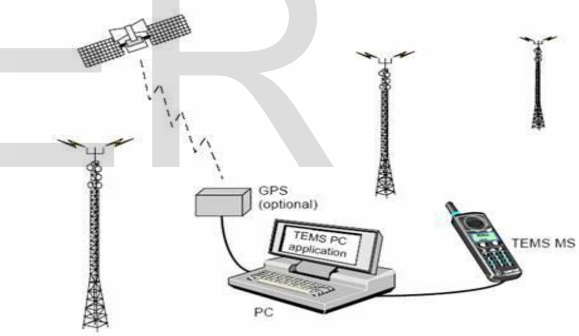

Figure 3: Drive Test Data Collection Set Up

It collected the data and recorded them in log files. Data were collected in the *drive test mode* and they were played back in the *replay mode* for inspection and analysis. The area to be covered was scanned before performing the drive test to avoid interference. A single frequency channel, Broadcast Control Channel (BCCH), was monitored and measured during each survey. The recorded log files were exported in text format for further data sorting and processing.

4.3 Drive Test Survey Route

The drive test survey route was carefully planned with the aid of road and vector maps such that the measurement collection process involved all the base stations earlier marked out for investigation. The survey route put the accessibility of the drive test vehicle to every sector of each base station into consideration. The distance covered was ensured to be long

IJSER

enough in order to allow the noise level of the receiver to be reached.

4.3 Data Sorting and Computations

At least 36 samples were collected over a distance of 40λ to satisfy Lee criterion [10]. The measured signal strength values over the distance of 40λ were averaged, with the mean signal level being the one stored. The data were sorted accordingly in Microsoft Excel and imported into the ATOLL network planning tool. The imported files contained the position of the measured data points in terms of latitude and longitude with the respective received signal strengths obtained at such points. Other relevant information includes serving cell BCCH, Base Station Identity Code (BSIC), Cell Name and Cell Identity. The propagation predictions were done in the ATOLL planning tool with the geographical mapping data of Lagos imported into the tool as required.

5 Results

The radio coverage predictions were obtained from the empirical radio propagation models embedded in the ATOLL network planning tool.

Figure 4 shows the prediction results of Okumura – Hata model, COST 231 – Hata model and Standard Propagation Model as compared with the actual field measured data collected on the GSM 1800 network deployed in the dense suburban clutter class of Lagos metropolis. From the results, it was observed that Okumura – Hata model, COST 231 – Hata model and Standard Propagation Model predicted mean received signal strength values of -51.09 dBm, -66.55 dBm and -60.69 dBm respectively. Meanwhile, the mean received signal strength obtained from the measurement carried out in the dense suburban area was -70.33 dBm.

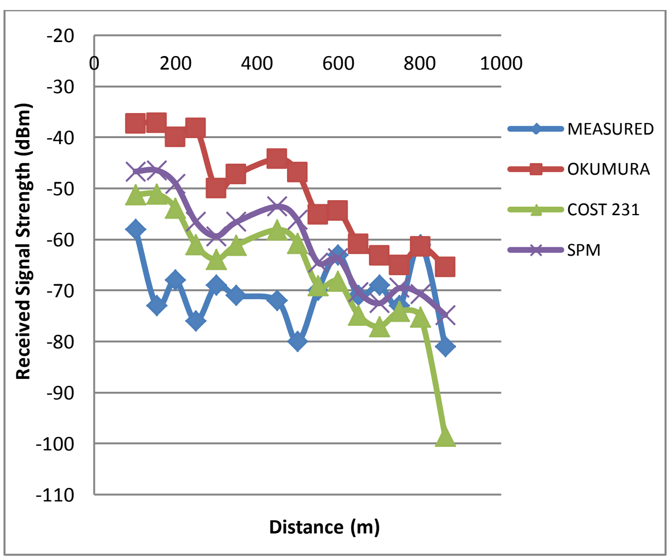

Figure 4: Prediction Results for Dense Suburban Area

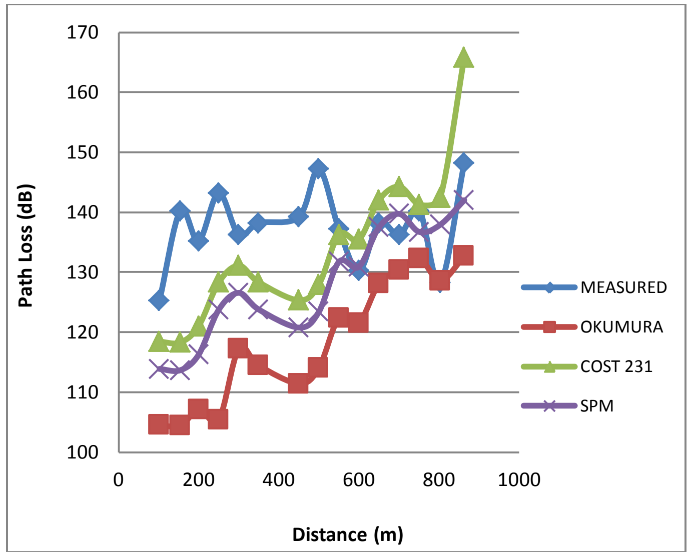

Figure 5: Path Loss Predictions for Dense Suburban Area

From the data represented in Figure 5, the mean measured path loss in the dense suburban clutter was found to be 137.53 dB. However, Okumura – Hata model, COST 231 – Hata model and Standard Propagation Model gave the mean path loss as 118.29 dB, 131.74 dB and 127.89 dB respectively.

Figure 6 shows the propagation coverage predictions of the empirical models as well as the field measured received signal strength values obtained on the network in the dense urban area of the metropolis. Mean received signal strength values of -75.29 dBm was obtained from the field measured data while Okumura – Hata model, COST 231 – Hata model and Standard Propagation Model gave prediction of -64.68 dBm, -66.60 dBm and -60.63 dBm respectively.

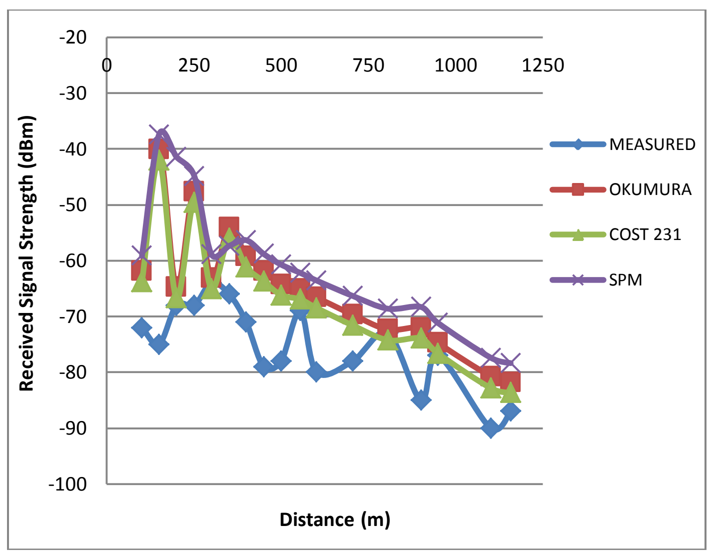

Figure 6: Prediction Results for Dense Urban Area

Figure 7 illustrates the path loss predictions of the models for the dense urban clutter class. The mean path loss value for the dense urban area was 142.49 dB as compared to the values of 131.88 dB, 133.80 dB and 127.83 dB predicted by Okumura – Hata model, COST 231 – Hata model and Standard Propagation Model respectively.

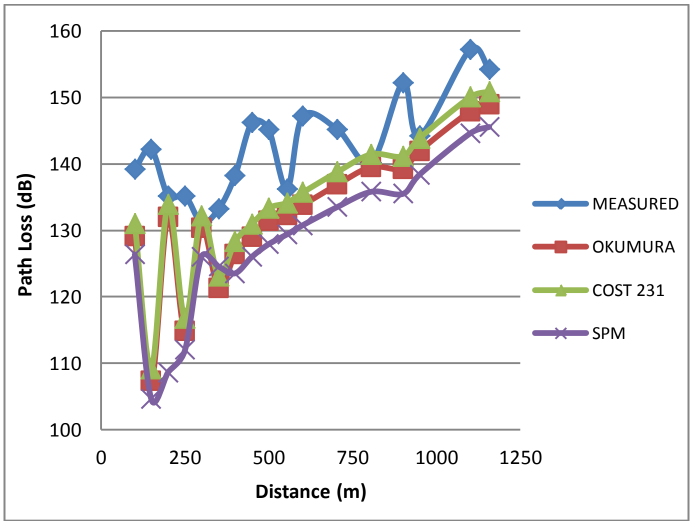

Figure 7: Path Loss Predictions for Dense Urban Area

6 Discussions

The performance of the empirical models was evaluated based on three different statistical parameters that measure the variations of the prediction results from the actual field measured data.

Figure 8 shows the mean error, root mean square error and the standard deviation of each of the models for the dense suburban area. COST 231 – Hata model gave the closest prediction results when compared with what was obtained on the GSM 1800 network. It has a root mean square error of 12.28 dB and a standard deviation of 6.42 dB for the dense suburban propagation environment.

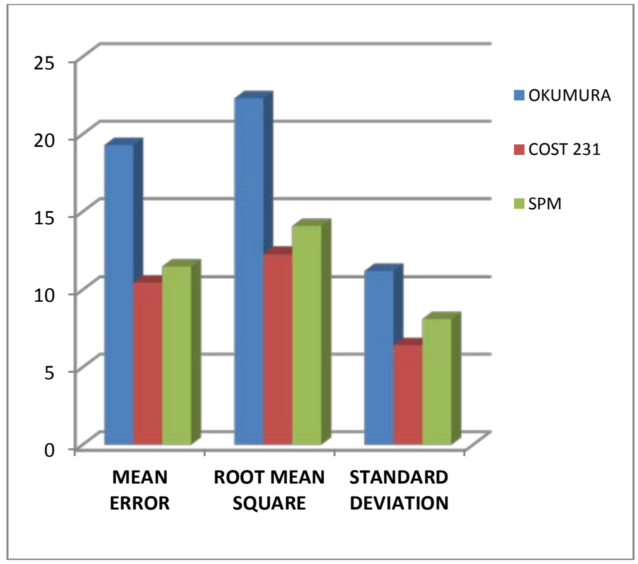

Figure 8: Statistical Results for Dense Suburban Area

Figure 9 shows the statistical model evaluation parameters for the dense urban environment. Here, COST 231 also gave the lowest mean error and standard deviation which are 11.82 dB and 7.88 dB respectively.

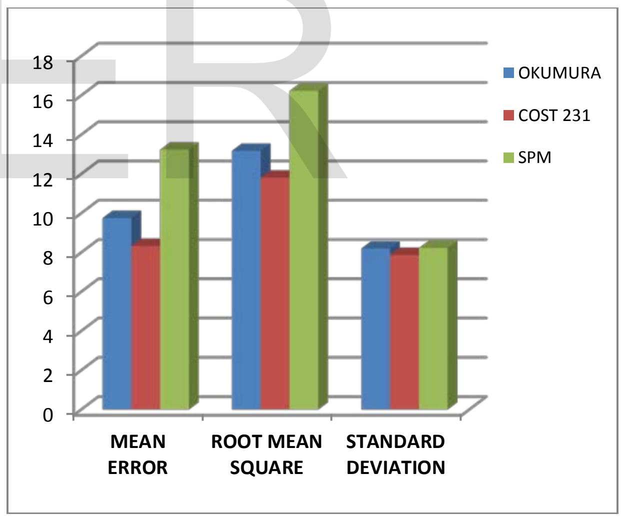

Figure 9: Statistical Results for Dense Urban Area

7 Conclusion

The findings of this research show that the average radio propagation path loss encountered in the dense urban area of Lagos metropolis is greater than that of the suburban environment. This is as result of the presence of natural and man-made physical obstructions which characterized the propagation environment. These physical obstructions cause reflection, scattering and diffraction of radio signals. Since these limitations are beyond the control of the site engineers, the path loss encountered must be accurately accounted for in the link budget during radio network planning.

Based on the results earlier discussed, COST 231 – Hata model was considered as the most suitable radio propagation path loss prediction model for GSM 1800 radio network deployment in both the dense suburban and dense urban areas of Lagos, Nigeria.

ACKNOWLEDGMENT

The authors wish to thank Mr. Henry Enumah of Alcatel Lucent Nigeria for his technical assistance during the data collection process.

REFERENCES

[1] H. Masahara, Empirical Formula for Propagation Loss in Land – Mobile Radio Services, *IEEE Transactions on Vehicular Technology, vol. 29, No 3*, 1980, pp 317 – 325.
[2] COST 231, Urban Transmission Loss Models for Mobile Radio in the 900 & 1800MHz band, *COST 231 TD (90) 119 Rev 2*, The Hague, Netherlands, 1991.
[3] ATOLL 3.2.0 Model Calibration Guide, *Release: AT 320_MCG_E2*. Forsk, France. Online access: www.forsk.com
[4] P.K. Sharma and R.K. Singh, Comparative Analysis of Propagation Path Loss Models with Field Measured Data. *International Journal of Engineering Science and Technology, Vol. 2(6)*, 2010, 2008 – 2013.
[5] O. Shoewu and O.F. Edeko, Analysis of Radio Wave Propagation in Lagos Environs. *American Journal of Scientific and Industrial Research, 2(3)*, 2011, 438 – 455.
[6] E.O. Ogundapo, L.I. Oborkhale and S.B. Ogunleye, Comparative Study of Path Loss Models for Wireless Mobile Network Planning, *International Journal of Engineering and Mathematical Intelligence, vol.2, No. 1 – 3*, 2011, 19 – 22.
[7] J.C. Ogbulezie, M.U. Onuu, J.O. Ushie, B.E. Usibe, Propagation Models for GSM 900 and GSM 1800 MHz for Port Harcourt and Enugu, Nigeria, *Network and Communication Technologies; vol. 2, No. 2*, 2013, 1 – 10.
[8] J. Chebil, A.K Lawas and M.D Islam, Comparison Between Measured and Predicted Path Loss for Mobile Communication in Malaysia, *World Applied Sciences Journal 21 (Mathematical Applications in Engineering)*, 2013, 123 – 128.
[9] TEMS Investigation Release Note, ASCOM, Document: NT11-21089, www.ascom.com/networktesting, 2011.
[10] ATOLL 3.2.0 Radio Planning & Optimization Software User Manual, Forsk, France. Online access: www.forsk.com

IJSER