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RESEARCH ARTICLE

A COMPARATIVE ANALYSIS OF COST 231 AND HATA MODELS WITH MEASURED PATH LOSS FOR SOKOTO METROPOLIS (A CASE STUDY OF MTN)

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ABSTRACT

For optimal characterization of radio communication channel, key parameters and a mathematical model are essential for predicting or determining the signal coverage, channel efficiency and capacity. Path loss prediction plays a basic role in planning and designing of every radio communication link. This paper investigates a suitable model capable of planning a better global system for mobile communication (GSM) network (MTN) with a view to address numerous complain of poor quality service by the subscribers, within Sokoto city using measuring tape, Basic Transreceiver System (BTS) app on mobile phone and mobile device distance. Received Signal Strength (RSS) were obtained from MTN base stations (network) located in State and path loss was analyzed. The experimental measurement of path loss was compared to theoretical models of COST231 and Hata models. The results showed that the COST231 was found most suitable path loss prediction model for Sub-urban region of Sokoto based on the validation test; however, the Hata model also produces reasonable estimates and can be use for path loss prediction model in the location.

KEYWORDS

COST 231 model, Hata model, measured path loss, received signal strength, Sokoto

1. INTRODUCTION

Since the advent of telecommunication, there have been researches on how to improve and enhance communication between people at various locations. This resulted in Global System for Mobile Communication (GSM) which is a wireless form of communication that propagates information (voice and data) in the form of an electromagnetic (EM) wave. Abhayawardhana stated that as mobile radio systems become more present, a basic understanding of radio frequency (RF) propagation for the purpose of RF planning becomes very important (Abhayawardhana, 2005). In wireless mobile communications, the information that is transmitted from one end to end to another propagates in the form of electromagnetic (EM) wave. He added that Reflection, Diffraction and Scattering are responsible for incurring path loss as electromagnetic waves propagate from source to destination during information transmission. Stutzman and Thiele opined that path loss may be due to many effects, such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption (Stutzman and Thiele, 1981).

It is also 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 or path attenuation is the reduction in power density of an electromagnetic wave as it propagates through space. Path loss is a major component in the analysis and design of a telecommunication system. This term is commonly used in wireless communications and signal propagation. According to the effects of these factors in signal propagation, a well-defined model which appropriately covers all propagation phenomena in a given environment will require an accurate computation of the mean or median path loss to further reduce the error margin and additional attenuation that is likely to occur (Ogbulezie, et al., 2013; Imohmoh, et al., 2021). Outcome to the information garnered from other related investigators, it is obvious that the area to which a particular BTS (Base Transmission System) can cover is not fixed, but, depends on the nature of the environment, terrain and the level of infrastructural development of such a location. According to Mawjoud network planning is vital in the prediction of path loss and hence the coverage area, frequency assignment and interference which are the main concerns in mobile network planning (Mawjoud, 2003).

The available empirical formulae cannot be generalized to different environments (urban, sub-urban, and rural). In general, suitability of these models differs for different environment. In another study, Isobana and Konyeha investigate urban area path loss propagation prediction and optimization in South-south Nigeria (Isobana and Konyeha, 2013). They assessed the similarities and differences of measured path loss with theoretical path loss obtained from Hata, SUI, Lee and Egli models. Hata model was synonymous with the measured values in their result. Subsequent to these, an optimized Hata model for the prediction of path loss experienced by Code Division Multiple Access (CDMA) 2000 signal in 800 MHz band, was developed. Ilesanmi and Oladunni proved that Hata and COST 231 models at the best in Ekiti State after their study on radio frequency attenuation path loss behaviour in suburban and rural area (Ilesanmi and Oladunni, 2018). Their study aimed at developing and optimizing a path loss based on existing path loss model and measurement using 900 and 1800 MHz. Imoize and Oseni, reported Okumura-Hata predicted path loss along 3 major highways in Lagos. Okumura-Hata (Imoize and Oseni, 2019). Walfisch-Ikegami, Ericcson, ECC-33, and Lee models were the models used in comparison with the measured data. In telecommunication studies, the radio refractivity, radio refractive index, refractivity gradient, radio field strength, effective earth radius and radio horizon distance are important parameters and were investigated in the study reported by to mention but a few (Akpootu and

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Iliyasu, 2017a; Akpootu and Rabiu, 2019; Akpootu et al., 2019a; Akpootu et al., 2021).

For practical cases, the path loss is calculated using statistical and deterministic methods. Statistical method; also called stochastic or empirical are based on measured and averaged losses along typical classes of radio links. Among the most commonly used such methods are Okumura-Hata, the COST Hata model, W.C.Y.Lee, Walfisch-Ikegami, Erceg, etc. these are also known as radio wave propagation models and are typically used in the design of cellular networks and public land mobile networks (PLMN). 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 (Stutzman and Thiele 1981). Deterministic method; is based on the physical laws of wave propagation are also used; ray tracing is one such method. These methods are expected to produce more accurate and reliable predictions of the path loss than the empirical methods; however, they are significantly more expensive in computational effort and depend on the detailed and accurate description of all objects in the propagation space, such as buildings, roofs, windows, doors and walls. For these reasons they are used predominantly for short propagation paths. In Seybold some of the factors affecting radio path loss are free space loss, diffraction, multipath, absorption losses, terrain and atmosphere (ionosphere and trosposphere) (Seybold, 2005). These factors are the major elements causing signal path loss for any radio system. As at the time of this study, no work on path loss models and measurement for Sokoto region has been reported in the reviewed literature. In view of this, the aim of this study is to identify a suitable model which best prove the path loss of measured data in Sokoto (Runjin Sambo gate to Tasha Ilela).

2. Methodology

2.1 Description of the Study Area

Sokoto is a major city located at the extreme end of the northwest of Nigeria on the border with the Republic of the Niger. It is located at near the confluence of the Sokoto River and Rima River with Sokoto, the largest city in the state as its capital. It lies between latitude of 10^0 and 14^0N and longitude 3^0 and 7^0E of the equator. Its population was projected to be 3.7million based on 2006 Census. Sokoto is in the Northwest geopolitical zone in Nigeria (one of the 36 states in the Country) with a total land mass of 25,973 km^2 (10,028 square meter). It is one of the hottest citites in Nigeria with 40^0C as the maximum daytime temperature and its dryness making the heat unbearable. There are two major seasons in Sokoto, namely wet and dry. The dry season starts from October, and lasts up to April in some parts and may extend to May or June in other parts. The wet season on the other hand begins in most parts of the state in May and lasts up to September, or October (Akpootu and Iliyasu, 2017b).

2.2 Data Acquisition

In this study, mobile communication signals were taken from a stable point at every 100 m through 5.6 km route between Abdullahi Fodio Road and Tasha Ilela and a database was created. A Microsoft Excel worksheet was used to record the measurement of signal strength. The program acquired the information from a mobile phone for MTN network, mobile communication signals were detected at each 100 m point. Assessments were made with the method of average analysis on this recorded data. To predict path loss model for cellular transmission, practical data from the field measurement are required. The test was carried out with Tecno Spark 4 using the Network Signal Info app – it is used to detect the signal strength at a particular location, BTS app – the app was used to detect the nearest base transmission station, Measuring Tape – it was used to measure the distance covered in kilometres. The reading was conducted from the BTS located at Runjin Sambo gate, close to NTA broadcasting station. The signal strength was recorded five times at 700 m interval on a spot to get the accurate mean to avoid error. A mobile phone – used to save the data collected on Microsoft Excel.

Experimental measurements were collected with the use of a Mobile Phone (Tecno Spark 4 – KC8) capable of measuring received signal power in decibel milliwatts (dBm) using Network Signal Info App. The transmitting antenna (owned by MTN) was located at a height, Ht of 30.00m and transmitting at frequencies 1500 MHz, with a radiated power, P = 46 dBm, transmitting antenna gain, G = 18 dB and Effective Isotropic Radiated Power, EIRP = 64 dBm and expected minimum received power for good link RM = 102 dBm. The antenna for Abdullahi Fodio and Yabo Roads is located near the vegetable market while that of Yabo Road to Aliyu Jordi is at Runjin Sambo. During measurements, readings of received signal powers were taken while moving away from the serving base stations. Precautions were taken not to enter into the serving regions of a next base station transmitting antennas, the receiving antenna which was the Tecno Phone, as mobile phones are known to be transreceiver, has a gain of 1.7 dB (GR = 1.76 dB)

2.3 Models Used for The Computation of The Path Loss

2.3.1 Cost-231 Model

The COST-231 model sometimes called the Hata model PCS extension is an enhanced version of the Hata model that includes 1800-1900 MHz (Seybold, 2005).

COST-231 model is for propagation in the PCS band. This is limited to cases where base station antenna is placed higher than the surrounding building, and it was applied in this study.

$$L_p = A + Blog_{10}(d) + C \quad (1)$$

$$A = 46.3 + 33.9\ log_{10}(f)13.82log_{10}(h_b) - a(h_m) \quad (2)$$

$$B = 44.9 - 6.55\log(h_b) \quad (3)$$

$$L_p = 46.3 + 33.9log_{10}(f) - 13.82log_{10}(h_b) - a(h_m) + [44.9 - 6.55\log(h_b)]\ log_{10}(d) + C \quad (4)$$

C = 0 for medium city and suburbans area with moderate tree density and 3 for metropolitan.

$a\ (h_m) = (1.1log_{10}f - 0.7)hr - (1.56\ log_{10}\ f - 0.8)$ for Sub – urban and rural areas.

$a\ (h_m) = 3.20\ (log_{10}\ (11.75\ hr))^2 - 4.97\ when\ f > 400MHz$ for Urban areas.

2.3.2 Hata's Model

The Hata model is an empirical formulation of the graphical path loss data provided by Okumura mode. Hata model was also employed in this study. It is valid over roughly the same range of frequencies 150 MHz to 1500 MHz. this empirical formula simplifies the calculation of path loss because it is closed form formula and it is not based on empirical curves for different parameters.

The path loss (in dB) is written as (Seybold, 2005).

$$L_{50}(dB) = 69.55 + 26.16\ log_{10}(fc) - 13.82\ log_{10}(htc) - a\ (hrc) + (44.9 - 66.55\ log_{10}(htc)]log_{10}(d) \quad (5)$$

for Urban areas

The parameters are the same as Okumura's model, a(hrc) is a correction factor for the mobile antenna height based on the size of the coverage area.

For small to medium size cities this factor is:

$$a\ (hrc) = (1.1log_{10}(fc) - 0.7)hr - (1.56\ log_{10}\ (fc)\ - 0.8)\ dB) \quad (6)$$

Corrections are made to urban model to get models for suburban and rural propagation.

To determine the path loss and derived an optimized empirical model for the area under investigation, RSS was gathered from the field. The path loss was predicted using two formula which are:

$$Case\ 1{:}\ L_p = EIRP - P_r \quad (7)$$

$$Case\ 2{:}\ P_l(di) = 10log_{10}\ (P_t/P_r) \quad (8)$$

Path loss exponent indicates the rate at which P_l increase with distance.

P_l was predicted using the data obtained from the field measurement.

P_r is the received power, P_t is the transmitter power, L_p is the path loss, EIRP is the Effective Isotropic Radiated Power and L_P is the path propagation loss.

The models are validated using percentage error test and is given mathematically as (Olowofeso, 2019).

$$Percentage\ error = \frac{error}{measurement} \times 100\% \quad (9)$$

Which gives

$$Percentage\ error = \frac{PL_m - Predicted\ COST\ 231}{measurement} \times 100\% \quad (10)$$

$$Percentage\ error = \frac{PL_m - Predicted\ Hata}{measurement} \times 100\% \quad (11)$$

Many researchers have reported that the lower the value of Mean Bias

Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE), the better is the model's performance (Akpootu and Iliyasu, 2015a; b; Akpootu and Sanusi, 2015; Akpootu et al., 2019; b,c,d,e; Akpootu and Abdullahi, 2022; Akpootu et al., 2022; Akpootu et al., 2023). The same is applicable to the percentage error test for validation of model's performance.

3. Results and Discussion

Table 1: Variation of measured path loss at various distances and RSS		
Distance (km)	**PL_m (Db)**	**RSS (dBm)**
0.095	135.20	-65.40
0.21	127.00	-81.60
0.24	136.40	-81.40
0.26	143.00	-69.60
0.39	145.40	-72.40
0.42	145.60	-71.20
0.49	133.60	-63.00
0.59	129.40	-79.00

Table 1 shows variation of measured path loss at various distances and Received Signal Strength (RSS). The table shows fluctuation in the RSS with distance indicating that the signal strength is independent on the distance from the transmitting antenna. The predicated COST 231 and Hata models were estimated at the corresponding distances and RSS respectively.

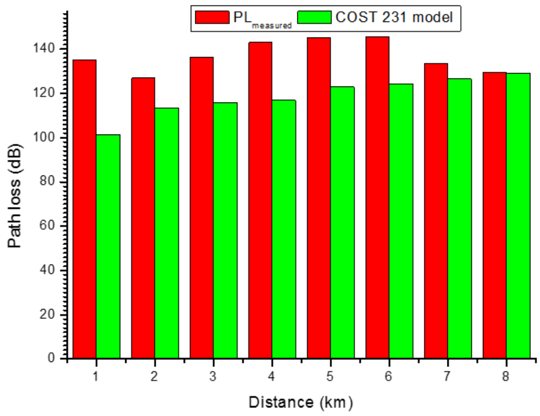

Figure 1: Comparison between measured path loss and COST 231 model

The results from the measured path loss (PL_m) were compared with the predicted COST-231 model, as Received Signal Strength (RSS) varies, as shown in figure 1. The results from the figure indicated that the values of the measured path loss are higher than the estimated values of COST 231 model for the varying distances and RSS. It is important to note that the distances 0.095, 0.21, 0.24, 0.26, 0.39, 0.42, 0.49 and 0.59 km was replaced with 1, 2, 3, 4, 5, 6, 7 and 8 km respectively as the measured distances are not done at regular intervals.

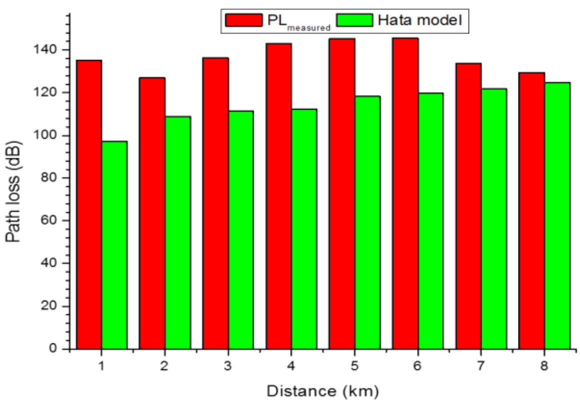

Figure 2: Comparison between measured path loss and Hata model

The results from the measured path loss (PL_m) were compared with the predicted Hata model, as Received Signal Strength (RSS) varies, as displayed in figure 2. The results from the figure indicated that the values of the measured path loss are higher than the estimated values of Hata model for the varying distances and RSS.

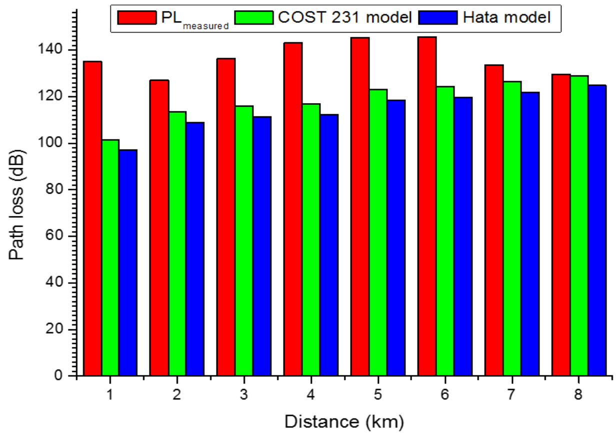

Figure 3: Comparison between measured path loss with COST 231 and Hata models

Figure 3 shows the results of the comparison among the measured path loss, predicted COST-231 model and the predicted Hata model, as Receieved Signal Strength (RSS) varies at different distances. The result shows that the COST 231 values are close to the measured path loss values than Hata's. The difference is vividly revealed in the figure. It is pertinent to note that the more the path loss, the less the available received power.

Table 2: Percentage error for COST 231 and Hata models			
Distance	**PL_m**	**COST 231 %Error**	**Hata % Error**
0.095	135.20	24.88	28.18
0.21	127.00	10.65	14.21
0.24	136.40	15.01	18.34
0.26	143.00	18.21	21.39
0.39	145.40	15.43	18.58
0.42	145.60	14.63	17.78
0.49	133.60	5.31	8.75
0.59	129.40	0.27	3.49
AVERAGE % Error		**13.05**	**16.34**

Table 2 shows the percentage error for COST 231 and Hata models. The result show that the COST 231 model account for an average percentage error of 13.05 % while Hata model account for an average percentage error of 16.34 % indicating that the COST 231 model was found more suitable for path loss prediction model in Sokoto as compared to Hata model. The result showed that the best signal strength was found at a distance of 0.59 km from the radiating antenna with percentage error of 0.27 % and 3.39 % for COST 231 and Hata models respectively.

4. Conclusion

This study was conducted to identify the best model for predicting path loss of MTN network in Sur-urban area of Sokoto State. The research was done using BTS app which has been installed on a mobile phone (Tecno spark 4) and measuring tape. The signal strength were measured, and used to compute and analyze COST 231 and Hata path loss models to identify the best model that suit the study area. After collecting and analyzing the data, it was concluded that the best model for MTN network at sub-urban areas in Sokoto is COST 231 with an average percentage error of 13.05 % as compared to Hata model with 16.34 %. However, the Hata model also gives a reasonable estimate as it produces insignificant percentage error.

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