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AJ-Olu-1: An Innovative Path Loss Model for Typical Nigerian Urban Environments

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Abstract
The modeling of outdoor path loss propagation is critical in the planning and construction of the Global System for Mobile Communication (GSM) coverage area. For GSM signal prediction at any location inside its service region, a precise forecast based on critical characteristics and a mathematical model is required. Numerous research findings on path loss propagation model forecast for GSM mobile networks conducted in various cities in Nigeria revealed that the COST-231-Hata model gives closer prediction to most of the practical measure path loss values. Based on the existing COST-23-Hata path loss model and outdoor measurements at 1800 MHz frequency range within Ilorin metropolis, this paper proposed a suitable path loss model. The developed model was used and validated in various locations throughout Ilorin city with the measured and COST-231 Hata models. The analysis of the results revealed that the developed model performed satisfactorily in terms of the closest path loss prediction to the practical measure path loss values at all study locations. It also has the lowest Square Root Means Error and Standard Deviation (SD) of any Base Station (BTS) tested in Ilorin, Nigeria. As a result, it is concluded that the newly developed AJ-Olu-1 model is more suitable for GSM 1800 network design and installation in Ilorin City, Nigeria, as well as other cities in Nigeria and other cities outside Nigeria with similar environments.

Nomenclature and units

P_L	Path Loss
f_c	Frequency of transmission
ah_m	Correction factor for antenna height
K_1	Inceptive offset intake parameter
K_2	Inceptive system absorption parameter
B	Establish slope of the model flexion

1.0 Introduction

Signal propagation forecast is one of the bases of GSM network setup, therefore propagation prediction models must be as precise as possible, giving consideration to the constrain that described the propagation territory. Path loss is a common problem in GSM services; as a result, poor reception and signal failures occur often in many locations, accounting for increasing attenuation of cellular network signal strength when a subscriber with a mobile phone goes from one point to another. Many factors effect path loss, including reflection, diffraction scattering, and so forth (Akanni et al. 2021).

Several research investigations on the behavior of GSM signals in various locations under varying geographical and environmental circumstances have been conducted. The study's findings gave birth to several propagation path loss models for evaluating GSM quality of service discharged. The resulting models are environment-specific.

Popoola and Oseni (2014a) states "that no model provides a precise match for the field observed data in all propagation conditions but COST-231-Hata model with the lowest MSR of 9.78 dB was assessed to be best appropriate for GSM 1800 network design and deployment in Makurdi City, Nigeria. Also, Akinwole and Biebuma (2013) presented a review of three empirical path loss models that covers urban, suburban, and rural using measured data for Rivers State, Nigeria and it was found that the COST-231 Hata model has the lowest MSE and SD, resulting in better forecasts.

Surajudeen-Bakinde et al. (2012) compared propagation models at 1800 MHz for two cities in Nigeria. The results show that no generic model is fit for all territories, and it is recommended that either the Hata or the COST 231 models be modified to suit the environment and the technology. Popoola and Oseni (2014b) study the performance evaluation of radio propagation models on the Nigerian GSM network. For radio coverage forecasts in the dense suburban and dense urban areas of Lagos, three models were explored. The COST 231-Hata model has RMSE and SD values of 11.82 dB and 7.88 dB for urban areas, respectively and was found to be the best appropriate for GSM 1800 network design and deployment.

Ogbulezie et al. (2013) studied two empirical propagation models in their effort to build adaptive and appropriate propagation path loss models for the cities of Port Harcourt and Enugu (2013). For each of the cities, two sites were selected, and driving test measures were taken along the major roadways. These findings were compared to the values anticipated by the Okumura-Hata and COST-231-Hata models. At 900 MHz, the mean square errors were from 0.8 to 5.04 dB for the Okumura-Hata model and from 0.6 to 4.76 dB for the COST-231-Hata model.

1.1 Related Works

Imhomoh et al. (2011) optimized the COST-231 Hata model for GSM (1800) signal propagation path loss prediction in Lagos, Nigeria, using a comparison technique. Several measured signal path loss data were collected along various routes, starting at 100 m from the base station and increasing in distance at 100 m intervals up to 2 km. The path loss exponent was calculated using least squares regression analysis, and optimization was carried out by calculating the differences in MSE between the observed and predicted route loss at each point. In metropolitan Lagos, the created model predicted observed path loss with acceptable mean square errors of 5.25dB.

Mardeni and Kwan (2010) explored the behavior of radio frequency attenuation path loss in Malaysian suburbs. The study concentrated on the development and enhancement of a path loss model based on the present Hata path loss model, as well as outside measurements with frequency ranges spanning from 400 MHz to 1800 MHz. The least squares method was utilized to optimize the procedure. The modified modal was tested for several base stations in, and it was revealed that almost all of them fit into the optimized model. The optimized Hata model was chosen to be the best since its relative error is the lowest when compared to the other models presented.

By combining the stochastic Weighted Least Squares technique with the Genetic algorithm, Bhuvaneshwari et al. (2018) proposed a stochastic hybrid Genetic Algorithm for improving mobile radio path loss models. Field strength tests at 900 MHz in the suburban area confirmed the established technique, which was used to refine the parameters of the Cost 231 Hata propagation model. The hybrid technique's performance was assessed using path loss comparison and error metrics, and the lowest values of MER of 0.2702, RMSE of 0.4798, and% Relative error of 3.96 indicated its tuning accuracy.

Garah et al. (2016) suggested an optimization path loss model for mobile communication. Following multiple studies on signal propagation path loss prediction on GSM 908-957 in Batna, Algeria, it was discovered that the COST-231 path loss mode delivers a value that is closer to the observed value than other empirical models. As a consequence, COST-231 was altered to allow for optimization using a genetic algorithm. The RMSE, MER, and PRE tests comparing actual and predicted data for multiple route loss models in Batna, Algeria, demonstrated that the modified COST-231 model performed better.

In Uyo, Nigeria, Orike et al.(2017) explored the modeling of GSM signal propagation loss. A model prediction equation was built using basic least square regression and Microsoft Excel based on the expected path loss versus distance inside the Uyo metropolitan area. A signal path loss comparison test between the developed model and three empirical models: Okumura-Hata model, COST-Hata model, and Egli model in three major routes within Uyo, Akwa-Ibom state, Nigeria, revealed that the developed model had a better comparison factor than the COST-Hata and Okumura-Hata models.

This compact evaluation of relevant literature reveals a paucity of relevant studies in the Nigerian system. Nonetheless, it is evident that a superior modeling technique is required. This study examines the challenges and seeks to offer solutions that are reasonably accurate and pertinent in the Nigerian environment.

1.2 COSTS-231-Hata Path Loss Model

The COST-231-Hata model takes its title from the European Co-operative for Sciences and Technical Research (EUROCOST), which is an institution that extends the Hata-Okumura model (Prajesh and Singh 2012). It is the most typically used empirical model (Deme et al. 2013). In the COST-231-Hata model, correction factor, C_m, was introduced, and the operating frequency was increased to 2000MHz (Dajab and Ogundapo 2008). The propagation of the Cost-231-Hata model is stated in equation (1) (Raturi et al. 2014) as:

$$P_L = 46.3 + 33.9\log_{10} f_c - 13.82\log_{10} h_b - ah_m + (44.9 - 6.55\log_{10} h_b)\log_{10} d + C_m \quad (1)$$

$$ah_m = \begin{cases} (1.1\log_{10} f - 0.7)h_m - (1.56\log_{10} f - 0.8), & \text{for medium small cities} \\ 3.20(\log_{10}(11.75h_m)^2) - 4.97, & \text{for large cities } f \geq 300 \text{ MHz} \\ 8.29(\log_{10} 11.54h_m)^2 - 1.1, & \text{for large cities } f \leq 300 \text{ MHz} \end{cases} \quad (2)$$

$$C_m = \begin{cases} 0 \text{ dB} & \text{for medium sized cities and suburan} \\ 3 \text{ dB} & \text{for metropolitan area} \end{cases} \quad (3)$$

Where, h_m is the height of MS (1-10m); h_b is the height of BS (30-200 m); d distance between BS and MS (km); f_c is the frequency transmission (1500-2000 MHz); and ah_m is the correction factor for height of the MS antenna.

2.0 Materials and Methods

Nokia phones (Mobile Station, MS) and a Global Positioning System GPS were employed in the experimental setup (Garmin-nuvi 40GPS). A built Transmission Evaluation Monitoring System (TEMS) investigative software linked Nokia phones to a laptop's serial connection. The signal strength values in Received Signal Strength Indication (RSSI) format, base station characteristics, and time read from the ports were saved to a text file. The coordinates and elevation of the study locations were collected using GPS.

Measurements were obtained on a homogeneous grid of outdoor spaces at specified locations across Ilorin (figure 2). This process has an advantage over the typical convectional drive-test technique that may not cover some inaccessible areas owing to African building architectural styles. Since continuous data are recorded at the same location, systematic errors are decreased by properly windowing and averaging data, which is another advantage over the driving test technique.

To ensure that the phone maintained in constant communication with the BTS, all measurements were done in mobile active mode. To do this, calls were launched to a set specified number at each point in the research sites, and the received signal strength assessed was recorded in a text file. For this study, two cases were studied. In the first scenario, a separate study location (Saw-mill area) representing the average terrain variation in Ilorin city was selected to develop the modified COST-231-Hata model to meet the environment under investigation. GSM signal strength was measured at each predetermined location within the research zone, beginning at approximately 0.1 km from the foot of the selected GSM operator's base transceiver station (BTS) labeled BTS 1 and continuing at intervals of about 0.1 km up to a distance of about 1.2 km. In the second scenario, eight regions (locations) were chosen based on acceptable places that match typical Nigerian environmental features. These places were chosen by resident characteristics such as valleys, hills, greenery, road width, high density (local population) areas, and low density areas (G.R.A). GSM signal strength measurements were performed in the eight selected regions (locations) as in the first case, but for eight different GSM operators labeled BTS 2 through 9, in order to validate the developed model's performance in terms of Root Mean Square error (RMSE) and Standard deviation (SD) when compared to the existing COST-231-Hata path loss model in order to test the created model's performance in terms of RMSE and SD when compared to the existing COST-231-Hata path loss models.

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Measurements were conducted on a uniform grid of outdoor positions at points along predefined regions (figure 2) within Ilorin city. This methodology has advantage over the usual convectional drive-test procedure which may not cover certain inaccessible areas because of the Africans buildings patterns. Since continuous measurement at the same point is captured, it reduces systematic errors by properly windowing and averaging data and this is another advantage over drive test method.

All measurements were obtained in the mobile active mode so as to ensure that the mobile phone was in constant touch with the BTS. To achieve this, for every point in the study locations, calls were initiated to a fixed designated number and the received signal strength measured was recorded in a text file. Two cases were considered for this study. In the first case, a distinctive study region (Saw-mill area) that represented the average terrain variation in Ilorin city was chosen to formulate the modified

COST-231-Hata model to suit the environment under study. GSM signal strength measurement was carried out at every predefined point within the study region, starting at about 0.1 km from the foot of the base transceiver station (BTS) of the chosen GSM operator labeled BTS 1 and at subsequent interval of about 0.1 km up to a distance of about 1.2 km. In the second scenario, eight regions (locations) were chosen based on acceptable regions that match typical Nigerian environmental qualities. These places were chosen by resident attributes such as valleys, hills, greenery, road width, high density (local population) areas, and low-density areas (G.R.A). GSM signal strength measurements were performed in the eight selected regions (locations) as in the first case, but for eight different GSM operators labeled BTS 2 through 9, in order to validate the developed model's performance in terms of Root Mean Square error (RMSE) and Standard deviation (SD) when compared to the existing COST-231-Hata path loss models.

2.1 Description of the Study Environment

Ilorin, a city in north central Nigeria, is situated between latitude 8.41^0 N and 8.55^0 N and longitude 4.49^0 E and 4.65^0 E and has an area of around $89km^2$(Aremu et al. 2014). With a population of approximately 700,000 (Aremu et al. 2014), it is characterized by a complex landscape owing to the presence of numerous hills and valleys within the city. Figure 1 depicts the Ilorin Metropolis.

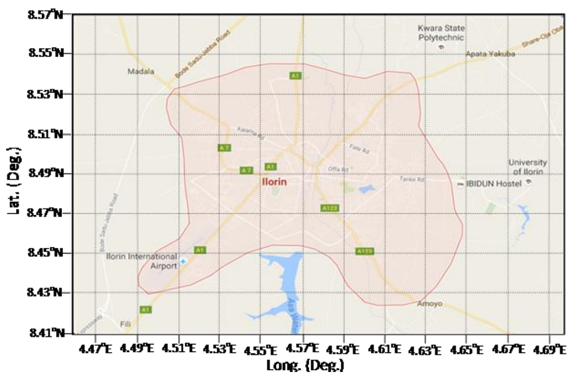

Figure1: Google Map of Ilorin Metropolis (Google Map May, 2013)

Figure 2: The Contour Map of the Study Location

2.2 Data Analysis

The MS antenna height was 1.5m in the data analysis, and the various base station characteristics utilized during the computation of corresponding path loss at different research locations are provided in Table 1. Figure 3 shows the relationship between power received, Pr, (dBm), and distance (km) for BTS1 at Saw-mill, Ilorin, Nigeria. The experimental results of the observed signal strength and distances related with the various BTS 1 were recorded at selected study areas (regions) inside Ilorin metropolis. The observed signal intensity and distances were used to compute the signal path loss from the measured signal value and also to modify the COST-231-Hata model using the statistical "Ad-in" tool in Microsoft EXCEL

Table 1: Selected Base Station Information

BTS No.	Study Location	Height (m)	Elevation (m)	Long. (m)	Lat. (m)	Freq. (MHz)
1	Saw-mill	30	328	4.53	8.47	1820.6
2	Taiwo Rd.	33	290	4.56	8.49	1826.2
3	G. R. A	28	335	4.58	8.49	1820.4
4	Unilorin	30	342	4.67	8.48	1851.2
5	Offa-Garage	30	326	4.61	8.49	1841.4
6	Tanke	28	356	4.61	8.49	1855.4
7	Oloje	30	294	4.52	8.52	1820.2
8	Edun/Emir's Rd.	28	281	4.56	8.49	1854.4
9	Post Office	25	264	4.56	8.50	1826.4

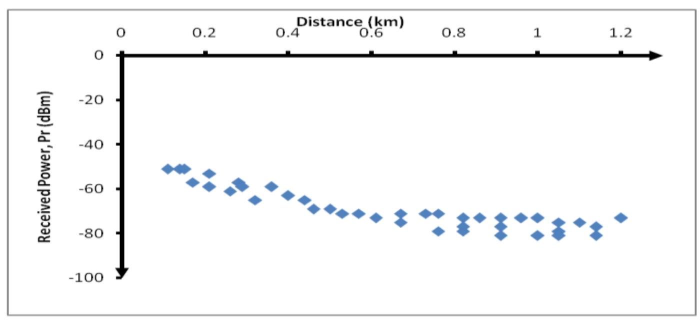

Figure 3: The variation of power received, P_r, (dBm) with distance (km) for BTS 1 at Saw-mill, Ilorin, Nigeria.

2.3 Path Loss Optimization Process

Following an in-depth assessment of several studies on path loss propagation model forecast for GSM mobile networks conducted in various cities throughout Nigeria, it was discovered that the COST-231-Hata model provides a more accurate path loss prediction than most practical measure path loss values. In this regard, the COST-231-Hata model is adapted to the context under investigation.

Since the majority of the variables represented by the chosen model (COST-231-Hata model) stay constant, the path loss in (1) may be expressed as follows:

$$P_L = 46.3 + 33.9\log_{10} f_c - 13.82\log_{10} h_b - ah_m + (44.9 - 6.55\log_{10} h_b)\log_{10} d + C_m \quad (4)$$

In order to examine the visual conclusion postulating that the other factors remain relatively unchanged, it was decided to restructure and redefined the representations to include the following parameters:

$$K_1 = 4.63 \quad (5)$$

$K_1 = Inceptive\ offset\ intake\ parameter$

$$K_2 = 33.9\log_{10} f_c - 13.82\log_{10} h_b - ah_m + C_m \quad (6)$$

$K_2 = Inceptive\ system\ absorption\ parameter$

$$K = K_1 + K_2 \quad (7)$$

$$B = B_1(44.9 - 6.55\log_{10} h_b) \quad (8)$$

$B = Establish\ slope\ of\ the\ model\ flexion\ parameter$

Least square technique is used to determine the value of K_1 and B_1

For a specified path$f_c, h_b\ and\ ah_m$are fixed and (4) is adjusted as follow:

$$P_L = (K_1 + K_2) + B\log_{10} d = K + B\log_{10} d \quad (9)$$

The function of the sum of deviation squares is minima when theoretical mode flexion is optimum to the experimental data i.e.

$$F(K,B) = \sum_{i=1}^{n}[P_i - P_r(d_i, K, B)]^2 \quad (10)$$

Where, P_i is the measured outcome at any distance d_i; $P_r(d_i, K, B)$ is the model forecast outcome at any distance d_i; K and B are parameters of model and n is the number of data set.

For optimization,

$$\frac{\partial F}{\partial A} = 0 \quad (11)$$

$$\frac{\partial F}{\partial B} = 0 \quad (12)$$

But $P_r = K + B\log_{10} d_i$

Let $\log_{10} d_i$be written as zfor simplicity,

Therefore,

$$P_r = K + Bz \quad (13)$$

Solving (11) and (12)

$$A = \frac{\sum z_i^2 * \sum p_i - \sum z_i * p_i}{n * \sum z_i^2 - (\sum z_i)^2} \quad (14)$$

$$B = \frac{n * \sum z_i * p_i - \sum z_i * \sum p_i}{n * \sum z_i^2 - (\sum z_i)^2} \quad (15)$$

The values of K and B in equations (14) and (15) are calculated with the aid of Microsoft EXCEL for$f_c = 1820.6\ MHz$, $h_b = 30\ m$ and $h_m = 1.5\ m$ to be 129.93 and 34.56 respectively.

Therefore,

$$K_1 = K - K_2 = 129.93 - 88.92 \approx 41.01$$

$$B_1 = \frac{B}{(44.9 - 6.55\log_{10} h_b)} = 0.994 \approx 1$$

Finally, the modified COST-231-Hata becomes:

$$P_L = K_1 + K_2 + B_1(44.9 - 6.55\log_{10} h_b)\log_{10} d$$

$$P_L = 41.01 + (33.9\log_{10} f_c - 13.82\log_{10} h_b - ah_m) + 1 * (44.9 - 6.55\log_{10} h_b)\log_{10} d + C_m \quad (16)$$

The developed path loss model defined as the AJ-OLU-1 model is

$$P_L = 41..01 + 33.9\log_{10} f_c - 13.82\log_{10} h_b - a_h + (44.9 - 6.55\log_{10} h_b)\log_{10} d + C_m \quad (17)$$

3.0 Results and Discussions

To confirm the level of accuracy of the modified path loss mode (AJ-OUL-1 path loss model), the path loss variation with distance associated with a specific operator (BTS) at different locations within the metropolis is plotted as shown in Figure 5 through Figure 12. The modified path loss model was validated for further performance accuracy. Validation was carried out by comparison of the RME and SD values (generated with the aid of Microsoft EXCEL) of signal path loss between the modified model and the COST-231 model associated with the different BTS at selected study locations within Ilorin metropolis. Table 2 shows statistical evaluation of RME and SD between the AJ-OLU-1 model and COST-231 Hata model associated with the several BTS at selected study locations.

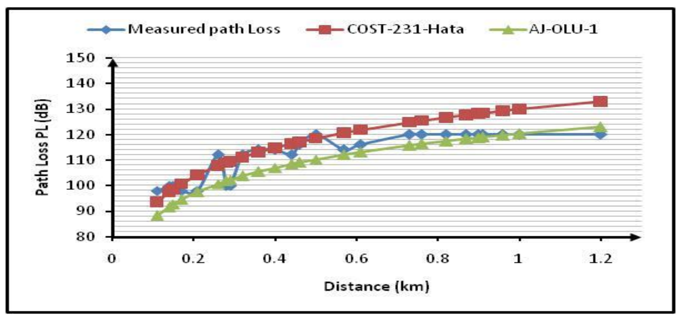

Figure 4: The path Loss (dBm) variation against distance (km) for BTS 1 at Saw-mill, Ilorin, Nigeria

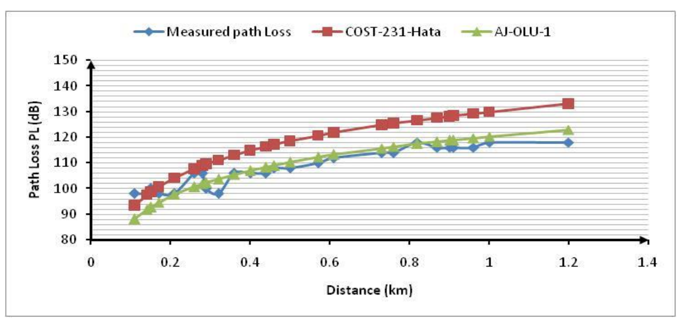

Figure 5: The path Loss (dBm) variation against distance (km) for BTS 2 at Taiwo Rd., Ilorin, Nigeria

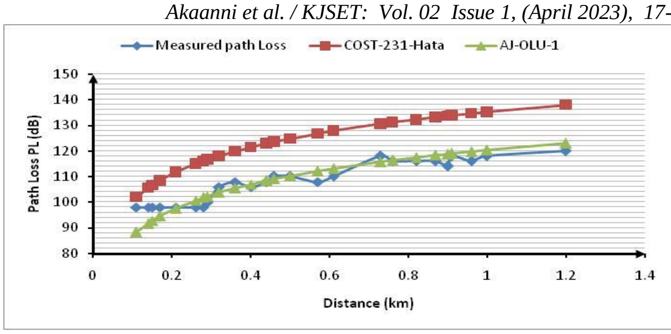

Figure 6: The path Loss (dBm) variation against distance (km) for BTS 3 at G. R. A. Ilorin, Nigeria

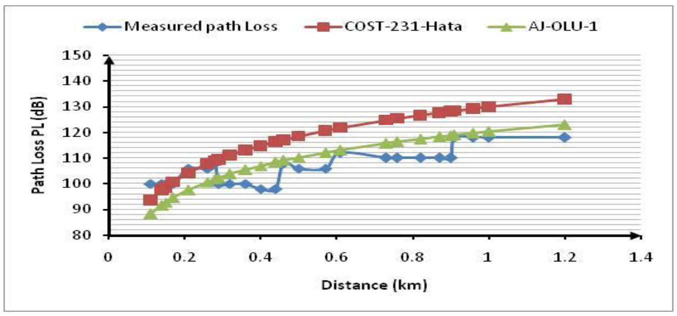

Figure 7: The path Loss (dBm) variation against distance (km) for BTS 4 at Unilorin, Ilorin, Nigeria

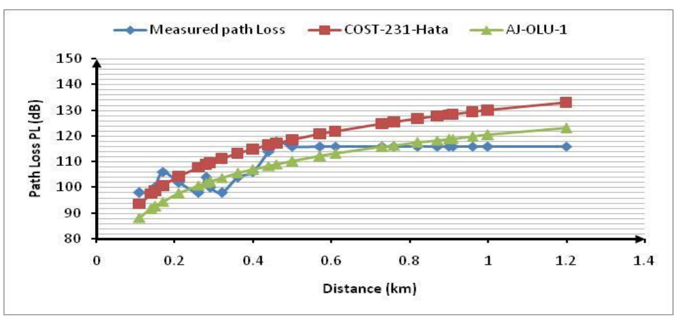

Figure 8: The path Loss (dBm) variation against distance (km) for BTS 5 at Offa Rd., Ilorin, Nigeria

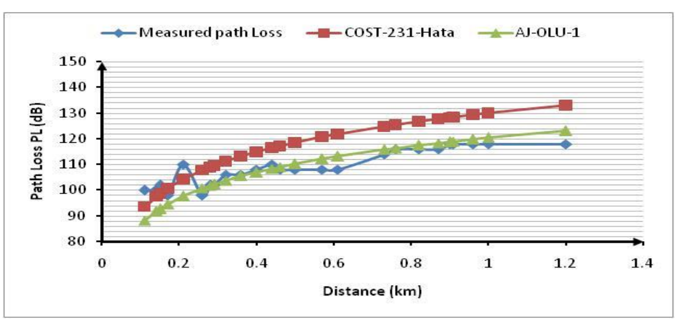

Figure 9: The path Loss (dBm) variation against distance (km) for BTS 6 at Tanke, Ilorin.

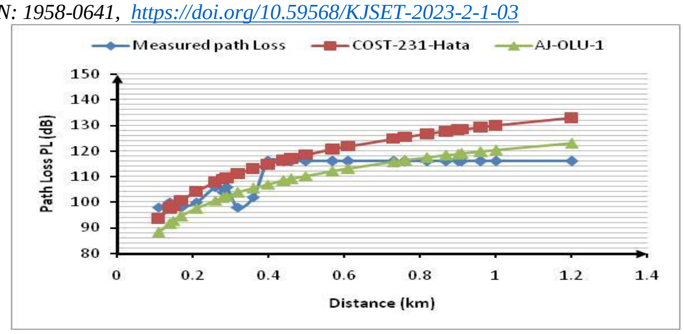

Figure 10: The path Loss (dBm) variation against distance (km) for BTS 7 at Oloje, Ilorin, Nigeria

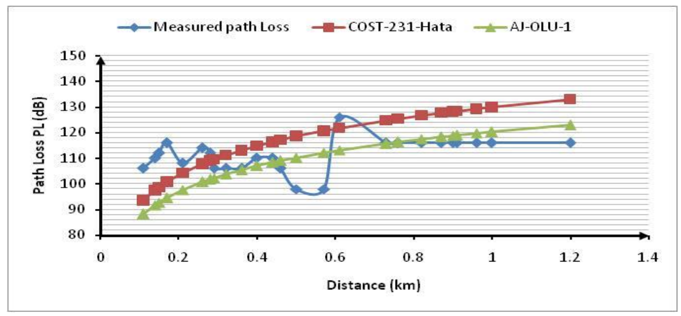

Figure 11: The path Loss (dBm) variation against distance (km) for BTS 8 at Edun/Emir's

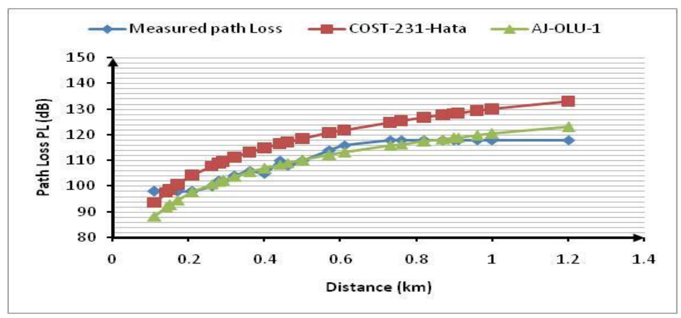

Figure 12: The path Loss (dBm) variation against distance (km) for BTS 9 at POST office, Ilorin

Table 2: Statistical Evaluation of RME and SD between AJ-OLU-1 model and COST-231-Hata model for various BTS at selected Study Locations.

Study Location	BTS No.	RMSE		SD	
		AJ-OLU-1	COST-231-Hata	AJ-OLU-1	COST-231-Hata
Saw-mill	1	2.73	23.74	3.81	24.47
Taiwo Rd.	2	4.42	18.68	4.66	19.70
G. R. A	3	3.94	18.33	4.16	19.32
Unilorin	4	3.30	21.84	3.41	22.55
Offa-Garage	5	4.12	18.35	4.28	19.04
Tanke	6	4.10	16.61	4.27	17.29
Oloje	7	4.58	16.36	4.81	17.16
Post Office	8	2.73	22.15	2.88	23.35

4.0 Conclusions

A modified COST-231 Hata path loss model (AJ-OLU-1 model) was developed. The developed model was used and validated with the measured and COST-231 Hata model in various locations throughout Ilorin city. The results analysis revealed that the developed model performed satisfactory given the closet path loss prediction to the practical measure path loss values at all the study locations. It also has the lowest Square Root Means Error and Standard Deviation (SD) of any of the tested Base Stations (BTSs) in Ilorin city Nigeria. As a result, it is concluded that the newly developed AJ-Olu-1 model would be more suitable for GSM 1800 network designing and installation in Ilorin City Nigeria as well as any other cities in Nigeria and other cities outside Nigeria with similar environment.

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