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Comparative Analysis of Received Signal Strength Prediction Models for Radio Network Planning of GSM 900 MHz in Ilorin, Nigeria

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Abstract— The quality of coverage of any radio network design depends on the accuracy of the propagation model employed during planning and initial deployment. For efficient radio network design, the propagation models are estimated from signal strength measurement taken in the area of interest. In this paper, the suitability of Okumura-Hata model, COST 231-Hata model and Standard Propagation Model for radio coverage prediction on terrains of Ilorin City, Nigeria was investigated. Field measurement data were obtained from the GSM 900 radio network deployed in the area through drive test. The actual Received Signal Strength (RSS) values were compared with those obtained from model predictions in ATOLL network planning tool. The predictions of Standard Propagation Model gave the minimum Root Mean Square Error (RMSE) of 5.52 dB, 12.73 dB and 18.4 dB on BS2501, BS2502 and BS2503 respectively. The deviation of the mean RSS predicted by Okumura-Hata was found to be the highest when compared with that of the actual data collected. Therefore, the use of Standard Propagation Model in radio network planning at 900 MHz will deliver a better Quality of Service (QoS) to mobile users in these propagation environments.

Index Terms—Drive test, Propagation Model, Received Signal Strength, Radio Network Planning

I. Introduction

Cellular system design has become more challenging in recent years as the wireless industry experience a phenomenal growth, both in terms of mobile technology and subscribers. This enormous growth raises the need for a reliable network planning tools to speed the process from network design to implementation [1]. GSM network in Nigeria is currently faced with the challenge of customers' dissatisfaction in the quality of service offered by the existing network operators due to frequent dropped calls, poor network interconnectivity, echoes and network congestion encountered [2]. This is largely as a result of poor coverage and capacity planning before initial deployment. Received signal strength prediction models play an important role in the Radio coverage planning and optimization as well as in efficient use of the available resources in wireless communication [3]. An understanding of the radio propagation characteristics of an environment is a necessary condition for effective radio network planning. This becomes serious issues today with the ever-increasing demand for radio channels following the explosion in the demand for mobile applications and services [4]. Accurate path loss predictions models are used to find network coverage gaps and areas with poor serviceability [5]. According to [6], an accurate knowledge of channel characteristics is required for cellular operators to optimize the coverage and maintain the interference at the lowest possible level. However, in spite of the development of numerous radio propagation prediction models so far, the generalization of these models to any environment is still questionable. They are suitable for either a particular area or specific cell radius. The suitability of each of the empirical path loss models largely depends on the propagation environment. Different environments are made up of unique localized physical obstructions and man-made structures which are arranged in diverse patterns. There exist a strong relationship between these models and the types of environments for which they are suitable. Though propagation models are available to predict received signal strength values at different antenna heights and separation distance between the base station and the mobile station, they are not very accurate in producing reliable radio coverage and received signal strength predictions for all propagation terrains. This is due to the fact that these models were designed based on measurement obtained elsewhere [7]. There are myriads of researches in the area of evaluating the suitability of path loss models for GSM network in different parts of Nigeria. However, most radio propagation predictions are carried out theoretically without a proper account for the land clutter classes and heights of the physical and man-made obstruction present in the propagation environment. To the best of the authors' knowledge, the use of ATOLL network planning tool which utilizes digital map of this study area for radio propagation prediction is novel to this research work. Therefore, this study evaluated the suitability of three of the empirical propagation models available in ATOLL network planning tool namely: Okumura-Hata model; COST 231-Hata model and Standard Propagation Model for radio coverage prediction of GSM 900 in Ilorin City, Nigeria. A drive test was conducted within the coverage area of each of the cell investigated.

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The results collected over the 'live' GSM network deployed in Ilorin City, Nigeria were compared with those predicted by the propagation models. The propagation prediction model with the best performance with respect to what was obtained on the propagation environment was recommended for use in any future radio network deployment at 900MHz within the area.

A. Okumura – Hata Model

Hata developed a model which is an empirical formulation of the graphical path loss data provided by Okumura [8]; 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 [8]. 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)
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

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,

$$a(h_r) = 8.29\,[\log(1.54h_r)]^2 - 1.1 \text{ for } f_c \le 300\text{MHz} \quad (3)$$
$$a(h_r) = 3.2\,[\log(11.75h_r)]^2 - 4.97 \text{ for } f_c \ge 300\text{MHz} \quad (4)$$

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,

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

B. 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 [9]. 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,

$$a(h_r) = 8.29\,[\log(1.54h_r)]^2 - 1.1 \text{ for } f_c \le 300\text{MHz} \quad (9)$$
$$a(h_r) = 3.2\,[\log(11.75h_r)]^2 - 4.97 \text{ for } f_c \ge 300\text{MHz} \quad (10)$$

and,

$$C_m = \begin{cases} 0\text{ dB} & \text{for suburban areas} \\ 3\text{ dB} & \text{for metropolitan areas} \end{cases} \quad (11)$$

Range of parameters

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

C. 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 distances ranging from 1 – 20 Km. It is best suited to GSM 900 and GSM 180, UMTS, CDMA 2000, WiMAX and LTE radio technologies [10].
The model is based on the formula:

$$P_r = P_t - \{K_1 + K_2\log(d) + K_3\log(h_t) + K_4.Diff\ Loss + K_5\,log(d).log(h_t) + K_6.h_r + K_7\log(h_r) + K_{clutter}.f_{clutter} + K_{hill}\} \quad (12)$$

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:

$$PL\ (dB) = A_1 + A_2log(f) + A_3log(h_t) + [B_1 + B_2log(h_t) + B_3.h_t][log(d)] - a(h_r) - C_{clutter} \quad (13)$$

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:

$$A_1 = \begin{cases} 69.55 & for\ 900\ MHz \\ 46.30 & for\ 1800\ MHz \end{cases} \quad (14)$$

$$A_2 = \begin{cases} 26.16 & for\ 900\ MHz \\ 33.90 & for\ 1800\ MHz \end{cases} \quad (15)$$

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$A_3 = -13.82$
$B_1 = 44.90$
$B_2 = -6.55$
$B_3 = 0$

Thus, for GSM 900,

$$PL\,(dB) = 69.55 + 26.16\,log(f) - 13.82\,log(h_t) + [44.9 - 6.55\,log(h_t)][log(d)] - a(h_r) - C_{clutter} \quad (16)$$

For GSM 1800,

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

II. MATERIALS AND METHODS

A. Terrestrial Description of the Propagation Terrain

Ilorin is one of the largest cities in Nigeria and is the capital of Kwara State. The city is located in the North-Central geo-political zone of Nigeria on Latitude 8°30′N and Longitude 4°33′E. The area under study can be categorized as a suburban environment with narrow streets and moderately high buildings. The buildings and the physical structures present in the propagation have an average height of 9m. Table 1 gives additional information about the land-use morphology of the propagation environment of each sector of the base station.

Table 1: Land-Use Morphology of Investigation Area

Cell Name	Average Altitude (m)	Average Clutter Height (m)
BS2501	326	10
BS2502	342	11
BS2503	331	7

Figure 1 Ariel View of the Propagation Environment

B. 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 [11].

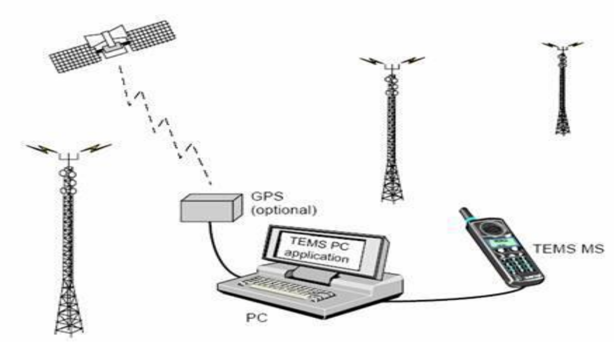

Figure 2 Drive Test Data Collection Set Up

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.

C. 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 enough in order to allow the noise level of the receiver to be reached. The routes covered in this study were Adeta road, Benin road and Oyun road which are within Ilorin City; this gives easy access to the coverage areas of the respective cells investigated.

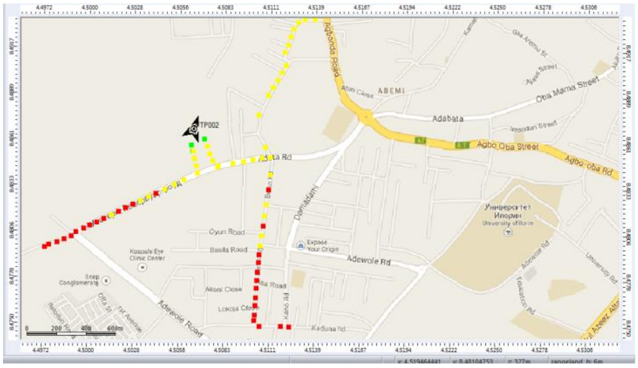

Figure 3 Road Map of the Drive Test Coverage Area

D. Data Sorting and Computations

At least 36 samples were collected over a distance of 40λ to satisfy Lee criterion [12]. 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.

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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 geographic mapping data of Ilorin City imported into the tool as required [13]. The mapping data include the Digital Terrain Map, clutter classes, clutter height and vector maps. The resolution of the map used is 20 m.

Table 2 Network Equipment Parameters

Parameter	Value
Base Station Transmitter Power (P_t)	43 dBm
Base Station Antenna Height (h_b)	30 m
Mobile Station Antenna Height (h_m)	1.5 m
Base Station Antenna Gain (G_b)	18 dBi
Cable Loss (P_c)	2 dB
Combiner Loss (P_{co})	2 dB

$$RSS = P_t + G_b - P_c - P_{co} - Path\ Loss$$

E. Prediction Model Statistical Validation

Mean Error gives the average of the sum of the differences (error) between the field measured values (RSS_m) and the model predicted values (RSS_p).

$$ME = \frac{1}{n}\sum_{i=1}^{n}\left|RSS_m - RSS_p\right|$$

Root Mean Square Error (RMSE) is a frequently used measure of the differences between values predicted by a model and the values actually observed. Basically, the RMSE represents the sample standard deviation of the differences between predicted values and observed values. These individual differences are called residuals when the calculations are performed over the data sample that was used for estimation, and are called *prediction errors* when computed out-of-sample. The RMSE serves to aggregate the magnitudes of the errors in predictions for various times into a single measure of predictive power [14]. The RMSE of predicted values RSS_p for times i of a regression's dependent variable RSS is computed for n different predictions as the square root of the mean of the squares of the deviations:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left|RSS_m - RSS_p\right|^2}$$

In statistics and probability theory, the Standard Deviation (SD) measures the amount of variation or dispersion from the mean error [15]. A low standard deviation indicates that the data points tend to be very close to the mean (also called expected value); a high standard deviation indicates that the data points are spread out over a large range of values. The standard deviation of a random variable, statistical population, data set, or probability distribution is the square root of its variance. It is algebraically simpler though in practice less robust than the average absolute deviation [16].

$$SD = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\left|RSS_m - RSS_p\right| - ME\right)^2}$$

III. RESULTS

A. Comparative Results of the Model Prediction with Field Measured Data

The prediction results of the three empirical propagation models employed in this study were presented graphically. The values of the predicted Received Signal Strength (RSS) and the field measured data were plotted against the distance of separation between the Base Station (BS) antenna and the Mobile Station (MS) antenna. Figure 4 presents the result of the RSS predictions as compared with the radio signal information collected on cell BS2501 propagation environment. The result of the drive test carried out within the coverage area of the cell reported a mean RSS of -71.43 dBm. Mean Received Signal Strength values of -54.35 dBm, -64.13 dBm and -69.24 dBm were predicted by Okumura-Hata model, COST 231-Hata model and Standard Propagation Model respectively.

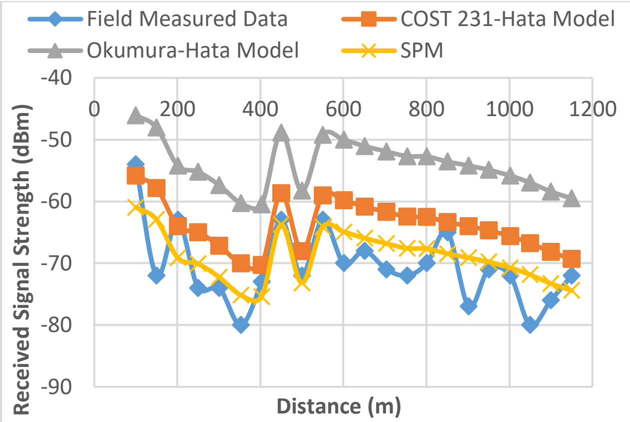

Figure 4 Model Prediction Results with Field Measured Data Obtained on BS2501

Figure 5 shows the radio propagation characteristics of the transmitted signal in the terrain covered by cell BS2502. Okumura-Hata model, COST231-Hata model and Standard Propagation Model predicted mean RSS values of -53.51 dBm, -63.30 dBm and -68.48 dBm respectively. The mean RSS obtained from the propagation environment within the radio coverage of the cell was -79.39 dBm.

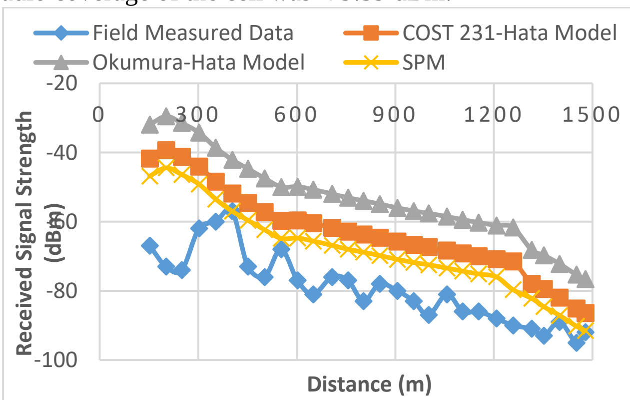

Figure 5 Model Prediction Results with Field Measured Data Obtained on BS2502

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The analysis of the drive test data of the BS2503 as presented in Figure 6 reported that the mean RSS received by the mobile users in that area covered is -80.28 dBm. The predictions of Okumura-Hata model, COST 231-Hata model and Standard Propagation Model gave mean values of -48.8 dBm, -58.59 dBm and -63.68 dBm respectively.

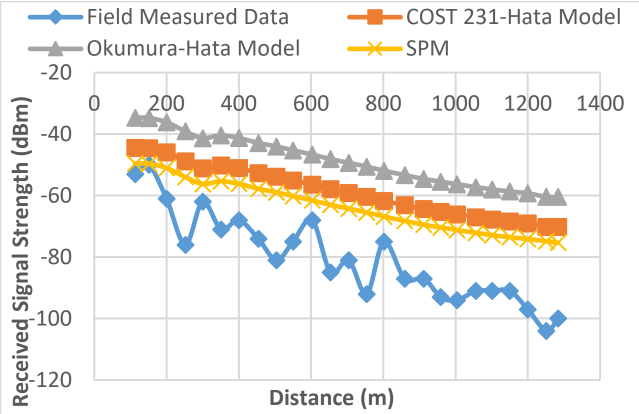

Figure 6 Model Prediction Results with Field Measured Data Obtained on BS2503

The summary of the analyses of the predictions and the field measurement on each of the cell under study is provided in Table 2.

Table 3 Mean Received Signal Strength (RSS) for Ilorin City, Nigeria.

	Mean RSS on BS2501 (dBm)	Mean RSS on BS2502 (dBm)	Mean RSS on BS2503 (dBm)	**Overall Mean RSS (dBm)**
Field Measurement	-71.43	-79.39	-80.28	**-77.03**
Okumura-Hata Model	-54.35	-53.51	-48.8	**-52.22**
COST 231-Hata Model	-64.13	-63.3	-58.59	**-62.00**
Standard Propagation Model	-69.24	-68.48	-63.68	**-67.13**

B. Statistical Analyses of Radio Propagation Prediction Models

Figure 7, 8 and 9 show the results of the statistical analyses of the three empirical prediction models utilized in this research work. These appraise the validity of each of the models on the different propagation terrains of Ilorin City based on the mean error, root mean square error and standard deviation computed.

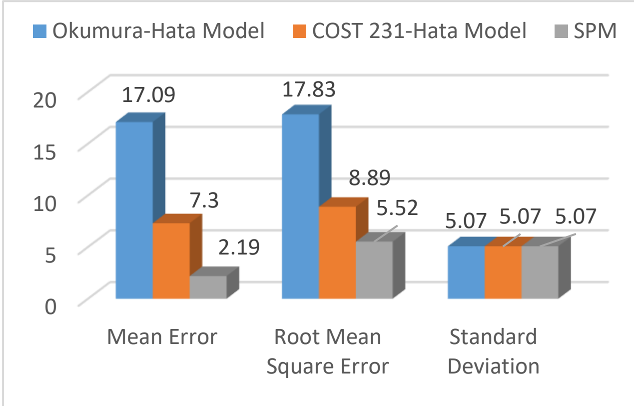

Figure 7 Statistical Model Validation on BS2501

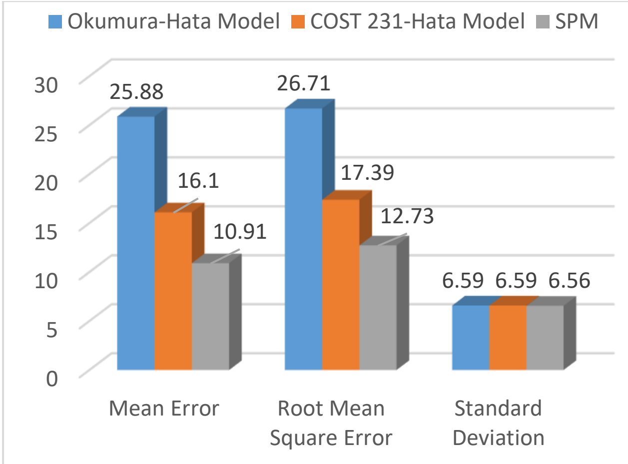

Figure 8 Statistical Model Validation on BS2502

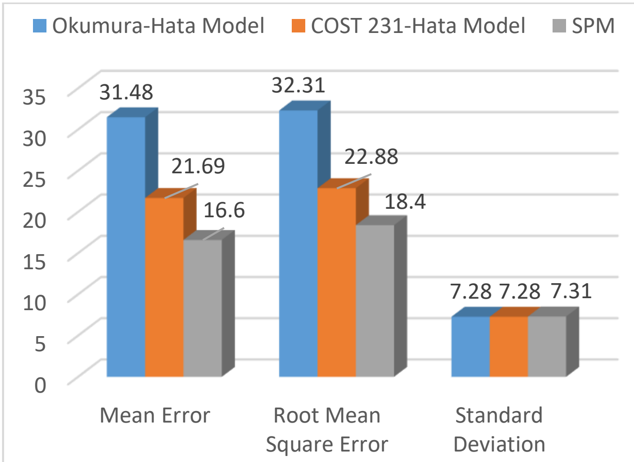

Figure 9 Statistical Model Validation on BS2503

IV. Discussions

The findings of this research showed that all the three empirical propagation prediction models investigated under-predicted the received signal strength of GSM 900 deployed in this area. However, Standard Propagation Model predicted the RSS values with smallest deviations from the actual RSS measured on the 'live' GSM 900 network deployed in the area.

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Okumura-Hata model has the highest RMSE with the field measured data throughout the three coverage area investigated. The model can be applied without correction factors for quasi-smooth terrain in an urban area but in case of other terrain types correction factors are needed. The weakness of the Okumura–Hata model is that it does not consider reflections and shadowing [17]. Similar studies were carried out in Makurdi City situated in the Northern part of Nigeria. Standard Propagation Model was found to be the most suitable model for radio coverage predictions on GSM 900 network in Makurdi City. The model gave the lowest RMSE value of 8.11 dB [18]. This agrees with the findings of this current study on the GSM 900 network deployed in Ilorin City. This can be traced to the fact that both cities are within the same region of the country; they have similar clutter and terrain features. According to [13] and [19], it was reported that COST 231-Hata model and Walfisch-Bertoni model are the most suitable for the urban environment of Lagos Metropolis and the Built-up cities of South-South, Nigeria respectively.

V. Conclusion

Radio propagation is environment-dependent. The performance of different coverage and capacity solutions are thus directly related to factors like land clutter, topography and building heights. The influence of these environmental factors must be emphasized and properly accounted for when radio planning applications are considered. To develop an entirely new path loss model will be time-consuming. Therefore, one of the best possible ways of obtaining a better radio channel characteristics is to optimize the existing path loss models based on the measurement data collected in the specific area. The use of Okumura-Hata model and COST 231-Hata model for radio coverage predictions during radio network planning and initial deployment within this environment will lead to poor Quality of Service (QoS) on the part of the mobile users. The network provider may have to consequently run into business loss due to poor link budget calculations and path loss predictions. This warrant the need for more precise and localized path loss models for an efficient radio network planning and initial deployment of better Quality of Service (QoS) in different terrains. From our study, the Standard Propagation Model was found to be the most suitable of all the three propagation models. This can be considered for radio coverage predictions as part of the essential planning procedures for future GSM 900 network deployment in Ilorin City, Nigeria.

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