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Research Paper

Optimization of COST-231 Hata Radio Propagation Prediction Model for GSM 4G FDD-LTE Operating at 1800 MHz in Tropical Region.

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ABSTRACT: *In mobile radio system, pathloss model is a key factor to be considered for proper planning because the type and profile of the terrain vary significantly in different regions. Therefore, there is no universal empirical model for prediction of the pathloss which is applicable in all propagation environment and scenarios. This studypresents empirical path loss models developed for GSM 4G frequency division duplex- long term evolution (FDD-LTE) microcells operating at 1800 MHz on live GSM Node base station in the urban, suburban, and rural environments in Ibadan, Oyo state, Nigeria (7.401962N, 3.917313E).Propagation measurements were carried out at 1800 MHz for a period of twelve months using Huawei Technologies drive test equipment. The measured pathloss were compared with Ericsson 9999, ITU-R and COST-231 Hata models. The results show that, Ericsson 9999 and ITU-R models overestimated the measured pathloss while COST-231 Hata model gave a betterprediction with measured data but with high RMSE The parameters of this model (COST-231 Hata) are modified based on a linear iterative tuning technique and the results are compared with original model. The optimized models developed reduced the model mean absolute percentage error (MAPE)by 8.25%, 9.72% and 10.11% dB in Urban, Sub-urban and Rural environments respectively. Also, the performance of the tuned models developed gives RMSE of 5.29, 5.62 and 8.59 dB for Urban, Sub-urban and Rural environments respectively, the values falls within the acceptable international standard range. Therefore, the models will be useful for network provider to ameliorate their service for mobile user satisfaction at different environments.*

KEY WORDS: *Empirical models, Enhanced model, GSM 4G, Pathloss, RMSE*

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I. INTRODUCTION

In radio communication, the signal transmitted from the base station to the receiver suffered from pathloss due to multipath and separation distance between the transmitter and receiver. The signal also suffered losses as a result of weather conditions up to an altitude of about 16 km at the equator or 8 km at the poles [1]. Pathloss estimation has been identified as important factor for the effective design of mobile system so as to enhance the performance of the system parameters. Correct prediction techniques areessential in order to determine these parameters that will increase the efficiency of service quality, increase coverage area and determine best base stations arrangement of a specified area [2] [3]. Since the atmospheric conditions and structural pattern of places differ from one another, therefore, there is no universal models for prediction of the pathloss that is fit in all environments and scenarios, which implies that, the path loss prediction models cannot be generalized. This problem can be ameliorate by tuning or adjusting the pathloss model parameters to an acceptable RMSE values taking into account the influence of the specified environment.According to available literatures, the performance of a pathloss model is considered acceptable if it provides an overall RMSE of about 6-7dB for urban areas and 10 -15dBfor suburban and rural areas [4][5][6]. Studies have also shown that, most empirical pathloss models have high prediction errors with RMSE above the given acceptable range for the particular environment being studied. Therefore, model tuning is usually employed to reduce the model prediction error so that the RMSE falls within the acceptable range. Hence, in this work, the results of measured pathloss as well as the enhance models capable of predicting pathloss at 1800 MHz in urban, sub-urban and rural environmentsare presented

II. RADIO PROPAGATION MODELS

The propagation path loss model is an empirical mathematical formulation to characterize behaviour of the radio waves as a function of frequency, surrounding environment and distance. The model describes the average signal propagation and it provides the maximum cell range with respect to the maximum propagation loss. It also depends on the following; Environments (urban, sub-urban and rural), separation distance between Tx and Rx, Frequency of operation, atmospheric conditions, Elevation[7]

2.1 COST-231 Hata Model

This model extended Hata's model to the frequency band $1500\,MHz \leq f \leq 2000\,MHz$ by analyzing Okumura's curves. The model is given as [8]

$$PL = 46.3 + 33.9log_{10}(f) - 13.82log_{10}(h_t) - a(h_m) + \left(44.9 - 6.55log_{10}(h_t)\right)log_{10}d + Cm \qquad (1)$$

where f is the frequency (MHz), d is the separation distance between the TX and RX, *ht* is the transmitter antenna height (m), *hr* is the receiver antenna height (m), *Cm* is the correction factor which has different values for each environment. Cm is 0 dB for rural and sub-urban areas while it is 3 dB for urban environment. The parameter $a(h_m)$ is set according to the type of environment

2.1.1 Rural or Sob-urban Environment

$$a(h_m) = (1.11\,log(f) - 0.7) * (h_t) - (1.56\,log(f) - 0.8) \qquad (2)$$

2.1.2Urban Environment

$$\mathrm{a(h_m) = 8.29[log(1.54h_{ms})]^2 - 1.1 \quad for\ for\ f_c\ \leq 300\ MHz} \qquad (3)$$

$$\mathrm{a(h_m) = 3.201\ (log(11.75h_m))^2 - 4.97 \quad for\ f_c\ \geq 300\ MHz} \qquad (4)$$

2.2 Ericsson 9999 model

This model is implemented by Ericsson as an extension of the Hata model. Hata model is used for frequencies up to 1900 MHz. In this model, the parameters can be adjusted according to the given scenario, this model is given as [9][10]

$$\mathrm{PL = a_0 + a_1 log_{10}(d) + a_2 log_{10}(h_b) + a_3 log_{10}(h_b).log_{10}(d) - 3.2\left(log(11.75)\right)^2 + g(f)} \qquad (5)$$

where$\mathrm{h_b}$ is the Transmitter antenna height(m), $\mathrm{h_r}$ = Receiver antenna height(m), g(f)is defined as

$$\mathrm{g(f) = 44.51log_{10}(f) - 4.79\left(log_{10}(f)\right)^2} \qquad (6)$$

The parameters $\mathrm{a_0}$, $a1$, a_2 and a_3 are constants, and can be change for better fitting specific propagation conditions. Default values are:$a_0\ =\ 36.2,\ a_1 = 30.2,\ a_2 = -12\ and\ a_3 = 0.4$.

2.3ITU-R Model

The ITU-R model is to be used for the outdoor to indoor and pedestrian (microcell) in urban and suburban environment,it is given as [11] [12]:

$$PL = 40 \log d + 30 \log f_c + 49 \qquad (7)$$

where: d is the distance between the base station and the mobile unit in km, fc is the frequency to 2000 MHz. The model is for Non-Line of Sight (NLOS) case only and describes worst condition deviation of 10dB for outdoor users.

III. MATERIALS AND METHOD.

3.1 Measurement campaign and procedure

Measurement of radio signal strength was conducted within Ibadan Metropolis (urban environment), Ibadan less city (suburban) and at a village around Ido local government (rural environment). A drive test was conducted to capture the signal strength using Samsung I9500 Galaxy S4 and hand-held spectrum analyzer. This mobile equipment has CellMapper and MyGPS coordinates android applications installed. The signal data captured by the CellMapper comprises the GSM 4G frequency division duplex- long term evolution (FDD-LTE) current and neighboring cells' RSS in decibels (dB).The current cell's ID (CID) and local area code (LAC) operating at 1800 MHz band which is one of the principal bands for the deployment of the LTE and LTE-Advanced. The received signal strength was noted and recorded concurrently with the latitude and longitude at each point,the measured signal strengths were converted to pathloss using the relation (8)

$$PL(dBm) = P_{BS} + G_{BS} + G_{MS} - L_{FC} - L_{AB} - L_{CF} - RSS\ (dBm) \qquad (8)$$

where P_{BS} is the transmitter power (43 dBm), G_{BS} is the transmitter antenna gain (12 dBi), G_{MS} is the receiver antenna gain (0 dBi), L_{FC} is feeder cable and connector loss (2 dB), L_{AB} = Antenna Body Loss (4 dB), and L_{CF} = Combiner and Filter Loss (4.5 dB). Therefore, equation (8) becomes

$$PL(dBm) = 44.5 - RSS\ (dBm) \tag{9}$$

A Garmin Digital Global Positioning System (GPS) was used to determine the separation distance (d) from the Base Station (BS) to the receiver.

The measured data were compared with empirical propagationmodels proposed by (Ericcson 9999, COST-231 Hata, and ITU-R) in order to determine the best model for pathloss prediction in this study area. To evaluate the performance of different models and the optimized model, two statistical tools(MAPE and RMSE) were chosen as metrics [13]. These were determined by comparing the predicted path loss with the measured data using (10) - (12) respectively.

The enhancement process was realized through the use of Least Square Algorithm taking into account the initial offset parameters and the slope of the model curve in Cost-231 model for the process.

$$\mathrm{MAPE} = \frac{1}{\mathrm{N}}\sum_{\mathrm{i}=1}^{\mathrm{N}}\left|\frac{\mathrm{P_{mt}} - \mathrm{P_{pt}}}{\mathrm{P_{mt}}}\right| \times 100\% \tag{10}$$

$$\mathrm{RMSE} = \sqrt{\frac{\Sigma\left(\mathrm{P_m} - \mathrm{P_p}\right)^2}{\mathrm{N}}} \tag{11}$$

$$\mathrm{MABE} = \sum_{\mathrm{i}=1}^{\mathrm{N}}\frac{\left|\mathrm{P_m} - \mathrm{P_p}\right|}{N} \tag{12}$$

3.2 COST-231 Hata Optimization Model (Least Square Algorithm)

Model enhancement or optimization is a set of procedures in which an empirical radio propagation model is modified using measured values obtained from measurement campaign. In this study, least square algorithm method was used to optimized the model[14]. The enhancement procedure is as follows: The COST-231 Hata model shown in equation (1) was divided into three parts as expressed by (13), (14) and (15) for proper optimization.

$$E_o = 46.3 - ah_m + C_m \tag{13}$$

$$E_{sys} = 33.9log_{10}f - 13.82log_{10}h_b \tag{14}$$

$$\beta_{sys} = (44.9 - 6.55log_{10}h_b)log_{10}d \tag{15}$$

where E_o is the initial offset parameter, E_{sys} is the initial system design parameter, βsys is the slope of the model. From the above expressions, the total pathloss model is given as [14]

$$PL = E_o + E_{sys} + \beta_{sys}.\ log_{10}d \tag{16}$$

For enhancement process, let $a = E_o + E_{sys}$ and $b = \beta_{sys}.log_{10}d$ Equation (1) can then be written as

$$PL = a + b\ log_{10}d \tag{17}$$

with $log_{10}d = x$, equation (17) becomes

$$PL = a + bx \tag{18}$$

The parameters a and b are constants for a given experimental values. The least square algorithm [18, 19] satisfying the best fit of experimental data is;

$$E_P(a, b, c, \ldots.) = \sum_{i=1}^{n}[y_i - F_R(x_i, a, b, c, \ldots)]^2 \tag{19}$$

where $F_R(x_i, a, b, c, \ldots)$ is the pathloss predicted by the model at various distance, x, based on enhancement; y_i is the measured pathloss values at distance x_i; $E_P(a, b, c, \ldots.)$ is the error function and a, b, c are the parameters of the model based on enhancement. The error function must be minimal; this is achieved by ensuring all partial differential of error function are zero as shown below;

$$\frac{\partial E}{\partial a} = 0\,, \quad \frac{\partial E}{\partial b} = 0\,, \quad \frac{\partial E}{\partial c} = 0$$

The error function with respect to parameter a is given as;

$$\frac{\partial E}{\partial a} = 0 \tag{20}$$

Substitute equations (18) and (19) into (20)

$$\frac{\partial}{\partial \mathrm{a}}[\mathrm{y_i} - (\mathrm{a} + \mathrm{bx_i})^2] = 0 \tag{21}$$

$$\frac{\partial}{\partial \mathrm{a}} = \left(\sum_{\mathrm{i}=1}^{\mathrm{n}} [\, \mathrm{y_i} - (\mathrm{a} + \mathrm{bx_i})^2] \right) = 0 \tag{22}$$

When equation (22) is reposition, expression (23) is obtained

$$\mathrm{na} + \mathrm{b} \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x_i} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{y_i} \tag{23}$$

From equation (23), the parameter a in terms of b is expressed as;

$$\mathrm{na} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{y_i} - \mathrm{b} \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x_i} \tag{24}$$

$$\mathrm{a} = \frac{\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{y_i} - \mathrm{b} \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x_i}}{\mathrm{n}} \tag{25}$$

In the same way, the partial differential of error function with respect to parameter b can be expressed as [19]

$$\mathrm{a} \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x_i} + \mathrm{b} \sum_{\mathrm{i}=1}^{\mathrm{n}} (\mathrm{x_i})^2 = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x_i y_i} \tag{26}$$

The parameter b can be obtained from equation (26) as;

$$\mathrm{b} \sum_{\mathrm{i}=1}^{\mathrm{n}} (\mathrm{x_i})^2 = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x_i y_i} - \mathrm{a} \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x_i} \tag{27}$$

$$\mathrm{b} = \frac{\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x_i y_i} - \mathrm{a} \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x_i}}{\sum_{\mathrm{i}=1}^{\mathrm{n}} (\mathrm{x_i})^2} \tag{28}$$

The statistically tuned average parameters $\bar{a}$ and $\bar{b}$ are obtained by substituting the variable a and b into equations (25) and (28), this is described as:

$$\bar{a} = \frac{\sum_{i=1}^{n} (x_i)^2 - \sum_{i=1}^{n} y_i \times \sum_{i=1}^{n} x_i}{\sum_{i=1}^{n} (x_i)^2 - (\sum_{i=1}^{n} x_i)^2} \tag{29}$$

$$\bar{b} = \frac{N \sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} y_i \times \sum_{i=1}^{n} x_i}{N \sum_{i=1}^{n} (x_i)^2 - (\sum_{i=1}^{n} x_i)^2} \tag{30}$$

IV. RESULTS AND DISCUSSION

4.1 Drive test results

Figures 1,2 and 3 showthe trends of pathloss with distance in urban, sub-urban and rural environment. It also depicts the simulations of empirical models considered (Ericsson 9999, ITU-R and COST-231 Hata) as well as optimized COST-231 Hata obtained for the three environments, the optimization was carried out by appropriate tunng of the parameters of the model. In urban environment, higher average pathloss was obtained (138.6 dB) compared to other scenarios. The variation in the experimental pathlosswas attributed to many obstructions like different tall buildings in the route which is in close proximity that leads to diffraction of radio signal and eventually increases the pathloss. It was noted that, in sub-urban area, the sudden rise of pathloss with average value (130.6 dB)was attributed to a sharp turn around a building at that particular location. Also, the fluctuations of pathloss was attributed to shadowing, reflection, diffraction or scattering due to the presence of few trees. For the rural environment, the presence of thick vegetation and hills might be responsible for the radio pathloss with mean value (126.2 dB).The results further revealed that, Ericsson-9999 model overestimated the measured pathloss having the highest predictions for the three environments (Urban, sub-urban and rural) with RMSEs of 12.87, 16.51 and 21.62 dB respectively. ITU-R model also overestimated the measured pathloss for the three environments (Urban, sub-urban and rural) environment with RMSEs of 23.53, 27.17 and 32.26 dB respectivelywhile COST-231 Hata model is in fairly good agreement with measured path loss as shown in Table 4.

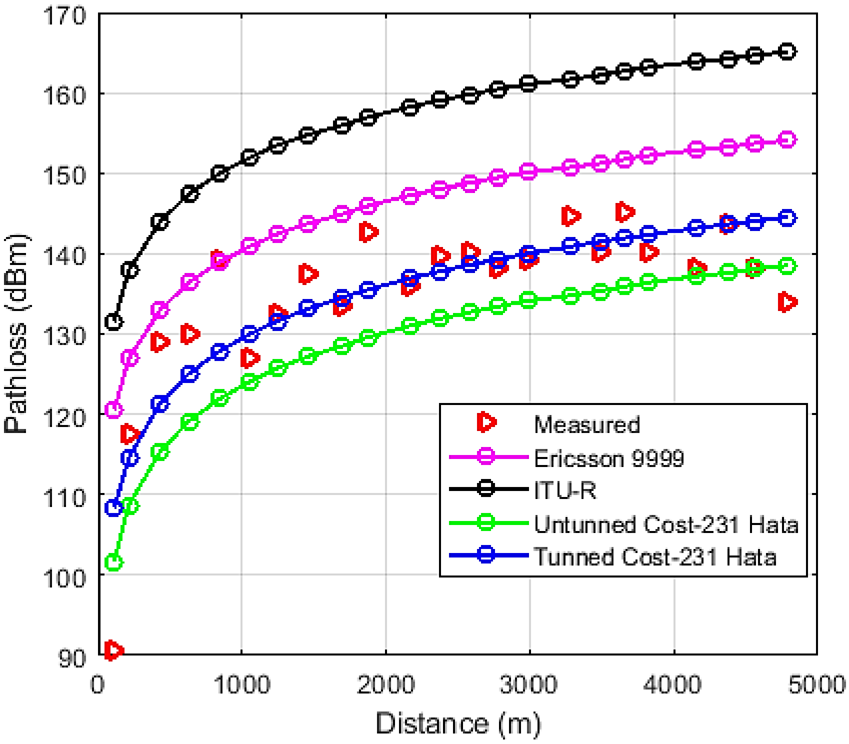

Fig. 1: Comparison of measured pathloss, empirical and tuned models for Urban environment

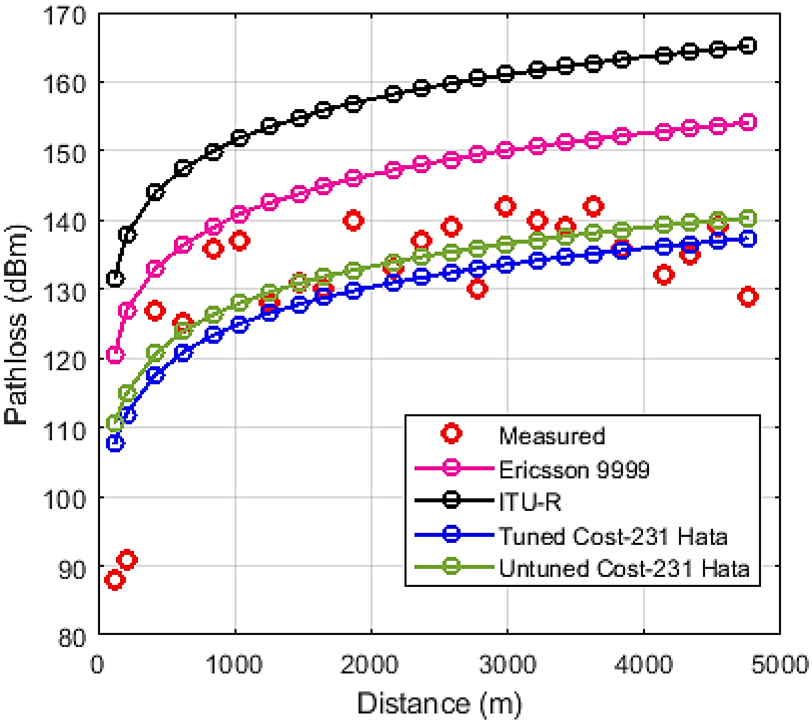

Fig. 2: Comparison of measured pathloss, empirical and tuned models for Sub-urban environment

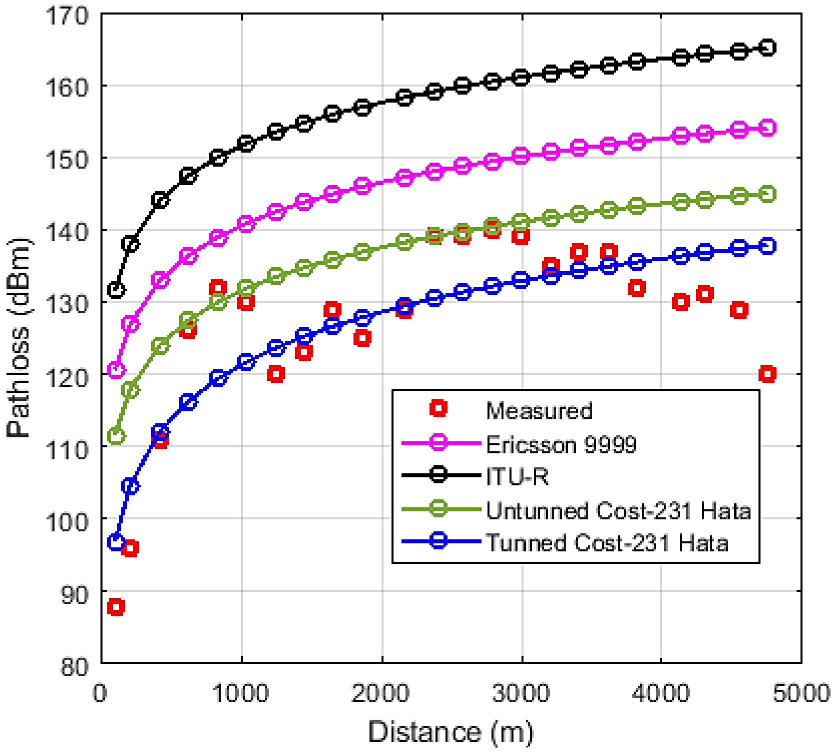

Fig. 3: Comparison of measured pathloss, empirical and tuned models for rural environment

4.2 Optimization of Cost-231 Model

The Ericsson-9999 and ITU-R models generally predicts the path loss in the tested areas with RMSEs higher than the acceptable range (Wu and Yuan, 1998) [17]. Hence, they are not suitable for radio pathloss prediction in these understudy environments. For correct pathloss prediction in these environments, it is necessary to enhance COST-231 Hata model, the enhancement procedure is shown in 3.2 above.The enhanced statistical parameters obtained using equations (29) to (32) are shown in Table 3

Table 3: COST-231 Hata enhancement parameters.

Environment	Parameters			
	$abE_o\beta$			
Urban	123.412	0.00474	30.18	0,0000771
Sub-urban	122.794	0.00144	37.56	0.0000234
Rural	114.893	0.00511	29.66	0.0000831

The enhanced parameter values of E_o for rural, sub-urban and urban environments were introduced into COST 231-Hata model and thus the improved COST 231-Hata model are shown in equation (33), (34) and (35) respectively. The comparison of the COST-231 Hata model before and after enhancement shows that equation (1) has to be changed as follows:

For rural environment;

$$PL = \mathbf{29.66} + 33.9log_{10}(f) - \ 13.82log_{10}(h_t) - a(h_m) + \left(44.9 - 6.55log_{10}(h_t)\right)log_{10}d + 0 \qquad (33)$$

For sub-urban environment;

$$PL = \mathbf{37.56} + 33.9log_{10}(f) - 13.82log_{10}(h_t) - a(h_m) + \left(44.9 - 6.55log_{10}(h_t)\right)log_{10}d + 0 \qquad (34)$$

For urban environment;

$$PL = \mathbf{38.18} + 33.9log_{10}(f) - 13.82log_{10}(h_t) - a(h_m) + \left(44.9 - 6.55log_{10}(h_t)\right)log_{10}d + 3 \qquad (35)$$

where *f* is the frequency (MHz), *d* is the separation distance between the TX and RX, *ht* is the transmitter antenna height (m), *hr* is the receiver antenna height (m), *Cm* is the correction factor which has different values for each environment. Cm is 0 dB for rural and sub-urban areas while it is 3 dB for urban environment. The parameter $a(h_m)$ is set according to the type of environment

The deviation of experimental path loss from the empirical and optimized models have been expressed in terms of performance measurement metrics using MAPE and RMSE for each environment understudy. The performance metrics were obtained using equations (10) and (11) respectively and this gave the deviation in mean rather than taking instance points in each distance. As presented in Table 4,the RMSE obtained for COST-

231 Hata model in Urban, Sub-urban and Rural environments were 6.05, 5.88 and 12.91 dB respectively with MAPE 5.56, 4.03 and 8.07 %, respectively while the RMSE obtained for optimized models in Urban, Sub-urban and Rural environments were 5.29, 5.62 and 8.59 dB respectively with MAPE 3.46, 3.55 and 4.88 %, respectively. a significant reduction in the RMSEs and MAPEs obtained indicates that the optimized model is valid. Hence, the optimized model gave better results as compared to the existing COST-231 Hata model.

Table 4: Performance analysis of the models at different environments

Environment	COST-231 Hata model		Tuned COST-231 Hata model	
	MAPE (%)	RMSE (dB)	MAPE (%)	RMSE (dB)
Urban	3.56	6.03	3.46	5.29
Sub-urban	4.03	5.88	3.55	5.62
Rural	8.07	12.91	4,88	8.59

4.3 Validation of the Optimized model

The optimized path loss model for each environment understudy was applied for path loss estimation so as to validate its performance. The result revealed that all the environmentsconsidered fit into the enhanced model with lower RMSE as depicts in figure 4. From the available literature, the performance of any pathloss model is considered acceptable if it provides an overall RMSE of 6 -7 dB for urban areas and 10 - 15 dB for suburban and rural areas [4]., [4]., [6]. From the results obtained as depicts in figure 4, the enhanced pahtloss model gave the best performance and good agreement for the entire study environments (rural, sub-urban and urban)compared with COST-231 Hata model and other models.

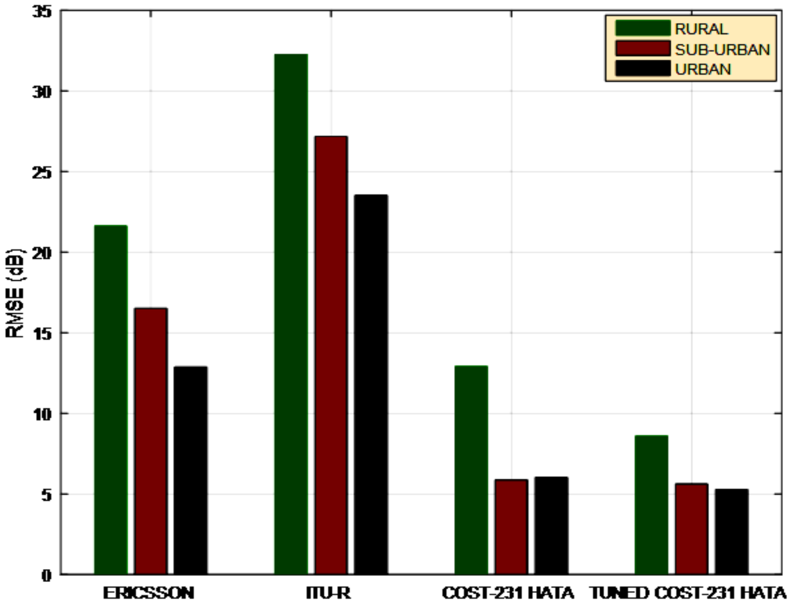

Figure 4: RMSE for all the empirical models at different environments

V. CONCLUSION

Statistical enhancement of COST-231 model for link budget design and analysis using a least square algorithm based on existing pathloss model is presented.The study is based on the outdoor field measurements in urban, suburban and ruralenvironments for a GSM 4G (FDD-LTE) mobilenetwork operating at 1800 MHz frequency band.The measured pathloss and predicted models for different environments (Urban, Sub-urban and Rural) are discussed. Also, the enhanced model is compared with empirical models (Ericsson, ITU-R and COST-231 Hata models) in terms of RMSE and MAPE.The study revealed that, COST-231 Hata models in the three environments shows a good agreement in terms of RMSE analysis and pathloss exponent. From the statistical error analysis, it was discovered that, the performance of the optimized models developed gives a RMSE of 5.29, 5.62 and 8.59 dB for Urban, Sub-urban and Rural environments respectively compared to COST-231 Hata model with RMSE 6.03, 5.88 and 12.91 dB for Urban, Sub-urban and Rural environments respectively. The enhanced models developed reduces the model prediction error and the RMSE falls within the acceptable international standard range. Therefore, the models shall be useful for network provider to ameliorate their service for better capacity and mobile user satisfaction at different environments

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