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Selection and Optimization of Most Suitable Path Loss Prediction Model for Suburban City in Nigeria Using Spline Interpolation

A. Danladi[1], N. W. Silikwa[1*], K. G. Gaya[1] and A. H. Augustine[1]

[1] *Department of Pure and Applied Physics, Adamawa State University, Mubi, Nigeria.*

Authors' contributions

This work was carried out in collaboration between all authors. Author AD designed the study, developed path loss prediction spline interpolation model, wrote the protocol and the first draft of the manuscript. Authors NWS, KGG and AHA managed the literature searches and proof read the manuscript, before all authors approved the final manuscript.

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ABSTRACT

Path loss is an attenuation of Global System for Mobile Communication (GSM) signal between Base Transceiver Station (BTS) and Mobile Station (MS). Path loss helps network engineers in planning, designing and implementing telecommunication networks. This work examines the applicability of Hata, COST 231, ECC – 33, Ericsson and SUI models in a medium city (Mubi) in Adamawa State, Nigeria. Root mean square error (RMSE) between the measured and the predicted losses (output of the models) is obtained as 7.632dB, 14.736dB, 10.593dB, 0.639dB and 23.491dB respectively. Ericsson model is found to have the least RMSE. Therefore, it is selected as the best fit model and modified. Furthermore, the modified model is optimized to recover missing or to eliminate unwanted information in the radio path using spline interpolation. The optimized model can be employed for the deployment of network resources in suburban areas of Nigeria, especially in Mubi town in Adamawa State, in order to significantly enhance GSM signal QoS. It is recommended that fuzzy logic and spline interpolation techniques may be integrated and employed to further minimize the error obtained in this work.

**Corresponding author: E-mail: alishalangwa@gmail.com;*

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1. INTRODUCTION

Path loss is one of the major tools that network engineers use to predict the behavior of radio channel, especially, the network coverage area, signal losses between the BTS and MS. In a nutshell, network engineers make use of path loss models to optimize their network resources [1,2]. Path loss is usually modeled based on the characteristics of the environment of interest, such as terrain of the area, vegetation, human activities and other parameters which include BTS and MS location, distance between the antennas, BTS height and gain, MS height and gain. The above-mentioned factors if not well managed can tremendously reduce the spectral efficiency or the quality of service (Q_0S) of the global system for mobile telecommunication (GSM) received by the subscribers [3]. In addition, MSs are free to move randomly within the coverage area which makes the network topology dynamic. The movement of MSs may not be free from transmission impairment [4], which in turn will lead to the loss of network Q_0S. This work proposes to examine the applicability of different path loss models in the study area such as Hata, Cost 231, ECC-33, Ericson and Standard University Interim (SUI) models in suburban area in Nigeria, especially in Mubi in Adamawa State. The following changes shall be addressed, to compare the predicted (output of the models) and measured path losses, select and optimize the best fit model by determining the root mean square error (RMSE) between the predicted and measured path losses, modify the selected model using RMSE value and apply spline interpolation on the modified path loss to recover missing or eliminate the unwanted information in the radio path. However, the contribution of this work lies within the concept of upgrading the efficiency of a complex radio channel in a suburban area, (i.e., by improving Q_0S receives by the MS). Usually, path loss starts with free space. This is where the GSM signal strength is not affected by reflection, refraction or absorption. Free space increases as frequency is raised as well as the distance.

The BTS radiates power uniformly over a considered area $\left(4\pi d^2\right)$ given by

$$P_{BTS} = 4\pi d^2 S \tag{1}$$

also, $P_{MS} = SA$ (2)

where S is the power density of the covered area and P_{MS} is the power density captured by the MS. In fact, for hypothetical receiving MS antenna the aperture (A) of the effective area is given by

$$A = \frac{\lambda^2}{4\pi} \tag{3}$$

by substituting Eqs. (1) and (3) into Eq. (2) yields

$$P_{MS} = P_{BTS}\left(\frac{\lambda}{4\pi d}\right)^2 \tag{4}$$

$$L = P_{BTS} - P_{MS} \tag{5}$$

Combining and solving Eqs. (4) and (5) give Eq. (6) in terms of logarithm as

$$L = 20\log_{10}(4\pi) + 20\log_{10}(d) - 20\log_{10}(\lambda) \tag{6}$$

Eq. (6) may be further simplified as given in Eq. (7)

$$L = 32.4 + 20\log_{10}(d) + 20\log_{10}(\lambda) \tag{7}$$

where *L* is the path loss, λ is the wavelength and d is the link distance between the BTS and the MS respectively [5]. Eq. (7) is the general path loss model. However, Eq, (7) can be adopted by different authors and modified for it based on the empirical data of the study area. (e. g, HATA, COST 321, ERICSSON, SUI and ECC are obtained from Eq. (7)). Furthermore, the characteristics of the models mentioned above shall be discussed.

1.1 Hata Model

Hata model requires that BTS should be higher than the adjacent roofs; operating frequency, from 150Hz-1500 MHz, MS height from 1m - 10m, BTS height from 30m - 200m and link distance (d) from 1km - 20km [6, 7]. Hata model is given by expression Eq. (8)

$$\begin{gathered} L = 69.55 + 26.16\log_{10}(f_c) - \\ 13.82\log_{10}(h_b) + a(h_m) + (44.9 - \\ 6.55\log_{10}(h_b))\log_{10} d - 2\left\{\log_{10}\left(\frac{f_c}{28}\right)\right\}^2 \end{gathered} \tag{8}$$

where 'f_c' is the operating frequency, 'h_b' is the BTS height, 'h_m' is the MS height, and '*$a(h_m)$*' is the antenna correction factor provided by

$$a\left(h_m\right)=\left\{1.1\log_{10}\left(f_c\right)-0.7\right\} h_m-\left\{1.56\log_{10}\left(f_c\right)-6.8\right\} \tag{9}$$

1.2 COST 231 Model

This model is the modification of Hata model aimed to improve the network $Q_O S$ and it is characterized by the following parameters such as link distance up to 20,000 m, frequency (150 - 2000 mHz), BTS height (30 m – 200 m) and MS height (1m - 10m), and is given by

$$L = 46.3 + 33.9\log_{10}\left(f_c\right) - 13.82\log\left(h_b\right) - a\left(h_m, f_c\right) + \left[44.9 - 6.55\log\left(h_b\right)\right]\log d + C \tag{10}$$

$$a\left(h_m, f\right) = \left(1.1\log\left(f\right) - 0.7\right)h_m - \left(1.56\log\left(f\right) - 0.8\right) \tag{11}$$

where 'C' is the propagation constant and '$a\left(h_{m,} f_c\right)$' is antenna correction factor for rural to suburban cities. Normally, 'h_m' must be proportional to the coverage area [8,9].

1.3 Ericson Model

Ericson model is also, an adjustment of Hata model. In this case, the model is studied according to the influence of the propagation parameters, such that,

$$L = a_o + a_1\log\left(d\right) + a_2\log\left(h_b\right) + a_3\log\left(h_b\right)\log\left(d\right) - 3.21\left(\log\left(11.75h_m\right)\right)^2 + g\left(f_c\right) \tag{12}$$

$$g\left(f_c\right) = 44.49\log\left(f_c\right) - 4.78\left(\log\left(f_c\right)\right)^2 \tag{13}$$

$a_o = 36.2, a_1 = 30.2, a_2 = -12$, $a_3 = 0.4$ are the propagation constants of suburban cities. In fact, the parameters change for specific propagation conditions [7]

1.4 SUI Model

The model was obtained by the Institute of Electrical and Electronics Engineering (IEEE) 802.16 broadband wireless access group. The model was obtained by optimization of Hata's model. In particular, frequency upgrades to 1900 Hz. Its propagation parameters are restricted to BTS height between 10 m – 80 m, MS height from 2 m to 10 m, link distance from 100-8000 m and frequency (0 - 3500 MHz). SUI model is denoted by Eq. (14)

$$L = A + 108\log\left(d/d_o\right) + X_f + X_n + K \tag{14}$$

'A' is the BTC aperture, 'd_o' the free space distance, '*K*' is the propagation constant, '*X_f*' and '*Xn*' are the lognormal or Gaussian distributions or the factors that account for the slow or shadow fading due to the vegetation and other clusters which must lie between 8.2dB to 10.6dB. A change in the terrain and clusters may be defined by equations (15-19)

$$A = 20\log_{10}\left(4\pi d_o\right) \tag{15}$$

$$K = u - vh_b + w/h_b \tag{16}$$

$$X_f = 6\log\left(f/2000\right) \tag{17}$$

$$X_h = -10.8\log\left(h_m/2000\right) \tag{18}$$

$$X_h = -20.0\log_{10}\left(h_m/2000\right) \tag{19}$$

K depends on the nature of terrain, where 'u', 'v', 'w', are constants that also depend on the terrain. For example, terrain with hilly moderate/dense trees, terrain with hilly/light/moderate/dense trees and terrain with flat/height tree density correspond to different cases [10].

1.5 ECC-33 Model

ECC – 33 was obtained from the optimization of Okumura - Hata model by the electronic communication committee (ECC). The model is characterized by the following features, link distance (100 m – 8000 m), frequency up to 3500 MHz, BTS height (10 m – 80 m), MS height (2 m – 10 m) and is given by

$$L = A_s + A_m - G_b - G_m \tag{20}$$

where 'A_s' is the free space attenuation factor, 'A_m' is the median path loss, G_b is the BTS gain and 'G_m' is the MS gain [11].

$$A_s = 92.4 + 20\log_{10}(d) + 20\log_{10}(f_c) \tag{21}$$

$$A_m = 20.41 + 9.83\log_{10}(d) + 7.894\log(f_c) + 9.56\left[\log_{10}(8)\right]^2 \tag{22}$$

2. STUDY AREA

Mubi town is a suburban city located at latitude 9.27^{0}N and longitude 13.25°E. The city is approximately 10 km in diameter and is characterized by short buildings, typically of height below 30 m. It has indigenous trees scattered around the city with a height of roughly 20 to 25 m [12 - 14] and several roads with moderate width from 10m to 15 m.

2.1 Method of Data Collection

Data is collected using path loss link planner software installed on a personal computer (PC). The PC is mounted on a car to transverse within the city from 1000 m – 6000 m away from the 'h_b' in order to measure the path loss. This measurement was carried out for a period of thirty days. The measurement was taken at a regular interval of '50 m'. At the time of the measurements, the weather condition was clear and all the measurements were conducted in the afternoon from 12:00 noon when all human activities were at the peak. The average measured path loss (L_m) and the predicted path losses (L) obtained from model equations mentioned earlier, are plotted against distance as presented in Fig. 1.

2.2 Determination of Root Mean Square Error

The root mean square error (RMSE) of the measured path loss and the predicted path loss of each model is computed using Eq. (23)

$$RMSE = \sqrt{\sum_{i=1}^{n}\left(\frac{L_m - L}{n}\right)^2} \tag{23}$$

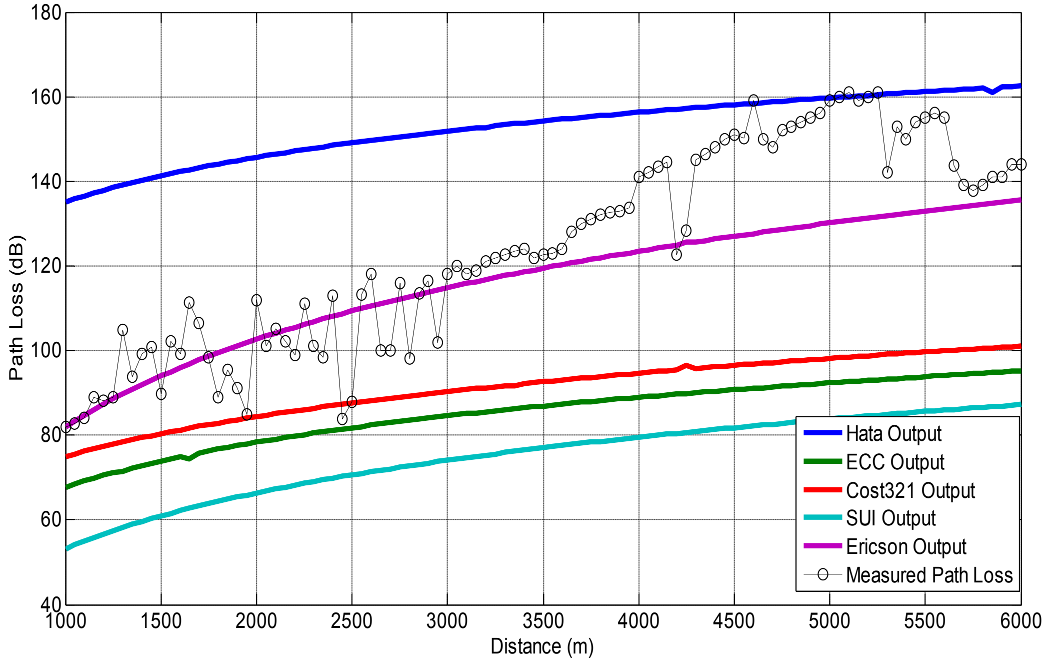

Fig. 1. Average path loss measured vs predicted path loss

where n is the number of the data set, ‘L_m’ is the measured path loss and, ‘L’ is the predicted path loss [4]. The best fit model shall be selected and modified.

2.3 Smoothing Spline Interpolation

The output of the modified model is then interpolated using Eq. (24) which is:

$$I = \rho \sum W\left(h_b - S\left(h_m\right)\right)^2 + \left[1 + \rho \int \left(\frac{d^2}{(dX)^2}\right)\right] dX \tag{24}$$

where ‘ρ’ is the piecewise interpolation parameter, ‘W’ is the weight of data measured, ‘S’ is a smoothing parameter and ‘X’ is the modified path loss [14]. The RMSE of the modified path loss and spline interpolated values is obtained using (25):

$$RMSE = \sqrt{\sum_{i=1}^{n} \left(\frac{X - I}{n}\right)^2} \tag{25}$$

where ‘I’ is the interpolation values

3. RESULTS AND DISCUSSION

Fig. 1 displays the average measured and predicted path losses. As can be noticed, when the distance increases, the path loss augments as reported by many authors [1-3]. The RMSE obtained using Eq. (23) of the predicted and the measured path losses are summarized in Table 1.

Table1. Root mean square obtained between the measured and the predicted path losses

Models	RMSE
Hata	7.632
COST321	14.736
ECC	10.593
SUI	23.491
ERICSON	0.639

As shown in Table1, the Ericson model has the lowest RMSE, followed by the Hata model and SUI reveals poor relationship with the measured path loss. Therefore, the Ericson model is selected as the best fit model. The latter model is modified using the RMSE = 0.639 as supplied by Eq. (26). Then, the modified path loss is compared with the predicted path loss found from the Ericson model as depicted in Fig. 2 which highlights that the path loss is minimized in the study area.

$$L = 35.36 + 30.2\log(d) - 12\log(h_b) + 0.4\log(h_b)\log(d) - 3.21(\log(11.75h_m))^2 + 44.49\log(f) - 4.78(\log(f))^2 \tag{26}$$

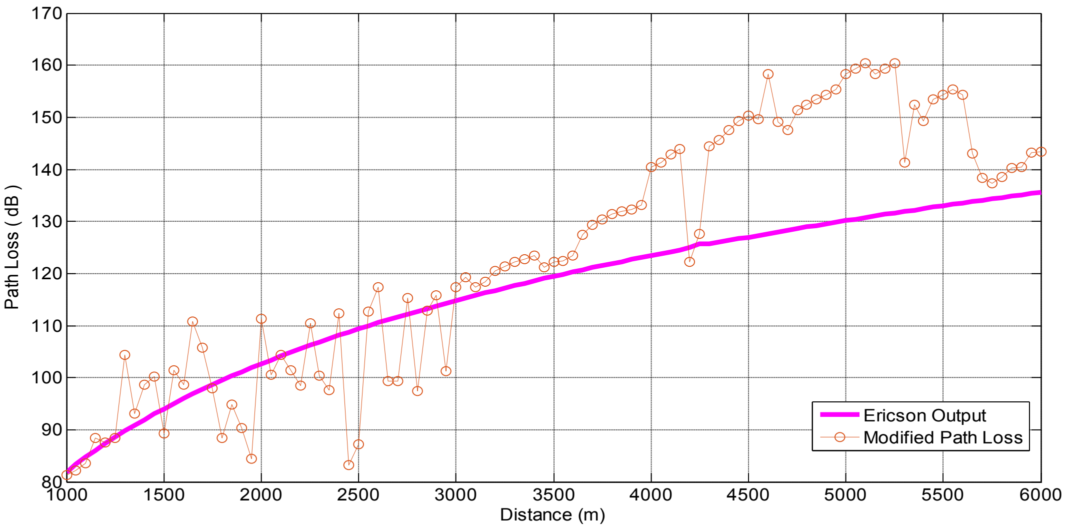

Fig. 2. Modified path loss, predicted path loss (Ericsson model output) against distance

Furthermore, the modified path loss is interpolated using the spline interpolation to further reduce the propagation error, recover missing data or eliminate unwanted signals as pointed out in Fig. 3. Eq. (26) is optimized using the RMSE = 4.516 gotten from Eq. (25). The optimized model is furnished by Eq. (27).

$$L = 31.03 + 36.2\log(d) - 12\log(h_b) + 0.4\log(h_b)\log(d) - 3.21(\log(11.75h_m))^2 + 44.49\log(f) - 4.78(\log(f))^2 \tag{27}$$

The optimized and the measured path losses are compared as brought up in Fig. 4. It is clearly illustrated that the path loss is minimized in the study area.

Several authors attempted to optimize the path loss in different environments as summarized in Table 2.

Table 2 shows diverse methods, environments, error techniques and modified models. It also compares methods for evaluating path loss in different environments and error techniques. It can be seen that, in this work, the propagation error obtained is less than what is reported by Atanarsor et al. 2017, Akinwole et al. 2017, Obat et al. 2013 and Nadir et al. 2008 by 19.47dB, 11.999dB, 3.269dB and 10.179dB respectively. This difference may be attributed to the choice of the method utilized in evaluating error, the complexity of the environments like the terrain, the vegetation, the human activities, the flat surfaces and the nature of the buildings (cities) in the study area.

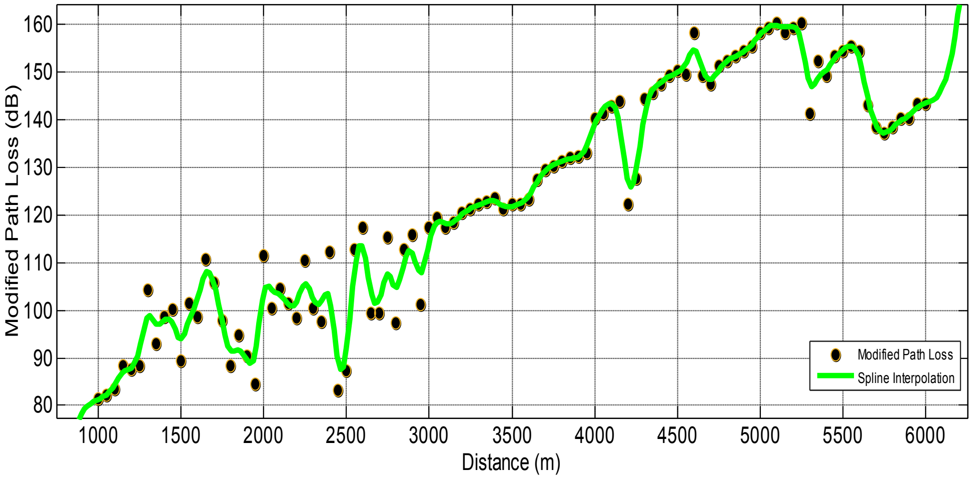

Fig. 3. Spline interpolation of the modified path loss

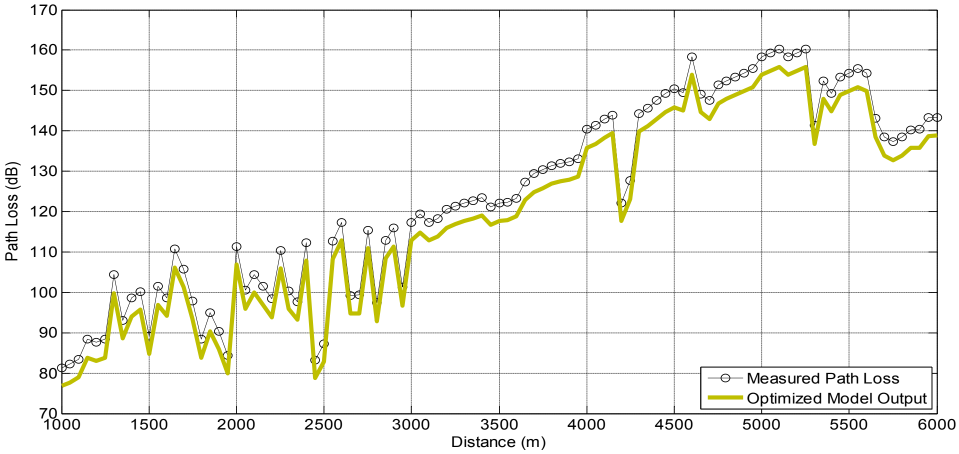

Fig. 4. Comparison of the optimized and the measured path losses

Table 2. Comparison of methods of path loss evaluation

Authors	Year	Environment	Method	Error technique	Model modified
Danladi et al	2018	Suburban	Spline Interpolation	RMSE = 5.131	Ericson
Atanarsor et al	2017	Urban	Statistical	RMSE = 24.60	Ericson
Akinwole et al	2013	Suburban	Statistical	MSE = 17.16	COST 231
Obot et al	2011	Urban	Statistical	MSE = 8.400	Egli
Nadir et al	2008	Urban	Spline Interpolation	RMSE = 15.31	Okumura - Hata

4. CONCLUSION

The path loss is expressed as the signal strength loss between the BTS and the MS. Its significant increase reduces the spectral efficiency as well as the QoS of the GSM network. Understanding path loss of a specific area helps the network engineers to manage their network resources properly. In this work, selection and optimization of the most suitable model for path loss prediction in suburban area are proposed. Applicability of the five models is examined on the study area and the most suitable one, the Ericson model, is selected and modified using the RMSE of 0.615. The amended model is further interpolated to eliminate the wanted signal or recover the missing data in the radio path. It is found that the path loss is minimized by 5.131dB in the study area, and recommended that fuzzy logic-spline interpolation may be used to reduce the propagation error in the study area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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