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Research Paper

A Modified Empirical Path Loss Model for 4G LTE Network in Lagos, Nigeria

A. O. Akande*(C.A.), F. A. Semire**, Z. K. Adeyemo**, and C. K. Agubor*

Abstract: The quality of signal at a particular location is essential to determine the performance of mobile system. The problem of poor network in Lagos, Nigeria needs to be addressed especially now that the attention is toward online learning and meetings. Existing empirical Path Loss (PL) models designed elsewhere are not appropriate for predicting the 4G Long-Term Evolution (LTE) signal in Nigeria. This research developed a modified Okumura-Hata model in 4G network. The Okumura-Hata model being the closest to the measured values was modified using the PL exponent. The modified model was enhanced by Gravitational Search Algorithm (GSA). The measured data, modified and existing models were simulated using MATLAB R2018a software. Root Mean Square (RMSE) was used to evaluate the performance modified and existing and models. The result showed that Enhanced GSA model outperformed the existing models. The study successfully developed a modified PL model for LTE in Lagos, Nigeria. Therefore, modified model will be a good model in network planning for voice and fast online data connection in 4G LTE network.

Keywords: Okumura-Hata, Path Loss, 4G LTE, Drive Test.

1 Introduction

THE mobile wireless system is the most widely used communication technology in recent times due to lots of services available in wireless systems such as voice call, internet browsing and short message services [1]. The signal remains unpredictable because of the obstructions along the communication paths [2]. This causes the signal to travel without any Line of Sight (LOS) and the distribution due to scattering follows Raleigh fading [3].

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*The authors are with the Department of Electrical and Electronic Engineering, Federal University of Technology Owerri, Nigeria.
E-mails: olukunle.akande@futo.edu.ng and cosmas.agubor@futo.edu.ng.
**The authors are with the Department of Electrical and Electronic Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.
E-mails: fasemire@lautech.edu.ng and zkadeyemo@lautech.edu.ng.
Corresponding Author: A. O. Akande.
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Also, there is a signal attenuation along the propagation path known as Path Loss (PL) [4]. In Lagos, some research work has been carried out previously on the existing network technology but not on 4G LTE using existing propagation models. These models may not be suitable for the prediction of attenuation of 4G signals in Lagos, due to terrain and transmission frequency. The most commonly used existing model for network prediction are COST-231, Egli, Okumura-Hata, Ecc-33, and Ericsson models [5]. Some of these existing models have the characteristics of slow response to different terrains and cannot perform well in 4G LTE network [6]. These models are inefficient for accurate analysis of path loss in urban, environment due to path loss deviation [7].

There are several works on the use of these models in path loss analysis. Authors in [8], worked on the Determination of an Empirical Model for LTE in Lagos. The PL data was obtained in 4G LTE network at 700 MHz frequency. The result showed that the Ericsson model best predicted the PL in FESTAC area of Lagos with a minimum deviation. The PL characterization of LTE network in Lagos was investigated in [9]. The data collected at 1900 MHz in selected hotspot areas were compared with the predictions made by existing PL models. The results showed that other existing models overestimated the PL, while COST 231-Hata model gave the best performance. However, operational frequency showed that the measured PL were on 3G network and the Minimum Mean Square Error (MMSE) adopted was not the correct optimization technique. The authors did not report any new model in the published work.

Elsewhere, authors in [6] worked on the determination of Probability Distribution Function (PDF) for PL model in wireless communication channels at 900 and 1800 MHz frequency. The data obtained at 900 and 1800 MHz is for GSM network and unlike 4G cannot support video streaming and some other multimedia services. The performance evaluation of a deployed LTE and WiMAX network suitability was reported in [10]. The work was on LTE at 2.6 GHz in Sub-Saharan Africa. Here, the effect of channel impairments and signal attenuation was not considered for effective PL prediction of the terrain.

Authors in [11], presented another work on PL propagation measurement of LTE network in a Lagoon environment at 1800 MHz [11]. COST 231 model was confirmed to be most accurate for the terrain. The author did not propose any new model for better network performance in the terrain. In [12], urban area PL optimization of Okumura-Hata model at 800 MHz in Benin City, Nigeria was presented. The existing PL models was selected for comparison with measured data.

In [13], the optimization of empirical model in GSM network was presented for Port Harcourt and Enugu, Nigeria. COST-231 model gave lower PL values for the terrain. Authors in [14] and [15], worked on GSM network in Mosul City, Iraq and in Kaduna, Nigeria, respectively. Here, both network used cannot provide support for data and multimedia services. Authors in [16], presented the analysis of PL propagation model for urban area network. Okumura-Hata model was shown to be the most accurate and reliable empirical PL model in 3G network as revealed from the Mean Square Error (MSE) analysis.

In [17], the PL characterization of 3G network in Port Harcourt City was investigated for urban and suburban environments. The proposed model lack the capacity to predict mobile signal due to omission of some important network parameters.

Comparative analysis of empirical models in GSM network using Artificial Neural Network (ANN) at 1800 MHz was presented in [18]. The ANN based PL model was compared with basic existing PL models. The RMSE result showed that Okumura-Hata model performed better in rural, while Egli model performed better in suburban area environment. In [19] the performance of empirical model in 3G network for Owerri City was investigated. The published model cannot accurately predict mobile signal because of missing network parameters, such as carrier frequency and height of antenna.

Most works as discussed above have been on GSM network standard which is only for voice communication and cannot provide support for data and fast internet connection. Many PL models were developed for 3G network, and may not be accurate for PL prediction in 4G LTE network due to deviation.

The motivating factor of this work arises from the fact that the existing PL models that can be used in Lagos for path loss prediction are 3G Network friendly. Since in Lagos the network infrastructure is 4G LTE, it becomes very necessary to replace existing models with improved models appropriate for current network. This is the main focus of this study. Its major contribution is the development of a modified and an Enhanced GSA model which unlike the models earlier reviewed can suitably be deployed for accurate signal prediction in 4G LTE network in Lagos.

2 Empirical propagation models

2.1 Okumura-Hata

This is empirical PL model suits the urban area propagation [20]. The range of frequency for Okumura model is between $150\ MHz - 1500\ MHz$, the Base Station (BS) antenna height ($\mathrm{h_{bt}}$) is up to 200 m depending on nature of the terrain [21]. The PL model ($\mathrm{PL_P}$) is expressed as:

$$PL_P\ (dB) = 69.61 + 26.21\ log\ f_c - 13.81\ log\ h_{bt} - y(h_{mts}) + P_{sys} \quad (1)$$

where, $P_{sys} = [44.92 - 6.62\ log\ h_{mt}]\ log\ d.$

f_c is the carrier frequency (MHz), $\mathrm{h_{bt}}$ is the BS antenna height (m), h_{mt} is the MS antenna height (m), $y(h_{mts})$ is the mobile antenna correction factor, and d is the distance between BS and MS (km).

Antenna correction factor $y(h_{mts})$ for large city is given as:

$$y(h_{mts}) = 8.3\,[log(1.54h_{mts})]^2 - 1.1\,dB,\quad f_c \leq 300\,MHz \tag{2}$$

$$y(h_{mts}) = 3.2\,[log(11.75h_{mts})]^2 - 4.97\,dB,\quad f_c > 300\,MHz \tag{3}$$

Antenna correction factor $a(h_{mts})$ for medium size city expressed as:

$$y(h_{mts}) = 1.1[log(f_c) - 0.7]h_{mt} - [1.56\,log(f_c) - 0.8]dB \tag{4}$$

Okumura-Hata PL calculation for suburban given as:

$$PL_P\,(dB) = PL_P(urban)dB - 2[log\frac{f_c}{28}]^2 - 5.5 \tag{5}$$

2.2 COST 231-Hata

COST 231-Hata is an extension of Okumura-Hata model developed by European Cooperative research team. The frequency of operation for the model is between 1500-2000MHz and BS antenna height of 30-200m. The distance between BS and MS antenna is between 1-20km [22]. The PL model is expressed as:

$$PL_P\,(dB) = P_0 - 13.81\,log\,h_{bt} - y(h_{mts}) + P_1 + C_{ACF} \tag{6}$$

Where:
$P_0 = 46.3 + 33.9\,log\,f_c$
$P_1 = [44.92 - 6.62\,log\,h_{mt}]\,log\,d$
C_{ACF} is the environmental correction factor, the value is $0\,dB$ and $3\,dB$ for suburban and urban area, respectively.
The mobile antenna correction factor for a large city is given by:

$$y(h_{mts}) = 8.3\,[log(1.54h_{mt})]^2 - 1.1\,dB\quad f_c \leq 300\,Mhz \tag{7}$$

$$y(h_{mts}) = 1.1\,\left[[log\ f_c - 0.7]h_{mt} - [1.16\,log\,(f_c) - 0.8]\right] \tag{8}$$

2.3 Ericsson Model

Ericsson 9999 model predict the PL by changing network parameters based on the propagation terrain. The maximum carrier frequency for Ericsson model is 1900 MHz [23]. The PL model is expressed as:

$$PL_P(dB) = a_0 + a_1\,log(d) + a_2\,log\,h_{bt} + K_0 - 3.2\ [log(11.8\,h_{mt})^2] + G(f_c) \tag{9}$$

where, $G(f_c) = 44.5\,log(f_c) - 4.8[log(f_c)^2$

$K_0 = [a_3\,log(h_{bt})\,log(d)]$

$g(f_c) =$ frequency correction factor.

The standard terrain correction parameters are given in Table 1.

Table 1 Parameters for Ericsson model [24].

Environment	a_0	a_1	a_2	a_3
Urban	37.21	30.19	12.10	0.11
Suburban	43.21	67.92	12.10	0.12
Rural	46.96	100.5	12.10	0.13

2.4 ECC-33 Model

The Electronic Communication Committee (ECC), is a model that extrapolated Okumura measurements and the assumptions was modified as given in [21], [24]. The PL model is expressed as:

$$PL_P(dB) = A_{FSA} + A_{MPL} - G_{tx} - G_{rx} \tag{10}$$

where, A_{FSA} is the free space PL, A_{MPL} is the median PL, G_{tx} the BS antenna gain, and G_{rx} is the MS antenna gain. The parameters are defined as:

$$A_{FSA} = 92.35 + 20\,log(d) + 20\,log(f_c) \tag{11}$$

$$A_{MPL} = 20.4 + 9.8\,log(d) + 7.9\,log(f_c) + 9.6\,[log(f_c)]^2 \tag{12}$$

$$G_{tx} = log\left(\frac{h_{bt}}{200}\right)\,[13.9 + 5.8(log\,d)^2] \tag{13}$$

MS gain factor for suburban and rural.

$$G_{rx} = [42.6 + 13.7\ log\ (f_c)\,]\,[\,log\ (h_{mt}) - 0.59] \tag{14}$$

MS gain factor for dense urban area:

$$G_{rx} = 0.76\,(h_{mt}) - 1.86 \tag{15}$$

2.5 Egli Model

The model was proposed by Egli to predict PL in different terrain. The model is good when there is no obstruction in the channel. The operation frequency is between 45 MHz-900 MHz and the maximum covering distance is 50 km [12]. The model is given as:

$$PL_{Egli}(dB) = 20\,log\,f_c + P_{sys} + 76.5 - 10\,log\,h_{mt}\,,\quad for\ h_{mt} \leq 15\,m \tag{16}$$

$$PL_{Egli}(dB) = 20\,log\,f_c + P_{sys} + 86.9 - 10\,log\,h_{mt}\,,\quad for\ h_{mt} > 15\,m \tag{17}$$

where, $P_{sys} = 40\,log\,d - 20\,log\,h_{bt}$, P_{sys} is the system factor.

3 Gravitation Search Algorithm (GSA)

GSA is based on law of gravity and data mass interactions [25], [26]. The global movement occurs when heavy masses move towards other objects [27], [28]. Slow movement of heavier masses in the space corresponds to good signal transmission known as exploitation step. The gravitational force (f) between two objects is expressed as:

$$f = \frac{G(M_a M_b)}{D^2} \quad (18)$$

where, G is the constant due to gravity, M_a and M_b are the masses agent, while D is the distance between objects.

The different steps of implementing GSA are given as:

○ **Step A:** Initialization: Data (agent) points are randomly initialized, the i^{th} position of a data, U_i is defined as:

$$U_i = (u_i{}^1, u_i{}^2, u_i{}^3, u_i{}^4, \ldots \ldots u_i{}^y), \quad for\ i = 1, 2, 3, \ldots \ldots y \quad (19)$$

where, u_i is the position of i^{th} agent (data points in the channel)

○ **Step B:** Fitness Evaluation: Good and poor fitness of each agent is performed, for j^{th} agents at iteration t.

$$good\ (t) = maxi\ fit_j(t) \quad j\epsilon 1, \ldots, Y \quad (20)$$

$$poor\ (t) = mini\ fit_j(t) \quad j\epsilon 1, \ldots, Y \quad (21)$$

where, $fit_j(t)$ is the fitness value.

○ **Step C:** Gravitational Value: The gravitational value $G_r(t)$ is obtained at iteration t.

$$G_r(t) = G_{r0} e^{(-at/T)} \quad (22)$$

where, G_{r0} and at/T reduces with time to control search accuracy, G_{r0} is the initial gravity value, t is the current iteration, and T is the total iterations. The force on the agent i from agent j at time t,

$$F_{ij}^x = G_r(t) \frac{M_{pi}(t) * M_{aj}(t)}{R_{ij}(t)} \quad (23)$$

where, F_{ij}^x is the applied force on agent, $R_{ij}(t)$ is the distance

○ **Step D:** Agent's Masses: The Gravitational mass, $m_i(t)$, and inertia mass, $M_{ii}(t)$ of agent i at iteration t are obtained through Eq. (24) and Eq. (25) as:

$$m_i(t) = \frac{fit_i(t) - good(t)}{good(t) - poor(t)} \quad (24)$$

$$M_{ii}(t) = \frac{m_i(t)}{\sum_{j=1}^{n} m_j(t)} \quad (25)$$

where, $m_j(t)$ is the mass of agent j.

○ **Step E:** Agent's Acceleration: According to the law of motion, applied force (f) is directly proportional to mass (M) and acceleration (a), which is expressed as:

$$f = kma \quad (26)$$

where, constant (k) is equal to 1.

Acceleration of agent in the direction x^{th}, according to law of motion is expressed as:

$$a_i^x(t) = \frac{F_i^x(t)}{M_{ii}(t)} \quad (27)$$

where, $a_i^x(t)$ is the acceleration, and $F_i^x(t)$ the total applied force on agent i^{th}.

○ **Step F:** Agent's Velocity and Position: Velocity and Position of agent (data) at next iteration $(t+1)$ are updated according to Eqs. (28) and (29) as:

$$vel_i^x(t+1) = rand_i * v_i^x(t) + a_i^x(t) \quad (28)$$

$$x_i^x(t+1) = x_i^x(t) + vel_i^x(t+1) \quad (29)$$

where $vel_i^x(t)$ and $vel_i^x(t+1)$ are the velocity of i^{th} agents during the iteration t & $(t+1)$ respectively, $rand_i$ is random variable in interval [0,1], $u_i^x(t)$, and $u_i^x(t+1)$ are the position of i^{th} agents during iteration t and $(t+1)$.

○ **Step G:** Repeat Steps B to F: Steps B to F are repeated due to changes in the velocity, every individual update its position to reach maximum limit and meet end criterion.

4 Method of Data Collection

The drive test method was adopted for data collection from 4G LTE network in the study area. The signal strength and PL were recorded on a log files using TEM 15.0 installed on the laptop. The Sony-Ericsson W995, Global Positioning System, and Power Supply Unit were interface with the system. 4G network parameters employed during the drive test are presented in Table 2.

Table 2 Drive test transmission parameters.

Transmission Parameters	
Carrier Frequency	2.3 GHz
Transmission Power	43dBm
Transmitter height	35m
Transmitter Gain	18dBi
Receiver Gain	1.76dBi
Mobile station height	1.5m

The recorded data on the log files are later processed with Actix software for further analysis. This is a new optimization algorithm that was used to enhance the developed Okumura-Hata model for better performance in the study area. The simulation of the gravitational algorithm and modified model was achieved using MATLAB software. This was carried out in different steps of GSA implementation. The Drive Test routes and measured data for L1, L2 and L3 are shown in Tables 3 and 4, respectively.

Table 3 Drive test routes

Designation (Location)	Area in Lagos
L1	Apapa- Oworonsoki Road
L2	Ikorodu Road
L3	Jibowu Street

Table 4 Measured PL values against distance for Lagos terrain.

Dist. (km)	Measured $PL_P(d_0)$ (dB) L 1	Measured $PL_P(d_0)$ (dB) L 2	Measured $PL_P(d_0)$ dB L 3	Average Measured $L_{PM}(d_0)\ dB$
0.1	95.1	87.20	100.10	94.13
0.2	103.1	124.00	102.00	109.70
0.3	149.0	116.10	118.10	127.73
0.4	112.2	102.20	168.30	127.57
0.5	140.0	152.00	112.20	134.73
0.6	116.0	120.30	141.20	125.83
0.7	150.1	104.10	114.10	122.77
0.8	111.3	131.10	134.10	125.50
0.9	180.2	107.20	150.30	145.90
1.0	138.1	119.30	123.10	126.83
1.1	116.0	105.10	135.10	118.73
1.2	102.0	128.20	101.30	110.50
1.3	145.0	116.00	142.10	134.37
1.4	130.0	130.30	110.20	123.50
1.5	104.0	121.10	121.10	115.40

5 Regression Analysis of 4G Let Data

The PL data obtained on 4G LTE network from three different locations in Lagos was analyzed using Regression Method (RM). The data at 0.1 km was taken as the reference measured PL value $(PL_{pM}\, d_0)$, the PL exponent (n) was subsequently obtained through quadratic solution technique. The regression analysis against distance for L1 is shown Table 5.

Table 5 Regression Analysis of the Measured Data for L1.

Dist. (m)	Measured PL $PL_{PM}(d_0)\ dB$	Predicted PL $PL_{PR}(d_i)\ dB$	$PL_{PM}(d_0) - PL_{PR}(d_i)$
100	95.1	95.1	0
200	103.1	95.1+3.01 x	008 - 3.01 x
300	149.0	95.1+4.77 x	053.9 - 4.77 x
400	112.2	95.1+6.02 x	017.1 - 6.02 x
500	140.0	95.1+6.99 x	044.9 - 6.99 x
600	116.0	95.1+7.78 x	020.9 - 7.78 x
700	150.1	95.1+8.45 x	0055 - 8.45 x
800	111.3	95.1+9.03 x	016.2 - 9.03 x
900	180.2	95.1+9.54 x	085.2- 9.54 x
1000	138.1	95.1+10.00 x	042.9 - 10.0 x
1100	116.0	95.1+10.41 x	020.9 - 10.41 x
1200	102.0	95.1+10.79 x	006.9 - 10.79 x
1300	145.0	95.1+11.14 x	049.9 - 11.14 x
1400	130.0	95.1+11.46 x	034.9 - 11.46 x
1500	104.0	95.1+11.76 x	08.9 - 11.76 x

For typical terrestrial radio applications, the signal strength decreases with distance due to channel impairments, such as PL, obstruction, multipath and shadowing effect [21]. The PL model $(PL_{(d_i)})$ is expressed as:

$$PL_{(d_i)} = PL_{PM}(d_0) + 10(x)log\left(\frac{d_i}{d_0}\right) \quad (30)$$

where, x is the PL exponent, d_i the distance and d_0 is the reference distance. The predicted PL $[PL_P(d_i)]$ was obtained by substituting Model Modified Factor (MMF_{sys}) and mobile antenna correction factor a($\mathrm{h_{mts}}$) into equation (30) as:

$$PL_P(d_i)\ dB = L_{PM}(d_0) + 26.1\ log\ f_{cf} - 13.8\ log\ h_{bt} + 10(x)log\left(\frac{d_i}{d_0}\right) - a(h_{mts}) \quad (31)$$

where,

$$MMF_{sys} = [26.1\ log\ f_{cf} - 13.8\ log\ h_{bt}]$$

$$a(h_{mts}) = 3.2\ [log(1.53h_{mt})]^2 - 4.96\ dB$$

For distances from 0.1km to 1.5km, the expression $[PL_{PM}(d_0) - PL_{PR}(d_i)]^2$ is the sum of square error obtained as:

$$1139.919x^2 - 7242.69x + 19989.57 \quad (32)$$

The loss exponent (x) is obtained using quadratic solution method as:

$$1139.919x^2 - 7242.69x + 19989.57 = 0$$

$$x = 3.18$$

The shadowing error as a result of obstruction in the terrain resulted in signal deviation. This deviation (δ_{SDf}) is evaluated from sum of square error using Eq. (33) as:

$$\delta_{SDf} = \frac{1}{N}\left(\sum([PL_{PM}(d_0) - PL_{PR}(d_i)]^2)^{\frac{1}{2}}\right) \quad (33)$$

Therefore, the shadowing error correction factor, $\delta_{SDf}\ (dB)$, about a mean value, can be determined from Eq. (33) as:

$$\delta_{SDf} = \frac{1}{15}([(1139.919)(3.2)^2 - 7242.69(3.2) + 19989.57]\ )^{\frac{1}{2}}$$

$$\delta_{SDf} = 23.7\ dB$$

Using $PL_{PM}(d_0)_{Ref}$, MMF_{sys} , x and adding $\delta_{SDf}\ (dB)$ to compensate for the error into Eq. (36). The modified path loss model for L1 is given as:

$$PL(L1) = 95.1 + [26.1\ log\ f_c - 13.8\ log\ h_{bt}] + 10(3.2)\ log\left(\frac{d_i}{d_0}\right) - a(h_{mts}) + 23.7\ dB \quad (34)$$

substituting for $PL_{PM}(d_0)_{Ref}$ (initial measured path loss at 100 m away from 4G LTE station), the path loss exponents (x) and shadowing deviation (δ_{SDf}). The modified path loss model for L2 and L3 are presented in Eqs. (35) and (36) as:

$$PL(L2) = 87.2 + [26.1\,log\,f_c - 13.8\,log\,h_{bt}] + 10(3.5)\,log\left(\frac{d_i}{d_0}\right) - a(h_{mts}) + 15.4\,dB \quad (35)$$

$$PL(L3) = 100.1 + [26.1\,log\,f_c - 13.8\,log\,h_{bt}] + 10(2.9)\,log\left(\frac{d_i}{d_0}\right) - a(h_{mts}) + 19.1\,dB \quad (36)$$

Therefore, substituting system parameter factor, the overall best performed modified PL model for Lagos terrain is obtained from Eqs. (33), (35) and (36) and presented in Eq. (37) as:

$$PL(Gen,) = 94.1 + [26.1\,log\,f_c - 13.8\,log\,h_{bt}] + 10(3.2)\,log\left(\frac{d_i}{d_0}\right) - a(h_{mts}) + 19.4\,dB \quad (37)$$

Table 6 presents the predicted PL results analysis for existing model, measured PL, modified and enhanced GSA models for L1.

6 Validation of Propagation Model

The RMSE and Mean Absolute Percentage Error (MAPE) are the performance metrics used to evaluate the amount of error in the existing and modified models given in [29] as:

$$RMSE = [\frac{1}{n}\sum_{i=1}^{n}\left(PL_{PM_i} - PL_{PR_i}\right)^2]^{1/2} \quad (38)$$

$$APE = \frac{1}{n}\sum_{j=1}^{n}\left|\frac{PL_{PM_i} - PL_{PR_i}}{PL_{PM_i}}\right| * 100\% \quad (39)$$

where, $PL_{PM_i}(dB)$ is the measured data, $PL_{PR_i}(dB)$ is the predicted data, and n is the number of data points. The RMSE and MAPE results analysis for existing, modified, and enhanced (optimized) GSA were carried out and compared to validate the developed empirical mode as presented in this work.

7 Results and Discussion

The results are presented in Figs. 1- 3 for L1 to L3. Fig. 1 shows the plot of PL values against distance at L1. At a distance of 0.60 km from BS, the PL values obtained were 127.4 dB, 132.8 dB, 159.1 dB, 221.2 dB, 323.7 dB, 126.0 dB, and 125.7 dB for Okumura-Hata, COST- 231, Ericsson, Egli, ECC-33, Modified, and Enhanced GSA, respectively. The corresponding values for MAPE are 0.265 %, 0.549 %, 1.970 %, 5.344 %, 10.86 %, 0.231 %, and 0.216 %. The RMSE results obtained are 4.903dB, 10.17dB, 36.49dB, 98.99dB, 201.1dB, 4.290dB, and 3.998dB. The Enhanced GSA model performed better than all other models making it a good model for signal prediction in 4G LTE network.

Fig. 2 depicts the plot of PL values against distance at L2. At a distance of 0.60 km from the BS, the PL values obtained are 127.4 dB, 132.8 dB, 159.1 dB, 221.2 dB, 323.7 dB, 126.3 dB, and 125.3 dB for Ok-Hata, COST, Erics, Egli, ECC, Modified, and Enhanced GSA, respectively. The MAPE results obtained are 0.611 %, 0.909 %, 2.401 %, 5.943 %, 11.73 %, 0.559 %, and 0.502 %. The corresponding RMSE results are 10.77Db, 16.04dB, 42.36dB, 104.90dB, 206.90dB. 9.875dB, and 8.859dB. The results show that ECC-33 over-estimated the PL due to high population density and signal attenuation by many tall buildings in the terrain. The Enhanced GSA model was observed the best compared to existing models in Lagos environment.

Table 6 Measured, predicted, modified and enhanced GSA path loss values for L1.

Dist. (km)	Ok - Hata (dB)	COST 231 (dB)	Erics (dB)	Egli (dB)	ECC-33 (dB)	Measured PL (dB)	Modified (L1) (dB)	Enhanced (GSA) dB
0.1	100.3	102.8	135.5	190.1	300.5	95.1	109.3	109.0
0.2	110.8	116.2	144.6	202.1	309.5	103.1	113.9	113.6
0.3	116.9	122.4	149.9	209.2	314.7	149.0	117.5	117.2
0.4	121.2	126.7	153.7	214.2	318.4	112.2	120.4	120.2
0.5	124.6	130.1	156.7	218.1	321.3	140.0	123.5	123.2
0.6	127.4	132.8	159.1	221.2	323.7	116.0	126.0	125.7
0.7	129.7	135.2	161.1	223.9	325.7	150.1	128.2	127.8
0.8	131.7	137.2	162.9	226.2	327.4	111.3	130.0	129.7
0.9	133.5	138.9	164.4	228.3	328.9	180.3	131.6	131.3
1.0	135.1	140.5	165.8	230.1	330.3	138.1	133.1	132.8
1.1	136.5	142.0	167.1	231.8	331.5	116.0	134.4	134.1
1.2	137.8	143.3	168.2	233.3	332.7	102.0	135.6	135.3
1.3	139.0	144.5	169.3	234.7	333.7	105.0	136.7	136.4
1.4	140.2	145.6	170.2	236.0	334.7	130.0	137.7	137.4
1.5	141.2	146.7	171.2	237.9	335.6	104.0	138.7	138.4

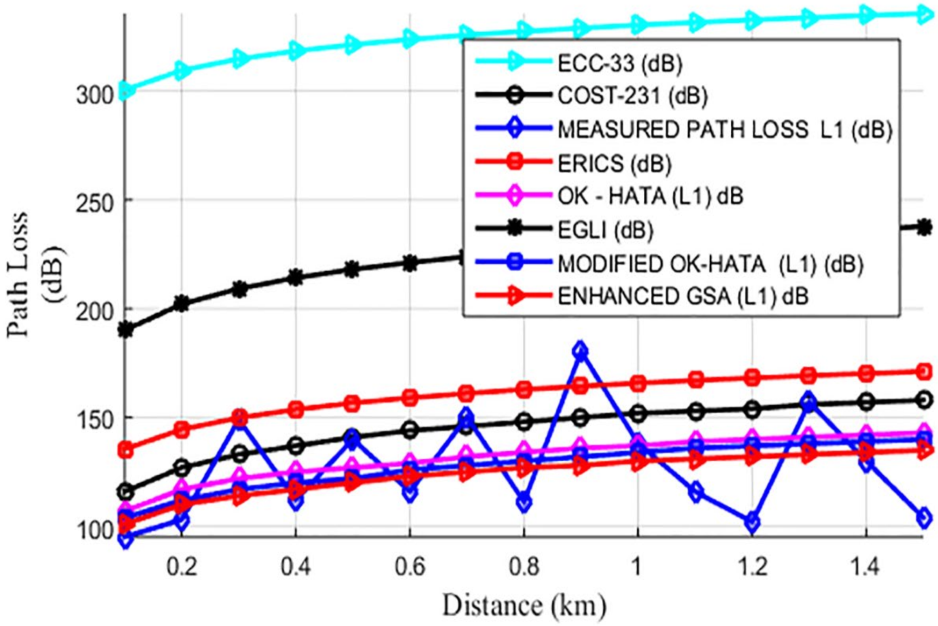

Fig. 1 Path loss values against distance with measured path loss for L1.

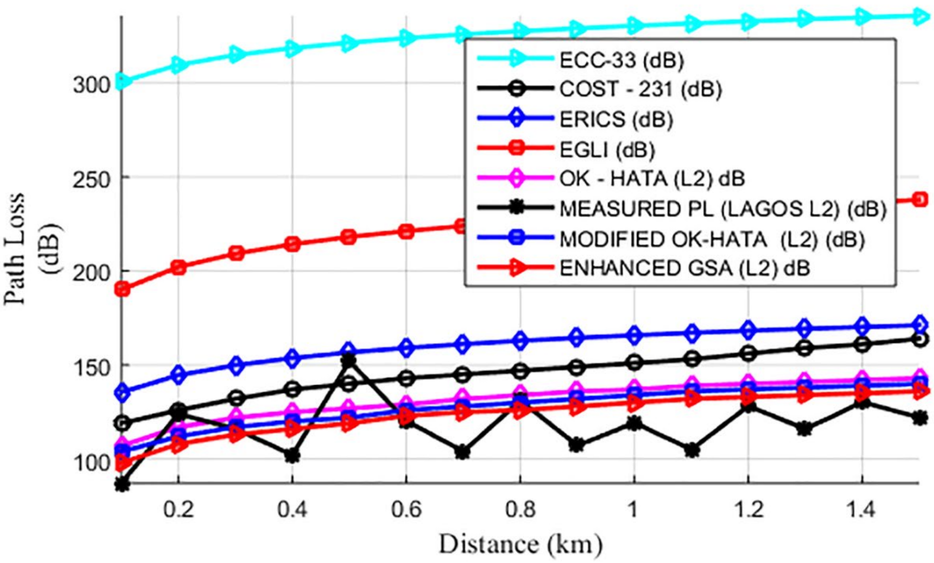

Fig. 2 Path loss values against distance with measured path loss for L2.

Fig. 3 shows the PL values against distance at L3. At a distance of 0.6 km from the BS, the PL values are 127.4 dB, 132.8 dB, 159.1 dB, 221.2 dB, 323.7 dB, 125.4 dB, and 124.0 dB for Ok-Hata, COST, Erics, Egli, ECC, Modified, and Enhanced GSA, respectively. The MAPE results obtained in 4G LTE are 0.187 %, 0.468 %, 1.872 %, 5.209 %, 10.66 %, 0.119 %, and 0.010 %. The corresponding RMSE values are 3.497 dB, 8.765 dB, 3.35 dB, 97.85 dB, 199.70 dB, 2.231 dB, and 1.870 dB. In this case, Enhanced GSA model performs better than all other models. Therefore, the model is good for 4G LTE network estimation and deployment in Lagos terrain.

Fig. 4 depicts RMSE plotted in bar chart against the existing and enhanced GSA model for L1, L2, and L3. The average RMSE values obtained are 6.39 dB, 11.66 dB, 37.98 dB, 100.5 dB, 203.6 dB, 5.47 dB and 4.91 for Ok-Hata, COST-231, Erics, Egli, ECC-33, Modified model, and Enhanced GSA, respectively. The result shows that Modified and Enhanced GSA models produce lower RMSE compared to existing empirical models. The model is good for 4G LTE network estimation in Lagos terrain. The new developed model can be deployed to mitigate the effect of path loss in 4G mobile network.

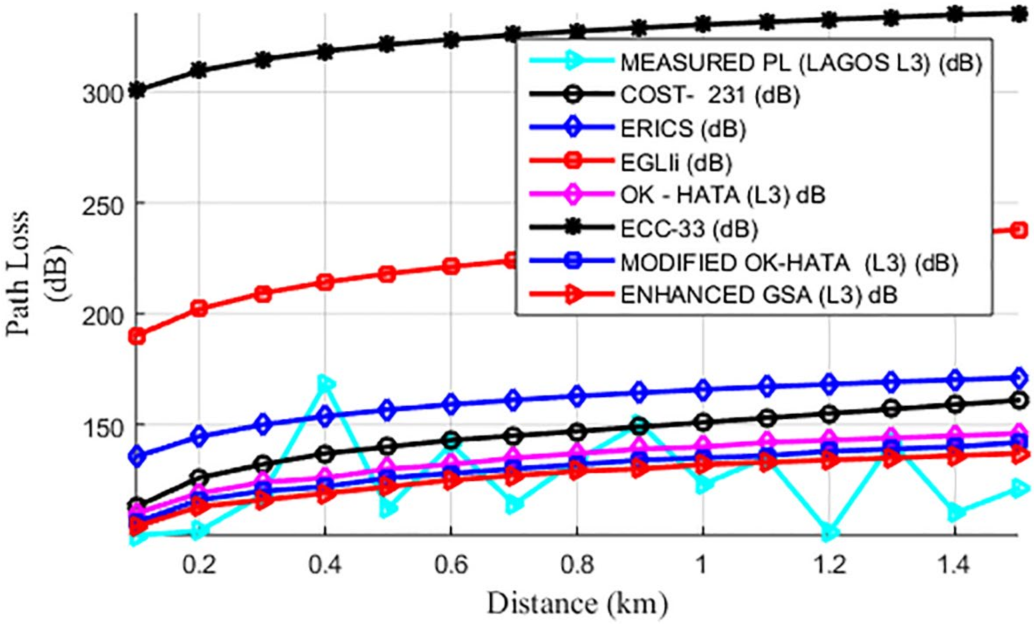

Fig. 3 Path Loss values against distance with measured path loss for L3.

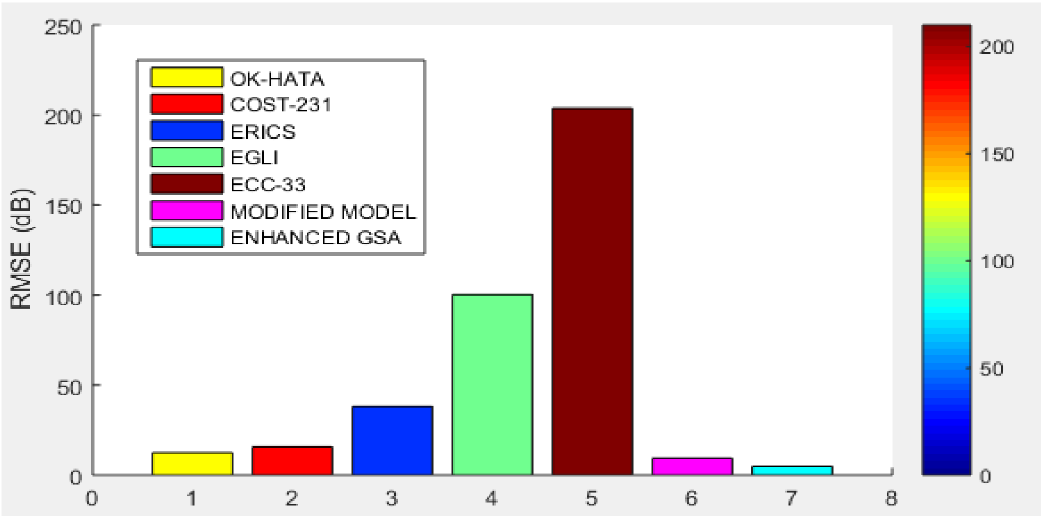

Fig. 4 Average RMSE against the existing, modified and enhanced models.

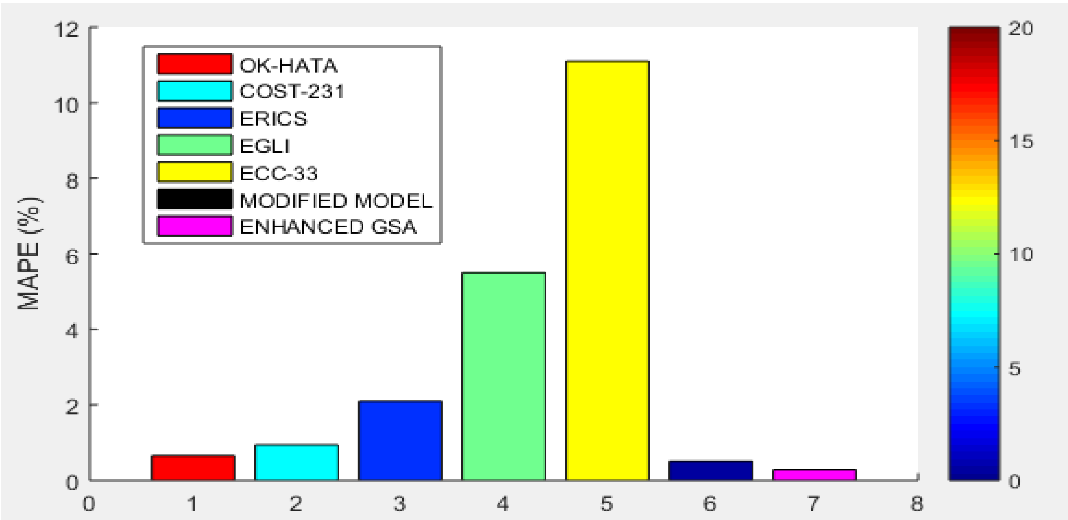

Fig. 5 Average MAPE against the existing, modified and enhanced GSA models.

Fig. 5 depicts the plot MAPE plotted in bar chart against the existing and enhanced GSA model for L1, L2, and L3. The average MAPE values obtained are 0.35 %, 0.64 %, 2.08 %, 5.50 %, 11.08 %, 0.30 % and 0.28 % for Ok-Hata, COST-231, Erics, Egli, ECC-33, Modified model, and Enhanced GSA, respectively. The Modified and Enhanced GSA models gave better results compared to the existing empirical model. The result shows that Enhanced model gave lower MAPE. The result also shows that Enhanced GSA model has the potential to solve the problem of path loss in Lagos.

8 Conclusion

The performance of existing empirical propagation model has been investigated over 4G LTE in Lagos, Nigeria. Drive Test (DT) method was used to collect mobile network data from 4G base stations along three different routes in Lagos. The measured PL was analyzed using Regression Analysis technique to obtain loss exponent for the terrain. The modified model gave the smallest propagation error compared to existing empirical models investigated for the terrain. The variance was enhanced to eliminate the error using GSA for better performance of the modified model. The measured data, modified model, enhanced GSA model, and existing model were simulated using MATLAB R2018a software. The performance of the existing and enhanced models was evaluated using RMSE and MAPE. The results showed that Enhanced GSA model predicts PL better than existing models in 4G LTE network at 2.3 GHz. This research has successfully obtained the accurate PL exponent for Lagos terrain. Also, the modified model has been developed for Lagos environment. The previous model proposed in 3G network is not good for fast online data and video steaming because of many missing network parameters observed in the model. The new proposed model is very unique in 4G network which can effectively handle fast internet connection and multimedia services. The model was developed with the inclusion of all necessary network parameters, such as distance (d), frequency (f_c), model modified factor (MMF), mobile antenna height (h_{mt}), and base station antenna height (h_{bt}). The proposed model gave good results with the inclusion of all 4G network parameters. The ability of the proposed model to obtain improved performance compared to existing models is a very good contribution of this work. Therefore, the enhanced GSA model could be deployed in 4G network for accurate signal propagation in Lagos, Nigeria.

Intellectual Property

The authors confirm that they have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing to publication, with respect to intellectual property.

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Credit Authorship Contribution Statement

A. O Akande: Idea & Conceptualization, Original Draft Preparation, Software and Simulation. **F. A. Semire:** Research & Investigation, Data Curation, Supervision. **Z. K. Adeyemo:** Idea & Conceptualization, Supervision, Verification. **C. K. Agubor:** Methodology, Analysis, Revise & Editing.

Declaration of Competing Interest

The authors hereby confirm that the submitted manuscript is an original work and has not been published so far, is not under consideration for publication by any other journal and will not be submitted to any other journal until the decision will be made by this journal. All authors have approved the manuscript and agree with its submission to "Iranian Journal of Electrical and Electronic Engineering".

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A. O. Akande obtained his B. Tech in 2007 from Electrical and Electronic Engineering in LAUTECH, Nigeria. He also obtained his M. Eng in 2013 from University of Ilorin, Nigeria and a PhD in Communication Engineering from LAUTECH in 2019. He is a Lecturer at Federal University of Technology, Owerri, Nigeria. His research interest includes mobile wireless communications Artificial Intelligent (AI) system, and 5G mobile network.

F. A. Semire holds a PhD in Electronic and Electrical Engineering from Universiti Sains Malaysia, Penang, Malaysia in 2014. Her M.Sc and B. Tech were obtained from University of Lagos, and Ladoke Akintola University of Technology (LAUTECH), Nigeria in 2000 and 2003, respectively. She is a Lecturer in the Department of Electronic and Electrical Engineering in LAUTECH, Nigeria. Her research interest includes radio-wave propagation, microwave and millimeter wave propagation.

Z. K. Adeyemo holds a Ph.D in Electrical and Electronics Engineering from Ladoke Akintola University of Technology, Nigeria. His B. Eng and M. Eng were obtained from University of Ilorin, Nigeria in 1994 and 2002, respectively. His research areas are mobile wireless communications mobile satellite communications, and antenna diversity. He is a Lecturer in the Department of Electronic and Electrical Engineering in LAUTECH, Nigeria

Cosmas Kemdirim Agubor obtained his B. Eng in Electrical and Electronic Engineering from Federal University of Technology, Owerri (FUTO) in 1991 and M. Eng from University of Port Harcourt, Nigeria in 2005. He also obtained a Ph.D in Communication Engineering from FUTO in 2015. He worked as a Telecommunication Engineer at NITEL Nigeria Limited from 1992- 2008 where he worked on RF and Optic Fiber systems. He is a Lecturer in the Department of Electronic Engineering, FUTO. His research interest includes radio-wave propagation, microwave and millimeter wave propagation.

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