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INVESTIGATION AND PATHLOSS MODELING OF FOURTH GENERATION LONG TERM EVOLUTION NETWORK ALONG MAJOR HIGHWAYS IN LAGOS NIGERIA

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ABSTRACT

This study presents propagation measurements of fourth generation long term evolution (4G LTE) network using Huawei Technologies drive test equipment. Measurements were taken from three transmitting evolved node base stations (eNodeBs) located along three major routes in Lagos Nigeria, at an operating frequency of 1800MHz.Measured pathloss was comparatively analyzed with respect to predictions made by free space, flat earth, Okumura-Hata, Walfisch-Ikegami, Ericsson, ECC-33, and Lee models. Results showed that the free space, flat earth, Walfisch-Ikegami, ECC-33, Ericsson, and Lee models over predict the path loss along the tested routes with root mean square errors (RMSEs) relatively higher than the specified range. The Okumura-Hata model showed the best performance with RMSEs of 7.42dB, 7.63dB and 9.64dB along the investigated routes 1, 2, and 3, respectively. This model was modified using the least square method in order to enhance its signal prediction accuracy. The modified Okumura-Hata model predicted the path loss along routes 1, 2, and 3, with RMSEs of 5.20dB, 4.89dB and 8.78dB, respectively. Overall, the modified Okumura-Hata model showed lower RMSEs closer to zero which are acceptable. This model could find very useful applications in the area of quality signal prediction and pathloss modeling for related wireless mobile environments.

Key words: Propagation measurements, 4G LTE network; measured pathloss; drive test; eNodeBs; Lagos highways; Okumura-Hata model; root mean square error; least square method

INTRODUCTION

The basic requirement of a fourth generation long term evolution (4G LTE) network is to meet coverage and quality targets. The coverage targets demand a high probability of network service availability within the geographical location. Key performance indicators such as handover, call success rate, drop call ratio that should be within the specified values, are related to the quality targets. In addition, environmental factors such as the geographical structure of the area, roads, location of cites, and other hotspot areas, are to be taken into consideration during network planning (Rappaport 1996; Sesia, Baker, & Toufik, 2011; Holma & Toskala, 2011).

When planning and designing a wireless mobile communication system, there is a need for adequate understanding of wireless communication systems, ability to deploy suitable propagation models, and to appropriately model the channels (Song & Shen, 2010). To ensure optimal performance of a network cellular structure, network planners rely on propagation models for planning and deployment of wireless communication systems. In a typical wireless communications system, propagation models are key requirements for effective network planning, interference management, frequency assignments, and cell parameters evaluation (Alim, *et al.,* 2010).

In Nigeria, some wireless network providers use the European Cooperation in Science and Technology – COST 231-Hata (Abhayawardhana *et al.,* 2005) and Okumura-Hata (Okumura, 1968; Hata, 1980) models for radio network planning. However, these models are developed for areas other than the Nigerian environment, and a model that works well for a particular environment may not work efficiently in another environment with different geographical characteristics. The efficiency and accuracy of existing models are limited when they are deployed for an environment that is different in terms of geographical formation from that for which they have been designed. It should be noted that network performance is largely dependent on the design and the accuracy of the model used for the design. In the planning phase of a wireless network, an important objective is to predict the loss in signal strength in the geographical area, and to ensure that handoff points agree closely to prediction in the optimization phase, and coverage follows the design specifications such as on street received signal strength (RSS).

In practice, the measurement of signal strength and other key performance indicators (KPIs) of the network is considered a key requirement to providing efficient network design and reliable coverage for an area (Bavarva *et al.*, 2015). Path loss information are used as determinants for wireless communication systems to achieve optimal performance and effective network planning (Rappaport, 1996; Molisch, 2012).

On path loss modeling for mobile terminals in a residential area with a curved road, Sasaki *et al.* (2012) reported new prediction formulas for the attenuation coefficient along a straight road in NLOS scenario. For a more accurate prediction, the additional loss due to road angles along the curved road was derived and model validation was done via measurements campaign conducted in a different residential area.

Deme *et al.*, (2013) reported a study on the application of the COST 231 Hata model in Maiduguri, northern Nigeria. Comparison was made among the measured data, COST 231 Hata model and predictions based on the least squares function. The root mean square error (RMSE) of the COST 231 Hata model was found to be 5.33dB, which falls within the acceptable range of up to 6dB, and it was concluded that this model is acceptable in the metropolis of Maiduguri, Nigeria.

In the densely populated Alagbado axis of Lagos Nigeria, Ibhaze *et al.*, (2017) compared measured path loss with several empirical models at 2100MHz at three different receiver antenna heights. The Ericsson model showed the best performance with respect to the experimental data when compared with the Okumura-Hata model, which is mostly in use for network planning in the tested areas.

More recently, Sewalker and Seitz (2019) reported a comprehensive survey and design considerations on vehicle-to-pedestrian (V2P) communication for vulnerable road users, and noted that V2P systems use different communication technologies and diverse mechanisms to interact with the users. However, it should be noted that Sewalker and Seitz report is quite different from the current paper as the pathloss experienced along the curved road was completely overlooked. The ever-increasing rate of handoffs between cells within the same network leading to frequent dropped calls, network congestions and poor handovers in and around highways, require further investigation. Therefore, the need for a propagation model that best predicts the pathloss with minimal loss cannot be over emphasized.

There are several reports on propagation measurements and channel modeling, especially for rural, suburban and urban areas (Ogbulezie, *et al.*, 2013; Okorogu, *et al.*, 2013; Rakesh & Srivatsa, 2013; Kale & Jadhav, 2013; Faruk, Ayeni, & Adediran, 2013; Ajose & Imoize, 2013; Nwalozie, *et al.*, 2014; Ramanathan, 2014; Nnamani & Alumona, 2015; Imoize & Adegbite, 2018), but we have not been able to identify any comprehensive report on 4G LTE pathloss modeling for pedestrian and roads. In order to fill this gap, this paper is focused on developing a most suitable propagation model, based on actual field measurements, for accurate signal prediction in and around the major highways in Lagos, Nigeria.

The goal of this study is to measure and estimate pathloss in and around the investigated routes, compare measured data with existing pathloss models, select and modify the characteristics of the best-fit model for optimal performance in the tested areas, and validate the accuracy of the optimized model for improved pathloss prediction in similar environments. It is anticipated that the validated model would pose great benefits for the network providers, to further improve network coverage and capacity, thereby enhancing the quality of service for mobile users' satisfaction.

The remainder of this paper is organized as follows. Section 2 gives propagation models, Section 3 presents materials and methods, comprising of the investigated environments, experimental set-up, measurements procedure, and modeling parameters. Section 4 presents results and discussion. Finally, the conclusion to the paper is given in Section 5.

PROPAGATION MODELS USED FOR COMPARISON

A brief description of the propagation models selected for comparison with measured data is presented. These models include free space, flat earth, ECC-33, Okumura-Hata, Walfisch Ikegami, Ericsson, and Lee models.

Free space loss

The free space model assumes an ideal situation where there is a line-of-sight (LOS) between the transmitter and receiver. In reality, radio wave propagation path usually follows None-Line-of-Sight (NLOS) conditions with obstacles surrounding the path of propagation. The free space model has limited application in reality because it is based on ideal situations. Due to obstruction caused by moving vehicles on highways, free space loss find useful applications in the estimation of path loss between the mobile station (MS) and the base station (BS) on bridges and roads. In addition, fast fading should be taken into consideration due to the changes in the environment caused by the rapid movements of vehicles with a Rice distribution due to the LOS condition, while log-normal distribution is used to account for the effects of slow fading (Rappaport, 1996).

In free space, the power density S at a propagation distance d is as shown in (1). The effective propagation area of the receiver antenna, which affects the received power, is given in (2) and the received power density is given in (3). By combining (2) and (3), the power received is given in (4).

$$S = \frac{P_t G_t}{4\pi d^2} \quad (1)$$

where

P_t = Power Transmitted

G_t = Gain of the transmission antenna

$$A = \frac{\lambda^2 G_r}{4\pi} \quad (2)$$

where

λ = Wavelength

G_r = Gain of the receiver antenna.

$$S = \frac{P_r}{A} \quad (3)$$

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \quad (4)$$

Free space path loss is the ratio of the transmitted power to the received power, which is given in its simplified form in (5). In logarithmic form, the free space loss is given in (6).

$$L = \left(\frac{4\pi d}{\lambda}\right)^2 \quad (5)$$

$$L = 32.4 + 20\log_{10} f + 20\log_{10} d \quad (6)$$

where

$f = frequency\ in\ mega\ hertz$

$d = distance\ in\ kilometers$

Flat earth model

This model gives a greater performance for short distances and takes into account the line of sight (LOS) between the MS and the BS. These conditions are suitable for radio wave propagation on highways and bridges. During times of traffic on bridges, the flat earth model finds its application alongside with the free space loss model for estimating path loss on bridges due to the presence of direct and reflected rays (Chebil Ali, & Rafiqul, 2013). This model is valid for distances between the BS and the MS satisfying equation (7).

$$d > \frac{5k h_{bs} h_{ms}}{\pi} \quad (7)$$

where

$h_{BS}\ and\ h_{MS} = height\ of\ BS\ and\ height\ of\ MS\ respectively$

$k = propagation\ constant$

When there is no traffic on the bridge, the free space loss model is first applied to a minimum distance, at the distance when the free space loss is equal to the flat earth propagation loss; the flat earth model is used. This in turn eliminates discontinuities in the attenuation curve. It is also important to note that it has been verified analytically that the intersection of both curves occurs always after the minimum distance of application of the flat earth propagation model. The propagation attenuation for flat earth is given as in (8).

$$L_{fe} = 120 - 20\log h_{bs} - 20\log h_{ms} + 40\log d \quad (8)$$

The height of the MS is dependent on the type of vehicle considered, and for cars, a typical value of 1m is to be used. The additional loss due to vehicle is also considered for propagation in bridges.

Okumura-Hata model

This model is a combination of Okumura (1968) and Hata (1980) models. It is applicable to macro cell environments and it is an empirical model based on series of field measurements performed by Okumura in and around the city of Tokyo, with results made public in graphical formats. The application of these measurements by Hata further resulted in a set of equations with additional correction factors for application in other terrains. Okumura-Hata model can be applied in quasi-smooth terrains in an urban area without the additional correction factors. Parameters for the Okumura-Hata model are as follows:

Frequency (f): 150MHz-1500MHz, with possible extension from 1500MHz-2000MHz, distance between MS and BS (d): 1-20km, transmitter antenna height H_b: 3-200m, receiver antenna height H_m: 1-10m. The governing equation for the Okumura-Hata model is given in (9). The mobile station antenna height correction factor is given in (10) and (11) and the parameter set for the Okumura-Hata model is as shown in Table 1.

$$L_{dB} = A + B\log_{10}(f) - 13.82\log_{10}(H_b) - a(H_m) + [44.9 - 6.55\log_{10}(Hb)]\log_{10}(d) + l_{others} \quad (9)$$

where

$f = frequency\ in\ Mega\ Hertz$

$h_b = height\ of\ base\ station\ antenna\ in\ meters$

$a(H_m) = mobile\ antenna\ correction\ factor$

$d = distance\ between\ the\ BS\ and\ MS\ in\ kilometers$

$l_{other} = additional\ correction\ factor$
$for\ area\ type\ correction$

For a small or medium city,

$$a(H_m) = [1.1\log_{10}(f) - 0.7]H_m - [1.56\log_{10}(f) - 0.8] \quad (10)$$

For a large city,

$$a(H_m) = \begin{cases} 8.29[\log_{10}(1.54H_m)]^2 - 11: & f \le 200MHz \\ 3.20[\log_{10}(11.75H_m)]^2 - 4.97: & f \ge 400MHz \end{cases} \quad (11)$$

where,
$H_m\ is\ the\ mobile\ station(MS)height\ in\ meters$

given as $1 \le H_m \le 10$.

Table 1: Parameter set for Okumura-Hata model

Parameters	Parameter set 1	Parameter set 2
City type	Small/medium city	Large city
Frequency	900MHz	1800MHz
BTS height	30m	30m
MS height	1.5m	1.8m
A	69.55	46.30
B	26.16	33.90

As shown in Table 1, letters A and B are dependent on the frequency in MHz as shown in (12) and (13).

$$A = \begin{cases} 69.55 & f = 150 - 1500MHz \\ 46.30 & f = 1500 - 2000MHz \end{cases} \quad (12)$$

$$B = \begin{cases} 26.16 & f = 150 - 1500MHz \\ 33.90 & f = 1500 - 2000MHz \end{cases} \quad (13)$$

The extension of the frequency range of this model up to 2000MHz makes it readily applicable to GSM1800 and some systems operating at frequencies from 1500MHz-2000MHz. However, this model does not give proper account for reflections and shadowing effects.

Walfisch-Ikegami model

This empirical propagation model is a combination of the works of Walfisch and Ikegami (Ikegami & Yoshida, 1980; Walfisch & Bertoni, 1988), and statistical tuning of this model have been well reported in (Rozal & Pelaes, 2007; Tahat & Taha, 2012). This model is applicable to both micro and macro cells and valid for the frequency range 800MHz to 2000MHz. The base station antenna height ranges from 4-50metres, mobile antenna height from 1-3metres and the distance between the transmitter and receiver is 20-5000metres. The Walfisch-Ikegami model has been categorized into two cases.

Case1: Line of sight (LOS) condition:

The path loss prediction equation for the LOS condition is given in (14).

$$L = 42.6 + 20\log_{10} d + 20\log_{10} f \qquad (14)$$

where

$d = distance\ in\ kilometers(km)$

$f = frequency\ in\ mega\ hertz\ (MHz)$

Case 2: None line of sight (NLOS) condition:

The path loss prediction for the NLOS condition is given in (15).

$$L = 32.4 + 20\log_{10} d + 20\log_{10} f + l_{rts} + l_{msd} \qquad (15)$$

where

l_{rts} = rooftop - street diffraction and scatter loss

l_{msd} = multiscreen diffraction loss

The path loss for the non-line-of-sight condition consist of three components: the rooftop street diffraction and scatter loss, multiscreen diffraction loss, and the free space loss as given in (16)-(24).

$$L_0 = 32.4 + 20\log_{10} d + 20\log_{10} f \qquad (16)$$

$$L = \begin{cases} L_0 + l_{rts} + l_{msd}: & l_{rts} + l_{msd} > 0 \\ L_0: & l_{rts} + l_{msd} \le 0 \end{cases} \qquad (17)$$

The rooftop-street diffraction and scatter loss is the loss that occurs when the radio wave is transmitted from the closet rooftop to the receiver.

$$l_{rts} = -16.9 - 10\log_{10} f - 20\log_{10} \left(h_{roof} - h_{RX}\right) - L_{ori} \qquad (18)$$

where

L_{ori} (φ) = street orientation with respect to direct radio path in degrees

$$L_{ori}(\varphi) = \begin{cases} -10 + 0.354\varphi: & for\ 0 \le \varphi < 35^0 \\ 2.5 + 0.075(\varphi - 35): & for\ 35 < \varphi < 55^0 \\ 4.0 - 0.114(\varphi - 55): & for\ 55 \le \varphi < 90^0 \end{cases} \qquad (19)$$

The multiscreen diffraction loss occurs when the radio wave is propagated from the base transceiver station (BS) to the rooftop, which is closest to the mobile station (MS).

$$L_{msd} = L_{bsh} + K_a + K_d + \log_{10} d + K_f 10\log_{10} f - 9\log b \qquad (20)$$

where

$$L_{bsh} = \begin{cases} -18(1 + (h_{BTS} - h_{roof}): & h_{BTS} > h_{roof} \\ 0: & h_{BTS} < h_{roof} \end{cases} \qquad (21)$$

$$K_a = \begin{cases} 18: & h_{BTS} > h_{roof} \\ 54 - 0.8(h_{BTS} - h_{roof}): & d \ge 0.5km\ and\ h_{BTS} \le h_{roof} \\ 54 - 0.8(h_{BTS} - h_{roof})\frac{d}{0.5}: & d < 0.5km\ and\ h_{BTS} \le h_{roof} \end{cases} \qquad (22)$$

$$K_d = \begin{cases} 18: & h_{BTS} > h_{roof} \\ 18 - 15\left(\frac{h_{BTS} - h_{roof}}{h_{roof} - h_{MS}}\right): & h_{BTS} < h_{roof} \end{cases} \qquad (23)$$

$$K_f = -4\begin{cases} 0.7\left(\frac{f}{925} - 1\right): & medium\ sized\ city\ and\ suburban\ centres \\ 1.5\left(\frac{f}{925} - 1\right): & urban\ centres \end{cases} \qquad (24)$$

The parameter K_a increases path loss if the BS is below the rooftop while the parameter K_d and K_f are used to make adjustment correlation between the distance and frequency with the multiscreen diffraction.

Ericsson model

This model is the implementation of the Hata model, and it allows for the modification of model parameters according to the propagation environment. The model is valid for use at 900MHz, and it can be extended for use at 1800MHz by the addition of 8.5dB extra path loss at each distance covered (Bernhardt, 1989;Milanovic, Rimac-Drlje, & Bejuk, 2007; Mollel & Kisangiri, 2014). The path loss equation for the Ericsson model is given in (25). The parameters a_0, a_1, a_2 and a_3 could be modified for improved fitting under specific propagation conditions as shown in Table 2.

$$L_{er} = a_0 + a_1 \log_{10} d + a_2 \log_{10} h_t + a_3 \log_{10} h_t . \log_{10} d - 3.2[\log_{10}(11.75 h_r)]^2 + g(f) \quad (25)$$

where

$$g(f) = 44.49 \log_{10} f - 4.78[\log_{10} f]^2 \quad (26)$$

f = frequency in MHz
h_t = transmitter antenna height in metres
h_r = receiver antenna height in metres

Table 2: Default values of parameters for the Ericsson model

Environment	a_0	a_1	a_2	a_3
Urban	36.20	30.20	-12.0	0.1
Suburban	43.20	68.93	12.0	0.1
Rural	45.95	100.6	12.0	0.1

ECC-33 model

The extensive measurements reported by Okumura were carried out in and around the city of Tokyo in Japan. Okumura subdivided the urban areas into two categories namely; "large city" and "medium city". Okumura provided correction factors for the application of the model to suburban and open areas. The electronic communication committee (ECC) extrapolated these original measurements provided by Okumura and modified its assumptions to develop an empirical model now referred to as the ECC-33 model (Abhayawardhana, *et al.*, 2005). The path loss equation for the ECC-33 model is given in (27).

$$L_{ecc} = A_{fs} + A_{bm} - G_b - G_m \quad (27)$$

where A_{fs}, A_{bm}, G_b and G_m are the free space attenuation, the basic median path loss, the base station height gain factor and the terminal receiver antenna height gain factor, respectively, are defined in (28)-(31).

$$A_{fs} = 92.4 + 20 \log_{10} d + 20 \log_{10} f \quad (28)$$

$$A_{bm} = 20.41 + 9.83 \log_{10} d + 7.894 \log_{10} f + 9.56[\log_{10} f]^2 \quad (29)$$

$$G_b = \{\log_{10}(h_b/200)\}\{13.958 + 5.8[\log_{10} d]^2\} \quad (30)$$

For medium city environments,

$$G_m = [42.57 + 13.7 \log_{10} f].[\log_{10} h_r - 0.585] \quad (31)$$

For large city environments,

$$G_m = 0.759,\ h_r = 1.892$$

where

f = frequency in GHz
d = distance between transmitter and receiver in km
h_b = base station antenna height in metres
h_r = receiver antenna height in metre

Lee model

Originally, the Lee model (Lee, 1980) was developed for radio waves propagation at 900MHz on flat terrains but recently, extensive data collection and propagation model validation have demonstrated that this model is applicable for frequencies up to 2GHz. The Lee model can be used for either point-to-point propagation or point-to-area propagation, and it is used to predict the path loss in urban, suburban, rural, and free space areas. The governing equations for the Lee model are given in (32)-(37).

Scenario 1: Urban path loss

$$L = 123.77 + 30.5 \log_{10} d + 10n\left(\log_{10}\left(\frac{f}{900}\right)\right) - \alpha_0 \quad (32)$$

Scenario 2: Suburban path loss

$$L = 99.86 + 38.4 \log_{10} d + 10n\left(\log_{10}\left(\frac{f}{900}\right)\right) - \alpha_0 \quad (33)$$

Scenario 3: Rural path loss

$$L = 86.12 + 43.5 \log_{10} d + 10n\left(\log_{10}\left(\frac{f}{900}\right)\right) - \alpha_0 \quad (34)$$

Scenario 4: Free space loss

$$L = 96.92 + 20 \log_{10} d + 10n\left(\log_{10}\left(\frac{f}{900}\right)\right) - \alpha_0 \quad (35)$$

where n is 3 for urban areas investigated, a_0 is the correction factor given as follows:

$$\alpha_0 = \alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5 \quad (36)$$

$$\alpha_1 = (h_b/30.48)^2$$
$$\alpha_2 = (h_m/3)^k$$
$$\alpha_3 = (P_t/10)^2$$
$$\alpha_4 = (G_b/4)$$
$$\alpha_5 = G_m$$

where k is chosen to be equal to 2.

$d = transmitter - receiver\ distance\ in\ km$

$f = transmitter\ frequency\ in\ MHz$

$f_c = carrier\ frequency\ in\ MHz$

$$n = \begin{cases} 2: & for\ fc < 450MHz\ in\ suburban\ and\ open\ area \\ 3: & for\ f_c > 450MHz\ in\ urban\ areas \end{cases} \quad (37)$$

$d_0 = nominal\ distace\ in\ km$

$\alpha_0 = correction\ factor$

$h_m = mobile\ antenna\ height$

$h_b = base\ station\ antenna\ height$

$P_t = Transmitter\ power$

$G_b = transmitter\ gain$

$G_m = receiver\ gain$

MATERIALS AND METHOD

Investigated environments

The extensive propagation measurements were carried out in Lagos Nigeria, one of the largest cities in Africa with an estimated population of over 22 million. It has tropical climate with an average annual rainfall of 1693mm, and located within the South-West geopolitical zone of Nigeria. Lagos has quality road networks that are highly congested in peak hours, due partly to the high population.

Experimental setup and measurements

Propagation measurements were taken at 1800MHz, from three evolved node base stations (eNodeBs) located along three different routes in Lagos, and the reference signal received power (RSRP) was measured for the three-eNodeBs, using Huawei technologies drive test equipment. These consist of a user equipment (UE), Genex probe, global positioning system (GPS) module, LTE modem, and a personal computer system. The LTE software was installed on the computer for recording user equipment readings and for post drive test processing. The user equipment comprises of Huawei E57765-601 mobile Wi-Fi,a high-speed packet access mobile hotspot, and it supports 1800MHz, and 2600MHz frequency division duplex (FDD), and 2300MHz time division duplex (TDD). The GPS module is connected to the computer, and it helps to determine the coordinates of the eNodeBs as shown in Table 3.

The experimental setup is as shown in (Imoize *et al.*, 2019), and it comprises of the mobile antenna positioned at a near constant height of 3m in single site verification (SSV). As the drive test vehicle moves away from the fixed eNodeB at an average speed of 30km/h but not exceeding 40km/h (Keawbunsong *et al.*, 2018), the reference signal received power (RSRP) from the three eNodeBs were collected for a propagation distance of up to 2km, at an interval of 50m from a reference distance (d_0) away from each eNodeB.

Table 3: Coordinates of the tested eNodeBs

Tested eNodeBs	Longitude	Latitude
eNodeB 1 located along route 1	3.37737146	6.51523044
eNodeB 2 located along route 2	3.44710083	6.43481388
eNodeB 3 located along route 3	3.36693333	6.55639500

Measurements and modeling parameters

The operating frequency was maintained at 1800MHz with a transmitter-receiver distance of 2km, the base station height is about 30m, and the receiver antenna height is about 3m. The average building height was taken to be 15m, building-to-building distance was assumed to be 20m, and street width was taken to be about 25m (Ibhaze *et al.*, 2017; Imoize & Dosunmu, 2018). Correction factors for shadowing effects: 10.6dB in urban and 8.2dB in sub-urban and rural environments (Erceg *et al.*, 1999). A summary of the measurements and modeling parameters is as shown in Table 4. It should be noted that some of the models have both LOS and NLOS, and the NLOS condition is considered in this paper. The measured path loss was used as a reference model for comparison, and the free space loss was considered in line with (Rappaport, 1996; Laiho, Wacker, & Novosad, 2006; Mishra, 2007).

Table 4: Measurements and modeling parameters

Parameters	values
Base station transmitter power	43dBm
Mobile transmitter power	30dBm
Transmitter antenna height	30m in urban area
Receiver antenna height	3m
Operation frequency	1800MHz
Building to building distance	20m
Average building height	15m
Street width	25m
Street orientation angle	$30°$ in urban area
Correction for shadowing	10.6dB in urban area
Distance between Tx-Rx	2km

RESULTS AND DISCUSSION

Pathloss of measured data

The signal strength for each of the route measured at a distance d (km) is converted to path loss PL_m (dB) (Rappaport, 1996), given in (38).

$$Path\ Loss PL_m(dB) = EIRP_t - P_r(dBm) \quad (38)$$

where

$EIRP_t = Effective\ isotropic\ radiated\ power\ in\ dBm$

$P_r = Mean\ reference\ signal\ received\ power (RSRP) in\ dBm$

The effective isotropic radiated power $EIRP_t$ (dBm) is defined as the sum amount of power density that is transmitted from the base station into the propagation medium given in (39).

$$EIRP_t = P_T + G_T - L_T \quad (39)$$

where

$P_T = Transmitter\ power\ in\ (dBm)$

$G_T = Transmitter\ antenna\ gain\ in\ (dBi)$

$L_T = Total\ Transmission\ losses\ (dB)$

The manufacturer of the equipment specifies the transmitter antenna gain in line with standard specifications. The total transmission loss between the transmitter antenna can be accounted for by transmitter losses, receiver losses, miscellaneous losses (fading margin, and antenna body loss), and cable loss between the base station antenna connector and the antenna (Mishra, 2007). The numerical values of the transmitter power, transmitter antenna gain and the total transmission loss are given as follows.

$P_T = 43dBm, G_T = 18dBi, \ L_T = 22dB,$

Substituting these numerical values into (39) gives:

$EIRP_t = 43 + 18 - 22$

$EIRP_t = 39dBm$

Here, path loss measured in dB is derived by substituting the value of the $EIRP_t$ (dBm) and the received level P_r (dBm) in (38). A comparison of the mean RSRP measured along routes 1, 2, and 3, respectively, are as shown in Figure 1. The pathloss of measured data along the routes and a comparison of measured pathloss with free space loss is as shown in Figures 2 and 3, respectively.

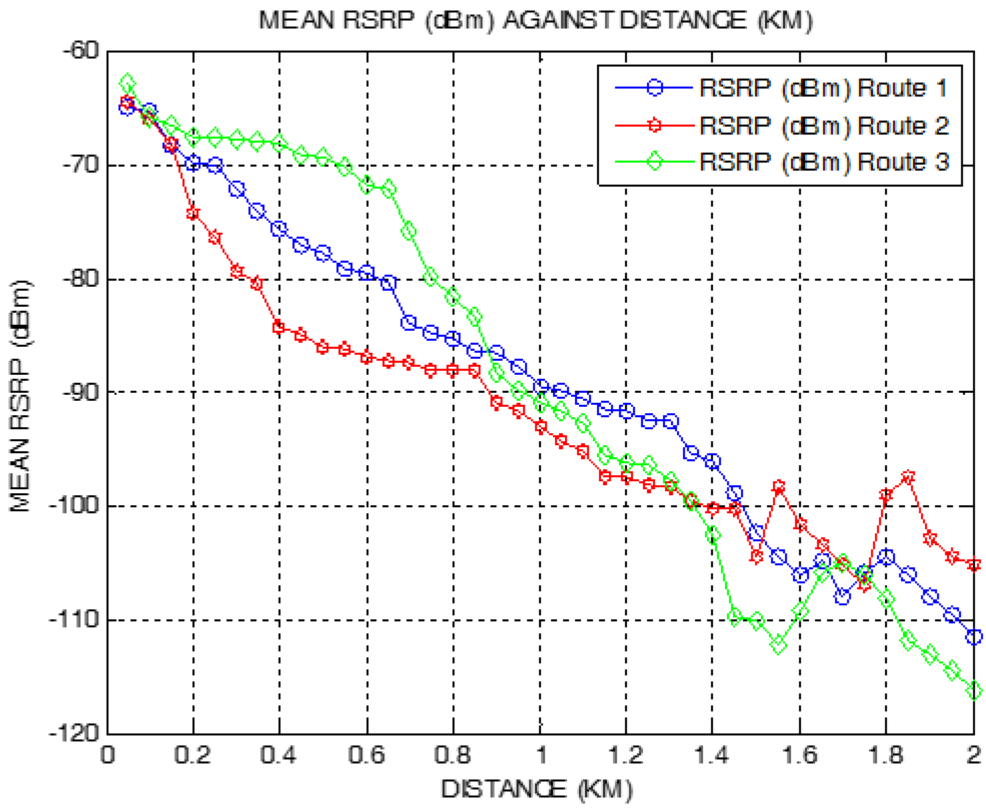

Figure 1. Measured reference signal received power along investigated routes

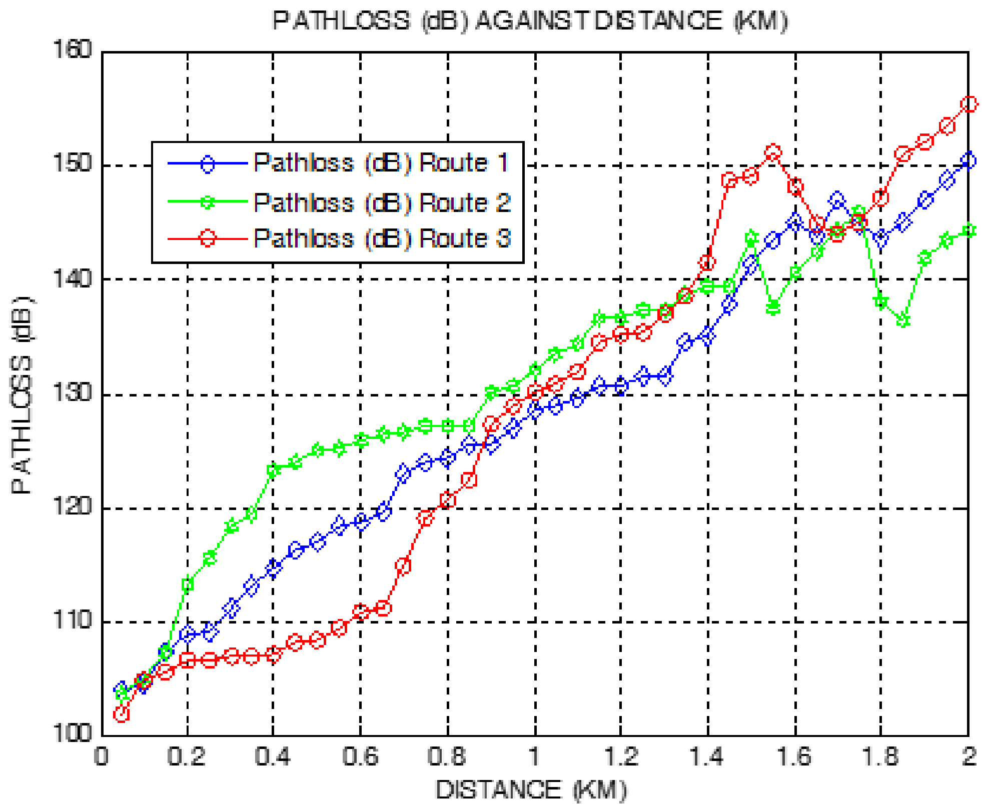

Figure 2. Measured pathloss along investigated routes

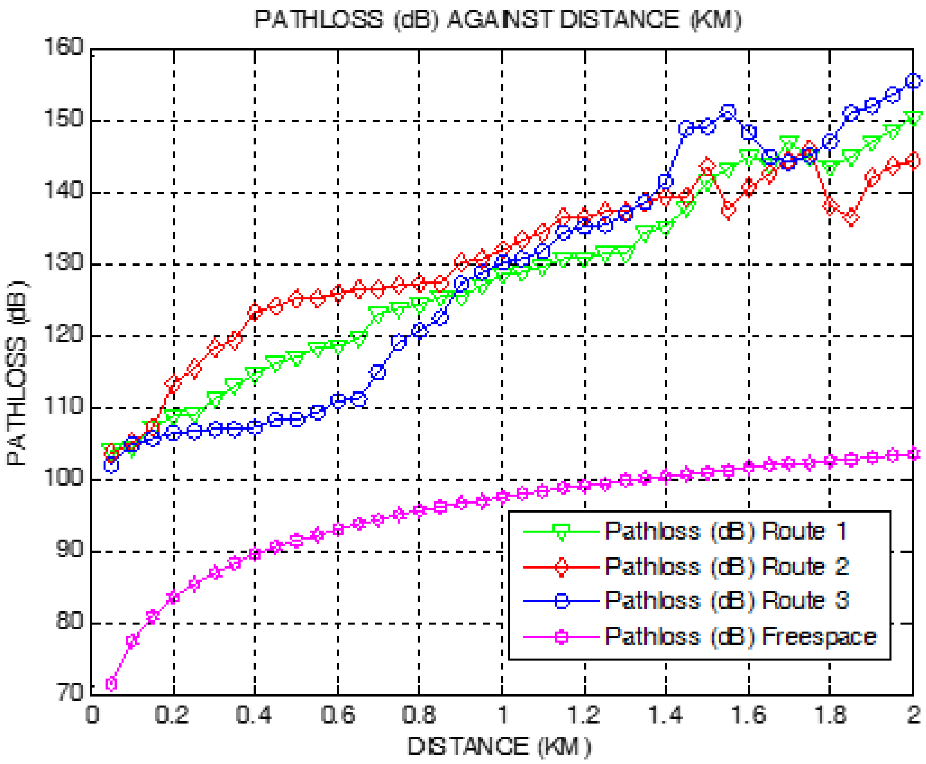

Figure 3. Comparison of measured pathloss against free space loss

Comparison of measured and predicted pathloss

The measured pathloss in the investigated routes is compared with the predicted free space loss, flat earth, ECC-33, Okumura-Hata, Walfisch Ikegami, Ericsson, and Lee models. These models have been selected for comparison in line with the frequency range for which they are most valid. Although, there are other empirical models that are valid at 1800MHz, these models are selected due to their ease of applicability and availability of correction factors. Results showing comparative descriptions of the measured and predicted pathloss for the investigated routes 1, 2, and 3 are as shown in Figures 4, 5, and 6, respectively.

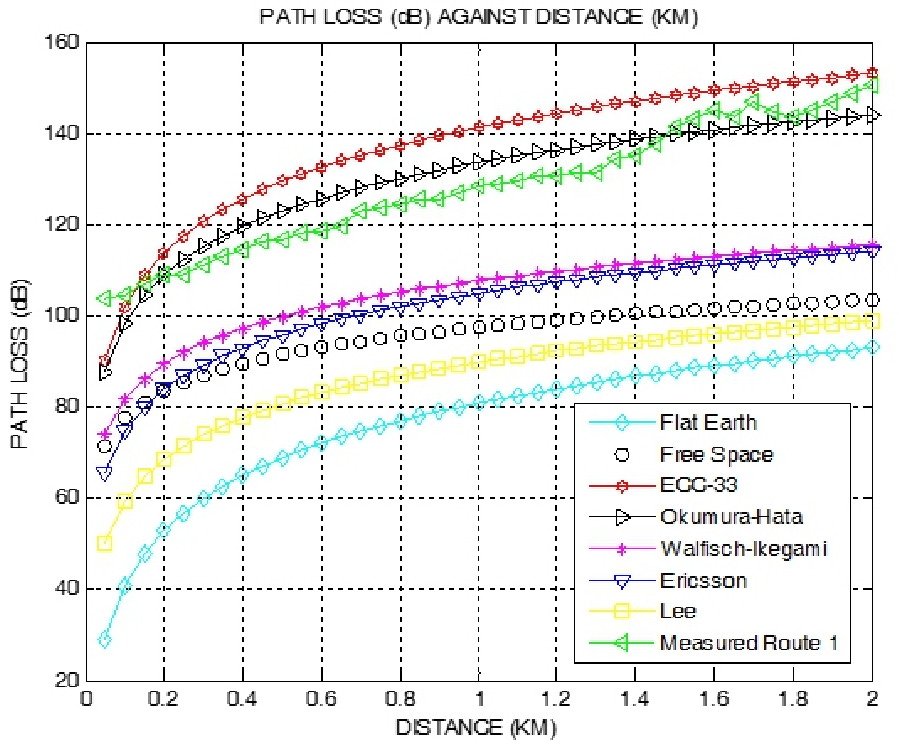

Figure 4. Comparison of measured and predicted pathloss along route 1

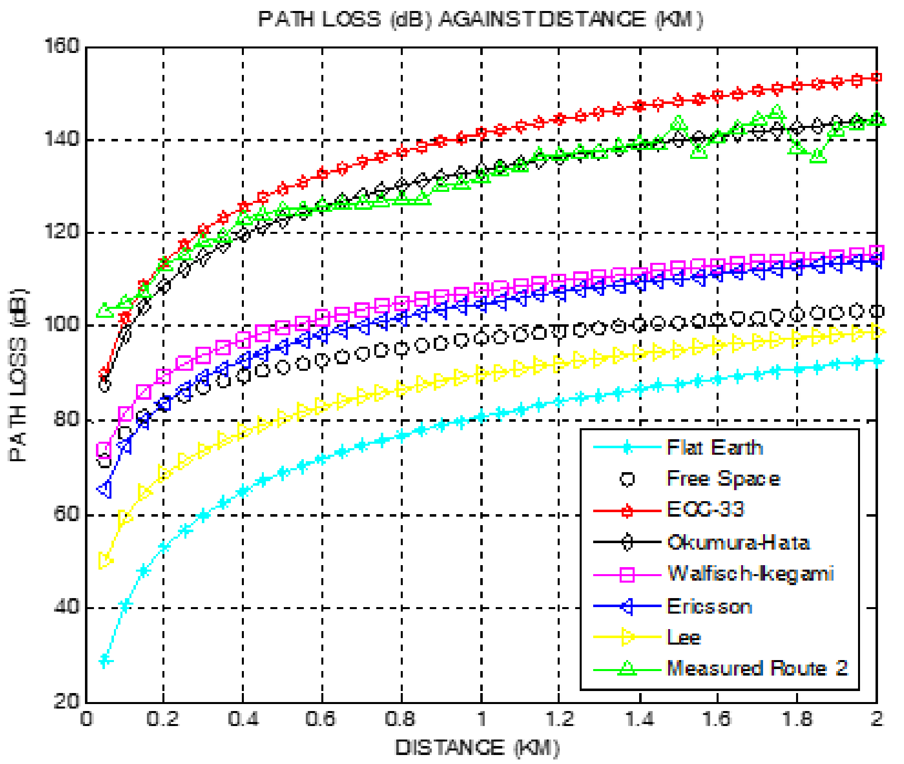

Figure 5. Comparison of measured and predicted pathloss along route 2

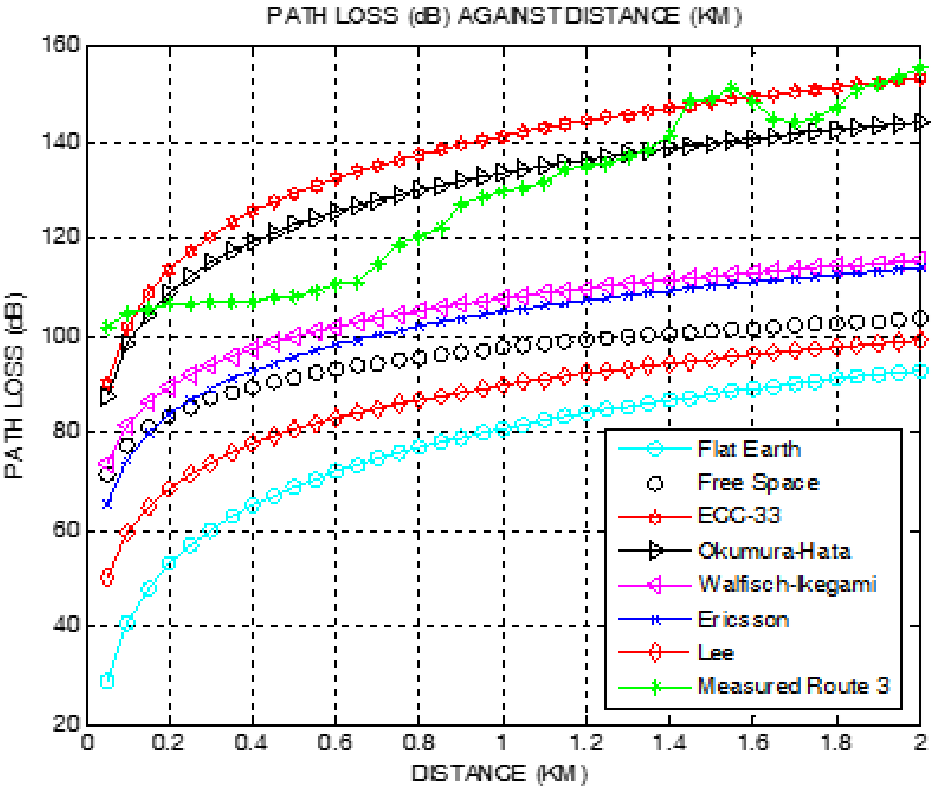

Figure 6. Comparison of measured and predicted pathloss along route 3

4.3 Statistical Analysis

A statistical approach is adopted to analyze experimental and predicted data as depicted in Tables 5 and 6. In addition, the standard deviation errors (Stroud and Booth, 2013), which are relevant to determining the best-fit propagation model are as shown in (40)-(41).

$$\sigma_{error} = |\sigma_{measured} - \sigma_{predicted}| \quad (40)$$

$$\delta_{error} = \left(\frac{|\sigma_{measured} - \sigma_{predicted}|}{\sigma_{measured}}\right) \times 100\% \quad (41)$$

where

$\sigma = Standard\ Deviation\ in\ dB$

$\delta_{error} = Standard\ deviation\ Error\ in\ \%$

$\sigma_{error} = Standard\ Deviation\ Error\ in\ dB$

$\sigma_{measured} = Standard\ Deviation\ of\ Measured\ Path\ Loss\ in\ dB$

$\sigma_{predicted} = Standard\ Deviation\ of\ Model\ Predicted\ Path\ Loss\ in\ dB$

Pathloss Exponent

The path loss exponent n, is obtained using linear regression analysis. It is expressed similar to (Ajose & Imoize, 2013) in (42).

$$e(n) = \sum_{i=1}^{k}[PL_m(d) - PL_r(d)]^2 \quad (42)$$

where

$$PL_r(d) = PL(d_0) + 10n\log(d/d_0) \quad (43)$$

Substituting (43) into (42) gives (44).

$$e(n) = \sum_{i=1}^{k}[PL_m(d) - PL(d_0) + 10n\log(d/d_0)]^2 \quad (44)$$

The numerical value of n, which reduces the mean square error (MSE) to a minimum value is obtained by equating the derivative of $e(n)$ with respect to n to zero as given in (45).

$$\frac{de(n)}{dn} = \sum_{i=1}^{k}[PL_m(d) - PL(d_0)] - \sum_{i=1}^{k} 10n\log\left({}^{d}/_{d_0}\right) = 0 \quad (45)$$

$$\sum_{i=1}^{k}[PL_m(d) - PL(d_0)] - \sum_{i=1}^{k} 10n\log\left({}^{d}/_{d_0}\right) = 0$$

Making n the subject of the formula from (45) gives (46).

Table 5: Basic statistics of measured path loss compared with predicted pathloss

Routes	Data statistics	Measured Path loss (dB)	Free space model (dB)	Flat earth model (dB)	Okumura-Hata model (dB)	Walfisch-Ikegami model (dB)	Ericsson model (dB)	ECC-33 model (dB)	Lee model (dB)
Route 1	Mean	128.79	95.44	76.79	129.91	105.02	101.86	137.21	86.69
	Median	128.86	97.71	81.33	133.92	107.98	105.31	141.70	90.17
	Mode	150.50	103.53	92.96	144.15	115.53	114.12	153.13	99.02
	Standard Dev	13.08	7.57	15.17	13.36	9.86	11.51	14.94	11.56
	Range	46.50	29.54	64.08	52.03	41.65	44.82	63.09	48.86
Route 2	Mean	130.58	95.44	76.79	129.91	105.02	101.86	137.21	86.69
	Median	132.69	97.71	81.33	133.92	107.98	105.31	141.70	90.17
	Mode	145.87	103.53	92.96	144.15	115.53	114.12	153.13	99.02
	Standard Dev.	11.12	7.57	15.17	13.36	9.86	11.51	14.94	11.56
	Range	42.34	29.54	64.08	52.03	41.65	44.82	63.09	48.86
Route 3	Mean	128.29	93.10	72.11	125.79	101.98	98.31	132.60	83.12
	Median	130.38	95.29	76.48	129.64	104.82	101.62	86.45	86.46
	Mode	155.29	71.48	28.87	87.72	73.88	65.51	90.04	50.16
	Standard Dev.	17.58	7.39	14.77	13.01	9.60	11.21	14.55	11.26
	Range	53.44	29.54	59.08	52.03	38.41	44.82	58.18	45.05

Table 6: Standard deviation and percentage errors of path loss models.

Routes	Data statistics	Measured Path loss (dB)	Free space model (dB)	Flat earth model (dB)	Okumura-Hata model (dB)	Walfisch-Ikegami model (dB)	Ericsson model (dB)	ECC-33 model (dB)	Lee model (dB)
Route 1	σ (dB)	13.08	7.57	15.17	13.36	9.86	11.51	14.94	11.56
	σ_{error} (dB)		5.49	2.09	0.28	3.22	1.57	1.86	1.51
	δ_{error} (%)		42.00	15.98	2.00	24.51	12.00	14.21	11.56
Route 2	σ (dB)	11.12	7.57	15.17	13.36	9.86	11.51	14.94	11.56
	σ_{error} (dB)		3.54	4.04	2.23	1.26	1.57	3.82	0.44
	δ_{error} (%)		31.80	36.39	20.11	11.34	34.81	34.30	4.00
Route 3	σ (dB)	17.58	7.57	15.17	13.36	9.86	11.51	14.94	11.56
	σ_{error} (dB)		10.00	2.42	2.24	7.73	6.07	2.64	6.02
	δ_{error} (%)		56.57	13.73	12.72	43.93	34.54	15.05	34.22

$$n = \frac{\sum_{i=1}^{k}[PL_m(d) - PL(d_0)]}{\sum_{i=1}^{k} 10n \log\left(d/d_0\right)} \quad (46)$$

where

$PL_m(d) = Measured\ Path\ loss\ in\ dB\ at\ a\ distance\ d\ in\ Km$

$PL(d_0) = modelled\ by\ the\ Free\ space\ path\ loss\ in\ dB$

$PL(d_0) = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right)$, for all areas.

where

$d_0 = Reference\ distance\ taken\ to\ be\ 0.05km\ (50m).$

$\lambda = Wavelength\ in\ meters.$

The value of λ can be obtained, using (47).

$$\lambda = \frac{c}{f} \quad (47)$$

where

$c = Speed\ of\ Light\ 3 \times 10^8$

$f = Operating\ frequency\ 1800MHz$

$$\lambda = \frac{3 \times 10^8}{1800 \times 10^6} = 0.167m$$

Therefore, $PL(d_0) = 20\log_{10}\left(\frac{4\pi \times 50}{0.167}\right) = 71.51dB.$

The values of $d = 0.05, 0.10, 0.15, 0.20, ..., 2km$ have been used to calculate the respective values of $PL(d_0)$ along the investigated routes. This is very useful to calculating values of the path loss exponent n along each route, as given in (48)-(50).The calculated pathloss exponents are as shown in Table 7. The values of pathloss exponents agree closely with the specified range of values of pathloss exponents for an urban cellular radio environment as shown in Table 8 (Rappaport, 1996).

$$\text{Route 1}, n = \frac{\sum_{i=1}^{k}[PL_m(d) - PL(d_0)]}{\sum_{i=1}^{k} 10n \log\left(d/d_0\right)} = \frac{1311.01}{479.12} = 2.74 \quad (48)$$

$$\text{Route 2}, n = \frac{\sum_{i=1}^{k}[PL_m(d) - PL(d_0)]}{\sum_{i=1}^{k} 10n \log\left(d/d_0\right)} = \frac{1404.62}{479.12} = 2.93 \quad (49)$$

$$\text{Route 3}, = \frac{\sum_{i=1}^{k}[PL_m(d) - PL(d_0)]}{\sum_{i=1}^{k} 10n \log\left(d/d_0\right)} = \frac{1313.02}{479.12} = 2.74 \quad (50)$$

Table 7: Path loss exponents of measured data

Measurement Routes	Pathloss exponent (n)
Measurements along route 1	2.74
Measurements along route 2	2.93
Measurements along route 3	2.74

Table 8: Path loss exponent for different environments

Environment	Path loss exponent (n)
Free Space	2
Urban area cellular radio	2.7-3.5
In building Line-of-sight	1.6-1.8
Obstructed in Building	4-6
Obstructed factory	2-3

Best model selection

Pathloss of measured data have been compared against predicted pathloss at 1800MHz. The predicted models used for our comparison include; free space model, flat earth mode, Okumura-Hata, Walfisch-Ikegami, Ericsson, ECC-33, and the Lee models. Among the contenders, the free space, Flat Earth, Walfisch-Ikegami, Ericsson, and the Lee models grossly over predict the path loss of measured data along the tested routes with very high root mean square errors (RMSE).

The flat earth model showed excess prediction of the path loss with the highest RMSEs of 51.77dB, 54.03dB and 52.16dB along routes 1, 2 and 3, respectively. The free space, Walfisch-Ikegami, Lee, and the Ericsson models followed this trend. Therefore, these models were not selected as most suitable for reasonable pathloss prediction along the investigated routes. The ECC-33 model showed a slightly better performance with RMSEs values of 10.58dB, 8.18dB, and 12.15dB along route 1, 2, and 3, respectively. However, these RMSEs are relatively higher as compared with those of Okumura-Hata model, and this model is not favored as the best candidate. Overall, the Okumura-Hata model showed the best performance with RMSEs values of 7.42dB, 7.63dB and 9.64dB along routes 1, 2, and 3, respectively. Therefore, it was taken as the best model for the prediction of path loss along the measured routes. In other to improve on the prediction accuracy of the Okumura-Hata model, the need to modify the model becomes imperative (Ajose & Imoize, 2013).

Modification of Okumura-Hata model

The modification of Okumura-Hata model was carried out using the least square algorithm reported in a related work (Shi *et al.*, 2015). The path loss predicted by the Okumura-Hata model is given in (51).

$$PL_{Okumura\text{-}hata} = 46.30+33.90\log_{10}(f)-13.82\log_{10}(H_b) - a(H_m) + [44.9 - 6.55\log_{10}(H_b)]\log_{10}(d) + l_{others} \quad (51)$$

where

$f = frequency\ in\ Mega\ Hertz$

$h_b = height\ of\ base\ station\ antenna\ in\ meters$

$a(H_m) = mobile\ antenna\ correction\ factor$

$d = distance\ between\ the\ BTS\ and\ MS\ in\ kilometers$

$l_{other} = additional\ correction\ factor\ for\ area\ type\ correction$

The receiver height correction factor $a(H_m)$ is given in (52) as; For a large city,

$$a(H_m) = \{3.20[log_{10}(11.75h_m)]^2 - 4.97: \ f \geq 400MHz \quad (52)$$

where h_m is the mobile station (MS) height in meters.

The coefficients of (51) were modified using the least square algorithm.

$$L=46.30+33.90\log_{10}(f)-13.82\log_{10}(H_b) - (3.20[\log_{10}(11.75H_m)]^2-4.97) + [44.9-6.55\log_{10}(H_b)]\log_{10}(d) \quad (53)$$

$$L=a_1+b_1\log_{10}(f)-c_1\log_{10}(H_b) - (d_1[\log_{10}(11.75H_m)]2-e_1) + [f_1-g_1\log_{10}(H_b)]\log_{10}(d) \quad (54)$$

where L is the path loss of Okumura-Hata model and a_1, b_1, c_1, d_1, f_1, and g_1 are the corresponding coefficients. Assuming that the total number of the receive signal received power (RSRP) is N and the path loss corresponding to the measured distance n is $L(n)$, and the instantaneous frequency is $f(n)$.

Applying the least square algorithm, the objective function of (54) is obtained as presented in (55).

$$F(a_1,b_1,c_1,d_1,e_1,f_1g_1) = \frac{1}{N}\sum_{n=1}^{N}[L(n)-a_1 - b_1\, log_{10}(f) + c_1\, log_{10}(H_b) + (d_1[log_{10}(11.75H_m)]^2 - e_1) - [f_1 - g_1\, log_{10}(H_b)]\, log_{10}(d)^2] \quad (55)$$

The partial derivative of the objective function in (55) is obtained with respect to a_1 as expressed in (56).

$$\frac{\partial F}{\partial a_1} = -\frac{2}{N}\sum_{n=1}^{N}[L(n) - a_1 - b_1\, log_{10}(f) + c_1\, log_{10}(H_b) + (d_1[log_{10}(11.75H_m)]^2 - e_1)\_[f_1 - g_1\, log_{10}(H_b)]\, log_{10}(d)] = 0 \quad (56)$$

Applying the same procedure for deriving (56), the partial derivatives of the objective function with respect to $b_1, c_1, d_1, e_1, f_1\ and\ g_1$ $\left(\frac{\partial F}{\partial b_1}, \frac{\partial F}{\partial c_1}, \frac{\partial F}{\partial d_1}, \frac{\partial F}{\partial e_1}, \frac{\partial F}{\partial f_1}\ and\ \frac{\partial F}{\partial g_1}\right)$ are obtained. The partial derivative of the objective function is expressed in a simplified matrix format as presented in (57).

$$M \cdot \begin{bmatrix} a_1 \\ b_1 \\ c_1 \\ d_1 \\ e_1 \\ f_1 \\ g_1 \end{bmatrix} = \begin{bmatrix} -\sum_{n=1}^{N} L(n) \\ -\sum_{n=1}^{N} \log f(n) \cdot L(n) \\ -\sum_{n=1}^{N} \log h_b(n) . L(n) \\ -\sum_{n=1}^{N} \log(11.75h_r(n)) \cdot L(n) \\ -\sum_{n=1}^{N} L(n) \\ -\sum_{n=1}^{n} L(n) \\ -\sum_{n=1}^{N} \log h_b(n) \cdot \log d(n) \cdot L(n) \end{bmatrix} \quad (57)$$

where M is a 7 x 7 dimensional matrix and $\{m_{uj}\}(i,j = 1,2,...7)$ are given in (58)-(61).

$$m_{11} = -N \quad (58)$$

$$m_{12} = -\sum_1^N \log f(n) \quad (59)$$

$$m_{13} = -\sum_{n=1}^{N} \log h_b(n) \quad (60)$$

$$m_{14} - \sum_{n=1}^{N} \log(11.75h_r(n)) \quad (61)$$

In order to solve (57), the optimal solution based on the least square algorithm is obtained as expressed in (62).

$$\begin{bmatrix} a_1 \\ b_1 \\ c_1 \\ d_1 \\ e_1 \\ f_1 \\ g_1 \end{bmatrix} = \begin{bmatrix} a_{1opt} \\ b_{1opt} \\ c_{1opt} \\ d_{1opt} \\ e_{1opt} \\ f_{1opt} \\ g_{1opt} \end{bmatrix} = M^{-1} \cdot \begin{bmatrix} -\sum_{n=1}^{N} L(n) \\ -\sum_{n=1}^{N} \log f(n) \cdot L(n) \\ -\sum_{n=1}^{N} \log h_b(n) \cdot L(n) \\ -\sum_{n=1}^{N} \log(11.75h_r(n)) \cdot L(n) \\ -\sum_{n=1}^{N} L(n) \\ -\sum_{n=1}^{n} L(n) \\ -\sum_{n=1}^{N} \log h_b(n) \cdot \log d(n) \cdot L(n) \end{bmatrix} \quad (62)$$

where

$a_{1opt}, b_{1opt}, c_{1opt}, d_{1opt}, e_{1opt}, f_{1opt}$, and g_{1opt}

are the optimal values of a_1, b_1, c_1, d_1, e_1, f_1 and g_1 respectively. Applying the parameters in Table 4 for f and h_b the computational complexity of (54) is reduced and simplified in (63).

$$L(n) = a_1 + b_1 \log d\,(n) \quad (63)$$

The objective function of equation (63) is obtained as expressed in (64), and the optimal coefficient vector is obtained as shown in (65).

$$F(a_1, b_1) = \frac{1}{N} \sum_{n=1}^{N} [L(n) - a_1 - b_1 \log d\,(n)]^2 \quad (64)$$

$$M \cdot \begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = \begin{bmatrix} -\sum_1^N L(n) \\ -\sum_1^N \log d \cdot L(n) \end{bmatrix} \quad (65)$$

where

$$M = \begin{bmatrix} -N, & -\sum_1^N \log d \\ -\sum_1^N \log d\,, & -\sum_1^N (\log d)^2 \end{bmatrix} \quad (66)$$

By substituting (66) into (65), we obtain the optimal values of a_1 and b_1 as given in (67) and (68).

$$\begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = M^{-1} \cdot \begin{bmatrix} -\sum_1^N L(n) \\ \sum_1^N \log d \cdot L(n) \end{bmatrix} \quad (67)$$

$$\begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = \frac{1}{(N \cdot \sum_1^N (\log d)^2) - (\sum_1^N (\log d)^2)} \cdot \begin{bmatrix} -\sum_1^N (\log d)^2, & \sum_1^N \log d \\ \sum_1^N \log d\,, & -N \end{bmatrix} \cdot \begin{bmatrix} -\sum_1^N L(n) \\ -\sum_1^N \log d \cdot L(n) \end{bmatrix} \quad (68)$$

where

$N = Total\ number\ of\ received\ signal$

$L(n)$ = Estimated Okumura-Hata model path loss corresponding to the sampling point.

From the least square algorithm computation;

$$\sum_1^N L(n) = 5196.54$$

$$\sum_1^N \log d \cdot L(n) = -338.83$$

$$\sum_1^N \log d = -4.13$$

$$\sum_1^N (\log d)^2 = 6.04$$

In order to obtain the optimal values of $\begin{bmatrix} a_1 \\ b_1 \end{bmatrix}$, the values from the least square algorithm computation are substituted into (68), and simplifying, gives (69).

$$\begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = \begin{bmatrix} 127.30 \\ 33.57 \end{bmatrix} \quad (69)$$

To obtain the modified Okumura-Hata model, the optimal values of a_1 and b_1 are substituted in (63) and the modified Okumura-Hata model is given in (70).

$$PL_{modified} = 127.30 + 33.57 * \log d\,(n) \qquad (70)$$

where $d(n) = distance\ in\ km$

Results showing the comparison of measured pathloss, the actual Okumura-Hata model and the modified Okumura-Hata model, for the investigated routes 1, 2, and 3, are as shown in Figures 7, 8 and 9, respectively.

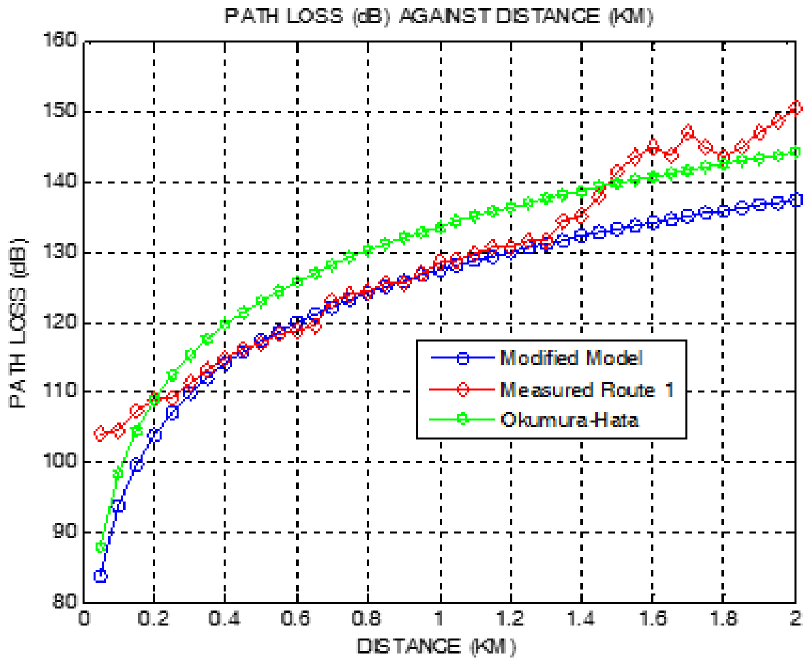

Figure 7. Comparison of measured pathloss and prediction by the modified Okumura-Hata model along route 1

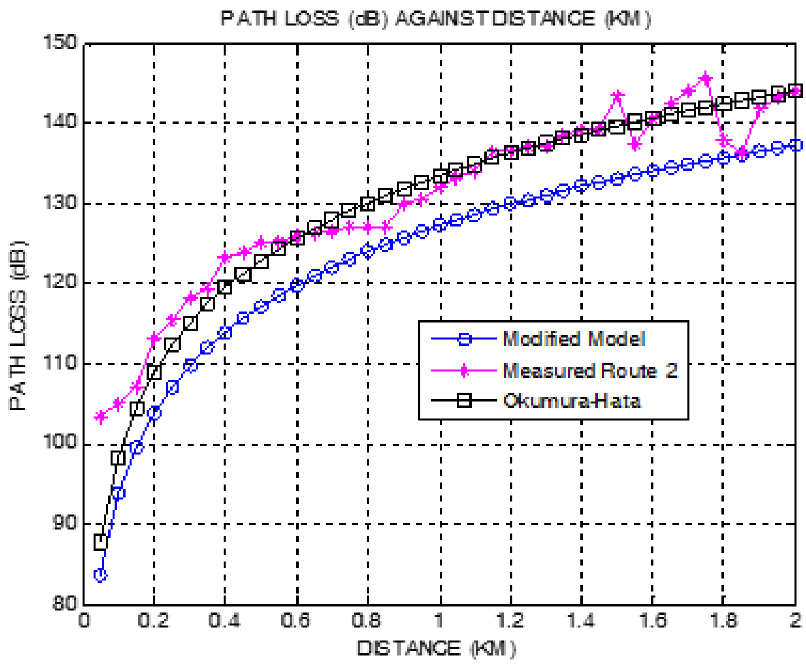

Figure 8. Comparison of measured pathloss and prediction by the modified Okumura-Hata model along route 2

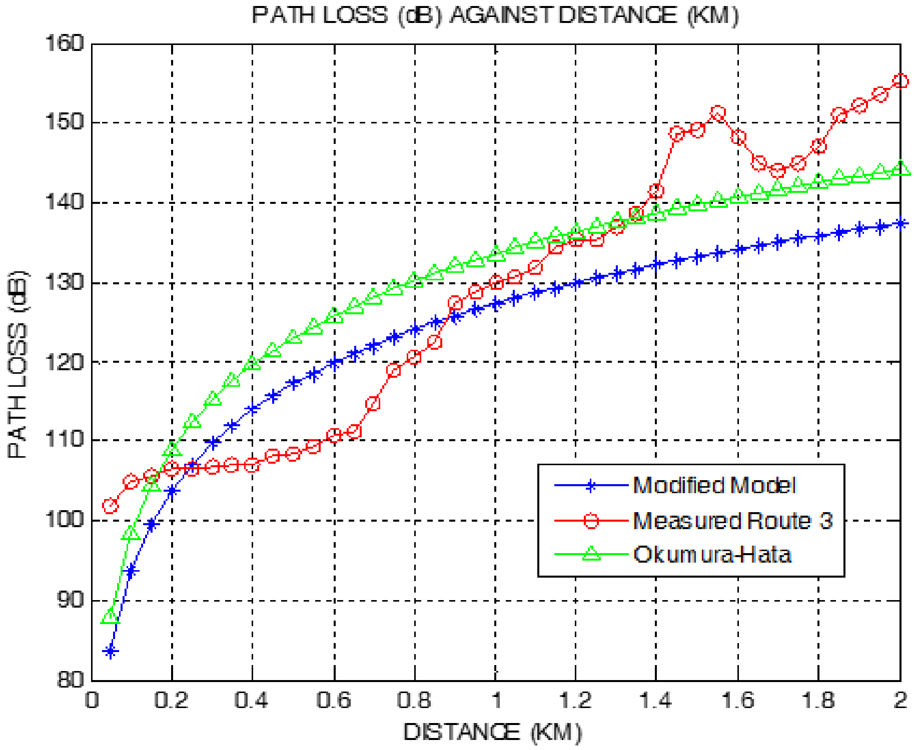

Figure 9. Comparison of measured pathloss and prediction by the modified Okumura-Hata model along route 3.

Validation of the modified Okumura-Hata model

The validity of the modified Okumura-Hata model was tested using the root mean square error (RMSE) as given in (71). The errors between the pathloss from actual measurements and the pathloss predicted by the modified Okumura-Hata model in (70) is calculated. The closer the values of the RMSEs to zero show improvements in the signal prediction accuracy of the model (Wu & Yuan, 1998; Ajose & Imoize, 2013; Imoize & Dosunmu, 2018; Imoize *et al.*, 2019).

$$RMSE = \sqrt{\sum_{=1}^{k} \frac{[PL_m(d) - PL_r(d)]^2}{k}} \qquad (71)$$

$PL_m(d) = Meassured\ path\ loss\ (dB)$

$PL_r(d) = Predicted\ Path\ Loss\ (dB)\ of\ the\ modified\ Okumura - Hata\ model$

$k = 40\ (Number\ of\ measured\ data\ points$

Applying (71), the RMSEs for the modified Okumura-Hata model along the routes are calculated as shown in (72)-(74). A comparison of the RMSEs for the actual and modified Okumura-Hata model is as shown in Table 9.

$$\text{Route 1,} \quad RMSE = \sqrt{\frac{1116.73}{40}} = 5.20 \qquad (72)$$

$$\text{Route 2,} \quad RMSE = \sqrt{\frac{958.11}{40}} = 4.89 \qquad (73)$$

$$\text{Route 3,} \quad RMSE = \sqrt{\frac{3085.50}{40}} = 8.78 \qquad (74)$$

Table 9: RMSEs of modified and predicted Okumura-Hata model

Investigated Routes	Okumura-Hata model RMSE (dB)	Modified Okumura-Hata model RMSE (dB)
Route 1	7.42	5.20
Route 2	7.63	4.89
Route 3	9.64	8.78

DISCUSSION

The measured RSRP is as shown in Figure 1 and the equivalent pathloss is given in Figure 2. In addition, the measured pathloss was compared with free space loss as shown in Figure 3, and a comparison of the measured pathloss against existing propagation models is as shown in Figures 4-6. In addition, the statistical analysis of measured and predicted pathloss is as shown in Tables 5 and 6. Results revealed standard deviations of 13.08dB, 11.12dB, and 17.58dB for measured data along routes 1, 2, and 3, respectively. Standard deviation errors of 2.00dB, 20.11dB, and 12.72dB, were recorded for the Okumura-Hata model, along routes 1, 2, and 3, respectively. In order to determine how the pathloss vary rapidly along the investigated routes, the pathloss exponent, which accounts for this rapid variation from the reference pathloss, is determined. Results showed pathloss exponents of 2.74, 2.93, and 2.74 for routes 1, 2, and 3, respectively. These were found to be in the range of values specified for urban areas in Table 8. Findings also revealed that the Okumura –Hata model showed root mean square errors of 7.42dB, 7.63dB, and 9.64dB for routes 1, 2, and 3, respectively. These RMSEs are smaller compared with the RMSEs recorded for other contending models. Therefore, the Okumura-Hata was selected as the best model among the contenders. In order to enhance the prediction accuracy of the Okumura-Hata model, it was modified by applying the least square method. The modified model showed improved RMSEs of 5.20dB, 4.89dB, and 8.78dB as shown in Figures 7-9, for the investigated routes 1, 2, and 3, respectively. However, it is observed that an RMSE of 8.78dB recorded for route 3, using the modified Okumura-Hata, is comparatively higher than the values obtained for routes 1, and 2. This is perhaps to be expected due to the high-density vehicular movements experienced on route 3 at the time of the measurements campaign.

CONCLUSION

This study was focused on propagation measurements and modeling of a 4G LTE network at 1800HMz for selected highways in Lagos, Nigeria. Field measurements of the reference signal received power was obtained for three different routes, using Huawei Technologies drive test equipment. Measured pathloss was taken and compared with predictions made by free space, flat earth, Okumura-Hata, Walfisch-Ikegami, Ericsson, ECC-33, and Lee models. Among the candidate models, the Okumura-Hata model showed the least root mean square errors of 7.42dB, 7.63dB, and 9.64dB along routes 1, 2, and 3, respectively. This model was selected and modified, using the least square algorithm. The modified model was seen to predict the pathloss of measured data with improved RMSEs of 5.20dB, 4.89dB, and 8.78dB, for the investigated routes 1, 2, and 3, respectively. RMSEs closer to zero show improvements in the prediction accuracy of the model, and the modified model could be very useful for revamping network planning, system design and wireless network deployment in and around the selected highways in Lagos, Nigeria. Future work would focus on providing correction factors for the modified Okumura-Hata model to ease its application to different environments.

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