A Versatile Wave Propagation Model for Very High Frequency Broadcasting Band in Vegetation and/or Rocky Environment

Jide Julius Popoola*‡, Aderemi Temitayo Adesanya*

*Department of Electrical and Electronics Engineering, School of Engineering and Engineering Technology, Federal University of Technology, P.M.B. 704, Akure, Ondo State, Nigeria

(jide.j.popoola@gmail.com, remtex7070@gmail.com)

‡ Corresponding Author; Jide Julius Popoola, P.M.B. 704, Akure, Ondo State, Nigeria, jide.j.popoola@gmail.com

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Abstract- Radio propagation models play a vital role in designing wireless communication systems. The models are used to estimate the location and number of transmitter stations as well as predict the transmitter coverage area. Different models have been developed in literature to predict radio propagation behavior for wireless communication systems in different operating environments. In this paper, least square regression analysis was employed to develop a versatile propagation model for very high frequency broadcasting radio station in vegetation and/or rocky environment. The developed model was later evaluated by comparing its path loss prediction result with two existing path loss models in literature. The results of the comparative performance analyses show that the two existing models predict highest difference in propagation path loss compared with that from the developed least square regression model. The developed model when compared with the estimated value was found to perform favorably well for each route and the entire coverage area of the transmitter station used as case study. In addition, the result of the study confirms the findings of other researchers that there is no single or universal propagation model that exactly fits all terrains, applications and environments.

Keywords Radio propagation, propagation mechanisms, shadowing, coverage areas, path loss.

1. Introduction

In radio communication, the presence of obstacles, such as vegetation, hill and high rising buildings, along the radio path usually cause signal attenuation as well as reduction in coverage area of the radio transmitter. Thus, a numerical or quantitative knowledge of propagation loss suffered by the radio signal propagated due to the presence of the obstacle is important for proper planning of communication link in any environment. Generally, radio wave propagation models, according to [1], play important role in planning, analysis and optimization of radio network. It is therefore important to develop effective propagation models for wireless communications in order to provide design guidelines for wireless communication systems. Therefore, propagation models are usually developed to predict the behavior of radio propagation in different environments.

By simple definition, a radio propagation model, according to [2], is an empirical mathematical formulation for the characterization of radio propagation as a function of distance. Thus, being empirical in nature, it means that radio propagation models can only be developed based on large collections of data for specific scenario. Basically, a single radio propagation model is usually developed to predict the behavior of propagation for all similar links under similar conditions. Therefore, a radio propagation model is usually formulated with the aim of formalizing the way radio waves are propagated from one place to another.

Fundamentally, the mechanisms which regulate radio wave propagation according to [3] are complex and diverse. Reflection, diffraction and scattering as reported in [4, 5] are the three primary propagation mechanisms that impact radio waves propagation in wireless communication. Reflection as one of the three mechanisms occurs when a propagating electromagnetic wave impinges upon an obstruction that has very large dimensions compared to the wavelength of the propagating wave [3, 5, 6]. On the other hand, diffraction occurs when a propagating electromagnetic wave between the transmitter and receiver encounters an obstructing surface that is impenetrable and large compared to the wavelength of the propagating electromagnetic wave. According to Huygen's principle, secondary waves are produced behind the obstructing body even though there is no line-of-sight (LOS) between the transmitter and receiver [3]. Primarily, diffraction explicates how radio frequency travels in both rural and urban environments without LOS path. This process, according to [3], is also called shadowing since the diffracted wave can reach a receiver even when it is shadowed by any obstruction.

Similarly, scattering occurs when the medium through which the electromagnetic wave travels or propagates consist of obstacles with dimensions that are small compared to the wavelength of the propagation signal. Most often, as reported by [6], scattered waves are usually produced by rough surfaces, small obstacles or irregularities in the channel. In addition, in practice, vegetations, lampposts, street signs, and stairs within buildings can induce scattering in radio communication signals. The three mechanisms which govern radio wave propagation are illustrated in Fig. 1.

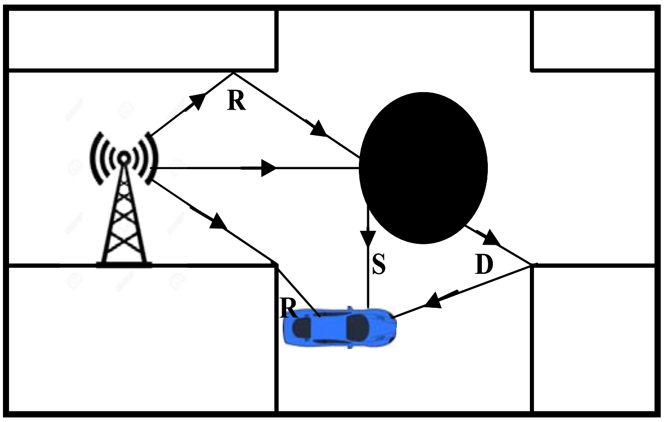

Fig. 1. Schematic description of the three mechanisms for radio wave propagation: reflection (R), diffraction (D) and scattering (S).

Thus, as shown in Fig. 1, it is obvious that during radio wave propagation, there is an interaction between the propagated electromagnetic waves and the environment, which results in attenuation of the signal level of the propagated electromagnetic waves. Also, the interaction causes path loss, which according to [7] invariably limits the coverage area of the transmitter. Therefore, in order to enhance the performance of radio transmitter, accurate path loss prediction is an essential factor in broadcasting station planning and setup. This makes determination of optimum transmitter location including obtaining appropriate data and estimating coverage area of a transmitter without conducting series of propagation measurement an indispensable act in broadcasting station planning and setup. Hence, before carrying out designs and affirming planning of any wireless communication system, accurate propagation features of the environment must be known. This is because propagation prediction provides useful information on both the large-scale path loss and small-scale fading statistics [8]. This is because while the path-loss information is important for the determination of the transmitter location for optimum coverage and performance, the small-scale information on the other hand is essential for providing statistical information on local field variation, which leads to the calculation of other parameters that help in combating multipath fading. However, when propagation predictions are not done, these parameter predictions can only be obtained by field measurements, which are expensive and time consuming.

Therefore, in this paper, a propagation model suitable for predicting optimum behavior of very high frequency (VHF) broadcasting band signal in a mixed vegetation-rocky environment was developed using an existing frequency modulation (FM) VHF broadcasting station in Ondo State, Nigeria. The study involved direct assessments of the FM signal and modeling of a suitable model for it. Detailed information on all the activities involved in carrying out the study is presented in Section 3. For both chronological and logical presentation of the paper, the rest of the paper is organized as follows. Section 2 presents brief review on propagation models which are identified as good solutions for fixed access signal optimum prediction. Detailed information on the methodology employed in carrying out the study is presented in Section 3. The results obtained are presented and discussed in Section 4 while the paper is finally concluded in Section 5 with summary of the findings.

2. Literature Review on Fixed Access Propagation Models

Propagation models are usually developed to predict the behavior or propagation parameters of radio transmitter in its coverage areas. According to [9], the coverage area of a broadcasting station is usually classified into three: primary, secondary and fringes areas. According to these authors, the primary coverage area of a broadcasting station is defined as a region about a transmitting station where the signal strength is adequate to override ordinary interference in the locality at all times. In this region, the signal strength is expected to be at least 60 dBμV [9, 10]. The quality of service enjoyed in this area is regarded as Grade A1. On the other hand, the secondary coverage area is defined as a region about a transmitting station where the signal strength is useful and often sufficient but not sufficient to overcome interference completely at all times. The signal strength in this region is expected to be at least 30 dBμV but less than 60 dBμV. The quality of service enjoyed in this area is regarded as Grade B1. While the fringe service area according to [9] is defined as a region where signal strength can be useful for some periods, but its service can neither be guaranteed nor protected against interference. The quality of service enjoyed in this area as reported in [9] is regarded as Grade B2. The signal strength in this coverage area is expected to be greater than 0 dBμV, but less than 30 dBμV.

This variation in signal strength experienced at these three coverage areas is primarily to prevent signal interference. However, the obtained signal strength in the three coverage areas is practically less than the expected values because electromagnetic waves obey the inverse-square law in the free space. Also, the variation in actual signal strength experienced at these three coverage areas is due to path loss that occurs during radio waves propagation between the transmitting antenna and the receiving antenna as the radio waves interact with its propagating environment. Thus, as reported by [11], path loss is defined as the difference between the effective transmitted power and the received power, which may or may not include the effect of the antenna gains. Generally, path loss phenomenon is mostly influence by terrain contours, propagation medium (dry or moist air), environment (urban or rural, vegetation and foliage), distance between the transmitter and the receiver, and the location of transmitter and receiver antennas. The path loss propagation or prediction models usually employed in obtaining actual behavior of radio signal are broadly divided into three classes: site-specific or deterministic models, theoretical or stochastic models, and empirical or statistical models [2, 6, 8, 12 - 14]. According to [14], site-specific or deterministic models require comprehensive data on the morphology, topology and orientation of the study area. The models, according to [15], make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. An example of a deterministic model is a ray tracing model [16]. These models produce reliable and accurate path loss prediction; however they are computationally complex. Due to this reason, these models are only used for short propagation path loss. On the other hand, stochastic models model the coverage radio environment as sets of random variables. Hence, the models generally require least information when compared with deterministic models. In addition, the models require much less processing power to generate path loss predictions. However, the models results are less accurate when compared with other models. Empirical models, on the other hand, are based on observations and measurements alone [15]. They use few parameters with statistical properties. The models are primarily used to predict path loss as reported in [14]. The models are simple and efficient to use. However they are not very accurate because the accuracy of the measurement employed usually has considerable influence on its results. However, they produce accurate results for environments with the same features as those where the measurements for their development were made. Hence, one of major drawbacks of these models is that they cannot be employed in different environments without modification.

In Nigeria, like in other parts of the world, observations show that most of the fixed wireless radio stations were planned using empirical path loss propagation models without fully taking into consideration the characteristic features of such stations' coverage areas. Also, since empirical models usually predict average path loss as a function of some parameters such as distance, terrain and antenna heights, it is obvious that lack of the adequate consideration of the characteristic features of fixed wireless access systems' coverage environments usually have adverse effects on their performance. Furthermore, according to [15], it has been observed that empirical propagation models for mobile systems have been comprehensively validated while their appropriateness for fixed wireless access systems has not been fully demonstrated.

Similarly, as reported in [12], a radio propagation model which gives an acceptable prediction in one scenario might not be suitable in another scenario. This indicates that a particular propagation model might not be directly applicable in different scenario without the use of suitable correction factor(s). This accounts for the reason why propagation models for different environments, terrains and applications had been developed by government agency, researchers, private organizations and standard body such as International Telecommunications Union. Two typical examples of these models are free space propagation (FSP) model and Hata model.

The free space propagation model is an ideal model [17] not only because it is the simplest model to measure only clear line-of-sight path but also because it implies equal radiation in all directions from the transmitting station to an infinite distance with no degration [18]. İn this model, th received power, P_r, depends on transmitter and receiver antennas gain, (G_t, G_r), transmitted power, P_t, wavelength, λ, and distance, d, between the receiver and transmitter. In this model, the received signal power, P_r, is expressed mathematically in [17] as;

$$P_r = \frac{p_t G_t G_r \lambda^2}{(4\pi d)^2} \tag{1}$$

For two isotropic antennas $(G_t = G_r = 1)$, hence equation (1) becomes;

$$P_r(d) = \frac{p_t \lambda^2}{(4\pi d)^2} \tag{2}$$

Thus, for two isotropic antennas with a diatnace, d, the free space path loss, L_p, is expressed mathematically in [12, 17, 18] as;

$$L_p(dB) = 32.44 + 20\log_{10}(d) + 20\log_{10}(f) \tag{3}$$

Free space loss propagation model requires detailed knowledge of the location and terrain features in the coverage area of transmitter. This makes usage of this model too complex and encourages the usage of empirical model. The primary advantage of empirical models is their computational efficiency and simplicity [12]. One of the empirical models in literature is Hata propagation model.

The Hata model, as reported in [8] is a formula-based of graphical-based Okumural model, which makes it application more effective. The model created series of representative path loss, L_p, mathematical models for each of the urban, suburban and rural environments [4, 11, 18] as expressed mathematically in equations (4-7) respectively as;

$$L_p(urban) = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_t) - a(h_r) + \{44.99 - 6.55\log_{10}(h_t)\}\log_{10}(d) \quad (4)$$

where f is the operating frequency in MHz, h_t is the transmitter antenna height, h_r is the receiver antenna height and d is distance between the transmitter and receiver.

$$a(h_t) = \{1.1\log_{10}(f) - 0.7\}h_r - \{1.56\log_{10}(f) - 0.8\} \quad (5)$$

$$L_p(suburban) = L_p(urban) - 2\left\{\log_{10}\left(f/28\right)\right\}^2 - 5.4 \quad (6)$$

$$L_p(rural) = L_p(urban) - 4.78\{\log_{10}(f)\}^2 + 18.33\log_{10}(f) - 40.94 \quad (7)$$

Another mostly used propagation model in literature is Egli model. Egli model according to [19] is a terrain model for radio frequency propagation. The validity range of this model is frequency between 40 MHz and 900 MHz with linking range less than 60 km. The prediction model was derived from real-world data on ultra high frequency (UHF) and VHF transmissions. It predicts the total path loss for a point-to-point link. There are two mathematical expressions applicable for Egli's propagation path loss model. The first is for the situation where $h_r \leq 10$ while the second is for the situation where $h_r \geq 10$. The two mathematical expressions for Egli's model at both conditions as reported in [19] are given as;

For $h_r \leq 10$;

$$L_p = 20\log_{10}(f) + 20\log_{10}(d) - 20\log_{10}(h_t) + 76.3 - 10\log_{10}(h_r) \quad (8)$$

For $h_r \geq 10$;

$$L_p = 20\log_{10}(f) + 40\log_{10}(d) - 20\log_{10}(h_t) + 85.9 - 10\log_{10}(h_r) \quad (9)$$

Since, these propagation models are developed using different terrains applications and environments, observations show that there is no single or universal propagation model [7] that exactly fit all terrains, applications and environments. This indicates that adopting an appropriate propagation model depends on system parameters (e.g. antenna height, operating frequency, etc.) and terrain parameters (e.g. urban area, suburban area, rural area, etc.). This necessitates the study presented in this paper whereby a new versatile wave propagation model is developed using appropriate system parameters and terrain parameters suitable for VHF broadcasting band in vegetation and/or rocky environment using existing frequency modulation station as a case study. The steps involved in developing the versatile model for the fixed wireless access station in this study are presented in the next section.

3. Methodology

The methodology involved in carrying out the study reported in this paper is divided into four stages as shown in Fig. 2. Activities involved in the first three stages are covered in this section while the fourth stage is covered in Section 4. Details on each of the first three stages were presented in the following sub-sections.

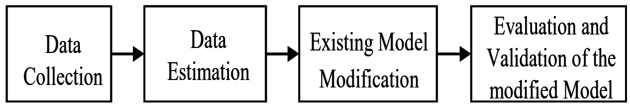

Fig. 2. Block diagram of the research methodology.

3.1. Data Collection Stage

This is the first stage of the methodology involved in carrying out the study presented in the paper. The stage is divided into two sub-stages: radio station or transmitter data collection and field measurement data collection. During the former sub-stage, peculiar data about the transmitting station were collection such as its site location or coordinates, transmitter frequency, transmitter antenna height and other relevant data as presented in Table 1.

Table 1. The radio station parameter

Parameter	Value
Site coordinates	Latitude 7.324390; Longitude 5.125180
Operating frequency	88.9 MHz
Bandwidth frequency	200 kHz
Transmitter power (maximum)	35 kW
Transmitter power (actual)	25 kW (i.e. $\approx$71% of maximum power)
Maximum deviation	295 kHz
Antenna gain	85.6 dB
Antenna polarization	Vertical
Antenna type/model	Yagi-Uda Antenna
Maximum antenna height	250 m
Maximum elevation	427 m

Similarly in the latter sub-stage, the received signal strength of the transmitting station at its four cardinal routes were determined using BC1173 Field Strength meter, which was coupled with a 75 Ω dipole antenna. The coordinates of each location where the signal strength values were measured were determined with the aid of global positioning system (GPS) meter known as Germin GPSMAP78s. The pictures of the two materials employed in the study are shown in Fig. 3. The four cardinal routes where the signal strength values were measured are: Route A or Eastern Route: Akure-Owo (55 km); Route B or Southern Route: Akure-Ore (67 km); Route C or Western Route: Akure-Ilesha (54 km); and Route D or Northern Route: Akure-Ifaki-Ekiti (56 km). The four routes are shown in Fig. 4. In each of the routes, readings were taken at an average of five different locations. In each location along each route, readings were taking at about five different spots at an average of 5 km apart. The coordinates of these spots in each route were also recorded. The five spots were marked A to E where A, B, C, D and E represent the centre of each location, 5 km eastward from the centre, 5 km westward from the centre, 5 km southward from the centre and 5 km northward from the centre respectively.

(a) (b)

Fig. 3. Picture of (a) the field strength meter (b) GPS meter used

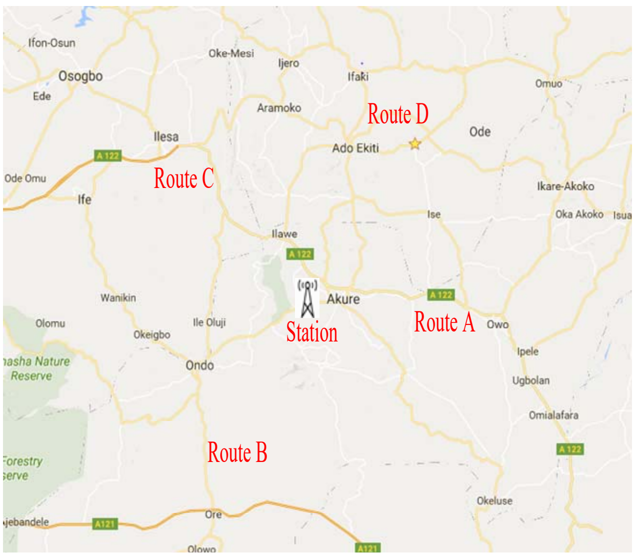

Fig. 4. The four cardinal routes with respect to the transmission station.

3.2. Data Estimation Stage

In this stage, estimation of the field strength values obtained during the field measuring was carried out using RadioWORKS software. The graphical representation of the estimation analysis results obtained in each of the routes is as shown in Fig. 5. The obtained graphs are of different elevation and distance as a result of each location elevation differences and differences in each location distance to the transmission station.

Critical observation of Fig. 5 shows the built up obstruction, vegetation and/or rock, along each of the routes. While the circular red color represents the Fresnel zone line plot, the black line represents the line of sight plot from the transmitter station to the maximum distance in each route. The fluctuating green line on the other hand represents the intensity of the obstruction along each route. The higher the height of the fluctuating green line in a particular route the higher the obstacle or obstruction to the signal propagation in such route. This is the reason why the radio station's reception is relatively poor in both the north and west routes because there are presence of thick vegetation and high mountain or rock in the two routes. The high fluctuation obtained shows the degree of signal obstruction along those routes compared to the other two routes where both vegetation and rock are relatively low.

3.3. Propagation Model Development

Least square regression test method was used to develop the proposed versatile propagation model because the measurements obtained along the four routes reveal linear relationship between the estimated path loss from the coverage area and corresponding line of sight distance. Hence, least square regression test method is employed for each route. The overall average value of the least square regression analysis for the four routes finally formed the developed model. The least square test plots for the four routes are presented in Fig. 6. From the result, the multiple R shows the correlation between the points and line of sight best fit which is between the ranges of 0.98-0.94 for all routes considered. Also, R square shows the percentage of points that falls on the straight line, which is between 97% and 90%. The variable is the slope at intercept point on which the line cross path loss axis. Hence x- variables and intercept were used to develop the equation for the path loss.

From Fig. 6, the obtained path loss propagation model for the western route or Route C is 89.18771 + 0.000345d where d is the distance in kilometer (km). The corresponding obtained path loss models for north, east and south routes are 91.6871213 + 0.00028032d, 92.6271 + 0.000258d, and 93.4001119 + 0.00022651d respectively. The overall obtained path loss propagation model developed is expressed mathematically as 91.72551 + 0.000277d. This obtained path loss propagation model is used to predict the path loss for the coverage areas of the station. The effectiveness of the obtained propagation path loss model is finally evaluated by comparing its performance with some selected standard models in literature. The results obtained are presented and discussed in Section 4.

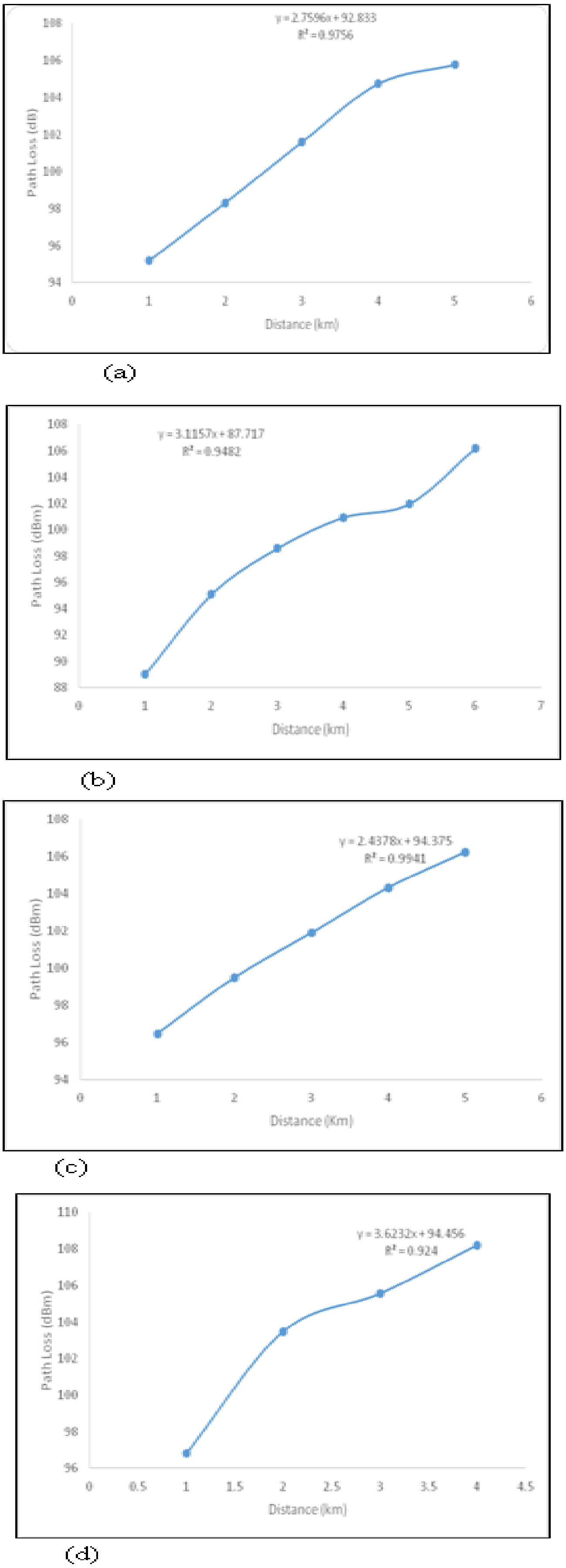

Fig. 6. Ordinary least square regression result for the four routes.

4. Results and Discussion

This section is devoted to the performance evaluation tests carried out on the developed propagation model. The tests are divided into two classes. The first class is the set of tests carried out to assess the performance of the developed model on routes basis. The result of these assessments is presented in the sub-section 4.1. The second class of the performance assessment test carried out is a comparative analysis between the propagation path loss, estimated results from the developed model and two other models in literature. The two existing models employed are free space path loss and Hata models. The comparative assessment result is presented in sub-section 4.2.

4.1. Developed Model Performance Assessment per Route

In this subsection, the developed model performance was evaluated by comparing the path loss estimation with the obtained measured path loss during measurement in each route. The comparative performance evaluation result per route is presented graphically in Fig. 7. Critical observation of Fig. 7 shows that the developed model predictions in all the four routes are similar to the estimated values obtained through measurement. This shows that the path loss prediction result obtained in each route by the developed model is perfectly in agreement with the actual experience in each route. The results also show that the developed least square (LS) regression model does not over-predict path loss. This is an indication that the received signal power that will be received using the developed LS regression model in each route will perfectly correspond with the measured received signal power from the radio station.

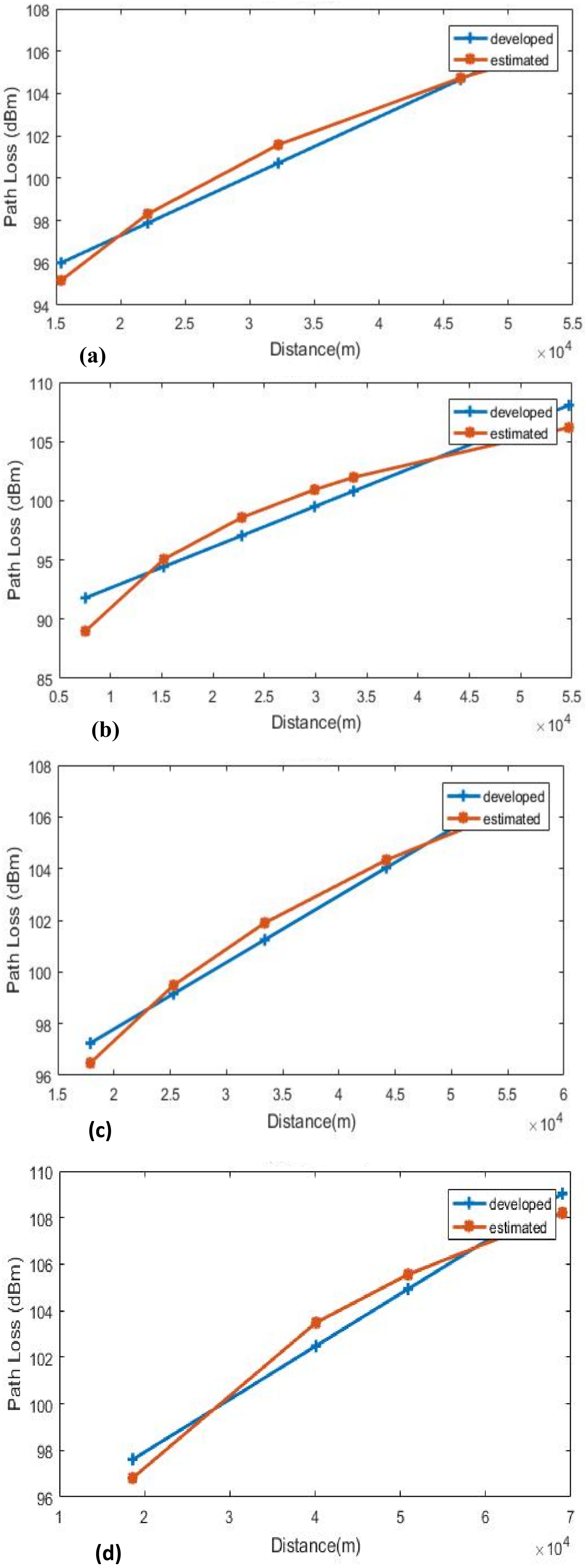

Fig. 7. Performance evaluation result for (a) North, (b) West, (c) East and (d) South routes respectively.

4.2. *Comparative Evaluation of developed Model with Existing Models*

In this subsection, the overall developed model was compared with two existing models in literature and the overall estimated path loss during measurement. The result obtained is presented graphically in Fig. 8. From Fig. 8, it shows that the path loss predictions by the existing models are relatively higher when compared with the results of both the estimated and the developed model. This indicates that the existing models are not suitable for the study environment as well as the fixed wireless access station used as case study. The result, therefore, buttress the finding in [7] that there is no single or universal propagation model that exactly fit all terrains, applications and environments. Similarly, the comparative result as shown it clearly the finding in [12], that a radio propagation model which gives an acceptable prediction in one scenario might not be suitable in another scenario. This shows that no predicted path loss of any model can be absolutely depend on especially when the terrains, applications and environments for its development are not the same without appropriate modification in another terrain or environment.

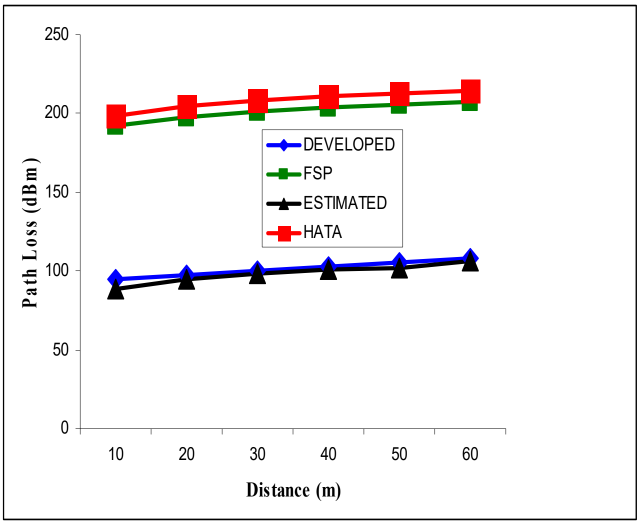

Fig. 8. Comparative performance evaluation of developed model with existing models.

On the other hand, critical observation of the performance of the developed model and the estimated path loss from measurement show that the two are closer. This shows that the path loss prediction from the developed model is the true picture of the situation in all the routes. In particular, as shown in Fig. 8, the high differences in the propagation path losses predicted by both FSP and HATA models compared with that from the developed LS regression model for the terrain shows that the developed propagation model for this study is the best fit for fixed wireless access used as case study for this study when compared with the references models. Also, the closeness of the overall developed LS regression model with the estimated path loss shows that the developed LS regression model is the most suitable for the study environment

5. Conclusion

The results obtained from the field measurements and the analysis carried out on the measured signal strengths show that there is significant reduction in power density of the fixed wireless access used as case study in this study along its coverage area as its signal propagates through space. This reduction, which may be due to free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss, absorption as well as influences by terrain contours and environment has been corrected by the developed propagation model for the station. The performance evaluation of the developed model shows that the developed model is more suitable compared to the two existing references propagation models. In addition, where the reference existing models predict heavy loss between 0 - 20 km and almost constant loss for 60 km, the developed model gives gradual path loss over the same distance and high path loss after where there is significant obstruction.

Furthermore, apart from the fact that the developed model performs favorably well compared with the existing models, its comparative performance evaluation also confirm the fact that different locations need an appropriate path loss models for effective and efficient signal propagation loss prediction and signal reception. Based on the integrity of result obtained from the developed model for this study, it is hereby recommended that the developed model for this study can be applied during planning of fixed wireless access in any terrain and environment with similar vegetation and/or rocky as this study. In addition, it is also recommended based on the result of this study that specific radio wave propagation model needs to be developed for accurate planning and designing of specific wireless application in order to enhance radio signal transmission and reception in such area as well as the efficiency of the wireless application.

References

[1] T. Rick, and R. Mathar, "Fast edge-diffraction-based radio wave propagation model for graphics hardware", Proceedings of the 2nd IEEE International ITG Conference on Antenna (INICA), Munich, Germany, 2007, DOI:10.1109/INICA.2007.

[2] K.J. Parmar, and V.D. Nimavat. "Comparative analysis of path loss propagation models in radio communication", International Journal of Innovative Research in Computer and Communication Engineering, Vol. 3, No. 2, pp. 840-844, 2015.

[3] J.B. Andersen, T.S. Rappaport, and S. Yoshida, "Propagation measurements and models for wireless communications channels", IEEE Communicationss Magazine, Vol. 33, No. 1, pp. 42-49. 1995.

[4] S. Joshi, "Outdoor propagation models a literature review", International Journal on Computer Science and Engineering, Vol. 4, No. 2, pp. 281-291, 2012.

[5] T.K. Sarkar, Z. Ji, K. Kim, A. Medour, and M. Salazar-Palma, "A survey of various propagation models for mobile communication", IEEE Antennas and Propagation Magazine, Vol. 45, No. 3, pp. 51-82, 2003.

[6] P. Rani, V. Chauhan, S. Kumar, and D. Sharma, "A review on wireless propagation models", International Journal of Engineering and Innovative, Vol. 3, No. 11, pp. 256-261, 2014.

[7] J. Milanovic, S. Rimac-Drlje, and I. Majerski, "Radio wave propagation mechanisms and empirical models for fixed wireless access systems", Technical Gazette, Vol. 17, No. 1, pp. 43-52, 2010.

[8] M.F. Iskander, and Z. Yun, "Propagation prediction models for wireless communication systems", IEEE Transactions on Microwave Theory and Techniques, Vol. 50 , No.3, pp. 662-673, 2002.

[9] M.O. Ajewole, O.D. Oyedun, A.T. Adediji, A.S. Moses, and J.O. Eiche, "Spatial variability of VHF/UHF electric field strength in Niger State, Nigeria, International Journal of Digital Information and Wireless Communications, Vol. 3, No. 3, pp. 231-239, 2013.

[10] NBC, Nigeria Broadcasting Code. 2002, p.1-196. Available at: http://www.nbc.gov.ng/uploads/nbc_documents/1466685527-code%20third%20edition.pdf, Retrieved January 24, 2017.

[11] A. Obot, O. Simeon, and J. Afolabi, "Comparative analysis of path loss prediction models for urban macrocellular environments", Nigeria Journal of Technology, Vol. 30, No. 3, pp. 50-59, 2011.

[12] C. Temaneh-Nyah, and J. Nepembe, "Determination of a suitable correction factor to a radio propagation model for cellular wireless network analysis", Proceedings of 5th IEEE International Conference on Intelligent Systems, Modelling and Simulation, Langkawi, Malaysia, p.175-82, 27-29 January 2014.

[13] P.K. Sharma, and R.K. Singh "Comparative analysis of propagation path loss models with field measured data," International Journal of Engineering Science and Technology, Vol. 2, No. 6, pp. 2008-2013, 2010.

[14] J.C. Ogbulezie, M.C. Onuu, D.C. Bassey, and S. Etienam-Umoh, "Site specific measurements and propagation models for gsm in three cities in Northern Nigeria, American Journal Journal of Scientific and Industrial Research, Vol. 4, No. 2, pp. 238-245, 2013.

[15] V.S. Abhayawardhana, I.J. Wassell, D. Crosby, M.P. Sellars, and M.G. Brown "Comparison of empirical propagation path loss models for fixed wireless access systems", Proceedings of 61st IEEE Vehicular Technology Conference, Stockholm, Sweden, pp. 73-77, 30 May-1 June 2005.

[16] G.E. Athanasiadou, A.R. Nix, and J.P. Mcgeehan, "A microcellular ray-tracing propagation model and evaluation of its narrowband and wideband predictions", IEEE Journal on Selected Areas in Communications, Wireless Communications Series, Vol. 18, 2000.

[17] P.T.Z. Tun, and A.S. Hlaing, "Modification of propagation prediction model for 2.4 GHz indoor wireless environment", Proceedings of International Conference on Advances in Engineering and Technology, Singapore, p. 360-64, 29-30 March 2014.

[18] Z. Nadir, N. Elfadhil, and F. Touati "Pathloss determination using Okumura-Hata model and spline interpolation for missing data for Oman", Proceedings of World Congress on Engineering, London, UK, Vol. I, 2-4 July 2008. Available at: http://iaeng.org/publication/WCE2008/WCE2008_pp422-425.pdf . Retrieved January 24, 2017.

[19] R. Mardeni, and K.F. Kwan, "Optimization of Hata propagation prediction model in suburban area in Malaysia, . Progress in Electromagnetic Research C, Vol. 13, pp. 91-106, 2010.