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ARTICLE

Development of a Path Loss Model for Radio Wave Signals for some Selected Routes in Enugu State, Nigeria

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Abstract: This research focuses on developing a path loss model for radio wave signals propagating in a wavelength range of 0.37–6.12 m along some selected routes in Enugu state, Nigeria. A cable television signal strength meter was used to measure signal strength at 2 km intervals along the routes. The television signals examined were those from NTA Enugu. Path loss values were derived from the received signal strength for each route. The path loss obtained was plotted against the distance and the result shows that the path loss increases with the distance along each of the routes. A path loss model was developed by analyzing the path loss variation with distance. The path loss values obtained from the developed model were plotted against the distance and compared with the measured path losses for the NTA signals to assess how accurate the model is for the path loss prediction at the study locations. Some statistical tools (RMSE, ME, and SDE) were used to validate the developed model. The model predicted the path loss of NTA-Enugu signals with RMSE very close to zero (0). In addition, the values of the developed path loss model for the NTA signals were compared with the values of other empirical models. The results show that the other empirical path loss models overestimate the path loss of NTA-Enugu signals.

Keywords: Nigeria Television Authority (NTA), Path loss, Radio waves, Signal strength, Terrestrial television, Ultra High Frequency (UHF).

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1. Introduction

The global television broadcasting system is undergoing considerable structural and technical changes [1]. Customers today have better access to television communication services and other media services than ever before. In the past, for example, television content was viewed by the viewer at a specific time and location. However, thanks to advances in technology, customers can now watch television programs at any time and through various wireless devices. While developments in television technology and the emergence of new products and services have increased overall competition in media markets, benefiting television regulators and consumers, some market developments have raised competition concerns, particularly in the area of signal strength and quality [2]. Ensuring universal access to television services can not only contribute to the digital divide but also contribute to poverty reduction and development. This is crucial for both industrialized and emerging economies for several socio-economic reasons [3]. This study focuses on terrestrial television networks operating in the VHF and lower UHF bands in the state of Enugu, Nigeria.

Terrestrial television signals are inherently distorted due to scattering phenomena, radio frequency (RF) barriers, and uneven terrain. The performance of television broadcasting systems is limited by the level of radio interference, the radio channel capacity and the type of propagation path between transmitter and receiver. The Nigerian Television Authority

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(NTA) television signals, like any other radio and television signal, have areas of weak signal reception. Some of these problems are not due to the station's technical deficit, but rather due to natural or man-made phenomena such as forests, hills, mountains, equipment, and others [1, 7, 11]. In contrast to audio signals, visual signals react significantly to these natural and artificial factors, which make viewers uncomfortable because they mostly do not enjoy the signal received in this way. The physical and atmospheric properties of the transmission environment affect the performance of television communication systems [4]. Mountains, buildings, vegetation, cars, billboards, and other physical obstacles in the transmission path often obstruct the line of sight (LOS) of radio and television. Electromagnetic waves reflect when they hit an object that is much larger than the wavelength of the transmitted signal [5]. These reflective fabrics include building roofs and the metallic sides of a window frame. Radio waves are absorbed when they penetrate thick objects such as trees, walls, furniture, and plants [6].

One of the most important features of a television signal transmission environment is path loss. Path loss is the difference between the actual transmitted power and the power received [7]. This is the decrease in power intensity of a radio wave as it propagates through space. In a television broadcasting system, path loss models are essential for adequate planning, frequency allocation, interference estimation, and estimation of television parameters that are important to the network design process [8]. Some of the causes of path loss include diffraction, refraction, loss of free space, reflection, absorption, penetration loss, and coupling loss. The path loss is also influenced by topography, type of settlement, medium of propagation, height and location of transmitting and receiving antennas, vegetation, atmospheric parameters, and the transmitter-receiver distance [9]. Path loss prediction is a term used to describe the computation of path loss. Empirical and deterministic models are the most widely used models for predicting path losses in television communication systems [10].

Television broadcasting services in the 54 to 806 MHz frequency bands, with their numerous advantages, also have several inherent problems, including network congestion, poor signal reception under various climatic conditions, and power and signal failures [11]. The television network operators in Nigeria have tried over the years to offer solutions to these inherent challenges. Some of these challenges are specific to all environments, regions, and climatic conditions, while others are specific to certain environments and regions [12, 13]. For example, foliage protection in the locations where these terrestrial television networks are deployed could present some challenges to signal propagation. Therefore, for each particular climatic environment, solutions to these particular problems must be sought within the location.

When a radio frequency signal transmitted from a base station's transmitter travels to a television receiver via wireless communication channels, it encounters losses due to the earth's environment. Transmission at the VHF and UHF frequency bands is frequently hampered by environmental conditions and seasonal variations, such as temperature, humidity, rain, vapor, and dew. This research was carried out along six (6) distinct routes in Enugu State, Nigeria. The study focused on NTA stations with wavelengths ranging from 0.37 m to 6.12 m. Enugu State is located in Nigeria's South East geopolitical zone. The state has diverse vegetation ranging from lush foliage in the southern parts to the desert or semi-desert areas in the north and extreme northern parts. It experiences a dry season from November to March (about five months) and a wet season from April to October every year (four to seven months). These seasons' variations foist noticeable changes in the environment [14]. The increase in moisture content of the surroundings during the wet season gives rise to better ground conductivity and vegetation. Television signal strength is likely to be affected by these environmental conditions, among other factors. Therefore, for more appropriate planning and accurate design of television broadcasting networks, the effects of ground conductivity and increased vegetation on signal strength should be properly taken into account, particularly in the region where such networks are being deployed [1, 4]. This study intends to develop a path loss model for radio wave signals on selected routes in Enugu State, Nigeria, given the unique climatic conditions and terrain features of the study locations.

2. Materials and methods

2.1 Materials

The materials used to carry out this research are a digital cable television (CATV) signal strength analyzer, a global positioning receiver system (GPRS), a receiving antenna, a travel distance application, MeteoTrend weather station software, etc.

2.2 Methods Adopted

An S110/S110D CATV signal level analyzer was used to assess the signals generated by the Nigerian Television Authority (NTA) along five (5) different navigable and accessible routes in Enugu, Nigeria. The NTA base station that was monitored for this study is NTA Channel 8 Enugu. The signal strength levels of each of the NTA stations examined were classified based on the paths taken for the measurements. The different ways of measuring the signal intensity are shown in Table 1. A distance tool was used to calculate the distances between the measurement locations and the base stations of the NTA transmitters examined.

The receiving antenna was pointed in various directions at the study location to see if the strongest signal came from a direction other than the transmitters. Measurements were taken every 2 kilometers along the designated signal strength measuring routes from the specific NTA emitter under investigation. During the signal level measurement, the receiving antenna was raised to a height of 5 meters in order to intercept the horizontally polarized signal to be examined. In the case of field strength measurements, it was agreed with the management of the NTA Enugu station that the transmission parameters would remain the same.

Most of the natural and man-made factors that affect the signal strength generated along the various signal strength measurement routes have been considered. Some of these factors include temperature, pressure, humidity, altitude, vegetation types, tall buildings, climate, and others. Measurements were taken from October 2020 to August 2021. In general, the signal strength measurement was carried out over several months, at different times of the day and at different temperatures, pressures, and humidity levels. The average field strength measurement results for the study period were obtained, and the given data were analyzed with Mat lab and Python programming to determine the performance of the signal strength generated by NTA transmitters along the selected routes.

TABLE 1. Routes description.

Routes	Description
Route A	Enugu-Abakaliki
Route B	Enugu-Okposi
Route C	Enugu-Umuahia
Route D	Enugu-Awka
Route E	Enugu-Agenebode

The five routes chosen are those that circumnavigate the NTA television stations under investigation. Despite the fact that the selected routes are nearly identical in terms of land topography, there are few differences in terms of vegetation, physical structures, population density, and so on. Low foliage and a few scattered structures characterize Route A. Routes B and C are structurally comparable in that they are both high-vegetation environments with a high population index. The vegetation along this route is an undulating cascade of tree canopies. In terms of geographical features, Routes D and E are comparable, with some very high-rise structures mixed in with low-rise buildings that reduce the signal's power. This area comprises interconnected buildings and is considered the state's commercial hub/area. Table 2 shows some of the transmitting parameters of the NTA Channel 8 Enugu. The gain of the receiving antenna is 20 ± 3 dB, and the signal strength transmitted by the transmitter is 76.5 dBμV.

TABLE 2. Transmitting parameters of NTA Channel 8 Enugu.

Serial No.	Transmitting parameters	Description
1	Base station frequency	189.25 MHz
2	Transmission Type	Rohde & Schwarz 10 KW
3	Base station transmitting power	7.8 KW
4	Base station channel	Channel 8
5	Height of transmitting antenna	186 m
6	Transmitting antenna gain	30.02 dB
7	Base station position	Long. 6.30° N Lat 7.30° E
8	Receiving antenna orientation	Omni-directional
9	Height of receiving antenna	4 m

3. Results and Discussion

The received signal strength levels were measured at intervals of 2 km along the various signal strength measurement routes, ranging from 2 km to 24 km. Inconsistent signals were averaged out using the average received signal at each measurement point. The mean value of the signal strength measured during the study period was obtained and tabulated, as shown in Table 3. The path loss for the various routes was then derived by further analysis of the signal strength values received at each of the measurement locations.

TABLE 3. Signal strength values of NTA Enugu along different routes in Enugu state.

Distance (Km)	Signal strength (dBμV)				
	Route A	Route B	Route C	Route D	Route E
2	40.7	39.3	39.8	38.5	38.9
4	34.4	34.9	33.1	34.0	33.5
6	30.7	29.5	30.0	28.6	31.4
8	28.9	28.1	27.5	26.7	27.1
10	28.2	27.2	26.3	25.6	26.6
12	25.6	26.0	25.6	24.1	25.2
14	25.3	24.5	24.7	23.8	23.4
16	24.5	23.6	24.1	23.2	22.5
18	23.3	22.7	23.6	22.2	21.6
20	22.6	21.9	21.2	20.4	20.8
22	21.3	21.7	20.7	19.9	19.2
24	20.3	18.4	18.9	19.2	17.6

3.1 Path Loss Calculation

Path loss is the deterioration of signals due to the effect of atmospheric parameters, the influence of the terrain, and other factors, such as interference, absorption, scattering, diffraction, etc. It is also the difference in decibel (s) between the transmitted power and received power [15]. The path loss in decibels was calculated from the measured values of the received signal strength (see Table 3) using the expression [16, 17]:

$$SPL = TSPT - TSSR \tag{1}$$

where SPL is the signal path loss, TSPT is the total signal power transmitted and TSSR is the total signal strength received.

$$TSPT = P_T + G_T + G_R - (L_T + L_R) \tag{2}$$

Substituting Eq. (1) in Eq. (2) gives the expression for the signal propagation path loss (dB) [18]:

$$SPL = P_T + G_T + G_R - C_L - TSSR \tag{3}$$

and $C_L = L_T + L_R$

where P_T = transmitted-power, G_T = transmitter-gain, G_R = receiver-gain, L_T = transmitter loss, and L_R = receiver's cable loss in decibel. The values for the measure path loss are presented in Table 4.

TABLE 4. Path loss values of NTA Enugu along different routes in Enugu state.

Distance (Km)	Path loss (dB)				
	Route A	Route B	Route C	Route D	Route E
2	35.8	37.2	36.7	38.0	37.6
4	42.1	41.6	43.4	42.5	43.0
6	45.8	47.0	46.5	47.9	45.1
8	47.6	48.4	49.0	49.8	49.4
10	48.3	49.3	50.2	50.9	49.9
12	50.9	50.5	50.9	52.4	51.3
14	51.2	52.0	51.8	52.7	53.1
16	52.0	52.9	52.4	53.3	54.0
18	53.2	53.8	52.9	54.3	54.9
20	53.9	54.6	55.3	56.1	55.7
22	55.2	54.8	55.8	56.6	57.3
24	56.2	58.1	57.6	57.3	58.9

Fig. 1 shows the variation in the measured path loss with distance for the NTA Enugu base station. The figure shows that the path loss measured for NTA Enugu signal propagation increases with distance along the various routes of the signal strength measurements. For example, in Fig. 1, the path loss values in decibels for routes A, B, C, D, and E for NTA Enugu are 35.8, 37.2, 36.7, 38.0, and 37.6, respectively, for a distance of 2 km. At a distance of 4 km, the path loss values for the same routes are 42.1, 41.6, 43.4, 42.5, and 43.0. Finally, at a distance of 6 km, the path loss values for routes A, B, C, D, and E are 45.8, 47.0, 46.5, 47.9, and 45.1, respectively. These show an increase in signal path loss as the distance between the transmitter and the receiver of the base station increases.

The environment in which the transmitter and receiver are located has a strong influence on path loss. Propagation path loss increases with frequency and distance in general. Communication path loss is almost unavoidable, and the level of signal loss is determined by topographical features and the types of activities carried out on the terrain. Figure 1 shows that the path loss is relatively high between 0 and 2 kilometers and then gradually decreases as the distance increases. This is primarily due to signal scattering caused by trees and structures, as well as reflections. Despite the fact that the signal transmitted is well received by viewers even at a distance of 24 kilometers, the signal degrades as the distance increases due to path loss. This is in agreement with [18]

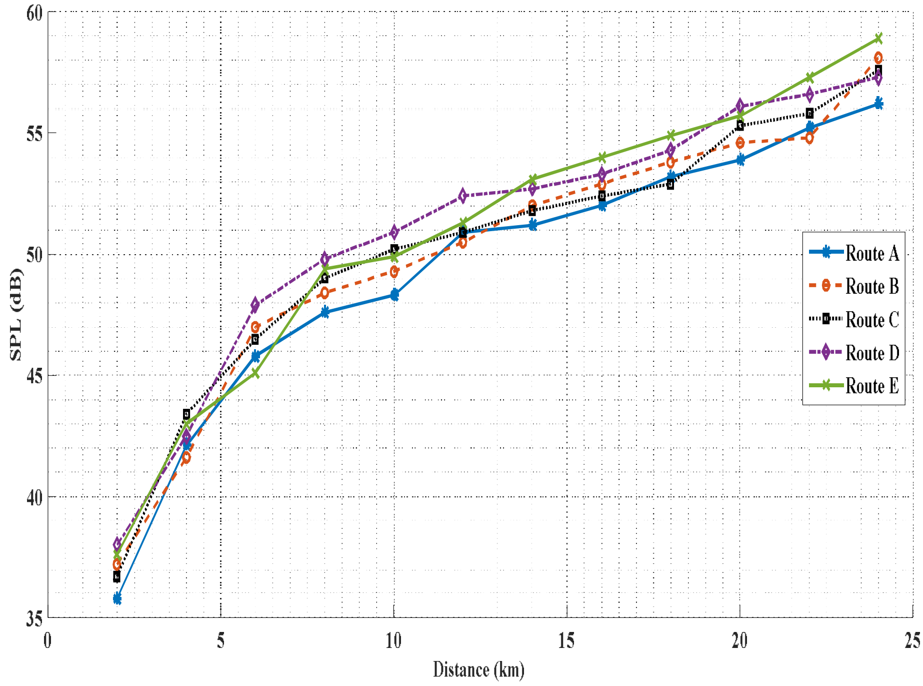

FIG. 1. NTA Enugu path loss along different routes in Enugu State, Nigeria.

3.2 Simulations and Path Loss Modeling

The propagation model in Eq. (4) was developed for this study to predict the path loss of the signals generated by NTA Enugu in Enugu state, Nigeria. In the model developed, the values of the path loss proponents for NTA Enugu transmitters were determined and used to characterize the television signal propagation along the selected routes. The resultant path loss model, capable of predicting the attenuation of NTA signals with distance in Enugu state, Nigeria, is given in Eq. (4).

$$SPL = M_n + Aelogd_a + Aelogd_r + S \qquad (4)$$

where SPL = signal path loss value, M_n = SPL value at a reference distance from the transmitter, assumed to be 1 km from the base station's transmitter. A is the coefficient of the logarithms, which has a constant value of 20. The parameter e is known as the path loss proponent or exponent that varies depending on the base station. d_a = actual distance (km) between the TX and the RX and d_r = reference distance from the transmitter's antenna taken to be 1 km. S is the correctional factor that accounts for the loss due to scattering, interference, dispersion, obstruction, absorption, reflection, etc. S is 1 for normal terrain, 2 for the high vegetation-covered areas, and 3 for densely populated and crowded environments. The values for the path loss predicting model parameters for the NTA Enugu transmitter are $M_n = 33\,dB$ and e = 0.77. The path loss exponent value e at the breakpoint for a particular site was obtained from the measured path loss values by the regression method. The calculated path loss model in Eq. (4) was developed by finding the appropriate values of e, M_n, and S for a given da.

The plot of the path loss values shows a trajectory that indicates that the path loss increases with the line-of-sight distance between the base station and the television receiving station, with a comparatively small scattering. After the breakpoint distance, attenuation and scattering become increasingly noticeable and irregular. However, the attenuation matches the property attributes of the environment of the transmitter base stations.

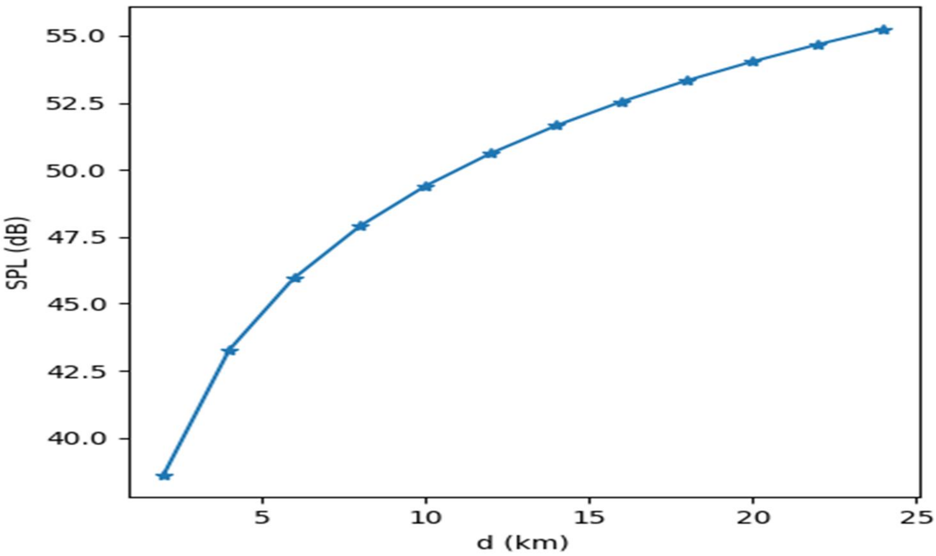

FIG. 2. Developed model's path loss against distance for NTA Enugu signals.

3.3 Model Validation and Verification

The performance of the different models for predicting path losses is assessed by means of error analysis. The three (3) main error metrics used in this study to select the most appropriate model for the environments under study are mean error (ME), standard deviation error (SDE), and root-mean-square error (RMSE). These statistical tools are employed to measure how close the best-fit line is to the data points [19, 20]. They describe the difference between the measured path loss (PL_m) values at a transmitter-receiver distance (da) and the empirical prediction path loss model (PL_c). The expressions for obtaining MSE, RMSE, and SDE are given in Eqs. (5), (6), and (7), respectively.

$$ME = \frac{1}{n}\sum_{i=1}^{n}(PL_m - PL_c) \quad (5)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(PL_m - PL_c)^2} \quad (6)$$

$$\sigma_e = \frac{\sigma}{\sqrt{n}} \quad (7)$$

where σ_e is the SDE, σ is the standard deviation, and N is the number of the given sample.

The lower the values of ME and RMSE, the more accurate the path loss propagation model is in predicting path loss. An RMSE value close to zero (0) is considered a better fit. However, the acceptable RMS error for a model is about 6 to 10 dB [21, 22, 23].

3.4 Comparative Analysis Between Experimental Path-Loss and Developed Model's Path-Loss

To determine the effectiveness of the calculated path loss model in predicting path losses for the NTA Enugu base station at the various research sites, the values obtained from the developed path loss model were compared with those from field measurements. The path loss value for route A for the base station NTA Enugu was compared to the calculated values. Mean error (ME), root-mean-square error (RMSE), and standard deviation error (SDE) are the statistical tools used to validate the path loss propagation model developed. Figure 3 shows the measured and predicted path loss variations for the investigated NTA station Enugu, depending on the distance. The figure shows that the predicted path loss values are very close to those of the measured path loss, especially between 6 km to 21 km, and both follow the same incremental trends with distance. The RMSE values for the calculated path loss are less than 7 dB, indicating that the model is very suitable for predicting path loss within the environments considered. The maximum RMSE values for urban and suburban environments for any model to be presumed correct for predictions are 8 and 15, respectively [19]. Other statistical tools used in this study to validate the performance of this developed prediction model also show that the calculated path loss developed is accurate and very suitable for predicting path loss values of NTA Enugu signals in Enugu State, Nigeria.

Table 5 lists the RSME and other statistical techniques used to evaluate the performance of the proposed path loss model. The RMSE, ME, and SDE of the estimated path loss values in Table 4 show that the proposed model is suitable for NTA path loss prediction in the state of Enugu, Nigeria, provided that all required transmission parameters and model values are accurately entered. The slight difference between the measured values and the calculated values can be attributed to obstacles in the signal paths at greater distances from the transmitter, terrain influences, and some human activities that interfere with electromagnetic waves. These effects are more likely to occur at distances closer to the transmitter and in environments with high-rise buildings, high population densities, mountains, and hills.

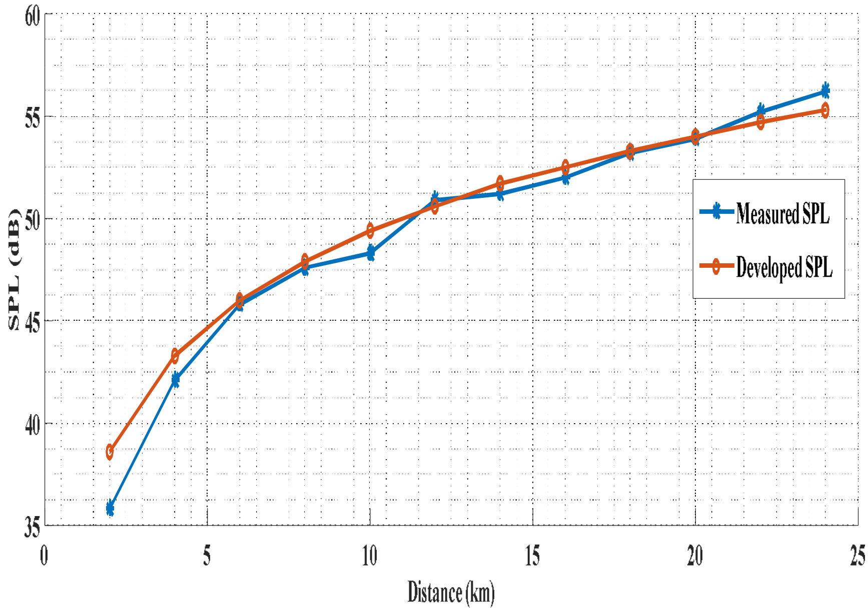

FIG. 3. Comparison of measured path loss values with the calculated path loss values for NTA Enugu in Enugu State, South-Eastern, Nigeria.

TABLE 5. Statistical parameters of the developed path loss values for the different NTA base stations.

NTA Stations	RMSE	ME	SDE
NTA Enugu	1.0120	0.4250	1.4604
NTA Umuahia	1.6482	1.2242	1.5664
NTA Aba	1.7517	1.3500	1.8025
NTA Owerri	2.8056	2.3500	1.8187
NTA Awka	1.6005	0.9000	1.6267
NTA Abakaliki	2.4898	1.9750	2.0629

3.5 Comparative Analysis of Different Path-Loss Models with Experimental Values

A comparative analysis was conducted between the proposed model and five (5) other conventional empirical path loss models, using measured path loss values for the NTA Enugu base stations monitored in Enugu state. The selected propagation models include Free Space Egli, Okumura, Cost-231 Hata, and Cost-231

Walfisch-Ikegami (Cost-231 W-L) models. These models are widely utilized in predicting signal drop or attenuation between transmitters and receivers over different and irregular terrains by applying appropriate correction factors [24]. Other models not mentioned for the prediction of path losses did not align well with the field values. Figure 4 illustrates the comparison of path loss values for measured, developed, and other models for NTA Enugu base stations in Enugu state, Nigeria. Aside from the proposed model, which predicted path loss relatively accurately, the other empirical models over-predicted the measured path loss value by approximately 48 dB, showing less agreement with the measured path loss values. The mathematical expressions for the different empirical models considered are listed below.

The free space path loss (FSPL) in wireless communications is the constriction of rf energy between the sources of two antennas caused by the combined application of the receiving antenna's coverage area and the insurmountable barrier, line-of-sight path through air. The mathematical expression of the free space path loss model is shown in Eq. (8) [18].

$$FSPL\ (dB) = 32.5 + 20logd + 20logf \quad (8)$$

where FSPL is free space path loss, d is the distance in kilometers (km), and f is the station's frequency in megahertz (MHz).

The Egli model is a radio frequency (RF) propagation terrain model. This model was created using real-world data from VHF and UHF television (TV) transmissions in a number of major cities. Eq. (9) represents the expression for the Egli path loss model [25].

$$L = 117 + 40logd + 20logf - 20\log(H_T - H_R) \quad (9)$$

Okumura's model is among the most commonly used signal prediction models in cities. This model is appropriate for frequencies ranging from 150 to 1920 MHz (though it is generally extended up to 3000 MHz) and distances ranging from 1 to 100 kilometers. It is suitable for base station antenna heights ranging from 30 to 1000 m. The model can be expressed as follows [26]:

$$L = L_{FSL} + A_{mu} - G_{hte} - G_{hre} - G_{area} \quad (10)$$

where, L = Okumura's path loss in dB, L_{FSL} = is the propagation loss in free space, A_{mu} is the median attenuation relative to free space, G_{hte} is the base station antenna height gain factor, G_{hre} is the mobile antenna height gain factor, and G_{area} is the gain due to environment type.

The COST Hata model is a path loss model that extends the urban Hata model (that is based on the Okumura model) to reach a broad frequency range of about 2 GHz. This model combines scientific and prescriptive models to estimate path loss in an urban area over a frequency range of 800 to 2000 MHz. The following is the path loss equation for the COST 231 Hata Model [27]:

$$L = 46.3 + 33.9logf - 13.82logh_B - a(h_r) + (44.5 - 6.55logh_b)logd + C \quad (11)$$

C is 0 for medium cities and suburban areas, C is 3 for metropolitan areas, L is median path loss in dB, f = frequency of transmission in MHz, h_B = base station antenna height in m, d = Link distance km, h_r = mobile station antenna effective height in m, and $a(h_r)$ mobile station antenna height correction factor as described in the Hata Model for urban areas.

For urban areas, $a(h_r) = 3.20[log10\ (11.75h_r)]2 - 4.97$; for f > 400 MHz and for sub-urban and rural areas, $a(h_r) = [1.1\log(f) - 0.7]h_r - 1.56\log(f) - 0.8$

The Walfisch-Ikegami model from COST 231 is a transformation of the Ikegami model. It is designed for urban areas and takes into account obstructing structure height and street depth, as well as other urban contextual factors. The Cost 231 Walfisch-Ikegami model is made up of three basic components, which are depicted below [28].

$$L = L_0 + L_{rts} + L_{msd} \quad (12)$$

L_0 is the free space path loss which is represented by; $L_0 = 32.5 + 20logd + 20logf$

The roof-top-to-street (rts) scatter and diffraction loss term is given by:

$$L_{rts} = -16.9 - 10log10^w + 10log10^f + 20log10^{(H_{roof} - H_m)} + L_{cri}$$

and the component of multi-screen diffraction loss is given by:

$$L_{msd} = L_{bsh} + ka + kdlog10^d + kflog10^f + 9log10^b$$

The following equation can be used for the special case when there is a line-of-sight path from the transmitter to the receiver in a given area, i.e., when the source transmitting device is below the rooftop [28]:

$$L_b = 42.6 + 25log10^d + 20log10^f \ for\ d \geq 0.020\ Km \quad (13)$$

In this study, Eq. (13) was used to calculate the Cost 231 Walfisch-Ikegami model.

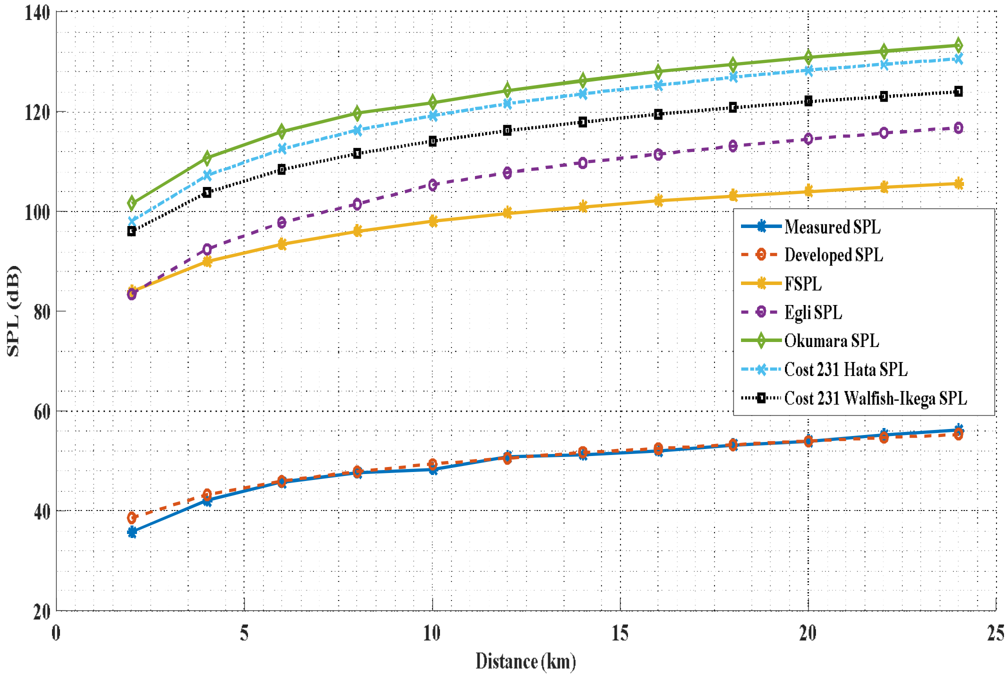

FIG. 4. Comparison of some experiential path-loss models with measured and calculated path-loss for NTA Enugu signals in Enugu State, Nigeria.

When compared to the observed and developed path loss values in the entire study area, the free space path loss model (FSPL) came closest. The Okumura and Cost-231 Hata models showed the highest deviation from the observed path loss and projected path losses of over 81.2 dB and 86.8 dB at all study locations. In general, FSPL forecast better than others, albeit they all overestimated the path losses.

3.6 Error Analysis of the Prediction Models

Based on the path loss comparisons in Fig. 4, the prediction errors of the different models under consideration were derived. The mean error, the root-mean-square error, and the standard deviation error of the above-mentioned existing path loss models, as well as the observed path loss values, were calculated as a function of the distance for all base stations examined. Table 6 shows the results of each of the statistical tools used to analyze the errors of the various predictive models with observed values. For each model, the mean error was calculated as the average of the difference between the measured and predicted loss.

The results of the various statistical tools in Table 6 show that the free space path loss (FSPL) model is closer to zero and therefore better suited for predicting at all study sites compared to other models with the exception of the newly developed path loss model. Although the FSPL appears to be closer to the observed and suggested path loss values, it is not suitable for predicting path losses in the examined environment. In order to make the FSPL model suitable for use at the study sites, the model was modified. The values in Table 6 were obtained by plugging relevant data into Eqs. (5), (6), and (7).

TABLE 6. Error analysis of the different prediction models with measured values for NTA Enugu signals.

Statistical tools	FSPL	Egli	Okumura	Cost 231 Hata	Cost W-L
RMSE	49.38	56.73	73.73	70.83	65.68
ME	49.37	56.91	73.84	70.95	65.74
SDE	1.898	2.962	2.753	2.856	2.461

3.7 Modification of Free Space Path-Loss Model

When compared to other predictive models, the path loss estimated using the free space path loss model correlates well with the measured path loss based on the lowest mean error, the standard error of the root-mean-square deviation, and the standard deviation. However, it is not accurate for path loss estimation. In order to have a different alternative path loss model than the developed path loss model for each NTA base station and environment examined, the parameters of the FSPL model were adjusted or tuned using a least squares method to obtain the appropriate error correction factor. The initial offset of the original FSPL model was taken into account for the adjustment process.

The expression for the free space path loss model is given as:

$$L_{fs}(dB) = 32.4 + 20\log(f) + 20\log(d) \quad (8)$$

The optimization value or the corrective factor is added to Eq. (8) to obtain the modified free space path loss model for NTA Enugu signals and environments investigated.

Equation (14) shows the general expression for the adjusted free space path loss (FSPL) model.

$$L_{fs}(dB) = 32.4 + 20\log(f) + 20\log(d) - C \quad (14)$$

The modified FSPL for NTA Enugu transmitting station in Enugu State South-Eastern, Nigeria is given in Eq. (15):

$$L_{fs}(dB) = 32.4 + 20\log(f) + 20\log(d) - 48.0 \quad (15)$$

The correctional factor [or error correction factor (ECF)] is 48. The correctional factor is intended to make the FSPL model suitable for use in the research setting. It was calculated by averaging the values of the root-mean-square error (RMSE) for the different routes considered, despite the fact that only one of the routes was used as a case study in this work.

3.8 Comparison between the Experimental Path-Loss Values and the Modified FSPL Values

The values obtained from the modified free space model were compared with the experimental (measured) path loss and the original free space path loss in order to check the suitability of the modified model in the application area. Figure 5 shows the comparison of the modified FSPL (MFSPL) values with the measured and the original FSPL (OFSPL) path loss values for the NTA Enugu signals examined. According to statistics, the initial free space path loss model overestimated the signal path loss of the studied NTA-Enugu signals in the specific environment under consideration, while the modified FSPL model successfully predicted the path loss of NTA-Enugu signals in the studied environment.

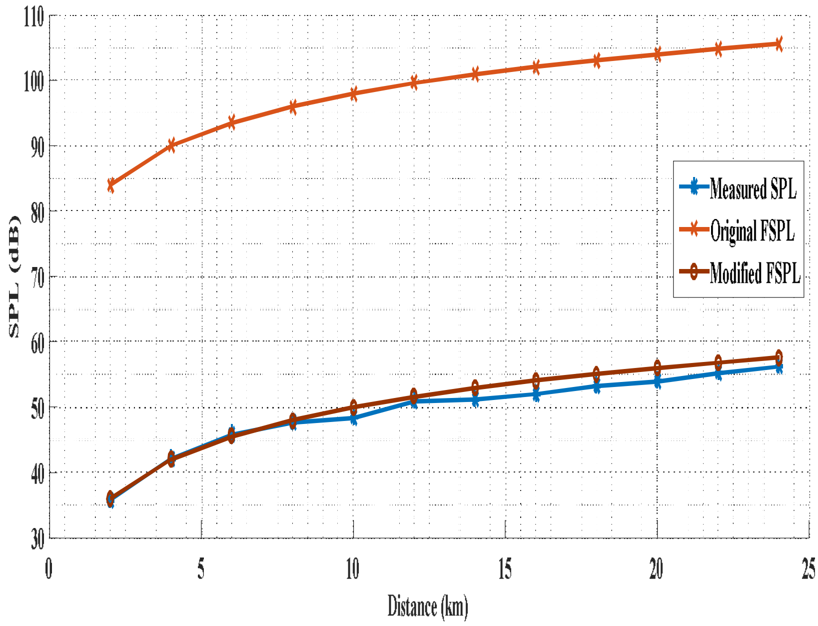

FIG. 5. Comparison between the measured path loss values and the modified free space path loss values for NTA Enugu in Enugu State, Nigeria.

3.9 Validation of Adjusted FSPL Model

To validate the adjusted free-space propagation model, the model was applied at the NTA Enugu base stations in the respective environments within the region in which the measurements were carried out. Comparison has also been performed in terms of mean error, root-mean-square error, and standard error between the original free space model and the adjusted free space model in all the environments. Table 7 shows the ME, RMSE, and SDE of the original and adjusted free space path loss models. The adjusted models showed a better agreement with the measured values in the various examined environments since the RMSE and ME are around the acceptable value.

TABLE 7. Validation of the adjusted free space path loss model for NTA Enugu signals.

Statistical tools	OFSPL	MFSPL
RMSE	49.1239	1.4000
ME	49.1167	1.1167
SDE	1.899	1.898

4. Conclusion

Based on the data collected in this study, it was discovered that the developed path loss model and the modified FSPL model are suitable for predicting and modeling path loss of NTA Enugu signals in the studied region. The results show that NTA Enugu signals suffer significant distortion in the investigated environments at a distance of approximately 0.3 km to 2 km from the base station and that other theoretical path loss models overestimate the path loss values in the examined environments. The propagation parameters developed in this study will be useful in designing wireless channels in the VHF and UHF bands in Enugu State, Nigeria.

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