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Analysis and modeling of path loss for terrestrial television in Nigeria

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ABSTRACT

The quality of services provided by television broadcasting corporations is significantly influenced by propagation path loss. The development of effective design and implementation of good quality signals is dependent on the accurate estimation of propagation path loss. Previous researchers have established several path losses models; however, these models cannot be applied to all situations and environments. The path losses of Nigeria Television Authority (NTA) Channel 6 Aba in Abia State, Nigeria were investigated in this study. A digital signal strength meter was used to measure the Received Signal Strength Level (RSSL) of the channel at 2 km intervals along 5 different routes around the base stations. Path loss values for each route were calculated using received signal strength. The obtained path loss was plotted against distance, and the result demonstrated that the path loss increases with distance along each of the routes. Further analysis of the variation of path loss with distance resulted in the development of a path loss model. To determine how accurate the model is in predicting path loss at the study sites, the developed model was compared with the measured path loss and some theoretical models for the NTA signals. Some statistical tools (RMSE, ME and SDE) were used to validate the developed model. Results also showed that the developed model predicted the path loss of NTA Aba signals very well, with an RMSE of 1.75. The existing theoretical path loss models considered overestimated the path loss values of NTA channel 6 Aba in the investigated environments, with RMSE values of 56.29, 75.68, 82.53, 79.03 and 72.61 for the FSPL, EGLI, okumura, Cost-231 Hata, and Cost-231 Walfisch-Ikegami models, respectively.

Keywords: Path loss, Signal strength, Nigeria television authority (NTA), Radio waves, Propagation model.

1. INTRODUCTION

Television broadcasting is a critical component of human development. People's desire for knowledge, entertainment, and information has increased as a result of their access to information through the use of television as noted by Imarhiagbe and Ojeh (2018). To that end, the three tiers of government in Nigeria have continued to establish television stations across the country to meet the people's longings and desires. The Nigeria Television Authority was established in 1977 as a government-owned entity. Since then, both the state and federal governments in Nigeria have had exclusive rights to the business of television broadcasting. However, over the last three decades, the federal government has opened the broadcasting industry to private investors to supplement the efforts of the state and federal governments. This has increased competition in the television broadcasting industry as in Akinbolati and Ajewole (2020).

Faruk et al. (2013a) suggested that the core concept in the configuration of any wireless system is the development of a transmission technique that enhances coverage while minimizing interference. As a result, researchers have continued to work hard to determine the exact distance coverage areas of some broadcasting stations, as well as the

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signal strength variations with distance from the transmitter base station. According to Yiyan et al. (2006), understanding the role of a radio propagation channel in a given environment is critical for the success and deployment of any technology designed to operate in that environment. Signal attenuation which is a characteristics of radio propagation channel increases with distance in all frequency bands; this is referred to as path loss. Sahoo and Behera (2011) disclosed that numerous signals may arrive at the receiving antenna, constructively or destructively, resulting in minor signal variations or multipath fading. Multipath fading may be caused by the refraction, diffraction, reflection, or scattering of the signal due to physical objects in the environment. The path loss model can be used to calculate the received signal level, signal-to-interference ratio, and carrier-to-interference ratio with high accuracy. In the view of Omolaye et al. (2015) path loss is the undesired signal strength reduction that occurs when a signal travels from the transmitter to the receiver.

Path loss is generally composed of propagation losses, penetration losses, and diffraction losses. The natural expansion of the radio wave front in free space, which usually takes the shape of an ever-increasing sphere, causes propagation losses. Diffraction losses occur when an opaque obstacle blocks a portion of the radio wave front. According to Purnima and Singh (2010) penetration losses occur when a signal passes through a medium that is not transparent to electromagnetic waves. The following are some of the most common causes of path loss: Bad line of sight, multipath, interference, weather conditions. Okumura, Hata, Walfisch-Ikegami, free space and Erceg are the most commonly used methods for wireless communications in the VHF and UHF frequency bands as reported by Akinbolati and Ajewole (2020).

Path-loss is a significant feature of the television signal transmission environment. It is the difference between the actual transmitted power and the power received. Faruk et al. (2013b) revealed that path loss models are required in a television broadcasting system for frequency allocation, proper planning, television parameter estimation, and interference estimation, all of which are critical to the wireless channel design process. Faruk et al. (2013b) further noted that path loss can also be caused by reflection, diffraction, free space loss, refraction, coupling loss, penetration loss, and absorption. Propagation medium, topography, settlement type, vegetation, transmit and receive antenna height and position, transmitter-receiver spacing, and atmospheric parameters all have an impact on path loss. The process of calculating path loss is known as "path-loss prediction." The most commonly used models for path-loss prediction in television communication systems are empirical and deterministic as noted by Iwuji and Emeruwa (2022).

The concept of deploying digital information processing television networks in developing countries such as Nigeria may not be realized in the near future, necessitating the need for alternative methods and techniques for utilizing the underutilized spectrum as spelt out by the works done Sarkar et al. (2003) and Oke et al. (2014). In light of this, researchers recently adopted traditional propagation models to predict TV coverage and keep-out distances, and also the wide spaces for stable and comfortable coexistence between direct and indirect networks. The television coverage of a primary user, on the other hand, is determined by the transmitter's power, height, transmission characteristics, and operating frequency. Researchers have used a variety of models to forecast these television service paths and coverage. Obota et al. (2011) proved that the most widely used empirical models are incompatible with Nigeria's tropical and humid regions. As a result, the error bounds of widely used empirical models based on measurements in Abia State, Nigeria, are misleading. Work done by researchers on television signals in the entire Eastern part of Nigeria shows that no single model provides a good fit, but free space path loss outperforms the other models used. This study focuses on developing a path loss model and determining the path loss model for NTA Aba in Abia State, Nigeria, as well as modifying the free space path loss (FSPL) for efficient path loss prediction of the station of interest in the study area.

The FSPL in telecommunications is the attenuation of electromagnetic radiation between the feed points of antenna arrays caused by the combined effect of the receiving antenna's coverage area and line-of-sight obstructions as presented by Lasisi et al. (2017). The loss between two isotropic radiators in free space, expressed as a power ratio, is referred to as free-space loss. It does not account for any power loss in the antennas due to defects such as resistance. Since radio waves propagate according to the inverse square law, the free space loss increases with the square of the distance between the antennas and decreases with the square of the wavelength of the radio waves as show by Segun and Olasunkanmi (2014). The FSPL is rarely used in isolation, but rather as component of the Friis propagation equation, which encompasses antenna gain. According to Popoola et al. (2018) it is a feature that must be included in a wireless transmission power link budget to ensure that adequate radio power reaches the receiver and that the transmitted signal is received coherently.

The Friis transmission formula is the source of the FSPL formula. This states that in a broadcasting system consisting of a transmitting antenna propagating radio waves to a receiving antenna, the ratio of received radio wave power (P_{RX}) to transmitted power (P_{TX}) is as follows:

$$P_{RX} = P_{TX} \frac{\lambda^2}{(4\pi)^2 d^2} \tag{1}$$

Where d = distance between receiver and transmitter, P_{RX} = received power, P_{TX} = transmitted power and λ = wavelength of the electromagnetic waves

From (1), we have

$$\frac{P_{RX}}{P_{TX}} = \frac{\lambda^2}{(4\pi)^2 d^2} \quad (2)$$

But

$$\frac{P_{RX}}{P_{TX}} = L_{fs} \quad (3)$$

Where L_{fs} is FSPL, converting Equation 3 to decibel

$$L_{fs} = -10\log_{10}\frac{P_{RX}}{P_{TX}} \quad (4)$$

The negative sign is due to the fact that P_{RX} is less than P_{TX}
Combining Equations 2 and 4;

$$L_{fs} = -10log_{10}\left(\frac{\lambda^2}{(4\pi)^2 d^2}\right) \quad (5)$$

Where, $\lambda = \frac{C}{f}$ and $C = 3\text{x}10^8$m/s

$$L_{fs} = -10log_{10}\left(\frac{C^2}{f^2}\frac{1}{(4\pi)^2 d^2}\right) \quad (6)$$

$$L_{fs} = -10log_{10}\left[(\frac{C}{4\pi})^2\frac{1}{d^2 f^2}\right] \quad (7)$$

Simplifying further gives;

$$L_{fs} = -10log_{10}\left(\frac{C^2}{4^2\pi^2}\right) - 10log_{10}\frac{1}{d^2} - 10log_{10}\frac{1}{f^2} \quad (8)$$

This gives:

$$L_{fs} = -147.6 + 20log_{10}d + 20log_{10}f \quad (9)$$

Where d = d (km) x 10^3 and f = f (MHz) x 10^6

$$L_{fs} = -147.6 + 20\ log_{10}(1\text{x}10^3) + 20log_{10}d\ (km) + 20log_{10}(1\text{x}10^6) + 20\ log_{10}f\ (MHz) \quad (10)$$

Thus,

$$L_{fs} = -147.6 + 60 + 120 + 20log_{10}d\ (km) + 20log_{10}f(MHz) \quad (11)$$

Therefore,

$$L_{fs}(dB) = 32.4 + 20\log d\ (km) + 20\log f\ (MHz) \quad (12)$$

FSPL is very important to this research because its values are the closest to the field strength values and the developed model when compared to other empirical models referred to in this work.

2. METHODOLOGY

This research was carried out along 5 different traversable and convenient routes in Aba, Abia State, Nigeria. 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, and other materials were used to conduct this research. An S110/S110D model CATV signal level analyzer was used to measure signals generated by the NTA in the study locations. The station monitored in this study is NTA Channel 6 Aba. The signal strength levels of the tested NTA station were classified based on the measurement paths. Table 1 shows the different routes of signal strength measurements for the TV station of interest. The distances between the measurement locations and the base station of the NTA transmitter under study were calculated using a travel distance tool.

At the study area, the receiving antenna was pointed in different directions to determine if the strongest signal came from a different direction other than the transmitters. Measurements were taken every 2 km from the specific NTA signal source under investigation along the designated signal strength measurement routes. The receiving antenna was raised to a height of about 4 meters during the signal level measurement to intercept the horizontally polarized signal under investigation. An agreement was reached with the management of the NTA stations under consideration to ensure that the transmission parameters remained constant for field strength measurements. Table 2 shows some of the transmitting parameters of NTA Channel 6 Aba. In particular, signal strength measurements were taken for several months at different times of day and at various temperatures, pressures, and humidity levels. The average field strength measurement results for the studied period were obtained, and the data was analyzed with Mat lab to determine the power of the signal strength generated by NTA transmitters along the chosen routes.

Table 1. Different routes of signal strength measurements

Routes	Description
Route A	Aba-Ikot Ekpene
Route B	Aba-Utu-Etim Ekpo
Route C	Aba-Portharcourt
Route D	Aba-Umuahia
Route E	Aba-Owerri

The receiver's antenna used for this research study is a directional antenna consisting of driven elements connected to a CATV analyzer via a transmission line. The antenna is a UHF and VHF signal receiver that helps decode data from digital and analog television by horizontally polarizing the transmitted data. It has a moderate gain of 6–10 dB, an impedance of 75 Ω, and operates within the frequency range of 47–862 MHz with front-back ratio of more than 15 dB. The antenna has a horizontal/vertical beam width of

H60°/V50°, high-tech double driven elements, and a length of approximately 300 mm. The image of the experimental set-up is as shown in Fig. 1.

Table 2. Transmitting parameters of NTA channel 6 Aba

Serial No.	Transmitting parameters	Description
1	Base station frequency	187.75 MHz
2	Transmission type	Rohde & Schwarz 10 kW
3	Base station transmitting power	4.2 kW
4	Base station channel	Channel 6
5	Height of transmitting antenna	226 m
6	Transmitting antenna gain	30.02 m
7	Base station position	Long 5.07°N Lat 7.22°E
8	Receiving antenna orientation	Omni-directional
9	Height of receiving antenna	4 M

Fig. 1. Picture of the experimental set-up

3. RESULTS AND DISCUSSION

The results of signal strength measurements were presented and analyzed in this section to determine the path of NTA channel 6 Aba over the study areas for both dry and wet season months. The RSSL were measured at 2 km intervals along the different signal strength measurement routes ranging from 2 km to 24 km. To average out inconsistent signals, the average received signal at each measurement point was used. Table 3 shows the mean signal strength measured during the study period, which was obtained and tabulated. After that, the path loss for each route was calculated by analyzing the signal strength values received at each measurement location.

Path loss (in decibels), which is the difference in decibels between the transmitted power and received power, was calculated from the measured values of the received signal strength using the expression:

Path loss (PL) = Total signal transmitted (TST) - Total signal received (TSR) (13)

Table 4 shows the values for the path loss measure.

Table 3. Signal strength values of NTA Aba along different routes in Abia state

Distance (km)	Route A	Route B	Route C	Route D	Route E
2	41.9	39.8	41.5	42.5	40.4
4	38.5	34.8	36.4	36.8	37.8
6	32.7	34.3	33.1	33.5	34.1
8	30.4	28.6	31.5	29.8	29.0
10	27.6	26.5	26.8	28.0	26.7
12	26.8	24.3	26.1	26.6	25.8
14	25.6	23.8	25.1	24.6	24.2
16	24.1	22.5	23.5	22.8	22.1
18	22.3	21.1	20.6	21.8	20.0
20	21.4	19.7	19.3	20.1	18.9
22	20.8	19.0	18.6	19.6	17.8
24	19.1	18.1	17.8	17.3	16.9

Table 4. Path loss values of NTA Aba along different routes in Abia state

Distance (km)	Route A	Route B	Route C	Route D	Route E
2	27.8	29.9	28.2	24.2	26.3
4	31.2	34.9	33.3	32.9	31.9
6	37.0	35.4	36.6	36.2	35.6
8	39.3	41.1	38.2	39.9	40.7
10	42.1	43.2	42.9	41.7	43.0
12	42.9	45.4	43.6	43.1	43.9
14	44.1	45.9	44.6	45.1	45.5
16	45.6	47.2	46.2	46.9	47.6
18	47.6	48.6	49.1	47.9	49.7
20	48.3	50.0	50.4	49.6	50.8
22	48.9	50.7	51.1	50.1	51.9
24	50.6	51.6	51.9	52.4	52.8

The variation of the measured path loss with distance for the NTA Aba base station is represented in Fig. 2. The graph demonstrates how the path loss measured for NTA Aba signal propagation increases with distance along the various routes of signal strength measurements. For instance, in Fig. 2, the path loss in decibels for NTA Aba routes A, B, C, D and E for a distance of 2 km is 27.8, 29.9, 28.2, 24.2 and 26.3, respectively. The path loss values for the same routes at 4 km are 31.2, 34.9, 33.3, 32.9 and 31.9, respectively; and at 6 km, the path loss values for routes A, B, C, D and E are 37.0, 35.4, 36.6, 36.2 and 35.6, respectively, in Abia state, Nigeria. As the distance between the transmitter and the base station's receiver grows, so does the signal path loss (SPL).

3.1 Path Loss Modeling

To predict the path loss of the signals generated by NTA Aba in Abia State, Nigeria, a linear propagation model was

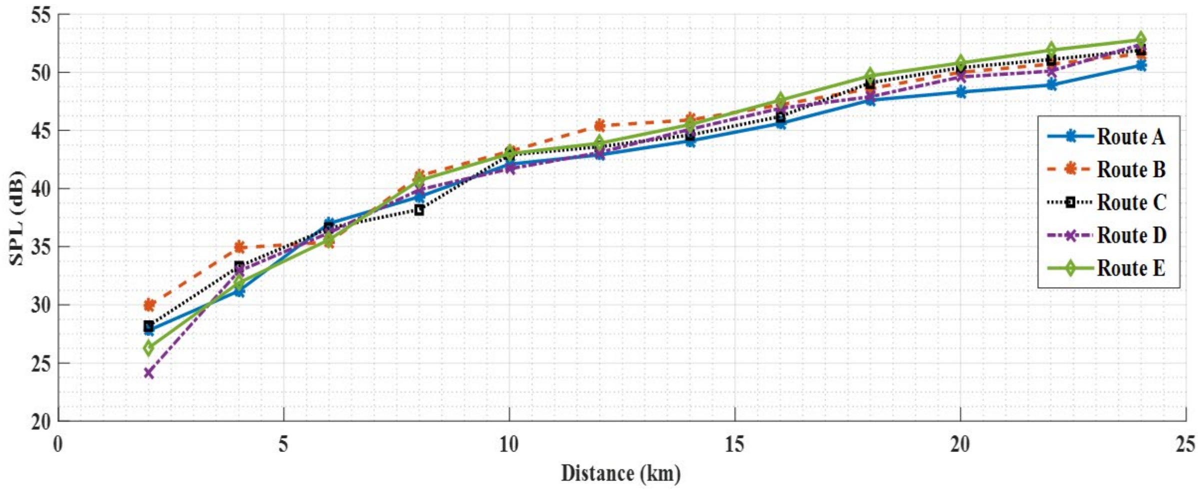

Fig. 2. NTA Aba path loss along different routes in Abia State, Nigeria

developed from the field data obtain. The values of the path loss proponents for NTA Aba transmitters were determined and used to characterize TV signal propagation along with the distance breakpoint in the developed model. The mathematical model shown in Equation 15 was developed based on the results of this study's field measurements, while taking into consideration the fundamental expression for path loss shown in Equation 14 as shown by Zakaria et al. (2015; 2016).

$$Ls(dB) = Lp + 10nlog\frac{d_1}{d_0} \quad (14)$$

where Ls is the transmitting signal's path loss in dB at a distance $d_1(km)$ between the transmitter and the receiver, Lp is the SPL at a constant distance $d_0(km)$ and n is the path loss exponent.

Equation 15 depicts the developed path attenuation model capable of predicting the attenuation of NTA signals with distance in Aba State, Nigeria. Y_x and e values were calculated directly from simulation of field data using Mat Lab software. When the path loss values from the field measurements were processed with the Mat Lab software, it produced values of Y_x and e for the various routes studied and automatically averaged them to produce the values stated in the work.

$$PL = Y_x + Melogd_a - Melogd_r + C \quad (15)$$

where PL denotes path loss value and Y_x denotes path loss value at a reference distance from the transmitter, which is assumed to be 1 km from the base station transmitter. M is the logarithmic coefficient, which has a constant value of 20. The parameter e, which varies depending on the base station, is known as the path attenuation promoter or exponent. $d_a$is the actual distance (in km) between the transmitter and the receiver, and d_r is the reference distance from the transmitter antenna, which is assumed to be 1 km. C is the correction factor for loss caused by scattering, interference, dispersion, obstruction, absorption, reflection, and other factors. C is 1 for normal terrain, 2 for areas with tall vegetation, and 3 for densely populated and crowded areas. Y_x = 23 dB and e = 0.95 are the path loss predicting model parameters for the NTA Aba transmitter. Linear regression was used to calculate the path loss exponent value e at the breakpoint for a specific site from the measured path loss values. The calculated path loss model in Equation 15 was developed by finding the appropriate values of e, Y_x, and C for a given da.

The path loss values are plotted as a linear line, indicating that the path loss increases with the line-of-sight distance between the base station and the television receiving station with relatively little scattering. After the breakpoint distance, attenuation and scattering become more noticeable and irregular. However, attenuation matches the property attributes of the transmitter base stations' environment. Fig. 3 shows the relationship between the SPL of the developed model and distance for NTA Aba signals.

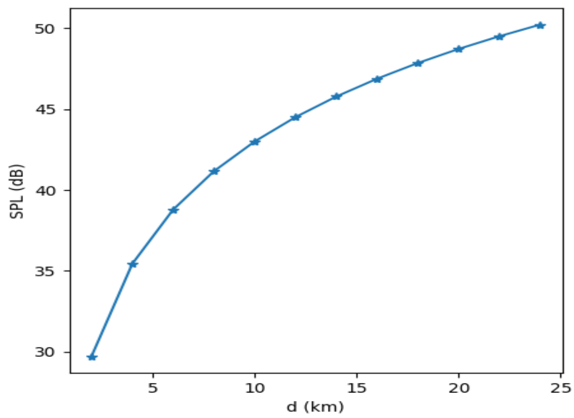

Fig. 3. Developed model's path loss against distance for NTA Aba signals

3.2 Performance Metrics for the Proposed Model

Key performance indicators were used to assess the performance and fitness of the proposed models for use in the study area. They are as follows: Mean Error (ME), Standard Deviation Error (SDE), and Root Mean Square Error (RMSE). The RMSE is a measure of the difference between the values predicted by a theoretical model and the values observed. It assesses the fit between the observed data and the predicted model. The most obvious metric for analyzing predictive model error is RMSE in Faruk et al. (2013c). Equations 16, 17 and 18 provide expressions for calculating MSE, RMSE and SDE, respectively.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(PL_m - PL_c) \quad (16)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(PL_m - PL_c)^2} \quad (17)$$

$$\sigma_e = \frac{\sigma}{\sqrt{n}} \quad (18)$$

PL_m = measured path loss values, PL_c = empirical prediction path loss values, σ_e is the SDE, σ is the standard deviation and n is the number of the given sample.

In general, when the RMSE, ME and $\sigma_e$value is close to zero (0), it indicates a better fit as argued by Popoola et al. (2019). According to Akinbolati and Ajewole (2020), for urban and suburban areas, the acceptable RMSE for a path loss model should be around 7 and 15 dB, respectively.

3.3 Comparative Analysis between Developed Model's Path-Loss and Experimental Path-Loss

The values obtained from the developed path loss model were compared with those from field measurements to determine the effectiveness of the calculated path loss model in predicting path loss for the NTA Aba base station at the various research sites. The calculated values were compared to the measured path loss along Route A. ME, RMSE, and SDE are the statistical tools used to validate the developed path loss propagation model. Fig. 4 depicts the measured and predicted path loss variations with distance for the studied NTA station Aba. The graph shows that the predicted path loss values are very close to the measured path loss values and they both follow the same incremental trends with distance. The RMSE values for calculated path loss are less than 7 dB, indicating that the model is very good at predicting path loss in the considered environments. The maximum RMSE values for each model believed to be correct for predictions in urban, suburban, and rural environments are 7, 10 and 15, respectively. Other statistical tools used to evaluate performance in this study Validation of this developed prediction model also demonstrates that the calculated path loss is accurate and well suited to predicting path loss values of NTA Aba signals in Abia State, Nigeria.

Table 5 shows the RSME and other statistical techniques that were used to assess the performance of the proposed path loss model. The RMSE, ME and SDE of the estimated path loss values in Table 5 indicate that the proposed model is suitable for NTA path loss prediction in Abia State, Nigeria, assuming that all required transmission parameters and model values are accurately input. The slight difference in measured and calculated values can be attributed to obstacles in signal paths further away from the transmitter, terrain influences, and some human activities that interfere with electromagnetic waves. These effects are more likely to occur at closer distances to the transmitter and in environments with high-rise buildings, hills, dense populations, and mountains.

Table 5. Performance metrics of the developed path loss values for NTA Aba

NTA Stations	RMSE	ME	SDE
NTA Aba	1.7517	1.3500	1.8025

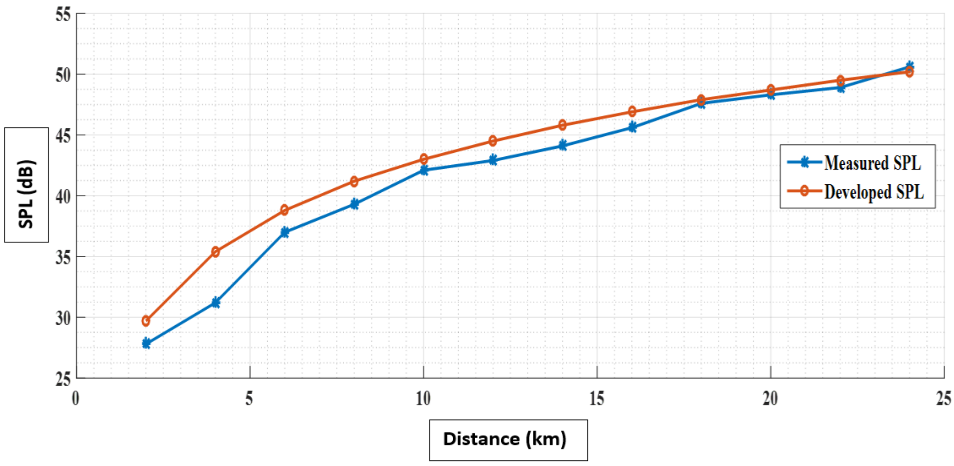

Fig. 4. Comparison of measured path loss values with the developed path loss values for NTA Aba in Abia State, South-Eastern, Nigeria

3.4 Comparison of Different Empirical Path-Loss Models with Experimental Values

The developed model was compared to 5 other conventional empirical path loss models as well as the measured path loss values for the NTA Aba base station in Abia State. Among the various propagation models are: The Egli, free-space, Cost-231 Hata, Okumura and Cost-231 Walfisch-Ikegami (Cost-231 WL) path loss propagation models used in this study are the most commonly used path loss propagation models for estimating the find signal drop or attenuation between transmitter and receiver over varied and irregular terrain by applying appropriate correction factors. Other path loss prediction models that are not listed fall far short of field values. Fig. 5 depicts a comparison of path loss values for NTA Aba base stations in Aba State, Nigeria, based on measured, developed, and other models. Except for the proposed model, which predicted the path loss fairly accurately, the other empirical models overestimated the measured path loss value by about 48 dB, indicating poor agreement with the measured path loss values. The FSPL Model came closest to the observed and developed path loss values across the study area. However, at all study sites, the Okumura and Cost-231 Hata models had the greatest deviation from the observed path loss and predicted path loss of over 81.2 and 86.8 dB, respectively. FSPL predicted better than others in general, though they all overestimated path losses.

The nature, type and terrain of the study area are the main reasons why the aforementioned theoretical models overstated the path loss of NTA channel 6 Aba. The area's vegetation is rainforest, with diverse species of bushes and tall forest trees growing across the area, both in mountainous and depressed locations. It has a population of about six million people and is located at a height of 205 meters (673 feet). The international markets in Aba, Nigeria, are one of the city's most notable features, with millions of daily trading operations highlighted by the use of machinery and devices that emit electromagnetic radiation. This electromagnetic radiation tends to interfere with that created by NTA channel 6 Aba, causing the transmitted signals to be antagonized. Furthermore, the towering structures within the research areas block the signals generated by the NTA channel 6 Aba's transmitter, preventing the signal from propagating. Given that the above-mentioned theoretical route loss was not constructed taking into account Aba's unique characteristics and the transmitting parameters of NTA channel 6 Aba, it is unlikely to provide appropriate path loss values for the signals under consideration.

3.5 Error Analysis of the Different Prediction Models

The prediction errors of the various models considered were calculated based on the path attenuation comparisons in Fig. 5. The ME, mean square error and SDE of the above-mentioned existing path loss models, as well as the observed path loss values as a function of distance, were calculated for all base stations examined. Table 6 displays the outcomes of each of the statistical tools used to analyze the errors of the various predictive models with observed values. The ME was calculated for each model as the average of the difference between the measured and predicted loss. The results of the various statistical tools in Table 6 show that, with the exception of the newly developed Path Loss model, the FSPL model is closer to zero and thus better suited for making predictions at all study sites than other models. Although the FSPL appears to be closer to the observed and proposed path loss values, it is insufficient for predicting path loss in the environment under consideration. The model was modified in order to make the FSPL model suitable for use at the research centers.

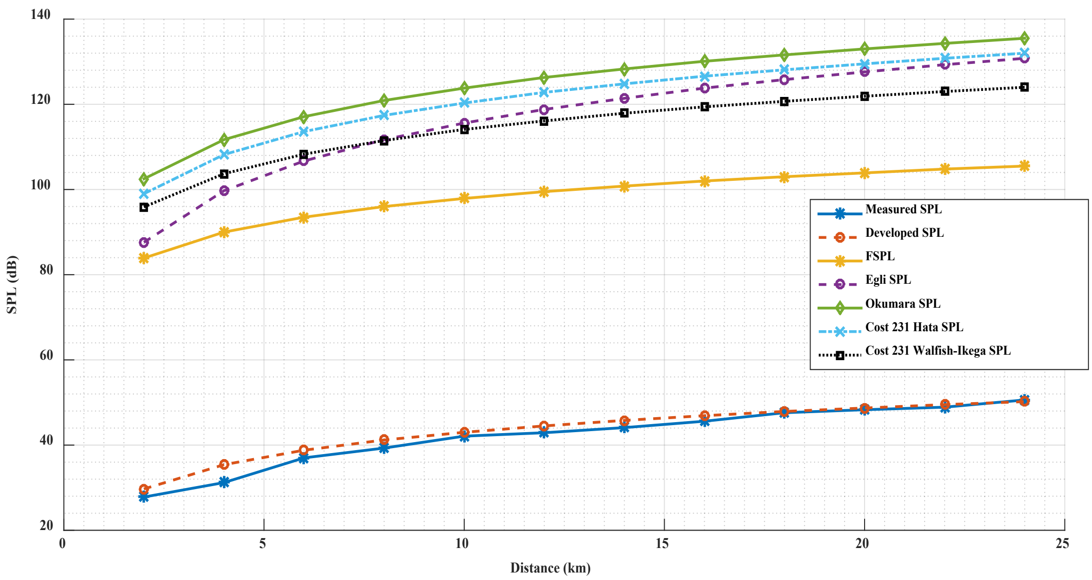

Fig. 5. Comparison of some experiential path-loss models with measured and calculated path-loss for NTA Aba in Abia State, Nigeria

Table 6. Validation of the developed path loss model

Statistical tools	FSPL	Egli	Okumura	Cost-231 Hata	Cost W-L
RMSE	56.29	75.68	82.53	79.03	72.61
ME	56.28	74.45	82.48	78.98	78.98
SDE	1.894	3.793	2.893	2.893	2.467

3.6 Adjustment of Free Space Path-Loss Model

The path loss estimated using the FSPL model correlates well with the measured path loss based on the lowest ME, the standard error of the mean square deviation, and the standard deviation when compared to other prediction models. However, it is ineffective for estimating path loss. To obtain a different alternative path-loss model than the developed path-loss model for the examined NTA base station and environment, the FSPL model parameters were fitted or tuned using the least squares method to obtain the appropriate error correction factor. The initial offset of the original FSPL model was taken into account in the adjustment. The FSPL model is expressed as follows:

$$L_{fs}(dB) = 32.4 + 20\log(f) + 20\log(d) \quad (19)$$

To obtain the modified free space path attenuation model for NTA Aba signals and examined environments, add the optimization value or correction factor to Equation 19. The general expression for the fitted FSPL model is shown in Equation 20.

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

The modified FSPL for NTA Aba transmitting station in Aba, Abia state is given in Equation 21.

$$L_{fs}(dB) = 32.4 + 20\log(f) + 20\log(d) - 48.0 \quad (21)$$

3.7 Comparison of Experimental Path-Loss Values and Modified FSPL Values

To validate the modified model's suitability in the field of application, the values obtained from the modified free space model were compared to the experimental (measured) path loss and the original FSPL. Fig. 6 depicts a comparison of the modified FSPL (MFSPL) values with the measured and original FSPL (OFSPL) path loss values for the NTA Aba signals under consideration. The existing FSPL model, according to statistics, overestimated the signal path loss of the examined NTA Aba signals in the specific environment under consideration. While the modified FSPL model correctly predicted the path loss of NTA Aba signals in the investigated environment.

3.8 Affirmation of the Modified FSPL Model

The adjusted free space propagation model is verified by applying it to the NTA Aba base stations in the measurement locations. In all environments, ME, mean square error and standard error were compared between the original free space model and the adjusted free space model. The ME, RMSE and SDE of the original and modified loss models for the free space path are shown in Table 7. The adjusted models demonstrated better agreement with the measured values in the studied locations, as their RMSE and ME are within acceptable limits.

Table 7. Affirmation of the adjusted FSPL model for NTA Aba signals

Statistical tools	OFSPL	MFSPL
RMSE	56.2910	1.0372
ME	56.2833	0.2083
SDE	1.894	1.876

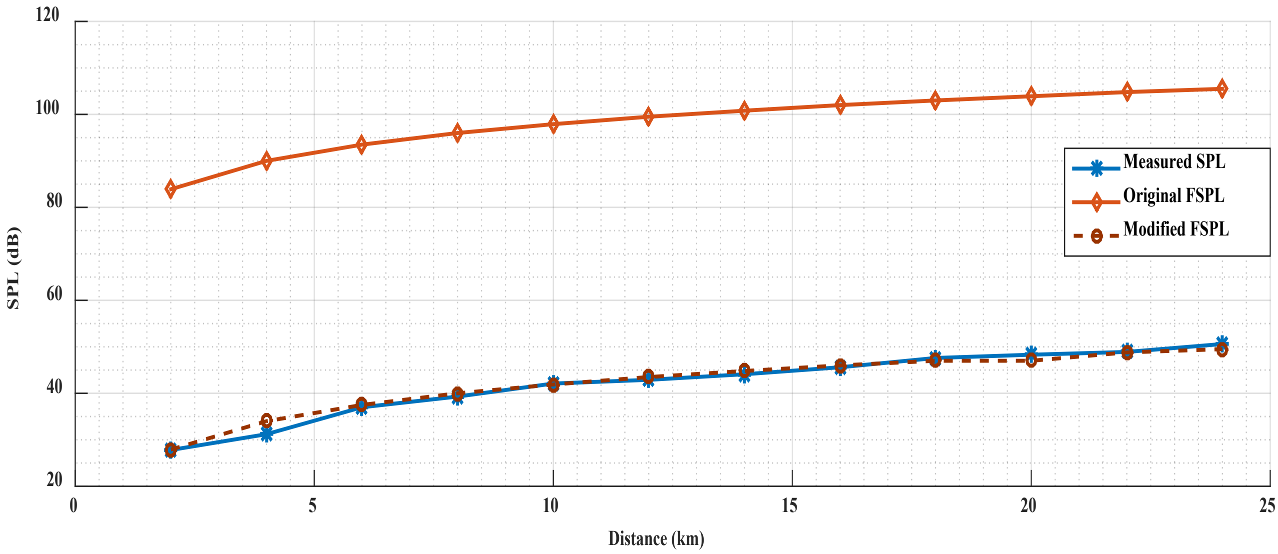

Fig. 6. Comparison of some experiential path-loss models with measured and calculated path-loss for NTA Aba in Abia State, Nigeria

3.9 Discussion of the Results

In regions where television broadcasting networks have or are being implemented, propagation models are invaluable in predicting signal propagation loss between a transmitter and its receivers. Research work on the use of empirical propagation models to predict the signal strength of terrestrial television in the south-eastern part of Nigeria, particularly in Aba-Abia State, is scarce, making it difficult for interested experts to estimate the signal attenuation of these television signals without conducting a routine check and investigation. Nonetheless, there is a time delay between data collection in the terrain and processing, which should not be overlooked, but the prediction helps to mitigate the negative impact of the response delay.

Different channels are distributed in television broadcasting systems with one thing in mind: the allocation must be efficient and effective. There should be no communication disruptions such as congestion, snow, signal degradation, resonance, or a lack of channel availability, among other things. When an electromagnetic wave from a particular channel propagates over space, television operators must be cautious to ensure that its signal strength and power density do not deteriorate. Path loss reduces the signal intensity and power density of an electromagnetic wave, which is unfortunate. As a result, path loss must be considered as one of the parameters that impact channel performance in mobile communication. Thus, it's critical to discover effective path loss reduction solutions that can help us reduce path loss and, therefore, improve channel performance. The path loss prediction model becomes crucial in this situation.

Existing path loss models are erroneous and unsuitable for use in this study area and for the NTA station examined so far. Path loss models developed by other researchers for other locations and television stations were likewise unsuitable for predicting NTA Aba path loss. This model was developed in response to this. When evaluated in this situation, the produced model operated perfectly and was shown to be very suited and efficient for the research location and similar terrain. Unlike other models, such as the two slope models developed by Abiodun et al. (2017), this developed model can predict path loss over a long distance (beyond 24 km). Because of their mathematical complexity, path loss models are often ambiguous, making them challenging to use by end-users. In a nutshell, the model established in this study is accurate, simple to use, appropriate, efficient, and can be deployed across a long distance, particularly in the study areas and similar terrain.

In general, it is clear from the developed and measured model path loss values that NTA Aba performs poorly at a distance of 22 km from the base station. This is mainly because of a number of factors, such as the low power and aged transmitter being used, the local vegetation, traffic due to the area's high population density, a large number of viewers tuning in, and interference from industrial machines that produce a lot of radio frequencies (RF), which interfere with the RF signals produced by NTA Aba. Aba has a high population index because it is an industrial area with one of Africa's largest markets. Viewers tune in on a regular basis to watch informative programs as well as to advertise their goods and services, causing traffic on the channels. In addition, the study location has massive buildings that obstruct television signals generated in the area. These factors all contribute to the reason why the NTA Aba signal performs poorly at a distance of 22 km.

The empirical model developed can be used to estimate path loss for a given line of sight along the different routes studied in the state. The values of the developed model show that the path loss of the NTA Aba signals varies directly with the line of sight. In all of the routes investigated, the field strength decays with distance. The linear fluctuations in path loss with distance are well justified in this way. Even though the NTA signal suffers from distortion between 0.3 and 2 km from the base station, the signal strength of this station was satisfactory between 0 and 12 km circumferential from the transmitter base, according to our findings.

4. CONCLUSION

This study provides an accurate path loss model and a modified FSPL model to improve coverage area estimations and predict a reliable network for NTA television propagation in Aba, Nigeria without physically carrying out measurements in the study location. It also provides field data that can be explored by NTA management to improve the efficiency of their signal as well as by other researchers as research tools.

In conclusion, the following results were derived from this study:

1. Existing theoretical path loss models presented overestimate the path loss values of NTA channel 6 Aba in the investigated environments. Although the FSPL Model came closest to the observed and developed path loss values across the study area, it is still not suitable for predicting the path loss of NTA Aba signals within the study area.
2. The data collected in this study revealed that the developed path loss model and the modified FSPL model are suitable for predicting and modeling path loss of NTA Aba signals in the studied region.
3. At a distance of 22 km from the base station, NTA Aba performs poorly.
4. The path loss proponent or exponent is environmental dependent

5. RECOMMENDATION

To ensure optimal planning of power budget and link design across study sites, the proposed models are recommended for use. Also, it is recommended that NTA Aba's management increase their output power to at least 10 kW to ensure that their subscribers receive signals well beyond 22 km. Furthermore, the signal propagation model developed for wireless network applications should be extended to other parts of the country with similar terrain and seasonal variations.

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