

Analysis of Path Loss and Propagation Characteristics for Independent Television, Benin City, Edo State

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ABSTRACT

Accurate path loss prediction is essential for maintaining television and radio broadcast quality. This study examined path loss for Independent Television (ITV) channel 22 operating on the Ultra-High Frequency (UHF) band in Benin City, Edo State, Nigeria. Signal strength measurements were collected at 0.1km along a route using a Tiny Spectrum Analyzer (SA). A path loss model was developed based on these measurements and compared to standard models of the Hata, Egli, and Free Space models. Results indicate a path loss increase of 39.6dB per decade in the urban area and that the developed model outperforms existing models. While the Hata model proved closest to the measured data a modified version provided the most accurate prediction with a Root Mean Square Error (RMSE) of 1.66dB. The path loss exponent is influenced by environmental factors, emphasizing the need for site-specific models. The developed and modified Hata models provide effective path loss prediction for Benin City's urban environment.

ARTICLE INFO

Article History
Received: May, 2024
Received in revised form: May, 2024
Accepted: June, 2024
Published online: September, 2024

KEYWORDS

Independent Television (ITV), Path loss, Signal strength, Radio waves, Propagation Model

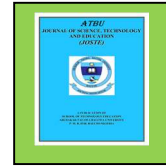
INTRODUCTION

Independent Television (ITV) is a trailblazing broadcast network in Nigeria, established in 1993 by Sir Chief Gabriel Osawaru Igbinedion, with its first transmission in 1997. It has played a pivotal role in shaping Nigeria's media landscape. The network is based at the Glass House on Airport Road, Oluku, Benin City, and is dedicated to providing news, educational content, and entertainment to the people of Edo State. A key challenge in wireless system design is maximizing coverage while minimizing interference. To enhance broadcast coverage and system performance, researchers have extensively studied how signal strength diminishes with increasing distance from transmission towers. Understanding signal propagation in various environments is crucial for effective network design. As radio waves travel from a transmitter to a receiver, signal degradation or path loss occurs, affecting all frequencies. This degradation can be exacerbated or reduced by multipath effects caused by reflections, refraction,

or obstacles in the signal path. Path loss models help estimate wireless systems' signal strength, interference, and overall signal quality. They are critical for television broadcasting systems, aiding in tasks such as frequency allocation, planning, parameter estimation, and interference management, which are all vital for designing wireless channels. Common path loss models for Very High Frequency (VHF) and Ultra High Frequency (UHF) include the Okumura, Hata, Free Space, Walfisch-Ikegami, and Erceg models. Path loss can result from several factors, including reflection, diffraction, free space loss, refraction, coupling loss, penetration loss, and absorption. Elements such as the propagation medium, topography, type of settlement, vegetation, antenna height, and position, the distance between transmitter and receiver, and atmospheric conditions all influence path loss. The process of calculating this loss is referred to as "path-loss prediction," with the most widely used models being empirical and deterministic (Oke and Raji, 2014). Researchers have recently

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adopted traditional propagation models to predict TV coverage, keep out distances, and identify white spaces for stable and comfortable coexistence between direct and indirect networks. The television coverage of a primary user, however, is determined by factors such as transmit power, antenna height, transmission characteristics, and operating frequency. Various models have been used to forecast these television service curves. It has been found that the most widely used empirical models are incompatible with Nigeria's tropical and humid regions (Obota, *et al.*, 2011).

REVIEW OF RELATED WORKS

Several research studies have been conducted to assess the effectiveness of path loss models. Typically, researchers collect measurement data from a specific environment and evaluate how well the models perform in that context. For example, Popoola *et al.* (2019) used the Feed-Forward Neural Network (FFNN) algorithm to predict path loss in their study. They gathered drive test measurements in Canaan Land Ota, Nigeria, and Ilorin, Nigeria, obtaining path loss data from 11 different 1,800 MHz base station transmitters at varying distances. The Transmission Evaluation and Monitoring System (TEMS) software, known for its capabilities in data collection, real-time network analysis, and post-processing, was used for these tests. The software ran on a laptop with an Intel Core i5-3210M CPU at 2.50 GHz, 4 GB of RAM, and a 64-bit Windows 7 operating system. A TEMS mobile station, USB dongle, and Garmin GPS were connected to the laptop, all placed in a vehicle driven at an average speed of 40 km/h. The results showed that the FFNN model, using a tangent activation function and 48 hidden neurons, achieved the lowest prediction error. The model produced mean absolute error (MAE), mean squared error (MSE), root mean square error (RMSE), standard deviation, and R values of 4.21 dB, 30.99 dB, 5.56 dB, 5.56 dB, and 0.89, respectively. However, their study did not develop a propagation model for network planning. Bakare *et al.* (2019) conducted a propagation analysis of the Love FM radio signal in Port Harcourt using a

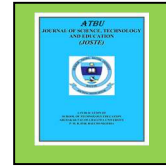
GPS band scanner. The scanner collected data on signal strength, spectrum, and Radio Data System (RDS) information at various locations. This data was processed using Deva Broadcast Ltd software to determine signal distance and strength. The analysis revealed that the Love FM transmitter antenna is not truly isotropic, as the signal strength values were not uniform in all directions. Signal strength was notably higher near the transmitter and diminished at greater distances. However, a limitation of this study was the lack of consideration of propagation models for analyzing the radio frequency signal, and the presentation of results was not adequately implemented. Imoize and Oseni (2019) also conducted a study using Huawei Technologies drive test equipment to measure the propagation characteristics of a 4G Long-Term Evolution (4G LTE) network. The setup included user equipment (UE), a Genex probe, a GPS module, an LTE modem, and a personal computer running software for recording UE readings and processing data post-drive test. Measurements were taken from three 1800 MHz eNode Bs located along major roads in Lagos, and the observed path loss was compared to predictions made by several models, including free space, flat earth, Okumura-Hata, Walfisch-Ikegami, Ericsson, ECC-33, and Lee models. It was found that the free space, flat earth, Walfisch-Ikegami, Ericsson, and Lee models overestimated path loss along the routes studied, with Root Mean Square Errors (RMSEs) significantly exceeding acceptable limits. A major limitation of this research was the exclusion of the UHF television spectrum band from the analysis. Kebiru *et al.* (2020) explored the effectiveness of propagation models for estimating TV white space in southern Nigeria. They derived statistical path loss models using data collected at 745.25 MHz from Edo Broadcasting Service (EBS) with the help of a Spectrum Analyzer (RF Explorer 3G combo model), a laptop with Touchstone RF Spectrum Analyzer software, a Mini USB cable, and a GPS receiver. Their analysis produced a path loss model showing an increase of 23.1 dB per decade in urban areas. By comparing the measured values with predictions from the Okumura-Hata

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model, and calculating a Mean Square Error (MSE) of 1.31 dB, they modified the model for improved accuracy. However, the study was limited by not accounting for new transmitters and a lack of detailed methodology. In another study, Erunkulu et al. (2020) reviewed existing techniques and mechanisms for predicting network coverage, providing an updated comparative analysis of path loss models to aid in cellular network planning and implementation. However, their work did not consider the UHF band, and the methodology for data acquisition was not clearly outlined. Similarly, Abu et al. (2020) developed a path loss model based on measurements collected in the urban environment of Onitsha, southeastern Nigeria. Received Signal Strength (RSS) data was gathered from the Nigerian Television Authority (NTA), operating at the 583.25 MHz frequency band, using a drive test setup with a spectrum analyzer, laptop software, USB cable, GPS receiver, and compass. Their model indicated a path loss increase of 3.10 dB per decade for the NTA Onitsha environment. A key limitation of their study was the absence of a Root Mean Square Error (RMSE) analysis to quantify the model's accuracy. Ukommi, et al., (2020), conducted a performance analysis of outdoor 2.4GHz Band Wi-Fi Networks within the Akwa Ibom State University. They gathered empirical data using a Wi-Fi radio, a GPS receiver, a laptop, a pen, and a recording book. Received Signal Strength (RSS) measurements on the Wi-Fi interface were captured using InSSIDer software running on the laptop their findings suggest the Cost 231-Walfisch-Ikegami model as the most suitable for network planning in the area due to its lower error compared to other models. However, a limited measurement area restricts the study's scope. Famoriji and Shongwe (2022), developed machine learning models for path loss prediction in the tropical Akure metropolis. They collected field strength data from three broadcast stations (Ondo State Radiovision Corporation (OSRC), Orange FM, and FUTA FM) using a TENMARS TM-195 RF Field Strength Meter and global positioning system (GPS) satellite receiver. The models were hybridized with classical methods and machine learning algorithms to

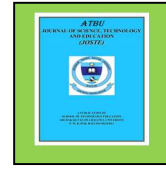
improve prediction accuracy, especially with limited data. The results demonstrate how the proposed sample expansion framework enhances prediction performance in the scenario of few measured data at a new frequency. Their study did not explore the practical application of the developed path loss model for planning, investigation, or optimization of mobile communication systems. Orakwue, and Ridha Al-Khafaji, (2022), analyzed different path loss propagation models based on 4G walk Test data. In their paper, four different path loss propagation models; the free space path loss (FSPL) model, the Okumura model, the Okumura-Hata model, and the COST 231-Hata model were compared using measurement data from Choba, Port Harcourt, Nigeria. The data was obtained from a 4G walk test using two mobile applications. The first mobile application Network used was Signal Info (version 5.68.07), which was used to acquire the received signal strength and distance between the BTS antenna and the mobile antenna. The second mobile application, G-Net Track Lite (version 14.8), was used to map out the track path followed during the test. Their result showed that the Okumura-Hata model and COST 231-Hata model had the closest predictions to the measured path loss. However, their work has a limitation of not considering the Television band. Oluwatoki et al. (2023), developed an empirical path loss model for LTE networks on the FUTA campus using drive test data collected with a smartphone app. Comparing their results to standard propagation models (free space and 3GPP TR 36.873), they found significant underprediction of the path loss average by 20-40dB and up to 88dB in some cases for the measured environment, with RMSE values between 1.895 and 9.159. This research provides valuable data for mobile operators to improve network performance. However, the study did not consider the UHF band of the television spectrum. Therefore, this study aims to measure path loss along the investigated route, compare it with existing path loss models, select and modify the best-fit model for optimal performance, and validate the accuracy of the optimized model for enhanced path loss prediction in comparable environments.

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THEORETICAL ANALYSIS

A. Review of Propagation Models

Wireless signal strength is affected by factors including distance, geographical features, obstacles, and weather conditions. This study will concentrate on empirical path loss models due to their practical advantages, computational efficiency, and accuracy in similar environments. Specifically, the Hata, Egli, and Friis Free space path Loss models will be investigated.

Friis Free Space Model

The free space model is a simplified representation of signal propagation where signal strength decreases as it spreads out in all directions without encountering obstacles. This idealized model provides a baseline for comparing real-world transmission losses. In free space, signals are neither reflected nor absorbed. Precise information about the transmitter and receiver is essential to accurately calculate free space path loss. This model is seen as the leading model in all wireless communication systems and is expressed mathematically (Emmanuel *et al.*, 2022):

$$L_p(dB) = 20\text{Log}_{10}(4\pi) + 20\text{Log}(d) - 20\text{LogLog}_{10}(\lambda) \quad (1)$$

Then substituting (λ (in km) = $0.3 / f$ (in MHz)) and rationalizing the equation produces the generic free space path loss formula, which is given as:

$$P_L(dB) = 32.44 + 20\text{Log}F_{MHz} + 20\text{Log}d_i \quad (2)$$

Where f = frequency in MHz and d = distance in km P_L is path loss in dB.

Hata for urban areas

The Okumura-Hata model, an improved version of the Okumura model, accounts for signal reflections, diffractions, and scattering caused by urban structures. It can be used for both direct

$$PL_{Hata}(dB) = 69.55 + 26.16\text{log}_{10}f_{MHz} - 13.82\text{log}_{10}h_b - a(h_m) + (44.9 - 6.55\text{log}_{10}h_b)\text{log}_{10}d_{km} \quad (3)$$

Where h_b and h_m represents the heights of the base station and mobile antenna, respectively, in

meters, d_{km} is the link distance, f_{MHz} is the frequency of transmission. The term $a(h_m)$ is an antenna height-gain correction factor influenced by environmental conditions (Kebiru *et al.*, 2020). This factor is zero when $h_m = 0$; otherwise, it equals to $3.2(\text{log}_{10}11.75h_m)^2 - 4.97$ with $f_{MHz} > 300$, which was the case in our study.

Egli Model

The model assumes a gently undulating landscape between the transmitter and receiver, without requiring detailed elevation information. Primarily used for direct communication between two points, it can function in environments with a clear line of sight, even over uneven ground. However, its accuracy diminishes in areas with rough terrain or substantial obstructions like dense vegetation halfway between the transmitter and receiver (Kebiru *et al.*, 2020). Its equations for the propagation loss are given as follows: (Fanan, *et al.*, 2017)

$$PL_{Egli} = \begin{cases} 20\text{log}_{10}f_{MHz} + P_0 + 76.3, & h_r < 10 \\ 20\text{log}_{10}f_{MHz} + P_0 + 83.9, & h_r > 10 \end{cases} \quad (4)$$

$$P_0 = 40\text{log}_{10}d_{km} - 20\text{log}_{10}h_t - 10\text{log}_{10}h_r \quad (5)$$

Where f_{MHz} is the frequency of transmission, d_{km} is the link distance, h_t is the base station antenna height in meters and h_r is the mobile station antenna height in meters.

METHODOLOGY

A. Study Area

Field measurements were conducted in Benin City, the capital of Edo State, Nigeria. Situated between Latitude $06^{\circ}19'E$ to $6^{\circ}21'E$ and Longitude $5^{\circ}34'E$ to $5^{\circ}44'E$ the city lies at an average elevation of 77.8m above sea level. The city consists mainly of three local government areas Oredo, Egor, and Ikpoba Okha Local Government Areas; it also consists Partly of Ovia Northeast and Umunwonde Local Government Areas. The land area of the three main local government areas is as follows: Oredo, 249 km²; Egor, 93 km² and Ikpoba Okha, 862 km². The total land area of all three local government areas is

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about 1,204 km². According to Google Earth, the total land area of the continuously urbanized area was estimated at 531sq km in 2016. It is Nigeria's fourth-largest city after Lagos, Kano, and Ibadan based on the 2006 census.

B. Description of base transceiver stations (BTS) used

Independent Television (ITV) is an analog terrestrial TV transmitter owned by a

private broadcasting company and located at Glass House, Airport Road, Oluku, Benin City. it operates on UHF channel 22 with a frequency of 479MHz. The transmitter has a 3050m mast, a 15KW power output, and is situated at coordinates at 6° 19' 2"N and 5° 37' 38"E. Its Effective Radiated Power (ERP) is 41.76dBw. Detailed specifications are provided in Table 1.

Table 1: Measurement parameters

s/n	Parameters	Independent Television (ITV)
1.	Frequency	479.25MHz
2.	BTS Antenna height	3050metres
3.	Transmitted power	41.76dBw
4.	Transmitter rating	15KW
5.	Channel	22 UHF
6.	Tower Coordinates	6° 19' 2"N, 5° 37' 38" E
7.	Spectrum Analyzer Antenna Height	1.5Metres
8.	Distance between Transmitter to Receiver	3Km

C. Experimental Setup for Measurement

The measurement equipment consisted of a Tiny Spectrum Analyzer connected to a laptop via a Mini Universal Serial Bus (USB) cable. This setup enabled high-resolution data acquisition. A global positioning system (GPS) receiver set was used to pinpoint base station locations and map the driving route. A compass aided in determining

directions. To optimize the path loss model, field data was collected at 100m intervals up to 3000m from the base station, with received signal strength (RSS) recorded in Comma-Separated values (CSV) format. The mobile device was maintained at a constant height of 1.5m. Figure 1 depicts the Google map location of the reference measurement site.

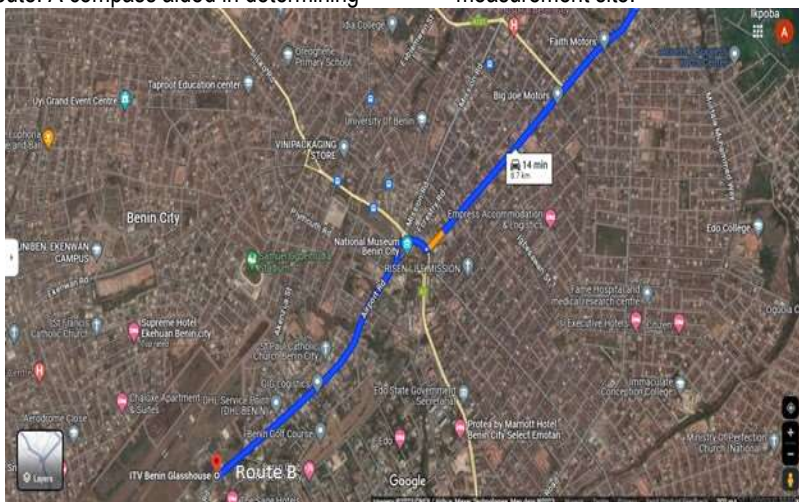


Figure 1: Google map of Route B, Glass House, Airport Road, Oluku, Benin City (Courtesy: Google Earth)

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D. Path loss Modeling and Derivation of Path loss Exponent for EBS

To have a comprehensible view of how propagation models can perform in the TV frequency band, ground truth assessment of the methods was implemented by conducting a real-time spectrum measurement campaign and equating values of the path losses obtained from the measurements against those predicted by the propagation models conversed in the previous section in Benin-City, Edo State, Nigeria. This section gives a detailed discussion of how the complete technique was carried out.

Recall that the gradual decrease of the Signal Strength (Power), of the transmitted electromagnetic waves as the Transmitter and Receiver (T-R) distance increases is termed Path Loss.

$$\text{Path Loss} = P_L(\text{dB}) = 10 \text{Log} \left(\frac{P_t}{P_r} \right) (\text{dB}) \quad (6)$$

Received Power, P_r in (dBm), at any distance D from the Transmitter, with Transmit Power, P_t in (dBm) is given by (Nwalozie, *et al.*, 2014).

$$P_r(\text{dBm}) = P_t(\text{dBm}) - L_p(\text{dB}) \quad (7)$$

P_r Can be evaluated from RSS-measured data, for any distance d_i using the formula:

$$P_r(\text{dBm}) = 10 \log P_r(d_0) \quad (8)$$

The average large-scale path loss for an arbitrary transmitter-to-receiver separation is expressed as a function of distance (Ifesinachi, *et al.*, 2021).

$$P_L(\text{dB}) = P_L(d_0) + 10\eta \text{Log} \left(\frac{d}{d_0} \right) \quad (9)$$

It was shown by Erceg, *et al.*, (1999) that for any value of d , the path loss $P_L(\text{dB})$ is a random variable with a log-normal distribution about the mean value due to shadowing. To compensate for shadow fading, the path loss beyond the reference distance can be written as:

$$P_L(\text{dB}) = P_L(d_0) + 10\eta \text{Log} \left(\frac{d}{d_0} \right) + \sigma \quad (10)$$

Where; η is the path loss exponent σ is the shadowing factor and it is a Gaussian random variable (in dB) and standard deviation σ (also in dB). The standard deviation is given as (Ifesinachi *et al.*, 2021)

$$\sigma = \sqrt{\sum \frac{[P_L(d_i) - P_L(d_0)]^2}{N}} \quad (11)$$

Where $P_L(d_i)$ is the measured path loss at a distance d_i , $P_L(d_0)$ is the estimated path loss

using equation 11 and N is the number of measured data points.

The path loss exponent η , is obtained from measured data by applying the method of linear regression analysis (Azubogu, *et al.*, 2011) or the method of least squares such that from

$$e(\eta) = \sum_{i=1}^m [P_L(d_i) - P_L(d_0)]^2 \quad (12)$$

Substitute 9 into 12 gives:

$$e(\eta) = \sum_{i=1}^m [P_L(d_i) - P_L(d_0) - 10\eta \text{Log} \left(\frac{d}{d_0} \right)]^2 \quad (13)$$

Taking the differential of 13 concerning η and equating to zero gives:

$$\frac{\delta e(\eta)}{\delta \eta} = -20 \log \left(\frac{d}{d_0} \right) \sum_{i=1}^m [P_L(d_i) - P_L(d_0) - 10\eta \text{Log} \left(\frac{d}{d_0} \right)] = 0$$

$$\sum_{i=1}^m [P_L(d_i) - P_L(d_0) - 10\eta \text{Log} \left(\frac{d}{d_0} \right)] = 0$$

$$\sum_{i=1}^m (P_L(d_i) - P_L(d_0)) = \sum_{i=1}^m (10\eta \text{Log} \left(\frac{d_i}{d_0} \right))$$

$$\sum_{i=1}^m (P_L(d_i) - P_L(d_0)) = \eta \sum_{i=1}^m (10 \text{Log} \left(\frac{d_i}{d_0} \right))$$

Solving for η gives:

$$\eta = \frac{\sum_{i=1}^m [P_L(d_i) - P_L(d_0)]}{\sum_{i=1}^m [10 \log_{10} \left(\frac{d_i}{d_0} \right)]} \quad (14)$$

Where:

$P_L(d_i)$ is the average path loss and it is the difference between the transmitting power (P_t) in dB and received power (P_r) in dBm. $P_L(d_0)$ is the path loss at close reference distance otherwise known as reference path loss, d_0 is close in reference distance, d_i is the distance at intervals from the Base station to the Mobile station.

Using measured data (Average Received Power) from Table 2 and Equation 6, at a close-in distance, d_0 of 100m, the Average Received Power is:

power (R_{xav}) = P_r = dBm = $-32.09dBm$.

The measured Path Loss value becomes:

$$P_L(d_i) = 10\text{Log}\left(\frac{40}{6.18016 \times 10^{-4}}\right) = 48dB$$

Path loss values for specified distances, ranging from 0.1 km to 3.0 km, were evaluated using the same procedure and are presented in Table 2.

The path loss exponent (η) is a crucial parameter in wireless communication systems, it quantifies how rapidly signal strength diminishes as the distance between the transmitter and receiver increases. Path Loss can therefore be predicted, using data obtained from field measurements, which are substituted into (9)

$$P_L(dB) = P_L(d_0) + 10\eta\text{Log}\left(\frac{d}{d_0}\right)$$

From field measurement at close distance, (d_0) of 0.1 km, $L_p(d_0) = 48$ dB

Predicted values of Path Loss at specified distances are calculated and the results are presented in table 2.

From equation 12 the path loss exponent can be calculated using the linear regression analysis;

$$e(\eta) = \sum_{i=1}^m [P_L(d_i) - P_L(d_0)]^2$$

From equation 11 the standard deviation, σ (dB) about the mean values can be obtained using:

$$\sigma = \sqrt{\frac{\sum [P_L(d_i) - P_L(d_0)]^2}{N}}$$

The Path loss exponent for ITV in Benin City was determined to be 3.96 with a Shadowing factor of 9dB. The reference path loss $P_L(d_0)$ was calculated as 48dB. By incorporating these values and an error correction term into equation 10, an empirical path loss model specific to the urban environment of Benin City, Edo State, was developed. This model is expressed as follows:

$$P_L(dB) = P_L(d_0) + 10\eta\text{Log}\left(\frac{d}{d_0}\right) + \sigma$$

$$P_L(dB) = 48 + 10(3.96)\text{Log}\left(\frac{d}{d_0}\right) + 9$$

(15)

The empirical path loss model for ITV Benin urban area is given as:

$$P_L(dB) = 57 + 39.6\text{Log}\left(\frac{d}{d_0}\right) \quad (16)$$

$$P_L(urban) = 57 + 39.6\text{Log}(D)dBm \quad (17)$$

RESULTS AND DISCUSSION

A. Analytical results

Table 2 presents the mean values of the measured RSS and the predicted Path Loss values for Independent Television (ITV) for quantified distances ($0.1 \text{ km} \leq d_i \leq 3.0 \text{ km}$), calculated using equation 6.

Table 2: Measured and predicted Path Loss for Independent Television (ITV)

Distance (km)	RSSI (dBm) Average	Measured path loss [$P_L(d_i)$]	Predicted path loss [$P_L(d_0)$]
0.10	-32.09	48	48
0.20	-39.00	55	$48 + 3.01 \eta$
0.30	-48.78	65	$48 + 4.77 \eta$
0.40	-55.69	72	$48 + 6.02 \eta$
0.50	-48.21	64	$48 + 6.98 \eta$
0.60	-75.84	92	$48 + 7.78 \eta$
0.70	-70.08	86	$48 + 8.45 \eta$
0.80	-64.90	81	$48 + 9.03 \eta$
0.90	-63.17	79	$48 + 9.54 \eta$
1.0	-65.48	82	$48 + 10 \eta$
1.10	-78.14	94	$48 + 10.4 \eta$
1.20	-68.93	85	$48 + 10.79 \eta$
1.30	-66.05	82	$48 + 11.13 \eta$
1.40	-64.32	80	$48 + 11.46 \eta$
1.50	-68.93	85	$48 + 11.76 \eta$
1.60	-64.90	81	$48 + 12.04 \eta$
1.70	-70.08	87	$48 + 12.30 \eta$
1.80	-81.02	97	$48 + 12.55 \eta$
1.90	-74.69	91	$48 + 12.78 \eta$
2.00	-87.93	104	$48 + 13.01 \eta$
2.10	-82.17	98	$48 + 13.22 \eta$
2.2	-105.19	121	$48 + 13.42 \eta$
2.3	-87.93	104	$48 + 13.62 \eta$
2.4	-94.26	110	$48 + 13.80 \eta$
2.5	-107.50	124	$48 + 13.98 \eta$
2.6	-86.20	102	$48 + 14.15 \eta$
2.7	-90.23	106	$48 + 14.31 \eta$

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2.8	-88.51	105	$48 + 14.47 \eta$
2.9	-82.17	98	$48 + 14.62 \eta$
3.0	-108.65	125	$48 + 14.77 \eta$

σ (dB)	9
$P_L(d_0)$	48

Furthermore, the measurement and analysis in this work led to the determination of $P_L(d_0)$, η and σ for ITV urban area is presented in Table 3.

Table 3: Path loss Exponent, Standard Deviation, and Reference path loss values

Parameter	Edo Broadcasting Service
η	3.96

A path loss exponent of 3.96 and a shadow factor of 9dB suggest that the environment is moderately obstructed, causing noticeable signal attenuation and significant variability due to shadowing effects. This information is crucial for designing and optimizing wireless communication systems in such environments to ensure reliable signal coverage and quality. Figure 2 depicts the average measured path loss for ITV Benin City.

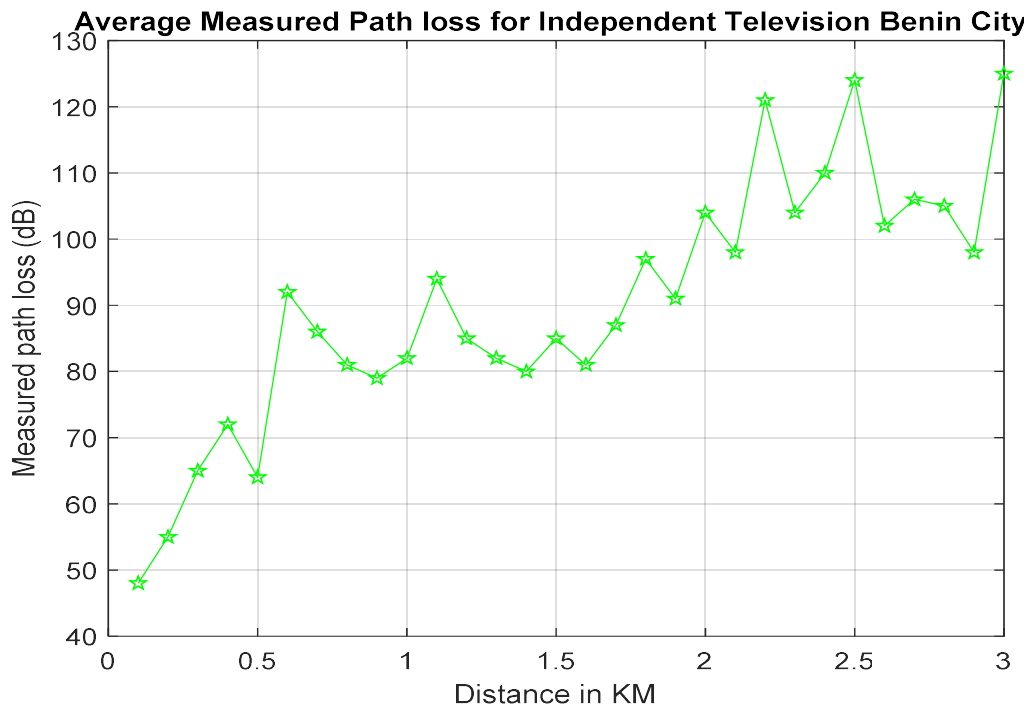


Figure 2: Graph Plot showing Average measured Path loss distance for ITV, Benin City.

Fig. 2 depicts the path loss values plotted as a linear line, showing that 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 pronounced and irregular. Nonetheless, the attenuation aligns with the

environmental characteristics of the transmitter base stations.

B. Comparison of EBS Empirical Path Loss Model with Existing Models

To validate the integrity of the proposed path loss model, this work compared the statistically predicted received signal strength (RSS) results and that of other existing

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(traditional) models with the measured results. Therefore, the RSS (P_r) was calculated under the same transmission conditions and simulation parameters. Using equation (2) for the Urban path loss determination of the free space model, equation (3) for the Hata model, and equation (5) for the Egli model, the test parameters were substituted ($f = 479.25$ MHz, $h_m = 1.5$ m, and h_b

$= 3050$ m) into these equations. The resulting plots are depicted in Fig. 3

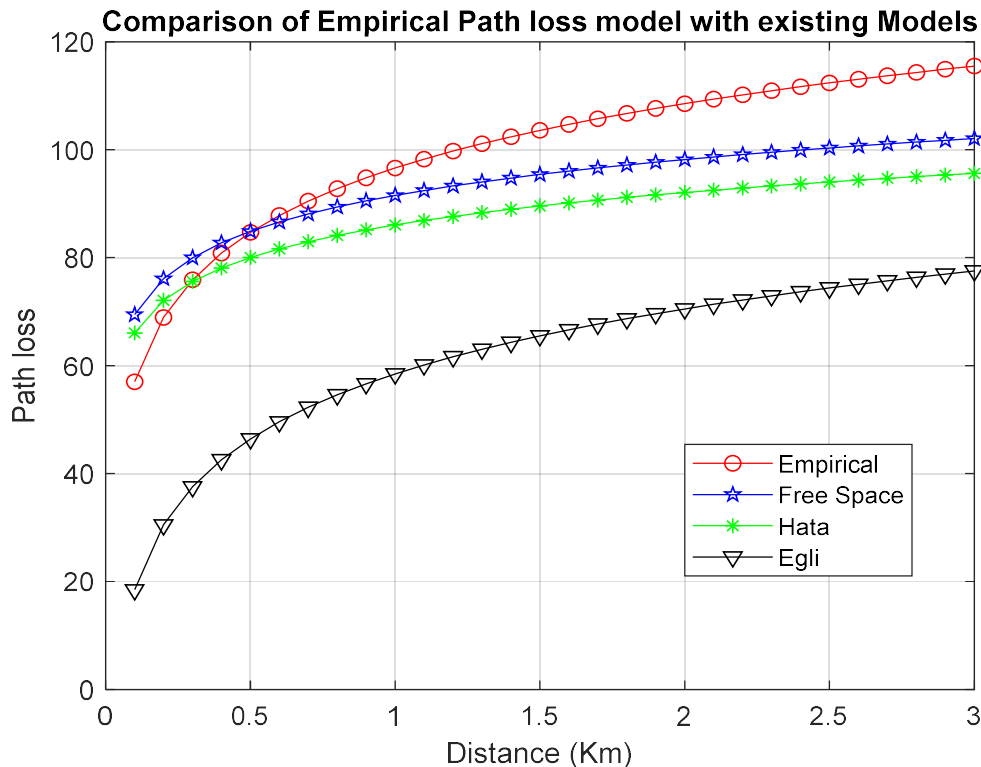


Figure 3: Graph plot showing the comparison of ITV Empirical with various Path Loss Models

From the plots of the path losses in Fig. 3, the Hata model is the closest model to the measurement due to the environment in which the measurement was carried out. The next model closest to the measurement was obtained from the Free Space and Egli path loss model. Comparisons between the models have shown some variations. These variations show that the FSPL model or any existing model cannot fit effectively into an environment other than that for which it was developed. To make such models

appropriate for different environments, they must be modified.

C. Modified Hata Model

The RMSE Key performance indicator was used to assess the performance and fitness of the proposed models for use in the study area. The RMSE can be expressed as 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 palpable metric for analyzing

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predictive model error is the RMSE (Faruk *et al.*, 2013). Equation 18 provides the expression for calculating the RMSE (Popoola *et al.*, 2019).

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (P_m - P_r)^2} \quad (18)$$

Where P_r is the predicted values (dB), and P_m is the measured values (dB), for each instance of distance d , and N is the number of measured data points.

$$RMSE = \sqrt{\sum_{i=1}^N (P_m - P_r)^2 / (N)} \quad (19)$$

In general, when the RMSE value is close to zero (0), it indicates a better fit. 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 free space path loss. The RMSE was found to be 1.66dB for ITV urban areas and was used to adjust the existing Hata models, and the results were compared to the measured values. The modified Hata model for ITV Benin urban area is given in equation 20:

$$PL_{Hata}(dB) = 67.89 + 26.16 \log_{10} f_{MHz} - 13.82 \log_{10} h_t - a(h_r) + (44.9 - 6.55 \log_{10} h_t) \log_{10} d_{km} \quad (20)$$

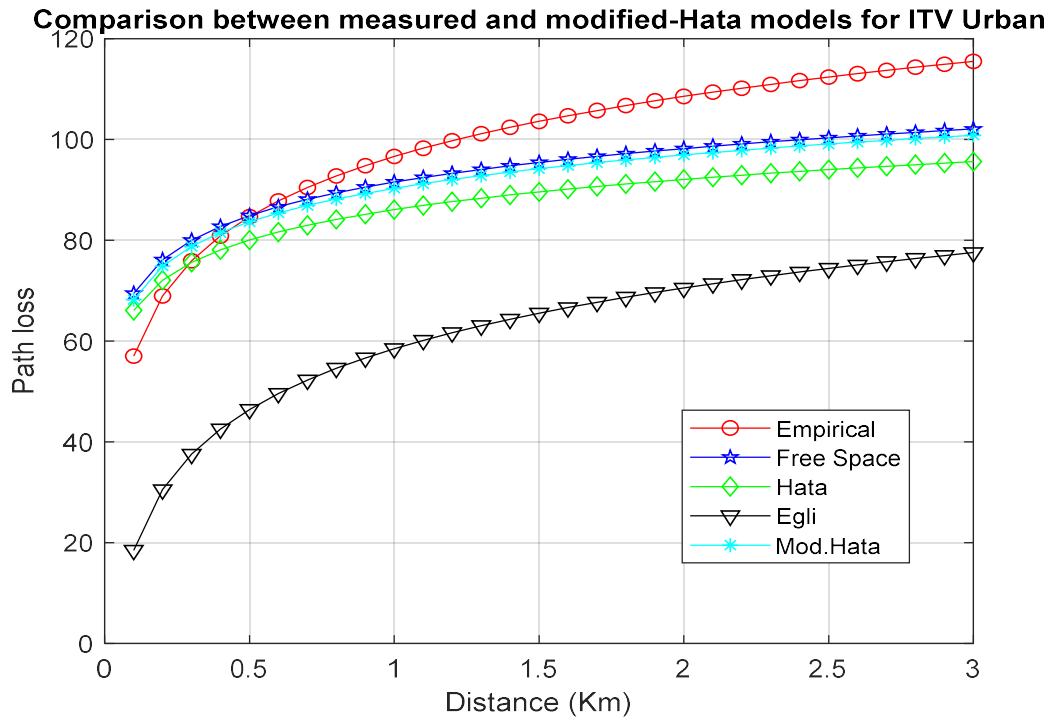


Figure 4: Shows the comparison between the measured and the modified-Hata Models for ITV Urban.

CONCLUSION

This paper develops a statistical path loss model for TVWS networks in Benin City, Edo State, Nigeria. By comparing measured data with the Hata model, and making necessary adjustments, we created a model tailored to the environment. Our findings demonstrate the

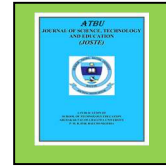
effectiveness of both the developed and modified Hata model for predicting path loss in the study area. Future work will focus on developing a TVWS software tool for optimized antenna placement.

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ACKNOWLEDGEMENT(S)

The authors wish to acknowledge and thank the Independent Television, Glass House, Airport Road, Oluku, Benin City, Edo State for the release of their Transmitting parameters used for this work.

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