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Pathloss Assessment of a Terrestrial Digital UHF Channel over Kano City, Nigeria

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ABSTRACT

Path loss assessment is an important factor in wireless communications to ensure quality of service. This study involves the measurement of Received Signal Strength (RSS) of Digital Terrestrial Television (DTTV) Star Times Station in Kano at 1 km intervals along three routes. Data were gathered during dry and wet season months in the year 2022. The path loss along the routes were computed based on the Okumura-Hata model. It was observed that path losses were higher during wet than dry season months. The result also indicates a higher negative correlation coefficient (R) of -0.745 between Line of Sight (LOS) and RSS for wet and -0.690 for dry season months respectively for route, A. Similarly, R, of -0.739 between LOS and RSS was also observed during wet and -0.589 for dry season months for route, B. In addition, R, of -0.420 was observed between LOS and RSS during wet and -0.328 for dry season months along route C. The average path loss for wet season is 133.90 dB and for dry season is 127.90 dB. Furthermore, this study introduced a Modified Hata Path Loss Model (MHPL) that takes into account the impact of specific tropospheric parameters such as LOS and elevation. Findings further indicated that the path loss predicted by the conventional Hata model exhibited a steady exponential increase with LOS. Similarly, MHPL followed a comparable trajectory, with some exceptions manifesting as peaks and valleys. The overall findings will be useful for power budgeting that will enhance quality of service of DTTV signal over Kano city.

Keywords:
Path loss,
DTTV,
Modified Okumura-Hata model,
Correlation coefficient.

INTRODUCTION

The accuracy of path loss prediction over Digital Terrestrial Television (DTTV) systems depends on various factors. Such as terrain and atmospheric variables (Akinbolati et al., 2020a). Accurate information about the geographical features, such as elevation and land cover, helps in predicting the pathloss accurately (Akinbolati and Ajewole, 2020). The most widely used model for Pathloss prediction over UHF channel is the Okumura-Hata model (Armoogum et al., 2010; Akinbolati et al., 2023). This model considers factors like distance, frequency, transmitter power, and antenna heights to estimate pathloss (Akinbolati and Agunbiade, 2020). Pathloss modeling is crucial for ensuring reliable signal reception in DTTV systems. It helps at estimating the signal strength at various places within the coverage area and aids in the planning and optimization of transmitter locations, antenna heights, and power settings (Fortune et al., 1995). Accurate pathloss modeling enables broadcasters to provide better quality service, improve coverage, and minimize interference in DTTV networks (Faruk et al., 2013).

DTTV was launched in Nigeria in April 30, 2016, after a period of planning and preparation. DTTV in Nigeria offers viewers more channels with improved picture and sound quality compared to the traditional analog broadcasting system. It also provides interactive services and improved technical capabilities. The transition to DTTV was driven by the need to enhance quality of service (QoS) for terrestrial television transmission and maximize frequency spectrum utilization (Ilori et al., 2022). In DTTV, Multiplex transmitters emit digital signals, which are radiated via the transmitting antenna, allowing for the reception of multiple channels in a single frequency range. DTTV signals are received via an antenna and a digital Set-Top Box (STB), which decodes the received signal for television processing and display (Wahyu et al., 2014). The networks consist of multiple terrestrial transmitters with specific coverage areas, which are influenced by factors such as transmitter output power, antenna height, terrain, and tropospheric effects (Akinbolati et al., 2020b). The advantages of DTTV over analog terrestrial television (ATTT) include spectrum efficiency and management, better signal quality with reduced interference and picture degradation, support for high-definition (HD) services and interactivity, encryption for pay television networks, and potential reduction in transmission network energy. DTTV utilizes digital broadcast technology to deliver multiple channels with improved quality using narrower frequency bandwidth compared to ATTT (Yang et al., 2017)

Pathloss modeling in DTTV considers the tropospheric terrain and atmospheric conditions where the signals propagate. The behavior of propagation is predicted using models that take into account variations in the radio refractive index of tropospheric air. Pathloss modeling is crucial for optimizing coverage, estimating signal strength, and ensuring a satisfactory level of service quality (QoS) for DTTV viewers (Armoogum et al., 2010).

The objectives of this study include modifying the Okumura Hata model and develop a path-loss model with selected location-based characteristics for the study's location. Furthermore, the study will evaluate the path-loss and signal propagation characteristics over DTTV transmissions in Kano City.

Path Loss Prediction models and Review of Related Work

Pathloss refers to the quantification of the attenuation of Radio Frequency (RF) experienced by a transmitted signal as it travels along a multi-wavelength channel to the receiver. It is stated as (Sarkar et al., 2003):

$$P_L(dB) = 10log\frac{P_t}{P_r} \quad (1)$$

P_t, is the transmitting power, P_r is the received power while P_L is the path loss.

Path loss prediction involves accurately forecasting the impact of channel features on a radio signal, specifically the attenuation effect. In wireless communication, various models have been developed to predict pathloss. Some are derived statistically based on field measurements, while others are formulated analytically considering the consequences of diffraction. To attain reasonable accuracy, each model makes use of specified parameters in predicting path loss (Akingbade and Olorunnibi, 2013).

Types of empirical models

Free Space Model or Friis Transmission Equation (FSPL)

In radio wave propagation, the Friis transmission equation is a simple path loss prediction model. Radio and antenna engineers use the simplified formula below to forecast path loss between two isotropic antennas in free space.

$$L = 20\log_{10}(\frac{4\pi d}{\lambda}) \quad (2)$$

where d is the distance (Line of Sight, LOS) between the transmitter and the receiver in meters, and λ is the wavelength of the wave in meters. T

Plane Earth Model

The effects of ground reflection on signal propagation are ignored in the free space concept (Boithias, 1997.) When a radio wave travels over the ground, some of its power is reflected by the ground and is thus received by the receiver. Relevant parameters for this scenario include the heights of the transmitting and receiving equipment, the distance between them, and the ground reflection characteristics. The plane earth model's path loss equation is (Ranvier, 2000):

$$L_{PE} = 40log_{10}(d) - 20log_{10}(h_1) - 20log_{10}(h_2) \quad (3)$$

where d is the distance (km) between transmitting and receiving, h_1 and h_2 (m) are the heights of the transmitting base station and receiving antenna respectively.

Okumura Model

One of the most often used macroscopic prediction models is Okumura's model. It was developed in the mid-1960s based on extensive studies carried out in Tokyo and its surrounding areas. The model was intended for usage in the frequency range 200 to 1920 MHz, primarily in urban propagation (Okumura et al., 1968). Okumura's model posits that in the terrestrial propagation environment, the route loss between the transmitter and receiver can be stated as:

$$L_{50\%} = L_{FSL} + A_{mu}(f,d) - G(h_{re}) - G_{AREA} \quad (4)$$

where:

$L_{50\%}$ is the median (50th percentile) value of propagation path loss in decibels(dB), L_{FSL} is free space propagation loss in decibels(dB), A_{mu} (f,d) is the fundamental median attenuation in relation to free space in dB, $G(h_{te})$ and $G(h_{re})$ are the base station and receiver antenna height gain correction factors, expressed in decibels (dB), and G_{AREA} is the dB gain caused by the environment.

Hata (Okumura-Hata) Model

The Hata Model for Urban Areas, also known as the Okumura-Hata Model, is the most extensively used radio frequency propagation model for forecasting the behavior of cellular transmission in built-up areas (Armoogum et al., 2010). This model extends Okumura's model's graphical information to account for the effects of diffraction, reflection, and scattering caused by urban structures. In addition to the base model, this extended version includes two additional variations specifically designed for transmission use in suburban and open areas. The Hata model forecasts total path loss along a terrestrial microwave or other form of communication link (Hata, 1980). The model can anticipate both micro and macro cells in the outdoors. This variant of the Hata model is relevant to radio propagation within metropolitan areas. This model is appropriate for both point-to-point and broadcast transmission (Okumura, 1968).

Okumura-Hata models for urban and sub urban areas are formulated as:

$$L_{(Urban)} = [69.55 + 26.16 logf - 13.82 logh_b - \alpha(h_m) + 44.9 - 6.55 logh_b) logd] \quad (dB) \quad (5)$$

For a large metropolis with a high transmission wave frequency f ≥ 400 MHz (Ranvier, 2000; Akinbolati et al., 2020b)

$$\alpha(h_m) = 3.2[\log(11.75 h_m)]^2 - 4.97 \qquad (6)$$

$L_{(urban)}$ is the path loss in urban areas in decibels, h_b is the antenna height in meters, h_m is the antenna height in meters, f is the frequency of transmission in MHz, $\alpha (h_m)$ the antenna height correction factor, and d is the line-of-sight distance between the base and mobile stations in kilometers.

By specifications, Okumura-Hata model has the following range for optimal results: Carrier frequency: $150 \le f \le 1500$ MHz, Base station height: $30 \le h_b \le 200$ m, Mobile station height: $1 \le h_m \le 10$ m, Distance between mobile and base station: $1km \le d \le 20km$ (Akinbolati et al., 2020).

For sub urban area, it is given by (Akinbolati et al., 2020):

$$L_{(sub-urban)} = (L_{(urban)} - 2[\log(\frac{f}{28})^2 - 5.4 \ (dB) \qquad (7)$$

The European Co-operative for Scientific and Technical Research (COST-231)

This was created by the European Co-operative for Scientific and Technical Research Team and has grown in prominence in the field. This model is an extension of the Okumura-Hata model that covers a large frequency range of (0.5-2 GHz) and is employed in medium to small towns (Nizirat et al., 2011). The model's expression is:

$$L(dB) = 46.3 + 33.9 log_{10}(f) - 13.82 log_{10}(h_b) + [44.9 - 6.55 log_{10}(h_b)] log_{10}(d) - \alpha(h_m) + C_m \quad (8)$$

$\alpha(h_m)$ is defined in (6), while C_m=0 dB for medium-sized cities and suburbs, and 3 dB for metropolitan areas.

The Okumura-Hata model and its choice for this work

The Hata Model for Urban Areas, commonly known as the Okumura-Hata Model, is an updated iteration of the Okumura Model it is a widely acceptable radio frequency propagation model. This model serves as a robust tool for projecting the behavior of cellular transmission in densely constructed regions (Armoogum et al., 2010). This study used the widely accepted Okumura-Hata model as a benchmark against which to evaluate the new models. ITU-R's adoption of the Okumura-Hata model for benchmarking new approaches on VHF/UHF channel (Armoogum et al., 2010; ITU-R, 2003) serves as one of the justifications. This model exhibits versatility, suitable for outdoor predictions of both micro and macro cells, suitable for both point-to-point and broadcast transmissions. The formulation of Okumura-Hata models extends to encompass urban and suburban environments.

MATERIALS AND METHODS

The research was conducted along major routes in Kano city, specifically Gidan Radio to Zaria Road, Gidan Radio to Katsina road, and Gidan Radio to B.U.K road. These locations were chosen to represent significant areas within Kano City.

Study Area (Kano city, Northwest Nigeria)

Kano is a city in Northwest Nigeria, which is also the capital city of the state with geographic co-ordinates 12.0^0N 8.59^0E. The city lies south of the Sahara Desert. The city has an average of about 980 mm of precipitation per year, large majority of which falls from June to September.

Kano's metropolitan characteristics, specifically its tall buildings and congested terrestrial features, make it a suitable study area for the Okumura-Hata model classification for urban city. Measurements were conducted using the Star Times Digital Terrestrial Television Base Station (DTTBS), situated within the premises of the Kano radio station. Data collection took place during both the dry and wet season month spanning from August 2021 to March 2022.

Figure 1 depicts the digital map of Kano city showing different route of measurement within the city while Table 2 presents the characteristics of the experimental station, the Star Times Digital Terrestrial Base Station in Kano.

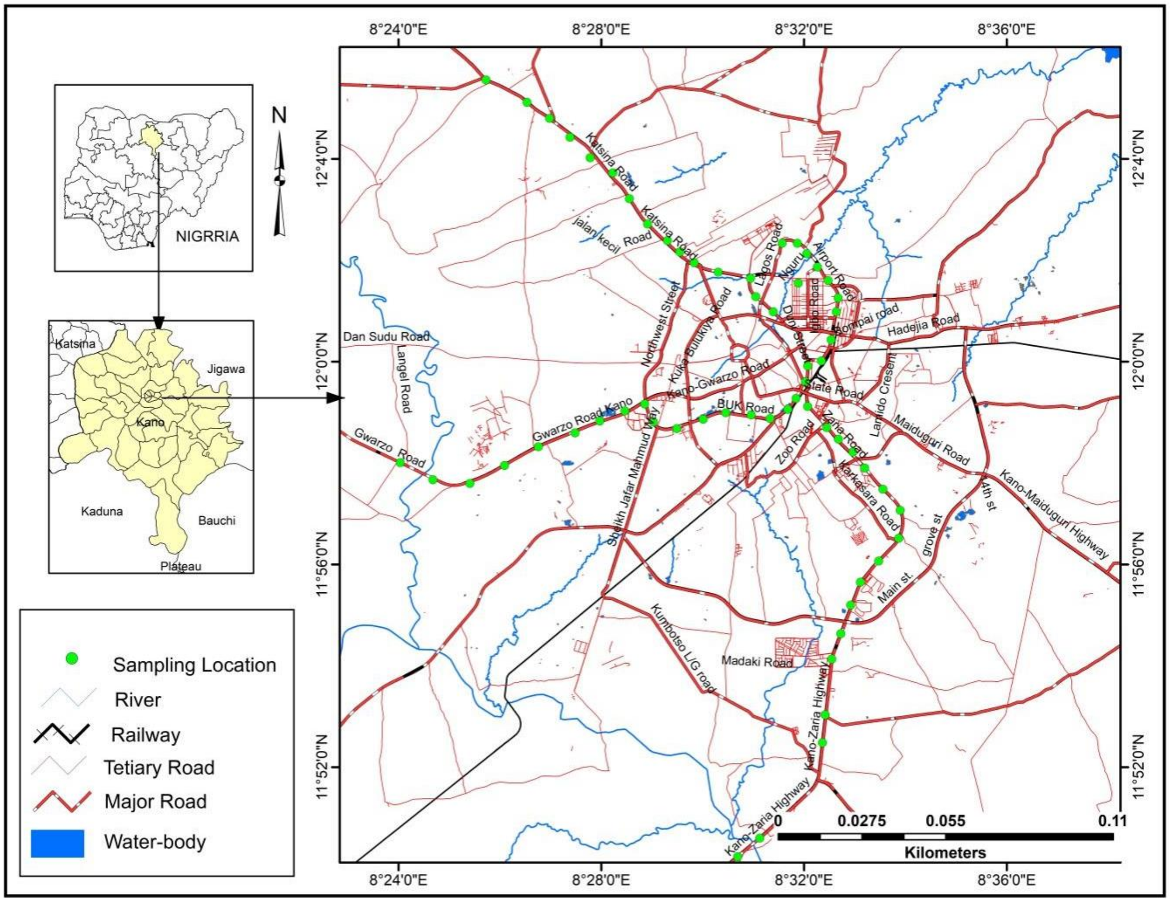

Figure 1: The map of Kano city depicting different routes where measurements were carried out

Table 1: The transmission characteristics of the transmitting station

PARAMETER	Gidan radio – Zaria route (route A)	Gidan radio – B.U.K route (route B)	Gidan radio – Katsina route (route C)
FREQUENCY	770 MHz	770 MHz	770 MHz
POWER TRANSMITED	1.3 kW	1.3 Kw	1.3 kW
HEIGTH OF BASE STATION	150 m	150 m	150 m
BAND WIDTH	8 MHz	8 MHz	8 MHz

Method of Data Collection

The measurements were done using drive test protocol along different routes, with the transmitting station serving as reference points. The receiving antenna was positioned at a height of 3.0 m, and the geographic coordinates were mapped using the GPS receiver of the transmitting antenna's location as the reference point for each route, spaced at 1km intervals. Throughout the drive test, the GPS monitored the line of signal, coordinates and elevation above sea level from the transmitting station at 1 km intervals up to a distance of 20 km for each route.

To facilitate the measurement process, Kano city was divided into three axes: Axis A, which ran from Gidan Radio to Zaria Road; Axis B, from Gidan Radio to B.U.K Road; and Axis C, from Gidan Radio to Katsina Road. Measurements were taken during both the wet and dry seasons. Figure 2 shows some pictorial representation during the measurement campaign.

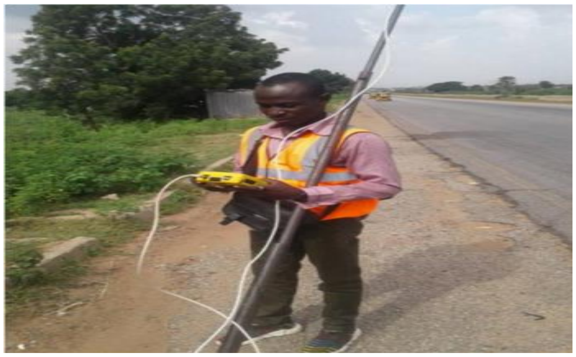

Figure 2: Pictorial representation during the measurement campaign

Data Analysis

Equations (6)-(8) were used to compute the quantitative path loss values for each of the routes and seasons using Microsoft excel. The degree of relationship between path loss and some of the location-based transmitting parameters were determined using correlation coefficient.

RESULTS AND DISCUSSION

The Okumura-Hata model was used to compute the path losses along the measurement routes in the study locations during the dry and rainy season months. The Okumura-Hata model was selected due to its widely recognized reputation and acceptance worldwide (ITU-R, 2003; Armoogum et al., 2010). This model provides reliable parameters for assessing and estimating novel strategies on the UHF channel. Terrain roughness parameters are not included in the model, which is one of its limitations.

Assessment of path loss over the three routes

Path loss was observed to increase as Line of Sight (LoS) separation distance from the base station increases in all the routes and seasons. The variation of path loss with distance follows similar trends in all the routes and seasons. Thus, typical samples are presented in Figures 3 and 4 for dry and wet seasons respectively. Figure 5 presents the comparison of the variation of the path loss for the three routes with line of sight. From the figure, it can be deduced that the losses for all the routes follow nearly the same pattern. Higher values were recorded during the wet season months compared to the dry season months. In addition, from Tables 4 and 5,

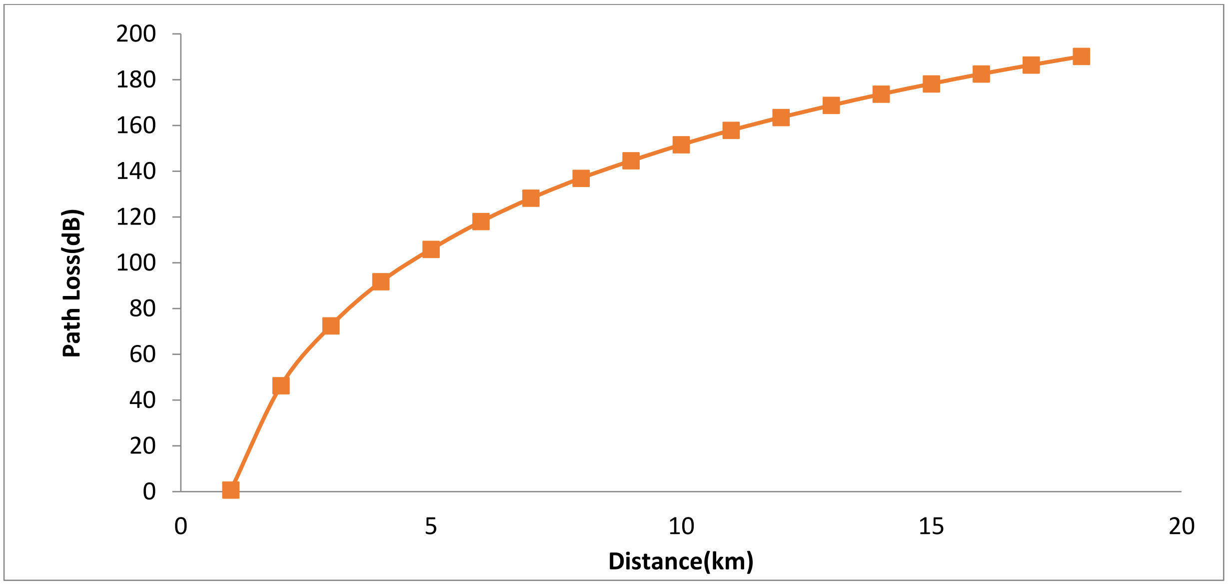

Figure 3: The impact of line-of-sight (LOS) distance from the Digital Terrestrial Television Base Station (DTTBS) on path loss along the Gidan Radio to B.U.K road during the dry season

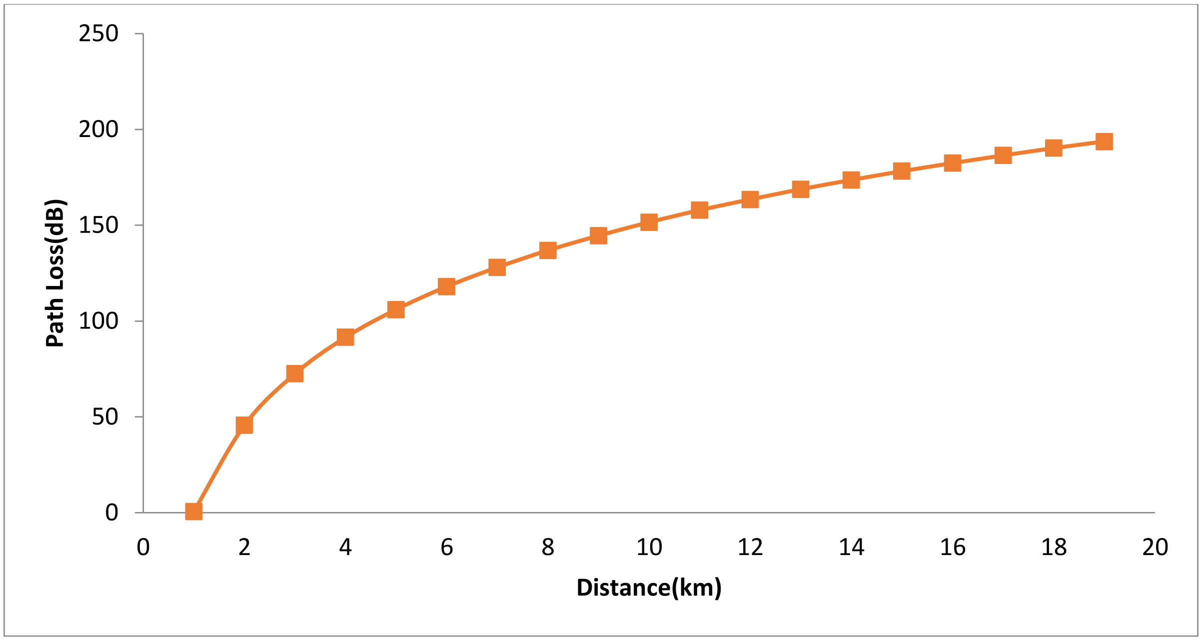

Figure 4: The impacts of line-of-sight (LOS) distance from the Digital Terrestrial Television Base Station (DTTBS) on path loss along the Gidan Radio to BUK road during the wet season

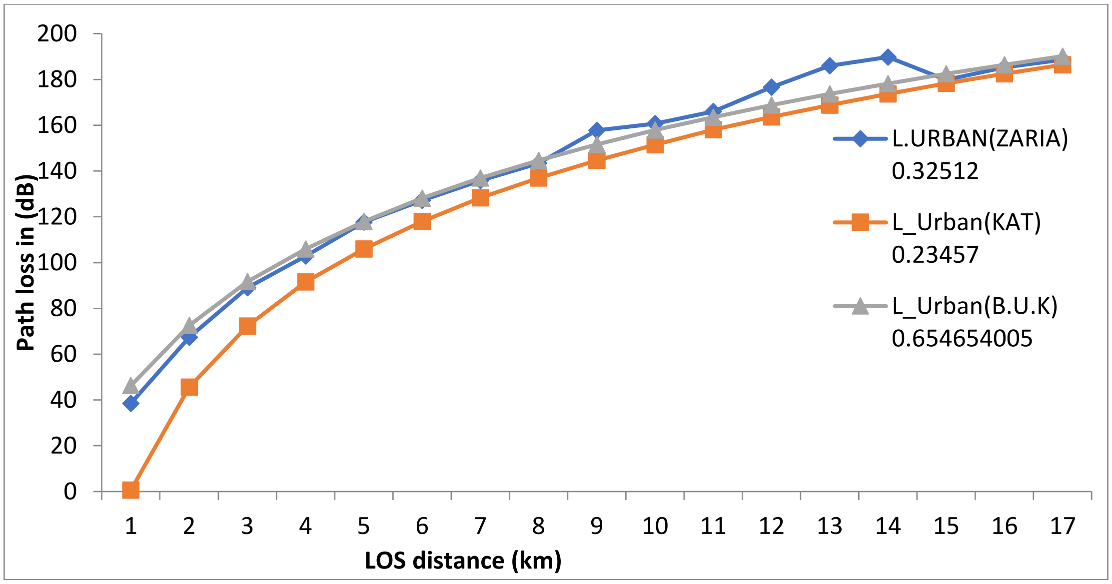

Figure 5: Comparison of the path loss variation for the three routes with line-of-sight (LOS)

Table 2: Obtained mean values during the dry season

	Mean RSS (dBm)	Mean Elevation(m)	Mean Okumura urban path loss (dB)
Gidan radio-Zaria route	-61.42	470.10	126.15
Gidan radio-Katsina route	-58.00	496.33	127.36
Gidan radio-B.U.K route	-52.38	484.27	123.16

Table 3: Obtained mean values during the wet season

	RSS (dBm)	Elevation(m)	L.O.S(km)	Okumura urban path loss (dB)
Gidan radio-Zaria route	-54.37	476.421	9.011	136.32
Gidan radio-Katsina route	-60.72	489.333	9.516	131.21
Gidan radio-B.U.K route	-53.33	490.11	10.01	133.14

An average path loss of 136.32 dB was evaluated during the wet season by employing receiver antenna heights of 3.0 m. While for dry season average path loss of 126.15 dB was recorded. Figure 3 presents the path loss variation with distance along route Gidan radio to Zaria road for wet seasons. Similarly, Figure 4 presents the pathloss variation for the same route during the dry season.

In addition, routes B and C have similar trend with that of route A. Path loss was observed to increase as LoS separation distance from the base station increases. Rewrite as:

In this study, the average path loss during the wet season was found to be 133.14 dB, whereas the average path loss during the dry season was found to be 126.19 dB.

Table 3 shows the correlation coefficient between LOS and RSS. Correlation coefficients of -0.743, -0.374, and -0.664 were obtained between RSS and LOS for Gidan Radio (Base Station) to Zaria road, B.U.K, and Katsina, respectively.

Table 4: The correlation coefficient between LOS separation distance and RSS over the study area

Study location	(R) wet season months	(R) dry season months	Average (R)
Gidan radio to Zaria road	-0.795	-0.689	-0.743
Gidan radio to B.U.K road	-0.421	-0.328	-0.374
Gidan radio to katsina road	-0.739	-0.588	-0.664

Modeling of Path Loss

The proposed model utilized the mean parameter values from various seasons. Multiple regressions were conducted, using path loss as the dependent variable, and RSS, location-based LOS, and elevation (ELV) as independent variables. The basis for this is to incorporate some location- based parameters to enhance the path loss predictions over the study areas. The resulting path loss model is referred to as the Modified Hata Path Loss (MHPL) model. Descriptive statistics of characteristics in Kano during the dry and wet seasons are presented in Tables 5 and 6. While equations 9 and 10 represent the modified-model developed in this study. The models can be used to predict the macrocell path loss over the study area.

Table 5: Statistics for the dry season month in Kano Metropolis

Basic statistics	Mean	R^2	Standard deviation	n
LOS distance from DTTBS (km)	9.013	0.915226	16.264	18
Okumura-Hata urban path loss	127.90	0.915226	16.264	18
Elevation	483.72	0.915226	16.264	18
Received Signal Strength	-57.11	0.915226	16.264	18

Table 6: Statistics for the wet season month in Kano metropolis

Basic statistics	Mean	R^2	Standard deviation	n
LOS from DTTBS (km)	9.513	0.93	16.881	18
Okumura-Hata urban path Loss(dB)	133.90	0.93	16.881	18
Elevation (m)	483.92	0.93	16.881	18
Received Signal Strength	-59.21	0.93	16.881	18

$$MHPL_{(DRY)} = -271.887 + 1.208RSS + 0.761ELV + 11.395L0S \quad (9)$$

Similarly for wet

$$MHPL_{(WET)} = -358.873 + 2.680RSS + 1.082ELV + 12.937LOS \quad (10)$$

where RSS, ELV and LOS are the Received Signal Strength, Elevation of the location above sea level and Line of Sight distance of data points from the base station.

These models are proposed for the accurate prediction of path losses over digital UHF channel in Kano city, Nigeria.

CONCLUSION

Path loss assessment and modeling over DTTV channel were investigated for both dry and wet season months over Kano City Nigeria. This research provides vital insights and concrete techniques for addressing signal propagation difficulties in the digital terrestrial television broadcasting system in Kano city. It presents a comprehensive dataset and modeling approach that can be used in academia and future studies on wireless communications and urban signal propagation on UHF band. The study also provides modified Hata- Path Loss Model (s) for both dry and wet season months that can be used for predicting losses over the channel. This will be useful for improving DTTV links and system's design that will ensure coverage areas and quality of service in urban environments, such as Kano, benefiting both viewers and industry stakeholders.

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