FUDMA Journal of Sciences (FJS)
ISSN Online: 2616-1370
ISSN Print: 2645-2944
Vol. 2 No.3, September, 2018, pp 79- 89

PATH LOSS PREDICTION MODELING FOR DIGITAL TERRESTRIAL TELEVISION (DTTV) IN THE TROPICAL RAIN FOREST ZONE OF NIGERIA

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ABSTRACT

This study investigated the channel losses of a Digital Terrestrial Television Base Station (DTTBS) operating on 722 MHz in a Tropical Rain Forest, Sub Urban City of Akure, South West, Nigeria. The digital field strength values of the base station were measured at intervals of 1km along three selected routes around the station using a digital signal strength meter (Satlink WS-6936 model). A GPS receiver was used to monitor the line of sight with the station as reference and to log the geographic coordinates and heights of data points. A compact wireless weather station model N96FY was used for the measurement of surface meteorological parameters of Temperature, Atmospheric Pressure and Humidity of data locations whereas, the corresponding surface radio refractivity values along the routes were derived from the atmospheric components recorded. Data were collected during dry and wet seasons for comparative studies. Path loss along the routes for each of the seasons was calculated using Okumura-Hata model. Results for all the routes and seasons revealed that path losses were higher when using receiver antenna height of 1.5 m compared to that of 3.0 m. Also, path losses increase with distance in all the routes and seasons, however path losses were more significant during wet seasons compared to the dry seasons. In addition, the data obtained were used to revalidate existing path loss model for use in the study area. The overall findings of this work will be useful in Digital Terrestrial Television (DTTV) Industry for channel optimization and equipment design.

Keywords: *DTTV, Path loss modeling, Tropical Rain Forest, Received Signal Strength (RSS)*

INTRODUCTION

Accurate predictions of channel losses are essential in radio wave propagation theory and equipment design. Channel losses depend on the nature of signal path (rural or urban), atmospheric components and terrain of the locations involved. Evaluation of losses are used for radio wave propagation planning and equipment design by radio scientists and engineers. Analogue and Digital Terrestrial Transmission of signal on the UHF broadcast band is by space wave which propagates on line of sight from the transmitter through the troposphere. Thus, the signal received at locations away from the transmitter could be the direct transmitted wave, the reflected wave or the diffracted wave (Kennedy and Bernard, 1992; Akinbolati *et al*., 2016; Ajayi and Owolabi, 1979). This could be due to the effect of terrestrial objects on the propagation path, atmospheric components and terrain (Armoogun *et al*., 2010; Bothias, 1987). Other well-known factors that determine the quality of signal received from the transmitter on the UHF band include: transmitter effective output power (EIRP) and transmitting antenna height. Others are transmitter-receiver distance (Line of Sight) and elevation of the receiver above sea level, the gain of the receiving antenna and the quality of the receiver (Armoogun *et al*., 2010; Akinbolati *et al*., 2016). There is also the attenuation effect on UHF signal that can be caused by precipitation (Ajewole *et al*., 2014) and foliage (Ayekomilogbon *et al*., 2013). Over the years, terrestrial television broadcasting has been on the analogue transmission and reception technology until the last few years that Digital Terrestrial Television (DTT) technology was proposed by the International Telecommunications Union (ITU). This was due to the quest to maximize the UHF band by releasing the upper UHF for other services and still ensure access to quality of service. The medium of propagation for both analogue and digital terrestrial television is the troposphere, where most weather phenomena occur (Bothias, 1987). It has therefore become expedient to carry out researches on the influence of terrain and key meteorological parameters in the troposphere on Digital Terrestrial Television Signal strength in the study area. This has become imperative because Path loss prediction models that were developed by radio scientists and engineers all over the World cannot fit in perfectly into all geographic locations across the globe. There is the need to carry out path loss modeling for DTTV in Nigeria that will incorporate local content of terrain and meteorological factors. Path loss prediction models have become veritable tools for radio scientists and engineers in radio wave propagation planning, design and channel estimation.

Meteorological Parameters, Surface Radio Refractivity and Radio Signal

The refractive index of the troposphere is an important factor at predicting performance of Terrestrial Radio Links. Refractive index variations of the atmosphere affect radio frequencies above 30 MHz, which becomes more significant only at frequencies greater than about 100 MHz especially in the Troposphere (Ayantunji *et al*., 2011) Surface radio refractivity

N, is a measure of deviation of refractive index n of air from unity which is scaled up in parts per million to obtain more amenable figures. Thus N is a dimensionless quantity defined and measured in N units. (Ayantunji *et al.*, 2011)

$$N_s = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right)(N - units) \quad (1)$$

where,

$$e = \frac{He_s}{100}(hPa) \quad (2)$$

and

$$e_s = 6.11\exp\left[\frac{17.502t}{t + 240.97}\right] \quad (3)$$

where, e_s = maximum (or saturated) vapour pressure at the given air temperature, t (°C) and H is the humidity. P is the air pressure (hPa), T is temperature (K) and e, is water vapour pressure (hPa). Generally, P and e decrease rapidly with height whereas T decreases slowly with height. (Ayantunji *et al.*, 2011, Adediji and Ajewole, 2011). Surface radio refractivity N_s, has a high correlation with radio field strength values while the surface refractivity gradient which depends on N_s, determines the refractivity condition of the atmosphere. This may result in a normal, sub-refractive, super refractive or ducting layer, each of which has important influences on propagation of VHF, UHF and microwaves in the atmosphere. (Ayantunji *et al.*, 2011; Oyedum and Gambo, 1994)

Path Loss Prediction Models

Path Loss in radio communications is the attenuation of signal strength resulting from the influence of terrain and atmospheric components on the path or channel of communication. There are different prediction models. Some of these models were derived in a statistical manner based on field measurements and others were developed analytically based on diffraction effects. Each model uses specific parameters to achieve reasonable prediction accuracy (Akingbade and Olorunnibi, 2013). Two globally acceptable models that can be used to benchmark new approaches will be discussed in this work.

Friis Transmission Equation

Friis transmission equation is a simplified path loss prediction model used in radio waves propagation. Radio and antenna engineers use the following simplified formula for path loss prediction between two isotropic antennas in free space (Kennedy and Bernard, 1992).

$$L = 20Log10\left(\frac{4\pi d}{\lambda}\right) \quad (4)$$

where d, is the distance (line of sight) away from the transmitter in meters, λ is the wavelength of the wave in m. The path loss, representing the attenuation suffered by the signal as it travels through the wireless channel is given by the difference of the transmitted and received power in dB and is expressed as:

$$PL(dB) = 10logP_t/P_r \quad (5)$$

The fields of an antenna can broadly be classified in two regions, the far field and the near field. It is in the far field that the propagating waves act as plane waves and the power decays inversely with distance.

Okumura-Hata Model for Urban Areas

The Hata Model for Urban Areas, also known as the Okumura-Hata model is a developed version of the Okumura Model and is the most widely used radio frequency propagation model for predicting the behavior of cellular transmissions in built up areas (Armogun et al). This model incorporates the graphical information from Okumura model and develops it further to realize the effects of diffraction, reflection and scattering caused by city structures. This model also has two more varieties for transmission in Sub-urban Areas and Open Areas. Hata Model predicts the total path loss along a link of terrestrial microwave or other types of communications (Hata, 1980). The model can be used for both micro and macro cell outdoor prediction. Table 1 presents details of prediction areas according to Okumura-Hata Model. This particular version of the Hata model is applicable to the radio propagation within urban areas. This model is suited for both point-to-point and broadcast transmissions and it is based on extensive empirical measurements taken in Tokyo Japan, in the year 1968 (Okumura, 1968).

Hata Models for Urban and Sub Urban Areas are formulated as (Hata, 1980):

$$L_{(urban)} = 69.55 + 26.16\log f - 13.82\log h_b - \alpha(h_m) + \left[44.9 - 6.55\log h_b\right]\log d\,(dB) \quad (6)$$

For large city with the wave frequency of transmission, $f \geq 400\,MHz$,

$$\alpha(h_m) = 3.2[log(11.75\,h_m)]2 - 4.97 \quad (7)$$

From equations (6) to (8),

Lu is the path loss in Urban Areas in dB, h_b, is the height of base station antenna in meters, h_m, is the height of mobile station antenna in meters, f, is the frequency of transmission in MHz, $\alpha(h_m)$ is the antenna height correction factor and d, is the line of sight distance between the base and mobile stations in kilometer.

By specifications, Okumura-Hata model has the following range for optimum result:

Carrier frequency: $150\,MHz \leq f \leq 1500\,MHz$

Base station height: $30\,m \leq h_b \leq 200\,m$

Mobile station height: $1\,m \leq h_m \leq 10\,m$

Distance between mobile and base station: $1\,km \leq d \leq 20\,km$. (Nizirat *et al* 2011, Akingbade and Olorunnibi, 2013)

For sub urban area, it is given by:

$$L_{(sub-urban)} = L_{(urban)} - 2\left[\log\left(f/28\right)\right]^2 - 5.4(dB) \quad (8)$$

Table 1: Description of prediction areas according to Okumura-Hata Model

Route	**Prediction area**	**Description**
1	**Open**	Open space, no tall trees or building in path
2	**Sub-urban**	Village or Town high way scattered with trees and houses, not very congested
3	**Urban**	Built up city or large town with large building and houses. Village with close houses and tall trees

Source: (Sylvian, 2004)

Table 2: Transmission Characteristic of the experimental DTTBS station

S/N	Parameter	Value /definition
1	Base station's location	Lat. $7^0$15' 08" N, Long. $5^0$07' 53" E
2	Base station transmitted power (kW)	2.50
3	Base station's frequency(MHz)/ Channel	722 / 52
5	Height of transmitting mast (m)	250
6	Height of transmitting antenna(m)	2.5
7	Transmitting antenna gain (dB)	1
8	Height of receiving antenna (m)	1.5, and 3.0 (Variable)

Regression and Correlation Analysis

Regression

Regression deals with obtaining mathematical model that describes relationship between two or more variables. It is used to predict or estimate the value of one or more variables from given values of other variables related to it. Given ***n*** independent observations $X_1, X_2, \ldots, X_n$ and ***n*** dependent observations $Y_1, Y_2, \ldots, Y_n$. in simple regression, the required model is of this form (Pedhazur, 1982):

$$Y = \beta_0 + \beta_1 x + \varepsilon \quad (9)$$

The variable ε represents the random error associated with the prediction of ***Y*** for a known or assumed value of ***X*** which is unpredictable. It is assumed that E (ε) = 0. Hence;

$$E(y) = \beta_0 + \beta_1 x + E(\varepsilon) = \beta_0 + \beta_1 x \text{ i.e. } \hat{Y} = b_0 + b_1 X \quad (10)$$

where b_0 is the intercept and b_1 is the slope or the regression coefficient,

$$b_1 = \frac{n\sum XY - \sum X \sum Y}{n\sum X^2 - (\sum X)^2} = \frac{Covariance\ XY}{Variance\ X} \quad (11)$$

$$b_0 = \frac{\sum Y - b_1 \sum X}{n} = \bar{Y} - b_1\bar{X} \quad (12)$$

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_m X_m + \mu \quad (13)$$

In this work, equation (13) was used for the modeling of Received Signal Strength (RSS) and the Improved Okumura- Hata Path Loss model (*IHPL*) as a function of, Elevation, (ELV), Line of Sight (LOS), surface radio refractivity, N_S and rainfall (R) to be in this form:

$$RSS = \beta_0 + \beta_1 LOS + \beta_2 ELV + \beta_3 N_s + \beta_4 R (dBm) \quad (14)$$

$$IHPL = \beta_0 + \beta_1 LOS + \beta_2 ELV + \beta_3 N_s + \beta_4 R (dB) \quad (15)$$

Correlation Analysis

Correlation studies the degree of relationship between two or more variables. Correlation coefficient ranges from $-1\ to +1$ indicating the degree of relationship. Several types of correlation coefficients exist for different forms of data. Karl Pearson's Product Moment Correlation Coefficient for continuous data is given in (16) was used in this work.

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} = \frac{COV\ XY}{\sqrt{Var\ X .Var\ Y}} \quad (16)$$

Bivariate correlation analysis of all possible pairs of variables (RSS-ELV, RSS-LOS, RSS-N and ELV-LOS) using (16) is obtained in order to observe the degree and direction of relationships between the pairs.

Instrumentation and Methods

Instrumentation

A digital Satlink WS-6936 model field strength meter was used for the DTTV signal strength measurement by connecting the output of DTTV UHF receiving antenna attached to a variable antenna stand to it and the desired DTT frequency is selected for measurement to be taken. Whereas a Global Positioning System receiver (GPS Map 78s personal navigator) was used for the measurement of elevation, geographic coordinates and the line of sight of the various data locations from the base station. Also, a compact wireless mobile weather forecaster model N96FY was used to measure the meteorological parameters of Temperature, Pressure and Humidity. Others are Rainfall, wind speed and the time of measurement corresponding to each data locations along the selected routes around the base station. A field vehicle was used for the field campaign.

Data Collection and Handling

Measurement of the Received Signal Strength (RSS) of the Digital Terrestrial Television Base Station, (DTBBS) in Oke Isikan , Akure was carried out radially from the base Station along three different routes in the State using a Star Times receiving antenna connected to a digital Satlink WS-6936 signal meter. Two sets of data were obtained for the RSS corresponding to two antenna receiver heights of 1.5 and 3.0 m for each location. The station's transmitting antenna was logged and used as the reference point by the GPS receiver for all the routes. The line of sight from the base station was monitored during the drive using the GPS, which equally measures the location's longitude, latitude, and the elevation. The wireless mobile weather forecaster was used for the measurement of the surface weather parameters of temperature, pressure, humidity, wind speed, and rainfall of data points. A field vehicle was used as a means of movement along the routes during the field work. The research crew usually stops at an interval of 1km LOS for measurement to be taken. At each point of data collection, all the equipment would be set and operated. The exercise usually takes about 20minutes for each point before moving to another point. The study was carried out during the dry and wet seasons. Detail of the routes categorization is as presented in Table 3

In summary, the RSS values, geographic coordinates, elevation above ground level as well as the line of sight of the various data locations were recorded. Also recorded were the meteorological parameters of temperature, pressure, humidity, wind speed, and rainfall for necessary analysis. Transmission parameters of the (DTBBS) were relatively constant throughout the period of measurement as confirmed by the records of transmission in the station.

Table 3: Routes categorizations for the field campaign

Route	Direction/ Definition
A	DTTBS in Akure towards Arakale-Oda Town (0-15km LOS)
B	DTTBS in Akure towards -Igoba- Ita Ogbolu (0-15 km LOS)
C	DTTBS in Akure towards – Ilaramokin - Igbara Oke (0-12 km LOS)

RESULTS AND DISCUSSION

Presented below are the results of the analysis carried out on the obtained data. Equations (1) - (3) were used tocompute the Radio Refractivity values for data points while equations (6) - (8) were used to compute the Okumura-Hata path loss values. Figures 1 and 2 depict the path loss plots for routes A and B during the dry seasons whereas figures 3 and 4 depict the plots for routes A and B during the wet seasons. The major findings in all the plots are as follows; Path loss increases as distance increases from the base station. Average path loss of 123.54 dB and 121.07 dB were recorded when using receiver antenna heights of 1.5 and 3.0 m respectively during the dry period. Higher values of path losses were recorded for lower receiving antenna height of 1.5 m compared to the values recorded when using receiving antenna heights of 3.0 m. For the wet seasons, average path loss of 127.54 dB and 126.44 dB were recorded when using receiving antenna heights of 1.5 and 3.0 m respectively. The implication of this is that the use of higher receiving antenna height reduces path loss on DTTV Channel for the two seasons. This is scientifically compliant because the use of higher antenna height reduces attenuation effects due to multipath effect and consequently reduction in path loss. On the other hand, path loss values for the wet seasons are higher than the dry season's which implies higher attenuation of DTTV signal during the wet seasons compared to dry seasons. This can be attributed to higher attenuation effects of the meteorological factors and surface radio refractivity as revealed in this work. Thus to enjoy quality of service at the reception end in the study areas at least a 3.0 m receiver antenna height is encouraged by subscribers. It will also be necessary that the management of the DTTBS increase the output power of their transmitter during the wet seasons to compensate for losses.

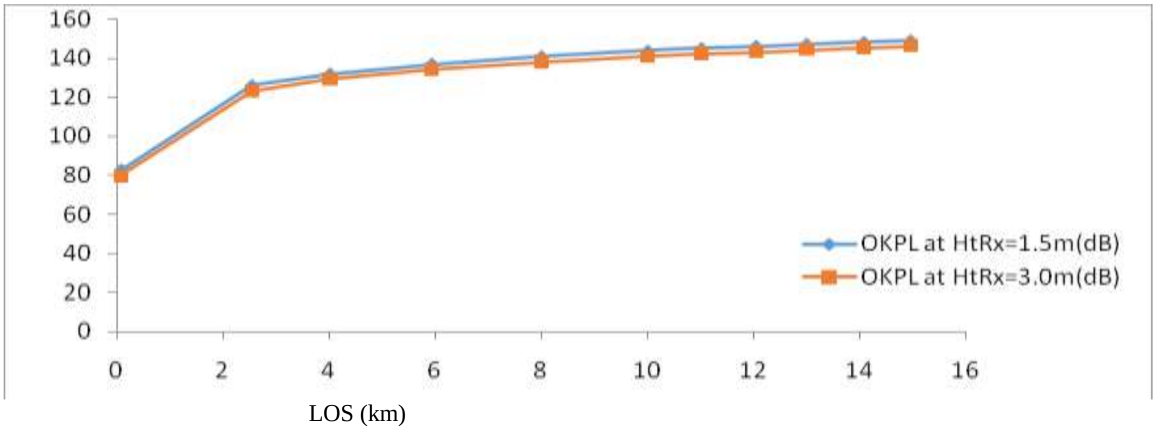


Fig.1: Okumura-Hata Path loss for Route A during Dry Seasons

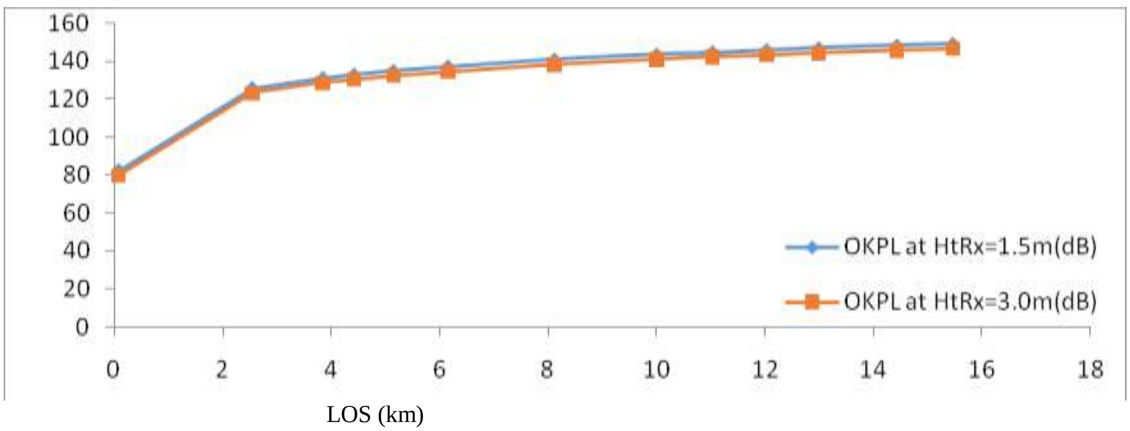


Fig.2: Okumura-Hata Path loss for Route B during Dry Seasons

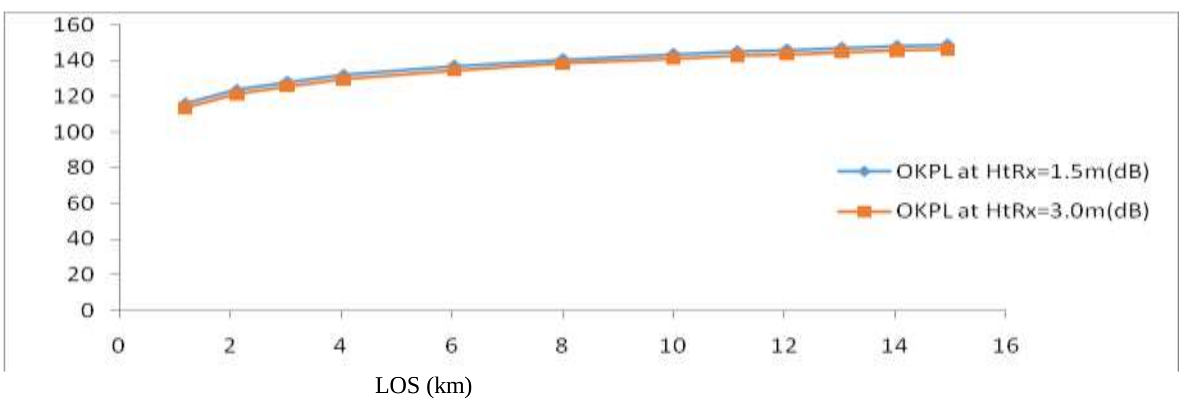


Fig.3: Okumura-Hata Path loss for Route A during wet Seasons

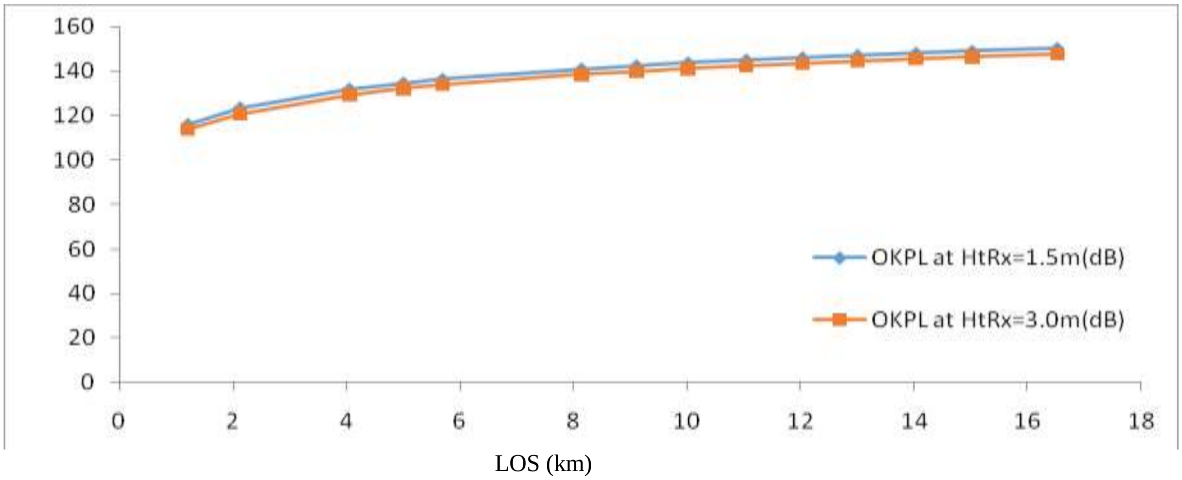


Fig. 4: Okumura-Hata Path loss for Route B during wet Seasons

Path Loss and Signal Strength (RSS) Modeling

Regression and correlation analysis were carried out on data to obtain the Received Signal Strength (RSS) and the modified Okumura-Hata models (Improved Hata Path Loss Model, *IHPL*) that incorporate the location based terrain and the surface radio climatic parameters. These proposed models were based on the analysis of data obtained when using the receiver antenna height of 3.0 m. This is premised on the fact that better signal quality and minimum losses were recorded while using the antenna height along all the routes of measurement. The models also have higher coefficients of multiple determination R^2 of, 0.973 and 0.830 respectively with better p-value for Analysis of Variance (ANOVA) based on α(0.05) than the models obtained for receiver antenna height of 1.5 m.

During the Dry Seasons

The models for the dry seasons are as presented:

$$IHPL_{dry} = 1403.290 + 4.997LOS - 1.128ELV - 2.270N_s - 2.409R_{amt} \tag{17}$$

$$RSS_{dry} = 138.615 - 1.881LOS - 0.051ELV - 0.393N_s - 1.265R_{amt} \tag{18}$$

During the Wet Seasons

The proposed path loss and RSS models for the wet seasons with coefficients of multiple determination R^2 of, 0.952 and 0.864 are respectively presented as:

$$IHPL_{wet} = 774.888 + 0.330LOS - 1.327ELV - 0.522N_s + 1.880R_{amt} \tag{19}$$

$$RSS_{wet} = 458.109 - 2.572LOS - 0.359ELV - 0.863N_s - 1.113R_{amt} \tag{20}$$

With all the parameters defined below:

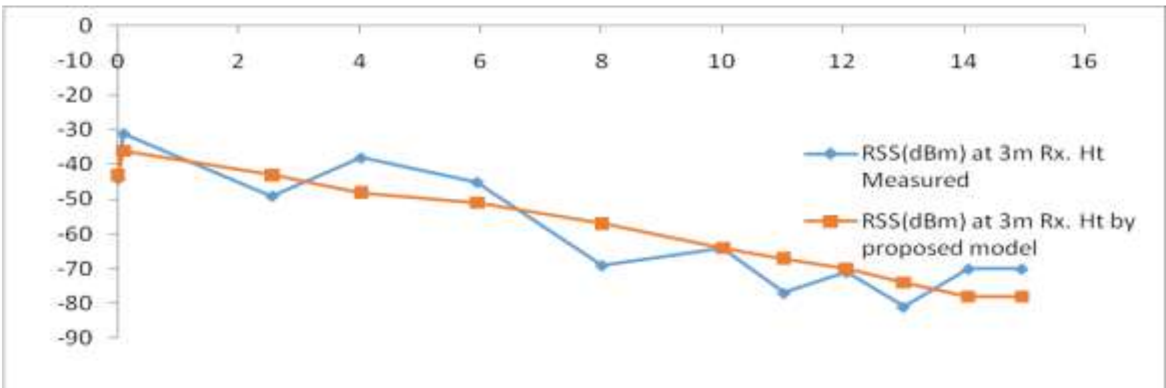
LOS	Line of Sight from DTTBS (km)
RSS_{dry}	RSS model (dBm) at 3.0 m RxHt for dry season
$IHPL_{dry}$	Improved Okumura-Hata sub- urban path loss (dB) at 3.0 m RxHt for dry season
$IHPL_{wet}$	Improved Okumura-Hata sub- urban path loss (dB) at 3.0 m RxHt for wet season
RSS_{wet}	RSS model (dBm) at 3.0 m RxHt for wet season
ELV	Elevation above sea level of data points (m)
R_{amt}	Amount of Rainfall (mm)

N_s	Surface Radio Refractivity (N- units)
RxHt	Receiver Height

All the models were checked statistically and found to be significant.

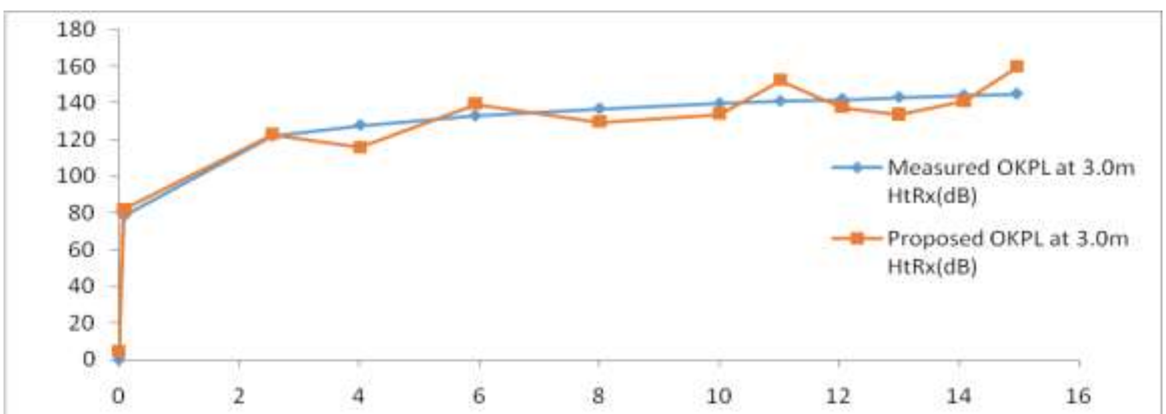
Comparison of measured Values of RSS and Path Loss with Proposed RSS and Path Loss Models.

Figures 5 depicts the plots of measured and proposed RSS for dry seasons, while fig. 6 depicts the plots of measured and proposed path loss models for dry seasons. From figure 5, it is observed that the proposed model is highly correlated with the existing model and shows a good inversely proportional relation to distance. Also the proposed path loss model (Fig. 6) seems to have moderated the existing model: 40% of its proposed values are slightly higher than the measured, 20% were exactly the same with measured values while 40% were slightly lower. This Means that there are data points that were possibly under estimated or over estimated by existing Okumura-Hata model that were corrected by the new model.



LOS (km)

Fig. 5: Comparison between measured and proposed RSS models during dry seasons



LOS (km)

Fig. 6: Comparison between existing and proposed path loss models during dry seasons.

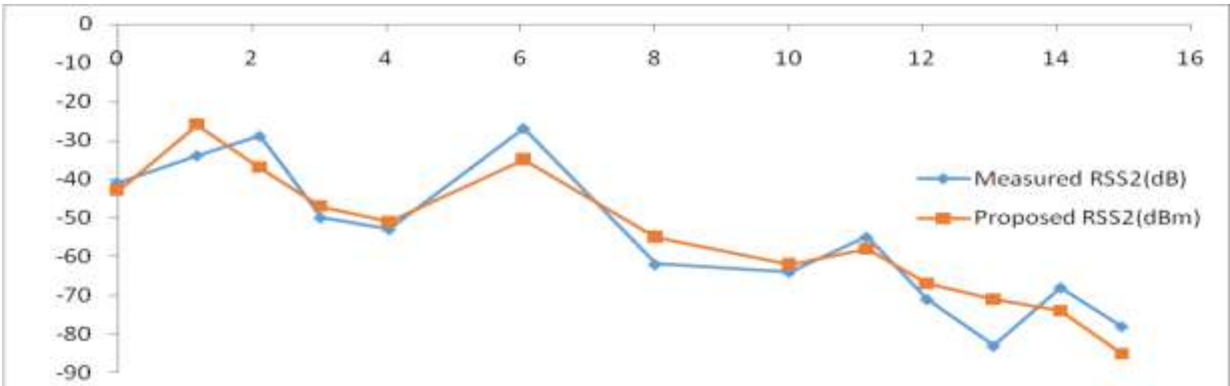
For the wet season

Figure 7 depicts the plots of the measured RSS to that of the proposed RSS for the wet seasons whereas fig. 8 shows the plots of the existing and modified path loss models.

The new model has moderated the measured values by taking the influences of elevation, LOS, radio refractivity and the rainfall of the study areas into consideration. About 40% of its projected values correspond to measured values while about

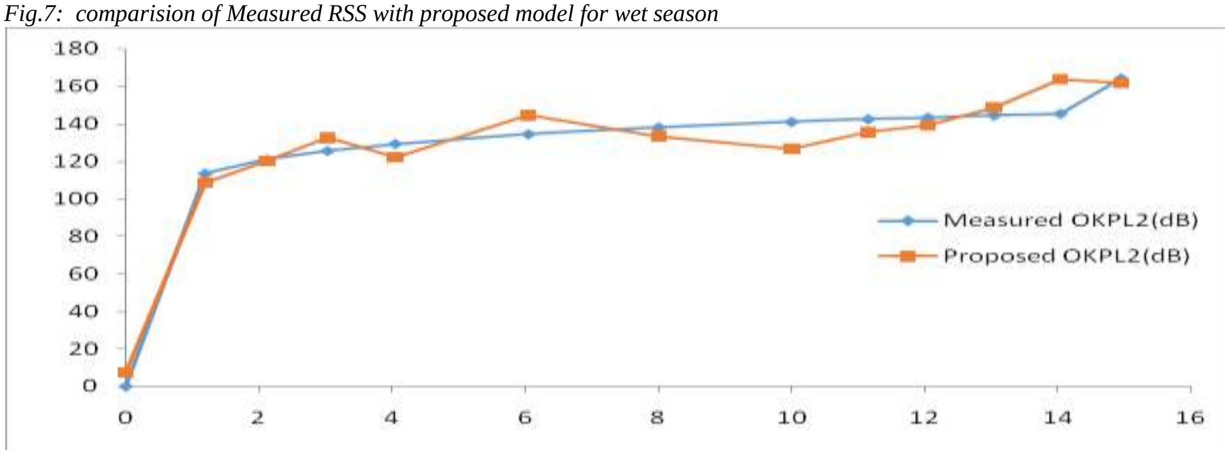
30% fall slightly lower and 30% slightly higher than measured values.

For the modified Hata path loss, the model is highly correlated and demonstrated a good improvement over the existing Okumura Hata model: 40% of its proposed values were exactly the same with measured values while 40% were slightly lower than the measured and 20% slightly higher than measured values as deduced from figure 13. Meaning that there are data points under estimated and over estimated by Okumura –Hata that were corrected by the new model



LOS (km)

Fig.7: comparision of Measured RSS with proposed model for wet season



LOS (km)

Fig.8: comparision of existing path loss with modified model for wet season

CONCLUSION

This work investigated the path losses associated with Digital Terrestrial Television (DTTV) channels in the tropical rainforest zone of Nigeria. Also investigated was the effect of some surface meteorological parameters and radio refractivity on DTTV signal. The obtained data were used to revalidate existing path loss model suitable for use in the locality. Furthermore, a new Received Signal Strength (RSS) useful to predict the power received from base station was proposed.

The proposed RSS models for the two seasons are given as:

$$RSS_{dry} = 138.615 - 1.881LOS - 0.051ELV - 0.393N_s - 1.265R_{amt}$$

$$RSS_{wet} = 458.109 - 2.572LOS - 0.359ELV - 0.863N_s - 1.113R_{amt}$$

Whereas the modified path loss models for the two seasons are as presented:

$$IHPL_{dry} = 1403.290 + 4.997LOS - 1.128ELV - 2.270N_s - 2.409R_{amt}$$

$$IHPL_{wet} = 774.888 + 0.330LOS - 1.327ELV - 0.522N_s + 1.880R_{amt}$$

The RSS proposed models are complete innovation of this work while the path loss models are improved versions of the Okumura Hata models for sub urban prediction. These models were tested statistically and practically and found to show high positive correlation with the measured values. The models have incorporated local content of location based terrain and some radio climatic factors. This is an enhancement over related work. The models are strongly recommended for use in DTTV links and Networking in the tropical sub urban cities of Nigeria. Other findings are as follows; Path loss increases as distance increases from the base station. Average path loss of 123.54dB and 121.07 dB were recorded when using receiving antenna heights of 1.5 and 3.0 m respectively during the dry period. For the wet seasons, higher values of path loss were recorded for lower receiving antenna height compared to the values recorded when using the receiving antenna heights of 3.0 m. In addition, average path loss of 127.54 dB and 126.44 dB were recorded when using receiving antenna heights of 1.5 and 3.0 m respectively. The implication of this is that the use of higher receiving antenna height reduces path loss on DTTV Channel for the two seasons. This is scientifically compliant because the use of higher antenna height reduces attenuation effects due to multipath effect and consequently reduction in path loss. On the other hand, path loss values for the wet seasons are higher than the dry season's which implies higher attenuation of DTTV signal during the wet seasons compared to dry seasons. This can be attributed to higher attenuation effects of the meteorological factors and surface radio refractivity. Thus to enjoy quality of service at the reception end in the study areas at least a 3.0 m receiving antenna height is encouraged for use by subscribers. It will also be necessary by the management of the DTTBS to increase the output power of their transmitter during wet seasons to compensate for losses. The overall results of this work will be of great importance to all stakeholders in the DTTV Industry for planning sustainable DTTV network that will ensure Quality of Service (QoS) in the study areas and other similar cities around the World.

Acknowledgment

i. NTA- Star Time's Team, Akure, for their cooperation.
ii. Communication's Team, Physics Department, FUTA, for releasing Equipment for the Research.
iii. Federal University Dutsin-Ma for my Study Fellowship

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