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Original Article

Investigated Performance of Okumura-Hata Model for Dvb-T2 Signal Propagation in Nigeria

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Abstract *- The choice of signal propagation model in the implementation and analysis of the digital terrestrial television broadcast (DTTB) signal performance level in the Telecommunication Industry remains pivotal to Engineers and Scientists. The success recorded in the design and implementation of any DTTB system is attributed to the choice of the predicting model adopted. The aim of this investigation is to establish the efficacy of the Okumura-Hata path-loss model in the application of the DTTB network in Nigeria. The measured path loss was relatively investigated with respect to Okumura-Hata and Free space propagation model using a simple drive test methodology. The Okumura-Hata model offered considerable RMSEs closer to zero, which is satisfactory for high performance in received signal strength compared to the other propagation model. However, it implies that the Okumura-Hata model could be preferred in the planning, design and implementation of the DTTB network in Nigeria due to its superior performance in the predicted signal strength using digital video broadcast–terrestrial (second generation - DVB-T2) technology.*

Keywords *- Digital Terrestrial Television Broadcasting, Digital Video Broadcasting-Terrestrial (Second Generation), Path-loss models, Radio coverage, Signal propagation.*

1. Introduction

The Path-loss is defined as the decline in power density of an electromagnetic wave as it propagates over space. The path-loss is a strategic factor in the analysis and design of the link budget of a wireless system [1]. Furthermore, path loss is a function of the effect of both environmental and atmospheric perturbations. These could be attributable to parameters such as free space loss, refraction, diffraction, reflection, aperture-medium coupling loss and absorption. It may also be subject to earth topography, environment (urban or rural, vegetation and foliage), propagation medium (dry or humid air), the distance between the transmitter and the receiver, and the height and position of antennas [2], [3]

The radio propagation model is an empirical mathematical design for describing radio wave propagation as a function of frequency, distance and other characteristics [4]. Furthermore, models are usually developed to predict the behavior of propagation for every similar link under similar constraints. The vital aim of signal propagation is to validate how the signal can propagate from one point to another in order to predict the path-loss effect on an area covered by a single-frequency network (SFN) or multiple-frequency network (MFN) [4]. In wireless communication technology, radio propagation between the transmitter and the receiver is affected by such mechanisms as scattering, diffraction and reflection. The radio coverage is established with the aid of radio signal path-loss, which rises with increased frequency [4]. The radio frequency (RF) power of radio signals would decrease when radio signals travel over a long distance. Therefore, generally, the systems with higher frequencies will not operate reliably over the distances required for the coverage areas with varied terrain characteristics [5].

2. Literature Review

2.1. A Survey on Propagation Models - Overview

The physical mechanisms of electromagnetic wave propagation are free space propagation, reflection, diffraction, and scattering. These mechanisms determine the propagation of electromagnetic signals. However, techniques and models have been developed over time for predicting radio wave propagation. The propagation models are divided into empirical-statistical models and deterministic-geometrical models [6]. This research will focus more on an empirical model predicting radio wave propagation. The empirical models are better adapted to a fast, approximate and reliable calculation of coverage area. The Empirical models calculate field strength without requiring extensive data on the terrain. These models use data collected from extensive measurements in different locations and the presentation of simple equations with negligible dependence on cartographic data [7].

2.2. Propagation Models

The radio-wave propagation model is essential for the calculation of DTTB coverage and analysis. The choice of propagation model depends on the availability of terrain height data for the service area and the propagation paths between interfering transmitters and the coverage area [8]. This technique delivers terrestrial point-to-area field strength prediction standards established on the empirical analysis of evaluated data found in Recommendation ITU-R P.1546 [9].

2.3. Okumura – Hata Model

The combination of Okumura (1968) and Hata (1980) models gave rise to the Okumura-Hata model [10], [11]. This model is best applied in a macro cell environment and is empirically centered on a series of field measurements performed by Okumura in and around the city of Tokyo, with results made public in graphical formats. The application of measurements carried out by Hata further resulted in a set of equations with extra correction factors for application in other terrains. This model could be useful in quasi-level terrains in an urban region without the extra correction factors. The possible operational range of the Okumura-Hata model is as follows: Frequency (f): 150MHz-1500MHz, with likely extension from 1500MHz - 2000MHz, the distance between the transmitter (TX) and the receiver (Rx), distance (d): 1-20km, transmitter antenna height hb: 3-200m, receiver antenna height hm: 1-10m.

Okumuru-Hata model is mathematically expressed as:-

$$L_p = 69.55 + 26.16\log fc - 13.82\log h_b - a(h_m) + 44.9 - 6.55\log(h_b)\log(d) + l_{others\ s}. \quad (1)$$

and

$$a(h_m) = [1.1 \log_{10}(f) - 0.7]\, h_m - [1.56 \log_{10}(fc)\ 0.8] \quad (2)$$

where;
fc is the carrier frequency in MHz,
d is the distance in kilometer (Km),
h_b is the transmitter antenna height in meters (m),
h_m is the antenna height in meters(m).
l_{others} is the additional correction factor

2.4. Compared Model: Free Space Path-Loss Model

The free space path loss is defined as the loss of strength or signal as it moves along free space [12]. The free space path-loss model adopts a supreme condition where there is a line-of-sight (LOS) between the transmitter and receiver. The radio wave propagation signal route generally obeys non-line-of-sight (NLOS) environments with obstructions affecting the signal paths [10]. In certainty, the free space model has limited application because it is based on ideal situations. The obstructions caused by perturbations like free space loss find useful applications in estimating path loss between the mobile station (MS) and the base station (BS) in difficult terrains. However, degradation and attenuation should be taken into consideration due to the changes in the environment caused by perturbations and other physical obstacles with respect to the LOS condition, while log-normal distribution is used to justify the effects of slow fading [13].

In free space, the power density S at a propagation distance d is shown in equation (3). The effective propagation area of the receiver antenna, which affects the received power, is given in equation (4) and the received power density is given in equation (5). By combining (4) and (5), the power received is given in (6).

$$S = \frac{P_t G_t}{4\pi d^2} \quad (3)$$

where;
P_t is the power transmitted
G_t is the gain of the transmission antenna

$$A = \left(\frac{\lambda^2 G_r}{4\pi}\right) \quad (4)$$

where;
$\boldsymbol{\lambda}$ is the wavelength
G_r is the gain of the receiver antenna

$$S = \frac{P_r}{A} \quad (5)$$

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \quad (6)$$

The free space path loss is the ratio of the transmitted power to the received power, which is given in its simplified form in (7). In logarithmic form, the free space loss is given in (11).

$$L = \left(\frac{4\pi d}{\lambda}\right)^2 \quad (7)$$

$$PL\ (dB) = 92.44 + 20 \log_{10} f\ (GHz) + 20 \log_{10} d\ (Km) \quad (8)$$

Alternatively, the path-loss lower frequency band is given as:

$$Lp\ (dB) = 20 \log_{10}(f) + 20 \log_{10}(d) - 20 \log_{10}(\boldsymbol{\lambda}) \quad (9)$$

Then substituting λ (in km) and f (in MHz)) and rationalizing the equation produces the generic free space path-loss formula, which is stated in equation (12):

$$Lp\ (dB) = 32.4 + 20 \log_{10}(d) + 20 \log_{10}(f) \quad (10)$$

$$L = 32.4 + 20\log_{10} F + 20\log_{10} d \quad (11)$$

where;
F is the frequency in mega hertz
d is the distance in kilometers

$$\lambda = C/F \quad (12)$$

2.5. Path Loss Measurement and Prediction

The path loss is a function of terrain, frequency of operation and antenna height varies with respect to the distance and power of the transmitter. Path loss is expressed mathematically as [6]:-

$$\text{Path-loss}, L_p = P_t(dB) - P_r(dB) \quad (13)$$

For a free space model, the relationship between P_t and P_r is given as

$$P_r = \frac{P_t \lambda^2}{(4\pi d)^2} \quad (14)$$

The wavelength of the carrier is $\boldsymbol{\lambda} = c / f$

$$P_r\ (dBm) = P_t\ (dBm) - 21\text{- }98 + 20\log_{10}(\boldsymbol{\lambda}) - 20\log_{10}(d) \quad (15)$$

$$L_p(d) = P_t - P_r = 21\text{- }98 - 20\log_{10}(\boldsymbol{\lambda}) + 20\log_{10}(d) \quad (16)$$

$$= Lo + 20\log_{10}(d) \quad (17)$$

Where,
Lo is the path-loss at the first meter (put d = 1) and 20dB per decade loss in signal strength
P_t is the transmitter power
P_r is the receiver power
$\boldsymbol{\lambda}$ is the wavelength of the RF carrier

The relationship between P_t and P_r over a distance is given by

$$P_r = Pt\boldsymbol{\lambda}^2/(4\pi)^2 d^2 \quad (18)$$

Where d is in meters, therefore

$$P_r\ (dBm) = P_t\ (dBm) - 21.98 + 20\log_{10}(\boldsymbol{\lambda}) - 20\log_{10}(d) \quad (19)$$

$$\text{Path loss} = L_{p} = P_t - P_r = 21.98 - 20\log_{10}(\lambda) + 20\log_{10}(d) \quad (20)$$

$$\text{Path-loss, } PL_m(dB)=EIRP_t-P_r(dB) \quad (21)$$

Where

$EIRP_t$ is the Effective isotropic radiation power in dBm

P_r is the Mean reference signal power in dBm

The effective isotropic radiated power $EIRP_t$ (dBm) is defined as the sum amount of power density that is transmitted from the base station into the propagation medium [14].

$$EIRP_t=P_t+G_t-L_r \quad (22)$$

Where;

P_t is the Transmitter power in (dBm)

G_t is the Transmitter antenna gain in (dBi)

L_r is the Total transmission losses (dB)

3. Related Works

The investigated propagation curves and coverage areas of DTTB base stations in the tropical zone in Nigeria with the aim of developing the propagation curve and classifying the coverage area of digital terrestrial television broadcast networks in Nigeria using drive test methodology revealed that digital terrestrial television signals do not generally decrease with distance as projected by the theoretical inverse square law. Rather, it undulates with respect to distance due to terrain and tropospheric components along its propagation path. The researchers could not establish the perturbation component that has a higher effect on signal propagation [15].

However, the predicted radio wave propagation by simulation of free space propagation path-loss aimed at determining how crucial path-loss is in the design of communication systems was achieved with the aid of MATLAB simulation methodology. The result obtained showed that path loss is a vital parameter in the design and implementation of the radio communications system. The researchers identified how high frequency affects the path-loss but failed to mention the effect of perturbations on signal propagation [12]. The investigated path-loss and modeling for DTT over Nigeria aimed at ascertaining the accurate prediction path-loss for DTT in ensuring the quality of service (QoS) with the application of field measurement methodology. The result obtained showed that path-loss calculated using the Okumura-Hata model was the best fit and equally revealed that path-loss increases with an increase in trans-receiver distances. Finally, the authors could not outline how the transmitting power affects path loss [16]. The investigated propagation models for wireless communication systems aimed at giving an overview of the propagation models in wireless communication systems, thereby identifying other additional path-loss models between the transmitter and the receiver, which was achieved using a simple field measurement campaign. The result obtained showed that other additive losses occurred, such as losses resulting from walls, floors and doors. However, no solution was proffered on how to manage these additive losses during transmission [17]. The path-loss model adaptation in urban radio propagation for a DVB-T2 system was investigated using the Quantitative measurement method. The measured data were analyzed using data processing based on the least squares (LS) method. The researchers concluded that the proposed model was more accurate in predicting the quantitative measurement of propagation data than the conventional Hata path-loss model but could not identify the obstacles experienced during the measurement exercise [7]. The path-loss modeling of the fourth generation long-term evolution network along major highways in Lagos, Nigeria, aimed at studying the comparative analysis of the measured path-loss with respect to predictions made by free space, flat earth, Okumura - Hata, Walfisch-Ikegami, Ericsson, ECC-33, and Lee models using simple field measurement campaign methodology. The results obtained showed that the Okumura-Hata model had the best performance with RMSEs of 7.42dB, 7.63dB and 9.64dB along the investigated routes 1, 2, and 3, respectively. The Okumura – Hata model was further modified using the least square method to enhance its signal prediction accuracy. The modified Okumura-Hata model predicted the path loss along routes 1, 2, and 3, with RMSEs of 5.20dB, 4.89dB and 8.78dB, respectively. Finally, the modified Okumura-Hata model showed lower RMSEs closer to zero, which was acceptable by the researchers but, in general principle, was still very high compared to zero [10].

4. Materials and Method

4.1. Investigated Environment

The measurement campaign was carried out in the City of Jos and its environs. The City of Jos is located in the north-central geo-political zone of Nigeria and is geographically classified as a Sahel region. The city is semi-urban in nature with few high-rise buildings but associated with hilly or rocky features capable of causing signal obstruction. The measurement campaign was carried out in the wet and dry seasons (July - August and October - November 2019) to establish the effect of terrain and rain on the DTT signal in the area investigated. A total of ninety-six (96) sample measurements were taken. The locations were divided into two major routes (routes A and B) across the investigated area. The two major routes were subdivided into: A_1, A_2 and B_1, B_2 (routes A_1 and A_2 are the same routes measured in different seasons - wet and dry seasons while B_1 and B_2 are the same routes but measured in different seasons - wet and dry season). The Nigerian Television Authority (NTA) signal Distribution Company -Integrated Television Services (ITS) signal was used for the measurement campaign. At the time of this measurement campaign, ITS was the only DTT network operator (free-to-air) in Jos, Plateau State. Figure 1 presents the geographical map of the study area.

The map in Figure 1 presents the geographical location of the seventeen (17) Local Government Areas (LGA) of the state with the coverage area. The map was downloaded from www.researchgate.net and modified to suit my purpose using geographical information system software (ArcGIS).

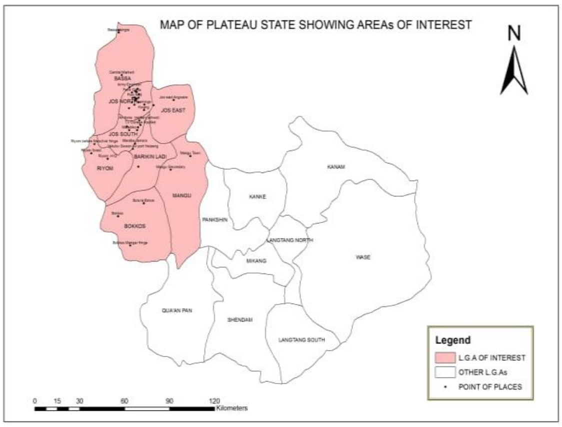

Fig. 1 The study map [18]

4.2. Experimental Setup and Measurements

To guarantee high permanence and relative precision using a spectrum analyzer in carrying out field measurement in broadcasting, ITU recommendations on field measurement, relevant equipment and specified settings were followed [19].

The measurement tool for the field test system comprises test equipment carried in a Van and driven to test locations within the selected areas. The test equipment used, as presented in Figure 2, includes;-

- A Calibrated Logarithmic Antenna
- Dedicated decoder (Digital Terrestrial Receiver) capable of decoding (DVB-T2) signals
- A Deviser Spectrum analyzer E8000A series
- A Television monitor capable of displaying SDTV and HDTV (DVB-T2) signals
- Global positioning satellite (GPS) enables smartphone
- 75Ω, 15m RF cable and connectors

The equipment setup in Figure 2 was in conformity with the ground and rooftop level measurement procedure in order to achieve acceptable results as laid down by ITU for frequency managers, monitoring services, and the Broadcasters.

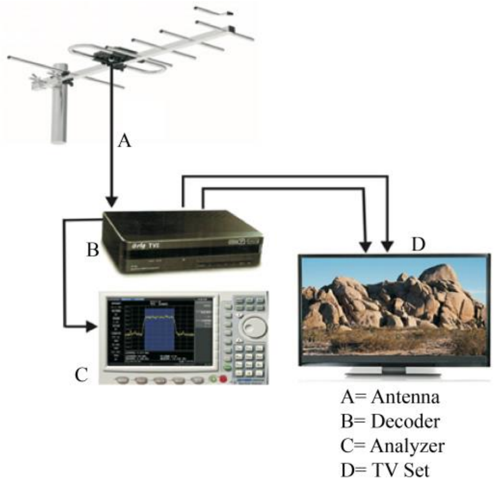

Fig. 2 Equipment setup for field measurement

4.3. Measurements and Modeling Parameters

The methodology adopted for the field measurement was a simple drive test. During the measurement exercise, eight (8) Local Government Areas were covered (Jos North, Jos East, Jos South, Bassa, Riyom, Barkin Ladi, Bokkos and Mangu). The key parameters measured were: - field strength (FS), channel power (CP) and received signal strength (RSS). The ITS transmitter parameters are summarized and presented in Table 1.

Table 1. ITS network parameters

S/N	Parameter	Values
1	TX frequency	522MHz
2	Effective isotropic radiated power (EIRP)	62.14 dBm
3	Base station location and Geographical Coordinate	Latitude: 9.89°, Longitude: 8.87°
4	Base station transmitted power (Kw)	1.3Kw
5	Base station frequency (MHz)	522MHz
6	Height of the transmitting antenna (m)	107m
7	Height of the mobile antenna (m)	10m
8	Antenna Pattern	Horizontal – Omnidirectional

5. Result and Discussion

This section presents the result of path-loss measured (PLm) and predicted data. The signal strength for each of the routes measured at a distance d (km) was used to determine the mean value path-loss measured and predicted, as presented in Tables 2 and 3. The graphical presentation of the path-loss Okumura-Hata model (PLO-HM) and path-loss free space model (PLFSM) vs. distance are presented in Figures 3 and 4.

Table 2. Table of signal analysis of field data in route A

Model Parameters	Mean	Standard Deviation	Low Value	High Value
PLm (B_1)	118.23	13.1	104.4	134.5
PLm (B_2)	115.61	12.6	98.6	129.8
PLO-HM	117.2	14.4	96.8	137.6
PLFSM	107.4	10.9	94.5	120.3

Table 3. Table of signal analysis of field data in route B

Model Parameters	Mean	Standard Deviation	Low Value	High Value
PLm (A_1)	122.84	15.9	103.7	135.5
PLm (A_2)	117.7	14.6	98.5	131.6
PLO-HM	121.1	20.5	95.6	146.6
PLFSM	109.9	11.8	93.7	126

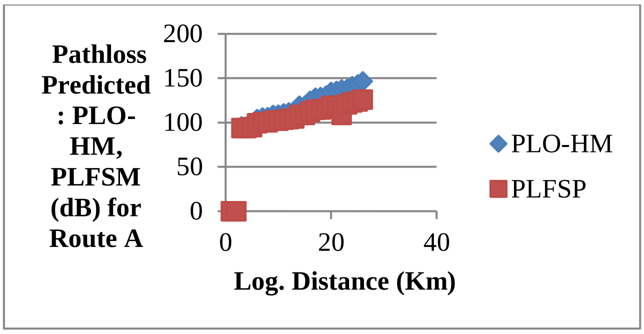

Fig. 3 Plot of PLO-HM / PLFSM vs. Distance in route A

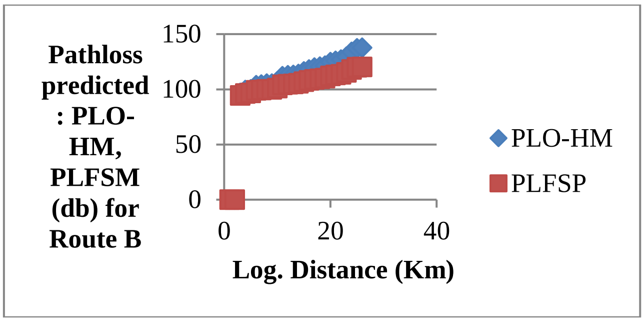

Fig. 4 Plot of PLO-HM/ PLFSM vs. Distance in Route B

The graphical presentation of the measured and predicted path-loss models is presented in Figures 5 and 6 actually to interpret the model with the best line of fit.

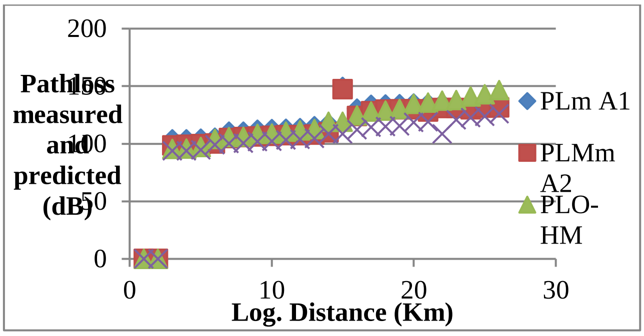

Fig. 5 Plot of Path-loss Measured and predicted in Route A (A1, A2) vs. Log. Distance

The results presented in Figures 5 and 6 imply that the path-loss Okumura-Hata model has a better agreement with the path-loss measured in both routes in Nigeria's wet and dry seasons.

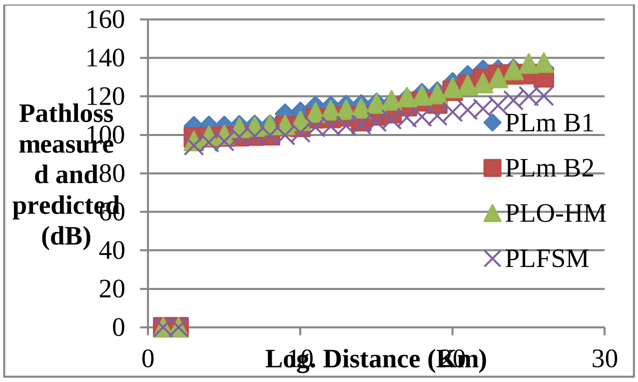

Fig. 6 Plot of Path-loss Measured and Predicted in Route B (B1, B2) vs. Log. Distance

5.1. Statistical Analysis

The statistical method was applied to compare the efficiency index of the path-loss models achieved through the use of a root mean square error (RMSE) statistical value between the Okumura-Hata propagation model (O-HPM) and the free space propagation model (FPSM).

5.2. Okumura –Hata Model Best Fit

The validity of the Okumura-Hata prediction model for DVB-T2 was tested using the root mean square error (RMSE). The validity of the result presented a performance value of 0.4 dB and 0.7 dB along routes A_1 and A_2 and 0.2 dB and 0.3 dB in routes B_1 and B_2. The closer the values of the RMSEs to zero, show better performance in the signal prediction accuracy of the model [20], [21].
This is expressed mathematically as:-

$$\text{RMSE}=\sqrt{\sum_{=1}^{k}\frac{[PL_m(d)-PL_r(d)]^2}{K}} \qquad \ldots\ldots\ldots\ldots\ 23$$

where;
PLm (d) is the measured path-loss (dB)
PLr (d) is the Predicted path-loss (dB)
K = 24 (number of measured locations on each route)
Example: the RMSE of routes A and B for Okumura-Hata are:-

$$\text{RMSE, } A_1 = \sqrt{\frac{(122.84-121.1)^2}{24}} = 0.4\text{dB}$$

$$A_2 = \sqrt{\frac{(117.7-121.1)^2}{24}} = 0.7\text{dB}$$

$$\text{For Route } B_1,\ \text{RMSE}_1 = \sqrt{\frac{(118.23-117.2)^2}{24}} = 0.2$$

$$B_2 = \sqrt{\frac{(115.61-117.2)^2}{24}} \quad 0.3$$

The RMSE of routes A and B for the free space model are:-

$$\text{RMSE of A1} = \sqrt{\frac{(122.84-109..9)^2}{24}} = 2.7dB$$

$$\text{RMSE A2} = \sqrt{\frac{(117.7-109.9)^2}{24}} = 1.6dB$$

$$\text{RMSE of B1} = \sqrt{\frac{(118.23-107.4)^2}{24}} = 2.2$$

$$\text{RMSE of B2} = \sqrt{\frac{(115.61-107.4)^2}{24}} = 1.7$$

Table 4 presents the statistical value of the root mean square error of PLO-HM and PLFSM in the investigated area.

Table 4. Root Mean square error values calculated from the path-loss prediction

Model	A_1 vs. A route	A_2 vs. A route	B_1 vs. B route	B_2 vs. B route
O-HPM (RMSE)	0.4	0.7	0.2	0.3
FSPM (RMSE)	2.7	1.6	2.2	1.7

6. Discussion

The statistical analysis of the predicted path-loss, as shown in Table 4 present, root mean squared errors value of 0.4dB and 0.7dB in routes A_1, A_2 and 0.2dB and 0.3 dB in route B_1, B_2 for Okumura-Hata while the free space propagation model statistics presented the values of 2.7 dB and 1.6 dB in route A_1, A_2 and 2.2 dB and 1.7 dB in route B_1, B_2 respectively. Further investigation in the analysis using root mean square error (RMSE) validates the fact that the Okumura-Hata propagation model serves better in Jos compared to the free space propagation model. The data presented in Table 4 validates the superiority of the Okumura-Hata model over the free space propagation model. The graphical presentation in Figure 5 equally established the effect of terrain on the DVB-T2 signal.

7. Conclusion

The result obtained from the research implies that rain and terrain tremendously affect the DTT signal propagation in Nigeria. However, the indicators from the RMSE value calculated confirmed that DTT signals are better in the dry season compared to the rainy season. This validates the fact that rain and its properties attenuate DTT signals in Jos and its environs.

The Okumura-Hata model presented the least RMSE of 0.4 dB, 0.7 dB, 0.2 dB and O.3dB along routes A and B. The RMSEs value closer to zero demonstrates a great improvement in the prediction exactness of the model. This model could be highly cherished for network planning, system design and wireless network deployment in and around Jos. This model could be very useful in the area of excellent signal prediction and path-loss modeling applications for related wireless mobile environments.

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