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PATH LOSS MODELING SUITABLE FOR MACRO CELL PREDICTION FOR ANALOGUE DECIMETRIC WAVES IN EKITI STATE, NIGERIA.

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ABSTRACT

Path loss modeling is an essential factor in radio wave propagation and equipment design. This work examined the path loss model suitable for macro cell prediction for decimetric waves (UHF waves) in Ekiti State, Nigeria. The electric field strength of the signal of the Broadcasting Service of Ekiti State (BSES Channel 41, 625.25 MHz, broadcast signal) was measured quantitatively across the state along four routes using a digital field strength meter (Dagatron TM 10) with the transmitting station as reference point. A global positioning system (GPS) hand held receiver was used to measure the geographic heights, the geographic coordinates and the line of sight of the various data points from the base station. Data obtained were used to calculate the free space path loss for all the routes using Friis equation. Whereas, Okumura-Hata models for macro cell path loss prediction were used to determine the losses along the routes. Results showed that Friis model grossly underestimated the signal losses along the routes and cannot be used to estimate losses for decimetric waves in the state. In addition, the result obtained using Okumura-Hata models for urban and sub urban were moderate and consistent. New empirical path loss models that can be used to predict channel losses and coverage areas in order to compensate for losses in the state were proposed based on Hata sub urban model. The findings of this work will enhance radio wave propagation on the UHF band and other similar channels in the study areas.

Keywords*: Decimetric waves, macro cell, path loss, geographic heights and models.*

INTRODUCTION

There are two common approaches to propagation modeling; the physical models and the empirical models. Physical models involve the use of physical radio waves principles such as free space transmission, reflection and diffraction. The empirical models make use of data obtained through measurement to generate path loss equation. The independent variables in this case are usually transmitter- receiver distance, output power of transmitter, frequency of operation, transmitting antenna height and receiving antenna height. Others are terrain, roof tops and antenna gain. Some of these models were derived in a statistical manner based on field measurements and others were developed analytically based on diffraction effects. (Okumura and Hata, 1980; Armoogun *et al.,* 2010). A reliable path loss model is such that calculates the path loss with maximum accuracy. This will help radio scientists and engineers in channel optimization to achieve quality of service (QoS.) (Armoogun *et al.*, 2010; Akinbolati *et al.*, 2016). Examples of path loss prediction models are ITU model, Long-Rice Model, Okumura-Hata's Model, COST 231 Model, Friis Model and Lee's Model.

This work uses two popular existing models, the Okumura-Hata and Friis transmission equation (free space path loss) to evaluate the measurement results that were obtained.

Choice of Okumura-Hata and Friss Models as reference for this work

Okumura-Hata model for macro cell prediction (1-20 km, outdoor) has been chosen as a reference for its wide acceptability and adoption by the International Telecommunications Union-Radio (ITU-R) as a standard to bench mark new approaches (Armoogun et *al*., 2010). In addition, the model has three components- rural, sub urban and urban areas, in which the study area fits in (as a sub urban). Friis model was chosen for the calculation of the free space loss due to its acceptability as a standard for calculating free space loss. The followings are the equations:

Okumura- Hata Model for urban areas is given by (Hata, 1980):

$$L(urban)(dB) = 69.55 + 26.16\, log f - 13.82\, log\, h_b - \alpha(h_m) + [44.9 - 6.55\, log\, h_b]\; log\, d \quad (1)$$

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

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

where $\alpha(h_m)$ is the correction factor for the mobile or receiving antenna height

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 distance between the base and mobile stations in km.

By specifications, Okumura-Hata model has the following range;

Carrier or radio wave 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: $1\, km \leq d \leq 20\, km$

For sub urban area, it is given by

$$L(sub-urban)(dB) = L(urban) - 2\,(\log\,(f/28))^2 - 5.4 \quad (3)$$

For open rural area, it is given by

$$L(open)(dB) = L(urban) - 4.78\,(\log(f)^2 + 18.33(\,log f) - 40.94 \quad (4)$$

(Armoogun, *et al.*, 2010; Nizirat, *et al.*, 2011; Akingbade and Olorunnibi, 2011)

Friis equation (free space loss) is given as:

$$L_{(dB)} = 20 Log 10 (\frac{4\pi d}{\lambda}) \quad (5)$$

where d, is the distance (line of sight) from the transmitter in meters, λ, is the wavelength of the wave in (m). (Friis, 1945). Equations (1) - (5) will be used accordingly.

Review of related work

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 (Ajewole, et al., 2014). This could be the effect of terrestrial objects on the propagation path (Ajewole, *et al.*, 2014; Akinbolati, *et al*., 2016). Other factors that determine the quality of signal received from the transmitter on the UHF band include: transmitter output power or the effective isotropic power of the transmitter (EIRP), transmitting antenna height, and the nature of the signal path. Others are transmitter-receiver distance, elevation above ground level of the receiver and the gain of the receiving antenna. (Kenedy and Bernard, 1992; Ajewole, *et al.*, 2013). There is also the attenuation effect on UHF signal caused by precipitation (Ajewole, *et al.*, 2014) and foliage (Ayekomilogbon, *et al.*, 2013). Other factors leading to distorted received signal strength are multipath effects and fading which are caused by atmospheric ducts, ionospheric reflection and refractions. The work of Armoogun (Armoogun, *et al.*, 2010) underscores the importance of path loss prediction and coverage areas in radio and television broadcast system, since the wave interacts with the environment leading to attenuation of signal. Nizirat (Nizirat *et al*., 2011) worked on terrain roughness correction factor for Hata Model at 900 MHz, in west of Amman, Jordan. He emphasized that accurate estimation of propagation path loss as a key factor for the good design of mobile systems. Such needs are of great concern to radio scientist and engineers to optimize system parameters such as number and locations of transmitters, power coverage and interference levels.

Materials and Method

Study areas and the experimental station

This study was carried out in Ekiti State, South West, Nigeria. The state presently has sixteen local government areas with a land mass of 6,353 km^2 and a population of 2,384,212 (2006 Nigerian Census). The South western part of Nigeria is the Premier of broadcasting Industries in Nigeria (Ajewole, 2010). By this very fact, the governments and the people in this geo political zone of Nigeria do not handle broadcasting issues with levity having known its importance on the socio economic lives of the citizen. Thus any study aimed at bringing about innovations and enhanced quality of service in this regard is always appreciated. Fig 1, presents the map of Ekiti State showing the direction of the measurement work. Table 1 presents the transmission parameters of the station.

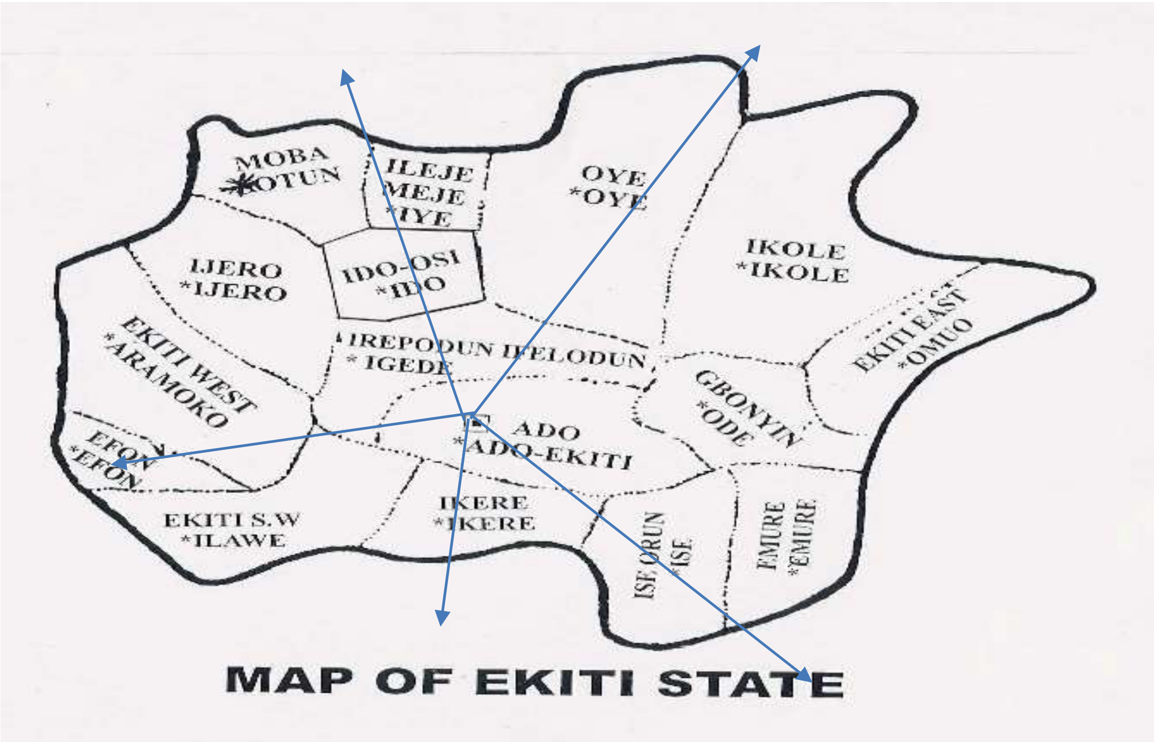

Fig. 1: Map of Ekiti State showing the directions for the field strength measurement.

Table 1: Transmission Parameter for Ch 41 TV Station, At Ado Ekiti

S/N	Parameter	Value
1	Base station's geographic coordinates	Lat. 7.71°N, Long. 5.21°E
	Base station's output capacity	20kW(20,000W)
1	Base station's transmitted power	80% (16,000W)
2	Base station's carrier frequency	631.25 MHz
3	Transmitter in use	Harris Maxima Solid State Model
4	Height of transmitting mast	200.0 m
6	Transmitting antenna gain	13dB
7	Height of receiving /mobile antenna	1.94 m (6ft)

Method

The electric field strength measurements of the transmitting station were carried out radially along different routes from the base station (as reference). These measurements were taken using a digital field strength meter while a GPS receiver (GARMIN MAP 76) model was used to measure the line of sight, geographic height and geographic coordinates of the different locations from the base station. Measurements were taken along four routes at an interval of 2 km along each route from the base station, and in all the towns and villages along the routes until the signal falls below the threshold measurement of 15 dBμV. Arrangements were made with the management of the station to ensure that transmitting parameters were kept constant during data collation period. Transmission parameters were monitored and found to be substantially constant throughout this period.

In summary, the electric field strength of the transmitted television signal for different locations with their corresponding distances (LOS) from the base station were recorded. Also, determined and recorded were the latitude, longitude and the geographic height of the various locations where data were collected. Data were collected in about 100 locations along different routes.

Table 2, presents the description of the routes for data collection in the state.

Table 2: Description of routes used for data collection

Route	Description	Line of sight (km)
A	Transmission base in Ado Ekiti towards Efon Ekiti	0-35
B	Transmission base in Ado Ekiti towards Otun- Ekiti	0-40
C	Transmission base in Ado Ekiti towards Ikere Ekiti	0-32
D	Transmission base in Ado Ekiti towards Igokosi– Ekiti	0-30

RESULTS AND DISCUSSION

Presented below are the results of this work, the analysis carried out on obtained data and discussion of the results. The study area fits into the sub urban and medium cities definition of the Okumura-Hata model. Thus, equations (1) - (3) were used for the Okumura Hata calculations for sub urban whereas, equation (5) was used for the free space calculation. Tables 3, 4, 5 and 6 present the calculated values for routes A, B, C and D respectively.

Table 3: Calculated path loss values along Route A (Ado -Efon)

LOS (km) from base station	1.50	5.03	10.00	13.57	23.25	26.80	33.10	35.00
Okumura-Hata Urban (dB)	115.268	130.892	139.79	143.50	150.73	152.57	155.30	156.01
Okumura-Hata Sub-Urban (dB)	117.00	132.53	141.53	145.24	152.47	154.31	157.04	157.75
Free space loss by Friis (dB)	31.97	42.48	48.45	51.10	55.78	57.01	58.85	59.33

Table 4: Calculated path loss values along route B (Ado Ekiti – Otun Ekiti)

LOS(km) from base station	1.00	6.41	14.00	20.00	24.70	30.00	36.40	40.40
Okumura-Hata Urban (dB)	109.97	134.034	144.15	148.78	151.58	154.03	156.53	157.88
Okumura-Hata , Sub-Urban (dB)	111.71	135.77	145.89	186.52	153.32	155.77	158.27	159.62
Free space loss by Friis (dB)	28.45	44.59	51.37	54.47	56.31	57.99	59.67	60.58

Table 5: Calculated path loss values along route C (Ado Ekiti – Ikere Ekiti)

LOS (km) from base station	1.20	4.50	10.50	20.08	23.02	31.80
Okumura-Hata Urban (dB)	112.33	129.45	140.43	148.26	150.60	154.78
Okumura-Hata Sub-Urban (dB)	114.06	131.19	142.17	150.00	152.34	156.52
Free space loss by Friis (dB)	30.04	41.52	48.88	54.51	55.69	58.50

Table 6: Calculated path loss values along route D (Ado Ekiti – Ikogosi Ekiti)

LOS (km) from base station	1.30	9.96	15.10	22.82	27.42	29.70
Okumura-Hata Urban (dB)	113.36	139.74	145.13	150.48	152.85	153.90
Okumura-Hata , Sub-Urban (dB)	115.10	141.48	146.75	152.22	154.59	155.64
Free space loss by Friis (dB)	30.73	48.42	52.03	55.62	57.21	57.91

Path Loss Modeling

Modeling of the path losses for all the routes as a function of Line of Sight (LoS) and Elevation (ELV) above sea level of the study areas were carried out using regression analysis on data. Okumura Hata path loss model for sub urban city was used because the locations under study fit into the sub urban definition. The Improved Hata Path Loss (IHPL) models are as represented by equations (6), (7) and (8) for routes A, B and C respectively. In addition, the corresponding Friss Free Space Path Loss Model (FSPL) generated are presented by equations (9) to (11

$$IHPL_{A(sub-urban)} = 97.881 + 0.967LOS + 0.059ELV(dB) \quad (6)$$

$$IHPL_{B(sub-urban)} = 33.068 + 0.044LOS + 0.220ELV(dB) \quad (7)$$

$$IHPL_{C(sub-urban)} = 149.089 + 1.204LOS - 0.068ELV(dB) \quad (8)$$

The coefficients of determination with their corresponding, p-value (significant level) for the derived models in (6) to (8) are 0.967 (0.001), 0.778 (0.098) and 0.925 (0.051) respectively. Thus, the derived model represented in (6) with the highest coefficient of determination and the most significant p-value of 0.001 is the most significant amongst the derived models with each of the parameters significant in the model. Ipso-facto, equation (6) is the best model that can be used to predict path losses for the Analogue Television Signal (ATT) in the study areas.

On the other hand, the derived free space path losses for routes A to C are respectively presented in (9) to (11)

$$FSPL_A = 19.030 + 0.647LOS + 0.040ELV(dB) \quad (9)$$

$$FSPL_B = 2.696 + 0.354LOS + 0.078ELV(dB) \quad (10)$$

$$FSPL_C = 55.632 + 0.806LOS - 0.051ELV(dB) \quad (11)$$

The coefficients of determination for the Free Space Path Loss (FSPL) and their corresponding p-value (significant level) for the derived models in (9) to (11) are 0.966 (0.001), 0.948 (0.003) and 0.924 (0.056) respectively. Thus, the derived model represented in (9) with the highest coefficient of determination and the most significant p-value of 0.001 is the most significant amongst the derived FSPL models with each of the parameters significant in the model. Ipso-facto, equation (9) is the best FSPL model that can be used in the study area.). However, FSPL generally underestimates the path losses and cannot be used to accurately predict path losses in the location areas.

CONCLUSION

This work has successfully investigated the path loss pattern of decimetric waves in Ekiti State Nigeria using two existing models; Okumura Hata and Friss (Free Space Path Loss) path loss models. New models that incorporate the elevation pattern of the study areas were proposed as improvement over the existing models. The Improved Hata Model (IHPL) and Free Space Path Loss (FSPL) are respectively given in (6) and (9) as:

$$IHPL_{C(sub-urban)} = 97.881 + 0.967LOS + 0.059ELV(dB)$$

and,

$$FSPL_A = 19.030 + 0.647 LOS + 0.040 ELV (dB)$$

The overall findings of this work will enhance radio wave propagation on the UHF band and other similar channels in the study areas.

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