Path Loss Prediction Model For UHF Radiowaves Propagation In Akure Metropolis

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Abstract

Propagation path loss models play an important role in the design of cellular systems to specify key system parameters such as transmission power, frequency, antenna heights, and so on. Several models have been proposed for cellular systems operating in different environments (indoor, outdoor, urban, suburban, and rural). This work sets out to predict the path loss of a UHF channel along three routes in Akure metropolis using existing models (Friis, Okumura-Hata). Broadcast signal field strength measurements were taken across the three routes. Measured values were compared with the different models prediction to determine model suitable for the city. Consequently, a modified Hata’ model was developed which can be deployed by engineers in radio communications system planning and design.

Keywords: Path Loss, Models, Measurements, Radio Wave, Friis, Okumura-Hata.

1. INTRODUCTION

During radio wave propagation, an interaction between waves and environment attenuates the signal level. It causes path loss and finally limits coverage area. Path loss prediction is a crucial element in the first step of network planning [1]. Theoretical and experimental studies of path loss prediction models can be found in many literatures. However, there is no assurance that the available models can fit in perfectly to all geographical locations. Most of the studies have been performed in developed countries using various experiments, whereas in tropical regions, especially in some Nigerian cities like Akure in Ondo State, studies are still needed to be pursued which may lead to new prediction model. Based on this reason, it is proposed to conduct these experiments so as to come up with a path loss prediction model of UHF waves for Akure Metropolis. The radio channel comprises of the propagation medium, the transmitting and receiving antennas. Radio transmission takes place from a transmitter to a receiver through propagation paths. These are referred to as propagation mechanisms arising out of the different interactions with the interfering objects along the path as said by Fleury and Leuthold (1996) [2]. Each of the models designed are site-specific and therefore in using them for analysis, they must be used for the right sites for which they were designed. The Okumura model is one of the models which are used for prediction of wireless propagation parameters across different terrains namely the urban, sub-urban and rural environments [3].

2. PATH LOSS 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. Rappaport et al [4] reported that urban radio channels provide more predictable path loss due to diffraction waves and wave guiding effects along city streets. Transmission in hilly terrains arrives at a greater delay after a direct line of sight (LOS) is established. Rappaport et al [4] noted that for mountainous regions amplitudes within 100dB of a direct signal at excess delay of 20μs or more can be arrived at according to the author’s study carried out. Ramakrishna [6] performed a path loss prediction in the areas where there is building and an assumption of the field to possess a flat terrain. The approach Ramakrishna used for validation was a three dimensional vector parabolic equation concept for calculating path loss in an urban environment and then compared to results produced by the uniform theory of diffraction (UTD). This model may not be an efficient prediction for transmission in an area without buildings especially for repeater stations located in isolated mountainous areas because they do not possess some field characteristics described. Neˇskovi´c et al [7] used four empirical models: SUI model, COST 231-Hata model, Macro and Ericsson model, which are most suitable for path loss prediction for such a system to work on radio frequency propagation mechanisms and empirical models for fixed wireless access systems. By using these propagation models the receiving signal levels are predicted for different types of environment for WiMAX (Worldwide Interoperability for Microwave Access) system installed in the city of Osijek, Croatia.

The long distance prediction models intended for macrocell systems use base station and mobile station antenna heights and frequency. On the other hand, the prediction models for short distance path-loss estimation use building heights, street width, street orientation, and so on. These models are used for microcell systems [3]. There are various propagation prediction models for mobile radio communications systems such as ITU models, Long-Rice model, Okumura-Hata’s model, Lee’s model, Durin’s model, Walfisch and Bertoni’s model, Friis transmission equation etc. In this work, particular attention is given to prediction model by Okumura-Hata and Friis transmission equation. This is because these models have wide acceptability and as such will be used to evaluate the propagation measurement results that were gotten from the investigation.

A. 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 $\boldsymbol{L}$, between two isotropic antennas in free space:

$$L = 20\, log_{10}\left(\frac{\boldsymbol{4\pi d}}{\boldsymbol{\lambda}}\right) \qquad (1)$$

where $\boldsymbol{d}$ is the distance (line of sight) away from the transmitter in meters, $\boldsymbol{\lambda}$ is the wavelength of the wave in MHz [4].

B. Okumura-Hata model for Urban Areas

The Hata Model for Urban Areas, also known as the Okumura-Hata model for being a developed version of the Okumura Model, is the most widely used radio frequency propagation model for predicting the behaviour of cellular transmissions in built up areas. 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 Suburban Areas and Open Areas. Hata Model predicts the total path loss along a link of terrestrial microwave or other type of cellular communications.

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.

Hata Model for Urban Areas is formulated as:

$$L_U = 69.55 + 26.16 \log f - 13.82 \log h_B - a(h_M) + [44.9 - 6.55 \log h_B] \log d \qquad (2)$$

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

$$a(h_M) = 3.2[log(11.75\ h_M)]^2 - 4.97 \quad (3)$$

From equations (2) and (3), L_U 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, $a(h_M)$ is the antenna height correction factor and d is the distance between the base and mobile stations in kilometer [8].

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

Carrier frequency: $150\ \text{MHz} \leq f \leq 1500\ \text{MHz}$

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: $1\ Km \leq d \leq 20\ Km$ [5].

3. RESEARCH METHODOLOGY

A. Physical Location Survey

Physical location survey was the preliminary stage conducted to select sites. During the site survey, any obstacle such as trees, hills and structures capable of causing obstruction of radio signal along the line of sight was taken note of. The routes along which locations were selected includes routes A, B and C representing OSRC/ Ilara/ Igbara Oke highway (Akure South), OSRC/ Iju/ Ado highway (Akure North) and OSRC/ Oyemekun/ Alagbaka highway respectively.

B.GPS and Field Strength Meter Measurements

The various air distances between the transmitting antenna at OSRC and the receiving antenna in the respective locations were mapped using the GPS receiver. The position of the transmitting antenna/base station was marked as a 'home' waypoint on the mark position page of the GARMIN GPS Map 76 receiver and stored in the memory [9]. A trip of about 20 Km with the aid of a slowly moving van away from the base station through Route A was taken at an incremental rate of approximately 1 Km line of sight (LOS). Measurements of received signal strength were taken as a function of distance away from the base station at each 1 Km LOS with the aid of the GPS and a receiving antenna attached to a field strength meter. This procedure was also used to determine straight line distance between the receiving antenna in the other routes and the transmitting antenna that was permanently fixed at OSRC, Akure. Elevation of locations, longitude and latitude, audio, video and peak components of the transmitted radio signal were determined, measured and recorded

C. Parameters for the Experiment

Based on the models used and the nature of this experiment, the following parameters were used.

TABLE 1: Experimental Parameter.

Parameter	Route A	Route B	Route C
Frequency	487.25 MHz	487.25MHz	487.25MHz
Power transmitted	16000 W	16000 W	16000 W
Height of base station	323.1 m	323.1 m	323.1 m
Height of mobile station	1.83 m	1.83 m	1.83 m

4. RESULTS AND ANALYSIS

The measured data collected at different locations along the three routes were analyzed using ordinary least square (OLS) regression with Microsoft Excel, with the graphs of the results plotted with the same software package. The respective path loss along each route was calculated using the experimental parameters used for this measurement as presented in Table 1. The mean error was then generated. From the results, a model was developed for the routes under observation.

A .Path Loss Calculations

Friis transmission equation and Okumura-Hata model were used to predict the path losses along the three routes and the results are shown in Tables: 2, 3, and 4. The graph of the path loss prediction against the respective LOS along the three routes established the fact that the path loss of radio signal being propagated increases with distance away from the base station.

TABLE 2: Path loss prediction along route A.

LOS(Km)	1.02	2.13	3.01	4.00	5.00	6.01	7.01	7.14	7.20	8.00	9.11	10.10	10.94
Friis model(dB)	86	93	96	98	100	102	103	103	103	104	105	106	107
Okumura-Hata(dB)	113	122	126	130	132	135	137	137	137	138	140	141	142

TABLE 3: Path loss prediction along route B.

LOS(Km)	1.02	2.00	3.02	4.00	5.00	6.04	7.02	7.57	8.00	9.00	10.00	11.00	12.00
Friis model(dB)	86	92	96	98	100	102	103	104	104	105	106	107	108
Okumura-Hata(dB)	113	121	126	130	132	135	137	138	138	140	141	142	143

TABLE 4: Path loss prediction along route C.

LOS(Km)	1.02	2.00	3.00	3.99	5.00	6.00	6.98	7.01	8.01	8.19	8.65
Friis model(dB)	86	92	96	98	100	102	103	103	104	104	105
Okumura-Hata(dB)	113	121	126	130	132	135	137	137	138	139	139

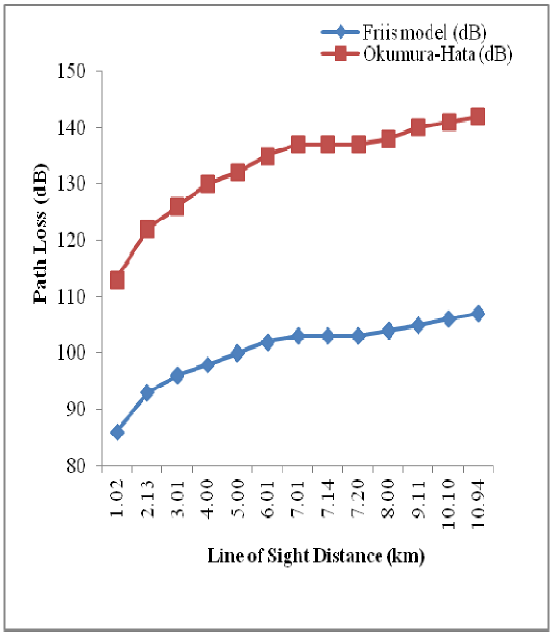

FIGURE 1: Graph of Path Loss against Line of Sight along route A.

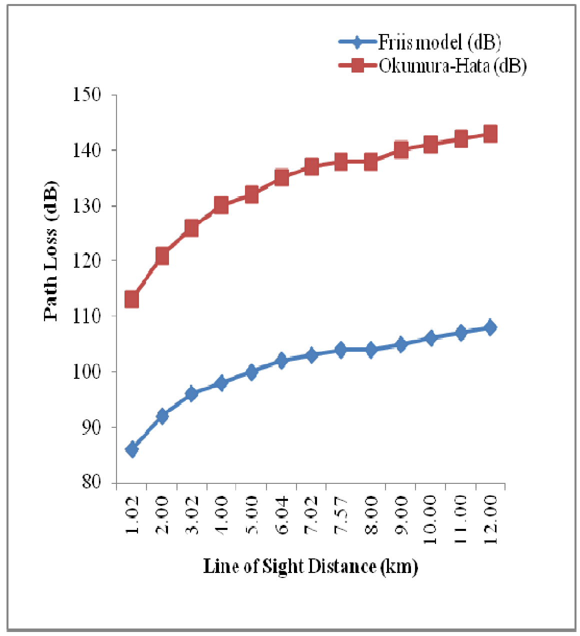

FIGURE 2: Graph of Path Loss against Line of Sight along route B.

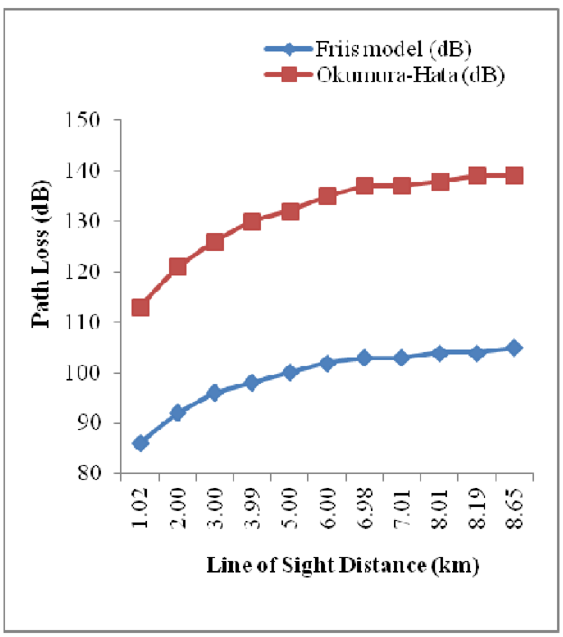

FIGURE 3: Graph of Path Loss against Line of Sight along route C.

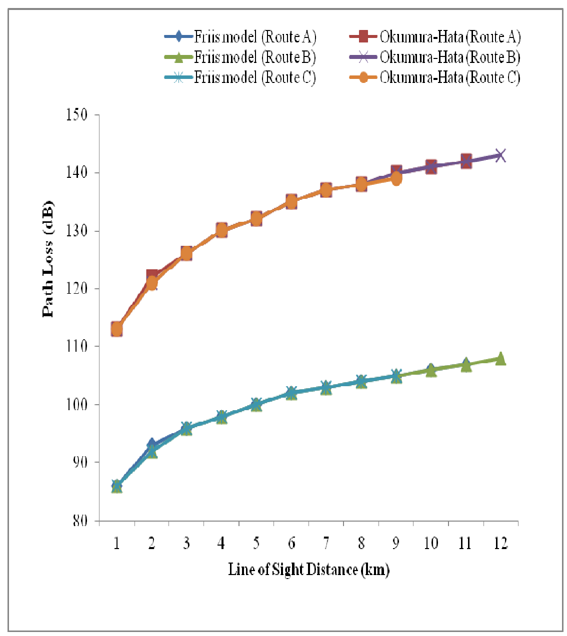

FIGURE 4: Graph of Path Loss against Line of Sight along routes A, B and C.

With ordinary least square (OLS) regression analyses carried out on the data presented in Tables 2, 3 and 4, the following equations of path loss for the graphs were derived:

$$L_{F_a} = 93.33 + 1.08 \times LOS \qquad (4)$$

$$L_{O_a} = 122.99 + 1.52 \times LOS \qquad (5)$$

$L_{F_b} = 93.04 + 1.11 \times \text{LOS}$ (6)
$L_{O_b} = 122.48 + 1.57 \times \text{LOS}$ (7)
$L_{F_c} = 87.59 + 2.16 \times \text{LOS}$ (8)
$L_{O_c} = 114.75 + 3.09 \times \text{LOS}$ (9)

From the equations above, $\boldsymbol{L_{F_a}}$, $\boldsymbol{L_{F_b}}$, and $\boldsymbol{L_{F_c}}$ are the Friis transmission path losses along routes A, B and C respectively; $\boldsymbol{L_{O_a}}$, $\boldsymbol{L_{O_b}}$ and $\boldsymbol{L_{O_c}}$ are Okumura-Hata model path losses also along routes A, B and C respectively and **LOS** is the line of sight. The equations above, when applied, gave the approximate values of the predicted path loss data on tables 2, 3 and 4.

B. Comparison with Measurements

The corresponding error statistics in terms of the mean prediction error are shown in the tables 5, 6 and 7. The prediction errors were calculated as the difference between the measurement and prediction. Tables 5, 6 and 7 compare the path loss obtained along Route A, B and C respectively against the measured values. They clearly show that both Friis and Hata’s model under predict the path loss with Friis’s model grossly under predicting the path loss.

TABLE 5: Comparison of path loss of empirical models with measurements along route A.

	FRIIS MODEL	**OKUMURA-HATA**
Path Loss Mean Error (dB)	54.83	22.35

TABLE 6: Comparison of path loss of empirical models with measurements along route B.

	FRIIS MODEL	**OKUMURA-HATA**
Path Loss Mean Error (dB)	52.33	18.97

TABLE 7: Comparison of path loss of empirical models with measurements along route C.

	FRIIS MODEL	**OKUMURA-HATA**
Path Loss Mean Error (dB)	59.00	26.63

C. The Developed Model

From the tables 5, 6 and 7, Hata’s model gave a closer prediction to the measurement in all the routes and so suitable for path loss prediction in the locations. Friis transmission equation gives mean errors of 54.83 dB, 52.33 dB, 59.00 dB with Okumura-Hata model giving mean errors of 21.33 dB, 19.17 dB and 25.40 dB along routes A, B and C respectively. The mean deviation errors were added to the original Okumura-Hata model to generate a path loss model suitable for prediction along the routes under observation in Akure metropolis. The original Okumura-Hata model from equations (2) and (3), with $\boldsymbol{L}$ being the path loss is given by:

$$L = 69.55 + 26.16\log f - 13.82\log h_B - a(h_M) + [44.9 - 6.55\log h_B]\log d \tag{10}$$

Therefore, with $\boldsymbol{L_A}$, $\boldsymbol{L_B}$, and $\boldsymbol{L_C}$ representing the path loss along routes A, B, and C respectively and all other terms remain as previously defined in equations (2) and (3); the following modified Okumura-Hata models were developed for the three routes under observation in Akure metropolis:

$$L_A = 69.55 + 26.16 \log f - 13.82 \log h_B - a(h_M) + [44.9 - 6.55 \log h_B] \log d + 22.35\ dB \quad (11)$$

$$L_B = 69.55 + 26.16 \log f - 13.82 \log h_B - a(h_M) + [44.9 - 6.55 \log h_B] \log d + 18.97\ dB \quad (12)$$

$$L_C = 69.55 + 26.16 \log f - 13.82 \log h_B - a(h_M) + [44.9 - 6.55 \log h_B] \log d + 26.63\ dB \quad (13)$$

D. *Comparative Evaluation*

The Friis transmission equation is a simple and idealistic model which assumes free space propagation where radio waves travel from the transmitter to the receiver without being affected by any obstacles in the radio wave channel [10]. However, the investigated routes are built-up urban areas hence why the model grossly under predicted the path loss as shown in tables 5, 6 and 7.

Okumura-Hata model, on the other hand, takes into consideration more factors which affect signal attenuation, particularly the environmental factors such as terrain characteristics [11]. However, the simplified model used in this work replaces the effective base station antenna height with the transmitting antenna height, by not considering the terrain characteristics. Also, the height of the broadcasting base station used in this work is 323.1m which is outside the model’s specification range for transmitter height (30 – 200m). This also may have contributed to the path loss error/deviation between the analytical and the field measurement values.

E. *Simulation Results*

Figures 1, 2 and 3 show the plots of path loss (dB) as a function of line of sight separation distance (km) between the transmitter (base station) and the receiver (mobile station) along routes A, B and C respectively. Each of the figures reveals that path loss increases with increasing separation distance. This agrees with the work of Nchimunya *et al* [12] which revealed that radio wave signal attenuates more with distance, though with consideration of other factors too.

Figure 4 then shows the overall plots of the path loss against separation distance for the three routes investigated in this work, and it reveals that the plots almost perfectly overlap. The observable slight difference can be attributed to differences in the terrain characteristics of the investigated routes. The work of Meng *et al* [13] carried out on palm plantation and rain forest terrains supports this.

5. CONCLUSION

Two empirical propagation models; the Friis transmission equation and Okumura-Hata model, were used to predict the path loss at some locations along three different routes in Akure metropolis and the results that were obtained established the fact that attenuation of electromagnetic waves increases as the wave fronts move farther away from the transmitter. Measurements taken were compared with the predictions made by the two propagation models used. Friis transmission equation showed large mean path loss error and hence grossly under predicted the path loss. Okumura-Hata’s model showed closer agreement with measurement results with lower mean path loss errors. Hata’s model shows that it is more suitable for use in path loss prediction in Akure metropolis giving the least error of 19.17 dB and showing the closest curve to the measured result. With the mean error values gotten, a modified Hata path loss model for all the routes under observation was developed. The models developed in this work, as presented in (11), (12) and (13) reveal that the path loss is also a function of the route or terrain, as evident in the different values for the different routes. It is also dependent on the antenna-height effect. Future works can be done to factor in these effects in a generalized modified model which will incorporate terrain characteristics and also cater for the effect of antenna height outside the specification range of the Okumura-Hata model and this will be an outstanding future research work.

6. REFERENCES

[1] Famoriji J. Oluwole and Olasoji Y. Olajide, “Radio Frequency Propagation Mechanisms and Empirical Models for Hilly Areas”, *Canadian Journal on Electrical and Electronics Engineering,* Vol. 4, No. 2, Canada, April 2013, PP. 65-70.

[2] Fleury, B. H. and Leuthold, P. E.(1996). Radiowave Propagation in Mobile Communications: An Overview of European Research, IEEE Communications Magazine, pp 70-81.

[3] Olorunnibi E.D., Path Loss Prediction Model for UHF Radio Waves in Akure Metropolis, A dissertation, Electrical and Electronic Engineering of the Federal University of Technology, Akure, Nigeria (2010).

[4] Rappaport S.T., Scott Y.S., and Rajendra S., 900-MHz Multipath Propagation Measurements for U.S. Digital Cellular Radio Telephone, IEEE Transactions on Vehicular Technology, 39(2), 132-139 (1990)

[5] Ramakrishna J., Path Loss Predictions in the Presence of Buildings on Flat Terrain; A 3D Vector Parabolic Equation Approach”, IEEE Transactions on Antennas and propagation, 51(8), 1716-1728. (2003)

[6] Neˇskovi´c A, Neˇskovi´c N, and Djordic Paunovi´c “Macrocell electric field strength prediction model based upon artificial neural networks”, IEEE Journal on Selected Areas in Communications, 20(6), 1170-1177 (2002)

[7] Vijay Garg (2007): “Wireless Communications and Networking”, Morgan Kaufmann Publishers, San Francisco, CA 94111.

[8] Adenike Folaponmile (2010): “Macrocell Path Loss Model for Tropical Savannah”, Journal of Research and National Development Vol. 8, No 1, June, 2010.

[9] GARMIN GPS Map 76 (2005): “Owner’s Manual and Reference”, GARMIN Cooperation, USA, 2005.

[10] Guilberth Martinez Vargas. “Development and Performance Evaluation of a Frequency-Agile Test Network” Master Thesis, RWTH Aachen University, 2009

[11] Erik Östlin. “On Radio Wave Propagation Measurements and Modelling for Cellular Mobile Radio Networks”, Doctoral Dissertation, Blekinge Institute of Technology, Sweden, 2009

[12] Nchimuya Chaamwe, Wenyu Liu and Hongbo Jiang. “Wave Propagation Communication Models for Wireless Underground Sensor Networks”

[13] Meng Y. S, Lee Y. H and Ng B. C (2010). “Path Loss Modeling for Near-Ground VHF Radio wave Propagation through Forests with Tree-Canopy Reflection Effect”, Progress In Electromagnetics Research M, Vol. 12, 131-141, 2010.