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Radio Frequency Propagation Mechanisms and Empirical Models for Hilly Areas

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ABSTRACT

Achieving better network performance is a paramount concern in wireless networks. This paper provides a survey of the basic mechanisms which influence the propagation of electromagnetic waves in hilly areas. Three empirical models: COST231-Hata, Okumura-Hata and Egli which are suitable for path loss prediction for such area are presented. By using these propagation models the broadcast signal strength are predicted for this type of environment. Measurement results of signal strength in UHF band obtained in Idanre Town of Ondo State Nigeria are presented and compared with the results predicted by using the propagation models. A modified COST231-Hata radiowave propagation model was developed and implemented with Matlab GUI (Graphical User Interface) for simulation. The model developed has 93.8% accuracy.

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1. INTRODUCTION

Achieving optimal performance is a paramount concern in wireless networks. During radiowave 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. The ability of determining optimum base-station locations, obtaining suitable data rates and estimating coverage without conducting a series of propagation measurements (which is very expensive and time consuming) can be achieved with empirical propagation models. Empirical propagation models are site specific; therefore selection of a suitable propagation model is the first step in the wireless network design. Okumura-Hata, COST231-Hata and Egli are widely used models for the path loss prediction in areas with high hill in frequency bands below 2 GHz. Another model for the band below 11 GHz has been developed by Stanford University, as an extension of the Hata model [1]-[3].

The COST-231 Hata wireless propagation model was devised as an extension to the Hata-Okumura model and the Hata model in [4]. The COST231-Hata model is designed to be used in the frequency band from 500 MHz to 2000 MHz. It also contains corrections for urban, suburban and rural (flat) environments. [4] reported :"although this models' frequency range is outside that of the measurements, its simplicity and the availability of correction factors has seen it widely used for path loss prediction at this frequency band". The basic equation for path loss in decibels (dB) is stated below as quoted from [4]:

$$PL = 46.3 + 33.9log_{10}(f) - 13.82log_{10}(h_b) - ah_m + \left(44.9 + 6.55log_{10}(h_b)\right)log_{10} + \ c_m \quad (1)$$

$$ah_m = 3.20\left(log_{10}(11.75h_r)\right)^2 - 4.97 \quad (2)$$

Where f is the frequency in MHz, d is the distance between access points (AP) and antennas in km, and h_b is the AP antenna height above ground level in meters. The parameter c_m is defined as 3 dB for urban environments. The parameter ah_m is defined for urban environments in "(2)".

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 behavior 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 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 model is suited for both point-to-point and broadcast transmissions and it is based on extensive empirical measurements taken. The Okumura-Hata model for urban area as stated in [5] is given below:

$$PL = 69.55 + 26.16logf - 13.82logh_B - a(h_m) + [44.9 - 6.55logh_B]logd \quad (3)$$

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

$$a(h_M) = 3.2[\log(11.75h_M)]^2 - 4.97 \quad (4)$$

For specifications, Okumura-Hata has the following range: Carrier frequency: 150MHz ≤ f ≤ 1500MHz, Base station height: 30m ≤ h_B ≤ 200m, mobile station height: 1m ≤ h_M ≤ 10m, distance between mobile station: 1Km ≤ d ≤ 20Km [5].

The Egli model was derived from real-world data on UHF and VHF televisions in several large cities. It predicts the total path loss for a point-to-point link. Typically used for outdoor line-of-sight transmission and it provides the path loss as a single quantity. Egli model is typically suitable for cellular communication scenarios where the transmission has to go over an irregular terrain [6]. However, it does not take into account travel through some vegetative obstruction, such as trees or shrubbery. The model is typically applied to VHF and UHF spectrum transmissions. The Egli model is mathematically expressed as stated in [6] below:

$$L = G_B G_M \left[\frac{h_B h_M}{d^2}\right]^2 \left[\frac{40}{f}\right]^2 \quad (5)$$

Where G_B is the gain of the base station antenna, G_M is the gain of the mobile station antenna, h_B is the height of the base station antenna in meters (m), h_m is the height of the mobile station antenna in metres (m), d is the distance from base station antenna in meters (m) and f is the frequency of transmission in megahertz (MHz) [6]. The limitation of this model is that it predicts the path loss as a whole; it does not subdivide the loss into free space loss and other losses. Our research develops a propagation model for path loss prediction in hilly areas. The following equations show the relationship between received power, path loss and field strength [7]:

$$P_r = \frac{P_t G_t G_r}{PL} \quad (6)$$

$$P_r = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4} \quad (7)$$

$$E\left(\frac{V}{m}\right) = \frac{\sqrt{30 P_t G_t}}{d(LOS)} \quad (8)$$

A modification of the ITU-R P. 1411 model to enhance prediction accuracy in urban environments is presented in [8] as well as measurement results at 217 GHz. In [9] experimental results for a system working at 35 GHz are compared against prediction made by different empirical propagation models. A simple empirical model based on measurements at 53 GHz was proposed in [10]. Since accuracy of the path loss prediction significantly depends on the type of environment, as more experimental data for different environments are available, therefore better model fitting to real conditions can be developed.

2. RESEARCH METHOD

Figure 1 shows the procedures of the research in form of block diagram. Idanre is a neighbouring town to Akure in Ondo State of Nigeria, were used as the study areas. Akure is situated in the tropics at Lat

7.25^0N, Long 5.2^0E, altitude 420m above sea level; an agricultural trade centre with light industries and is minimally influenced by industrial pollutants or aerosols [11]. Idanre is located in the tropics at latitude 9.5^0N, Long 5.5^0E, altitude 1194ft. It is also an agricultural trade centre, majorly surrounded by hills of different heights (400m, 600m and 800m as obtained from Google Earth Software). Transmitter is situated in Akure while the measurements were obtained within Idanre. A series of readings of television broadcast signal strength were carried out in the UHF band (470-862 MHz) using Yagi array antenna coupled through a 50-ohm feeder to the UNAOHM model EP742A field strength meter, during dry period when trees were almost out of leaves. Topographical map was used to determine the line of sight distance between the transmitter and the location of measurement. These measurements allow us to study signal strength degradation as a result of the hills, tree density and humidity.

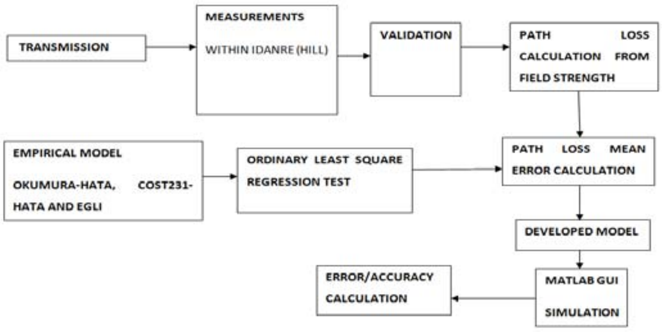

Figure 1. Research Procedure

The research work embraces three models; Okumura-Hata model, COST-Hata model and Egli because their specifications and conditions were met by the transmission under consideration (Idanre) except for the Okumura –Hata whose distance is below the LOS in the experiment. Path losses for the three models were calculated based on the specifications for each LOS value and were compared with the measurement taken. Mean error path loss was calculated for each measurement to determine the best model applicable to Idanre town.

3. RESULTS AND ANALYSIS

Figure 2 shows the performance of the three empirical models while Table 1 shows the comparison of mean path loss error of empirical models with measurements taken in the hilly areas. Path losses were calculated from the signal field strength measured by using Equation 6, 7 and 8.

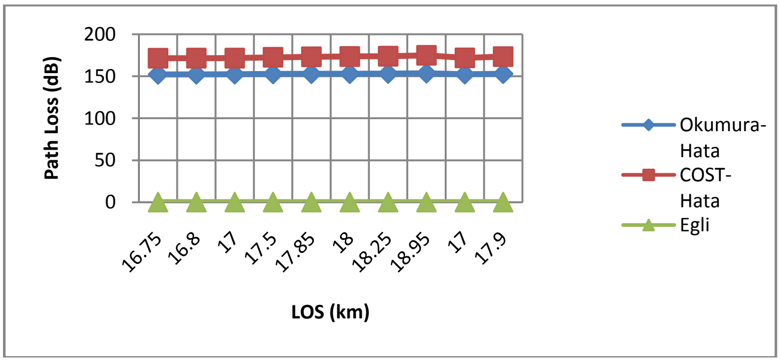

Figure 2. Performance of Empirical Models under consideration

Table 1. Comparison of Mean Path Loss error of Empirical Models with Measurements within Hilly Areas

Model	Okumura-Hata	COST-Hata	Egli
Path Loss Mean Error (dB)	21.85	2.39	174.51

3.1. The Developed Empirical Model

Table 1 shows that Okumura-Hata model under predicted the path loss with 21.85dB, Egli model grossly under predicted the path loss with 174.51dB, but COST-Hata model gave a closer prediction of 2.39dB to the measurement taken within hilly areas, so suitable for path loss prediction in this area. The mean deviation error (of 2.39dB) was added to the original COST-Hata's model presented in Eqn. 1 to generate a path loss model suitable for prediction in the hilly area of Idanre. The modified COST-Hata model developed is presented below:

$$PL = 46.3 + 33.9log_{10}(f) - 13.82log_{10}(h_b) - ah_m + \left(44.9 + 6.55log_{10}(h_b)\right)log_{10}d + c_m + 2.39dB \quad (9)$$

Where:

$$ah_m = 3.20\left(log_{10}(11.75h_r)\right)^2 - 4.97 \quad (10)$$

3.2. Matlab Simulation Results

The model developed is implemented with Matlab GUI (shown in Figure 3). Table 2 shows the results of simulation and the calculated path losses from the measurements.

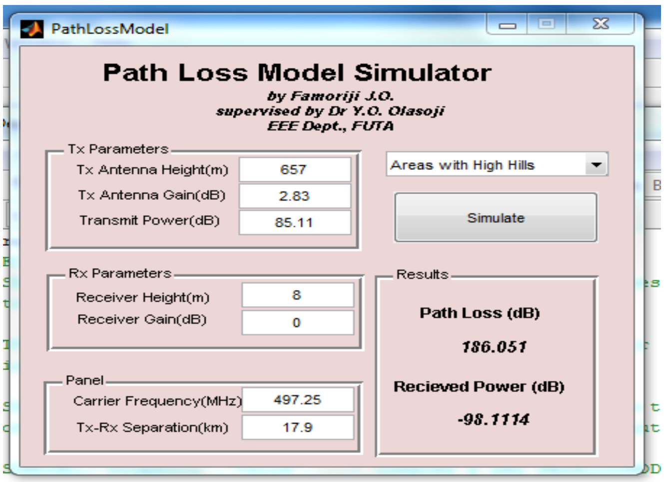

Figure 3. Matlab GUI for the developed model

Table 2. Calculated Path Losses with Simulation Path Losses

LOS (km)	Calculated Path Loss Prediction (dB)	Simulated Path Loss Prediction (dB)
16.75	181.75	184.224
16.80	181.10	184.306
17.00	172.54	184.631
17.50	173.25	185.429
17.85	173.11	185.974
18.00	172.66	186.204
18.25	173.28	186.584
18.95	174.20	187.619
17.00	172.06	184.631
17.90	173.69	186.051

Comparing the two results produces relative error in path loss as calculated from the formula:

$$Relative\ Error = \left|\frac{True\ Value - Approximate\ Value}{True}\right| \quad (11)$$

$$Accuracy = 1 - Relative\ Error \quad (12)$$

The model has relative error of 0.062 and 0.938 accuracy. Therefore the model developed has 93.8% accuracy and it can be deployed in areas with high hill (Idanre).

4. CONCLUSION

Three empirical propagation models: Okumura-Hata model, COST-Hata model, and Egli model were used to predict the path loss in the Idanre (hilly area). However, Okumura-Hata model and Egli model showed large mean path loss error and grossly under predicted the path loss while COST-Hata model showed closer agreement with the measurement result with lower mean path loss error of 2.39dB.The performance of COST-Hata model shows that it is more suitable for use in path loss prediction in Idanre. A modified COST-Hata model was developed for deployment in this area with an accuracy of 93.8%.

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Famoriji John Oluwole received his B. Tech degree from Ladoke Akintola University of Technology, Ogbomoso, Nigeria in Electrical and Electronics Engineering with special interest in wireless communication option, with second class upper division in the year 2009. He bagged Master degree (M. Eng) in Electrical and Electronics Engineering with special interest in wireless channel characterization modelling and Sounder design in 2013 with distinction at Federal University of Technology, Akure, Nigeria. He is presently an academic staff of the Federal University of Technology, Akure, Nigeria.

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