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Development of a Radiowave Propagation Model for Hilly Areas

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Abstract – **Achieving optimal performance is a paramount concern in wireless networks. One of the strategies is to use wireless empirical models to predict wireless link quality factors such as path loss and the received power in any given transmission domain with irregular terrain. Measurement results of signal strength in UHF band obtained in Idanre Town of Ondo State Nigeria were validated against theoretical estimations. Okumura-Hata model, COST231-Hata model and Egli model applicable for path loss prediction in area with high hill were examined. These models predictions were compared with predictions from measurements taken in Idanre to determine the path loss prediction error for each model. Consequently, modified COST231-Hata model was developed for path loss prediction in the hilly areas. The model developed has 6.02% error which made it applicable for hilly areas (Idanre).**

Keyword – **Path Loss, Okumura-Hata Model, COST-Hata Model, and Egli Model.**

I. Introduction

The phenomena that influence radio wave propagation can generally be described by three basic mechanisms: reflection, diffraction, and scattering. The propagation mechanisms need to be studied for the development of propagation prediction models. The wave propagation phenomena depend on the environment and differ whether one considers flat terrain covered with grass, brick houses in a suburban area, or buildings in a modern city. Propagation models are more efficient when only the most dominant phenomena are taken into account. Propagation over hilly terrains is often adversely affected by obstructions such as hilltops. Path loss resulting from such obstruction is termed diffraction loss. Kirchhoff's theory on diffraction has been found useful for predicting path loss along a transmission path containing mountain ridges and similar obstructions [1].

II. Wireless Propagation Models

Radio propagation models are empirical in nature, which means they are developed based on large collections of data collected for the specific scenario. For any model, the collection of data has to be sufficiently large to provide enough likeliness (or enough scope) to all kind of situations that can happen in that specific scenario. Like all empirical models, radio propagation models do not point out the exact behavior of a link, rather, they predict the most likely behavior the link may exhibit under the specified conditions. Different models have been developed to meet the needs of realizing the propagation behavior in different conditions [2].

III. The COST-231 Hata Model for Urban Environment

The COST-231 Hata wireless propagation model was devised as an extension to the Hata-Okumura model and the Hata model as reported by Abhayawardhana et *al.*,[3]. The COST-231Hata 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. [3] also noted that "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 obtained from Abhayawardhana.

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

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

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 equation (2).

IV. 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 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 model is stated in equation 3.

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

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

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

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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 [4].

V. EGLI MODEL

The Egli model is a terrain model for radio frequency propagation. This was first introduced by John Egli in his 1957 paper, 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. 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 equation 5.

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

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) [5]. 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.

Ibrahim and Parsons in [6] proposed a model by analysis of measurement data collected in London at carrier frequencies of 168, 445 and 896MHz. A good fit with the forth-power law was obtained for antenna separation distances up to 10 km for fc (carrier frequency) of 168 and 455MHz. Lee model in [7] was based on experimental results at 900MHz and operates in two modes (point-to-area and point-to-point). Corrections for sloping terrain and path obstructions may be incorporated. Propagation parameters are given for free space, open space (rural), suburban and urban (Philadelphia, Newark and Tokyo). Walfisch–Bertoni model [8, 9] is a theoretical model originally developed to predict the effect of buildings on the median transmission loss. Applicable in suburban and urban areas where buildings are reasonably uniform in height and are built in rows with small separation distance between adjacent buildings. JRC model [10, 11] is a terrain based technique adopted by the Joint Radio Committee (JRC) in the United Kingdom (UK). Terrain path profiles were computed from digital elevation maps (DEMs) with a 0.5 km resolution. Line of sight (LOS) and Fresnel zone clearance are checked and free space and plane earth losses are incorporated together with Epstein–Peterson construction method for up to three knife-edges. For more than three knife-edges the Bullington construction method is used to simplify the problem. In general, the JRC method underestimates the path loss. Blomquist–Ladell model [12] is the same types of losses as in the JRC method are considered. The losses are combined differently to provide smoother transitions between points where the predictions are based on free space and plane earth, respectively.

VI. MEASUREMENT

Neighbouring towns; Akure and Idanre, in Ondo State of Nigeria, were used as the study area. Akure is situated in the tropics at Lat 7.25^{0}N, Long 5.2^{0}E, altitude 420m above sea level; an agricultural trade centre with light industries and is minimally influenced by industrial pollutants or aerosols [13]. Idanre is located in the tropics at latitude 9.5^{0}N, Long 5.5^{0}E, altitude 1194ft. It is also an agricultural trade centre, majorly surrounded by hills (as shown in Figure 1) of different heights (400m, 600m and 800m as obtained from Google Earth Software [14]). 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.

Fig.1. Area View of Idanre Town (Study Area).

The research work embraces three models; Okumura-Hata model, COST-Hata model and Egli model in the equations: 3, 1 and 5, 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.

VII. Results

The measured broadcast signal strength was compared to the theoretical signal field strength calculated using equation 6 as obtained from Odongo, 2008 as shown in Figure 2.

$$E\left(\frac{V}{m}\right) = \frac{\sqrt{30P_tG_t}}{d(LOS)} \quad (6)$$

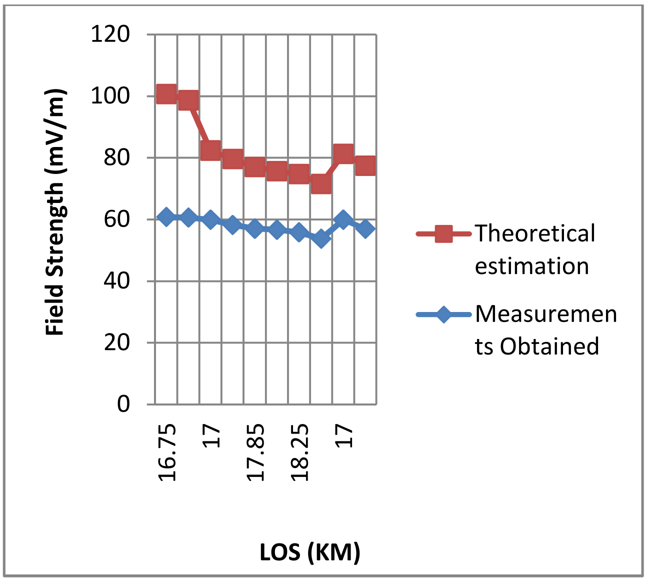

Fig.2. Graph showing the relationships between the Measurements Obtained and the Theoretical Measurements.

A. Path Loss Calculation

Okumura-Hata model, COST-Hata model and Egli model were used to predict the path losses in the area and the results are as shown in Figure 3. The reason behind the choice of these models for path loss prediction lies in the fact that; they form part of existing models which have wide acceptability and are currently in use for mobile radio propagation. And their specifications and conditions were met by the parameters of this research work.

B. Comparison of Empirical Models with Measurements

The corresponding error statistics in terms of the mean prediction error were calculated. The prediction errors were calculated as the mean of the difference between the measurement and prediction for each of the model. Table 1 shows that all the three empirical models considered under predicted the path loss with Okumura-Hata model and most especially Egli's model grossly under predicted the path loss. Consequently, COST-Hata's model is most suitable for path loss prediction in the hilly areas.

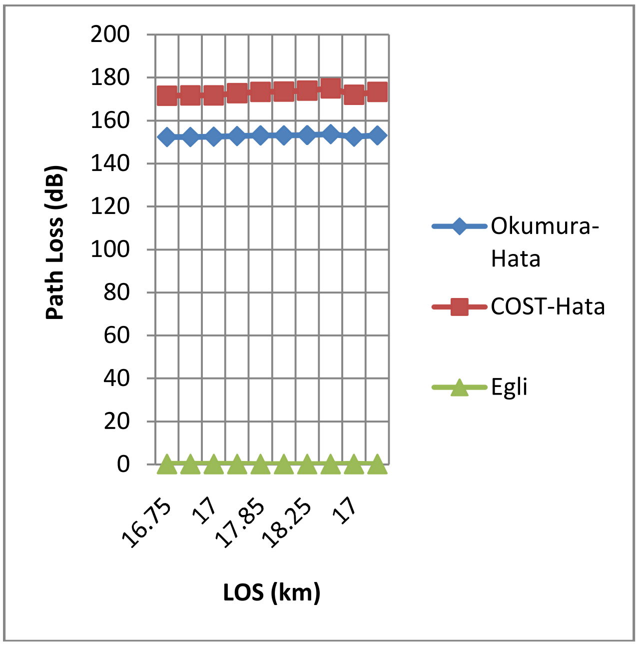

Fig.3. Graph showing the performance of the models in path loss prediction.

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

C. The Developed Model

From Table 1, shows that COST-Hata model gave a closer prediction to the measurement taken within hilly areas, so suitable for path loss prediction in this area. The mean deviation error was added to the original Okumura-Hata model to generate a path loss model suitable for prediction in the areas where there is no high hill. Also, the mean deviation error was added to the original COST-Hata's model to generate a path loss model suitable for prediction in the hilly areas. The original COST-Hata model is presented in equation 1 and the modified or developed model is presented below:

$$PL = 46.3 + 33.9log_{10}(f) - 13.82log_{10}(h_b) - ah_m + \left(44.9 + 6.55log_{10}(h_b)\right)log_{10}d + c_m + 2.39dB \quad (7)$$

where:

$$ah_m = 3.20\left(log_{10}(11.75h_r)\right)^2 - 4.97 \quad (8)$$

The model developed was compared to the path loss calculated from the measurements to determine the error by the use of equation 9.

$$Relative\ Error = \left|\frac{True\ Value - Approximate\ Value}{True}\right| \quad (9)$$

The model has relative error of 0.062 (6.02%). Therefore it can be deployed in areas with high hill (Idanre).

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VIII. Conclusion

In this research work, three empirical propagation models: Okumura-Hata model, COST-Hata model, and Egli model were used to predict the path loss in the 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. COST-Hata model show that it is more suitable for use in path loss prediction in hilly areas. A modified COST-Hata model was developed for deployment in areas with high hill.

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