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# Evaluation and Modelling of UHF Radiowave Propagation in a Forested Environment

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***Abstract-Wireless network optimal performance is a major interest in communication engineering. Radio wave propagation in forested environment has been the interest of much theoretical and experimental research over the years. One of the concepts is to use wireless empirical models to predict wireless link quality of service such as path loss and the received power in a transmission domain with irregular terrain. Measurement results of signal strength in UHF band obtained during the two prominent seasons; raining season (when the trees are in leaf) and dry season (when the trees are relatively out of leaf) Idanre-Apomu axis of Ondo State Nigeria were validated against theoretical estimations. However, using the least squared error fit for several sets of measurement data, an empirical model was developed and incorporated into Matlab graphical user interface (GUI) which can be deployed by wireless communication network providers in wireless networks design for path loss prediction and received power in a forested environment.***

***Keywords*: Forested environment, measurements, empirical model, UHF band, Matlab GUI.**

## I. INTRODUCTION

In 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]. In order to predict, simulate, and design high-performance communication systems, accurate propagation characteristics of the complex environment have to be known. One of the well-known complex environment is the forest. The appearance of the foliage medium in the path of the communication link has significant effects on the quality of the received signal. This is because, discrete scatterers in the forest such as the randomly distributed leaves, twigs, branches and tree trunks can cause attenuation, scattering, diffraction, and absorption of the radiated propagating waves. This will severely constrain the design of communication systems, and therefore has been of interest to researchers for many years [2]. Since the 1960s, a significant amount of work has been done to investigate the radio wave propagation in forest environment. Both analytical and empirical works on the modeling and characterization of the forested channel have been carried out. Some useful and significant results and analysis are reported in [3]. It is reported that the foliage medium can attenuate the propagating radio wave significantly. There are many external factors that will cause the variation in radio wave propagation and even the complete breakdown of communication link in the forest. Analytical [4, 5] and experimental [6, 7] work have been performed. However, there is still a significant amount of research work that needs to be performed, especially for the empirical work [6, 7] which is site-specific, and limits the practical application of the existing research work. In order to build a robust system that operates well in dense foliage environment, the implementation of MIMO and UWB techniques is often examined. These techniques provide a potential solution to the implementation of a reliable wireless sensor network. However, the successful employment of these techniques in forest environment requires detail knowledge of the effects of the foliage medium on the propagating radio waves.

## II. THEORETICAL BACKGROUND

In radio wave propagation, the free space path loss model shown in equation 1 acts as a lower bound for the estimation of path loss [8]

$$L_{free}(dB) = -27.56 + 20log_{10}(f) + 20log_{10}(d)$$

Where f is the frequency in MHz, d is the distance between the isotropic transmit and receive antennas in meters. When the radio wave propagates near the ground with a line of sight (LOS) condition, the path loss can be better described by the plane earth (PE) path loss model [8] rather than the free space model. The plane earth path loss model includes the effect of ground reflection and is given as

$$L_{PE}(dB) = 40log_{10}(d) - 20log_{10}(h_T) - 20log_{10}(h_R)$$

Where d is the distance between the isotropic transmit and receive antenna in meters, $h_T$ and $h_R$ are the transmit and receive antenna heights, respectively, also in meters. In this model, there is an assumption that d is much larger than the $h_T$ and $h_R$.

## III. RADIO WAVE PROPAGATION IN THE FOREST

Radio waves propagating in the forest naturally experiences multiple scattering, diffraction, and absorption of radiation. These different propagation mechanisms, when combined, can result in severe fades in the received signal, and produce an excess vegetation induced loss as compared to terrestrial propagation. These fade effects have to be considered in order to establish a highly reliable near ground communication link. As a supplement to the well-established theoretical studies [9]–[14] of radio wave behavior in the forest environment, some significant experimental works [15] have been

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carried out to gain a practical insight into the forested radio wave propagation. These practical works are summarized below. In 1966, Burrows [15] proposed an algorithm which can be used to predict the path loss in a jungle with antenna height included, and its formulation in dB is expressed as

$$L_{forest}(dB) = 40log_{10}(d) - 20log_{10}(h_T) - 20log_{10}(h_R) - 20log_{10}$$

where $R_0$ is the radiation resistance of the dipole antenna in free space and R is the total antenna resistance in the vicinity of the ground and foliage. $F_s$ is the shadow factor that accounts for the effect of the curvature of the earth, $F_j$ is the factor that accounts for the effect of the jungle, and $h_T$ and $h_R$ are the transmit and receive antenna heights, respectively. The relationship between the antenna height and the path loss in equation 3 is verified in [14] through measurements performed within a tropical jungle with foliage depth of up to 6.4 km in Thailand. In the experiment, horizontally polarized antennas were used at a frequency of 100 MHz, with the transmit antenna height, kept at a constant of 24.2 m, and the receive antenna height, varied from 5–30 m. Later, in 1984, Tewari *et al.* [16] performed an in-depth empirical modeling of antenna height gain on the path loss in the forest, based on the measurements conducted in various tropical rainforest, with foliage depths of up to 4 km in India. Both vertically and horizontally polarized antennas at frequencies from 50 to 800 MHz were used with the transmit antenna height $h_T$, varying from 3.95–16.45 m, and the receive antenna height $h_R$, varying from 1.5–3.5 m above the ground, while maintaining the condition of $h_T.h_R>10$. They then derived the antenna height gain on the path loss in the forest as shown in equation 4

$$G_{AH}(dB) = -12 - 4log_{10}f + 20log_{10}h_T + 20log_{10}h_R$$

Comparatively equations 3 and 4 with the plane earth path loss model in equation 2 shows that, the ground reflected wave has a predominant effect on VHF and UHF radio wave propagation over large foliage depths. This ground reflected wave tends to cancel the direct wave and results in the received field strength (path loss) being proportional (inverse proportional) to the product of the antenna heights for a fixed foliage depth. This reflection effect will be more apparent when the antenna height is low, i.e., near ground.

## IV. AN OVERVIEW OF THE EMPIRICAL FOLIAGE LOSS MODELS

Much attention has been put into the empirical modeling of the foliage induced excess loss at different frequencies and geometries [17]–[20]. The following summarizes these well-known empirical foliage loss models, which will be discussed and evaluated in this study of the near ground forested radio wave propagation. Based on the ray geometry of the propagating wave, the foliage loss modeling and prediction with tree/lines of trees can be classified as, i. horizontal path as shown in Fig. 1; the elevation angle is usually below $3^0$, and both the short foliage path through 1 or 2 trees and long foliage path through many trees (a line or several lines of trees but not form as a forest) can be experienced.

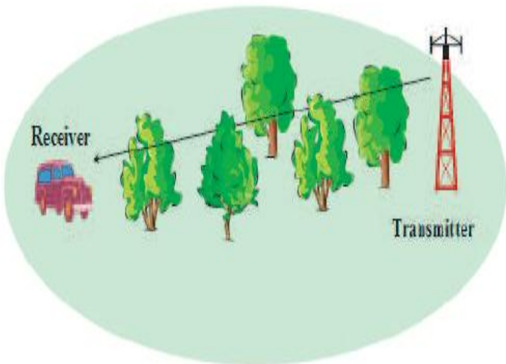


**Fig 1: Schematic Diagram of the Horizontal Foliage Path.**

ii. Slant path as shown in Fig. 2; the elevation angle is usually above $10^0$ and short foliage path through 1 or 2 trees. These result in different methodologies in the modeling of the foliage-induced loss. But horizontal path is the interest of this study.

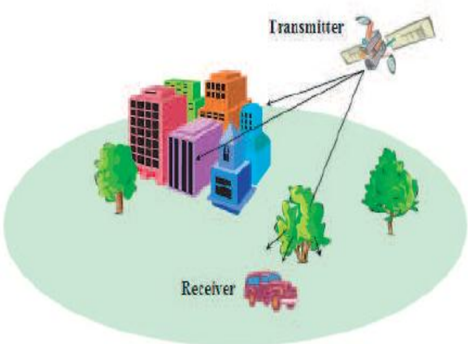


**Fig 2: Schematic Diagram of the Slant Foliage Path**

The proposed empirical foliage loss models for the horizontal propagation path can be classified as the modified exponential decay (MED) models, such as Weissberger model [21], ITU Recommendation (ITU-R) model [22], COST235 model [23] and fitted ITU-R (FITU-R) model [24]; the modified gradient model, such as Maximum attenuation (MA) model [25], Nonzero gradient (NZG) model [25], and Dual Gradient (DG) model [26]. These models are summarized in Table 1 for reference, and the review of comparative studies among these models is the focus of this subsection. The exponential decay model was first proposed by Weiss-berger [21], and its main modified versions include ITU-R model [22], COST235 model [23] and FITU-R model [24] as shown in Table 1. In general, the exponential decay model has the following form,

$$L(dB) = A \times f^B d^C \quad (5)$$

Where *A*, *B*, and *C* are the fitted parameters from a variety of experiments with regression techniques.

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Different parameter values have been proposed depending on the frequency, foliage type, and propagation mechanisms etc. The advantage of the exponential decay model lies in its simplicity, but it has a major drawback that it does not take into account the measurement geometry as indicated by Savage et al. in [27].

**Table 1: Summary of the Main Empirical Foliage Loss Models for the Horizontal Path**

| Model | Expression |
|---|---|
| Weissberger model [21] | $L_w(dB) = \begin{cases} 1.33 \times f^{0.284} d^{0.588} & 14m < d \le 400m \\ 0.45 \times f^{0.284} d & 0m \le d < 14m \end{cases}$ <br> f is the frequency in GHz, and d is the tree depth in meter |
| ITU-R model [22] | $L_{ITU-R}(dB) = 0.2 \times f^{0.3} d^{0.6}$ <br> f is frequency in MHz, and d is the tree depth in meter (d<400m) |
| COST235 model [23] | $L_{COST}(dB) = \begin{cases} 26.6 \times f^{-0.2} d^{0.5} & out-of-leaf \\ 15.6 \times f^{-0.009} d^{0.26} & in-leaf \end{cases}$ <br> f is frequency in MHz and d is the tree depth in meter |
| FITU-R model [24] | $L_{FITU-R}(dB) = \begin{cases} 0.37 \times f^{0.18} d^{0.59} & out-of-leaf \\ 0.39 \times f^{0.39} d^{0.25} & in-leaf \end{cases}$ <br> f is frequency in MHz, and d is the tree depth in meter |
| | |

## V. RESEARCH METHODOLOGY

Idanre-Apomu axis in Ondo State Nigeria is a neighbouring town of Akure where the base station is sited. Being a tropical region, the town has a large share of non-uniformly distributed tall trees. The trees of this dense forest can be categorized into three: The tallest trees are distinguishable through their individuality and often about 45m in height; next to these are trees between 23m and 3.6m tall, whose branches extend to one another thereby forming quasi expansive canopy; while the last and most common species of trees in this area are of hard wood. These trees combine with those in others to form impenetrable forest [28]. Signal field strength measurements were carried out in two seasons: wet season in the month of August and dry season in the month of December using a professional TV signal field strength meter type UNAOHM model EP742A. A Yagi array receiving antennae covering both VHF and UHF frequency bands was used for measurements. This was mounted on support about eight meters above the ground to prevent grounding adverse effect on the reception. The Yagi array was coupled through a 50-ohm feeder to a UNAOHM TV strength meter type EP742A, designed for monitoring and measuring TV broadcast signals (vision and audio), in the VHF/UHF Bands I, III, IV and V. GPS (Global Positioning Satellite (GERMIN model) was used to determine line of sight (LOS) distance between the transmitter with different trees density and the observation points. Equation 6 as obtained from Rappaport 2002 [29] was used to determine theoretical estimations. Plate 1, 2 and 3 are some of the observation points.

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

**Plate 1: Point of Observation**

**Plate 2: Point of Observation**

**Plate 3: Point of observation**

## VI. RESULTS AND DISCUSSION

The UHF broadcast signal strength measured was compared to the theoretical signal field strength calculated using equation 6 and the result is as shown in

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Figure 3 as a plot of signal field strength against line-of-sight distance LOS.

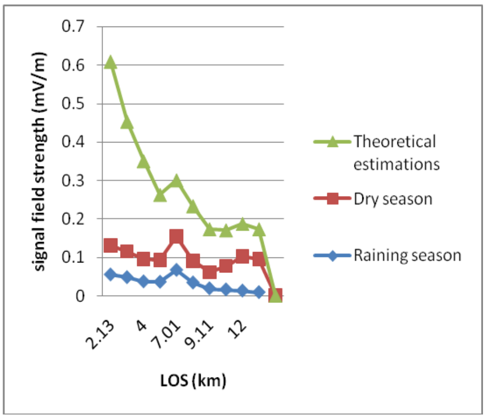


**Fig 3: Graph of Signal Field Strength against Line-Of Sight Distance**

Except for the losses due to distance "inverse square law", the tree density which is not uniformly distributed and with different permittivity is also responsible for the signal degradation. In the neutral atmosphere, delays are induced by refractivity of gases, hydrometeors, and other particulates, depending on their permittivity and concentration, and forward scattering from hydrometeors and other particulates. Changes in temperature, moisture, and pressure in the atmospheric column cause a change in atmospheric density, which in turn causes variations in the intensity of waves in both the vertical and horizontal. Reflection and diffraction caused by obstruction and the effect of tree density with foliages in that area. The presence of vegetation produces a constant loss, independent of distance between communications terminals that are spaced 1 km or more apart. Since the density of foliage and the heights of trees are not uniformly distributed in the area. The change in the humidity of forests correspondingly results in a variation in the electrical constants (conductivity and permittivity) of the forests, and thereby can influence the radio wave propagation. From the study of existing established model, it is found that the foliage induced excess loss in general, can be well represented in equation 5. The three parameters, A, B, and C in equation 5 was empirically determined using the least squared error fit (Matlab) for several sets of measurement data, depending on the type of foliage, where A and B are the two parameters which indicate the frequency dependence and the distance dependence of the foliage induced excess loss in the proposed model. The results of the least squares error fit for both wet and dry seasons are shown in figures 4 and 5 respectively.

From figure 4, the values of A, B and C are 0.6133, 0.8026 and 0.2774 respectively for wet season. Figure 5 gives 4.616, 0.4857 and 0.2774 for A, B and C respectively. The resulted empirical model developed is presented below (in equation 7):

$$PL_{forest} = \begin{cases} 4.1616 \times f^{0.4857} d^{0.273} & out-of-leaf \\ 0.6133 \times f^{0.8026} d^{0.2774} & in-leaf \end{cases} \quad (7)$$

$$P_r = \frac{P_t G_r G_t}{PL} \quad (8)$$

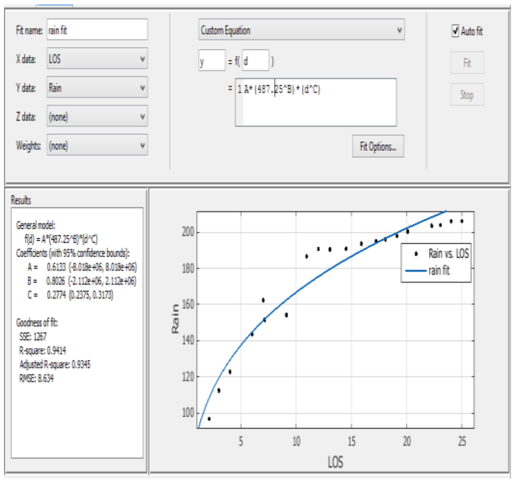

**Fig 4: Least Square Error Fit for Wet Season**

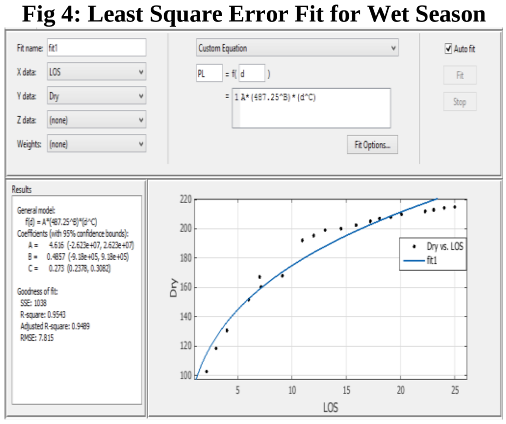

**Fig 5: Least Square Error Fit for Dry Season**

The model developed (equation 7) was merged with equation (8) as quoted from Rappapot (2002) [29] then incorporated into Matlab GUI for simulation of results. The GUI is presented in Figure 6. This can be used for path loss prediction and received power which is a major factor in network planning in any irregular forested terrain.

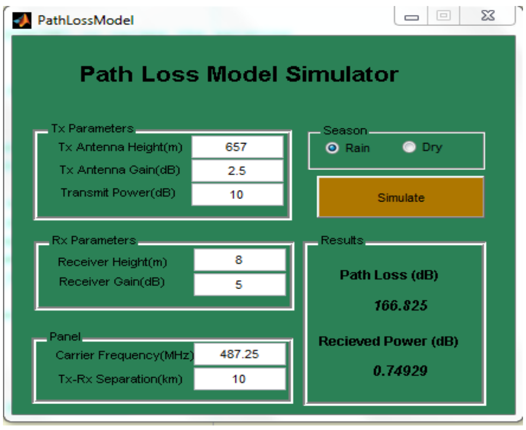


**Fig 6: Matlab GUI for the model developed**

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## VII. CONCLUSION

In this research paper, UHF band radiowave propagation in a forested environment was investigated for the two prominent seasons in Nigeria. It is found that, many factors such as antenna heights; depolarization etc. can affect the radio wave propagation within a forested channel. However, a wireless Matlab based GUI empirical model was developed for path loss prediction and received power which are the major factors in wireless network planning in communication system. Results from this research work are useful for the planning of a reliable communication link in the forest environments.

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