Empirical Modelling of Very High Frequency Radio Propagation Loss in Tropical Forest.

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ABSTRACT

Empirical path loss modelling is presented using Least Square Error Fit regression technique on the measurement data obtained in a 40 km range tropical forest in Oyo State, Nigeria, during the dry and the wet forest conditions, at VHF frequency.

The comparative analysis with: COST235, ITU-R, Fitted ITU-R, Lateral ITU-R, Wiessberger and free space with due considerations to canopy and ground reflection losses ($P_{LCOST235}$, $P_{L(ITU-R+CGR)}$, $P_{L(FITU-R+CGR)}$, $P_{L(W+CGR)}$, $P_{L(LIT-R+CGR)}$ and $P_{L(FS+CGR)}$) models showed that, the proposed empirical models for dry and wet forest conditions, P_{LD} and P_{LW} presented better path loss predictions than the above listed popular models with RMSE values of 6.04 dB and 5.55 dB, respectively. ITU-R and Fitted ITU-R models with due considerations to canopy and ground reflection losses, slightly under-predicted the tropical forest path loss at VHF in dry forest condition with some RMSE values of 9.37 dB and 10.48 dB, respectively as shown in Figure 3 (a). Wiessberger, lateral ITU-R and free space with considerations to canopy and ground reflection losses: greatly under- predicted the tropical forest path loss with RMSE values of 16.68 dB, 18.75 dB, and 19.56 dB, respectively, as presented in Figure 3 (a).

However, when tropical forest is wet, ITU-R and Fitted ITU-R, Lateral ITU-R, Wiessberger and free space with due considerations to canopy and ground reflection losses models greatly under-predicted the tropical forest path loss with RMSE values of 16.91 dB, 21.93 dB, 24.16, and 30.34 dB respectively, while, COST235 model greatly over-predicted the path loss through tropical dry and wet forest environments, respectively.

(Keywords: high frequency, radio propagation, Lateral ITU-R, Wiessberger)

INTRODUCTION

VHF radio wave propagation through the forest environment has often been affected by the futures and elements of the physical forest (namely: range, type, dryness/wetness of the forest, etc.) in the path of communication link. The forest medium does not only affect the quality of services for a radio communication system, but also, could lead to disruption in communication [1; 2; 9]. The cumulative effect of the forest medium on the propagated radio wave leads to path loss, which is the difference in decibel between the transmitted radio wave and the received signal.

Although several studies have been carried out using COST235, Weissberger, ITU-R, LITU-R and FITU-R in Europe, America and Asia over short terrestrial paths, mixed sea and land paths, the prediction of radio wave propagation is not adequately covered. The inadequacy, could further be attributed to lack of suitably collated experimental data on forest path loss [2; 6], particularly in the long tropical forest at VHF.

Some of the useful models expressed in Table 1 are: The free space path loss reported by [5] as expressed in Equation 1 forms the basis for computing forest path loss at near field. Weissberger's modified exponential decay model in Equation 2 which was developed by [15] using measurement data collected at a frequency range of 230 MHz to 95 GHz. It finds application where a ray path is blocked by dense, dry, in-leaf trees found in temperate climates.

COST235, which was proposed based on measurements made in millimeter wave frequency band of (9.6-57.6 GHz) through a forest range of less than 200 m in two seasons in Europe was reported by [11,12,13] and It is given by the expression in Equation 3 .

ITU-R model in Equation 4, which was developed from measurements taken at frequency range of 200 MHz to 95 GHz in Asia is proposed for situations where the forest range is less than 400 m, so that the greater percentage of the signal propagates through the trees [3].

The work of Al-Nuaimi and Stephens (1998) who found out the fitted ITU-R model in Equation 5 using least square error fit on several sets of measurement data collected during in-leaf and out- of- leaf states, at frequency band of 11.2 and 20 GHz was reported by [16]. The model is limited to a forest range of 6.4 km only. [8], used experimental method to examine near ground radio wave propagation in a tropical plantation in Malaysia at VHF and UHF bands to obtain the lateral ITU-R model expressed in Equation 6.

Later, Meng, in [11] used the method of geometrical ray tracing technique over a short ranged propagation in palm plantation in Asia to obtain a model that integrated the foliage-imposed effect and the effect from the ground reflection and tree canopy reflection at UHF for ground and possible tree canopy reflection as shown in Equations 7 and 8. [2] presented, the effects of ground and air temperature on VHF radio wave propagation in a 12 km forest range environment located in South Western Nigeria in which three mathematical models were produced. These models showed the relationships between path loss and each of the following: ground temperature, air temperature and relative humidity as shown in Equations: 4, 5, and 6. However, the effects of dry and wet forests on radio wave propagation at VHF are lacking in the literature thus, there is a need for experimental modelling of VHF radio path loss in dry and wet tropical forest environments respectively. In this paper the effects of long tropical forest is investigated and new measurement models developed and evaluated experimentally as shown in the succeeding section.

MATERIALS AND METHODS

In this section the measurement site and the systematic step by step approach required in the experiment are explained.

The Experimental Site

The experimental measurements were conducted as a case study in a 40 km tropical forest environment that is located in Oyo State, in Southwestern Nigeria (Figure 1). The forest terrain is not flat but undulating with valleys and consists of different tree types arranged in tiers.

The tree types are: Mahogany, Iroko, Teak, Mango, Cashew, Cocoa and Palm trees just to list a few. The tree types are irregularly spaced with separations ranging from 3 m to 7.5 m,. The upper layer of the tropical forest under consideration consists of trees with average height of 30 m and main trunk diameter of 0.8 m. While the middle layer of the rain forest considered, has trees of average height of 15.45 m and main trunk diameter of 1.08 m with leaves that form a dense canopy.

The undergrowth of scrubs and saplings is relatively sparse and have heights of 1 m to 2 m. Plate 1 shows the various tree types of various sizes present in the forest. In this tropical forest the period between rains is very short, such that, the leaves do not dry out completely but remain ever green. The dry and wet weather conditions of the forest affect the electrical properties of the forest and consequently impact on the propagation of electromagnetic waves through it.

Plate 1: Different tree types of various sizes present in the long tropical forest in Southwestern Nigeria.

Measurement Setup

This work is based on experimental measurement technique. The Oyo State Broadcasting Cooperation, Ajilete 92.1 FM was employed, as a case study, as a transmitting station. The frequency and power of transmission are 92.1 MHz and 2.5 kW, respectively. The transmitting antenna height is 130 m.

Plate 2 (a), shows the transmitter within the long tropical forest environment. The receiver unit consisting of a 0.5 m, 50 Ω standard dipole antenna coupled to a (GSP 810) Spectrum analyzer was used to measure the power received. In addition, the receiver unit had a power supply unit consisting of a deep cycle battery and an inverter to provide the necessary power for the spectrum analyzer. This receiver unit was mounted on the ground as shown in Plates 2 (b).

(a)

(b)

Plate 2 (a): The Transmitter and **(b)** The Receiver used in the Measurement.

Table 1: Presents the Models for other Researchers on Radio wave Propagation in Forest Environments.

Name	Models	Equation Number
Free Space	P_{LFS} (dB) = $32.44 + 20\log_{10} f + 20\log_{10} d$	(1)
Weissberger	$L_W = \begin{cases} 1.33 f^{0.284} d^{0.588} & 14 < d \leq 400\ m \\ 0.45 f^{0.284} d & d \leq 14\ m \end{cases}$	(2)
COST235	$L_{COST} = \begin{cases} 26.6 f^{-0.2} d^{0.5} & out\ of\ leaf \\ 15.6 f^{-0.009} d^{0.26} & in\ leaf \end{cases}$	(3)
ITU-R	$L_{ITU-R} = 0.2 f^{0.3} d^{0.6}$ at UHF and d<400m	(4)
FITU-R	$L_{FITU-R} = \begin{cases} 0.37 f^{0.184} d^{0.59} & out\ of\ leaf \\ 0.39 f^{0.39} d^{0.25} & in\ leaf \end{cases}$	(5)
LLITU-R	$L_{LITU-R} = 0.488 f^{0.43} d^{0.13}$	(6)
Meng et al.	$P_{L(FS+GR)} = P_{LFS} + 10 log_{10}(\Delta \emptyset)$	(7)
	$P_{L(FS+CGR)} = P_{LFS} + 10 log_{10}(1 + 2\Delta\emptyset_1 \Delta\emptyset_2)$	(8)
Alade	Pl=21.8ln(GT)+196	(9)
	Pl= -7.5ln(AT)+150	(10)
	Pl=2.319ln(RH)+115	(11)

Source: [2, 3, 5, 8, 11,12,13,15, 16]

In Table 1, where *f,* is the frequency of the transmitted signal, *d* is the separation distance between the transmitter and the receiver. AT and GT are the atmospheric and ground temperatures, while and RH is the relative humidity of the forest. For $\Delta\O_1$; $h_{tx} = h_r = h_2$ while, for $\Delta\O_2$; $h_{tx} = h_r = h_1$, where, h_1 and h_2 are the effective heights of the receiver and the difference in height between the trunk and the receiver in meters which are often substituted for their respective effective heights, h_{e1} and h_{e2}.

The effective heights could be determined using Equations 12 and 13, respectively:

$$h_{e1} = \sqrt{{h_1}^2 + {h_{f0}}^2} \quad \textbf{(12)}$$

$$h_{e2} = \sqrt{{h_2}^2 + {h_{f0}}^2} \quad \textbf{(13)}$$

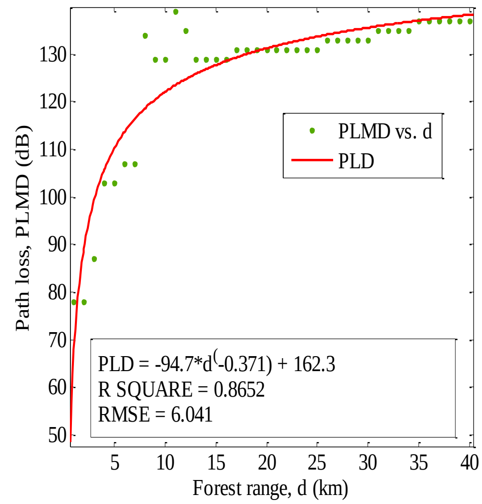
RESULTS AND DISCUSSION

This section presents the results of the analysis of the data collected using, least square fit regression technique and comparison with six popular model combinations with canopy and ground reflections, with the aid of MATLAB 7.12.0 (R2011a) and Graphpad Prism 5.01.

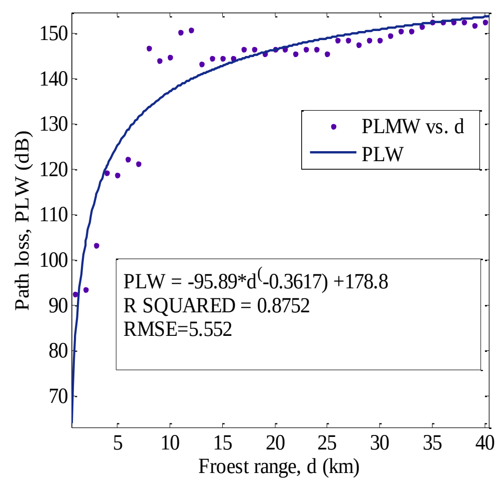
Figures 1 (a) and (b) present the results of the least square fit regressions for path loss data obtained in dry and wet forest conditions which gave rise to empirical models for dry and wet forest environments respectively, using MATLAB 7.12.0 (R2011a). The proposed empirical path loss models are expressed in Equations 14 and 15, respectively.

$$\mathrm{PLD} = -94.7d^{-0.3716} + 162.3 \quad \textbf{(14)}$$

$$\mathrm{PLW} = -95.89d^{-0.3617} + 178.8 \quad \textbf{(15)}$$

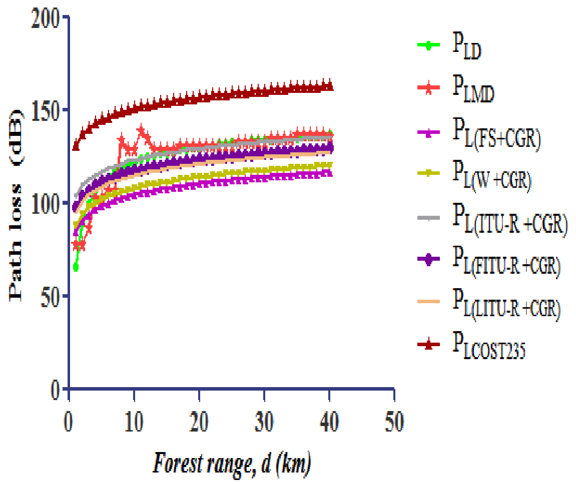


(a)

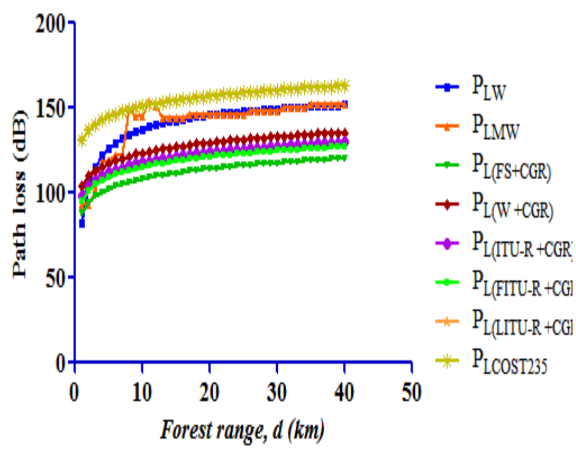


(b)

Figure 1: The Least Square Fit Regression Models for the Measured Path Losses through the **(a)** Dry and **(b)** Wet Environments.

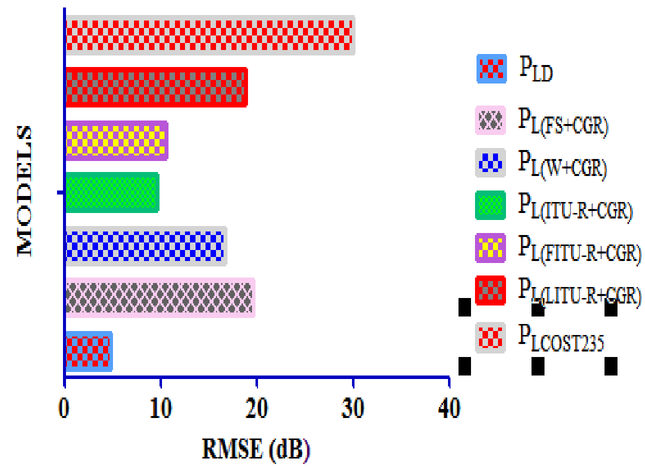


(a)

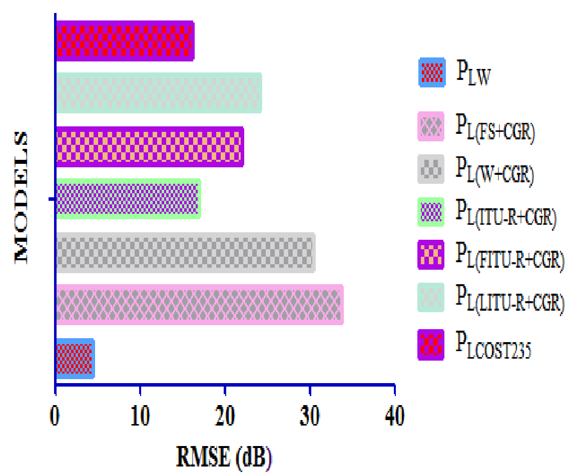


(b)

Figure 2: Comparative Plot of the Empirical Path loss models, COST 235, Models Combination of: Free Space, Wiessberger, ITU-R, Fitted ITU-R and Lateral ITU-R with Canopy and Ground Reflections with Reference to the Measurement Data Obtained in **(a)** Dry and **(b)** Wet Forest Conditions, respectively, using MATLAB 7.12.0 (R2011a).



(a)



(b)

Figure 3: The Separated Bar Graph of the RMSE values for the popular path loss models namely, COST 235, models combination of: Free Space, Wiessberger, ITU-R, Fitted ITU-R and Lateral ITU-R with Canopy and Ground Reflections and the Proposed Forest Path Loss Models with the Aid of Graphpad Prism 5.01 in **(a)** Dry Forest and **(b)** Wet Forest.

The performance of the proposed empirical models were tested by method of comparison with other existing models using, RMSE. Figures 2 (a) and (b) provide the plot of the measured, proposed empirical and other existing path loss models as a function of forest depth.

Figures 2 (a) and (b) show the comparison of the proposed experimental path loss models for dry and wet forest environments (P_{LD} and P_{LW} respectively) with popular path loss models namely, COST 235, models combination of: Free Space, Wiessberger, ITU-R, Fitted ITU-R and Lateral ITU-R with canopy and ground reflections with special references to the measurement data obtained in dry and wet forest conditions respectively, using MATLAB 7.12.0 (R2011a).

In Figure 2(a) the path loss for the proposed empirical model for dry forest environment, P_{LD}, increases gradually with increase in forest depth. Thus, it follows the trend of other existing path loss models but with different gradient. It is further observed that, the proposed empirical path loss model, for the dry forest environment, (P_{LD}) gave an acceptable path loss prediction with a RMSE of 6.04 dB which is within the range of acceptable RMSE of 6 dB – 8dB stated by [3; 4]. However, ITU-R and fitted ITU-R models with due considerations to canopy and ground reflection losses, $P_{L(ITU\text{-}R+CGR)}$ and $P_{L(FITU\text{-}R+CGR)}$, slightly under-predicted the tropical forest path loss at VHF in dry condition with some unacceptable RMSE values of 9.37 dB, 10.48 dB ,respectively.

Wiessberger, lateral ITU-R and free space with considerations to canopy and ground reflection losses: $P_{L(W+CGR)}$, $P_{L(LIT\text{-}R+CGR)}$, $P_{L(FS+CGR)}$ models greatly under- predicted the tropical forest path loss with RMSE values of 16.68 dB, 18.75 dB, 19.56 dB respectively. The underestimation is due to the fact they are meant for short forest ranges of 200 m – 5 km and forest environments. Conversely, COST235, $P_{L(COST235}$ over predicted the path loss with a value of 29.85 dB. This overestimation of the path loss by $P_{L\ COST235}$ could be attributed to its optimization from a measurement data at millimeter wave (up to 57.6 GHz), which led an unacceptable prediction value of the path loss at VHF. It is inferred that the proposed empirical model gave the best path loss prediction in the dry tropical forest environment while COST235 provided worst prediction.

Figure 2 (b) shows that the path loss for the proposed empirical model for wet forest environment, P_{LW}, increases gradually with increase in forest depth. Thus, it follows the trend of other existing path loss models but with different gradient. It is further observed that, the proposed empirical path loss model, for the wet forest environment, (P_{LD}) gave an acceptable path loss prediction with a RMSE of 5.55 dB which is within the range of acceptable RMSE of 6 dB – 8 dB stated by Al-Salameh, (2014) and Faruk el al ,(2013). However, ITU-R and Fitted ITU-R, Lateral ITU-R, Wiessberger and free space with due considerations to canopy and ground reflection losses ($P_{L(ITU\text{-}R+CGR)}$, $P_{L(FITU\text{-}R+CGR)}$, $P_{L(W+CGR)}$, $P_{L(LIT\text{-}R+CGR)}$), models greatly under- predicted the tropical forest path loss with unacceptable RMSE values of 16.91 dB, 21.93 dB, 24.16, and 30.34 dB, respectively, as presented in Figure 3 (b).

The under-estimation is due to the fact that they are meant for short forest ranges of 200 m – 5 km without due consideration to the wetness of the forest environment. Conversely, COST235, $P_{L(COST235}$ only showed good prediction to the path loss in wet forest environment at 8 km and 12 km respectively, while beyond 12 km it greatly over predicted the path loss with a RMSE value of 16.19 dB. This overestimation of the path loss by $P_{L\ COST235}$ could be attributed to its optimization from a measurement data at millimeter wave (up to 57.6 GHz) without due consideration to the wet condition of the forest. It is inferred that, the proposed empirical path loss model for wet forest gave the best path loss prediction, while, none of the popular forest path loss models could give a good prediction at long forest range of 40 km under wet condition. It is to be noted that the free space model with consideration to canopy and ground reflections presented the worst performance when the forest is wet and long.

CONCLUSION

This paper presents the empirical modelling of path loss using measurement data obtained in a tropical forest in a forest in Oyo State, Southwestern Nigeria, during the dry and wet conditions, at a frequency of 92.1 MHz.

The comparative analysis with: COST235, ITU-R and Fitted ITU-R, Lateral ITU-R, Wiessberger and free space with due considerations to canopy and ground reflection losses ($P_{LCOST235}$, $P_{L(ITU-R+CGR)}$, $P_{L(FITU-R+CGR)}$, $P_{L(W+CGR)}$, $P_{L(LIT-R+CGR)}$ and $P_{L(FS+CGR)}$) models showed that when the forest is dry, the proposed empirical model for dry forest condition P_{LD} presented a better path loss prediction than the above listed models combination. However, ITU-R and Fitted ITU-R models with due considerations to canopy and ground reflection losses, slightly under-predicted the tropical forest path loss at VHF in dry forest condition with some RMSE values of 1.37 dB and 2.48 dB lower than the max acceptable RMSE, respectively.

Wiessberger, lateral ITU-R and free space with considerations to canopy and ground reflection losses: greatly under- predicted the tropical forest path loss with RMSE values of 16.68 dB, 18.75 dB, 19.56 dB respectively. Conversely, COST235, greatly over predicted the path loss with a RMSE of 29.85 dB. In addition, when tropical forest is wet, the proposed empirical path loss model, for the wet forest environment, (P_{LD}) showed that the proposed empirical path loss model presented a better prediction than the others with a RMSE of 5.55 dB. However, ITU-R and Fitted ITU-R, Lateral ITU-R, Wiessberger and free space with due considerations to canopy and ground reflection losses models greatly under- predicted the tropical forest path loss with RMSE values of 16.91 dB, 21.93 dB, 24.16, and 30.34 dB respectively.

The great under-estimation is due their formulation for short forest ranges of 200 m – 5 km without due consideration to the wetness of the forest environment. Furthermore, COST235 greatly over- predicted the path loss through tropical forest at VHF frequency. The over-prediction of path loss could be attributed to its optimization from a measurement data at millimeter wave (up to 57.6 GHz) without consideration to the dry and wet conditions of the forest. It is inferred that the proposed empirical model gave the best path loss predictions in the dry and wet tropical forest environments respectively, while COST235 and $P_{L(FS+CGR)}$) provided worst predictions in dry and wet forest environments, respectively. However, more research is needed to ascertain the excess path loss due to dry and wet vegetations.

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