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ORIGINAL RESEARCH ARTICLE

EXPERIMENTAL VALIDATION OF A BEST-FIT MODEL FOR PREDICTING RADIO WAVE PROPAGATION THROUGH VEGETATION

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ABSTRACT

In this study, a model for predicting radio wave propagation through vegetation at 900 and 1800MHz is proposed. An integrated model comprising of ground and foliage induced effects is evaluated with respect to experimental data obtained through drive test in and around a vegetation environment, using Test Mobile System (TEMS) investigation tools. Measured path loss was compared against predictions made by four empirical vegetation models. Results indicate that the European Cooperation in Science and Technology (COST) 235 model gives the best prediction and compare favourably with measured path loss in areas where vegetation is dominant. Although, this model showed the most accurate prediction of foliage loss in the investigated area, there is a need to modify it for enhanced signal prediction. The modified model was found to predict the measured path loss with Root Mean Square Errors (RMSEs) of 6.98dB and 10.00dB at 900 and 1800MHz, respectively. Overall, findings revealed that these RMSEs are within the acceptable range of up to 15.00dB, for quality signal prediction in related environments

1.0 Introduction

The importance of vegetation in maintaining the stability of the ecosystem and conserving the ozone layer from further depletion cannot be overemphasized. However, when vegetation, such as a thick forest is located along the path of a radio signal, network performance is usually affected by strong multi-scattering attenuation, diffraction and absorption of propagating electromagnetic waves, and this imposes excess signal attenuation in addition to loss due to free space propagation (Koh, *et al.,* 1999; Usman and Adefalu, 2010; Ndzi, *et al.,* 2012). Since actual vegetation environments are too complex to accurately describe, empirical models have been developed using results of experimental data obtained through drive test at various frequency bands for such environments.

In the rain forest zone of Nigeria, a vast part of the land is predominantly covered with dense vegetation, and radio wave attenuation would occur due to the presence of heavy foliage (Rahman *et al.,* 2013). In addition, busy highways for road travels are constructed through vegetation environments where travelers often experience poor quality of service, frequent call drops, and poor inter-connectivity (Mishra, 2007; Ajose and Imoize, 2013).

Al Salameh (2019) reported a recent study that is quite close to the results reported in this paper. The author presents a novel propagation model, which find a very useful application in the evaluation of fading characteristics of wireless communication signals in a forest environment. The model takes into account among other features, the rainfall and snowfall effects, and makes it easy to derive or estimate pathloss at varying frequencies in the VHF/UHF bands, which are currently in use by cognitive radios. In the study, the author modeled the vegetative environment such that it comprises of five distinct material layers; scrubs, soil, trunk of trees, small plants under the trees, foliage of trees, and free space, and the least square algorithm was adopted for the optimization of the model parameters. In order to validate the model, the author compared its performance characteristics with measured data taken in the Jordanian environment, and the model was found to be in good agreement with real world measurement results. Different from our work, this study did not consider the case where ground and foliage induced effects are included in the model for application in areas where vegetation is evergreen.

Propagation models are derived from experimental data for different areas under well-defined environmental conditions, and they are not globally applied to all environments due to varying terrain features from one environment to another (Chebil, *et al.,* 2013; Ayekomilogbon, *et al.,* 2013). In order to effectively apply models designed for a particular environment to another environment, the parameters of a well-established model could be fine-tuned to suit the environment of interest (Adegoke and Siddle, 2012; Ndzi, *et al.,* 2012; Ibhaze *et al.,* 2017). Therefore, this study presents a model for predicting radio wave propagation through vegetation at 900 and 1800MHz in South - Western Nigeria.

Field measurements were taken from selected base stations located in and around a vegetation terrain in the neighborhood of Lagos and Ondo States, Nigeria, using Test Mobile System (TEMS) investigation tools and a Global Positioning System (GPS) for accurate mobile location tracking. Propagation measurements with forest depth included were compared against predictions made by the Weissberger's modified exponential decay model (Weissberger, 1982), Radio-communication sector of International Telecommunication Union (ITU-R) vegetation model (Meng *et al.,* 2009; CCIR, 1986; ITU, 2012), COST 235 model (Hall, 1996), Fitted ITU-R (FITU-R) model (Al-Nuaimi and Stephens, 1998), each model combined with the Plane Earth (PE) model (Li *et al.,* 1999a).

In order to determine the model, which best predicts the path loss of measured data in the investigated environment, the Root Mean Square Error (RMSE) was applied, and a modification of the best-fit model is proposed. In practice, foliage medium can greatly influence the quality of the received signal, especially when the receiver is located in a dense forest area (Al-Nuaimi and Stephens 1998; Meng *et al.,* 2009; Meng *et al.,* 2010).

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As the number of mobile users increases, network operators need to increase system capacity and this requires the location of transmission antennas at heights relatively higher than the surrounding trees and buildings (De Jong and Herben, 2004).

Notably, limited knowledge of pathloss modeling could pose great difficulties in implementing theoretical models, though these models can predict signal attenuation with reasonable accuracy. The empirical foliage loss models, which are derived from specific measurements data, rarely apply to all environments because of complex terrain features varying from one environment to another (Rappaport, 2002; Saunders and Aragón-Zavala, 2007; Mishra, 2007; Joshi, 2012; Chebil *et al.,* 2013; Ayekomilogbon *et al.,* 2013). Therefore, the need for an appropriate model for predicting path loss especially for busy highways crossing dense vegetation terrain at 900 and 1800MHz becomes imperative.

1.1 Problem Statement

There is currently a huge demand for propagation models for planning radio networks in forested environments, since it is quite difficult to avoid vegetation for most wireless outdoor channels, especially for military communications. However, radio wave propagation through dense foliage is unavoidably demanding and highly expensive due to the random characteristics of the channel. Unfortunately, the behaviour of radio signals propagating through tropical vegetation has not been given adequate treatment in the available literature. Different from existing reports (Tharek and Zahri, 1992; Cavalcante *et al.,* 1999; Koh *et al.,* 1999; Blaunstein *et al.,* 2003; Meng *et al.,* 2009; Meng *et al.,* 2010; Al Salameh, 2019), this paper focuses on characterizing a typical vegetation terrain, especially as it applies to a dense vegetation environment, with a view to determining the best fit propagation model for the environment. The specific objectives are to investigate the behaviour of radio waves in the vegetation environment via measurements campaign, compare measured pathloss with well-known empirical propagation models, select the best-fit empirical model, and demonstrate a modification of the best fit model for quality signal prediction in related vegetation environments.

1.2 Types of propagation models

Propagation models are used mainly for network planning, more specifically for carrying out feasibility studies and during initial wireless network deployment (Ajose and Imoize, 2013). In addition, these models are key to performing interference studies and management of available radio resources, as mobile network deployment proceeds (Sarkar *et al.,* 2003). These models are broadly classified into three categories namely; deterministic, empirical and statistical models.

1.2.1 Deterministic models

These models utilize Maxwell's equations alongside with reflection and diffraction laws. These models use detailed information from the environment to give near precise prediction of the desired radio signal. However, these models require very rigorous mathematical operations and they are often applied to simplified environments (Joshi, 2012).

1.2.2 Empirical models

Unlike the deterministic models, the empirical models make use of a set of equations obtained from measurements campaign. The accuracy of these models is dependent on the location, frequency bands, range, and clutter characteristics of the environment (Milanović *et al.,* 2010).

1.2.3 Statistical models

These models rely on probability analysis by finding the probability density function as a function of various parameters. These models utilize measured and mean losses for different types of radio links, and are generally used for cellular network planning, estimating the coverage of mobile radio links, and planning for broadcast coverage (Milanović *et al.,* 2010).

1.3 Propagation models used for comparison

1.3.1 Free space propagation

Ideally, there is no obstacle in the path of radio wave propagation in free space. This implies a direct line of sight between the transmitter and the receiver, and this is very difficult to achieve in real life scenario. Rappaport (2002) and Saunders and Aragón-Zavala (2007) give the free space propagation loss as in Eq. (1).

$$P_{FS}(dB) = 32.4 + 20log_{10}(d) + 20log_{10}(f) \quad (1)$$

where *f = frequency (MHz)* and *d = distance (km)*

1.3.2 Weissberger's Modified Exponential Decay (MED) model

The modified exponential decay model as proposed by Weissberger (1982) is given in Eq. (2).

$$L_W(dB) = \begin{cases} 1.33f^{0.284}d_f^{0.588} & 14 < d_{f\leq} \leq 400m \\ 0.45f^{0.284}d_f & 0 \leq d_f < 14m \end{cases} \quad (2)$$

where L_W = Weissberger predicted loss; *f* = frequency in GHz; d_f = depth of the trees in meters.

1.3.3 Early International Telecommunication Union (ITU) model

The early ITU model proposed by the international telecommunication union (ITU) mainly for foliage attenuation (CCIR, 1986; ITU, 2012) is given in Eq. (3).

$$L_{ITU}(dB) = 0.2xf^{0.3}d_f^{0.6} \quad (3)$$

where L_{ITU} *(dB)* = Early ITU predicted loss, *f* = frequency in GHz and d_f = depth of the trees in meters.

1.3.4 International Telecommunication Union Radio (ITU-R) model

Al-Nuaimi and Stephens (1998) presented a modified version of the ITU-R model to cater for both in-leaf and out-of-leaf cases at 11.2GHz. Raheemah *et al.,* (2016) reported a further modification to the parametric equation for the ITU-R model as given in Eq. (4).

$$L_{ITU-R}(dB) = 0.2xf^{0.3}d^{0.6} \quad (4)$$

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1.3.5 COST 235 model

The COST 235 model (COST 235, 1996) is a proceed of the COST project involving extensive field measurements in the millimeter wave frequencies. The measurements were carried out when the trees are in-leaf and out-of-leaf (Phaiboon and Seesaiprai, 2012). The model can be applied to frequencies between 200MHz to 95GHz. The parametric equations for this model are given in Eq. (5).

$$L_{COST}(dB) = \begin{cases} 26.6f^{0.2}d^{0.5} & out-of-leaf \\ 15.6f^{-0.009}d^{0.26} & in-leaf \end{cases} \quad (5)$$

1.3.6 Fitted ITU-R (FITU-R) model

The foliage induced path loss can be represented by Eq. (6).

$$L(dB) = Axf^{b}d^{c} \quad (6)$$

where *A, f* and *d* are variables of fitted values derived from field measurements. The three parameters *A*, *b* and *c* can be obtained using empirical methods, depending on the type of foliage, where *b* and *c* are the two parameters that show the frequency and distance dependence of the foliage induced excess loss in the specified model. Al-Nuaimi and Stephens (1998) earlier performed an optimization of these three parameters using the least square error fit for several sets of measured data to derive the fitted ITU-R (FITU-R) model, and in a similar fashion, Meng *et al.,* (2009) extended the application of this model with validity at 11.2GHz to 20GHz as given Eq. (7).

$$L_{FITU-R}(dB) = \begin{cases} 0.37f^{0.18}d^{0.39} & out-of-leaf \\ 0.39f^{0.39}d^{0.25} & in-leaf \end{cases} \quad (7)$$

1.3.7 Plane earth model

As compared to the through-vegetation loss models proposed by (Tharek and Zahri, 1992; Cavalcante, *et al.,* 1999; Meng, *et al.,* 2009) for radio wave propagation in forests, other propagating components such as ground reflected waves and lateral waves etc., are desirable as reported in (Li, *et al.,* 1999b; Wang and Sarabandi, 2007; Michael, 2013). When the radio wave propagates near the ground, the plane earth (PE) model can better describe the path loss. The plane earth model includes the effect of ground reflection and it is modeled as given in Eq. (8).

$$L_{PE}(dB) = 40log_{10}(d) - 20log_{10}(h_t) - 20log_{10}(h_r) \quad (8)$$

where *d* is the distance between the isotropic transmit and receive antennas in meters; h_t and h_r are transmit and receive antenna heights in meters, respectively.

1.4 Pathloss and root mean square error

1.4.1 Pathloss of measured data

The path loss of measured data $PL_m(dB)$ is given by (Rappaport, 2002; Saunders and Aragón-Zavala, 2007; Mishra, 2007) in Eq. (9).

Measured path loss was obtained by substituting the computed values of the effective isotropically radiated power $EIRP_t\ (dBm)$ and the values of $P_r(dBm)$ into Eq. (9).

$$P_{Lm}(dB) = EIRP_t - P_r(dBm) \quad (9)$$

where $EIRP_t$ = *Effective isotropic radiated power (dBm) and* P_r = *Mean power received in dBm*.

The effective isotropic received power *EIRP$_t$ (dBm)* is given in Eq. (10).

$$EIRP_t = P_{BTS} + G_{BTS} - G_{MS} - L_{FC} - L_{AB} - L_{CF} \quad (10)$$

P_{BTS} = *Transmitter power (dBm),* G_{BTS} = *Transmitter Antenna Gain (dBi),* G_{MS} = *Receiver Antenna Gain (dBi),* L_{FC} = *Feeder Cable and Connector Loss (dB),* L_{AB} = *Antenna Body Loss (dB),*

L_{CF} = *Combiner and Filter Loss (dB).*

$P_{BTS} = [30 + 10log_{10}40] = 46dBm$

$G_{BTS} = 16dBd = [16 + 2.15] = 18.15dBi$

$G_{MS} = 0dBi, L_{FC} = 2dB, L_{AB} = 2dB, L_{CF} = 3.5dB$

Substituting these values into Eq. (9) gives;

$$EIRP_t = 46 + 18.15 - 2 - 2 - 3.5 = 56.7dBm$$

1.4.2 Root mean square error

In order to determine the performances of the propagation models, the root mean square error (RMSE) between the measured path loss and the predicted path loss was calculated using Eq. (11). This error describes how good the propagation model matches the experimental data, and values of RMSEs closer to zero show a better fit (Ajose and Imoize, 2013; Ibhaze *et al.,* 2017; Imoize *et al.,* 2019).

$$RMSE = \sqrt{\sum_{i=1}^{k} \frac{[PL_m(d) - PL_r(d)]}{k}} \quad (11)$$

where $PL_m(d)$ = Measured path loss (dB), $PL_r(d)$ = Predicted path loss (dB) and *k = 20 (Number of measured data points).*

2.0 Materials and method

2.1 Investigated environments

The typical vegetation environment where the measurements were carried out is located in the suburb of Epe (geographical coordinates are Latitude 6° 35' 0" North, and Longitude 3° 59' 0" East) in Lagos State and Ore axis (geographical coordinates are 6° 43' 0" North, 4° 53' 0" East) of Ondo State, and these areas are located in the South-West zone of Nigeria. The terrain is a tropical region characterized by non-uniformly distributed trees of average height roughly 12m. A tarred road crosses the forest layer thereby creating a discontinuity of the vegetation and provides a mixed path environment as shown in Figure 1. Here, in-leaf vegetation is assumed since the environment of study is in the tropics and the forest is evergreen (De Jong and Herben, 2004).

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Figure 1: A pictorial view of a drive section of the investigated environment showing a road crossing a natural vegetation

2.2 Methodology

This study adopted experimental approach, loss due to the presence of vegetation was obtained using Test Mobile System (TEMS) investigation tools installed on a personal computer, and the global positioning system (GPS) receiver was used for accurate location tracking. The operating frequency is set from the computer and other readings such as transmitter-receiver distance, received signal level, and locations are viewed from the personal computer (Imoize *et al.,* 2019). Measured data was compared with existing empirical models at 900 and 1800MHz, two frequency bands used by mobile operators in Nigeria. The radio path was monitored at distances of 100m interval up to 2km from the fixed transmitter, and the comparison between the integrated model and the measured foliage loss was done using MATLAB, following the method reported in (Ajose and Imoize, 2013; Imoize and Oseni, 2019).

2.3 Measurements procedure

The experimental setup for the measurements campaign is presented in a companion report (Imoize *et al.,* 2019). Further details of the equipment and measurements specifications are available in recent reports (Imoize and Adegbite, 2018; Imoize and Dosunmu, 2018; Imoize and Ogunfuwa, 2019). The test locations were concentrated mainly within a maximum propagation distance of 2 km from each base station, starting from a reference distance (d_O) of 100 m. Over 2000 readings were recorded at 200 measurement locations from the base stations. Each location measurement is an average of ten different readings taken at an interval of 60 seconds of various parameters including the received signal power in dBm. This was repeated for each of the ten base stations (BTS1 - BTS10) with various heights of approximately 30-45m. Field measurements were taken in the year 2017 and 2018, and measured data were taken at a mobile receiver height maintained close to 1.5 m. Finally, measured data was extracted and analyzed in MATLAB, following the method in earlier reports (Wang and Sarabandi, 2007; Meng *et al.,* 2010; Imoize and Oseni, 2019).

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3.0 Results and discussion

3.1 Results

The mean power received (dBm) from the vegetation environment for BTS1 to BTS10 at 900 and 1800MHz are as shown in Figures 2 and 3, respectively. In addition, measured path loss was obtained by substituting the computed values of $EIRP_t\,(dBm)$ and the values of $P_r(dBm)$ into Eq. (9). Measured path loss at 900 and 1800MHz are as shown in Figure 4. Furthermore, the computed results showing the variations of predicted path loss with measured path loss plus additional ground reflection at 900 and 1800MHz are as shown in Figures 5 and 6, respectively. In order to obtain the RMSEs between the measured and predicted pathloss, Eqn. (11) is applied to the predicted models with and without the Plane Earth (PE) loss for the frequency bands, and the RMSEs obtained are as shown in Table 1.

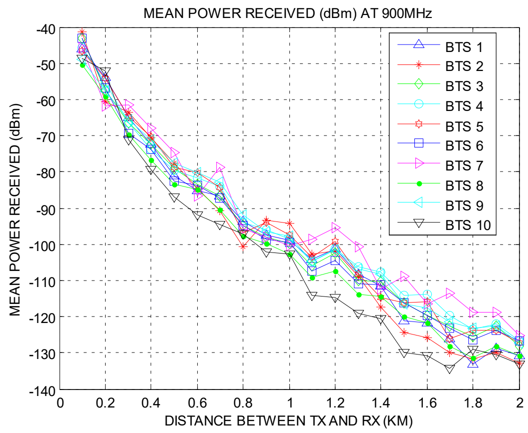

Figure 2: Mean power received from BTS1 to BTS10 at 900MHz

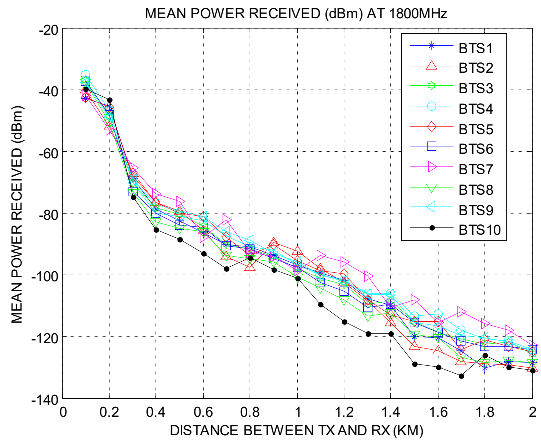

Figure 3: Mean power received from BTS1 to BTS10 at 1800MHz

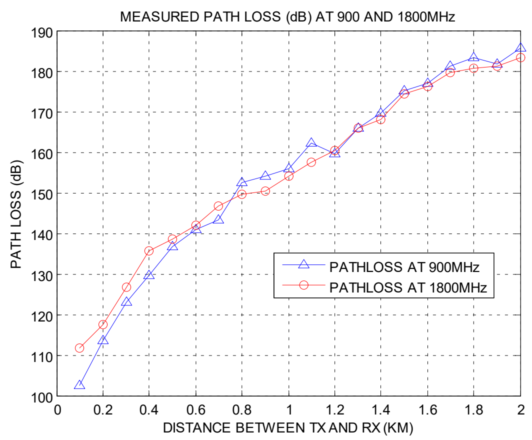

Figure 4: Measured path loss at 900MHz and 1800MHz

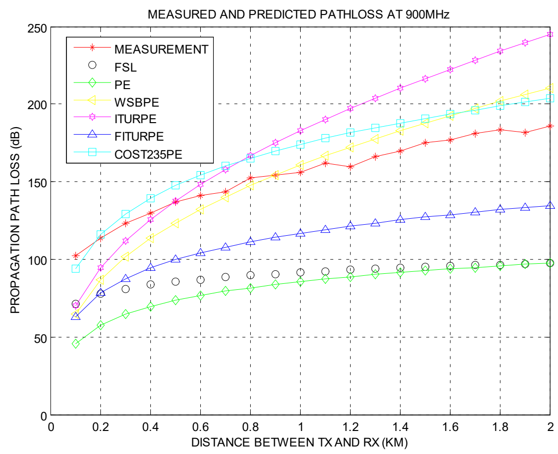

Figure 5: Comparison of measured and predicted path loss at 900MHz

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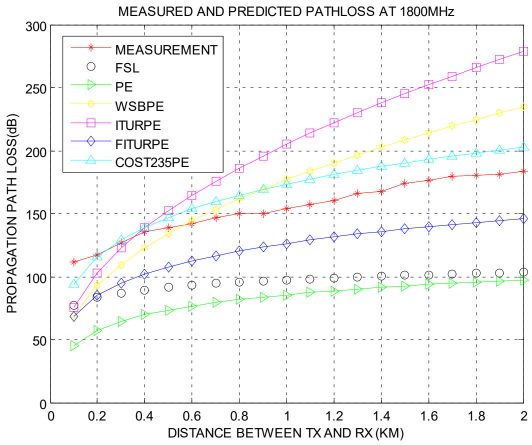

Figure 6: Comparison of measured and predicted path loss at 1800MHz

Table 1: Root Mean Square Errors for predicted models with and without integrated plane earth model at 900 and 1800MHz.

Root Mean Square Error (RMSE) in dB		
Path loss model	900MHz	1800MHz
Free Space	66.96	60.83
Weissberger WSB	81.19	66.50
WSBPE	17.11	30.72
ITU-R	60.49	43.99
ITU-RPE	34.54	57.88
FITU-R	125.77	116.21
FITU-RPE	42.44	33.25
COST235	69.25	69.88
COST235PE	15.20	15.89

3.1.1 Modification of *$COST\ 235_{PE}$* model

From Table 1, it is seen that the $COST235_{PE}$ model predicted the measured loss due to foliage with the greatest accuracy. However, the $COST235_{PE}$ model predicted the path loss with RMSEs of 15.20dB at 900MHz and 15.89dB at 1800MHz, which are relatively higher than the specified range of up to 15dB (Parson, 1992; Blaunstein *et al.,* 2003). Therefore, there is a need for the modification of the $COST235_{PE}$ model for improved signal prediction. The modification of $COST235_{PE}$ is fundamental to this study since its initial development followed propagation measurements carried out in a different environment. The modification is achieved by subtracting the RMSEs obtained in Table 1 from the calculated values for the $COST235_{PE}$. The modified $COST235_{PE}$ denoted by $COST235_{modifed}$ is given in Eqns. 12 and 13 for 900 and 1800MHz, respectively.

The measured path loss, $COST235_{PE}$ model and the $COST235_{modifed}$ at 900 and 1800MHz are as shown in Figs. 7 and 8.

$$COST235_{modified} = COST235_{PE} - 15.20 \text{ at 900MHz} \quad (12)$$

$$COST235_{modified} = COST235_{PE} - 15.89 \text{ at 1800MHz} \quad (13)$$

where

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$$COST235_{PE}(dB) = L_{COST235}(dB) + L_{PE}(dB) \quad (14)$$
$$L_{COST235}(dB) = 15.6xf^{-0.009}d^{0.26}\ in-leaf \quad (15)$$
$$L_{PE}(dB) = 40log_{10}(d) - 20log_{10}(h_t) - 20log_{10}(h_r) \quad (16)$$

At 900 and 1800MHz, we have Eq. (17) and (18), respectively.

$$COST235_{modified} = 14.67\ (d^{0.26}) + 40log_{10}(d) - 49.60 \quad (17)$$

$$COST235_{modified} = 14.58\ (d^{0.26}) + 40log_{10}(d) - 50.29 \quad (18)$$

where *d =0.1, 0.2... 2.0 km*

3.1.2 Validation of the modified model

The Root Mean Square Error (RMSE) was used to compute the error between the measured and the predicted path loss (Imoize *et al.,* 2019). This is obtained by applying Eq. 11 to the calculated values of the measured and predicted path loss. The RMSEs between the measured and predicted path loss based on the $COST235_{PE}$ and the modified $COST235_{PE}$ models are as shown in Table 2. From Table 2, it is observed that the RMSEs for the $COST235_{modifed}$ are lower compared with the RMSEs for the $COST235_{PE}$. Here, lower values of RMSEs for the $COST235_{modifed}$ indicate improvements in the signal prediction capability of the model (Ajose and Imoize, 2013). For clarity, a comparison of the measured, predicted, and the modified pathloss models for the two frequency bands is as shown in Figures 7 and 8, respectively, and it is seen that the modified models show better agreement with measured pathloss when compared with the original predicted model at the operating frequencies.

Table 2: RMSEs for $COST235_{PE}$ and $COST235_{modifed}$

Root mean square errors (RMSEs) in dB		
Model	900MHz	1800MHz
$COST235_{PE}$	15.20	15.89
$COST235_{modifed}$	6.98	10.0

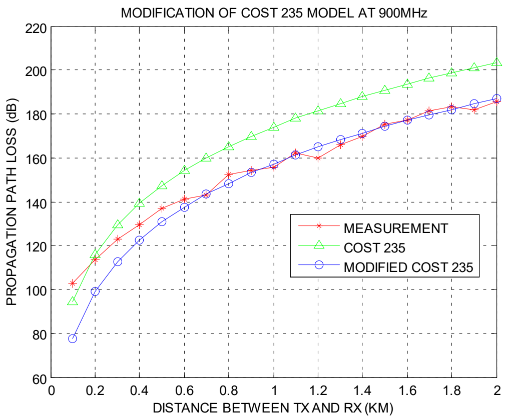

Figure 7: Measured path loss, $COST235_{PE}$ model and $COST235_{modified}$ model at 900MHz

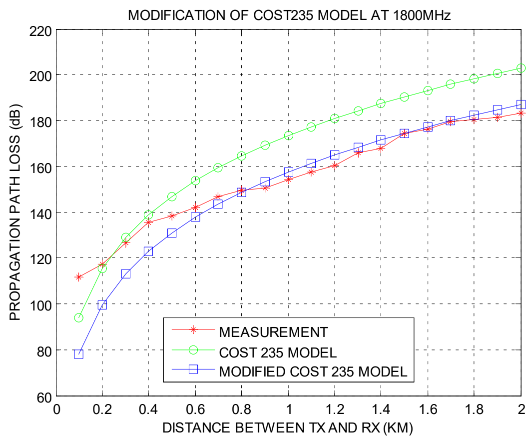

Figure 8: Measured path loss, $COST235_{PE}$ model and $COST235_{modified}$ model at 1800MHz

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3.2 Discussion of Results

As shown in Figures 2 and 3, it is observed that the mean received signal level decreases with an increase in the transmitter to receiver distance. This is in agreement with practical design of antennas revealing poor reception as the mobile receiver is farther away from the fixed transmitter (Rappaport, 2002). As seen in Figure 4, the pathloss increases as the propagation distance between the transmitter and receiver increases. This is in line with the results reported in related works (Li *et al.,* 1999a; Li *et al.,* 1999b; Wang and Sarabandi, 2007; Al Salameh, 2019). The measured pathloss at 900 and 1800MHz show a relatively close agreement from 1.2 to 1.6km, and the widest departure is seen at 0.1 and 0.4km from the transmitter. This explains the fact that pathloss varies with the frequency of transmission of radio waves from the transmitter to the receiver.

As shown in Figures 5 and 6, the predicted pathloss and the measured pathloss show an increase in pathloss as the antenna separation distance increases. However, some models were seen to overestimate or over-predict the measured pathloss. As presented in Table 1, the predicted models without the additional plane earth loss tend to overshoot the pathloss of measured data with very high RMSEs at both frequencies. However, when the plane earth loss was introduced to the actual empirical model, the RMSEs reduce appreciably. Overall, the COST 235 model with plane earth loss ($COST235_{PE}$) was observed to be the most accurate.

Propagation measurements at 900 and 1800MHz have been compared using some well-known vegetation models, and taking into consideration both the foliage induced losses and the loss due to ground reflection. The comparison showed that the integration of the plane earth model into the empirical vegetation models significantly reduces the RMSEs and improves how the propagation model matches the measured pathloss.

In addition, the WSB_{PE}, $ITU\text{-}R_{PE}$ and $FITU\text{-}R_{PE}$ models show high values of RMSEs at 900MHz with 17.11dB, 34.54dB and 42.44dB, respectively. Similarly, these models show RMSEs of 30.72dB, 57.88dB and 33.25dB, respectively, at 1800MHz. The $COST235_{PE}$ model with ground reflection showed the best performance at the 900 and 1800MHz frequency bands with RMSEs of 15.20dB and 15.89dB, respectively. Therefore, the $COST235_{PE}$ model was selected as the best among the contenders, for better signal prediction at the tested frequency bands. However, RMSEs of 15.20dB and 15.89dB comparatively overshoot the accepted range of up to 15dB, thus the need to modify the $COST235_{PE}$ model for improved performance.

Furthermore, Table 2 shows the RMSEs for the predicted and the modified COST 235 model with additional plane earth loss. The RMSE is seen to reduce sharply from 15.20dB for the $COST235_{PE}$ model to 6.98dB for the $COST235_{modified}$ model at 900MHz, and fall appreciably from 15.89dB for the $COST235_{PE}$ model to 10.0dB for the $COST235_{modified}$ model at 1800MHz as illustrated in Figures 7 and 8. As seen in Figure 7, the modified COST 235 model is in close agreement with the measured data at 900MHz, except at 0.1km where there is an obvious variation of about 22dB. Also, the existing COST 235 appears to align closely with the measured pathloss up to around 0.4km from the transmitter. After 0.4km from the transmitting station, the modified COST 235 shows appreciable agreement with measurements results up to 2km, except at 1.2km, where a little deviation is observed. As depicted in Figure 8, there is a sharp deviation of the modified COST 235 from the measured data at 0.1km. However, this trend decreases gradually till 0.8km, but the COST 235 shows better agreement with the measured data at 0.1km, and afterwards, deviates sharply with the most deviation observed at 2km. This implies that the modified model has shown better prediction of foliage loss due to dominant vegetation in the investigated environment.

4.0 Conclusion

This study has presented a model for predicting radio waves propagation through vegetation at 900 and 1800MHz. The performances of four empirical models were analyzed with respect to experimental data obtained through drive test, using TEMS investigation tools, and the most accurate model for the investigated environment was determined, using the root mean square error. For improved signal prediction, this model was fine-tuned, and the modified model was found to predict the measured path loss with greater accuracy at the operating frequency bands. Finally, the evolved model showed characteristics, which bear direct relevance to radio waves propagation through foliage, and could give very useful information to enhance accurate design of link budget for related environments. Further work would focus on improving on the prediction accuracy of the WSB_{PE}, $ITU\text{-}R_{PE}$ and the $FITU\text{-}R_{PE}$ models.

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