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Measurement and Characterization of Vegetation effects on Wireless Communication System at VHF Band

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Abstract – Vegetation is an indispensable feature of most outdoor wireless channel environments. The interaction between Radio waves in vegetation has been researched for several decades. This work presents a measurement on Radio waves path loss through tropical vegetation in Nigeria. The frequencies selected were 100MHz and 300MHz. the height of transmitter and receiver were 1.22 and 2.21m above the ground respectively. The measured signal is represented in the form of path loss and is studied as a function of vegetation depth (distance between transmitter and receiver) and frequency. The experimental data analyzed based on the best fit curve shows that, generally, the signal strength in vegetation decreases with increase in vegetation depth. The lower frequency suffered less path loss of meanvalue (89.05d Bm**) while the higher frequency suffered much path loss of mean value (104.52dBm). Two empirical path loss prediction models (Ray tracing and Weisberger model) have been used to evaluate the measurement data. Weisberger model gave a better fit to the experimental data with mean square error 13.8 and 2.4dBm for both 100 and 300MHz respectively. The result is in fairly good agreement with the acceptable international range and a new model is proposed.**

Index Terms – Frequency, path loss, vegetation, Weisberger.

1. INTRODUCTION

In Radio wave propagation and communication system, an interaction between the electromagnetic waves and environments causes path loss or attenuation, that is, the reduction in signal strengths. Path loss is a major factor to be considered in order to predict, simulate and design high performance communication systems, accurate characteristics of the complex environment has to be known [1]. One of the complex environments is vegetation. The study of propagation through vegetation is challenging due to variations in vegetation density, measurement geometry, and vegetation composition. Path loss may be due to many effects, such as diffraction, refraction, absorption and scattering [2]. It is also influenced by vegetation, height and location of antenna. Vegetation may block the Line of Sight (LOS)path, and also scatter the radiated wave, forcing it to follow different paths (multipath)to the receiver. Waves may be diffracted, reflected and scattered along the propagation path, a situation that may be degraded signal quality and reduce link distance. Also due to absorption and diffractions the radiated wave may be attenuated as it- propagates through trees to the received antenna. The amount of attenuation is determined by the density of the tree elements (e.g. leaves, branches, and twigs). Also the attenuation is dependent on the frequency, depth of penetration into the tree geometry and leaf state (either wet, dry, full leave or no leave) propagation signals in trees may suffer attenuation in the range of 10s of decibel especially at VHF band [3]. It was reported that the foliage medium can attenuate the Radio signal propagation significantly. In the presence of wind, tree elements e.g. leave; twigs and branches are prone to a forced movement that can affect the quality of received signal. The swaying of these randomly orientated leaves, twigs and branches introduces temporal variation in the received signal [4].

2. RELATED WORK

Over the years, researchers in Radio systems engineering have made concerted efforts to study the characteristics of waves propagated in vegetation for the purpose of efficient network planning. These studies have led to the formulation of different propagation prediction models which have been summarizedunder three (3) different categories.

- Empirical models
- Semi-empirical models
- Analytical models

2.1 Empirical models

This model exponential decay (EXD) was first proposed by (Weissberger 1982), and a modified version was included in the International Radio Consultative Committee (CCIR 1986) recommendations. [5]

$$L(dB) = 0.26f^{0.77}d_f \quad (2.1)$$

Where L is the propagation loss in decibels, $f$is the frequency in GHz and d is the vegetation depth in meters. This model is applicable in frequency range of 100 MHz to 3200 MHz.

The Exponetial decay model is seen to overestimate the propagation loss. In order to mitigate the shortcomings associated with the EXD model [6] through results from experimental investigations proposed a modified exponential decay(MED) model, which incorporates thickness of the foliage into its formulation and is given by [7]

$$L(dB) = 1.33f^{0.284}df^{0.588} \quad (2.2)$$

$$L(dB) = 0.45f^{0.284}df \qquad 0 \le df < 14 \quad (2.3)$$

Lis the propagation loss in decibels, is the frequency in GHz and is the vegetation depth in meters. The MED model is suitable for the prediction of propagation loss due to vegetation when propagation is through groves of trees and covers a maximum depth of 400 m [7].

The parametric equation describing MED shows a break point at 14 m into the vegetation. The reason for this is that at about 14 m into the forest, the incoherent (diffuse) component takes prominence over the direct component due to scattering and this gives a reduced attenuation rate. A generic form of this relation is

$$L(dB) = xf^{y}d_f^{z} \quad (2.4)$$

Where x, y and z are variables in which their values can be obtained through measurements. and are two parameters that indicate the frequency and distance dependences of vegetation-induced excess loss in the parametric equation. Following this trend, the ITU-R in 1986 developed a model for foliage attenuation using the MED general format and is given as:

$$L(dB) = 0.2f^{0.3}df^{0.6} \quad (2.5)$$

Where f is in MHz and is in meters.

This model is suitable for loss prediction when the depth of vegetation is less than 400 m and in the range of frequencies between 200 MHz to 95 GHz. In a bid to get a more generic model, researchers [8] under the auspices of European Co-operation in Science and Technology (COST), developed another model called COST 235 in 1996. This model was developed using measurements conducted on sycamore, horse chestnut, pecan, apple and lime trees covering a range of frequencies between 9.6 GHz and 57.6 GHz. Measured data were used to evaluate the parameters in Equation 2.5 which resulted in a standard deviation of 26.6 dB and 22.1 dB respectively for both in-leaf and out-of-leaf states. Using a least square fit, an improvement to this model was suggested and given by [10]

$$L(dB) = 15.6f^{0.009}df^{0.26} \quad (2.6)$$

$$L(dB) = 26.6f^{0.2}df^{0.5} \quad (2.7)$$

The received signal will show time varying phase changes due to periodic changes in path length and will result in fading.

The result produced an enhanced model called the fitted ITU-R (FITU-R) model and it predicts for both in-leaf and out-of-leaf case. The FITU-R model is recommended for use in the frequency range of 10-40 GHz and is given as

$$L(dB) = 0.39f^{0.39}df^{0.25} \quad (2.8)$$

$$L(dB) = 0.37f^{0.18}df^{0.9} \quad (2.9)$$

2.2 Semi empirical model

Owing to the shortcomings of empirical models, researchers at the Rutherford Appleton Laboratory (RAL) developed a Non-Zero Gradient (NZG) model which is semi-empirical in form and considers the effect of geometry in its formulation. The model postulated dual slope attenuation as a function of distance. For this dual slope, the initial slope describes loss due to coherent (direct) component while the second slope describes the loss due to scattering (by vegetation elements) and which occurs at a much reduced rate [11]

$$L(dB) = R_\infty d + k\left(1 - e^{-\frac{(R_o - R_\infty)d}{k}}\right) \quad (2.10)$$

Where R_0 and R_∞ are the initial and final specific attenuation values in dB/m and K is the final attenuation offset. This model was optimized with respect to all of the in-leaf and out-of-leaf measurement data obtained at 3.0 GHz and 5.0 GHz. Values for the parameters,$R_{o,}R_\infty$and K are given in table 2.1.

Table 2.1 constant parameters for NSG model.

Constant parameters	In-leaf	Out-of-leaf
$R_\infty(dBm^{-1})$	0.33	0.24
$R_o(dBm^{-1})$	19.82	6.25
$k(dBm^{-1})$	37.87	6.45

2.3Analytical models.

An analytical model offers an insight into the physical processes involved in the propagation of radio waves through trees and involves the use of numerical methods in its formulation. The numerical evaluation may be intractable and may depend on input variables that can only be obtained from experimental data.

Aremu*et.al.,(*2014) A study was undertaken to investigate signal attenuation through vegetation in Shasha forest Osun state ,Nigeria ($7^0 30N, 4^0 50^0 E$) about 310.80km^2.The study was conducted using three different frequency(2.40,2.45 and 2.50) at different sites. In his work, the behaviors of signal propagation through coniferous trees and foliage were presented. The obtained experimental results were used to evaluate some existing model such as Weissberger, COST235, ITU-R and FITU-R models. There results show that 2.45GHz frequency has the least root mean square error (RMSE) compared with the other frequency used. Their work was compared with an existing model and it shows a good agreement with the values given in the ITU-Recommendation [12]

A similar attempt was made by Li *et* to model propagation of radio waves in forests using analytical method but with little modification. The authors considered forest to be a horizontally stratified inhomogeneous medium with canopy, trunk, ground and over-canopy proposed four-layered model to characterize forests. In this model, the trunk and canopy layers were considered lossy and isotropic [13]. But Tamir , T claimed that this assumption is said to hold for frequencies 2-200 MHz So above 200 MHz, a four-layered medium is used to model forest [14]. In 1983, Cavalcante*et al.* considered the vertical non-homogeneities of forest and representation of forest is inaccurate at frequencies above 200 MHz since trees cannot be regarded as a homogeneous medium at such frequencies (i.e. above 200 MHz). This assumption is more accurate and realistic because looking at the vertical profile of trees, a clear distinction between trunk and canopy is visible which implies its inhomogeneous nature. This concept models tree trunk and canopy as electrically anisotropic slabs. While the ground and over-canopy region are taken as electrically isotropic.

2.3.1 Ray tracing model.

For the radio-wave propagation in free space, the path loss can be predicted by the free space loss [15]

$$P(dB) = -27.56 + 20Log_{10}(f) + 20Log_{10}(d) \qquad (2.11)$$

where*f* is the frequency in MHz, *d* is the distance between the isotropic transmitting and receiving antennas in meters. As a plane terrain appears, ground reflection may occur. The boundary can be determined with the help of the 1st Fresnel zone, since the energy transmitting from transmitter to receiver concentrates mainly on this region. The size of the 1st Fresnel zone surrounding the geometrical ray paths is shown in Fig. 2.1 is given as [16]

$$h_{0=}\frac{1}{2}\sqrt{\pi d} \qquad (2.12)$$

Where $\pi$is the wavelength. The outer bound of the 1st Fresnel zone varies with the propagating frequency. The large ellipse (dash line) represents the 1st Fresnel zone at low frequency, and the small ellipse (solid line) represents the 1st Fresnel zone at high frequency.

This is because the low frequency signal has a large propagating wavelength. When there is a single ground-reflected ray, the path loss can be described by

$$L_{1\,Refl}(dB) \cong L_{FSL}(dB) - 20Log_{10}\Delta\emptyset \qquad (2.13)$$

where$\Delta\emptyset$ is the phase difference between the direct and reflected rays given by,

$$\Delta\emptyset = \frac{4\pi h_T h_R}{\pi d} (2.14)$$

Here$h_T$and $h_R$are the transmitting and receiving antenna heights over the ground in meters, respectively. It is assumed that *d* is much larger than$h_R$and h_R .

In this project, a second reflected wave caused by the tree canopy for short-range forested propagation is introduced since the radio-wave is coherent. Therefore, when this second reflected wave is present, the path loss can be described by

$$L_{2-refl}\,(dB) \cong L_{FSL}(dB) - 10log_{10}(1 + 2\Delta\emptyset_1\Delta\emptyset_2) \quad (2.15)$$

where$\Delta\emptyset_1$ and $\Delta\emptyset_2$ are the phase differences between the direct and the ground-reflected rays, and the direct and possible tree-canopy reflected rays, respectively. The phase difference $\Delta\emptyset_1$ and $\Delta\emptyset_2$can be computed by (2.15)

whereh_T=h_R= h_2 for the ground-reflected ray and h_T= h_R= h_1 for the tree-canopy-reflected ray as shown in our study.

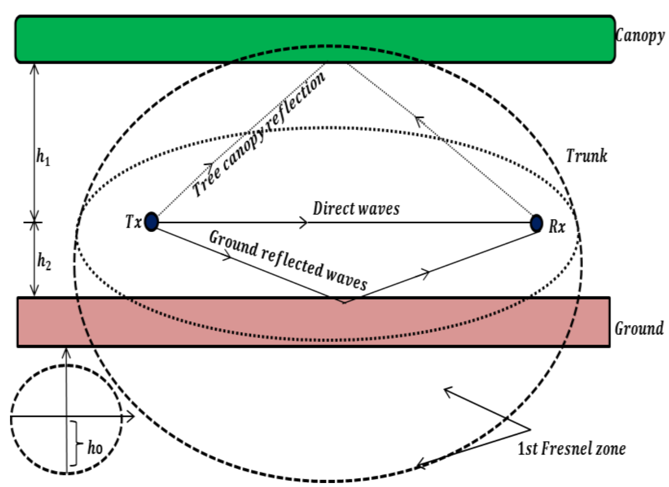

Figure 2.1 Ray tracing geometry.

For the radio-wave propagation through the foliage medium, there is an additional (excess) loss on the propagating components such as direct wave and reflected waves. Much effort has been put in the empirical modeling of the foliage-induced excess loss at different frequencies and geometries, and has been summarized in.

(*i*) Weissberger modified exponential decay model is applicable where a ray path is blocked by dense, dry, in-leaf trees found in temperate climates. It is applicable in the situations where the propagation is likely to occur through a grove of trees rather than by diffraction over the canopy top, and is given by [17]

$$L_W(dB) = \begin{cases} 1.33 \times f^{0.284} {d_f}^{0.588} & 14\, m < df \leq 400m \\ 0.45 \times f^{0.284} d_f & 0\, m \leq d_f 14\, m \end{cases} \quad (2.16)$$

where$f$ is the frequency in GHz, and $df$is the foliage depth in meters.

(*ii*) ITU Recommendation (ITU-R) was developed from measurements carried out mainly at UHF, and was proposed for the cases where either the transmitting or receiving antenna is near to a small (df<400 m) grove of trees so that the majority of the signal propagates through the trees. It is described as [18]

$$L_{ITU-R}(dB) = 0.2 \times f^{0.3} df^{0.6} \quad (2.17)$$

(*iii*) COST235 model which was proposed based on measurements made in millimeter wave frequencies (3Hz to 5GHz) through a small (df<200 m) grove of trees is

$$L_{COST}(dB) = \begin{Bmatrix} 26.6 \times f^{-0.2} df^{0.5} \\ 15.6 \times f^{-0.009} df^{0.26} \end{Bmatrix} \quad (2.18)$$

In COST235 model (2.20) measurements were performed over two seasons, when the vegetation is thick and when we have a free space where there is no vegetation. For both ITU-R and COST235 models, f is the frequency in MHz, and df is the foliage depth in meters.

3. METHODOLOGY AND MEASUREMENT

3.1 Measurement campaign

The tropical vegetation where the experiment took place is located around the Faculty of science, North campus, The Polytechnic Ibadan (LAT 7.4546^0 N, LONG 3.8496 E) Ibadan. The vegetation can be classified as medium dense to vegetation with mixed different types of plants. Figure 2 shows some part of the vegetation. The vegetation consists of types of plants like thick mahogany, plantain tree, mango tree etc. Thick canopies are formed by the leaves of the tree. The average thickness (trunk diameter) and height of the trees ranges between 0.76m to 2.56m and 5.07m to 15.3m respectively. The vegetation ground is covered with scrub as shown in plate 3.1

Plate 3.1 Measurement campaign site.

3.2 Methodology

3.2.1 Measurement of signal strength in clear weather.

This work based on the measurement of signal strength at VHF band for both clear weather and vegetation. The measurement was carried out using a VHF/UHF FM transmitter placed at a height of 1.22m. A cord was used to connect the transmitter with Sony xperial phone and audio signal (music) was transmitted at 100MHz. The audio signal was received at the other side by using a dual band monopole antenna designed and constructed; this antenna was coupled through a 50Ω feeder to a GSP730 spectrum analyzer. This was used for receiving and measuring audio signal strength being transmitted at 100MHz. The peak signal was read off and recorded in dBm at 10m interval starting from 20m to 200m along the vegetation channel.

Plate 3.2 Measurement in clear weather.

The computation and statistical analysis were achieved with the aid of MATLAB 2015a. The procedure was repeated by setting the center frequency of spectrum analyzer to 300MHz while the transmitting frequency was adjusted to 300MHz.

3.2.2 Measurement of signal strength in vegetation

The measurement was carried out by using a distance measuring wheel. This instrument is an accurate instrument for measuring the distance between the transmitter and the receiver.

The VHF/UHF FM transmitter was used to transmit the audio signal. The signal was sent by plugging a phone to the transmitter. The spectrum analyzer was set to a lower frequency of 50MHz, center frequency of 100MHz and higher frequency of 150MHz.We got the peak of the signal and it was recorded at each point, starting from 20m with 10m interval up till 200m.

Plate 3.3 Measurement in vegetation.

4. RESULTS AND DISCUSSION

Figure 4.1 and 4.2 shows the results of measured path loss in clear weather and computed path loss.it could be seen that the path loss increase as distance between the transmitter and receiver increases for both 100 and 300MHz frequency considered. The VHF audio signal strength measured was compared to the computed path loss (Ray tracing model) in a clear weather taking into consideration the ground reflection/conductivity using equation 2.13.

Ground reflection shows little effects on the measured signal strengths with the mean value 0.15 and 0.45dBm respectively. Also, frequency 100MHz suffered less path loss compared to 300MHz.

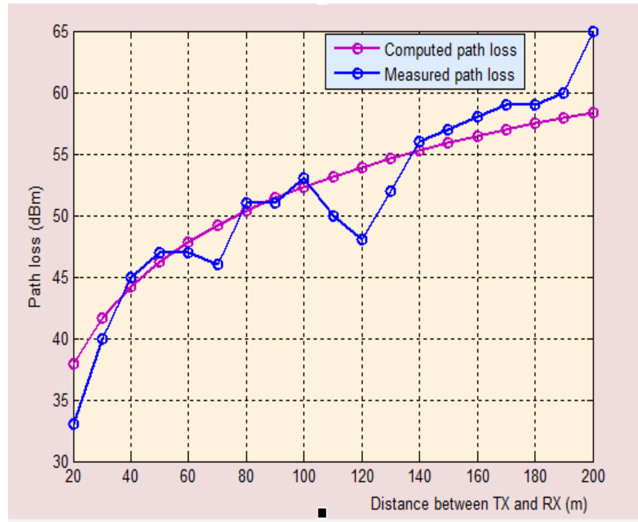

Figure 4.1: Graphical representation of measured and computed path loss in clear weather at 100MHz.

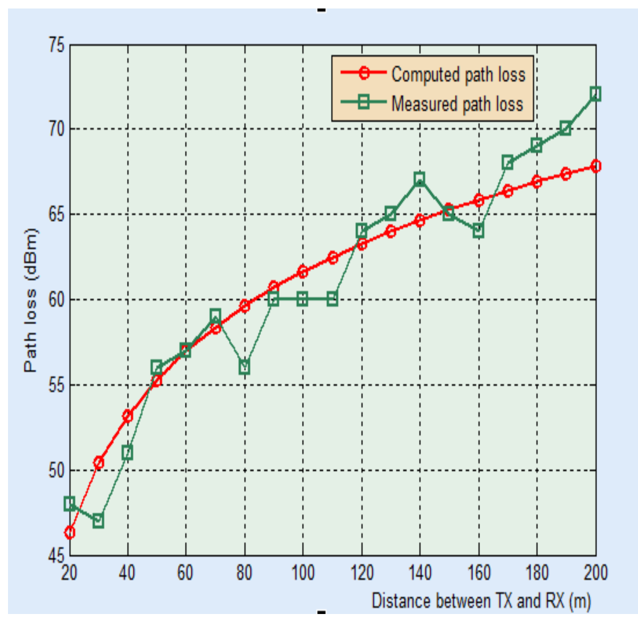

Figure 4.2: Graphical representation of measured and computed path loss in clear weather at 300MHz

Figure 4.3 and 4.4 shows the results of path loss in vegetation. It was discovered that the tree density which is not uniformly distributed and with different permittivity was responsible for the path loss.

A more accurate comparative analysis for determining the best path loss prediction model for macro environments is the use of the mean square error (MSE) approach. The MSE is the ratio of dispersion of measured path loss values and describes how good the propagation model matches experimental data. It is commonly used to verify the accuracy of path loss models. The standard deviation and MSE is given by:

$$\sigma = \frac{\sqrt{\sum(P_m - P_r)^2}}{N} \qquad (4.1)$$

Where Pm = measured path loss (dB)

Pr = predicted path loss (dB)

$$\mu = \frac{\sigma}{\sqrt{N}} \qquad (4.2)$$

Table 4.1 shows the mean square error and the mean path loss for the frequencies considered.

Table 4.1 Statistical analysis of data.

Frequency (MHz)	Mean path loss (dBm)	Weisberger model		Ray tracing model	
		σ	μ	σ	μ
100	89.05	60.05	13.80	166.90	38.00
300	104.52	10.32	2.80	193.90	44.00

The results showed in figure 4.3 and 4.4 shows that the path loss in vegetation increases as distance increases. Table 4.1 shows the mean path loss for the two frequencies considered. 100MHz frequency suffered less path loss (89.05dBm)compare to 300Hz (104.52dBm).

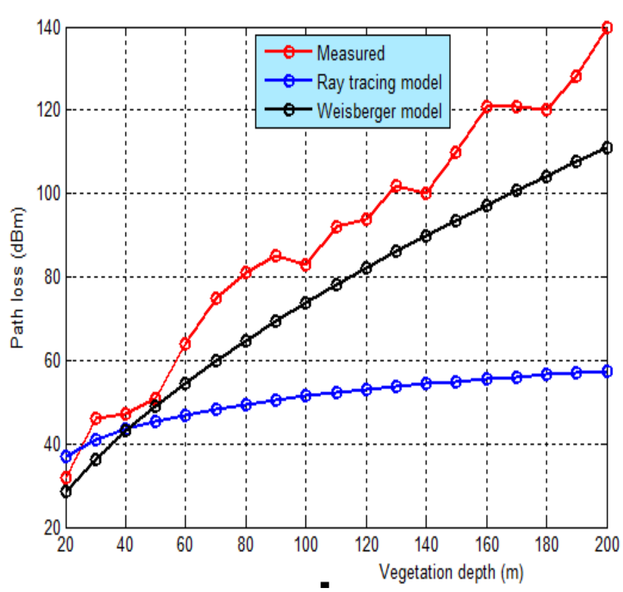

Figure 4.3 Graphical representation of measured path loss in vegetation at 100MHz

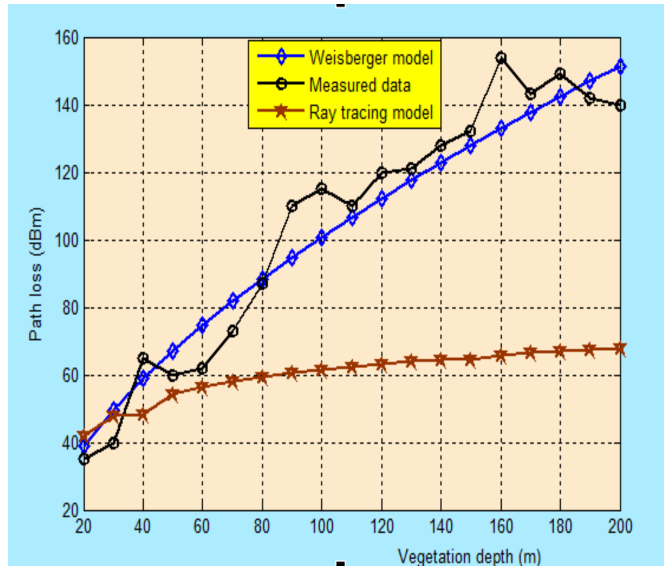

Figure 4.4 Graphical representation of measured path loss in vegetation at 300MHz.

4.1 Newly proposed model

In this work, a new path loss model as a function of distance has been proposed as shown below

For 100MHz frequency

$$PL = 5.139 \times d^{0.6142}$$

For 300MHz frequency

$$PL = 5.914 \times d^{0.6189}$$

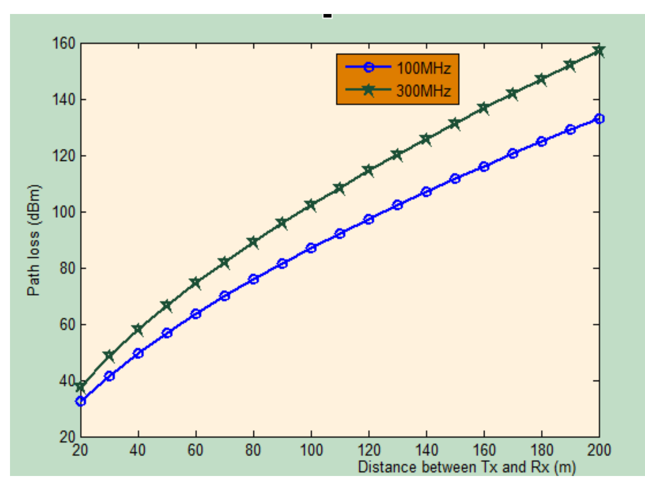

Figure 4.5Simulation of the newly proposed model.

5. CONCLUSION

In this work, the variation of path loss as a function of vegetation depths and frequency at VHF band has been investigated so as to give accurate estimation for the efficient design of VHF network in this area. Different empirical models have been analyzed and compared with experimental results. Weisberger model gave a fairly good agreement with the measured data with mean square error 13.8dBm and 2.8dBm for 100 and 300MHz frequencies considered respectively. The mean path loss for various vegetation depths at 100 and 300MHz were 89.05 and 104.52 dBm respectively. Hence, lower frequency suffered less path loss.

A new model has been proposed for the Radio network optimization. These models will provide a platform to aid in the system optimization process for improve performance. The model can be used to characterize the quality of Radio coverage in this area.

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