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Path Loss Prediction Model for Propagating Radio Wave in Woodland

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This paper presents new empirical prediction models for loss estimation in forest environment. Experimental investigations were carried out on groups of trees in form of woodland and lines of trees at SHF band under different operational contexts. In the experimentations, two major measurement geometries (propagation "into" and propagation "inside" forest) were adopted on site to site basis. Results from all the sites displayed a common trend, in that they all showed a persistent decay in signal power with the depth of vegetation and which is dependent on the measurement geometries.

Using a "Power Law" theory, a new empirical loss prediction model has been proposed for each propagation scenario using parametric equations which are in line with the general formulations of the ITU-R models. These new models were tested with the standard empirical loss prediction models and gave a statistical adherence with the fitted ITU-R model.

It is anticipated that these new models will address the inadequacy in the existing prediction models which have not taken cognizance of the differences in operational contexts of each propagation scenario in their formulations.

Keywords: Propagation into; propagation inside; loss; empirical; woodland; prediction model.

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1. INTRODUCTION

Vegetation either in form of single trees or group of trees can cause impairment to propagating radio waves, leading to signal attenuation [1]. Over the years, several attempts had been made by researchers [2-11] to characterise radio waves propagation in vegetation. This has led to the development of series of prediction models for different propagation scenarios. Getting a generic propagation model that accurately predicts well in all scenarios is relatively difficult to achieve due to the inexhaustible complex parameters of trees (e.g. leaf size, leaf shape, leaf orientation, twigs and branches orientations). However, a basic framework for radio characterisation in vegetation and prediction models is contained in the International Telecommunication Union (ITU-R) Recommendations P.833-8 [12].

For radio propagation in forest environment, two propagation geometries (propagation ‘into’ and ‘inside’) have consistently been adopted by researchers in the field for measuring the excess loss. But in the literature, single prediction models have always evolved to predict losses for the two geometries. A probable research question is whether a single prediction model would predict adequately well for the two scenarios [13-21].

This work has therefore seek to verify this further, by carrying out investigations on same with a view of determining any likely variation in measured losses at the two geometries and validate suitability of a single prediction model or otherwise.

2. MATERIALS AND METHODS

2.1 Site Description

Two different experimental sites with about twelve (12) measurement locations were considered for this investigation. These are Victoria Park and Bruntingthorpe Proving Ground, all located in Leicestershire, UK. Victoria Park is a public park with a total landmass of 279,000 m^2 located in the south-east of the city (Leicester) and backing onto the University of Leicester. The park has a nearly flat terrain with different sporting facilities and pedestrian pathways through avenues of trees. It has a series of lines of trees with heights between of 12 m to 15 m and spaced approximately 9 m apart. The predominant tree species at the park are horse chestnut (*Aesculus Hippocastanum*), sycamore maple (*Acer Pseudoplatanus*), London plane (*Platanus X Hispanica*) and silver birch (*Betula Pendula*). It also has series of short-depth woodlands with irregularly planted trees of about 0.6trees per square metre. Each of the woodland has a high concentration of saplings with heights of up to 1.2 m in addition to few underbrushes. Bruntingthorpe Proving Ground is typical woodland which is rectangular in form, 60 m deep and about 250 m in length. It consists of regularly planted mixed vegetation of 20 m height with a variation of about 1.5 m. The trunk diameters vary between 16 cm to 60 cm and are separated from each other by approximately 3 m. Average tree density is 0.36 trees per square metre. The predominant tree species are oak, pine and ash trees with tree canopies overlapping. The terrain is relatively flat with saplings and underbrushes all of which disappear during winter to be replaced with dried, fallen leaves. The flat terrain enables easy accessibility and smooth movement of the trolley. Full details of equipment description is as presented in [1].

3. MEASUREMENT DETAILS

3.1 Woodland Investigations

The first sets of measurements were carried out in the woodland at Bruntingthorpe site. The objective was to investigate depth dependence of excess loss and also investigate the effect of measurement geometry on the propagation loss. The first geometry adopted is termed as ‘propagation into’ forest where the transmit antenna is located outside the woodland and the observation points located within the woodland. The transmit and receive antennas were adjusted to a height of 2.5 m. At some points during the investigations, the transmit antenna height was adjusted to 5.0 m. Also at the initial point, the transmit antenna boresight direction was placed perpendicular to the woodland edge and subsequently adjusted to make inclination angles of 24° and 45°. This is aimed at verifying possible effects of penetration angles on measured loss. Measurements (at 3.5 GHz and 5.0 GHz) were taken at different points along these paths with the separation distance between successive observation points being irregular due to non uniformity of tree arrangement along the paths. Furtherance to this, the measurement geometry was changed to “Propagation inside” whereby both transmit and receive antenna were located within the woodland. Some of the results are as presented in Figs. 1 and 2.

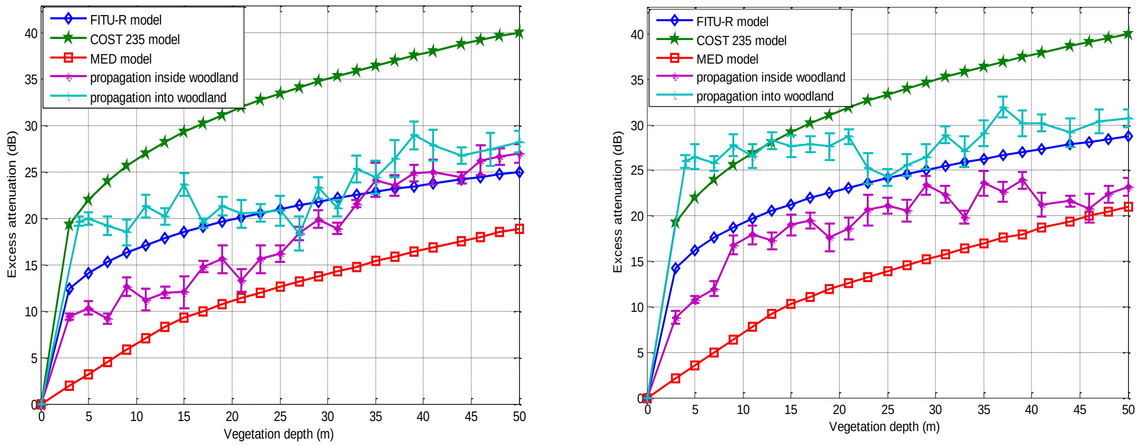


Fig. 1. **Fig. 2.**

Figs. 1 and 2. Excess loss versus depth for propagation (into and inside) woodland at 3.5 GHz and 5.0 GHz respectively

As can be seen above, the two plots show initial steeper slope with increase in depth which is more pronounced in 'into' geometry. There was no direct tree obstruction at the first observation point for 'inside' geometry and this is why the initial slope is less steep. A more linear decay in measured attenuation is recorded at this (inside) geometry. As a result, a difference of 4.7 dB and 7.9 dB is seen between the two geometries at 3.5 and 5.0 GHz respectively. The general trend shows lesser attenuation values for 'inside' geometry compared with 'into' geometry but not with appreciable margin. This is likely to be more significant in a high-dense forest and at higher frequencies. An inference that can be drawn from this is that for wireless communication in woodland or forest, localising the two nodes inside the vegetation would give better performance in terms of overall signal impairment. The measurement data showed high variation in RSS and this is due to the weather condition during the period of experiment which could generally be described as too windy. A variation of up to 6 dBm was observed especially for 'into' geometry. All the measured data at both geometries gave a good statistical adherence to FITU-R model with low error values.

As a follow up to this, further experiments were conducted in Victoria Park site. Here, measurement and antenna geometries are similar to the one adopted at Bruntingthorpe but with differences in physical parameters of the trees (i.e tree density, heights, trunk size etc). Some of the results obtained are as presented in Figs. 3 and 4.

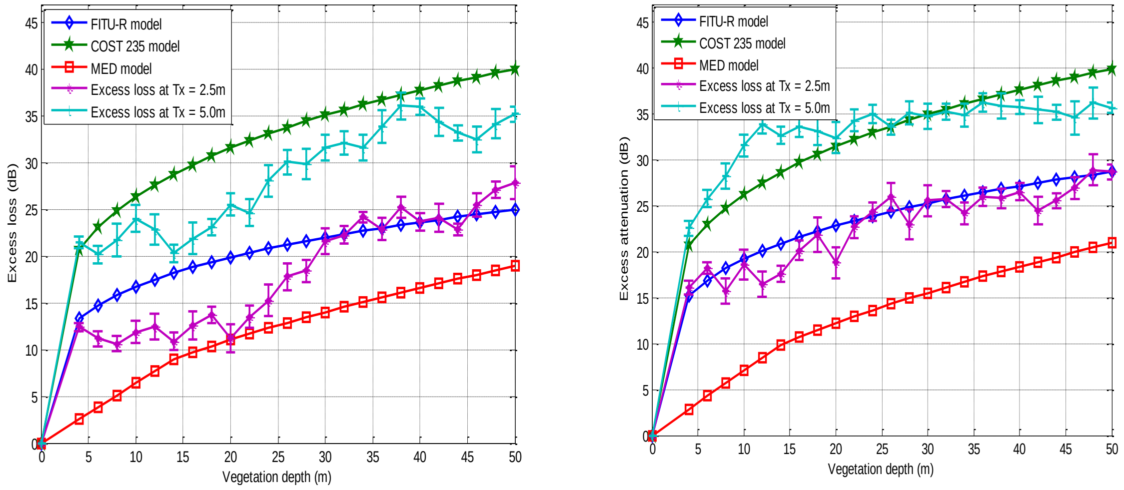


Fig. 3. **Fig. 4.**

Figs. 3 and 4. Excess loss at two antenna heights compared with empirical models at 3.5 GHz and 5.0 GHz respectively

From the above plots, it is apparent that an additional loss of 10 dB (approximately) is recorded when transmit antenna height was elevated to 5 m. At a height of 5 m, the antenna was at canopy level which results into large blockage of radiated field. When this data is fitted with empirical models, a good qualitative agreement is seen with COST 235 model which is an interesting result. With this, one may say that COST 235 model would show good prediction ability in a high dense woodland or forest. The same parameter (antenna height effect) was investigated at Bruntingthorpe and result did not show any appreciable difference in measured loss. A possible explanation for this is the differences in geometry of the woodlands (i.e physical parameters of the trees). This therefore shows that it is not sufficient enough to use the antenna height alone in predicting the amount of excess attenuation likely to be suffered by radio waves in trees. Rather, the height of the antenna relative to that of tree canopy should be considered.

Summary of propagation geometries, mean loss values and corresponding standard deviation values across some of the sites are as presented in Table 1.

Table 1. Summary of propagation geometry and mean attenuation values

	Propagation geometry	**Link distance (m)**	**Mean attenuation values (dB)**		**Standard deviation (dB)**	
			3.5 GHz	**5 GHz**	**3.5 GHz**	**5 GHz**
1	Into woodland, T_x = 24°	40	14	19	1.6	2.9
2	Into woodland, T_x = 45°	50	19	22	2.8	1.7
3	Into woodland, T_x = 90°	50	19	23	5.4	5.0
4	Into woodland, T_x = 90°	50	23	28	4.0	2.7
5	Into woodland, T_x = 90°	50	21	28	2.8	2.2
6	Into woodland, T_x = 90°	50	23	24	2.9	1.7
7	Inside woodland	50	18	19	6.0	4.3
8	Inside woodland	50	18	20	2.7	2.3
9	Inside woodland	50	21	22	5.6	5.3

3.2 Lines of Trees

The first set of Measurements here was conducted on two lines of trees at Victoria Park which covers a depth of 50 m. The trees are of identical species; London plane (*Platanus X Hispanica*) with an average height of 13 m and spaced approximately 9 m apart. Most of the trees have their branches appearing at 2.3 m above the ground level with overlapping canopy foliage. The geometrical view of measurement scenario is as shown in Fig. 5. The space between the lines of trees is 8 m which serves as pathways for pedestrians and cyclists.

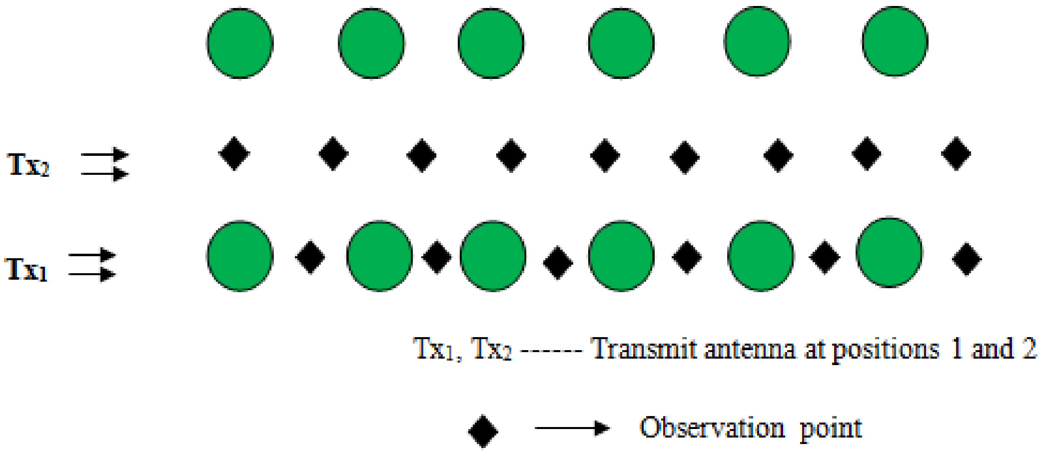


Fig. 5. Line of trees measurement

Two measurement paths were chosen as indicated by T_{X1} and T_{X2}. At every measurement point, antenna alignment was ensured. Both transmit and receive antennas were positioned 2.3 m above ground. The path T_{X1} describes propagation within a line of trees in which receive antenna was positioned between successive trees. The separation distance between successive observation points is not uniform owing to interception by tree trunks which possibly could leave the receive antenna in a shadow zone. On the other hand, path T_{X2} represents propagation between two lines of trees. Here, successive receive antenna positions are uniform. As a way of providing varieties of data for comparison, a similar experiment was conducted on a regularly planted line of trees within woodland at Bruntingthorpe. Both transmit and receive antennas were placed inside the woodland and observation points were positioned between successive trees. Some of the results from the two experimental sites are as presented in a combined form.

From Figs. 6 and 7, Line 1 represents data from Victoria Park for two lines of trees with a pedestrian pathway in between while Line 2 represents a woodland data from Bruntingthorpe site to simulate lines of trees. The plots show excess attenuation curves with changing gradient and also exhibit some features similar to the woodland data. With the measurement geometry adopted, diffraction around tree trunk and scattering are expected to be more significant. When transmit and receive antenna were placed in between the two lines of trees (at Victoria park), measured attenuation was low with values of few decibels above free space loss. A simple inference from this is that there is less interaction between propagating radio waves and the tree elements. Hence, propagation is dominantly by LOS transmission. For Line 1 data, the two lines of trees are located between either side of pathway for pedestrians and cyclists and as such movement of people (especially cyclists) could not be controlled during the course of the experiment. As a result, reflections from moving cycles were normally noticed (in some instances) thereby making it a dominant propagation mode and leading to increase in RSS. A variation in RSS of up to 5 dBm was noticed in some cases. This was normally observed most especially as cycles approach the transmitter section. Efforts were made to curtail this by carrying out repeat experiments when such incidences occur. Overall, Line 2 has shown greater attenuation values (at both frequencies) compared with Line 1. This is likely due to the fact that Line 2 assumes a woodland structure with saplings and nearby trees all in the vicinity of antenna's beamwidth. All these would produce additional propagation effects on the radio waves leading to higher attenuation. Measurement data along Line 1 at 3.5 GHz shows higher disparity (about 8 dB approximately) with its counterpart data in line 2. A possible explanation for this is the fact that the 3.5 GHz has a higher beamwidth. At 5.0 GHz, a disparity of about 2 dB is noticed between Line 1 and Line 2 data and this is expected due to differences in operational context and physical

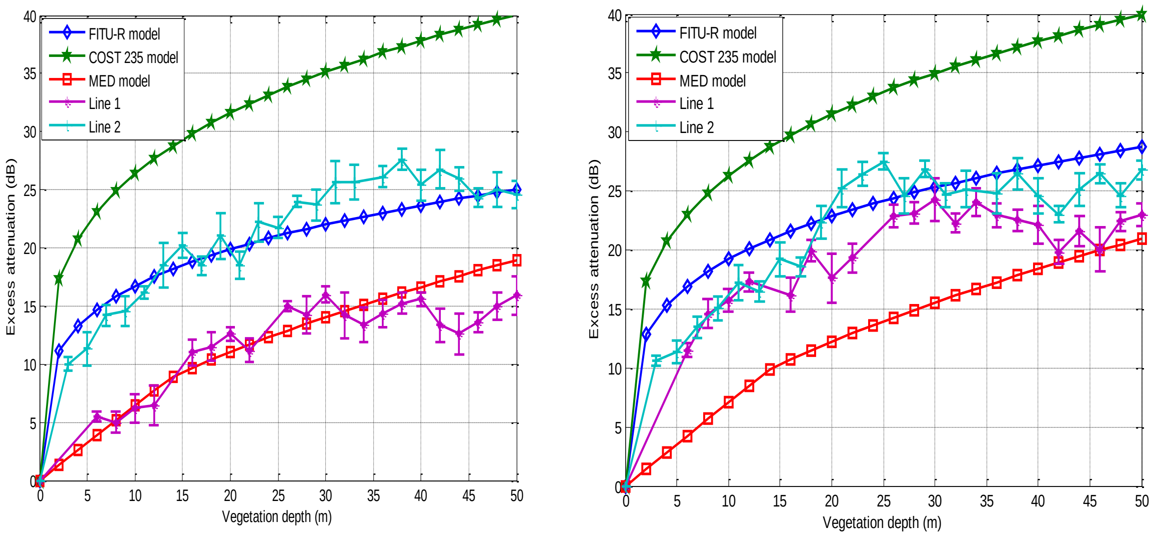


Fig. 6. **Fig. 7.**

Figs. 6 and 7. Excess attenuation for lines of trees at 3.5 GHz and 5.0 GHz respectively

parameters of the trees. However, movement of pedestrian did not give any noticeable variation in RSS in Line 1 data.

4. LOSS PREDICTION MODELLING FROM THE EXPERIMENTAL DATA

Modelling of propagation loss in a group of trees or forest is very challenging and complex as demonstrated in the experimental data. This complexity arises from variations in operational contexts and physical parameters of the vegetation e.g tree type, tree density, leaf size, foliage density, measurement geometry, terrain feature, antenna height etc. Also, characterising each of these parameters is very deterministic. But in all, transmission loss in a typical woodland or forest can be decomposed into different components such as:

$$L_T(dB) = L_{fs} + L_{veg} + L_{sy} \qquad (1.0)$$

Where L_T = Total channel loss, L_{fs} = free space loss, L_{veg} = vegetation loss and L_{sy} = system loss.

After necessary extraction process, Equation 1.0 is now reduced to:

$$L_{veg} = [L(x)_T - L(x)_{fs}] \qquad (2.0)$$

$L(x)_T$ and $L(x)_{fs}$ are vectors representing measured loss in woodland and in an open grassy field respectively at observation points x (where x = 1,2,3,4,5,… n).

From the experimental results, it is evident that the signal power decays with the depth of vegetation. So, a ‘power law’ function has been used in the modelling for channel characterisation as in 3.0:

$$L\,(dB) = aK^b \qquad (3.0)$$

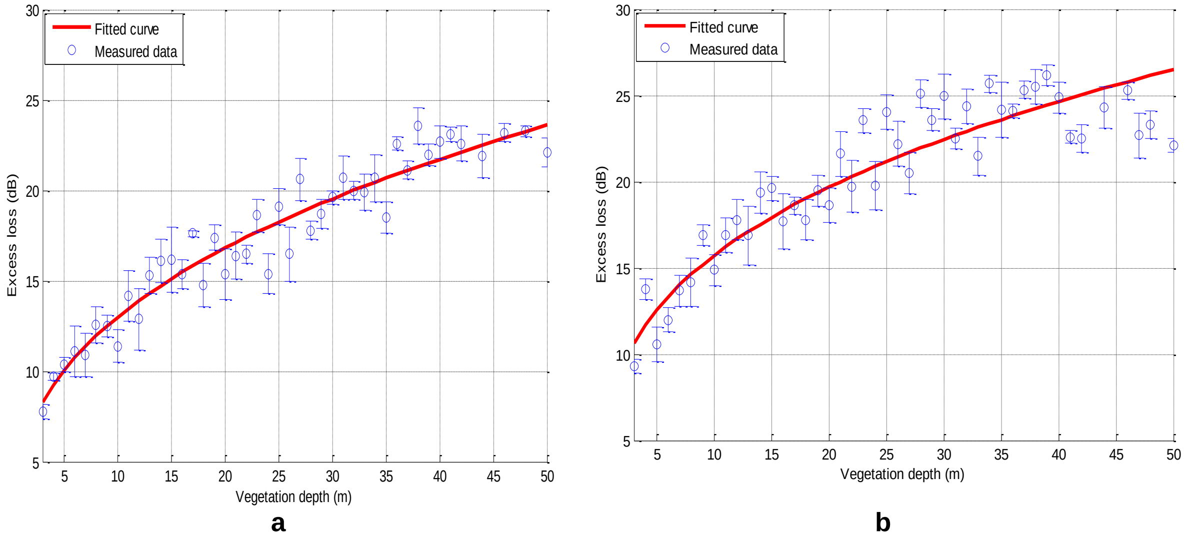
Where K represents the parameter under investigation e.g depth of vegetation (d_f). *a* and *b* are variables that were obtained through method of least square fit which was well optimised to give the best fit to the experimental data. In order to arrive at a model that will be of more general use, combined data from different sites and paths with similar operational contexts have been grouped together and average values taken. These are as represented in the plots below as getting a best fit out of this combined data would reduce site-dependent anomalies and make the resulting prediction model more generic.

The resulting parametric equations that best describe the fitted curves in Fig. 8 are:

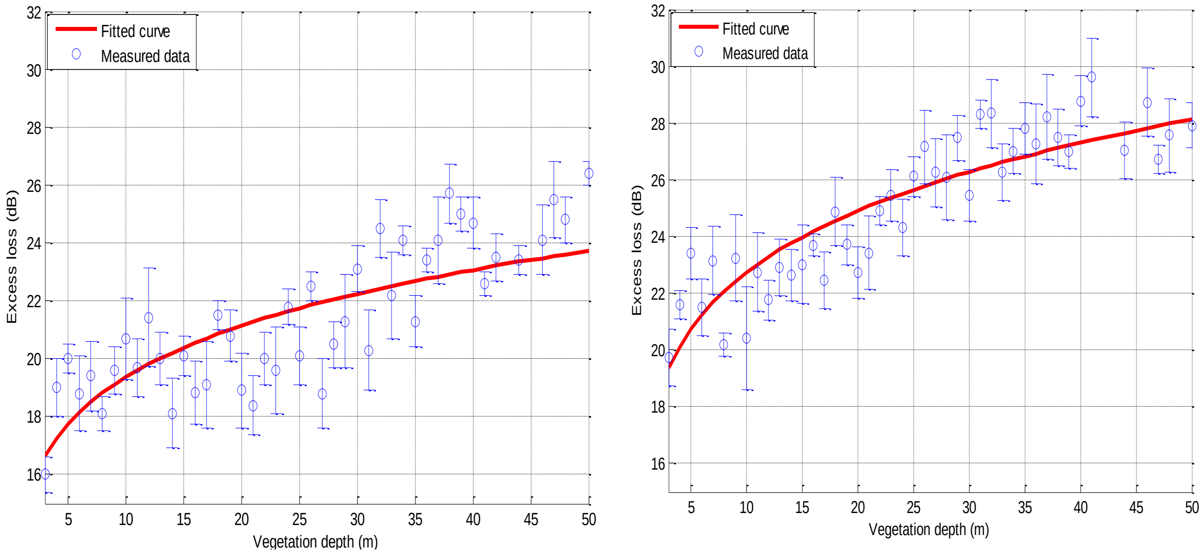
‘Inside’ Geometry:

$$L\,(dB) = 5.53\, {d_f}^{0.37}\, (at\ 3.5\ GHz) \qquad (4.0)$$

$$L\,(dB) = 7.46\, {d_f}^{0.32}\, (at\ 5.0\ GHz) \qquad (5.0)$$



Figs. 8a and b. Excess loss for ‘inside geometry’ fitted with a curve using the combined data at 3.5 GHz and 5.0 GHz



c

d

Figs. 8c and d. Excess loss for 'into geometry' fitted with a curve using the combined data at 3.5 GHz and 5.0 GHz

'Into' Geometry:

$$L\ (dB) = 14.49\ d_f^{\ 0.13}\ (at\ 3.5\ GHz) \qquad (6.0)$$

$$L\ (dB) = 16.75\ d_f^{\ 0.13}\ (at\ 5.0\ GHz) \qquad (7.0)$$

From the parametric equations of 4.0 to 7.0, a new prediction model was developed using the generic empirical prediction format given as

$$L\ (dB) = x\ f^y\ d_f^z\ (8.0)$$

Where values for x, y and z in Equation 8.0 have been obtained for both 'into' and 'inside' geometries as in Table 2 and the resulting equations are as in 9.0 and 10.0.

$$L\ (dB) = 0.56 f^{0.39}\ d_f^{\ 0.15}\ ('into'woodland) \quad (9.0)$$

$$L\ (dB) = 0.28\ f^{0.39}\ d_f^{\ 0.31}\ ('inside'\ woodland) \qquad (10.0)$$

In the modeled equation above, the frequency is expressed in MHz while depth of penetration is in metres. Positive values have been obtained for y and z which is an indication of increase in propagation loss as frequency and separation distance increases.This is in consistence with the anticipated behaviour of propagating radio waves in vegetation.

In order to test for validity of these new models in Equations 9.0 and 10.0, comparisons were made with well known empirical models FITU-R, MED and COST 235. The comparative accuracy in each case has been assessed using rms error function. In all, FITU-R gave the best fit to the new formulated models. The 'into' geometry shows least rms error values of 1.6 dB and 1.8 dB at 3.5 GHz and 5.0 GHz respectively. The 'inside' geometry also measures 2.6 dB and 3.0 dB rms error values at 3.5 GHz and 5.0 GHz. Generally, this (FITU-R) model has demonstrated a good prediction ability with our measurement data. This is due to the fact that its (FITU-R) formulation is based on measured data from a number of sites with different geometries, tree types and at a short foliage depth of less than 120 m [6].

Table 2. Parameter values for x, y and z

Geometry	x	y	z
Inside	0.28	0.39	0.31
Into	0.56	0.39	0.15

5. CONCLUSION

This work has presented an empirical model for predicting propagation loss in forest environment taking cognizance of the two dominant measurement geometries. The data used in deriving this model is obtained from extensive measurement campaigns in typical woodland and lines of trees, for in-leaf state. Two propagation geometries ("into" and "inside" woodland) have been considered in the investigations. Our findings revealed that the "into" geometry recorded higher attenuation values than the "inside" geometry. A simple inference from this is that for wireless communication in woodland or forest, localizing the two nodes inside the vegetation would give overall best performance in terms of signal impairment, link budget and link distance.

All the measured data have been evaluated using FITU-R, MED and COST 235 models. In all, the FITU-R which is a derivative of ITU-R model gave a better fit to our experimental data. In order to improve on predictability of the current empirical models, we therefore developed (from the measurement data), new empirical prediction model for each propagation scenario using parametric equations which are in line with the general formulations of the ITU-R models.

It is worthy of note that the measurement database used for this proposed model is limited in quantum, site specific and applicable to only in-leaf state. Obviously, further work is recommended to expand the scope of the database to other measurement sites and geometries. This will pragmatically guarantee universal application of the model and make it more generic.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Adegoke A.S, Measurement of propagation loss in tress at SHF frequencies. PhD Thesis, University Of Leicester, United Kingdom; 2014.
2. Hashim MH, Stavrou S. Dynamic impact characterization of vegetation movements on radiowave propagation in controlled environment. IEEE Antennas and Wireless Propagation Letters. 2003;2:316-8.
3. Al-Nuaimi MO, Hammoudeh AM. Measurements and predictions of attenuation and scatter of microwave signals by trees. IEE Proceedings-Microwaves, Antennas and Propagation. 1994;141(2):70-6.
4. Al-Nuaimi MO, Stephens RB. Measurements and prediction model optimisation for signal attenuation in vegetation media at centimetre wave frequencies. IEE Proceedings-Microwaves, Antennas and Propagation. 1998;145(3):201-6..
5. Savage N, Ndzi D, Seville A, Vilar E, Austin J. Radio wave propagation through vegetation: Factors influencing signal attenuation. Radio Science. 2003;38(5):9-1.
   DOI:10.1029/2002RS002758, 2003.
6. Meng YS, Lee YH, Ng BC. Empirical near ground path loss modeling in a forest at VHF and UHF bands. IEEE Transactions on Antennas and Propagation. 2009;57(5):1461-8.
7. Seville A, Craig KH. Semi-empirical model for millimetre-wave vegetation attenuation rates. Electronics Letters. 1995;31(17):1507-8.
8. Adegoke AS, Okpeki UK, Green O. Radio wave propagation In a forested channel. Journal of Engineering Research and Reports. 2022;22(9):33-40.
   DOI: 10.9734/JERR/2022/v22i917562,
9. Elechi P, Luckyn BJ, Kum MN. Investigation of global system for mobile communication signal coverage in faculty of engineering, Rivers State University, Port-harcourt, Nigeria. Journal of Network Security Computer Networks. 2021;7(3):27-39.
10. Myagmardulam B, Tadachika N, Takahashi K, Miura R, Ono F, Kagawa T, Shan L, Kojima F. Path Loss Prediction Model Development in a Mountainous Forest Environment. IEEE Open Journal of the Communications Society. 2021;2:2494-501.
11. Olabisi O, Adeniran AO, Ebisemiju AG, Areo SO. Investigation on effect of homogenous multiple lines of trees on wireless communication system. Pacific Journal of Science and Technology. 2021;22(2):101-107.
12. International Telecommunication Union (ITU), Attenuation in Vegetation, ITU-R Recommendation 833-8. Geneva; 2012.

13. Caldeirinha RFS, Morgadinho S, Frazao L, Cuinas I, Sanches M, Al-Nuaimi MO, Wind incidence effects on channel dynamics in vegetation media at 40GHz. IEEE International Conference on Geoscience and Remote Sensing, Denver CO; 2006.
14. Caldeirinha RFS. Radio characterisation of single trees at micro- and millimetre wave frequencies, Ph.D Thesis , University of Glamorgan; 2001.
15. Benzair B, Characterisation of radio wave propagation inside buildings and through vegetation. PhD Thesis, University of Bradford; 1993.
16. Amajama A, Donathus EB, Daniel EO. Novel effect of vegetation (foliage) on radio wave propagation. International Journal of Engineering Research and General Science. 2015;3(6).
17. Agugo FO, Adekunle AS. Characterization of near-ground radiowave propagation profile of the mangrove and rain forest areas of nigeria. In3rd IEEE International Conference on Adaptive Science and Technology (ICAST 2011). 2011;249-255. IEEE.
18. COST 235. Radio propagation effects on next-generation fixed-service terrestrial telecommunication systems. Final report, Luxembourg; 1996.
19. Michael AO. Further investigation into VHF radio wave propagation loss over long forest channel. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. 2013;2(1):705-10.
20. Ndzi DL, Kamarudin LM, Ezanuddin AA, Zakaria A, Ahmad RB, Abd Malek MF, Shakaff AY, Jafaar MN. Vegetation attenuation measurements and modeling in plantations for wireless sensor network planning. Progress In Electromagnetics Research B. 2012;36:283-301.
21. Meng YS, Lee YH. Investigations of foliage effect on modern wireless communication systems: A review. Progress In Electromagnetics Research. 2010;105:313-32.
22. Meng YS, Lee YH, Ng BC. Measurement and characterization of a tropical foliage channel in VHF and UHF bands. In 2006 10th IEEE Singapore International Conference on Communication Systems. 2006;1-5. IEEE. DOI:10.1109/ICCS.2006.301406, 2006.
23. Jain M, Kuriakose G, Balakrishnan R. Evaluation of methods to estimate foliage density in the understorey of a tropical evergreen forest. Current Science. 2010;508-15.
24. Dias MH, de Assis MS. An empirical model for propagation loss through tropical woodland in urban areas at UHF. IEEE Transactions on Antennas and Propagation. 2010;59(1):333-5.
25. Adegoke AS, Siddle DR. Broadband wireless access in vegetated channel. IEEE (electron devices) Colloquium, University of Manchester, United Kingdom; 2013.

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