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Radio Wave Propagation in a Forested Channel

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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

The appearance of vegetation along radio communication channel can significantly reduce quality of propagating signal. Hence, the need for wireless signal operators to understand the characteristic of channel components for effective radio planning and deployment.

This paper has investigated the influence of vegetative channel on wireless signals and examined the dependence of signal loss on path geometry. Measurements were conducted in a sort-depth forest (at SHF frequencies) following two different paths (paths 1 & 2) within the woodland. The experimentation was conducted in autumn and summer so as to determine likely seasonal effect on losses along different path geometries.

Results show decay in signal level as the depth of penetration increases which also varies from path to path. These (results) were later compared with standard empirical models MED, FITUR and COST 235 and it shows a statistical adherence with only one of the models, the MED.

It is therefore imperative that for effective signal deployment devoid of significant impairment, wireless network operators must take cognisance of the channel characteristics and path geometries in order to guarantee proper planning, modeling and deployment.

Keywords: Vegetative channel; attenuation; empirical; modelling; forest.

1. INTRODUCTION

The presence of vegetation along wireless radio path can cause adversity to telecommunication services as they may block the line of sight (LOS) path, upon which the signal is forced to follow different paths to the receiver [1]. Forest is a complex environment that consists of trees

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arranged in a random manner, twigs, branches and leaves. Naturally, radio waves propagating in such environment will experience scattering, diffraction and absorption due to these complex components that make up the forest. The overbearing effect of these propagation phenomena is that the propagating signal will suffer attenuation (signal loss) and as a result, reduction in link distance. This has to be considered and compensated for by network planners in order to establish a highly reliable communication especially in a forested environment.

The study of radio propagation in forest environment finds its application in the military (for battlefield communication), search and rescue operation and surveillance. Since the 1960, a lot of works have been done by researchers in the field to investigate the effects of forest environment on radio wave. Theoretical efforts by [2-5] and experimental investigations by [6-12] are all aimed at estimating the influence of vegetation on radio waves. Experimental investigations leading to empirical formulation is easy to accomplish but their application may not be universal due to variations in measurement environment and are site specific. However, theoretical formulation is more universal in application, but requires a more complex mathematical computations. The international telecommunication union (ITU), through their collaborative works have provided a framework for the characterization of radio wave in vegetated channels. From their work, radio wave propagated in a vegetative channel is seen to suffer loss which is dependent on frequency and depth of penetration into the vegetation. A generic empirical prediction model was proposed by ITU which is

$$L\,(dB) = x\,f^{y}\,d_f^{z} \qquad (1.0)$$

Where f is the Frequency and d_f is the depth of penetration into the vegetation. x, y and z are variables in which their values can be obtained through measurements. y and z are two parameters that indicate the frequency and distance dependences of vegetation-induced excess loss in the parametric equation.

In furtherance to this, [13] carried out measurement in a forest covering a depth of 64km at a frequency of 92.1MHz (VHF). The forest has a mixture of Mahogany, Mango, Iroko and Palm trees with dense canopies. Their result shows that the propagation loss recorded in the forest is due to the trees canopies and ground reflections, rather than foliage induced loss only. The ground reflection here is probably due to the measurement geometry adopted and the link distance involved. In an earlier work by [10], an experimental investigation was conducted in a short depth forest of 46m having copse of Sycamore and Lime trees at 38GHz. Their result shows different attenuation values with changing gradient. At greater depth, the measured data appeared to depict zero gradient and gave a poor agreement with MED model. The authors later proposed a prediction model in line with the standard ITU format as in

$$L(dB) = 0.37\,f^{0.3}\,{d_f}^{0.38} \qquad (2.0)$$

In a similar manner, [14] carried out investigation in a forest grown with Mango and Palm plantation in the frequency range of 400MHz to 7.2GHz. The measurement followed different path geometries within the plantation. Their result shows different attenuation value which is dependent on the path geometry. An inference from this work is that for a wireless sensor network application in vegetation, the communicating nodes should be placed at the trunk level for optimal signal coverage.

A little more of advanced finding to this was reported by [9] where lateral wave was discovered to have taken prominence at higher propagation depth. This lateral wave is a diffracted field component that travels mostly in the lossless air region by skimming over the tree tops which is later intercepted by the receiving antenna. The authors carried out an extensive study on near ground path loss modelling at VHF and UHF bands in the forested environment in Singapore covering a distance of over 1 km. Their result shows that at short forest depth (< 400 m), the standard empirical models are all in agreement with measured data. But at a depth of over 400 m, all the predicted models over-estimated the losses significantly by up to 40 dB. This is attributable to the presence of lateral wave at such distance. This lateral wave mechanism can enhance radio wave propagation over a large foliage depth and reduces the path loss considerably. The authors formulated a new prediction model, called the Lateral ITU-R model, which takes into account the lateral wave effects and is given as

$$L\,(dB) = 0.48\,f^{0.43}\,d_f^{0.13} + P.E \qquad (3.0)$$

Where f and d_f are as defined in Equation 1.0.

P.E is the plane earth model and is given as

$$P.E = 40log_{10}(d) - 20log_{10}(H_T) - 20log_{10}(H_R) \quad (4.0)$$

Where d is the distance between transmit and receive antennas in metres. H_T and H_R are the transmit and receive antenna heights respectively in metres [15-21].

It is therefore evident from the literature that radio waves obstructed by vegetation suffer some losses in excess of free space. These losses are frequency and vegetation depth dependent. Other factors are tree type, whether trees are in leaf or out-of-leaf, dry or wet, static or dynamic etc. Accurate modelling of this excess loss is highly desirable for wireless operators to serve as a useful tool in RF planning which will guarantee good quality of service (QoS), cell coverage optimisation and link availability in point-to-point communication.

The objective of this work is to investigate the behaviour of wireless signals in a vegetative channel with a view of determining the associated impairment and its dependencies on path geometry.

2. METHODOLOGY

This experimental investigation was conducted at Bruntingthorpe Proving Ground in Lutterworth, Leicestershire UK. This experimental location consists of a typical woodland which is rectangular in form, 60 m deep and about 250 m in length. It has a 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 transmit antenna was located outside the vegetation and placed at an inclined angle of 24° to the edge of the woodland while the observation point was situated within the woodland. This geometrical arrangement is best described as “Propagation into” the woodland. The inclined angle of 24° was arbitrarily chosen in order to see possible effects of penetration angle on measured loss. The propagation path is tagged ‘Path 1’ which covers a short depth of 40m. Measurements (at 3.5 GHz and 5.0 GHz) were taken at different points along this path with both transmit and receive antennas height fixed at 2.5 m. The separation distance between successive observation points is irregular due to non uniformity of tree arrangement along the path. In all, 18 observation points were considered for data loggin along the path. At each observation point, 50 samples of RSL data were logged in at an interval of 10 seconds in succession. Then, average values in dBm were estimated during post experimental processing exercise while the spread values were taking at same time. These measurements were conducted in autumn with a repeat experiment along same path in summer in order to verify likely effects of foliation.

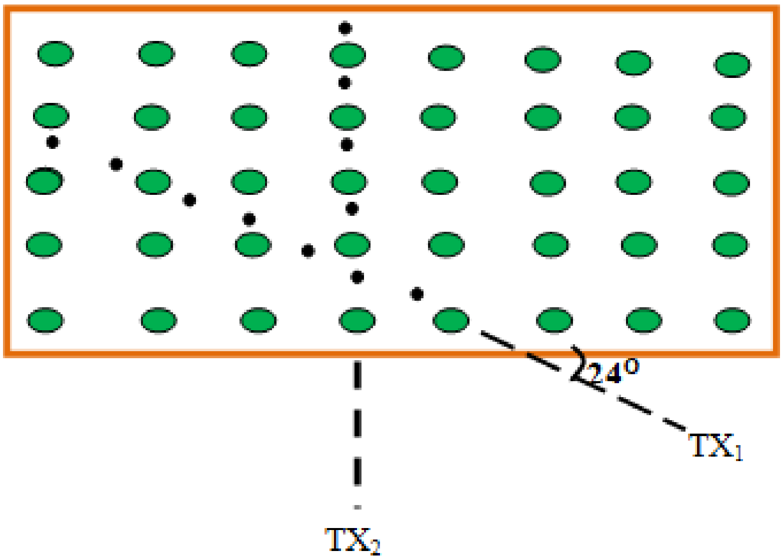

Fig. 1.0. Link configuration for woodland experiment

= Trees • = Observation points

T_{X1} = Propagation along path 1, T_{X2} = Propagation along path 2

Another path (tagged 'path 2') was chosen at this site which covers up to 50 m and measurements taken. Here, the transmit antenna was placed perpendicular to the edge of the woodland (as shown in Fig. 1.0). Same approach was followed here as in path 1 above. In addition to depth dependence verification, this is further aimed at verifying path geometry effects. The same antenna geometry (e.g antenna orientation and alignment as above) was adopted. Also, at some points during this experimentation, receive antenna height was changed to 7.5 m in order to verify component of top diffracted signal. However, this could not be sustained for long due to the terrain and difficulties of moving the antennas across clusters of interlocked tree branches. Results of findings and discussion are as presented below.

3. RESULTS

Figs. 2.0 and 3.0 show the plots of excess loss along path 1 in Autumn and Summer at 3.5 GHz and 5.0 GHz. From each of the curves, a changing gradient is seen. At a depth of between 0 to 7m (for summer data) a specific attenuation of 2.14dB/m and 2.57dB/m was recorded. But at larger depth, the gradient becomes shallower and specific attenuation reduces to about 0.6dB/m. The reason for this as reported in [7] is that at short vegetation depth, propagation is dominated by strong attenuation of line of sight (LOS) which forms the coherent component. The barrier created by the interlocked tree branches at the woodland edge also provided a form of site shielding. This (barrier) completely blocks the incident waves' LOS leading to high loss in signal power at the initial depth. But as the transmission moves deeper into the vegetation, isotropic scattering from tree to tree becomes the significant mode of propagation which results into a less attenuation rate. This different propagation mechanism is expected with radio waves propagating in woodland since woodland consists of random medium with many scatterers such as leaves, branches and trunks. The changing gradient was observed at millimetric frequency (38 GHz) as reported in [10] and also further observed at microwave frequencies in [7] and [5]. According to [7], the high specific attenuation at short vegetation depth is caused by the significant diminuition of the coherent (direct) component of the propagating wave. As the vegetation depth increases, the received wave changes from one predominantly influenced by the coherent component to one which consists of mostly diffused components due to forward scatter caused by leaves and branches. Among all the prediction models used in this evaluation, MED gave the closest fit with the measurement data at both frequencies.

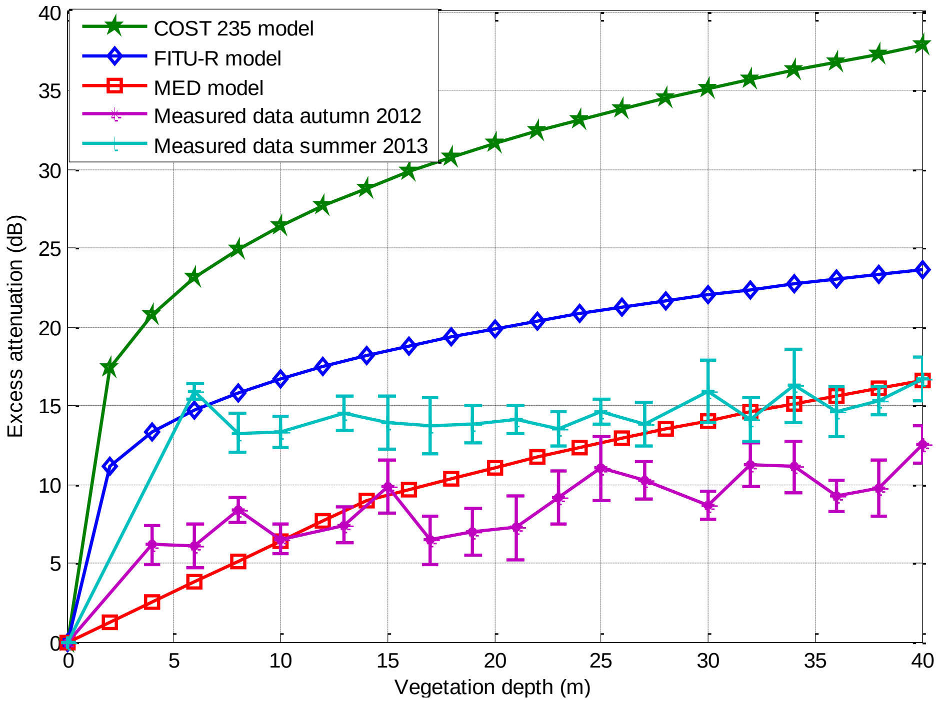

Fig. 2.0. Excess attenuation versus depth in autumn and summer at 3.5 GHz for path 1

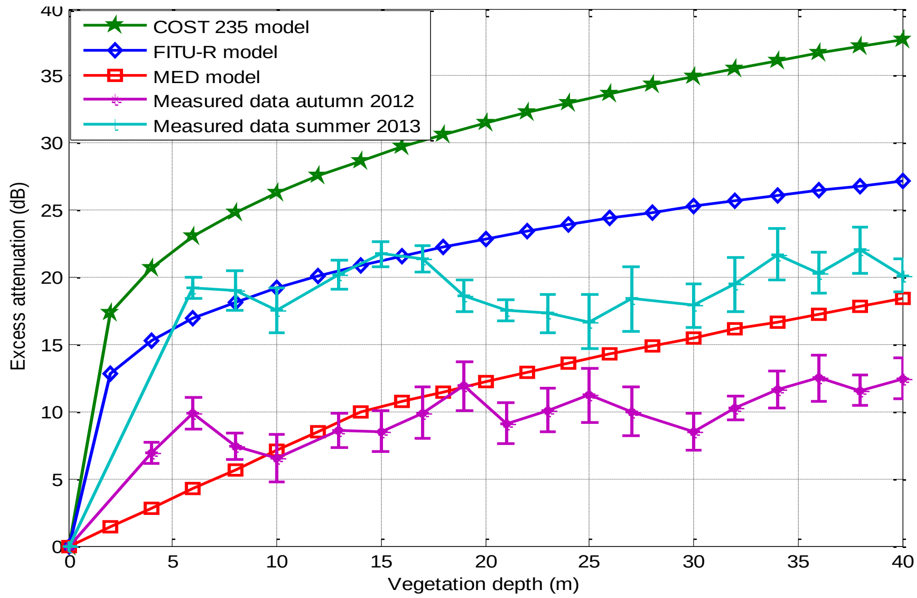

Fig. 3.0. Excess attenuation versus depth in autumn and summer at 5.0 GHz for path 1

Also, between the autumn and summer data, 6.0 dB and 9.5 dB extra losses were recorded in summer over autumn at 3.5 GHz and 5.0 GHz respectively. This is obviously due to the season of experimentation (summer) when the trees are well foliated and suggests that additional foliation along the path geometry has induced excess loss. An unusual feature is noticed in the summer data where the attenuation diverges from linear tendency along the path and approaching zero gradient. This trend is not typical of radio wave behaviour in vegetation. The reason for this is that during the period of this investigation (summer), the chosen path had suffered natural tree logging around 15 m to 40 m depth. This has therefore widen up the gaps between the trees. Thus, radio waves along such paths are made to travel more in a lossless air medium giving rise to high RSS.

In a similar manner, result of findings along path 2 is as indicated in Figs. 4.0 and 5.0.

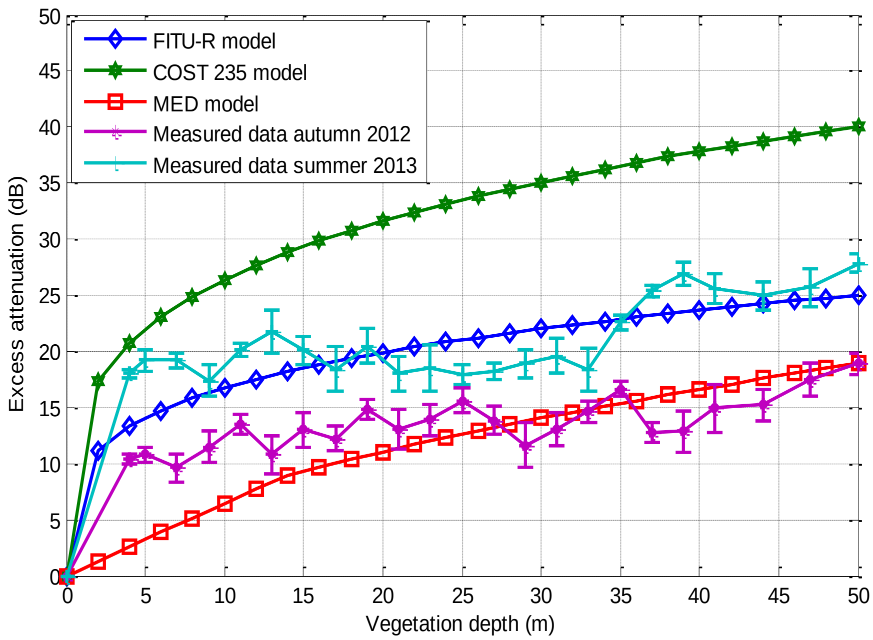

Fig. 4.0. Excess attenuation versus depth at 3.5 GHz for path 2

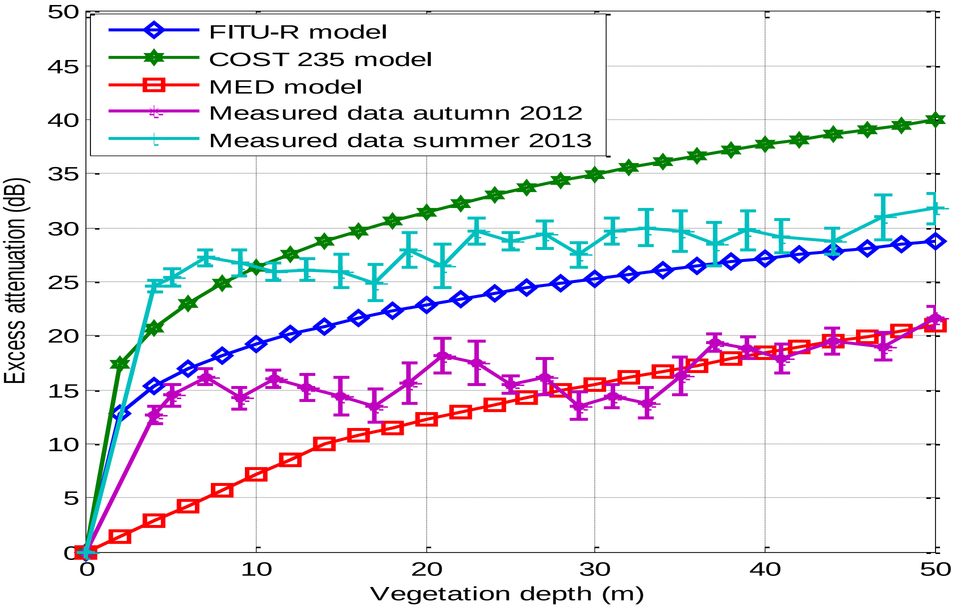

Fig. 5.0. Excess attenuation versus depth at 5.0 GHz for path 2

Several observations can be made from the plots of Figs. 4.0 & 5.0. First, a considerable variation in attenuation is recorded between autumn and summer data. Overall, an extra loss of 7.5 dB and 11.7 dB over autumn data was recorded in summer at 3.5 GHz and 5.0 GHz respectively and this is due to same reason as given in the discussion above. The signal level in each case decays at a considerably faster rate at short vegetation depth. A linear and higher dependence of attenuation on depth is seen along this path compared with observed trend along path 1. Measured attenuation is consistently higher along path 2 (by 7 dB to 10 dB) compared with path 1. This is due to high density of tree components along the path (path 2). The unformity of trees along path 2 is also a contributing factor. A preliminary conclusion that can be drawn from here is the dependence of propagation loss on path geometry.

4. CONCLUSION

The results obtained from experimental data and their analysis show an overall increase in propagation loss with depth of vegetation. However, the trend shows variation from path to path. Apparently, propagation loss along different paths within same woodland was seen to give different values of attenuation even using same antenna geometry (antenna height, separation and orientation). The main factor is the non-homogeinity of the woodland and density of tree parameters along the chosen paths.

It therefore becomes imperative for network designers and planners to take cognizance of channel components along any chosen path for effective estimation of the link budget.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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