MEASUREMENT AND ANALYSIS OF TEMPORAL FADING DUE TO MOVING VEGETATION

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INTRODUCTION

Increasing wireless network capacity and improving system quality of service (QoS) requires a deeper understanding of how the environment surrounding the transmitter and receiver influences radiowave propagation. In areas like residential, rural or even urban environments, vegetation is one of the features that contributes fading effects to the propagated radiowave. While considerable attention has been given in the literature on the effects of absorption and scattering effect of assumed static vegetation bulk [1,2,3], relatively few studies have dealt with the effects of moving vegetation under the influence of wind [4,5]. For an accurate prediction of channel characteristics, adverse conditions should be taken into consideration. Thus, static representation of vegetation effects does not represent these conditions, as trees are subjected to movement under strong wind influence. This paper reports on an experimental study of temporal variations of the received signal in areas that are shadowed by deciduous vegetation structures at frequencies of 0.9 GHz and 1.8 GHz. Wind speed, polarisation and the frequency dependency of multipath-induced temporal fading characteristics were investigated. The measurement approach used is described in the following section. The main results presented include the received power levels during different wind conditions. Next, the fast fading statistics of the signal are extracted, analysed and discussed. Finally, conclusions drawn from this study are provided at the end.

MEASUREMENT APPROACH

The experiments were conducted outdoors, where signal strength and environmental data were acquired. One experimental site for 0.9 GHz and three experimental sites for 1.8 GHz were identified. During the measurements, the transmitter and receiver remained in stationary positions. These scenarios were set to allow the recording of received signal power variations due to the movements of the vegetation structure. The transmitted signal from an existing mobile operator base station was recorded in line of sight (LOS) and vegetation shadowed conditions. A dual-band Global System for Mobile (GSM) scanning receiver with typical scanning speed of 300 samples per second was used to collect data at all experimental sites. In the measurement campaign, the strongest channel available was sampled at a rate of 200 Hz for both frequencies. A dual-band directional patch antenna with 3dB beamwidth of 80^o x 80^o was mounted on a tripod at a height of 2 meters above ground for all measurements. The antenna was placed in front of the vegetation bulk for the LOS condition and behind the vegetation bulk for the shadowed configuration measurements facing towards the base station about 3-4 metre from the centre of the tree structure. All experimental sites were populated by deciduous vegetation. Figure 1 and 2 show the samples of experimental sites.

Figure 1: Site 1 for 0.9 GHz measurements

Figure 2: One of the three sites for 1.8 GHz measurements

The wind speed, in m/s, and direction data were sampled every 10 seconds. A combination of an anemometer and wind vane was mounted on a 2-metre-high tripod and placed in an open area nearby in order to measure the wind speed incident onto the trees. The speed information was then categorised into Low (0-2 m/s), Medium (2-5 m/s) and High (above 5 m/s) ranges for analysis purposes.

MAIN RESULTS

The data collected from all experimental sites were combined and sorted according to the wind speeds, frequencies and polarisation to represent the general effects of deciduous vegetation. Typical examples of time dependent received signals acquired at 1.8 GHz are illustrated in figure 3 and 4 during low and high wind speed. It can be clearly seen from the figures that lower

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and slower RF power variations occurred during low wind speed.

Fading and power variations were enhanced as the wind speed increased. However, slower variations and low deep fades were observed in the received signal at 0.9 GHz.

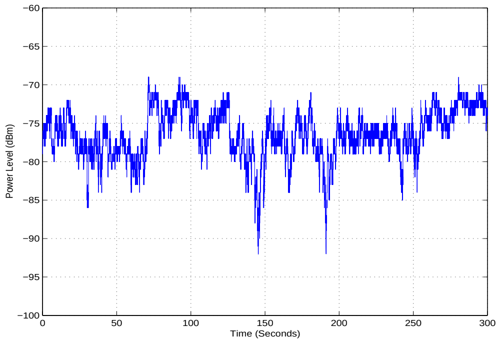

Figure 3: Signal variations during low wind speed at 1.8 GHz

For the 1.8 GHz data, the fast fading is expected to be the result of the temporal variations of the relative phase of multipath components resulting from the motion of individual leaves and branches within the tree structure.

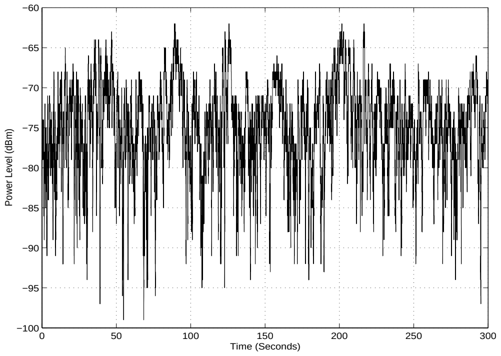

Figure 4: Signal variation during high wind speed at 1.8 GHz

In addition, a degree of relatively slow fading is also apparent in the fading signals shown in the above figures, which is believed to be caused by absorption and scattering from the larger tree structures such as the trunk and large branches.

FAST FADING STATISTICS

In order to study the characteristics of the fast fading components in the received signals, the first-order statistics, namely probability density function (PDF) and approximation of the Rice k-factor, and second-order statistics, namely the level crossing rate (LCR), were constructed from the measured data files. Approximately 5 hours worth of power measurement data collected for various conditions and surroundings were used in the analysis. The fast fading analysis was carried out together for all data for all trees for specific frequency. Comparisons of the fast fading statistics with respect to wind speed, frequency and polarisation were carried out and are explained in the next sections.

First-order statistics

The probability functions constructed from the measured data were compared to the Rayleigh and Rician distributions. In order to verify the goodness of fit between the measured voltages and the theoretical distributions mentioned above, the Chi-Square-Goodness-Fit test was chosen [6] as it was used in [4]. The values obtained from Chi-Square, measured voltages showed a better fit to the Rician than Rayleigh distribution. Data during medium and high wind speeds follows the Rician distribution closer than the low wind speed data. An example comparison of distributions is shown in figure 5. Figure 6 illustrates a sample comparison of PDFs over wind speeds at 1.8 GHz for co-polarised measurements. The PDF plots for signal at 1.8 GHz – cross-polarised and 0.9 GHz – co-polarised measurements are not included here but are discussed in this section.

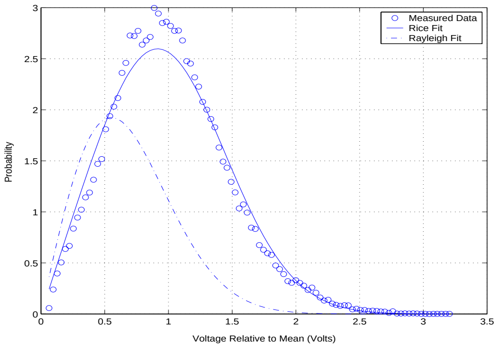

Figure 5: Fit to the distribution at 1.8 GHz – high wind speed

As can be seen from figure 6, there is a significant difference between the PDF curves during low wind speed and medium or high wind speeds. On the other hand, radio frequency (RF) signal behaviour is very similar during medium and high wind speeds.

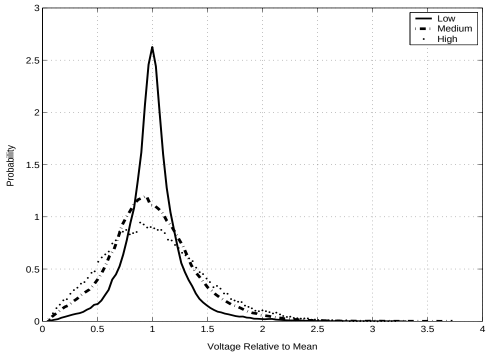

Figure 6:PDF results for 1.8 GHz – co-polarised measurements

Strong wind speed dependence can be inferred during the transition from low to medium wind speed. However, during medium to high wind speed condition, the signal variations no longer depended on the wind speed alone. It is suspected that other parameters such as short-term wind speed variations may have some contribution to the RF behaviour at this level. Similar results were found in [5]. No distinct change has been observed over the range of wind speeds for RF signals at 0.9 GHz. From the comparison of PDFs between the two polarisation configurations, the cross-polarised data PDF at 1.8 GHz was steeper than the co-polarised data shown in figure 7 for low wind speeds.

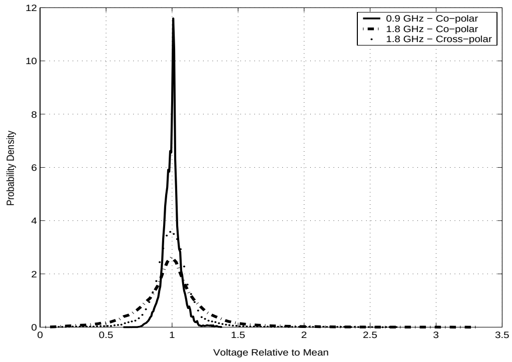

Figure 7: PDF results at low wind speed

However, as the wind speed increased to the medium and high ranges, both co-polarised and cross-polarised PDFs become similar, as can be seen in figures 8 and 9 respectively.

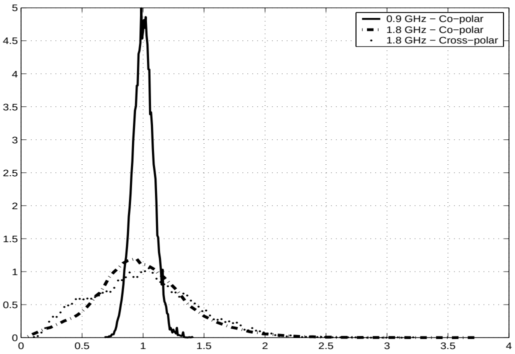

Figure 8: PDF results at medium speed

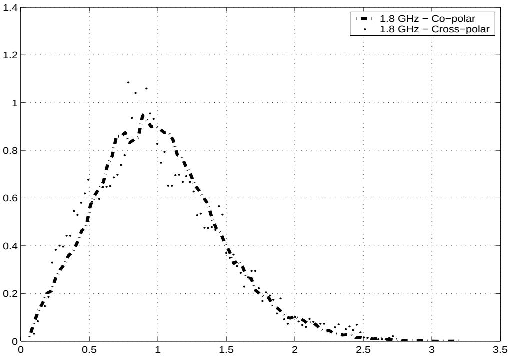

Figure 9: PDF results at high wind speed

There were less RF signal variations when the receiver antenna was in the cross-polarised configuration compared with the co-polarised configuration during low wind speed, but no significant difference was observed as soon as the wind speed picked up. Since the signal distribution during windy conditions can be approximated using the Rician distribution, one of the statistical characteristics of the fast fading can conveniently be described by the physical interpretation of its k-factor [7]. High k-factor represents a strong mean/coherent component relative to multipath and low value explains relatively high multipath contributions. The Rice k-factors approximated from the measured data for deciduous vegetation are indicated in figure 10. An exponential fit was used in order to visualise the variation of k-factor with wind speed. From the figure, it can be concluded that the k-factor decreases with increasing wind speed. The same behaviour of k-factor was found at 0.9 GHz and 1.8 GHz. For 0.9 GHz the fast fading distribution tends to be Gaussian with large k-factor values. In other words, there is always a dominant ray present. As wind speed increases, the Rician distribution degenerates towards the Rayleigh distribution with low k-factor values. The k-factor is presented as a linear power ratio. Two empirical functions relating the k-factor and the wind speed for 1.8 GHz (co-polarised) and 1.8 GHz (cross-polarised) were derived as follows, where v is the wind speed in metres per second. For f = 1.8 GHz, co-polarised:

$$k_{co} = 24.9e^{-5.4v}$$

For f = 1.8 GHz, cross-polarised:

$$k_{cross} = 51.4e^{-0.8v}$$

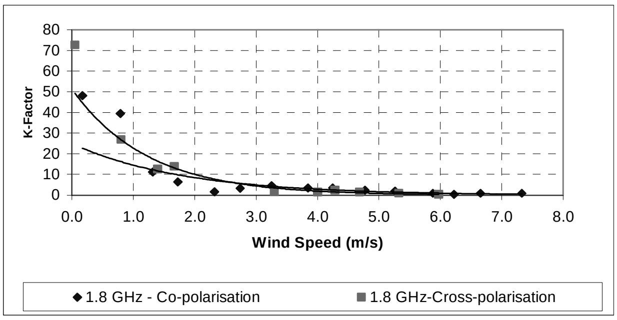

Figure 10: Variation of k-factor with wind speed at 1.8 GHz

Second-order statistics

Second-order statistics in the form of level crossing rates (LCR) have been derived from the measured data. Results for typical windy conditions at 1.8 GHz, (co-polar measurements), are shown in figure 11. The curves indicate highest concentration of level crossings per second round the 0 dB, root mean square (RMS) level. The concentration of level crossing at 0 dB is at the highest value during low wind speed and reduced during medium and high wind speed. This suggests that the signal changing activity at RMS level had been reduced over increasing wind speed. In addition, the overall LCR curves appeared to be widened (increase in level crossing at given signal level) at higher wind speed. However, the distinction between LCR curves during medium and high wind speed is less obvious than the distinction between LCR curves during low and medium wind speed. These results reinforce the findings that greater signal variation occurred at higher wind speeds and the mechanism has moved from coherent to a multipath-dominated situation. Similar observations were gathered from the 1.8 GHz – cross-polarised and 0.9 GHz – co-polarised measurements. Nevertheless, at 0.9 GHz, only minor LCR differences were noticed over the wind speed. No data is available during high speeds. In addition to the comparison of fast fading LCR over wind speed, a comparison study of signal behaviour with frequency was carried out using the data at 0.9 GHz and 1.8 GHz with the same polarization.

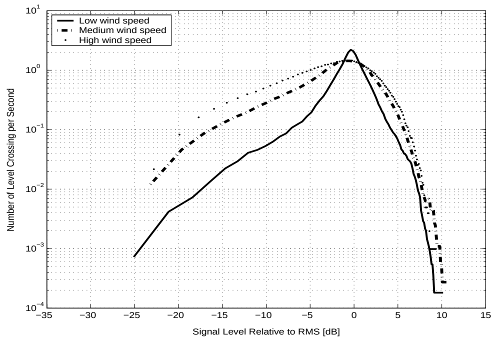

Figure 11: LCR results at 1.8 GHz – co-polarised measurements

Figures 12 and 13 show the LCR comparisons during low and medium wind speeds respectively.

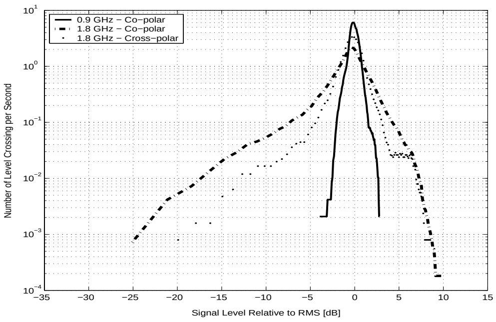

Figure 12: LCR results during low wind speed

It is apparent that the LCR curve at 1.8 GHz is flatter and wider than at 0.9 GHz in both cases.

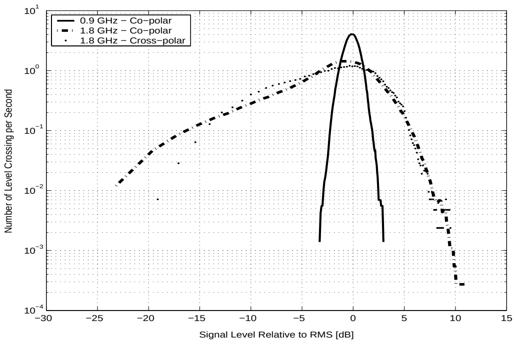

Figure 13: LCR results during medium wind speed

The LCR curve derived from cross-polar measurement data at 1.8 GHz, as shown in figure 12, appeared to be narrower than co-polar during low wind speed. But, LCRs (co- and cross-polarised) during medium and high speeds resemble each other except in the deep fade region, (region below the RMS value), where the number of level crossings for cross-polar is less and the curve is narrower (figure 14).

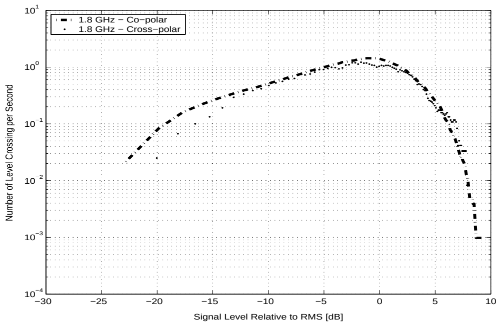

Figure 14: LCR results during high wind speed

CONCLUSIONS

In order to study the wind speed dependency of radiowave propagation in vegetation environment, measurements have been performed on various types of deciduous trees at 0.9 GHz (co-polarised) and 1.8 GHz (co- and cross-polarised). Strong wind speed dependency of RF signal was found as wind speed increased from low to medium speed. However the signal behaviour did not vary significantly from medium to high wind speeds. At 0.9 GHz, the fade statistics were not greatly dependent on wind speed. The cross-polarised configuration of the receiver was less affected by vegetation during low wind speed than co-polarised configuration. Finally, it was concluded that RF propagation transmission through vegetation is strongly dependent on wind speed characteristics, frequency and to an extent on polarisation.

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