Near Ground Channel Characterization and Modeling for a Tropical Forested Path

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Abstract

Application of the short range military sensor network in the foliage environments requires a full understanding of the forested channel in order to optimize its performance. This paper reports the details of the near ground narrowband and wideband forested channel characterization at VHF and UHF bands. From these experimental results, it is observed that, when the frequency increases, the attenuation rate (path loss exponent $n$) decreases, while the delay spread statistics increases. This is due to the tree trunk induced scattering. As the frequency increases, the signal wavelength becomes comparable to the tree trunk size which results in more scattering components.

1. Introduction

Radio wave propagation through the forested area have been an interesting research topic since Tamir [1] proposed a half-space model to deal with radio wave (1-100MHz) propagation in forests over large depth (more than 1km) and explained the associated phenomenon dominated by a lateral wave mode of propagation. After that, narrowband (900-1800MHz) investigations have been performed on the effects of foliage on cellular base-to-mobile propagation [2-3]. The temporal variation of the received signal due to the effects of wind has been examined and found to be Rician distributed. In recent years, however, there has been a growing interest in the near ground (1~3m above ground) communications at short range due to the military applications such as communications between dismounted soldiers and/or vehicles. Besides J. Goldman et al. [4] reported an exponentially increase of the path loss with distance, G.G. Joshi et al. [5] have conducted a wideband channel characterization with foliage effect at VHF and UHF bands. However, from open literature, little research is done on the short range near-ground channel characterization in a tropical forested area which is often quite damp, and therefore, results in a higher propagation loss as compared to sub-tropical or temperate foliage.

The objective of this paper is to conduct an experimental channel characterization in a typical tropical forest at VHF and UHF bands. Path loss exponent $n$ and delay spread statistics will be discussed and compared to some published results. This will help us to gain a detailed understanding of channel characteristics to model and optimize communication performance.

2. Measurement Campaign

The foliage environment chosen for this study is located at East Coast Park, Singapore. This is a rectangular shaped site (an area of 550m²) planted with palm trees (analogous to coconut tree), 10m in height. The forested terrain is fairly flat, consisting of soil and sand. The trees are nearly equally spaced with a separation of 1.2m and their trunks with a diameter of 20cm. The leaves of these trees are approximately 0.4×1.3m. The plantation is close to the seaside therefore, the environment is considered to be damp. The photograph in Fig. 1 shows part of the foliage at the experimental site.

Two setups were used in this study. 1) Narrowband measurement: The transmitter, consisting of an Agilent 8648D signal generator and a vertically polarized, omni-directional antenna–AX-71C which has a typical gain of 2.4 dBi. The receiver used is a HP8593E spectrum analyzer for the measurement of signal strength at 40MHz, 80MHz, 250MHz, and 550MHz. The received signal passes through the same vertically polarized antenna and a low noise amplifier with a typical gain of 19dB, then into the spectrum analyzer. 2) Wideband measurement: A HP8753E vector network analyzer (VNA) performs the transmission and reception of the radio wave signal. The frequency
response over the three bands of interest (30-80MHz, 200-250MHz, and 540-590MHz) was measured with proper setting. The measured complex data from the VNA was stored in a computer via a GPIB interface through a LABVIEW control program. Post-processing of the data was performed offline using Matlab. For both measurements, the data was collected in a sunny weather with a constant antenna height of 2.15m.

Fig. 1: Photograph of the Palm Plantation

3. Results and Analysis

Before embarking on the processing of the narrowband and wideband results, proper data calibration was performed separately to minimize the system effect. In the following part, narrowband (path loss exponent $n$) and wideband (delay spread statistics) results are discussed individually, and some consistent findings are observed.

3.1 Path Loss Exponent $n$

In order to determine the path loss exponent, $n$, a similar technique as detailed in [2, 4-5] is used. A logarithmic fitting to the foliage local mean path loss as foliage depth increases is done using (1):

$$\text{Pathloss} = C + 10n\log_{10}d + X_s$$

where $C$ is a constant, $d$ is the foliage depth, $n$ is the path loss exponent and $X_s$ is a Gaussian random variable, with zero mean and variance $\sigma^2$. The $n$ and $\sigma$ value are empirically estimated by using the linear regression techniques. Fig. 2 (a) shows a typical scatter plot of the path loss variation versus distance at 250MHz referring to the free space loss. It can be found that the forest environment induces an additional loss as compared to the free space propagation. By the linear regression method, the path loss exponent $n$ is found to be 5.8, which corresponds to 58dB attenuation per decade of distance at this frequency, while the stand deviation $\sigma$ is found to be 4.52dB, which indicates the shadowing effect induced by the foliage medium, such as the tree trunks, the major scatterer in this palm plantation.

Empirical path loss exponent, $n$, at other frequencies are calculated and plotted in Fig.2 (b). It can be seen from Fig.2 (b) that, generally, path loss exponent, $n$, decreases as frequency increases for the short range radio wave propagation. This is due to the fact that the antenna height of 2.15m is at the tree trunk level. Therefore, the received signal has contributions from signals propagating through the forested area between the ground and the tree canopies. The high attenuation rate (path loss exponent $n$) for short range propagation is caused by the significant diminution of the coherent component of the propagating wave. As the frequency increases, the received wave changes from one predominately influenced by the coherent component at lower frequency to one which consists gradually of the incoherent components due to the forward scattering caused by tree trunk at higher frequency. At higher frequencies, the wavelength of the signal becomes comparable in size with the dimensions of the tree trunk, hence, more incoherent components due to the forward scattering caused by dense tree trunks. This forward scattering process as the frequency increases can counteract the loss due to absorption and attenuation caused by the palm tree trunks, hence the much lower attenuation rate. The increased scattering effect as frequency increases has been verified through the estimated $\sigma$ values in our experiment. It is found that, as frequency increases from 40MHz to 550MHz, the empirical $\sigma$ value increases from 4.31dB to 5.70dB.
Further, the estimated path loss exponent $n$ is compared to the results obtained by other researchers [4], and plotted in Fig. 2 (b). Both results were extracted from data measured at the tree trunks level and at same frequency band. From Fig. 2 (b), it can be observed that there is a same trend for the path loss exponent $n$. That is, as frequency increase, the path loss exponent $n$ will decrease generally. However, the path loss exponent $n$ in [4] is lower as compared to ours, except at 163.4MHz which is due to the wind-induced motion of foliage as reported by the authors. The main reason for the higher path loss exponent $n$ in our experiment as compared with [4] is due to the damp foliage environment as the plantation is located directly beside the sea and in a tropical environment.

![Typical scatter plot of propagation path-loss with distance at 250MHz](image1)

![Variations of path loss exponent $n$ with Frequency in MHz](image2)

Fig. 2: Narrowband results at VHF and UHF bands in the palm plantation

3.2 Delay Spread Statistics

In this part, the channel impulse response $|h(\tau)|$ is obtained by performing the Inverse Fast Fourier Transform (IFFT) on the calibrated channel transfer function ($S_{21}$) and is modeled with an exponential model as shown in Equation-2.

$$h(\tau) = \sum_{k=0}^{N} a_k \exp(j\beta_k)\delta(\tau - \tau_k)$$

where $a_k$, $\tau_k$, and $\beta_k$ are the strength, delay and phase of the $k^{th}$ multipath component, and $N$ is number of the multipath components. Fig. 3 shows a typical power delay profile (PDP) in the palm plantation at 200-250MHz band, which is proportional to $|h(\tau)|^2$. From Fig. 3, it is obvious that there are multiple received components, which may be due to the ground reflection, tree trunk scattering, etc.

![Typical power delay profile in the palm plantation at 200-250MHz band](image3)

Fig. 3: Typical power delay profile in the palm plantation at 200-250MHz band
Next, the delay spread statistics such as mean delay spread and root-mean-square (RMS) delay spread \( \tau_{rms} \) are used to characterize the PDPs. The RMS delay spread, which measures the standard deviation of the delay spread of the PDP about its mean delay, is defined as the square root of the second central moment of the PDP and given by:

\[
\tau_{rms} = \sqrt{\frac{\sum_{k=1}^{N} (\tau_i - \bar{\tau})^2 a_i}{\sum_{k=1}^{N} a_i^2}}
\]

(3)

where mean delay \( \bar{\tau} \) is given by

\[
\bar{\tau} = \frac{\sum_{k=1}^{N} \tau_i a_i^2}{\sum_{k=1}^{N} a_i^2}
\]

(4)

The estimated mean value of the RMS delay spread and mean delay spread at foliage depth of 35m to 45m are listed in Table 1. From Table 1, it can be found that as frequency increases, the delay spread statistics increases. That is, more multipath components are received. This is consistent with the previous findings on the path loss exponent \( n \). More scattered components will be produced as the signal wavelength becomes comparable to the size of the tree trunk.

Table 1. The empirical delay spread statistics in palm plantation

<table>
<thead>
<tr>
<th>Frequency band</th>
<th>30-80MHz</th>
<th>200-250MHz</th>
<th>540-590MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS delay spread</td>
<td>0.037µs</td>
<td>0.051µs</td>
<td>0.108µs</td>
</tr>
<tr>
<td>Mean delay spread</td>
<td>0.076µs</td>
<td>0.102µs</td>
<td>0.394µs</td>
</tr>
</tbody>
</table>

4. Conclusions

In order to study the short range forested radio wave propagation in VHF and UHF bands, narrowband and wideband measurements were carried out in East Coast Park, Singapore. By analysis of the path loss exponent \( n \) and delay spread statistics, it can be concluded that the tree trunk in the palm plantation is a major scatterer that can produce a significant amount of multipath components. As the frequency increases, the received wave changes from one predominately influenced by the coherent component at lower frequency to one which consists gradually of the incoherent components due to the forward scattering caused by tree trunk at higher frequency. Finally, it can be drawn that the damp tropical environment can result in a higher propagation loss rate as compared to sub-tropical or temperate foliage. These finding will be helpful to develop and optimize the modern military sensor network.

5. References


