VHF and UHF Propagation through a Coconut Plantation

Yee Hui Lee[1], Yu Song Meng[2]
School of Electrical and Electronic Engineering, Nanyang Technological University
Block S2, 50 Nanyang Avenue, Singapore 639798
[1]eyhlee@ntu.edu.sg, [2]meng0006@ntu.edu.sg,

Abstract

This paper reports the study of propagation through tropical coconut foliage channel for VHF and UHF bands. From the narrowband experimental data, the variation of path loss with distance in the foliage area is analyzed and compared with known values published by other researchers. Frequency domain measurements were also conducted to evaluate the effects of multipath fading on the propagating signal in foliage. All these results indicate that tree trunk in the coconut plantation is a major scatterer at high frequency, and tree canopy affects the low frequency signal a lot in short range propagation.

1. INTRODUCTION

Growing interest on radio-wave propagation in forested environments started from 1967 [1]. Since then, much effort has been placed in this are by researchers [2-3]. Several classical models for megahertz frequencies have been proposed. Tamir [1] raised the concept of lateral wave which is dominant for the propagation at treetop heights. Lagrone [2] treated the edge of the forest as a source of diffracted fields when modelling the path loss to subscribers located in a clearing within the forest. Recently, Dal Bello et al. [3] reported analysis of statistical nature of the time fading in UHF band and examined the range dependence and the base station height gain. However, details of megahertz signal propagation at tree trunk level over a short range has not been reported, and is significant for modern military application.

This paper reports on experimental studies of propagation over a forested channel for frequencies in the range of 30MHz–1400MHz.Various effects on signal propagation, such as tree trunks and canopies, has been investigated.

2. MEASUREMENT SETUP AND ENVIRONMENTAL DESCRIPTION

A. Measurement Setup

Two setups were used in this study. 1) 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. The received signal passes through the same vertically polarized antenna and a ZJL-3G amplifier (typical gain of 19dB), then into the spectrum analyzer. A maximum transmit–receive distance of 62m is used. 2) A HP8753E vector network analyzer (VNA) performs the transmission and reception of RF signal with a ZJL-3G amplifier at the transmitter end. Frequency sweep sounding techniques as introduced in [4] is used to measure frequency response over the bands of interest at 6 distances, 39.7m, 39.9m, 40.3m, 41.9m, 43.9m and 45.9m. The complex data from the VNA was stored in a computer via a GP-IB interface through a LABVIEW control program. Postprocessing of the data was performed offline using Matlab. The experimental specifications are tabulated in Table 1.

TABLE 1: OUTLINE OF THE MEASUREMENT

	Link distance	Frequency covered
Setup 1	31m to 62m (1 m separation)	30MHz to 1400MHz
Setup 2	39.7m, 39.9m, 40.3m, 41.9m, 43.9m,45.9m	30-80MHz 525MHz-575MHz 1350MHz-1400MHz

The schematic diagram of the setup is shown in Fig.1, where experimental Setup 1 is performed along the dotted line towards the receiver with 1 meter separation per measurement and experimental Setup 2 is performed at the locations marked with a '*'.

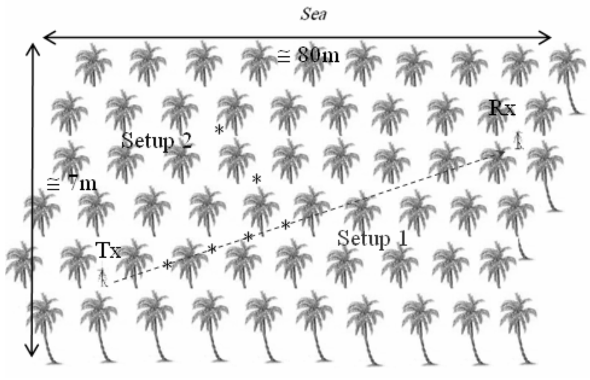


Fig. 1: The Schematic Diagram of the Experimental Setups

For all measurements, the receive antenna is kept at a fixed location whereas the transmit antenna is moved. The height of both antennas is kept constant at 2.4m.

B. Environment Description

The foliage environment chosen for this study is located at East Coast Park, Singapore. This is a rectangular shaped site (an area of 550m^2) planted with coconut trees, 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 radius of 10cm. 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. 2 shows part of the foliage at the experimental site.

Fig. 2: Photograph of the Coconut Plantation

3. Data Analysis and Results

The data collected using the VNA system is the frequency response of the devices connected between its two ports, including the channel, antennas, cables and frequency response of the VNA itself. To compensate the effect of the system on the measurement, a calibration of the system has to be carried out. The measurement system was set up in an open field test site to measure the systems' frequency response, $H(f)_{hardware}$. This result was automatically subtracted from the subsequent measurements, $H(f)_{measured}$ thus reducing the effect of the system on the measured data. The channel transfer function, $H(f)_{channel}$ can then be obtained in (1).

$$H(f)_{channel} = \frac{H(f)_{measured}}{H(f)_{hardware}} \quad (1)$$

A. Propagation Loss

The mean received power in dBm of the signal measured at each location with Setup 1 was extracted and used to determine the path loss between two antennas. For small range of distances in a foliage environment, path loss can be modelled using (2) as shown in [3],[5],[6].

$$Pathloss = \gamma + 10n\log_{10}d \quad (2)$$

where γ is a constant and the n is the slope index of the variation of path loss with distance. Fig. 3 shows a typical scatter plot of the path loss variation versus distance at 500 MHz with logarithmic fit. By least mean square method, the slope index n is found to be 6.8, which corresponds to 68dB attenuation per decade of distance at this frequency.

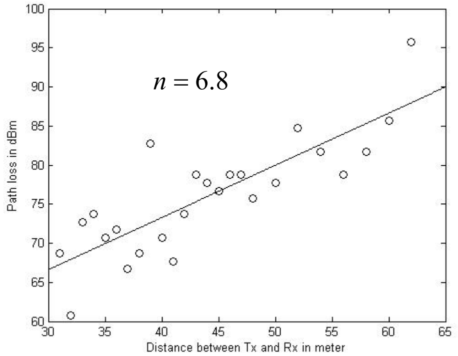


Fig. 3: The Path Loss Variation with Distance at 500MHz

Empirical slope indices n at other frequencies are calculated and plotted in Fig. 4. It can be seen from Fig. 4 that, generally, path loss index n decreases as frequency increases. This is due to the fact that the antenna height of 2.4m 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 for short range propagation in coconut plantation is caused by the significant diminution of the coherent component of the propagating wave as introduced in [7]. As the frequency increases, the received wave changes from one predominately influenced by the coherent component at lower frequency to one which consists mostly of the incoherent components due to the forward scatter 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 trunks, hence, more incoherent components due to the forward scattering were generated. This forward scattering process as the frequency increases can counteract the loss due to absorption and attenuation caused by the coconut tree trunks, hence the much lower attenuation rate.

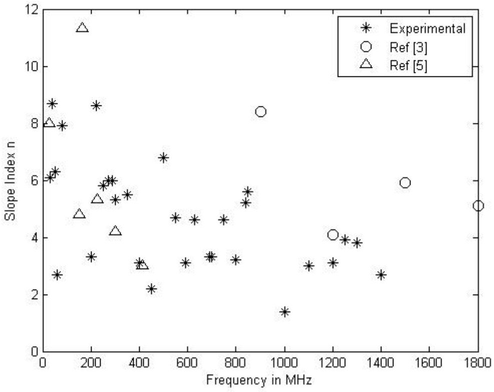


Fig. 4: Variations of Slope Index n with Frequencies in MHz as Compared with Others

Moreover, the larger fluctuation of the slope index *n* at lower frequencies is due to the diffused reflection of coherent component from the bottom of dense canopies. This can be explained with the help of Fresnel zone [8]. Based on the foliage depth used in this setup, the largest first Fresnel radius occurs at 30MHz, varying from 8.8m to 12.4m. As frequency increases to 1400MHz, the first Fresnel radius reduces (as shown in Fig. 5(b)) to between 1.3m to 1.8m. While comparing the first Fresnel radius with the antenna height of 2.4m and coconut tree canopy height of about 10m, it is found that the randomly distributed broader leaves of the canopy lies within the first Fresnel zone at the low frequency, as shown in Fig.5(a). This results in the large variance of the path loss slope index *n* at low frequencies.

(a): Plot of 1st Fresnel Zone at Low Frequency.

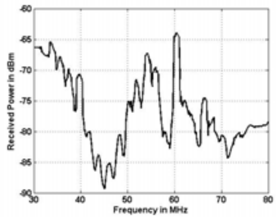
(b): Plot of 1st Fresnel Zone at High Frequency.
Fig. 5: Plot of 1st Fresnel Zone at different frequencies.

Further, results for path loss slope index *n* obtained using the same method at similar and higher frequencies can be found in [3] and [5]. Both results were extracted from data measured at the tree trunks level and shows similar trends (Fig. 4). In [3], the higher attenuation rate at a higher frequency range is due to attenuation from the crowded vehicular traffic in the surrounding avenue during daylight when the measurements were made. In [5], the results are lower than those presented here, except at 163.4MHz. This is due to the wind-induced motion of foliage as introduecd by the authors. The reason for the higher attenuation rate in our experiment compared with [5] is due to the damp tree trunk as the plantation is located directly beside the sea.

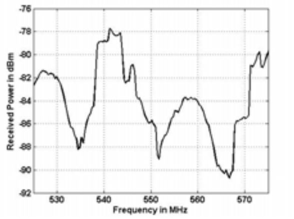
B. Coherence Bandwidth

It is well known that depending on the frequency range used and the propagation path, as different frequency signals propagate over the same paths, each frequency is affected to a varied extent. Hence, frequency selective fading is a manifestation of multipath propagation with different time delays.

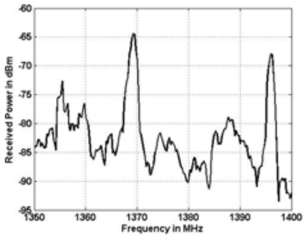
From previous studies, it has been found that tree trunk in the coconut plantation is a major scatter at high frequency, and tree canopy can affect low frequency signal quit a lot. This results in a significant amount of multipath propagation with different time delay. In order to evaluate the amount of multipath components in the interested frequency bands, coherence bandwidth is used. The results for 30-80MHz, 525-575MHz and 1350-1400MHz bands are presented in the following part.



(a): Low Frequency at 30-80MHz.



(b): Middle Frequency at 525-575MHz



(c): High Frequency at 1350-1400MHz.
Fig. 6: Plot of the Processed Received Signal Power with Frequency

Fig. 6 shows the power level over the frequency bands of interest. As seen, there is frequency selective fading since certain frequencies are attenuated more than others.

The frequency-selective behaviour of the propagation channel can be described in terms of the auto-correlation function for a wide sense stationary uncorrelated scattering (WSSUS) space channel. The complex autocorrelation of the channel of interest is obtained from (3) directly, where *H(f)* is the complex transfer function of the channel, *Δf* is frequency shift and * denotes the complex conjugate of the transfer function.

$$R(\Delta f) \cong \int_{-\infty}^{\infty} H(f)H^*(f+\Delta f)df \qquad (3)$$

The estimated coherence bandwidth B_c from (3) represents the statistical average bandwidth of the radio channel over which signal propagation characteristics are correlated in a certain value established which is known as coherence level. In this paper, a typical coherence level of 0.5 is chosen.

Fig. 7 shows the typical normalized frequency correlation function (3) for the 3 frequency bands at the distance, 43.9 meters. It is found that the frequency-correlation function decreases rapidly with respect to the frequency separation. It is also seen that the decrease is not monotonous as compared with the result from LoS propagation because the presence of significant scatters from tree trunks in the foliage generates an oscillation on the general trend of the curve. From the frequency correlation function obtained, coherence bandwidth B_c at coherence level 0.5 can be estimated.

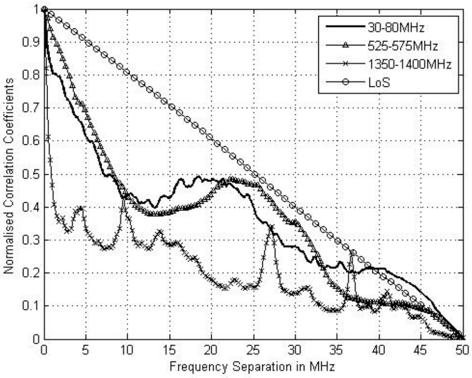


Fig. 7: Typical frequency coherence functions at 43.9m.

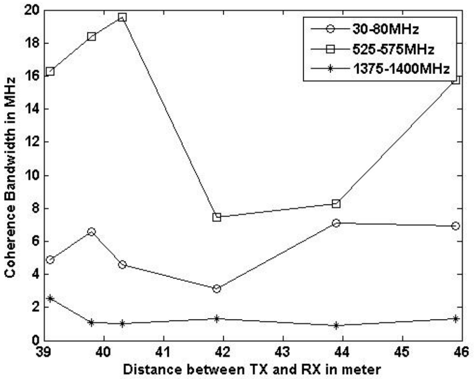


Fig. 8: Variations of coherence Bandwidth with Distance.

The coherence bandwidth as a function of the separation between transmitter and receiver antennas is plotted in Fig. 8. From Fig. 8, it is found that the coherence bandwidth at high frequency (1375-1400MHz band) is smallest due to the signal wavelengths of this band is the smallest compared with the other two bands and comparable in size with the physical dimensions of the tree trunk, hence, easily scattered.

However, it is observed that at low frequency range (30MHz to 80MHz), the coherence bandwidth is smaller than that of the middle frequency range (525MHz to 575MHz band). This is due to the fact that the coconut tree canopy at this frequency range lies in the Fresnel zone, thus, generating more diffused and reflected components.

Finally, it can also be found from Fig. 8 that the coherence bandwidth is highly variable with the location of the transmitter with respect to the fixed receiver at lower frequency and much steadier at higher frequency. This can also be explained by the mechanism of the propagation for short range propagation in a foliage environment. The highly scattered components at higher frequency produce less site-dependent results, while the lower frequency signal is more reliant on antenna location and the propagating path.

4. Conclusions

In order to study the propagation over coconut foliage in VHF and UHF bands, measurements were carried out in East Coast Park, Singapore. The slow shadowing and fast fading characterisation were both investigated.

The slope index *n* for the slow shadowing is found to be strongly frequency and site dependent as compared with some values found by other researchers. Coherence bandwidth results from frequency domain measurement are also presented. All these results indicate that tree trunk in the coconut plantation is a major scatterer that can cause a significant amount of multipath propagation, and tree canopy affects the low frequency signal quite a lot in short range propagation which can be analyzed with the help of Fresnel zone.

These are preliminary results in coconut plantation. Further experiments and analysis will be performed in other plantation to study in details the propagation loss and the effects of leaves, branches and tree trunks on different types of tropical foliage.

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