VHF and UHF Channel Characterization in a Tropical Rainforest

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Abstract—**This paper presents an analysis of radio wave propagation through a tropical foliage area, Marina South, located at the southern end of the Singapore Island. The propagation loss results obtained at VHF and UHF bands are presented and the effects from leaves, branches, and tree trunks are analyzed. The effect of wind on the propagation is also examined. From the measured data, the slope index *n* of the variation of path loss with distance in the foliage area is determined and compared with those reported by other researchers. Statistical analysis of the temporal variations of the received signal is performed. Results show that tree trunk is a major contributor of scattered signals in this frequency range when measurements are taken at tree trunk level. Scattering is found to increase as frequency increases.**

Keywords-VHF and UHF; channel characterization; tropical foliage

I. INTRODUCTION

There has been growing interest on radio wave propagation in forested environments since 1967 [1]. Much effort has been put in this area by many researchers [2-8]. Their studies revealed that attenuation in foliage depends on both the operating frequency and the type of vegetation including factors such as the size, shape, and angular distribution of the leaves and branches. Tamir [1] raised the concept of lateral wave which is supposed to be dominant for the propagation at treetop heights in the VHF and UHF regions, and experiences less loss as compared to other propagating components such as diffracted and multipath components. Lagrone [2] treated the edge of the forest as a source of diffracted field when modeling the path loss to subscribers located in a clearing within the forest. Range dependence, beam broadening, and depolarization of millimeter-wave beams in vegetation and the frequency dependency of these effects have been investigated in [3] both experimentally and theoretically. Al-Nuaimi *et al.* [4] presented measurement and modeling for signal attenuation in vegetation medium at centimeter wave frequencies, and Dal Bello *et al.* [5] reported the theoretical and experimental study on cellular base-to-mobile propagation with the foliage effect, and examined the range dependence and the base station height gain. Temporal characteristics of received signal have been investigated in [7-8] recently. It is reported that the variations are mainly due to the wind-induced movement of leaves and branches on foliage obstructed line-of-sight (LoS) channel.

In many of the studies above, the measurements were performed mainly using a continuous wave (CW) transmission at different frequencies and in sub-tropical or temperate foliage. In our study, frequency-domain measurement is used to characterize short range tropical foliage channel at VHF and UHF bands. It is because, the existence of the lateral wave at VHF and UHF bands[1] makes the propagating components experience less attenuation and may be less relevant to the wind influence. Moreover, as compared to the previous cellular base-to-mobile propagation studies (the slant propagation path) [5, 7-8], our study will focus on the ground to ground (point to point) communication (the horizontal propagation path). This is very significant and important for the modern military application, and little has been published in the open literature, especially for the propagation in a tropical region.

This paper presents propagation parameters and fading characteristics extracted from the experimental data obtained within the frequency range of 20MHz to 1 GHz. In Section II, brief introduction of the measurement setup is presented as well as the measurement environment. This is followed by Section III, which reports the details of the experimental results, such as path loss variation with distance and wind-induced temporal effect. Analysis and comparisons have been conducted. This is quite useful and helpful for the future studies, and is followed by conclusions (Section IV).

II. METHODOLOGY

A. Measurement Setup

An HP 8753E vector network analyzer (VNA) was used to measure the frequency response of the radio channel in the 20MHz to 1 GHz frequency band at Marina South foliage area. The measurement setup can be seen in Fig. 1. The signal generated from port one of the VNA was transmitted via a vertically polarized, omni-directional antenna AX-71C which has a typical gain of 2.4 dBi. After propagation through the foliage, the signal was received via an identical antenna which was fixed at a distance R from the VNA. The complex data from the VNA was stored in a computer via a GP-IB interface through a LABVIEW control program. Post-processing of the measured data is performed using Matlab.

In this experiment, the receiving antenna is placed at a fixed distance of R (62m) from the data collection point, and the transmitting antenna at a distance of ∂d, where ∂d varies from 65m to 97m with a step size of 1m. The angle between

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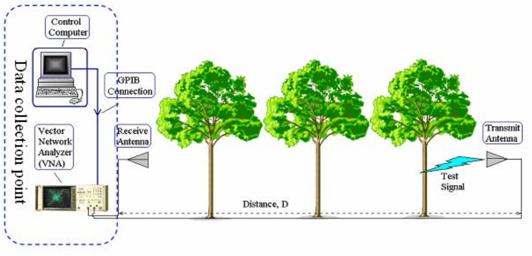
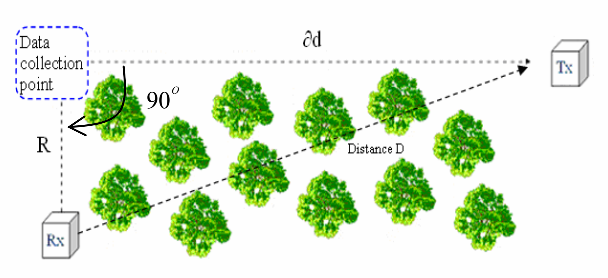
the transmitting and receiving antenna is 90° as seen in Fig. 1(b). The height of both antennas is kept constant at 2.15 meter.



(a) Cross sectional view



(b) Top view

Figure 1: The experimental setup in Marina South measurement site

B. *Environment Description*

The foliage environment chosen for this study is located at the southern end of the Singapore Island, Marina South. The vegetation covers a square area of about 500m^2 and is surrounded by tarmac roads. The nearest building is about 1km away to ensure a good test environment. This site is similar to a tropical rainforest with densely spaced trees of approximately 10m high. The trees are spaced with a distance of 2m to 3m, and surrounded by dense undergrowth of scrubs and saplings. The radius of trunks is around 8cm to 10cm. It is classified as “dense” foliage in this study. The photograph in Fig. 2 shows part of the foliage at the experimental site.

Figure 2: The photograph of Marina South measurement site

The measurement was conducted in May 2005 during the dry season. Two test signals were used; one covers the lower frequency range of 20MHz to 200MHz; and the other covers the higher frequency range of 200MHz to 1GHz. A step frequency signal is transmitted for both the lower and higher frequency ranges which span over a sweep time of 3.75 and 7.5 seconds at 201 and 401 frequency step points, respectively. The measurement was carried out at different conditions, with and without wind.

III. DATA ANALYSIS AND RESULTS

The data collected by the VNA measurement 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 measurements, 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 system frequency response, $H(f)_{hardware}$. This result was subtracted from the subsequent measurements, $H(f)_{measured}$, thus reducing the effect of the system on the measurements. The channel transfer function, $H(f)_{channel}$, can then be obtained as shown in (1).

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

A. *Path Loss Variation*

The narrowband mean received power in dBm from the wideband frequency sweep measurements at each location was extracted and used to determine the path loss between the two antennas. Fig. 3 shows a typical scatter plot of the path loss variation with distance at 28.1 MHz.

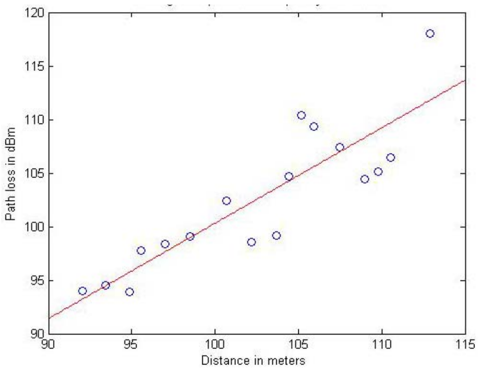


Figure 3: Path loss variation with distance at 28.1MHz

In spite of the small range of measurement distance (90 to 115 meters in this experiment), path loss can be modeled using (2) as shown in [5], [6] and [9].

$$Pathloss = \gamma + 10n\log_{10}D \qquad (2)$$

where γ is a constant and n is the slope index of the variation of path loss with distance.

Empirical slope indices n are calculated based on logarithmic fit and shown in Fig. 4. It can be seen from Fig. 4 that in general path loss index n decreases as frequency increases. Since the antenna height of 2.15m is at tree-trunk level, the received signal has contributions from signals propagating through the forested area between the ground and the tree canopies mainly. The high attenuation rate at lower frequency 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 becomes more dominant in the incoherent components due to the forward scattering caused by tree trunks. The increase in scattering is because the wavelength of the signal becomes comparable in size with the tree trunk as frequency increases. The forward scattering process that happens as frequency increases can counteract the loss due to absorption and attenuation from the rainforest vegetation, hence the much lower attenuation rate at higher frequency.

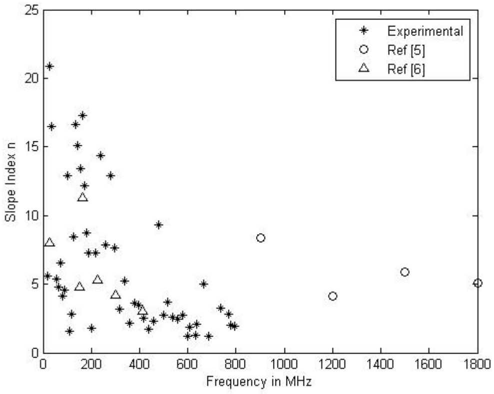


Figure 4: Variations of slope index n with frequencies in MHz

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 radius [10] which is defined as:

$$r_m = \sqrt{\frac{m\lambda d_1 d_2}{d_1 + d_2}} \qquad (3)$$

where m is the order of Fresnel zone, λ is the wavelength of the propagating signal and d_1, d_2 are the distances of the intercepting point with the transmitter and receiver. Practically, the first Fresnel zone (m=1) is concerned since the energy transmission from transmitter to receiver concentrates there, and the Fresnel radii are largest midway between terminals. The largest Fresnel radii for the signal propagating through the rainforest at selected frequencies are shown in Table 1.

Table.1. Largest 1ST Fresnel Radius with Frequency

Frequency(MHz)	33.5	114.5	452	630	1000
1st Fresnel Radius(m)	15.9	8.6	4.3	3.7	2.9

As can be seen from the previous instruction, the antenna height is kept constant at 2.15 meter and the top of canopy is approximately 10m to the ground. This makes the dense tree canopies to lie within the first Fresnel zone for lower frequency, and it will influence the propagating coherent components significantly. This is also an excess source for higher attenuation rate at lower frequencies. The relatively greater fading structure as the groups of leaves and branches due to the dense tree canopies that are enclosed in the first Fresnel zone can block or attenuate the coherent signal further. Moreover, the composition and geometry of canopies are not uniformly distributed. This enhances the variance of path loss slope index *n* at lower frequencies.

Results of path loss slope index *n* obtained using the same method at similar and higher frequencies can be found in [5] and [6]. Both results were extracted from data measured at the tree trunk level. These results are plotted and compared in Fig. 4 and are found to exhibit similar trends to those found in this experiment. In [5], the higher attenuation rate in the higher frequency range is due to attenuation from the crowded vehicular traffic in the surrounding avenue during daylight when the measurements were made. In [6], the results are lower than those found in this experiment. This is due to the dense undergrowth in our experiment site whereas there is little undergrowth in [6].

B. Attenuation Distribution

Temporal variation of the received power is expected as the leaves and branches in a foliage move in a random manner due to wind. This can be analysed through probability density functions (*PDF*). *PDF* curves for samples of measured data from the VNA at selected frequencies at a distance of 110m are shown in Fig. 5. The data was collected in the middle of the night where the signal propagation is good and there is no or little influence from the surrounding vehicles on the tarmac roads. Similar results are obtained at other distances.

Fig. 5 shows the *PDF* curves with their mean attenuations centered at 70dB, 68dB, 98dB and 102dB for 33.5MHz, 114.5MHz, 452MHz and 630MHz respectively. For foliage signal transmission, the flatter and wider curves represent more variation in the RF signal, hence being more susceptible to fading events [7]. From the processed results, it can be seen that the curves at 452MHz and 630MHz are much flatter and wider than those at lower frequencies like 33.5MHz and 114.5MHz. This suggests that the received signal at high frequency has more random scattered components (incoherent components), which is consistent with the observations in the previous section.

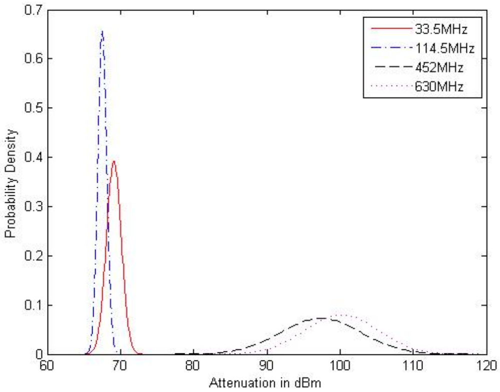


Figure 5: Typical *PDF* for leaved foliage at separation 110m without wind

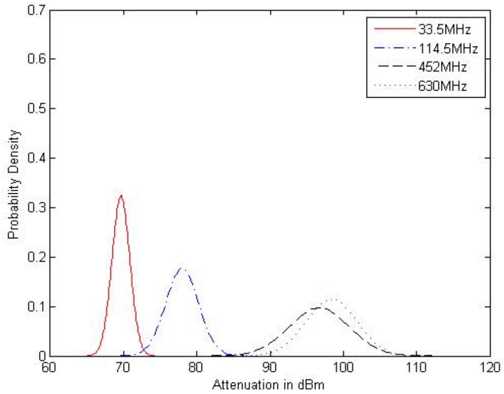


Figure 6: Typical *PDF* for leaved foliage at separation 110m with wind

Fig. 6 shows the *PDF* curves for the same frequency signals measured at the same distance also in the middle of night, but this time, with the effect of wind. It can be observed that the *PDF* curves have changed as compared to those in Fig. 5. As can be seen, the *PDF* at lower frequencies has become broader and flatter. This change is due to the movement of the foliage medium caused by the wind. It can be due to the effect from the dense canopies and undergrowth.

The canopy effect is quite obvious as found before, especially at lower frequencies. The supposition of the wind effect from the dense undergrowth is then verified through an artificial wind which is “simulated” by shaking the saplings with ropes tied to them. The simulated site is in the deep of the selected rainforest where there is a large field with scrubs and saplings as shown in Fig. 7. The distance between the transmitting and the receiving antenna is 34m.

Figure 7: The photograph of measurement site used for wind simulation

Fig. 8 and Fig. 9 present the *PDF* results at 33.5MHz (lower frequency) and 452MHz (higher frequency) to analyze the wind effects on the undergrowth. From Fig. 8 and Fig. 9, the effects of wind on the undergrowth can clearly be seen.

In both plots, the *PDF* has shifted and the spread of the *PDF* is also larger. As expected, at higher frequency, the average attenuation is larger (≅71dBm) as compared to that at lower frequency (≅44.8dBm). It is also observed that the *PDF* curves for the lower frequencies are influenced much more by the effect of wind than those at higher frequencies. This can be explained by the mechanism of the propagation for short range transmission in a foliage environment as introduced before. The wind effect strongly depends on the dominant propagating components, coherent or incoherent. There is a larger amount of received scattered components as stated at higher frequency. Therefore, the influence from wind-induced motion of the undergrowth is less as this also contributes to the scattered components. However, at lower frequency, the received wave is dominant by the coherent component in the static environment. The wind-induced motion causes canopies and undergrowth to move and scatter the propagation component, thus introducing an increased amount of incoherent components. This results in a larger spread in the *PDF* at lower frequency due to the motion caused by the wind.

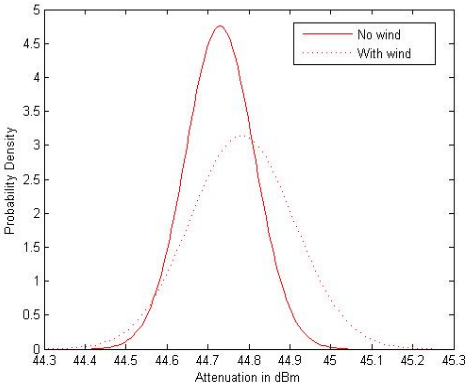


Figure 8: *PDF* at 33.5MHz (artificial wind)

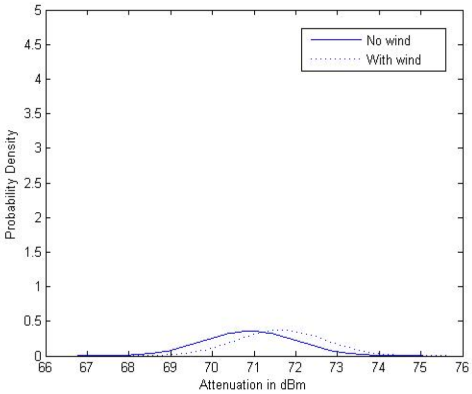
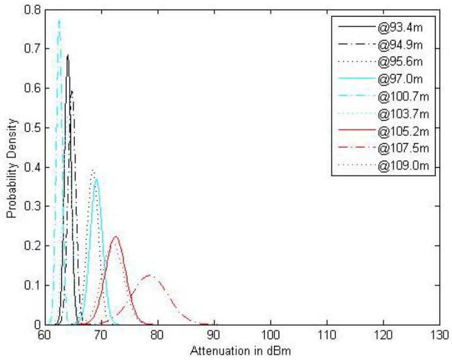


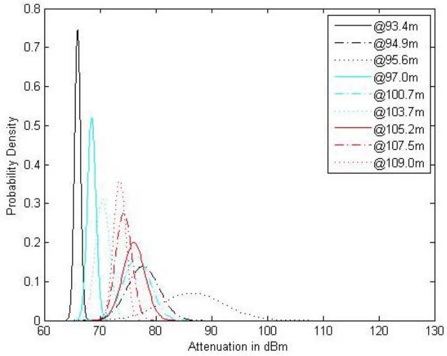
Figure 9: *PDF* at 452MHz (artificial wind)

Fig.10 shows the variation of the shapes and locations of the *PDF* curves when the separation between the transmitter and the receiver is increased from 93m to 109m at frequencies, 33.5MHz, 114.5MHz, 452 MHz and 630MHz, respectively.

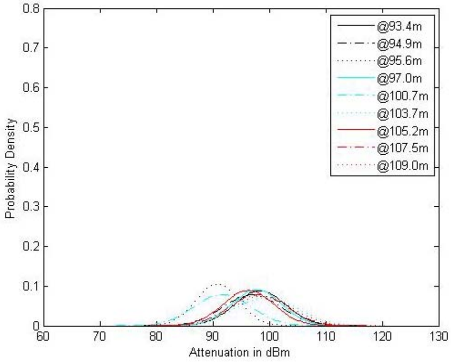
It can be seen that at lower frequencies, the *PDF* curves vary a lot. The higher the operating frequency, the less the variation in the *PDF* curves. At 630MHz (Fig. 10(d)), the *PDF* curves for different separations are almost similar. This is because higher frequency signal is mainly scattered by the more ordered tree trunks due to its smaller Fresnel zone while lower frequency signal can be influenced by more randomly positioned and oriented branches and leaves of canopies as stated before.



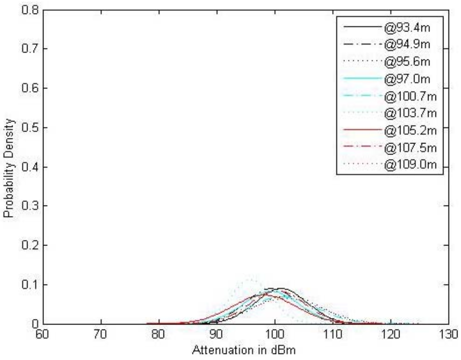
(a)*PDF* at 33.5MHz



(b) *PDF* at 114.5MHz



(c)*PDF* at 452MHz



(d) *PDF* at 630MHz

Figure 10: Variation of *PDF* with Foliage Depth

Finally, comparing the results from wind-induced motion of undergrowth and canopies and the physical propagating path-geometry change, it can be concluded that undergrowth and canopies in the typical rainforest has an influence on the temporal variations of the received power, especially on the lower frequency which has a dominate coherent component for the short range propagation in a foliage environment. Examination of all these results from *PDF* curves leads us to the hypothesis that the foliage area selected for measurement is analogous to a homogenous medium, particularly obvious at high frequencies due to its easily to-be-scattered property.

IV. CONCLUSIONS

This paper presents an investigation of a typical rainforest foliage channel with thick undergrowth at frequency band 20MHz to 1 GHz. The main propagation parameters and fading characteristics reported are slope index *n* of path loss variation and the probability density function for the received signals. Different effects of undergrowth, canopies and tree trunks are analyzed. The wind effect has also been examined.

It is found that tree trunk in the rainforest is a major form of scatterers at tree-trunk level measurement at higher frequencies. The high frequency can be easily scattered due to its wavelength being comparable in size with tree trunk. At lower frequency, dominant signal exists which arises from the attenuated wave through undergrowth and the reflected wave from dense canopies. Therefore, at lower frequencies, the path loss is dependent heavily on the composition and the geometrical arrangement of the forest itself.

Narrower *PDF* at lower frequencies prove that dominant signal exists in this dense foliage channel. However, at lower frequencies, the signal can be affected by wind-induced vegetation motion or the change of physical propagating path-geometry easily. It can be concluded that, the "dense" vegetation in this study can be seen as a homogenous medium, at high frequency, path loss is almost constant and wind effect is almost negligible.

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