Analysis of Angular Spread Characteristics of Mobile Radio Wave Dispersion through Foliage

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1. Introduction

Presence of foliage in propagation path plays a significant role in the propagation of radio waves. The foliage medium provides a rich scattering environment which largely affects the spatial and temporal characteristics of the received signal in wireless communications systems. A better understanding of the effects of foliage on the radio channel characteristics allows us to better evaluate the performance of multi-antenna systems such as diversity combining and MIMO systems. In the past years, in many studies in the field of radio wave propagation through foliage, there have been a number of theoretical as well as empirical path loss models developed in literatures [1]. A theoretical description of penetration into vegetation is given by the theory of radiative energy transfer. These models are generic and applicable to any foliage wave propagation scenario, but are more complicated than the empirical models. The empirical models are based on specific measured data and fail to relate the foliage path-loss to the foliage dependent parameters such as tree species and density. All the models, as mentioned above, are focused mainly on path loss characteristics. An important aspect in the understanding of radio wave propagation in rural areas are the spatio-temporal characteristics of the channel. Of special note is the angular spread of the radio channel, which is essential parameter for diversity combining and MIMO systems. Currently, there are few studies on the directional analysis of the dispersion effects of foliage in the radio channel. The spatio-temporal channel characteristics on the MS side in the foliage environment based on measurements using a channel sounder has been studied [2]. The results show that some large spreads in azimuth and the distance of the nominal azimuth values from zero may be related to the dispersion caused by the foliage. However, this result only investigated the direct path with the location of the MS fixed. Further investigation is essential to extract the effects of other paths that may be present in the environment.

This paper investigates the effects of foliage on the angular spread characteristics of propagating radio waves by employing the SAGE algorithm to provide angle of arrival estimates of the multipath components. The selection of the SAGE algorithm as the estimation technique is attributed to several factors: accuracy, rapid convergence, and robustness in low SNR scenarios. A wideband channel sounder was employed to perform a directional measurement of polarimetric signal through dense forest in the rural areas in Kanagawa. In order to understand the statistical characteristics, such as the angular spread, analysis of the multipoint mobile measurement acquisition results was performed.

2. Measurement

The measurement was performed using a channel sounder at a center frequency of 2.22 GHz and an operation bandwidth of 44.8 MHz, and with a transmit power of 40 dBm. A sleeve and a slot antenna were used to send the vertically and horizontally polarized signals. Transmission signal is wideband multitone with 897 tones. The receiver antenna array was installed on the roof-top of a measurement van with the horizontal distance between the transmitter and receiver ranging from 109 to 123 m. This antenna array is a stacked polarimetric uniform circular patch array (SPUCPA). It comprises of 4 stacked

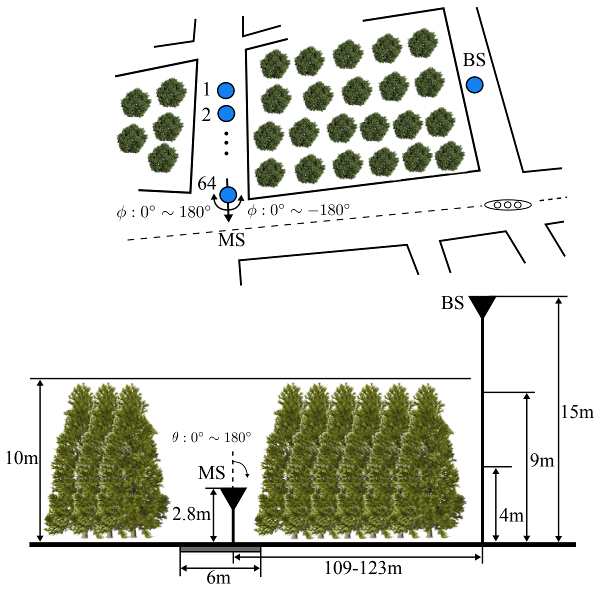


Figure 1: Measurement scenario.

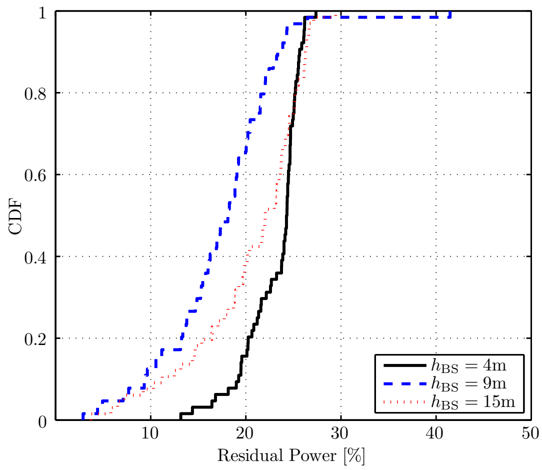


Figure 2: CDFs of the residual power.

rings of 24 polarimetric patches, and this antenna has dual polarized antenna elements to obtain the polarization characteristics yielding 192 ports in total. The MS was equipped with a differential global positioning system (GPS) to accurately track its location.

A measurement campaign was carried out in a forest at Kanagawa on October 26–27, 2009 (Figure 1). The measurement area is around 9000 square meters and it is surrounded by other forests, low rise housing, and a nearby sea. Roughly 90 percent of this forest consists of a specie of Japanese pine tree as shown in Fig. 2. No scatters other than trees is observable around the MS. The average height of the trees is 10 m and spread out with the average density of 0.32 per square meter. The BS antenna height was varied from 4 to 15 m by using a man lift, whereas the MS antenna was mounted on a van with a height of 2.8 m. When the signal is received at the MS, the measurement car is parked. The number of measurement points per each BS antenna height was 64 with 1 m interval.

3. Analysis Approach

In the data analysis, the parameters of each impinging wave are estimated from measurement data using the SAGE algorithm. This algorithm is based on maximum likelihood estimation. A detailed description of the SAGE algorithm is shown in [3]. Although the SAGE algorithm is capable of estimating a large number of propagation paths, not all of these estimated paths are meaningful. There are two reasons for this. First, the received power of most of the paths after extracting the 80th path was less than the actual power level threshold of 25 dB, which had no significant contribution to the power transmission from BS to MS. Second, the detected paths were not always reliable due to the low SNR. In this regard, only paths falling within the 25 dB dynamic range were used to find the delay and angular spread. The paths that do not fall within the dynamic range were not used for further analysis.

The received power estimated by SAGE algorithm is dependent on the environment and the number of extracted discrete multipath components (MPC). The total power of the extracted paths are in general lower than the power of the observed signals. The calculated CDFs of the relative residual power can be seen in the Figure 2. All 64 measurement positions of the MS per each BS antenna height have been used in calculating the CDF. The residual signal power is less than 25% in most cases. This result shows that the discrete multipath modeling is an effective approach for analysis of the wave propagation through foliage.

The angular dispersion is an essential parameter for the characterization of a spatial channel. In this paper, Fleury's direction spread [4] is used to evaluate the angular dispersion of radio waves in mobile channels. Fleury proposed an alternative approach to represent the angular spread to avoid the ambiguity

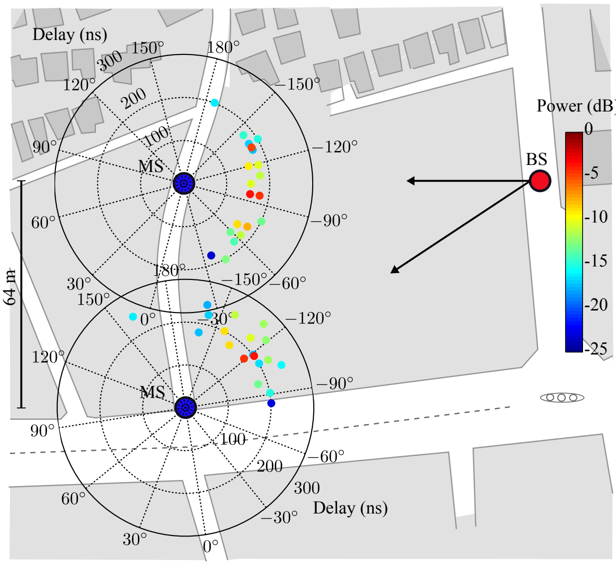


Figure 3: The obtained SAGE estimates of the mobile measurement at the first and last points.

Table 1: Statistics of average direction spread

Average spread		V		H	
		σ_θ	σ_ϕ	σ_θ	σ_ϕ
4 [m]	mean	5.9°	27.6°	6.6°	22.6°
	std.	1.3°	5.4°	1.9°	6.6°
9 [m]	mean	5.2°	25.9°	5.7°	22.3°
	std.	1.4°	5.8°	1.5°	7.1°
15 [m]	mean	7.1°	26.9°	7.6°	25.3°
	std.	2.3°	5.3°	2.7°	5.7°

of angular definition due to the rotational periodicity. 2-dimensional definition of Fleury's direction spread is introduced:

$$\sigma_\phi = \sqrt{\frac{\sum_{l=1}^{L} \mid \exp(j\phi_l) - \mu_\phi \mid^2 \cdot P_l}{\sum_{l=1}^{L} P_l}}, \tag{1}$$

with

$$\mu_\phi = \frac{\sum_{l=1}^{L} \exp(j\phi_l) \cdot P_l}{\sum_{l=1}^{L} P_l}, \tag{2}$$

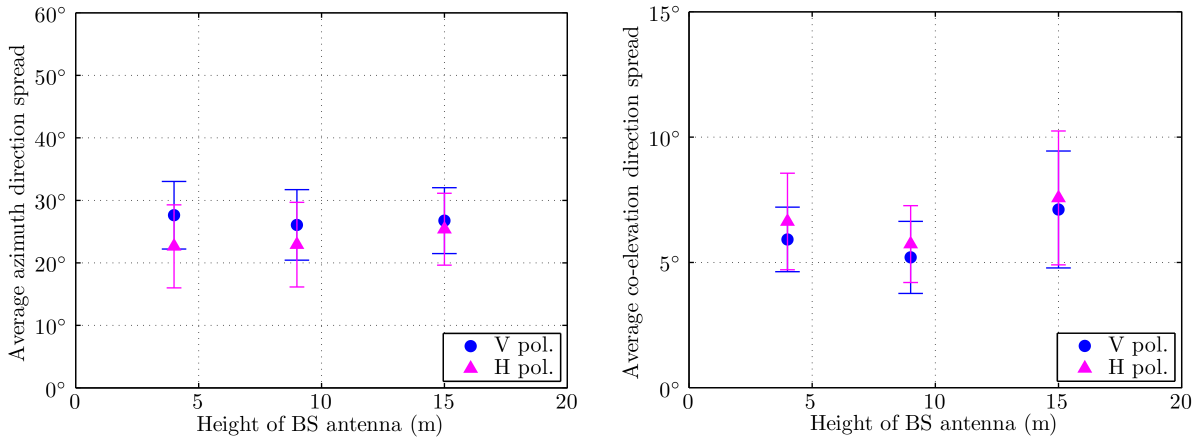
where P_l is the normalized azimuth angular power spectrum. It is noted that the direction spread in (1) is close to the root-mean-square (RMS) azimuth spread when the impinging waves are highly concentrated within small azimuth range [4]. By replacing ϕ with the co-elevation angle θ in (1) and (2), we can compute the co-elevation direction spread σ_θ.

4. Results

In Figure 3, the extracted strongest 20 paths are plotted for the MS positions at the first and last points with a BS antenna heigh h_{BS} of 15 m. The MS positions at the first and last points correspond to the movement distance of 0 m and 64 m, respectively. The color of the markers represents relative power amplitude level on dB scale. This plot allows to make some important conclusions about the propagation processes:

- It can be confirmed that the nominal direction of arrival calculated by (2) seen from MS is quite close to the actual direction.
- The stronger the path, the closer the nominal direction of arrival is to the actual BS direction.

Figure 4 shows the average direction spread for the azimuth and the co-elevation domains as function of the BS antenna height. It can be confirmed that the average azimuth direction spread for V polarization is always greater than that for H polarization, and the opposite is true in the case of co-elevation direction spread. The relatively high values of azimuth direction spread indicate that the incoming field at the MS is highly varying in azimuth. For the co-elevation, the BS direction is set to 1°, 3.5° and 7° corresponding to the BS antenna height h_{BS} of 4 m, 9 m, 15 m, respectively. However, the co-elevation spreads are larger than 6° in most cases. This is because the power of waves which are diffracted on the top of trees near



(a) Average azimuth direction spread.

(b) Average co-elevation direction spread.

Figure 4: Average direction spread.

the MS is stronger than the waves scattered through trees. The relatively low values of co-elevation direction spread indicate that the incoming field at the MS is highly concentrated in co-elevation. It can be seen from the figures that changes in the BS antenna height produce significant changes in the co-elevation direction spread values, but there is no clear relation found between h_{BS} and co-elevation direction spread. Furthermore, when the BS antenna height is 9 m, all the values are minimum. In this case, a better understanding of the mechanism of radio wave propagation is required to describe this result. Table 1 summarizes the statistics of azimuth direction spread and co-elevation direction spread. The average azimuth direction spread is about 25° for all BS antenna height, and the average co-elevation direction spread is about 6°. This value is close to the average azimuth spread which was found to be about 25° in [5].

5. Conclusion

In this paper, the effect of the foliage on the radio wave propagation has been analyzed by using the SAGE algorithm. It has been shown that the estimates given by SAGE algorithm agree well with the geometry of the measurement site. The analysis results show that the azimuth direction spread for V polarization is always more than that for H polarization, and the opposite is true in the case of co-elevation direction spread. The average azimuth direction spread was found to be about 25° and the average co-elevation direction spread was about 6°.

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