Characteristic Evaluation of Dual Polarized 4x4 MIMO through Propagation Measurement

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1. Introduction

The Multiple-Input Multiple-Output (MIMO) system employed in mobile WiMAX and 3GPP Long Term Evolution (LTE) has a high-speed wireless data transmission capability without increasing the bandwidth. MIMO achieves a high information-theoretic capacity with multiple antennas in transmitter (Tx) and receiver (Rx) site [1]. It is because the efficiency by spatial multiplexing of MIMO increases linearly according to the number of antennas. It is important to estimate the efficiency of spatial multiplexing represented by the eigenvalues of channel matrix for MIMO because the capacity is calculated by Signal-to-Noise Ratio (SNR) and the eigenvalues.

There are the spatial multiplexing and the polarized multiplexing for MIMO. The spatial multiplexing efficiency of MIMO is especially large in a non-line-of-sight (NLOS) environment because the spatial correlation among multiple propagation channels is relatively low [2]. However, the capacity of the spatial multiplexing for 2x2 MIMO with single polarized antennas (SP-MIMO) is degraded in a LOS environment because the spatial correlation is relatively high. On the other hand, it is confirmed that the polarized multiplexing of MIMO with the orthogonal-dual polarized-antenna (DP-MIMO) is effective in a line-of-sight (LOS) environment under outdoor conditions [3]. The DP-MIMO uses a vertical (V) and horizontal (H) polarization. It achieves lower channel correlation than SP-MIMO even in a LOS environment thanks to the orthogonality of V and H polarizations in an ideal LOS environment. DP-MIMO also offers reasonable efficiency in an NLOS environment because the channel correlation is low [3].

The propagation characteristics of DP-MIMO with increasing the number of antennas have been researched widely. The results of experimentally measured channel characteristics by the dual-polarization 4x4 MIMO are shown [4][5]. In particular, it is said that the strong direct wave results in two dominant eigenvalues due to the polarization in the LOS environment [5]. These papers explain the phenomenon that only the two eigenvalues are high and the other eigenvalues are low in LOS even though 4 or more antennas is used. However, the measurement results given in this paper differ from their results. Some of the 3rd and 4th eigenvalues measured by our experiments in the LOS are as high as in the NLOS. The others of the eigenvalues are surely low in the LOS. These results imply that the eigenvalues in DP-MIMO cannot be characterized only by the LOS or NLOS environments.

This paper evaluates the measured eigenvalues characteristics for 4x4 DP-MIMO in a LOS or an NLOS environment. Moreover, the relation between the eigenvalues and the correlation between the antennas is analyzed. The next section describes the measurement environment. Section III presents and discusses the measurement results. Section IV presents the conclusions.

2. Measurement Environment

The measurement of 4x4 MIMO propagation channels was conducted in typical urban areas in Yokohama-city, Kanagawa, Japan. Figure 1 shows a photograph of the measurement area as seen from the Tx. The Tx antenna was placed at a height of 3m above the rooftop of a 24-meter-high building. The Tx and Rx antennas in DP-MIMO are shown in Fig.2 (a) and (b), respectively. The antenna configuration is shown in Fig.3. Both the Tx and Rx sites consist of two antenna radomes, each of which contains V and H polarization antennas. The half-power beam width of each antenna is 80 degrees. The Rx antennas were mounted on the rooftop of the measurement vehicle at the height of 2 meters. To decrease the antenna correlation sufficiently the separation between antennas for the Tx and Rx was set to 5 and 2 wavelengths, respectively. In the Rx site, the received radio signals were recorded as the waveform by IF sampling. The channel matrix was derived from the recorded data by the offline processing. The clock timing signals for synchronization at both sites

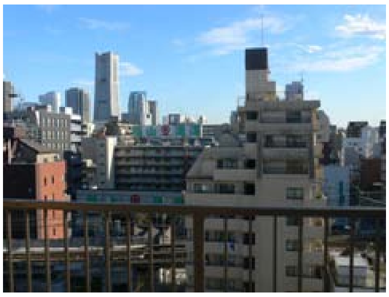
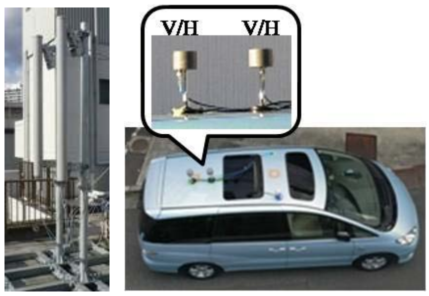


Figure 1: Measurement area seen from Tx.



(a) (b)

Figure 2: (a)Tx and (b)Rx antenna.

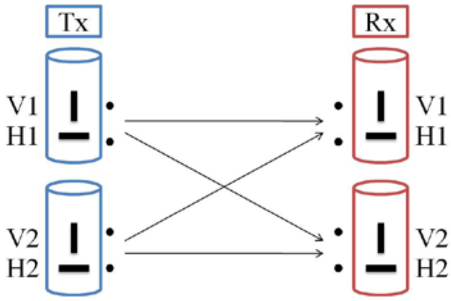


Figure 3: Antenna configuration.

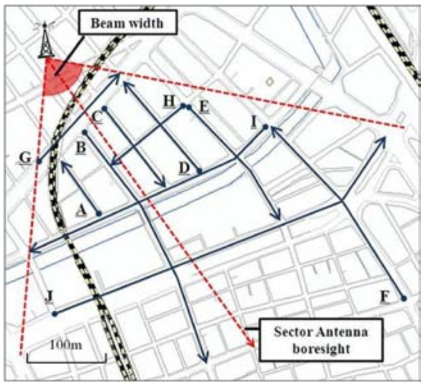


Figure 4: Measurement courses.

Table 1: Specification of measurement

Carrier frequency	2127.5 [MHz]	Tx power/antenna	1 [W] (30 [dBm])
Frequency bandwidth	5 [MHz]	Tx antenna height	24 [m]
Sampling rate	10 [M sample/s]	Rx antenna height	2 [m]
Sub-carrier spacing	9.76 [kHz]	Cyclic prefix length	25.6 [usec]
Number of sub-carriers	512	Frame duration	1.25 [msec]
OFDM symbol length	102.4 [usec]	Tx antenna	Directional dual polarized antenna with 17dBi
Number of antennas	Tx:4 (V:2, H:2) Rx:4 (V:2, H:2)	Rx antenna	Omni-directional dual polarized antenna with 2dBi

are provided by a GPS 1-PPS (pulse per second) signal. The other specifications of the measurement systems are provided in Table 1. The measurements courses are depicted in Fig.4. The measurement was conducted on 10 courses within a 500-meter distance from Tx, where the average speed of the vehicle is around 30 kilometers per hour. The measurement was conducted for the forward link only.

3. Analysis of Measurement Results

To identify the LOS or NLOS environment in the measured data, this paper introduces normalized RSSI (NRSSI). The NRSSI in dB is defined as the relative received radio signal strength to that assumed in a free space and is given by

$$NRSSI = P_r - \left(P_t + G_{\theta,\varphi}\right) + 20\log\left(\frac{4\pi d}{\lambda}\right). \tag{1}$$

P_r is the measured RSSI. P_t is the transmitting power. $G_{\theta,\varphi}$ is the antenna directional gain taking account of the azimuth and the elevation offset angles, θ and φ, respectively, from the boresight. Given the distance d [m] between the Tx and Rx sites and the wavelength λ [m], the third term represents the free space propagation loss. When the propagation condition is LOS, the NRSSI becomes close to zero, otherwise the NRSSI becomes negative.

Four eigenvalues are obtained from the channel matrix between four Tx antennas and four

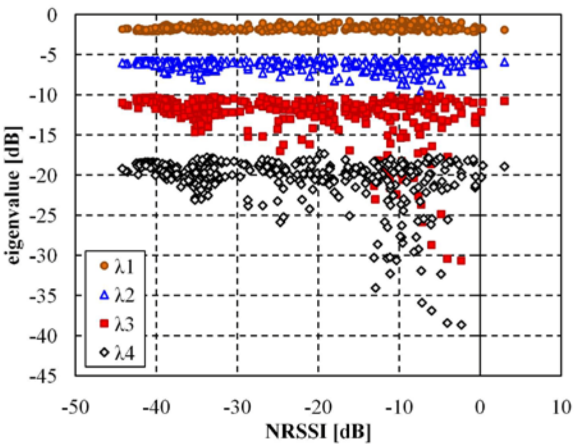


Figure 5: The eigenvalues versus NRSSI.

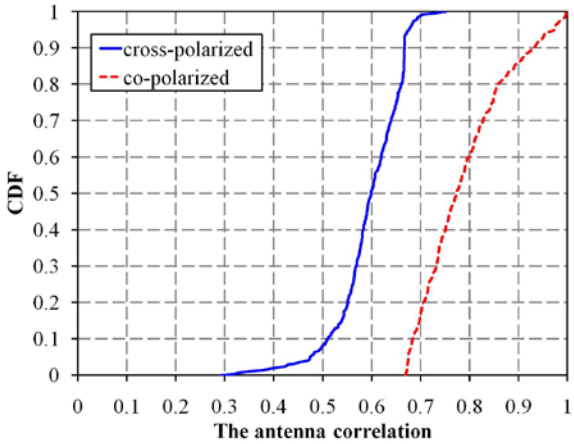


Figure 6: CDF of the cross-polarized and co-polarized antenna correlation in Tx site.

Rx antennas. The channel matrix is normalized by its Frobenious norm so that the sum of eigenvalues is 1. These eigenvalues are derived for each OFDM sub-carrier and 1.25ms radio frame and averaged for 1 second and all 512 sub-carriers.

Figure 5 shows the first, second, third and fourth eigenvalues, λ_1, λ_2, λ_3, λ_4, in dB for 4x4 DP-MIMO as a function of the NRSSI. When the NRSSI increases, it is confirmed that some of the 3th and 4th eigenvalues decrease, whereas the 1st and 2nd eigenvalues are constant. It is assumed that the same phenomenon in the LOS environment as reference [4] [5] is occurred. However, some of the 3rd and 4th eigenvalues are high when NRSSI is high. The phenomenon of the decreasing 3rd and 4th eigenvalues cannot be identified only by the environment; LOS or NLOS.

Figure 6 shows the cumulative distribution function (CDF) of the cross-polarized and co-polarized antenna correlation for Tx site. The cross-polarized antenna correlation is averaged all combination of the different polarized antennas in Tx site. The co-polarized is averaged all combination of the same polarized antennas in Tx site. The antenna correlation ρ of the Tx site is calculated in Equation (2)(3),

$$\boldsymbol{B}^{H}_{r(m,n),t(i,j)}\boldsymbol{B}_{r(m,n),t(i,j)} = \begin{bmatrix} h^*_{m,i} & h^*_{n,i} \\ h^*_{m,j} & h^*_{n,j} \end{bmatrix} \begin{bmatrix} h_{m,i} & h_{m,j} \\ h_{n,i} & h_{n,j} \end{bmatrix} = \begin{bmatrix} |h_{m,i}|^2 + |h_{n,i}|^2 & h^*_{m,i}h_{m,j} + h^*_{n,i}h_{n,j} \\ h^*_{m,j}h_{m,i} + h^*_{n,j}h_{n,i} & |h_{m,j}|^2 + |h_{n,j}|^2 \end{bmatrix} \quad (2)$$

$$\rho_{r(m,n),t(i,j)} = \frac{h^*_{m,i}h_{m,j} + h^*_{n,i}h_{n,j}}{\sqrt{|h_{m,i}|^2 + |h_{n,i}|^2}\sqrt{|h_{m,j}|^2 + |h_{n,j}|^2}} \quad (3)$$

where $\boldsymbol{B}_{r(m,n),t(i,j)}$ is the channel matrix for combination of the *m*-th and *n*-th antennas of the Rx site (r) and that of the *i*-th and *j*-th antennas of the Tx site (t). $\bullet^H$ is the conjugate transpose and $\bullet^*$ is the conjugate. The antenna correlation is averaged for 1 second and all sub-carriers. Figure 6 can be seen that the co-polarized antenna correlation is high from 0.65 to 1. On the other hand, the cross-polarized antenna correlation is low from 0.3 to 0.75. The correlation between the cross-polarized antennas is less than that between the co-polarized antennas. It is because the orthogonality is kept in a LOS and the propagation channel is sufficiently different. Therefore, it is considered that the degradation of the 3rd and 4th eigenvalues is effected by the co-polarized antenna correlation.

Attention is focused on the antenna correlation of the measurement data corresponding to the high NRSSI. The high NRSSI is defined that the NRSSI is higher than -15dB because most of the low 3rd and 4th eigenvalues exist when the NRSSI is higher than -15dB. Figure 7 shows the eigenvalues as a function of the averaged antenna correlation of the Tx site corresponding to the high NRSSI. The 3rd and 4th eigenvalues are low when the correlation is high. In particular, when the correlation value is about 0.85, degradation of these eigenvalues is identified. Therefore, the phenomenon which the 3rd and 4th eigenvalues are low should be evaluated by the correlation between antennas.

For 4x4 DP-MIMO, there are the combinations by 36 kinds of the Tx and Rx antenna for calculating the antenna correlation. Each antenna correlation is different. Moreover, the received

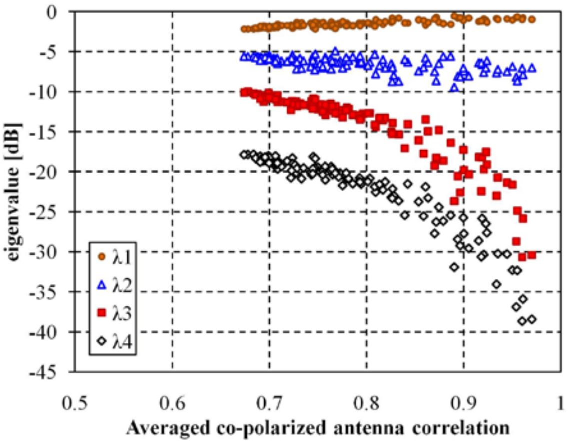


Figure 7: The eigenvalues versus the averaged antenna correlation in Tx site.

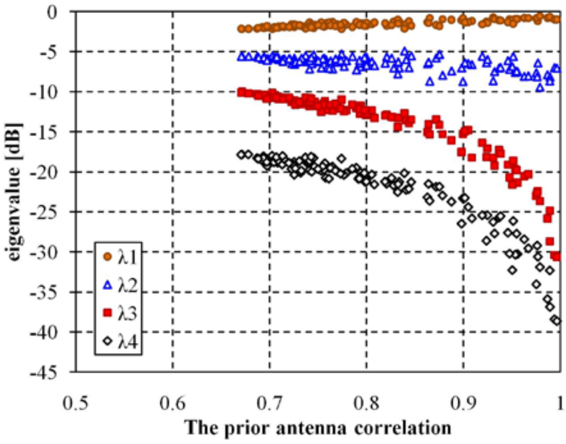


Figure 8: The eigenvalues versus the prior antenna correlation in Tx site.

power of the channel corresponding to each antenna is also different. These differences occur for DP-MIMO with 4 or more antennas because the channel between the cross-polarized antennas differs compared to the co-polarized antenna. Therefore, it is assumed that the correlation of the channel, received by the Rx antenna that received power is higher than that of others, impacts to the 3rd and 4th eigenvalues dominantly. To evaluate the assumption, Fig.8 shows the eigenvalues as a function of the prior antenna correlation. The prior antenna correlation is the averaged correlation values between Tx antennas had the channel that received power is the highest and the second highest. Compared to Fig.7, the 3rd and 4th eigenvalues are clearly low when the antenna correlation is high. Then, it can be seen that the spreading of the 3rd and 4th eigenvalues is lower than that of Fig.7. Therefore, it is considered that the correlation between antennas had the channel of the high received power is related to the eigenvalues dominantly.

4. Conclusion

This paper shows the propagation characteristic of 4x4 DP-MIMO in the LOS and NLOS environment based measurement in Yokohama-city, Kanagawa, Japan, which is a typical urban area. When NRSSI increases, it is confirmed that some of the 3rd and 4th eigenvalues decrease and the others of these eigenvalues do not decrease. Therefore, the phenomenon of these eigenvalues cannot be characterized only by a LOS or an NLOS environment. In this paper, It is shown that the phenomenon can be characterized by the co-polarized antenna correlation in Tx site. In particular, the antenna correlation corresponding to the channel of the high received power is related these eigenvalues dominantly. Therefore, the 3rd and 4th eigenvalues tend to degrade by increasing both the received power for co-polarized antennas and the co-polarized antenna correlation.

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