

Estimation of 2x2 MIMO Capacity with Dual-Polarized Antennas Under Received Power Imbalance Through Propagation Measurements

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Abstract— MIMO (Multiple-Input Multiple-Output) is a promising technology for increasing the transmission capacity of cellular mobile systems in proportion to the number of antennas in both transmitter and receiver. Due to their physical size, dual-polarized antennas are superior in this system to single-polarized antennas on the transmitter sides. This paper examines a 2x2 MIMO with dual-polarized antennas on both transmitter and receiver. It is important to estimate MIMO capacity accurately in cellular mobile systems because optimization of cell coverage planning is advantageous in the deployment of service areas. The authors have proposed a MIMO capacity estimation method in terms of a 2x2 MIMO with dual-polarized antennas, whose capacity can be estimated using only the average SNR (signal to noise ratio) because the eigenvalue ratio, which is a key factor for estimating MIMO capacity, is large and its dependency on the propagation environment is small [1]. This paper focuses on the received power imbalance, which might for example be caused by different antenna gains due to the side lobe patterns of transmitter antennas. Measured results verify that the eigenvalue ratio is strongly dependent on the received power imbalance, decreasing in proportion to that imbalance. It is important to consider the received power imbalance to estimate the 2x2 MIMO capacity accurately.

I. INTRODUCTION

The use of multiple-input multiple-output (MIMO) is one of the most promising technologies for providing high transmission capacity in cellular mobile systems without expanding the frequency band. The use of polarization may be one way to obtain a more compact antenna array layout by providing another dimension of diversity for the MIMO radio channel [2]. In the deployment of cellular mobile systems, careful attention should be paid to the optimization of cell coverage planning. Thus, it is important to estimate MIMO capacity adequately in MIMO wireless systems. MIMO propagation characteristics have been analyzed in a series of studies under outdoor conditions for dual-polarized antennas [1-4]. These studies clarified the propagation characteristics required to specify a MIMO channel or its capacity. However, no study has identified the key parameters needed to estimate the MIMO capacity of MIMO wireless systems in cell coverage planning. The authors have estimated MIMO capacity using an eigenvalue ratio, which is a key performance index for estimating 2x2 MIMO capacity, and the average received power at receiver antennas [1]. This

paper evaluates the effect of the received power imbalance on the eigenvalue ratio. An early study [5] indicated that the received power imbalance degraded channel capacity, but it was based on software simulations. The present study clarifies the relationship between eigenvalue ratios and received power imbalance from actual propagation measurements. This is a very important issue because the MIMO capacity depends directly on the eigenvalue ratio.

II. MEASUREMENT ENVIRONMENTS

The experimental measurements of MIMO transmission were conducted in Fujimino (Saitama Prefecture), Japan. The measurement area is classified as a residential area with buildings two stories high on average [6]. Specifications of the measurement system are shown in Table 1. The transmitter antenna was placed 3 m above the rooftop of an 18-meter-high building. The transmitter had two orthogonal dual-polarized directional antennas with half-power beamwidths of 80 degrees and 5 degrees in both horizontal and vertical planes. Both transmitter antennas had the same antenna gain for the main lobe in the vertical and horizontal planes. In this paper, the vertical and horizontal polarization antennas are designated by V and H. The separation between transmitter antennas was 5 wavelengths. The tilt angle of each transmitter antenna can be changed manually. This study considers identical tilt angles of 0° (tilt diff 0°), and tilt angles differing by 3° (tilt diff 3°) between the H and V antennas. The receiver, with an orthogonal dual-polarized omni-directional antenna, was mounted on the rooftop of the measurement vehicle at 2 meters. Fig. 1 shows a configuration of transmitter and receiver antennas.

Measurements were conducted along a course within 400 meters of the transmitter at an average vehicle speed of around 30 kilometers per hour, as shown in Fig. 2. Propagation measurements were conducted on the same course for two scenarios: one with the same tilt angle and the other with different tilt angles for the two transmitter antennas, to increase the volume of data with a received power imbalance. In practice, the different antenna gain of side lobes between transmitter antennas is one of the reasons for the received power imbalance even with the same antenna tilt angle.

Table 1. Measurement specifications.

Carrier frequency	2.13 GHz
Frequency bandwidth	5 MHz
Sub-carrier spacing	9.76 kHz
Number of sub-carriers	512
OFDM symbol length	102.4 usec
Cyclic prefix length	25.6 usec
Frame duration	1.25 msec
Transmitting power	1 W (30 dBm)
Tx antenna (Gain)	Directional antenna (17 dBi)
Rx antenna (Gain)	Omni-directional antenna (2 dBi)
Tx antenna height	21 m
Rx antenna height	2 m
Number of antenna ports	Tx:2 (H,V), Rx:2 (H,V)

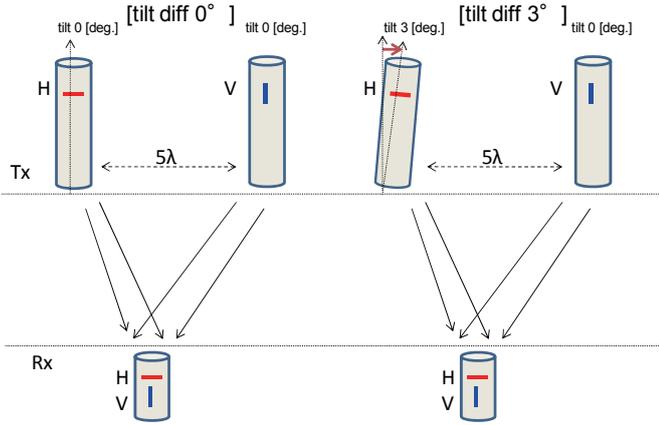


Fig. 1: Tx and Rx antenna configurations.

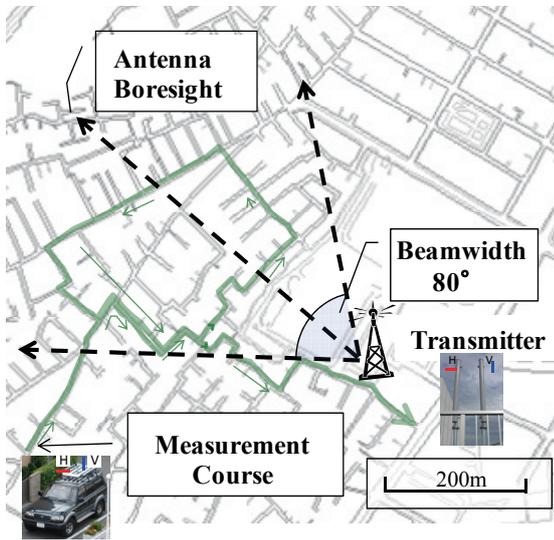


Fig. 2: Tx and Rx antennas with measurement course.

III. DATA ANALYSIS

In the transmitter, the OFDM (orthogonal frequency division multiplex) signals, which consisted of 512 sub-carriers per OFDM symbol, modulated by a different Walsh code for each antenna for each frame were kept in synchronization and transmitted in the 2.1 GHz band. The receiver recorded the signal waveform at 10 MHz IF sampling, while the recorded data were demodulated by different Walsh codes per antenna, and the channel matrix was derived by using the average data of each channel response between antenna pairs in each frame with offline processing.

To evaluate spatial multiplexing efficiency, we defined the eigenvalue ratio as the ratio of the second eigenvalue to the first, where each eigenvalue was obtained from a channel matrix. The 2x2 MIMO channel capacity was expressed as a function of the eigenvalue ratio k and the average signal to noise ratio (SNR) γ_0 of the receiver antennas as shown in Equation (1) [7]. The eigenvalue λ_i is normalized so that those totals are the total number of transmitter and receiver antennas.

$$C = \log_2 \left(1 + \frac{2\gamma_0}{1+k} \right) + \log_2 \left(1 + \frac{2k\gamma_0}{1+k} \right) \quad (1)$$

$$\sum_{i=1}^2 \lambda_i = 4 \quad (2)$$

$$k = \frac{\lambda_2}{\lambda_1} \quad (3)$$

It is obvious that the MIMO spatial multiplexing efficiency increases when the eigenvalue ratio increases. In this paper, the eigenvalue ratios of each sub-carrier are calculated every frame (1/800 sec.) and averaged for all sub-carriers. After that, the eigenvalue ratios are averaged every second. This paper focuses on the behaviour of the eigenvalue ratios under imbalanced receiver antenna configurations.

IV. MEASURED RESULTS

The received power imbalance is generally given simply by the difference in the received power between receiver antennas. However, in 2x2 MIMO using dual-polarized antennas, the received power of the diagonal components of a channel matrix \mathbf{H} is important because the non-diagonal components of \mathbf{H} becomes small when the polarization orthogonality between transmitter and receiver antennas is maintained. Thus, in this study we define the received power imbalance as follows:

$$\Delta G = 10 * \left| \log \frac{\langle h_{11}^2 \rangle}{\langle h_{22}^2 \rangle} \right|, \quad \mathbf{H} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \quad (4)$$

h_{ij} is the channel response between the j -th and i -th elements in Tx and Rx. $\langle h_{ij} \rangle$ is the sum of all sub-carriers, which is averaged every second.

Figure 3 shows the received SNRs for each receiving antenna which includes H and V antennas with the tilt differences of 0° and 3° . It is verified that the SNR of the V antenna is larger than that of the H antenna when the tilt difference is 3° because the tilt angle of the H antenna is 3° steeper than that of the V antenna. In our measurement environment, the main lobe in the elevation plane is directed to the center of the measurement area when the antenna tilt is 0° .

Figure 4 shows the relation between the average SNRs of receiver antennas and the eigenvalue ratios for (a) tilt diff 0° and (b) tilt diff 3° . The received power imbalance between receiver antennas increases in some areas in line with an antenna side lobe, so the SNR is smaller than that of the antenna main lobe in these areas. In particular, the received power imbalance increases for a tilt difference of 3° due to the difference of transmitter antenna tilt angles. As a result, the eigenvalue ratios decline when the SNR decreases. On the other hand, the SNR of the areas where main lobes of both transmitter antennas are directed increases. In these areas, there is only a small effect from the received power imbalance.

Figure 5 shows a scatter diagram in decibels between the received power imbalance and the eigenvalue ratio for (a) tilt diff 0° and (a) tilt diff 3° . Both figures show that the eigenvalue ratio declines with the imbalance in received power. The parameter ΔG can characterize the decline in the eigenvalue ratio relative to the received power imbalance. The effect of the received power imbalance on the eigenvalue ratio has a major impact as ΔG increases. Triangle symbols in Fig. 5 show the eigenvalue ratios when the non-diagonal components of \mathbf{H} in equation (4) are regarded as zero for each ΔG . It has been verified that the eigenvalue ratios decline along the line of triangle symbols when ΔG is larger than 8 dB. In contrast, no decline in eigenvalue ratios is seen in the range of ΔG from 0 to 4dB. A gap between the eigenvalue ratios and the triangle symbols in that range is caused by the fact that the contribution of the non-diagonal components to the eigenvalue ratios becomes larger than the received power imbalance of the diagonal components.

Table 1 shows the average eigenvalue ratios and the channel capacity when SNR is 15dB for each range of ΔG . The channel capacity is calculated from equation (1) and normalized by that of a single-input single-output (SISO). It is confirmed that the channel capacity decreases as ΔG increases. Note that larger ΔG values are caused mainly by differences in the antenna gains within the transmitter antenna pairs. ΔG is calculated by accurately defining the antenna gains for each transmit antenna in cell coverage planning. Therefore, the channel capacity of 2x2 MIMO with dual-polarized antennas can be obtained from the average SNR and eigenvalue ratio which can be estimated from ΔG .

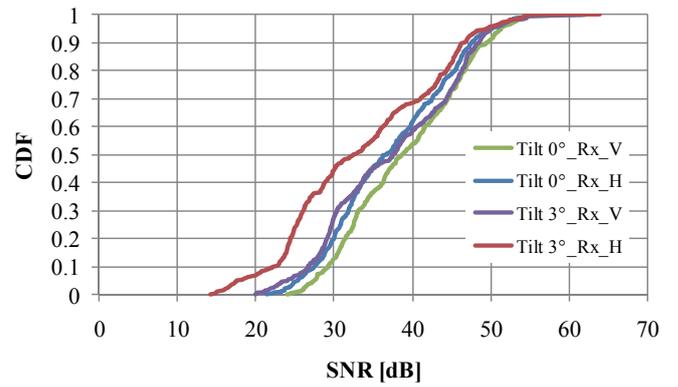
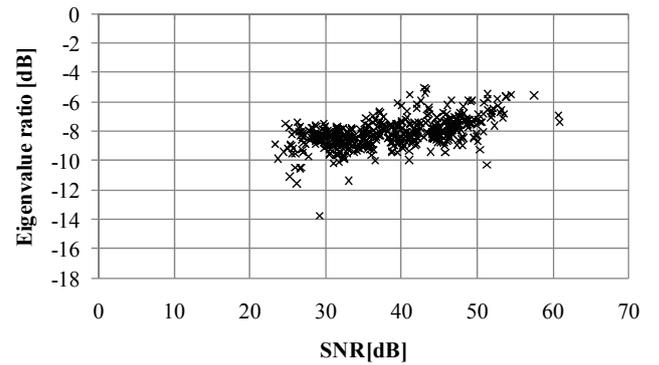
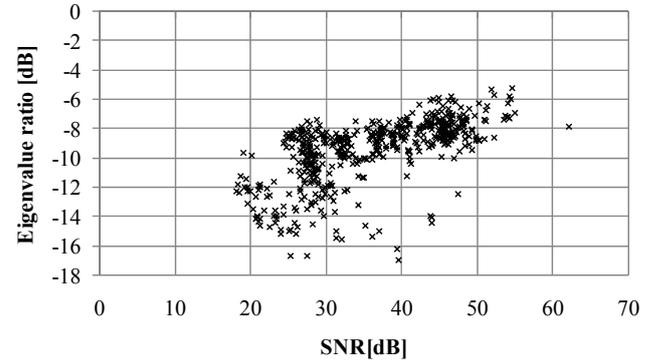


Fig. 3: Cumulative probability of SNR for tilt diff 0° and 3° .

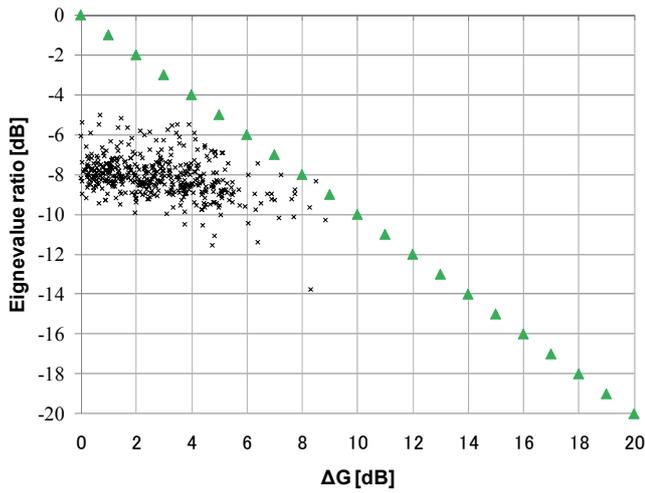


(a) tilt diff 0°

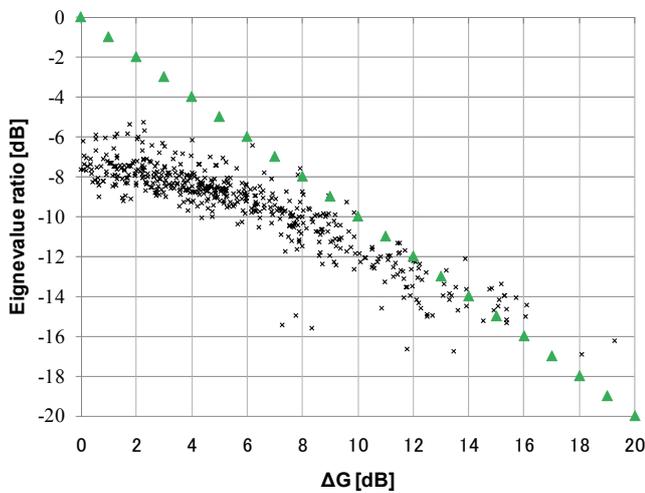


(b) tilt diff 3°

Fig. 4: Average SNR vs. eigenvalue ratio



(a) tilt diff 0°



(b) tilt diff 3°

Fig. 5: Eigenvalue ratio to absolute value of ΔG .

V. CONCLUSIONS

This paper clarifies the relationship between the eigenvalue ratio and the received power imbalance of dual-polarized transmitter antennas from propagation measurements at 2.1 GHz. When the received power imbalance was smaller than 4dB, eigenvalue ratios did not change significantly. In contrast, when the received power imbalance was greater than about 8 dB, the eigenvalue ratio declined linearly with the increasing difference of received power. Therefore, it is important to consider the decline in eigenvalue ratios to estimate 2x2 MIMO capacity in cell planning by considering the received power imbalance. Finally, the channel capacity of 2x2 MIMO with dual-polarized antennas can be obtained from the average SNR and eigenvalue ratio, which can be estimated from ΔG .

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Table 1: Average eigenvalue ratios and channel capacity for the ranges of ΔG when SNR is 15dB.

ΔG [dB]	0-4	4-8	8-12	12-16	16-20
Average eigenvalue ratio [dB]	-7.8	-8.8	-11.3	-13.8	-15.5
Normalized channel capacity	1.8	1.8	1.7	1.5	1.5