Evaluation of Propagation Characteristics in Indoor Environment for MIMO System

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1. Introduction

It is common knowledge that the efficiency of multiple-input multiple-output (MIMO) system is closely related to the radio propagation characteristics, its performance varies as propagation condition changes. Recent studies show the advantage of antenna array utilizing two orthogonal polarizations, so called dual polarized antenna array [1]. This paper depicts how physical phenomena arising from polarization and localization of scatterer affect the characteristics of MIMO channel from the view point of propagation analysis, with giving simple model of line-of-sight (LOS) and non-line-of-sight (NLOS) environment respectively. The analysis is carried out by means of computer simulation based on ray-tracing method.

2. Calculation of Eigenvalues and Capacity

Ray-tracing simulation is performed in an indoor environment shown in Fig. 1. The room is assumed to be of 4m x 4m x 3m. Tx antennas are set on the wall in XZ plane with 2.0m and 1.5m distances from Z and X axes respectively. Calculation is performed every λ/8 for both directions of the X and Y axes in the 2m x 2m area in the room with 1.5m height from the floor. The number of calculation points is 128 points per a direction for both the X and Y axes, which comes to be 16384 points totally. Note that the partition is removed for calculation of LOS environment. A simplified model is used to focus on our objective of clarifying the effect of physical phenomena depending on radio propagation on MIMO system. All the information of the simulation conditions are shown in Table 1. Table 2 shows the conditions of antenna arrangement for the four cases: single V-V (vertical) polarization, single H-H (horizontal) polarization, dual V-H polarization, dual ±45 polarization for Tx antennas. Note that, in the following, "case (a)" indicates two cases of a-1 and a-2, and "case (b)" two cases of b-1 and b-2.

In this paper, the channel capacity for the MIMO system is obtained as

$$C = \log_2 \det\left[\boldsymbol{H}\boldsymbol{H}^H / \sigma^2 + \boldsymbol{I}_{N_t}\right] \qquad (1)$$

where σ^2 is the power of noise, $\boldsymbol{H}$ is the MIMO channel matrix obtained through ray-tracing simulation and whose elements are denoted as h_{ij} for $i \in [1, 2, \cdots, N_r]$, $j \in [1, 2, \cdots, N_t]$, where N_r and N_t are the number of receive and transmit antenna elements respectively. A normalized channel matrix $\boldsymbol{H}'$ is then calculated by

$$\boldsymbol{H}' = \frac{\boldsymbol{H}}{\sqrt{\frac{1}{N_r N_t}\sum_{i=1}^{N_r}\sum_{j=1}^{N_t}\left|h_{ij}\right|^2}}, \qquad (2)$$

on which singular value decomposition (SVD) is performed for derivation of the eigenvalues.

3. Results

3.1 LOS environment

Fig. 2 shows the results for the LOS environment for the cases a-1 and b-1, each of which consists of distribution of 1st eigenvalue in the figure on the upper left, 2nd eigenvalue on the upper right, channel capacity on the lower left, and receiver correlation on the lower right. It can be seen that the cycle length of change in the four results is

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approximately half of wavelength. The capacity comes to be lower as Rx antenna becomes distant from Tx antenna for both the case a-1 and b-1. This is because of span loss which leads to downslide of the SNR with the increase of distance from Tx antenna. Comparing the case (a) with (b), it turns out that the receiver correlation of the case (b) is much lower than that of (a), which gives wholly higher eigenvalue and capacity distribution to the case (b) than (a). In addition, for the case a-1, the receiver correlation becomes lower as Rx antenna becomes distant from Tx antenna.

Table 3 shows the average value of SNR, capacity, and eigenvalues for all the four cases. First, let us see the results of the cases a-1 and a-2. The capacity of the case a-2 is noticeably worse than that of the case a-1. One of the reasons for this is the low 2^{nd} eigenvalue for the case a-2. From this, it can be expected that the receiver correlation for the case a-2 is extremely high. Next, for the cases b-1 and b-2 in Table 3, the results for the cases b1 and b2 are almost the same. Comparing the case (a) with (b), the average SNR for the case (b) is about 3 dB lower than that of case (a). This is because of 3dB power loss for using dual polarized antenna. However, the average capacity of case (b) is slightly higher than that of (a). This result is given by the high 2^{nd} eigenvalue for the case (b), which accordingly overwhelms 3 dB power loss. In other words, the two eigen-path corresponding the two eigenvalues works effectively in the case (b). These high eigenvalues are originally derived from preferable low-correlation for the case (b).

3.2 NLOS environment

Fig. 3 presents the results for the NLOS environment for the cases a-1 and b-1, which consist of the same items as Fig. 2. The results for the NLOS have similar pattern and feature to those of the LOS. However, seeing the channel capacity, the effect of span loss as seen in the LOS is not observed in the NLOS environment because of the absence of direct path. Furthermore, the capacity is extremely low in the vicinity of the partition. This is because that it is impossible to ensure high SNR since there is no chief path from reflection around this area.

Seeing the results for the cases a-1 and a-2 in Table 4, the SNR for the case a-2 is about 2.5dB lower than that of the case a-1, which accounts for the low capacity of the case a-2. This is because that there are more rays with high Tx antenna gain reaching Rx point in the V polarized case, that is the case a-1, than in the H polarized case, that is the case a-2, since rays can reach Rx point passing through the both sides of the partition in the case a-1 while rays can reach Rx point passing through only the upper side of the partition in the case a-2. From this, it turns out that the V component becomes more dominant than the H one in this model. Concerning results for the cases b-1 and b-2, there is no noticeable difference in all results. Comparing the case (a) with (b), the capacity for the case (b) keeps almost the same value as the case a-1 with the advantage of eigenvalues, nevertheless the case (b) has lower SNR than the case a-1. However, in the NLOS environment, the dual polarized case doesn't outperform the single polarized case because of the dominance of the V component which gives high SNR and capacity to the single V polarized case.

4. Conclusions

This paper presented that receiver correlation was drastically lowered with using dual polarized antenna array in both the LOS and the NLOS environments. In the LOS environment, the difference of the angle of polarization made no difference for both of the single and the dual polarization case, and the advantage of eigenvalues for dual polarization worked effectively. On the other hand, in the NLOS environment, although the advantage of eigenvalue for the dual polarized case was observed, it didn't overwhelm the power loss deriving from dual polarization. This was because the V component became dominant comparing the H component with the existence of partition, which gave high SNR and capacity to the single V polarized case in the calculated model. Finally, it is necessary to reexamine these results in more realistic simulation model and in experimental method.

References

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[2] Paul Goud Jr., "Indoor MIMO Channel Measurements Using Dual Polarized Patch Antennas, " 2003 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing, 2003.

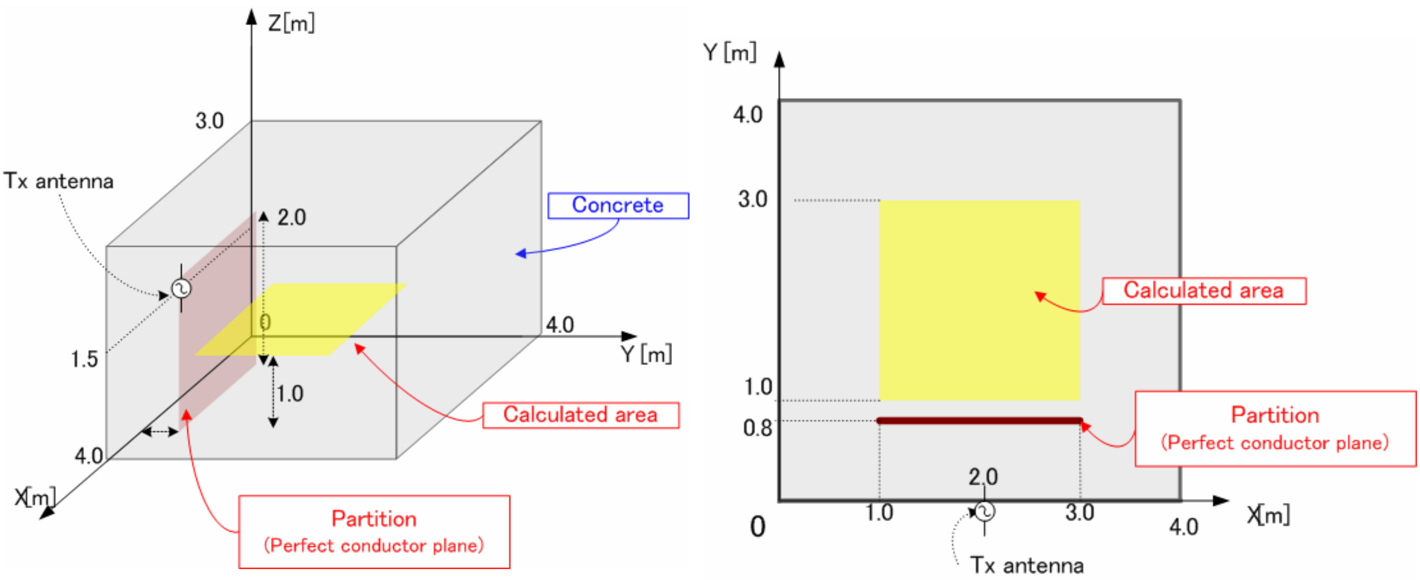


Fig. 1 Indoor test environment for calculation

Table 1 Simulation conditions

Number of antenna element	Tx : 2, Rx : 2
Frequency	2.4 GHz
Transmit power	0 dBm
Noise floor	-70 dBm
Height of Tx antenna	1.5 m
Antenna type.	Infinitesimal dipole
Material of building	Concrete (Relative permittivity : 5.5, Conductivity : 0.023)
Material of partition	Perfect electric conductor
Considered wave	Reflected wave of up to 5 times 1 time diffracted wave
Calculation spacing	λ /8 (for both axis X and Y)
Total calculation points	128 x 128 = 16384 points

Table 2 Calculation case

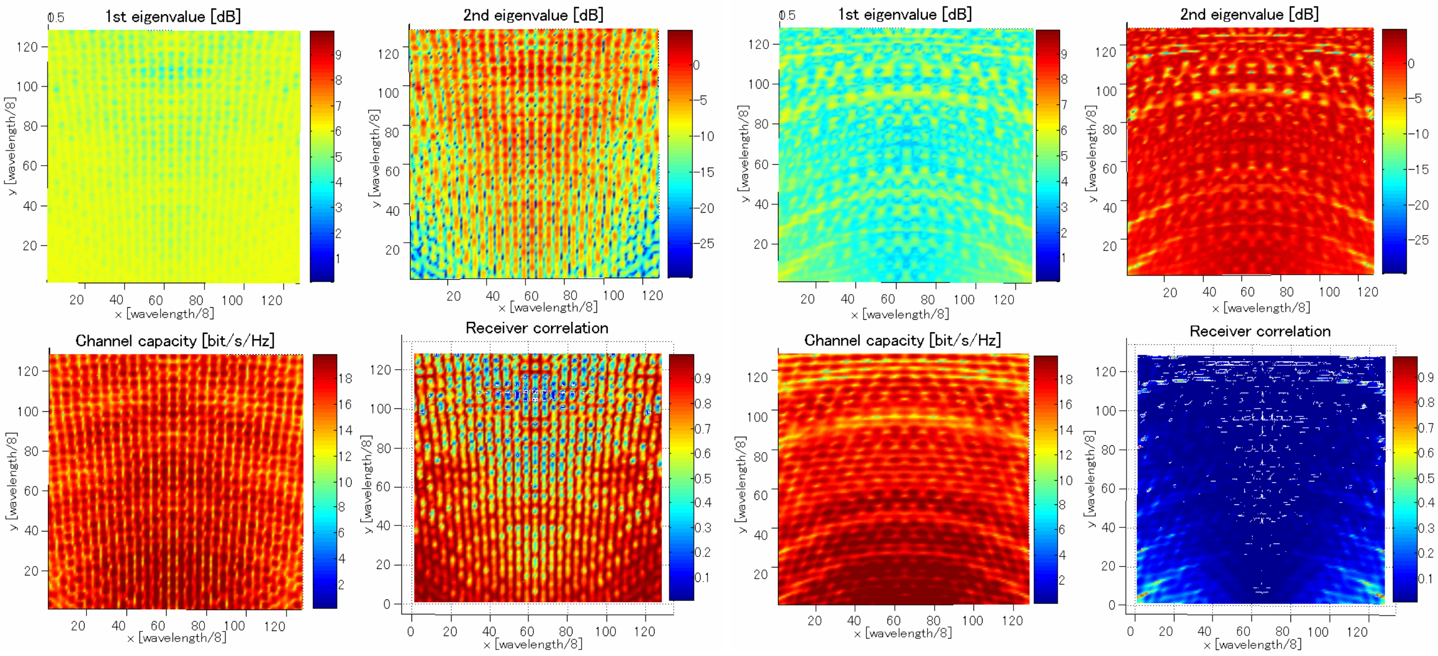
Case	a-1	a-2	b-1	b-2
Tx antenna polarization	Single		Dual	
	V-V	H-H	V-H	± 45 deg.
Rx antenna polarization	Single		Dual	
	V-V	H-H	V-H	V-H
Antenna spacing (for both of Tx & Rx)	λ /2	λ /2	-	-

Table 3 Calculated average SNR, capacity, and eigenvalues in LOS environment

Case	a-1	a-2	b-1	b-2
Average SNR [dB]	30.02	29.37	26.91	26.91
Average capacity [bit/s/Hz]	17.02	13.62	17.46	17.46
Average 1st eigenvalue	3.75	3.96	2.80	2.81
Average 2nd eigenvalue	0.25	0.04	1.20	1.19

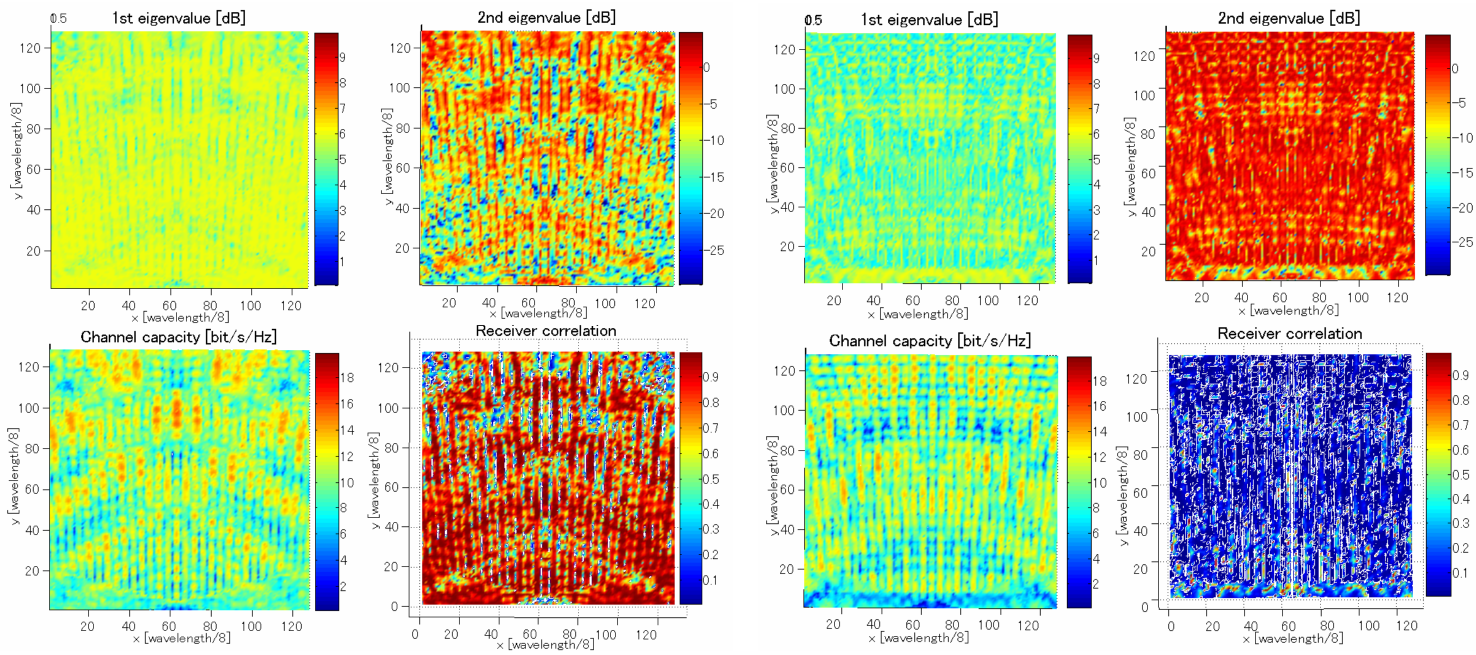
Table 4 Calculated average SNR, capacity, and eigenvalues in NLOS environment

Case	a-1	a-2	b-1	b-2
Average SNR [dB]	19.23	16.66	15.30	15.30
Average capacity [bit/s/Hz]	10.24	9.01	9.58	9.57
Average 1st eigenvalue	3.72	3.66	3.05	3.05
Average 2nd eigenvalue	0.28	0.34	0.95	0.95



(a) Single polarized antenna array (case a-1)   (b) Dual polarized antenna array (case b-1)

Fig. 2 Distribution of eigenvalues, channel capacity and receiver correlation in LOS environment



(a) Single polarized antenna array (case a-1)   (b) Dual polarized antenna array (case b-1)

Fig. 3 Distribution of eigenvalues, channel capacity and receiver correlation in NLOS environment