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Analysis of Effect of Antenna Position on Indoor MIMO Channel Capacity

#Xiao Peng YANG, Qiang CHEN, and Kunio SAWAYA
Electrical and Communication Engineering, Graduate School of Engineering, Tohoku University
6-6-05 Aza-Aoba, Aramaki, Aoba-ku, Sendai, 980-8579 Japan
E-mail: yang@ecei.tohoku.ac.jp

1. Introduction

The performance of Multiple Input Multiple Output (MIMO) communication system is strongly affected by the wireless propagation channel. Besides the propagation environment, the antenna position of transmitter and receiver has also the influences on MIMO system. As the positions of transmitting antennas and receiving antennas are changed, it usually causes the transfer path and the relative position between antenna and scatterer different so that the characteristic of propagation channel will be changed, especially in indoor wireless propagation environment. When the transmitting antennas are fixed, the effect of receiving antenna positions has been analyzed by the Finite Difference Time Domain (FDTD) method [1] and the measurement [2]. When the receiving antennas are fixed, the effect of transmitting antenna positions has also been investigated by the experiment [3]. In order to find the suitability of antenna location for MIMO system, the theoretical analysis has been done by using the movement of transmitting and receiving antennas to optimize the distribution of singular values of MIMO channel transfer matrix for the best Shannon capacity [4]. The Distributed Antenna System (DAS) method for improving MIMO channel capacity has been proposed [5]. The measurement to enhance MIMO channel capacity by adapting the locations of antenna elements has also been done [6]. However, it is unfortunate that the suitability of antenna positions for indoor MIMO system has not yet been investigated.

In this paper, the effect of antenna positions on MIMO channel capacity in the Line Of Sight (LOS) and the Non Line Of Sight (NLOS) indoor environments is investigated by using a numerical hybrid method of Method of Moments (MoM) and Finite Difference Time Domain (FDTD) method [7]. The receiving antennas are moved randomly in the local receiving area, and the positions of transmitting antennas are changed relative to the wall. In order to analyze the effect of antenna positions sufficiently, the eigenvalues of MIMO channel covariance matrix are also statistically analyzed in the different indoor environments.

2. Simulation Conditions

A single user to single user narrow band 2×2 indoor MIMO system with uniform power allocation is considered. The geometry of the analysis model of indoor MIMO system is illustrated in Fig. 1. The length, width and height of the analysis region are 8.6 m, 7.1 m and 3.4 m, respectively, and the inner size of the room is 7.5 m × 6 m × 2.25 m. The wall is made of uniform material, and the relative permittivity, conductivity and thickness of the wall are 3, 1.95×10^{-3} S/m and 0.2 m, respectively. The vertical half wavelength dipole antennas are used as the transmitting and receiving antennas, and the array spacing is 0.2 m. The distance between the transmitting antennas (Tx.) and the wall is 0.28 m. The receiving array antennas are moved randomly in the local receiving area (0.75 m × 5.4 m × 1.7 m) in order to obtain the spatial statistical characteristics of received signals and the distance between the receiving area and the wall is 0.2 m. The spatial sampling interval is 1.875 cm in three dimensions, so that there are 10^6 receiving points in the receiving area. When there is no scatterer except for the wall in the propagation channel, it is named as Case 1, namely LOS indoor environment. When there are 4×7 metallic scatterers placed uniformly in the middle part of indoor environment, it forms the NLOS indoor environment and

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named as Case 2. The size of the scatterer is 0.4 m × 0.4 m × 2.25 m, and the spacing between each scatterer is 0.4 m. The distance between the scatterer area and the wall is also 0.4 m. In our research, the effect of wall construction is also investigated. When the wall behind the local receiving area (Rx.) is not presence, the indoor environments are named as Case 11 (LOS transfer path) and Case 21 (NLOS transfer path). When one side wall, which is relative to the link line of Tx. and Rx. and is near to the origin of coordinate, is not presence, the indoor environments are named as Case 12 (LOS transfer path) and Case 22 (NLOS transfer path). In the simulation, MIMO channel transfer matrix is obtained by using the hybrid technique of the MoM and the FDTD method. In the hybrid technique, the FDTD method is used to analyze the transmitting antennas and the propagation channel, and the MoM is applied to analyze the receiving array elements to obtain the received signals [7]. The whole analysis region is divided into 458 × 378 × 178 Yee cells with the 8-layer Perfectly Matched Layer (PML) absorbing boundary. Each Yee cell has a size of 1.875 cm × 1.875 cm × 1.875 cm, and the number of time step is 16384. In the MoM analysis, each receiving dipole antenna is divided into 9 segments, and the operation frequency is 800 MHz. The total transmitted power is -20 dBm, and only the additive white Gaussian noise with a power of -94 dBm is considered on each receiving branch.

In our research, the four positions of transmitting antennas (Tx.) relative to the wall are investigated, which are also illustrated in Fig. 1 and named as P1, P2, P3 and P4, respectively. P1 (Position 1) denotes that the Tx. is placed in the centre part relative to the wall. P3 (Position 3) denotes that the Tx. is placed in the corner of the room, and the distance between the Tx. and the edge of wall is 0.2 m. All of the positions of Tx. are on the same yz coordinate plane.

3. Simulation Results

The effect of antenna positions of Tx. on MIMO system is statistically investigated in LOS (Case 1) and NLOS (Case 2) indoor environment. The Complementary Cumulative Distribution Function (CCDF) of MIMO channel capacity is analyzed and the results are shown in Fig. 2. It is found that MIMO channel capacity in Case 2 is smaller than that in Case 1 because of the obstruction of scatterers. In both Case 1 and Case 2, the highest MIMO channel capacity is obtained when the Tx. is located in Position 1 (P1) and the lowest MIMO channel capacity is obtained when the Tx. is located in Position 3 (P 3). When the wall behind the local receiving area (Rx.) and one side wall are not presence independently in Case 1 and Case 2, the effect of antenna positions of Tx. on MIMO channel capacity is also investigated and the results are shown in Fig. 3 and Fig. 4, respectively. It is found that when the wall behind the local receiving area (Rx.) is not presence (Case 11 and Case 21), the effect of antenna positions of Tx. on MIMO channel capacity is almost same with those in Case 1 and Case 2. The wall behind the local receiving area has small effects on MIMO system. When one side wall is not presence (Case 12 and Case 22), MIMO channel capacity is smaller than the corresponding values in Case 1 and Case 2; however, the change of MIMO channel capacity with the different antenna positions of Tx. in Case 12 and Case 22 is same with those in Case 1 and Case 2. From Fig. 2, Fig. 3 and Fig. 4, it is found that when the Tx. is located in the centre part relative to the wall, the highest MIMO channel capacity is obtained. When the Tx. moves to the edge of wall, MIMO channel capacity is degraded significantly regardless of LOS and NLOS indoor environment. Especially, when the Tx. is near to the corner of the room, MIMO channel capacity becomes much smaller.

According to the general Shannon channel capacity formula of MIMO system and the singular value decomposition (SVD) of channel matrix, MIMO channel capacity is determined by the transmitted power and the eigenvalue of MIMO channel covariance matrix. In our simulation, the total transmitted power is fixed and uniform power allocation is applied. Therefore, the effect of transmitting antennas (Tx.) on the eigenvalue of MIMO channel covariance matrix is statistically analyzed in the different indoor environments, and the results are shown in Fig. 5 when CCDF is 50%. It is found that both of the eigenvalue $\lambda 1$ and $\lambda 2$ in NLOS indoor environment are smaller than those in LOS indoor environment because the presence of indoor scatterers causes severely path loss. In Case 1, Case 11 and Case 12, the first eigenvalue is affected insignificantly by the antenna positions, but the second eigenvalue is affected obviously. Therefore, in LOS indoor environment, the effect of antenna positions on MIMO channel capacity is caused mainly by the change of the second eigenvalue of MIMO channel covariance matrix. In NLOS indoor environment, both of the eigenvalue λ1 and λ2 are affected significantly by the antenna positions.

4. Conclusions

The effect of antenna positions on 2×2 MIMO system in LOS and NLOS indoor environment has been investigated. It has been found that the channel capacity of indoor MIMO system is affected significantly by the antenna positions. The highest MIMO channel capacity is obtained when the transmitting antennas (Tx.) are located in the centre part relative to the wall. When the transmitting antennas (Tx.) are near to the edge of wall, MIMO channel capacity is degraded significantly. Especially, when the transmitting antennas (Tx.) are at the corner of the room, the smallest MIMO channel capacity is obtained. In order to analyze the effect of antenna positions sufficiently, the eigenvalues of MIMO channel covariance matrix have also been statistically analyzed in the different indoor environments. It has been found that in LOS indoor environment, the effect of antenna positions on MIMO channel capacity is caused mainly by the change of the second eigenvalue of MIMO channel covariance matrix. In NLOS indoor environment, both of the eigenvalues are affected significantly by the antenna positions.

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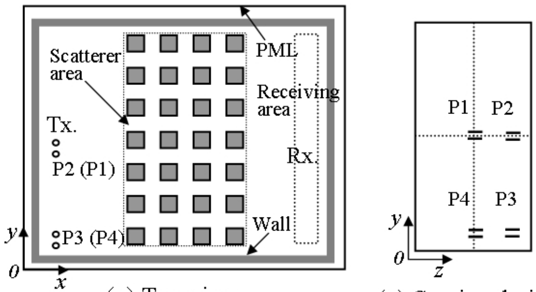
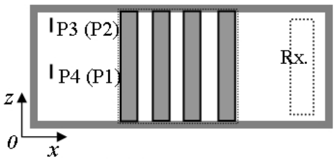


(a) Top view

(c) Sectional view



(b) Side view

Fig. 1: Geometry of analysis model of indoor MIMO system and the definition of relative positions of the transmitting antennas (Tx.) to the wall.

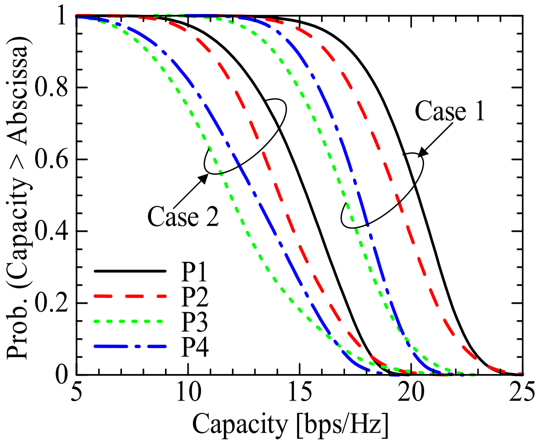


Fig. 2: CCDF of MIMO channel capacity with the positions of transmitting antennas (Tx.) in LOS (Case 1) and NLOS (Case 2) indoor environment.

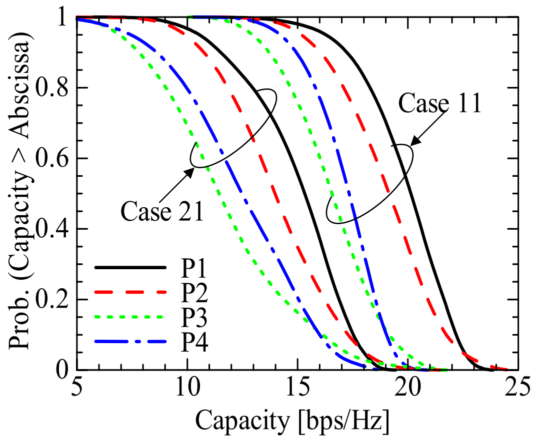


Fig. 3: CCDF of MIMO channel capacity with the positions of transmitting antennas (Tx.) in LOS (Case 11) and NLOS (Case 21) indoor environment when the wall behind the local receiving area (Rx.) is not presence.

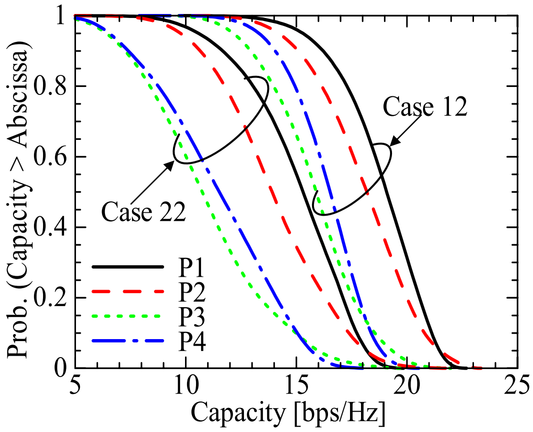
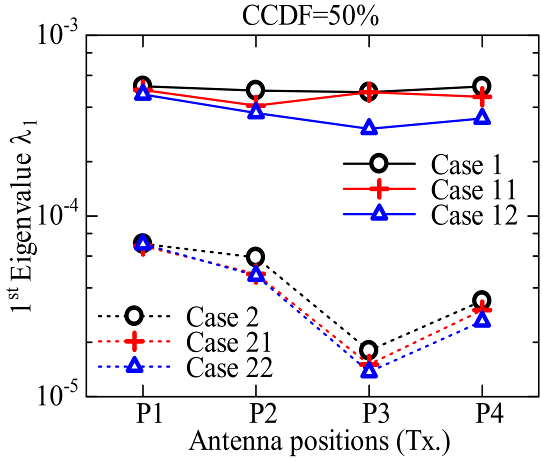
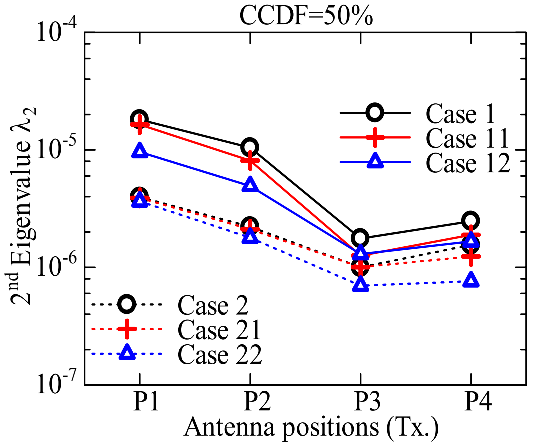


Fig. 4: CCDF of MIMO channel capacity with the positions of transmitting antennas (Tx.) in LOS (Case 12) and NLOS (Case 22) indoor environment when one side wall is not presence.



(a) The first eigenvalue λ_1



(b) The second eigenvalue λ_2

Fig. 5 CCDF of eigenvalues of MIMO channel covariance matrix with the positions of transmitting antennas (Tx.) in the different indoor environment when CCDF is 50%.