Effect of Antenna Locations on Indoor MIMO System

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***Abstract*—The effect of antenna locations on multiple-input–multiple-output (MIMO) communication system in the line of sight (LOS) and the nonline of sight (NLOS) indoor environments is investigated by a numerical hybrid method of the method of moments (MoM) and the finite difference time domain (FDTD) method. The channel capacity, the received power and the effective degrees-of-freedom (EDOF) of multipaths of MIMO system are statistically analyzed. It is found that the channel capacity of indoor MIMO system is affected significantly by the antenna locations. However, in the case of ignoring of path loss, MIMO channel capacity in NLOS indoor environment is almost independent of antenna locations.**

***Index Terms*—Channel capacity, effective degrees-of-freedom (EDOF), indoor channel, multiple-input–multiple-output (MIMO).**

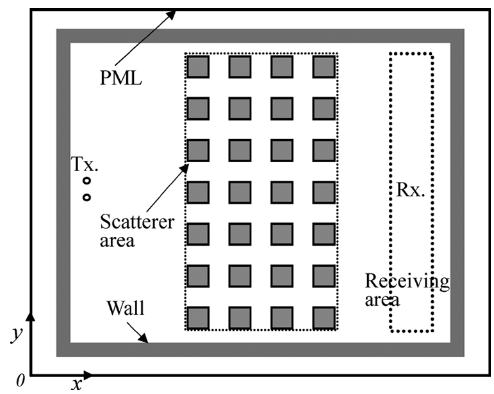

Fig. 1. Top view of analysis model of indoor MIMO system.

I. Introduction

IT HAS BEEN well known that the performance of multiple-input–multiple-output (MIMO) communication system is strongly affected by the wireless propagation channel [1]–[6]. Besides the propagation environment, the antenna locations of transmitter and receiver also have the influences on MIMO system. When the transmitting antennas are fixed, the effect of receiving antenna locations has been analyzed by the finite difference time domain (FDTD) method [2] and the measurement [3], [4]. When the receiving antennas are fixed, the effect of transmitting antenna locations has also been investigated by the experiment [7]. 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 [8]. The distributed antenna system (DAS) method for improving MIMO channel capacity has been proposed [9]. The measurement to enhance MIMO channel capacity by adapting the locations of antenna elements has also been done [10]. However, it is unfortunate that the suitability of antenna locations for indoor MIMO system has not yet been investigated.

In this paper, the effect of antenna locations on MIMO system in the line of sight (LOS) and the nonline of sight (NLOS) indoor environments is investigated by a numerical hybrid method of the method of moments (MoM) and the finite difference time domain (FDTD) method [6]. The receiving antennas are moved randomly in the local receiving area, and the locations of transmitting antennas are changed relative to the wall. MIMO channel capacity is investigated mainly. In order to analyze the effect of antenna locations sufficiently, the average received power and the effective degrees of freedom (EDOF) of multipaths of MIMO system are also statistically analyzed.

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II. 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, 7.1, and 3.4 m, respectively, and the inner size of the room is $7.5 \times 6 \times 2.25$ 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 $(0.75 \times 5.4 \times 1.7\ \mathrm{m})$ 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 959646 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 the 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 named as Case 2. The size of the scatterer is $0.4 \times 0.4 \times 2.25$ 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 the simulation, MIMO channel transfer matrix is obtained by using the hybrid technique of the MoM and the FDTD method [6]. In the hybrid technique, the FDTD method is

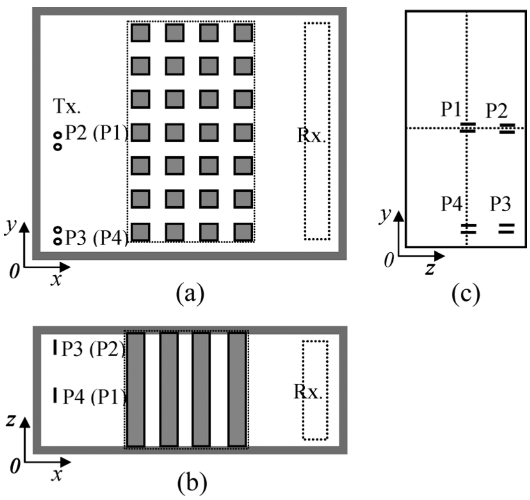

Fig. 2. Relative locations of the transmitting antennas (Tx.) to the wall. (a) Top view. (b) Side view. (c) Sectional view.

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. The whole analysis region is divided into $458 \times 378 \times 178$ Yee cells with the eight-layer perfectly matched layer (PML) absorbing boundary. Each Yee cell has a size of $1.875 \times 1.875 \times 1.875$ cm, and the number of time step is 16384. In the MoM analysis, each receiving dipole antenna is divided into nine 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.

III. Simulation Results

In the simulation, the four locations of transmitting antennas (Tx.) relative to the wall are investigated, which are illustrated in Fig. 2 and named as P1, P2, P3, and P4, respectively. P1 (Position 1) denotes that the Tx. is placed in the center 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.

The effect of antenna locations 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 firstly analyzed and the results are shown in Fig. 3. 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 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.

It is well known that MIMO channel capacity is determined by the received power and the multiple paths of MIMO propagation channel [5]. In order to analyze the effect of antenna location sufficiently, the received power on each receiving branch and the EDOF of multipaths are also investigated, and the results are shown in Fig. 4 and Fig. 5, respectively.

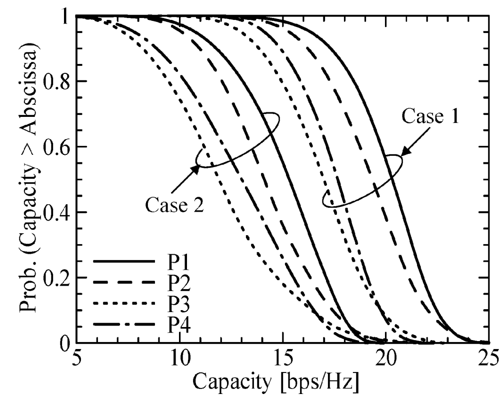

Fig. 3. CCDF of MIMO channel capacity with the locations of transmitting antennas (Tx.) in LOS (Case 1) and NLOS (Case 2) indoor environment.

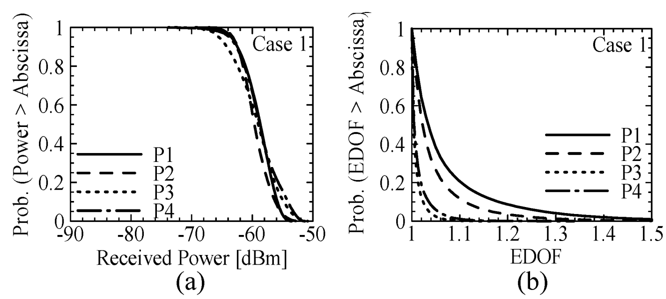

Fig. 4. CCDF of received power and EDOF of MIMO system with the locations of transmitting antennas (Tx.) in LOS indoor environment (Case 1). (a) Received power. (b) EDOF.

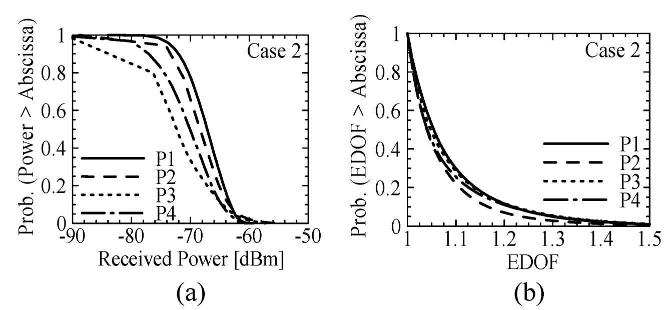

Fig. 5. CCDF of received power and EDOF of MIMO system with the locations of transmitting antennas (Tx.) in NLOS indoor environment (Case 2). (a) Received power. (b) EDOF.

EDOF is a number of effective parallel sub-channels which can be formed by MIMO propagation channel and is calculated by

$$\mathrm{EDOF} = \sum_{i=1}^{n} \lambda_i / \max[\lambda_i], \tag{1}$$

where λ_i is the ith eigenvalue of MIMO channel transfer covariance matrix [5]. It is found that the received power is not affected significantly and the EDOF is affected obviously by the antenna locations of Tx. in LOS indoor environment (Case 1),

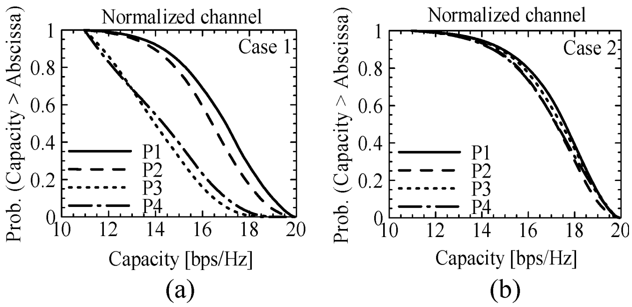

Fig. 6. CCDF of MIMO channel capacity with the locations of transmitting antennas (Tx.) when the path loss is normalized out and received SNR is 30 dB. (a) LOS indoor environment (Case 1). (b) NLOS indoor environment (Case 2).

and the opposite phenomena are found in NLOS indoor environment (Case 2). Therefore, in LOS indoor environment, the EDOF of multipaths affected by the antenna locations of Tx. is the dominant factor to analyze MIMO channel capacity. However, in NLOS indoor environment, the received power affected by the antenna locations of Tx. is the dominant factor.

In previous researches on MIMO channel capacity, the effect of path loss is usually ignored. In this paper, when the path loss is normalized out, the effect of antenna locations of Tx. on MIMO channel capacity is also analyzed and the results are shown in Fig. 6. The Frobenius norm given by

$$\sum_{i=1}^{Nr}\sum_{j=1}^{Nt}|B\cdot h_{ij}|^2 = Nt\cdot Nr \tag{2}$$

is used to normalize MIMO channel transfer matrix to make the transfer power between a single transmitting antenna and a single receiving antenna be unity [5], where h_{ij} is the entry of MIMO channel transfer matrix, B is a normalization constant, Nt and Nr are the number of transmitting and receiving array elements. It is found that MIMO channel capacity in NLOS indoor environment is almost independent of antenna locations of Tx. when the path loss is ignored.

IV. Conclusion

The effect of antenna locations on 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 locations. The highest MIMO channel capacity is obtained when the Tx. is located in the center part relative to the wall. When the Tx. moves to the edge of wall, MIMO channel capacity is degraded significantly. Especially, when the Tx. is at the corner of the room, the lowest MIMO channel capacity is obtained. The EDOF of multipaths affected by the antenna locations of Tx. is the dominant factor to analyze MIMO channel capacity in LOS indoor environment, and the received power affected by the antenna locations of Tx. is the dominant factor in NLOS indoor environment. However, in the case of ignoring of path loss, MIMO channel capacity in NLOS indoor environment is almost independent of antenna locations.

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