LETTER

Effects of Wall Reflection on Indoor MIMO Channel Capacity

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SUMMARY The effects of wall reflection on indoor MIMO channel capacity are statistically investigated with consideration of the average received power, the effective degrees of freedom (EDOF) of multipaths and the eigenvalues of transfer channel covariance matrix. It is found that the stronger wall reflection can lead to higher MIMO channel capacity.

key words: *MIMO, channel capacity, indoor channel, hybrid method, reflection coefficient*

1. Introduction

Recently, the indoor MIMO communication system has attracted considerable research attention [1]–[5]. Because the wall is an important scatterer in the indoor environment, the effects of wall on MIMO system are worth investigating. Although the effects of complex wall have been analyzed by using the finite difference time domain (FDTD) method [1], [2], those analyses were limited only in two dimensions (2-D). The three dimensional (3-D) indoor model has been analyzed by using the array decomposition fast multipole method (AD-FMM) [3], and the measurements have also been carried out [4], [5]. However, the effects of wall have not been investigated enough because of the limitation of conventional methods. Therefore, a new hybrid numerical method with combination of FDTD method and method of moment (MoM) has been proposed by the authors [6], which is suitable to analyze the complex indoor wireless channel with consideration of the spatial statistical characteristics of received signals. By using the hybrid method, the effects of wall material on indoor MIMO channel capacity have been investigated [7], where the effects of wall were analyzed based on a certain thickness of the wall. However, the wall thickness can also bring some effects on MIMO system. A more practical analysis model reflecting the effects of material, thickness and structure of wall should be investigated.

In this paper, the effects of physical parameters of the wall, i.e. relative permittivity, conductivity and thickness, on MIMO channel capacity are investigated. Then the indoor MIMO channel capacity is statistically investigated with the wall reflection. In order to analyze the MIMO channel capacity sufficiently, the average received power, the effective degrees of freedom (EDOF) of multipaths and the eigenvalues of transfer channel covariance matrix are also statistically analyzed with the wall reflection.

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2. Simulation Model

In the simulation, a single user to single user narrow band 2×2 indoor MIMO system with uniform power allocation is considered. The vertical half wavelength dipole antennas are used as the transmitting and receiving antennas and the array spacing is a half of wavelength. In order to investigate the effects of wall mainly, only the wall is considered and the other scatterers are not included in the analysis model. The geometry of the analysis model of indoor MIMO system is illustrated in Fig. 1.

The length, width and height of analysis region are 8.6 m, 7.1 m and 3.4 m, respectively. The wall thickness is changed from 0.05 m to 0.4 m, but the inner size of room is fixed as $7.5\,\mathrm{m} \times 6\,\mathrm{m} \times 2.25\,\mathrm{m}$. The receiving array antennas move randomly in the local receiving area ($0.4\,\mathrm{m} \times 0.4\,\mathrm{m} \times 0.4\,\mathrm{m}$), in which there are 29791 receiving points, and the distance between the transmitting array antenna and the center of local receiving area is 6.8 m. The whole analysis region is divided into $688 \times 568 \times 272$ Yee cells with 8-layer perfectly matched absorbing boundary (PML). Each Yee cell has a size of $1.25\,\mathrm{cm} \times 1.25\,\mathrm{cm} \times 1.25\,\mathrm{cm}$, and the number of time step is 16384. In MoM analysis, each receiving dipole antenna is divided into 15 segments, and the operation frequency is 800 MHz. The total transmitted power is −20 dBm, and only the additive white noise with a power of −93.98 dBm is con-

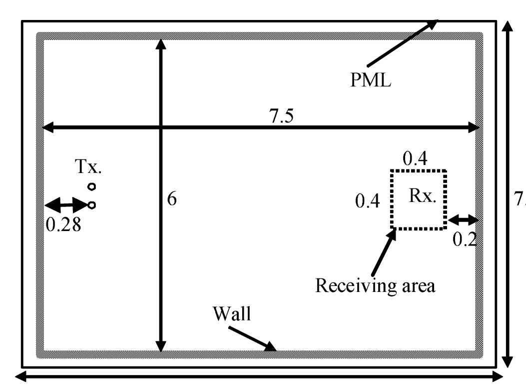

Fig. 1 Geometry of indoor MIMO analysis model.(unit:m)

sidered on each receiving branch.

3. Numerical Analysis

The effects of electrical parameters and thickness of wall on indoor MIMO channel capacity are investigated according to the channel transfer matrix obtained by using the hybrid method of FDTD method and MoM [6]. The relative permittivity ϵ_r is from 1.5 to 8.5, the conductivity σ is from 0.001 to 1 S/m and the thickness D is from 0.05 m to 0.3 m. These numerical results are shown in Fig. 2, Fig. 3 and Fig. 4, respectively, where the channel capacity is the average value in local receiving area. It is found that there is no simple correlation between MIMO channel capacity and the individual physical parameters of wall. It is well known that the indoor electric field distribution is directly affected by the wall reflection which includes the effects of relative permittivity, conductivity and thickness of wall together, therefore, it is worth investigating the relationship between wall reflection and MIMO channel capacity.

The MIMO channel capacity is statistically analyzed with wall reflection coefficient, and the results are shown in Fig. 5, where the wall reflection coefficient is calculated by using a lossy slab model with 48.5° oblique incident wave. The incident angel is determined by the transmitting and receiving array antennas and the reflection point on the side wall. It is found that the stronger wall reflection can lead to higher MIMO channel capacity, and there is almost linear relationship between them. Therefore, the wall reflection coefficient is a suitable parameter instead of the physical parameters of wall to analyze indoor MIMO system.

It is well known that MIMO channel capacity is determined by the received power and multipaths. In order to analyze the effects of wall reflection sufficiently, the average received power on each receiving branch and the EDOF of multipaths are also analyzed with wall reflection coefficient, and the results are shown in Fig. 6. EDOF is the number of effective parallel sub-channels which can be formed by MIMO wireless channel and is calculated by

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

where λ_i is the ith eigenvalue of $HH^\dagger$. H and $\dagger$ denote the MIMO channel transfer matrix and the complex conjugate transpose, respectively. The EDOF is a real number larger than unit and less than the minimum number of transmitting and receiving array antennas, and the effect of path loss is not included [7]. From Fig. 6, it is found that the received

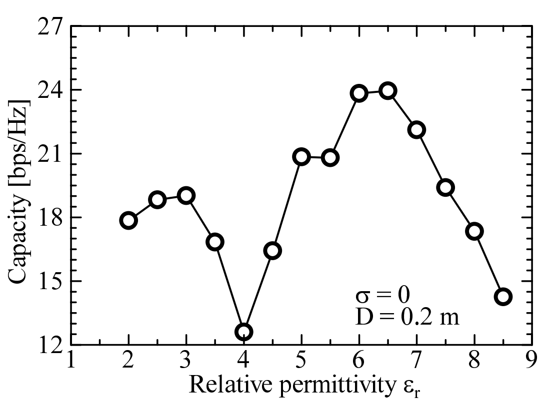

Fig. 2 MIMO channel capacity versus relative permittivity of wall when the conductivity and the thickness are 0, and 0.2 m, respectively.

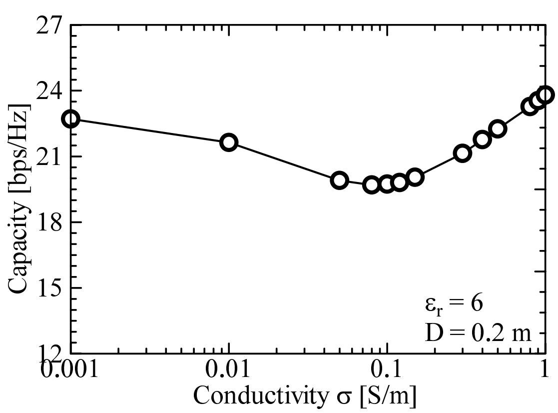

Fig. 3 MIMO channel capacity versus conductivity of wall when the relative permittivity and the thickness are 6, and 0.2 m, respectively.

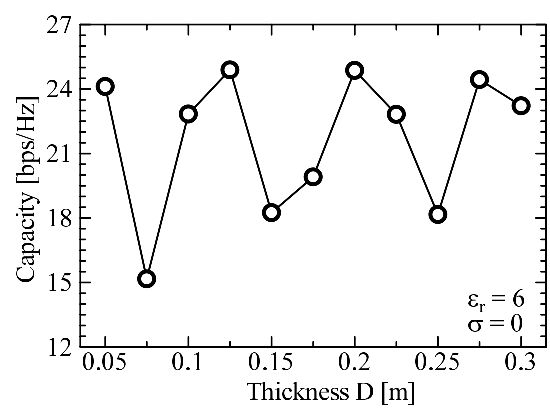

Fig. 4 MIMO channel capacity versus wall thickness when the conductivity and the relative permittivity are 0, and 6, respectively.

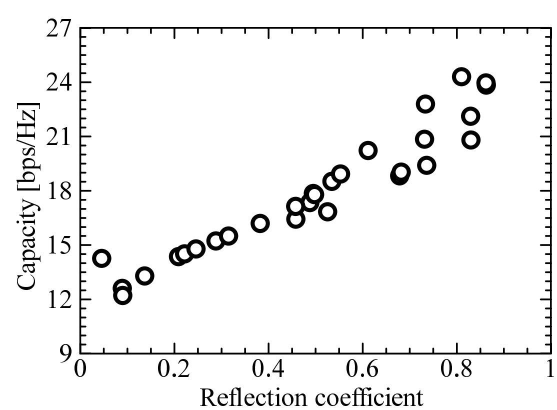

Fig. 5 MIMO channel capacity versus wall reflection coefficient.

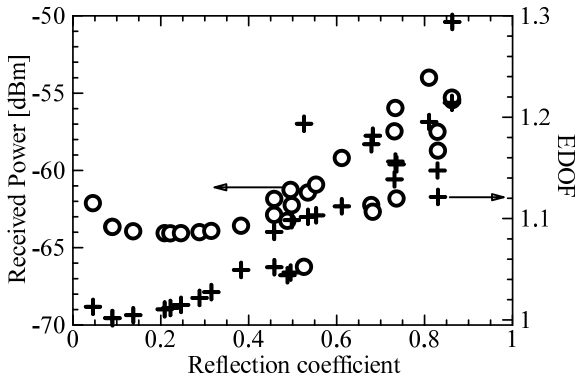

Fig. 6 Received power on each receiving branch and EDOF versus wall reflection coefficient.

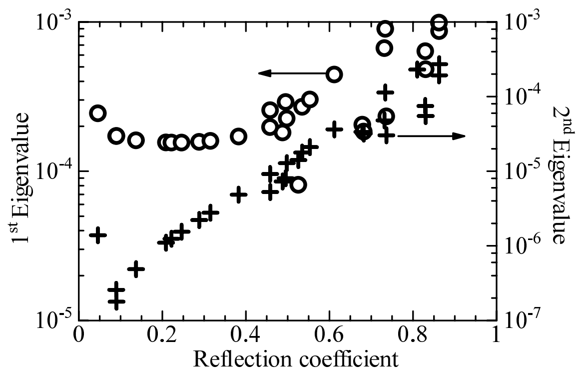

Fig. 7 Eigenvalues of $HH^{\dagger}$ versus wall reflection coefficient.

power and the EDOF of MIMO system are improved with the increase of wall reflection. Therefore, when the wall reflection becomes stronger, MIMO channel capacity is improved.

The eigenvalues of $HH^{\dagger}$ are also analyzed with wall reflection and the results are shown in Fig. 7. It is found that the eigenvalues increase with the increase of wall reflection, and the second eigenvalue increase much more than the first one. When the total transmitted power is fixed, MIMO channel capacity can be improved with the increase of the eigenvalues. Therefore, the higher wall reflection can bring benefit to indoor MIMO channel capacity.

4. Conclusions

The effects of the physical parameters and the reflection of wall on indoor MIMO channel capacity have been investigated. It has been found that there is no simple correlation between MIMO channel capacity and the individual physical parameters of wall. By statistically analyzing MIMO channel capacity with wall reflection coefficient, it has been found that the stronger wall reflection can lead to higher MIMO channel capacity because the average received power, the EDOF and the eigenvalues of transfer channel covariance matrix increase with the increase of wall reflection.

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