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Channel Capacity Improvement of MIMO System by Using Directional Antennas

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1. Introduction

MIMO (Multiple-Input Multiple-Output) system [1] attracts much attention and has been put into a practical use. It makes high speed wireless communications possible by using plural antennas for each station without extending frequency band width.

In the indoor MIMO system, it is considered that a basestation is located at the center of the wall. At this situation, it is expected that good propagation characteristics can be obtained when directional antennas are used rather than using omni-antennas as basestation antennas [2]. Moreover, the space filtering algorithm might affect the optimal basestation antennas.

This paper describes the channel capacity improvement of indoor MIMO systems by using directional antennas. And, the influence of the space filtering algorithm on the selection of the optimal basestation antennas is investigated based on the calculated results, it is shown that the channel capacity is improved greatly using directional antennas than the case of omni-antennas for basestation antennas. Moreover, it is confirmed that the optimal basestation antennas should be changed according to the space filtering algorithm. The antennas with narrow beams should be chosen when the MMSE is applied. On the other hand, the antennas with a wide beam should be chosen when the MLD is applied.

2. Analysis Model for Indoor MIMO System

2.1 Propagation Analysis Model

The room model used for propagation analysis is shown in Fig.1. The room size is 20m in length, 20m in width, and 3m in height. The relative dielectric constant and the conductivity of walls are 5.0 and 0.05S/m, respectively. The propagation characteristics are calculated by using the ray-tracing method.

Carrier frequency is 5GHz and the reflection at walls is considered up to 5 times. The channel response matrix is obtained by normalizing complex received voltage matrix. We consider the 2x2 MIMO system which consists of two basestation antennas and two terminal antennas. The spacing between the antenna elements for both a basestaion and a terminal is a half-wavelength, respectively.

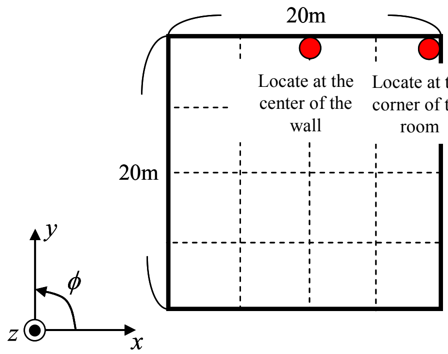

Figure 1: Room Model

The location for the basestation considered in the simulation is shown in Fig.1. The basestation antennas are located apart 50cm from the wall and 1m height from the floor. The complex channel response matrices are calculated for every combination of wireless terminal location at intervals of 1m in x direction and y direction. Namely, the number of calculated points for terminal location is 361.

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Four types of location of antennas for the wireless terminal as follows are considered for calculating the complex channel response at each measurement point.

- The antennas are located in the *x*-axis direction ($\phi = 0$ degree).
- They are located in the *y*-axis direction ($\phi = 90$ degrees).
- They are located in the slant direction ($\phi = 45$ degrees, 135 degrees).

2.2 Antenna Element Pattern

It is assumed that the half power beam width (HPBW) in the vertical plane is θ_{HP}=78 degrees for both of the basestation and the wireless terminal.

The HPBW of horizontal plane of basestation antennas ϕ_{HP} is varied as a parameter as shown in Fig.2. Here, the following equation is used for the electric field pattern of the elements. θ_0 and ϕ_0 are the direction of the beam center in the vertical and the horizontal planes, respectively. $E_{\max}$ is an electric field gain, the antennas of the terminal are omni-directional [3].

$$E(\theta,\phi)=\begin{cases} E_{\max}\cos\left\{\dfrac{\pi}{2}\dfrac{\theta-\theta_0}{\theta_{HP}}\right\}\cos\left\{\dfrac{\pi}{2}\dfrac{\phi-\phi_0}{\phi_{HP}}\right\} & (|\theta-\theta_0|\le\theta_{HP}, |\phi-\phi_0|\le\phi_{HP}) \\ 0 & others \end{cases} \quad (1)$$

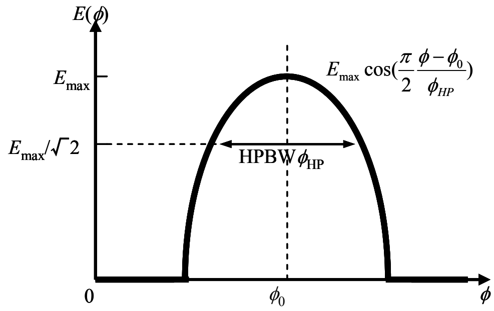


Figure 2: Element Pattern Model

2.3 Beam Direction of Basestation Antennas

As shown in Fig.3, the beam direction is set up as follows.

- The antenna elements are located on the parallel direction facing a diagonal wall.
- The direction of the center of beams is separated symmetrically from the direction of the opposite side wall.
- The beam direction is determined by the angle difference ϕ_B of the direction of these two beams.

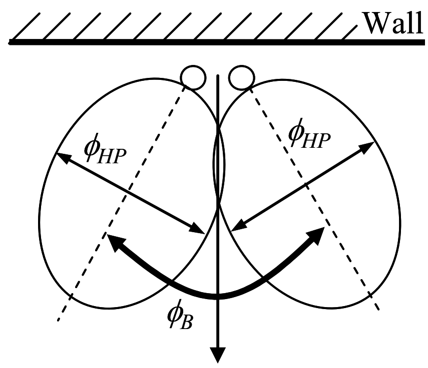


Figure 3: Basestation Location and Beam Directions

2.4 Calculation of Channel Capacity

Control of the weight coefficient in the MIMO system is based on the MMSE (Minimum Mean Square Error) or MLD (Maximum Likelihood Detection). Channel capacity is calculated with the MMSE algorithm using following equation (2), and with the MLD algorithm using following equation (3) [4].

$$C = -\sum_{j=1}^{N_t} \log\left(1 - h_j^H\left(HH^H + N_t I_{N_r}/\gamma_0\right)^{-1} h_j\right) \quad (2)$$

$$C = \sum_{j=1}^{N_t} \log\left(\lambda_j \gamma_0 / N_t + 1\right) \quad (3)$$

Here, H is the channel response matrix, upper subscript H means Hermite-transpose, h_j is the j-th column of H matrix, I is a identify matrix, γ_0 is the average receiving signal to noise ratio (SNR). N_t is the number of transmission antennas. λ_j is the eigenvalue of the diagonal column. The channel response matrix was found by conducting ray tracing using the propagation analysis model. HPBW of the horizontal plane ϕ_{HP} and angle difference of the beam ϕ_B mentioned in Section 2.1, Section 2.2 and Section 2.3, is changed as parameters. The channel response matrix is substituted for H of the equation (2) and (3), and the channel capacity is obtained by setting up the average SNR. Here, the transmission power is determined so that the SNR becomes 20dB at 10m apart from a transmitter in free space.

3. Improvement of Channel Capacity Using Directional Antennas

Figure 4 shows the channel capacity when the omni-antennas and the directional antennas are used under the optimal HPBW of horizontal plane of basestation antennas ϕ_{HP} with the MMSE and MLD algorithms [5].

As shown in Fig.4, with the MMSE algorithm, the maximum channel capacity is between 4bits/s/Hz to 5bits/s/Hz when ϕ_B =90 degrees. While it is between 2bits/s/Hz to 3 bits/s/Hz using the omni-antennas for basestation antennas. Thus, the capacity is increased approximately 1.8 times by using the directional antennas as the basestation compared with the case of omni-antennas.

On the other hand, with the MLD algorithm, the maximum channel capacity is between 7bits/s/Hz to 8bits/s/Hz, it is obtained when ϕ_B =60 degrees. While it is between 5bists/s/Hz to 6 bits/s/Hz using the omni-antennas for basestation antennas. Thus, the capacity is increased approximately 1.4 times by using the directional antennas as the basestation compared with the case of omni-antennas.

It is confirmed that the channel capacity is improved greatly using directional antennas than the case of omni-antennas for basestation antennas. This means that radiation to a useless radiation is suppressed by using the directional antennas, thereby high received power can be obtained.

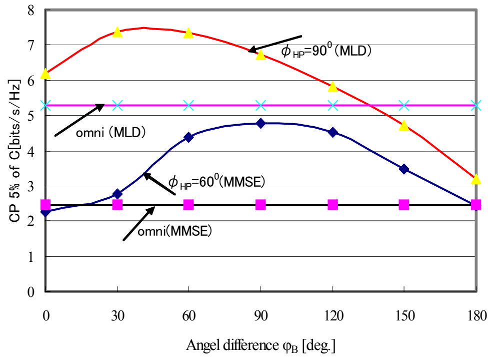


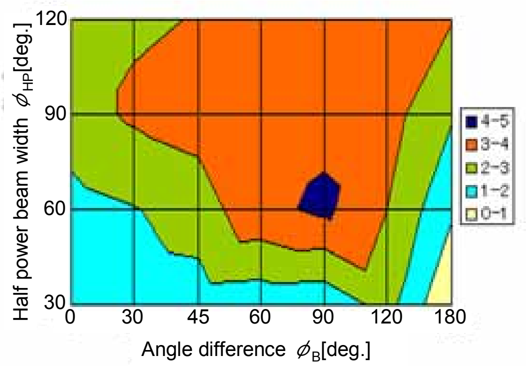
Figure 4: Effect of Angle Difference on Channel Capacity (Cumulative Probability:5%)

4. Effect of Space Filtering Algorithm on Optimal Basestation Antennas

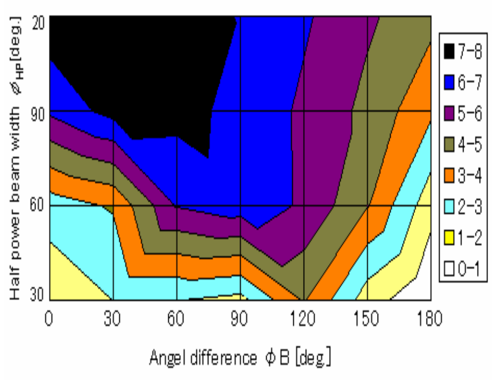
Figure 5 shows the variation of the channel capacity when the directivity of elements and the beam direction are varied with the different space filtering algorithm: MMSE and MLD. It shows the average channel capacity when cumulative probability is 5%, the horizontal axis indicates the angle difference ϕ_B of the beam, and the vertical axis indicates the HPBW ϕ_{HP} of horizontal plane.

Figure 5(a) is the channel capacity calculated with the MMSE algorithm; Fig.5(b) is the channel capacity calculated with the MLD algorithm. As shown in Fig.5(a) the maximum channel capacity is obtained in the case of MMSE when ϕ_{HP} =60 degrees and ϕ_B =90 degrees. On the other hand, in case of MLD in the Fig.5(b), the maximum channel capacity is obtained when ϕ_{HP} =90 degrees and ϕ_B =60 degrees.

From the comparison between Fig.5(a) and Fig.5(b), we can find that the antennas with narrow beams should be chosen when the MMSE is applied. On the other hand, the antennas with wider beam should be chosen when the MLD is applied.



(a) MMSE Algorithm



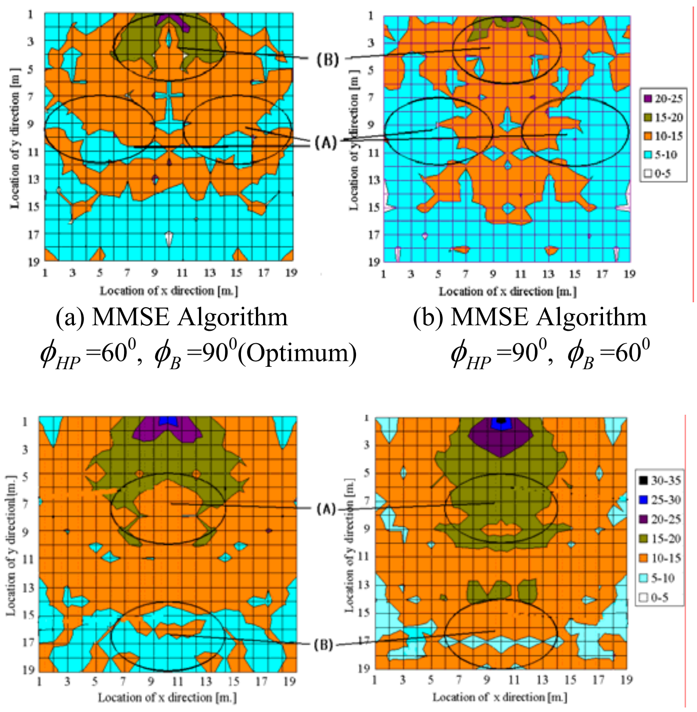
(b) MLD Algorithm

Figure 5: Distribution of Channel Capacity (Cumulative Probability: 5%)

To discuss the difference of the optimum beam width and the beam direction between control algorithms, the distributions of channel capacity in the room in case of several conditions are drawn in Fig.6.

Figure 6(a) and Fig.6(b) are the cases when the MMSE is applied. Figure 6(a) is the optimum condition while the Fig.6(b) is non-optimum condition. We can find by comparing the figures that not only the capacity at the room side indicated (A) but also the basestation side indicated (B) is decreased when the difference of the beam direction is narrower than the optimum condition.

On the other hand, Fig.6(c) and Fig.6(d) are the cases when the MLD is applied. Figure 6(c) is non-optimum condition while the Fig.6 (d) is the optimum condition. We can find by comparing the figures that the capacity at the room center indicated (A) and (B) is increased by narrowing the difference of beam direction ϕ_B . But, the capacity at the room side is not decreased even when the difference of beam direction is set at narrow. To illuminate the whole room with narrow angle difference, the directional antenna with wide beam should be chosen when MLD is applied. This is why the optimum beam width in case of MLD is wider than the case of MMSE.



(a) MMSE Algorithm ϕ_{HP}=60^0, ϕ_B=90^0(Optimum)

(b) MMSE Algorithm ϕ_{HP}=90^0, ϕ_B=60^0

(c) MLD Algorithm ϕ_{HP}=60^0, ϕ_B=90^0

(d) MLD Algorithm ϕ_{HP}=90^0, ϕ_B=60^0(Optimum)

Figure 6: Distribution of Channel Capacity

5. Conclusion

The performance of the indoor MIMO system using directional antennas was studied. It was shown that the capacity of the MIMO system was improved by using directional antennas rather than the case of omni-directional antennas as the basestation antennas. Moreover, it was confirmed that the optimal basestation antennas should be changed according to the space filtering algorithm. The antennas with narrow beams should be chosen when the MMSE was applied. On the other hand, the antennas with a wide beam should be chosen when the MLD was applied.

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