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Optimum Beam Direction and Width for Directional Antenna Indoor MIMO Systems

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1. Introduction

Recently, the MIMO (Multiple-Input Multiple-Output) systems are expected as a technology of achieving a high transmission capacity in wireless communication systems. In the MIMO system, SDM (Space Division Multiplexing) method and E-SDM (Eigenbeam SDM) method are proposed [1]. The former is the method transmitting sub-stream with an equal transmit power from all transmitting antennas, and the latter is the method forming orthogonal channel by using SVD (Singular Value Decomposition) of a channel matrix **H**. The transmission capacity of SDM is not higher than that of E-SDM, however, the transmission performance of SDM method is not degraded by a change of channel characteristics, and it provides a simple system because of not using transmitting weight and its system has already been introduced in wireless LAN [2].

To obtain high performance and low cost MIMO system, we have proposed the introduction of the directional antenna to the base station for the indoor propagation environment in the SDM system [3]. When the directional antenna is used for an actual environment, there are a lot of variety of room shapes, such as, office, meeting room, and etc. Then, the beamwidth and the beam direction of base station antennas should be optimized to maximize the channel capacity depending on the room shape. This paper presents the optimum beam width and the direction of base station antenna for various room shapes using by ray-tracing method to obtain the maximum channel capacity in MIMO system used under indoor propagation environment.

2. Simulation model

Figure 1(a) shows a simulation model used in this paper. The room size is given by $6 \times 10t \times 2.7[m]$, and the aspect ratio of the room is changed by parameter t, where the real size is $100\lambda \times 100\lambda t \times 45\lambda[m]$ for the 5GHz band. We examine 2×2 MIMO system. It is an open area between transmitter (Tx) and receiver (Rx) and no objects are placed. Tx is set in the position of $0.2[m]$ below the ceiling, and the pencil beam with an infinite Front-to-Back (FB) ratio givens as eq. (1a), (1b) is assumed in this simulation.

$$D(\theta) = \begin{cases} \cos^{\Theta_H}(\theta) & (0 \leqq \theta \leqq \pi/2, 3\pi/2 \leqq \theta \leqq 2\pi) \\ \alpha_{F/B} \cos^{\Theta_H}(\theta) & (\pi/2 \leqq \theta \leqq 3\pi/2) \end{cases} \tag{1a}$$

$$\Theta_H = -\frac{\log_{10} 2}{\log_{10} \cos(\theta_H/2)} \tag{1b}$$

$$Gain[dB] = 10 \log_{10} \frac{4\pi}{\theta_{HP}\phi_{HP}} \tag{2}$$

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where, θ_{HP} and ϕ_{HP} are half-power beam width in the θ and ϕ plane, respectively [4]. The MIMO channel model is given by ray-tracing method by adding up the electric fields in each path, where the time deviation, the diffraction and scattering are not considered. The room size is denoted as x_{room} and y_{room} as shown in Fig. 1(b), and its channel responses are calculated at the 25 points inside the area of $x_{room} \times 1/6$[m] by $y_{room} \times 1/6$[m] by moving Rx. Omni directional antennas are used for Rx and the channel matrix $\mathbf{H}$ is estimated by using complex sliding correlation. As a evaluation factor, the channel capacity is defined as follows,

$$\begin{aligned} C &= \log_2[\det[\mathbf{I} + \frac{P_t}{2\sigma^2}\hat{\mathbf{H}}\hat{\mathbf{H}}^H]] \\ &= \sum_{i=1}^{2} \log_2 \frac{P_t \lambda_i}{2\sigma^2} \qquad [bits/s/Hz] \end{aligned} \tag{3}$$

where, $\hat{\mathbf{H}}$, P_t, σ^2 and λ_i are estimated channel matrices, the total transitting power, noise power, and the eigenvalues of $\hat{\mathbf{H}}\hat{\mathbf{H}}^{\mathbf{H}}$, respectively [5]. After the above simulation, the average channel capacity of 25 points is used as channel capacity of the room. The simulation parameters are shown in Table 1.

3. Simulation result

The separation angle (θ_S) between two Tx beams is changed from 0° to 180° to calculate the average channel capacity inside the room, where half-power beam width (θ_H) is changed from 30° to 150° in every 30° and the aspect ratio (t) of the room is 0.5 to 2. Figure 2 shows the results of the above parameters together with those of omni-directional antenna [6]. The Tx beam has the optimum θ_S to maximize the average channel capacity. The channel capacity is increased for small θ_S in the case of the aspect ratio $t > 1$ and is higher than that of omni antenna.

Figures 3 (a) and (b) show the optimum half-power beam width and the angle between beams to maximize the average channel capacity as a function of aspect ratio. The optimum beam for θ_H and θ_S are less than 90° and 100°, respectively. These optimum angles are inversely proportional to the aspect ratio, especially for $t > 1$, however, the beam with $\theta_H = 60°$ is almost the optimum. In the next step, θ_S is changed by using optimum beam width $\theta_H = 60°$. Figure 4 (b) shows the optimum incident angle of the main beam against on the wall side θ_1 defined in Fig. 4 (a) as a function of t, where the dotted line shows θ_{1limit}, the angle of incident beam pointing to the room corner. The optimum θ_1 is increased following to this dotted line, which indicates the optimum θ_1 is approximately given by θ_{1limit}. To confirm this approximation, the channel capacities for the optimum θ_1 and θ_{1limit} are compared in Fig. 5 (a). Two curves are almost the same, which shows the optimum beam direction for $\theta_H = 60°$ should point toward the room corner. Figure 5 (b) shows the eigenvalue for the beam with $\theta_H = 60°$ and $\theta_1 = \theta_{1limit}$ for $t = 2$ as the example. These results show that the 1st eigenvalue relating to the direct path is effective to increase the channel capacity. Pointing the beam direction toward the corner makes the dominant direct path inside the room.

4. Conclusions

In this paper, the optimum beam parameters for the directional antenna in MIMO indoor system was presented by simulation using ray-tracing method. As a result, the beam direction should point toward the room corner for the case of beamwidth of $\theta_H = 60°$ to maximize the channel capacity by using the dominant direct path. The research in the case of changing the size of rooms is left for the future problem.

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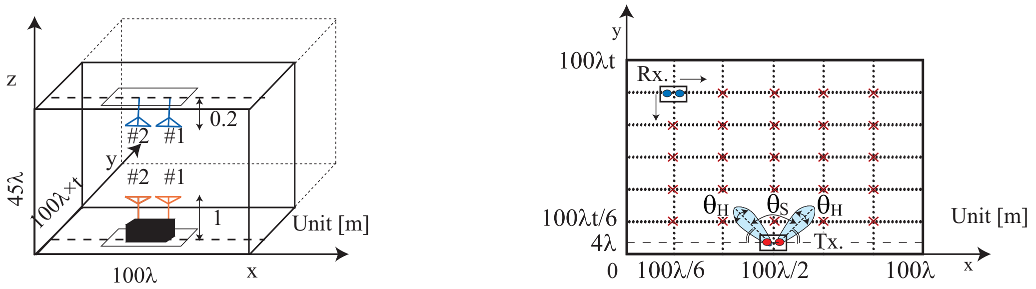
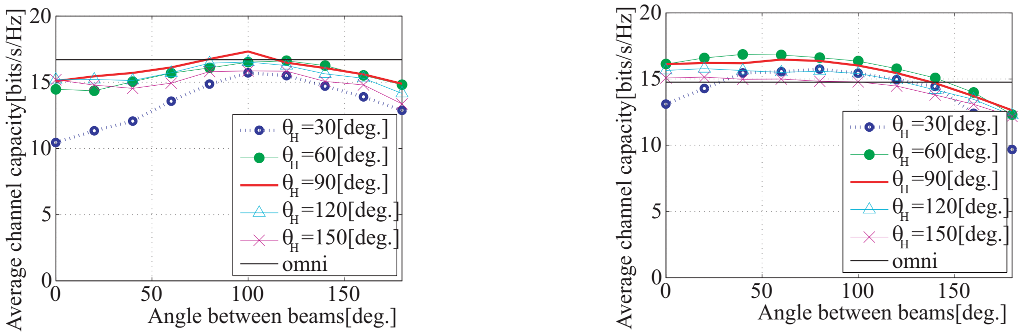
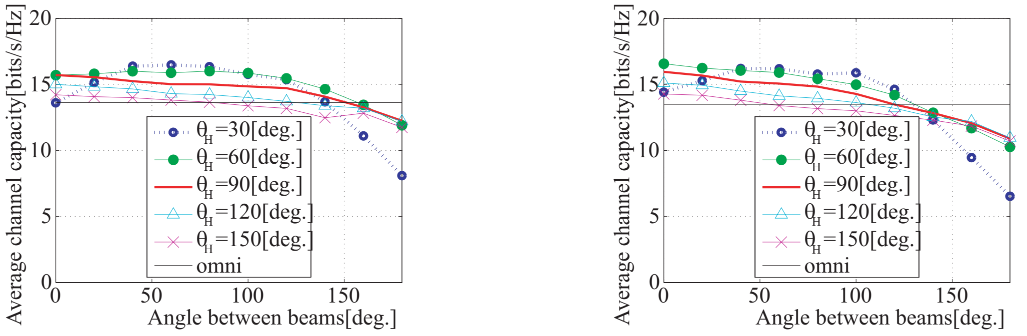


(a) Roomsize (b) Range of reception

Fig. 1: Simulation model



(a) Aspect ratio 1:0.5 (b) Aspect ratio 1:1

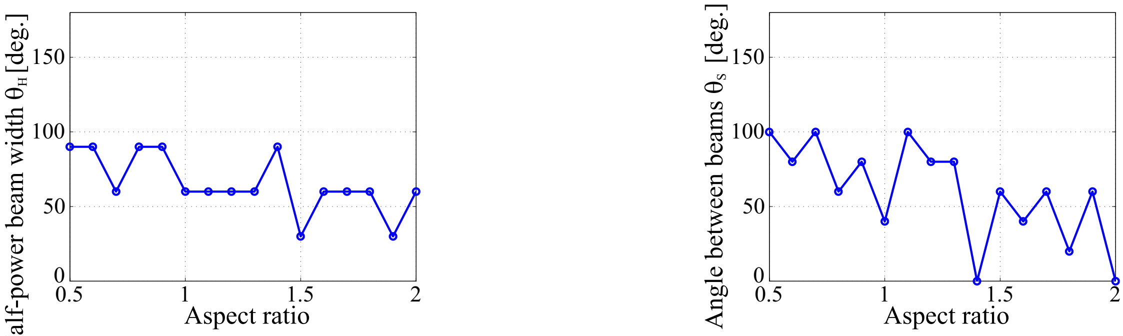


(c) Aspect ratio 1:1.5 (d) Aspect ratio 1:2

Fig. 2: Average channel capacity

Table 1: Simulation parameter

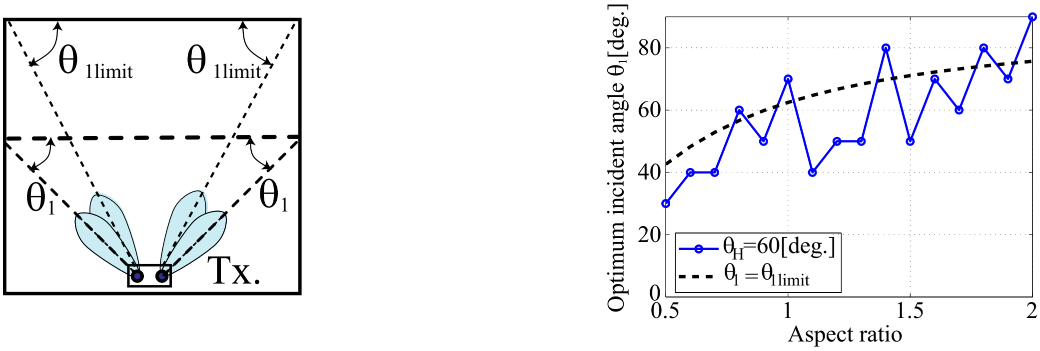
MIMO	2×2	Symbol rate	4Msps
Carrier frequency	5[GHz]	Modulation method	QPSK(header),16QAM(data)
Antenna spacing	Half a wave length	Wall material	Concrete
Transmitting power	-5[dBm/ch]	Noise power	-85[dBm]



(a) Optimum θ_H

(b) Optimum θ_S

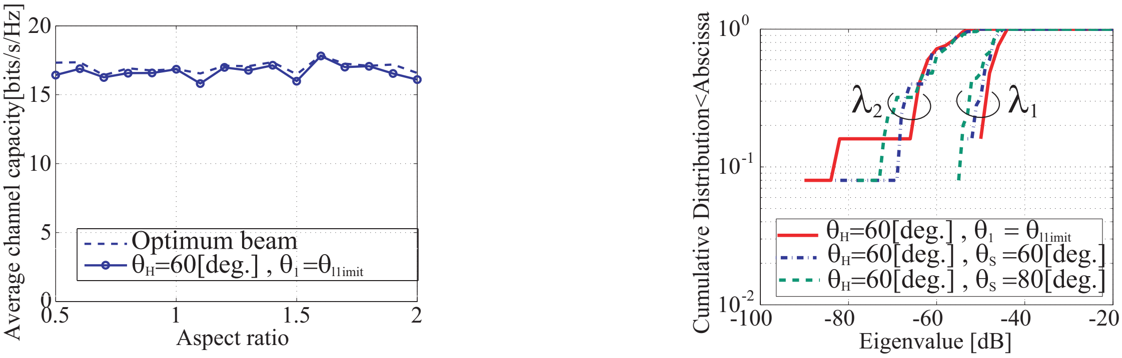
Fig. 3: Optimum θ_H and θ_S



(a) Setting of angle

(b) Angle of incidence of the main beam

Fig. 4: Angle of incidence of the main beam



(a) Channel capacity of θ_H=60[deg.] , θ_1=θ_{1limit}

(b) Eigenvalue of θ_H=60[deg.] , θ_1=θ_{1limit} (t=2)

Fig. 5: Beam of $\theta_H = 60^\circ$, $\theta = \theta_{1limit}$