2B2-4

Proceedings of ISAP2012, Nagoya, Japan

Improvement of MIMO Channel Capacity Using Tunable Transmit-Array Antenna

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1. Introduction

When the number of propagation paths is limited, channel capacity is decreased by a key hole effect in Multiple-Input Multiple-Output (MIMO) systems [1]. Recently, the studies on the reflect-array which reflect radio wave in a specific direction, have been pursued for improving MIMO channel capacity [2]- [3]. In this paper we propose improvement method of MIMO channel capacity using tunable transmit-array antenna for an environment with the limited propagation paths. The channel capacity is maximized by tuning the termination condition of the antenna elements in the transmit-array. The improvement effect by the transmit-array with tunable elements on the MIMO channel capacity is evaluated based on the raytrace analysis in indoor environment. Also, the effect of the element spacing and aperture size of the transmit-array are studied to show the proposed transmit-array has a fair performance even with a feasible configuration.

2. Proposed theorem and configuration of reflector array

Figure 1 shows the sketch of the proposed transmit-array and the definition of the channels dealt with in our discussion. H_{RT} is a propagation channel between the transmitter (Tx) and the receiver (Rx), H_{PT} is a propagation channel between Tx and transmit-array (Px), and H_{RP} is a propagation channel between Px and Rx. Here, all of the channels are defined by assuming all of the antennas including transmit-array elements are terminated by the reference impedance, Z_0. For simplicity, the antenna elements for Tx, Rx and Px are half-wavelength dipole antennas. inter-element spacing is set to d. The number of Px elements is $N \times N$. By optimizing the reactance value $\boldsymbol{X} = [X_1, X_2, ..., X_n]$ of the load impedance of each Px element, the scattering wave is varied. The channel capacity can be improved by controlling the propagation environment with $\boldsymbol{X}$. The scattering parameter of the reactance set, $\boldsymbol{\Gamma}$, can be expressed as,

$$\boldsymbol{\Gamma} = \mathrm{diag}\left(\frac{jX_i - Z_0}{jX_i + Z_0}\right) (i = 1, 2, \ldots, n) \quad (1)$$

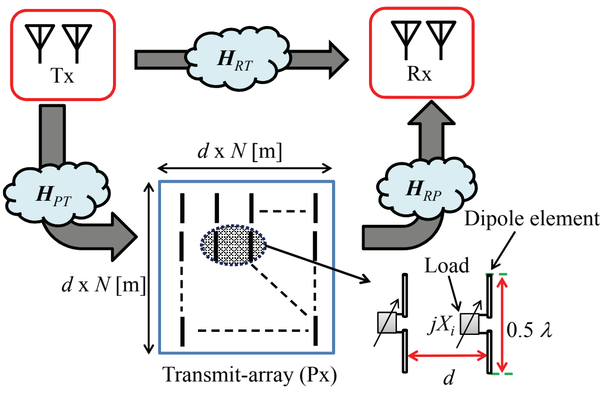

Figure 1: Proposed transmit-array and definition of the channels.

Now, define (1) and $\boldsymbol{S}_{PP}$ as termination condition, and S-parameter of Px, respectively. When the transmit-array antenna is connected with with $\boldsymbol{\Gamma}$, the observed propagation channel $\boldsymbol{H}'_{RT}$ can be expressed as

$$\boldsymbol{H}'_{RT} = \boldsymbol{H}_{RT} + \boldsymbol{H}_{RP} \left(\boldsymbol{\Gamma} - \boldsymbol{S}_{PP}\right)^{-1} \boldsymbol{H}_{PT} \quad (2)$$

The channel capacity is computed by using (2), and maximum value of channel capacity is computed by using steepest gradient method.

3. Numerical results

Figure 2 shows the indoor propagation environment model. The room is divided into 2 symmetrical rooms by the partition wall that has an aperture in the center of it. The size of the partitioned room is 6.8 x 7.8 x 2.5 m^3. The aperture size is 1.0 x 1.0 m^2 and the Px is placed at a center of it. The overall shape of the Px is square and the width one side of the square is $d \times N$ [m]. $T_a \sim T_e$ and $R_a \sim R_e$ indicate the positions of the transmitter, and receiver, respectively. $T_a \sim T_d$ and $R_a \sim R_d$ are located with the 1 m distance from the walls, and T_e and R_e are located at the center of the rooms. h represents the height of the Tx and Rx, and the value is set to 0.2 m and 1.0 m. The number of the antenna elements in Tx and Rx is 2, and the inter-element spacing, d, is 0.5 λ (λ : wavelength in vacuum). The permittivity and loss tangent of the wall are $\varepsilon_r = 6$, tanδ = 0.03, respectively. Frequency is set to 2.4 GHz, and variable range of reactance value is set to $-100 \leqq X \leqq 10$. In the raytrace simulation, the partition is assumed to be a non-transparent wall except the aperture part, and the number of the reflection times is up to 6.

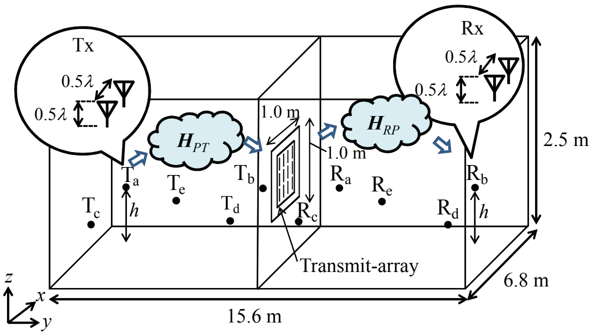

Figure 2: Propagation environment model

Figure 3 shows the $N \times N$ transmit-array configuration with constant element spacing. The element spacing, d, is $0.5 lambda$, and the size of the transmit-array varies depending the number of the elements. The value of N is set as 2, 4, 6, and 8.

Figure 4 shows the configuration of the transmit-array with the constant aperture size. d in Fig. 4 is the inter-element spacing of dipole antenna and d is determined as

$$d = \frac{0.5\lambda \times (N_{MAX} - 1)}{N - 1} \quad (3)$$

where N_{MAX} is maximum number of N and $N_{MAX} = 8$. Aperture area of transmit-array is 0.5×0.5 m^2, that size is 8×8 transmit-array whose inter-element spacing is 0.5 λ.

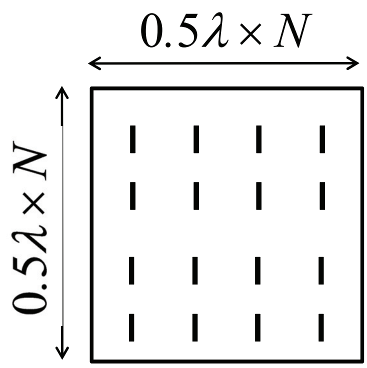

Figure 3: Reflector array configuration with constant element spacing

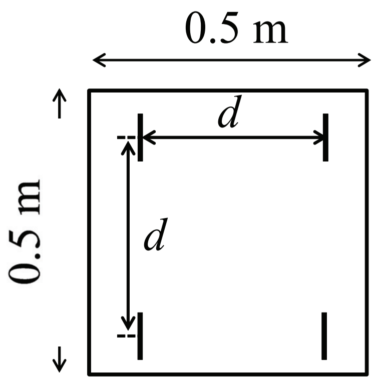

Figure 4: Rflector array configuration with constant aperture size

3. 1 MIMO channel capacity

Figure 5 indicates Cumulative-Distribution-Function (CDF) of the channel capacity with three different cases. (a) indicates the CDF of channel capacity without Px, (b) indicates the channel capacity with Px (Px elements are terminated by fixed reactances value), and (c) indicates the channel capacity with Px (Px elements are terminated by optimized reactances that achieve the maximum channel capacity).

It can be seen that 50 % capacity of (c) is higher by 6 bits/s/Hz than that of (a), whereas the capacity of (b) is slightly improved from (a). On the other hand, compared with (a), (b) and (c) improve the capacity by 4 and 10 bits/s/Hz in 10 % value, respectively. Therefore, it is found that the transmit-array has a great impact on the capacity enhancement especially in the low percentage values.

3. 2 Average channel capacity versus number of elements

Figure 6 shows the average channel capacity versus number of elements, where the element spacing is constant. From the results in the Fig. 6, it can be seen that average channel capacity is improved by increasing the number of elements. This is because the aperture area of the transmit-array is expanded in proportion to N^2, and this enhances the gain of the transmit-array. Moreover, it is found that optimization the reactance of elements greatly enhances the channel capacity compared with the results of the fixed reactance case.

Figure 7 shows the average channel capacity versus number of elements when the aperture size is constant. For comparison, the average channel capacity of the transmit-array with the fixed terminations also shown. From the results in the Fig. 7, it is found that the average channel capacity is improved by increasing the number of elements. Moreover, it is found that tunable load impedance improves the channel capacity by up to 3.8 bits/s/Hz.

Figure 8 shows average channel capacity versus number of elements. Here, the capacities with the constant element spacing and constant aperture size are compared. From the results in the Fig. 8, it can be seen that the average channel capacity of the constant aperture size exceeds that of the constant element spacing where number of element is 4, 16 or 36. Improvement of average channel capacity of the constant aperture size is as well as constant element spacing where number of element is 64, because these are same configuration.

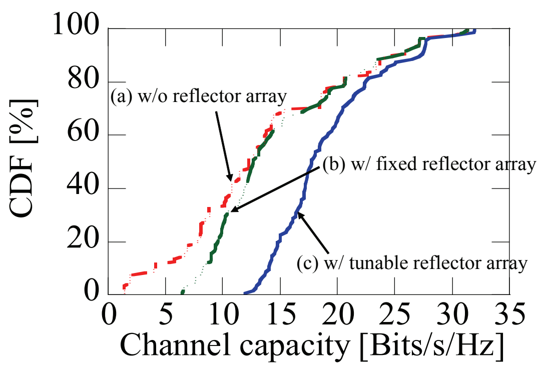

Figure 5: CDF of channel capacity

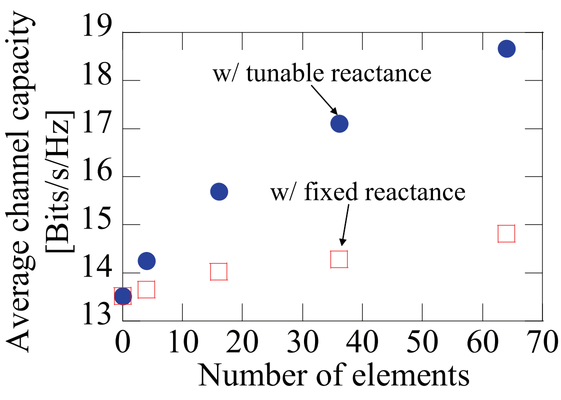

Figure 6: Average channel capacity with constant element spacing

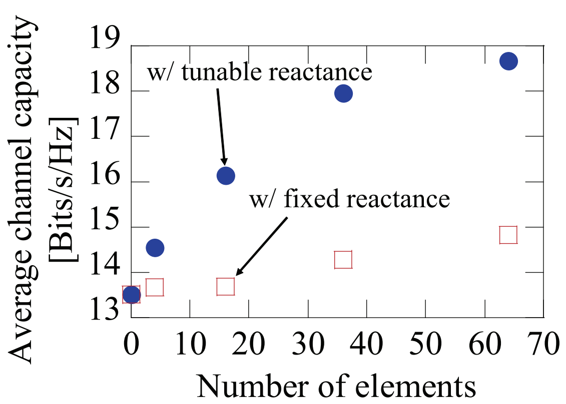

Figure 7: Avarage channel capacity with constant aperture size)

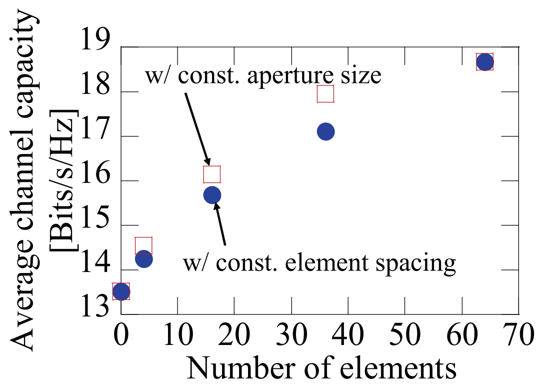

Figure 8: Comparison for average channel capacity of the constant element size and the constant aperture size

4. Conclusion

In this paper, we proposed improvement method of MIMO channel capacity using transmit-array with tunable reactance for the environment suffering from the key-hole effect. The tunable transmit-array is placed at the aperture of the enclosed room to increase the number of the paths. From the numerical result, it is found that the 50 %, channel capacity of the arbitrarily optimized termination condition of the transmit-array elements is improved by 6 bits/s/Hz compared to that without transmit-array. Moreover, the 10 %, channel capacity with the arbitrarily optimized termination condition is improved by 10 bits/s/Hz compared to that without transmit-array. It is found that the larger the aperture of the transmit-array becomes the higher the channel capacity becomes. These results have demonstrated the validity of the improvement of MIMO channel capacity using transmit-array with tunable reactances.

Acknowledgments

This reserch was partinally suposed by MEXT KAKENHI (22760261)

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