MIMO Channel Capacity Enhancement by Antennas Using Phase Control

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1. Introduction

Recently, the high speed data transmission is requested by the appearance of various applications in the upcoming cellular phone service. The mobile communication system is developing beyond 3G which is the broadband and high speed in the high dimension, then the MIMO system is expected for efficient improvement use of the frequency.

In this paper, we investigate four antennas combined through analog phase shifters provided by two output ports to the receiver to obtain large capacity by setting various phase differences. As the method to select the optimum phase difference, we select the phase condition at the RSSI level [1]. As another approach, this paper propose that the optimum phase difference is decided by the correlation coefficient derived by the complex radiation pattern to obtain channel capacity higher than that of the RSSI level. We also confirm the validity of the correlation coefficient method by considering the presence of a simple shape of the human head model.

2. Analytical model

Antennas investigated in this paper are mounted on the top of the mobile terminal as shown in Fig. 1, where four (Inverted F-shaped Antennas) IFAs are arrayed. The IFA #1 and #2 are combined through an analog phase shifter to obtain the adaptive pattern control, which gives a single antenna port for a pair of IFAs. The IFA #3 and #4 are also fed in the same way. As a reference array, four IFAs are mounted on it as shown in Fig. 1 without making a phase difference between the #1 and #2, the #3 and #4, respectively. The frequency is 3.7GHz, and the impedance matching at the feed is given by adjusting a position of a shortening stub. A propagation model used in this paper is shown in Fig. 2. Two pairs of IFAs are arrayed in orthogonal, and the direction of direct wave is given as $\phi$. Here, we consider this analytical model only in the horizontal plane. This analysis is assumed as an indoor propagation environment or a small-scale outdoor propagation environment, and under the Nakagami-Rice propagation model. The scattering wave is given by the Kronecker model [2], where the SNR is 20dB and the Rician K-factor is 3dB throughout this paper.

This paper presents the method to select the optimum phase difference for the antenna configuration in Fig. 1. As a method deciding the phase difference, we have proposed the method to select the phase difference to maximize the antenna gain. This method is easy applied to the pattern with the direct wave from 0, 90, 180, 270-degree in the horizontal plane as shown in Fig. 3 by changing the phase differences. These radiation patterns are shown in Fig. 4 for Array 1 and in Fig. 5 for Array 2. From these results, we selected the optimum phase difference to get the large antenna gain in these four incoming wave directions as $\pm 60$ degree phase difference for each pair of antennas. The channel capacity for this antenna pattern with $\pm 60$ degree phase difference is shown in Fig. 6, where the direction of incoming wave is used as a parameter. The proposed antenna array in Fig. 1 provides high channel capacity in all the direction-of-arrivals compared to the reference model by switching the phase combinations. The channel capacity increases by 9.2% in the maximum and its average of 6.2% compared to the reference. However, the phase switching is necessary for the model in Fig. 1. Then we consider the insertion loss and the cost of the analog phase shifter. To solve this problem, as an alternative, we propose the method to improve the characteristics without switching the phase combinations in the next section.
3. Complex radiation pattern correlation coefficient method

As another phase selection method, the optimum phase difference is decided by the correlation coefficient derived by the complex radiation pattern. This coefficient $\rho$ is expressed in the following equation under the condition of large incoming wave with the amplitude of Rayleigh distribution.

$$\rho = \frac{g_{12} (\theta, \phi) \cdot e^{j 2 \pi r (\theta, \phi)}}{\sqrt{g_{11} (\theta, \phi) \cdot g_{22} (\theta, \phi)}}$$

(1)

where $g_{ij}$ is the cross polarization power ratio. This evaluated coefficient is shown in Fig. 7. We select $\pm 150$-degree to obtain the minimum correlation coefficient for the optimum phase difference, and the phase difference of the IFA #1 and #2 and the one of the IFA #3 and #4 are the reverse phase in each other. The channel capacity calculated by this phase difference is shown in Fig. 8. The model in Fig. 1 provides high channel capacity in all direction angles compared to the reference without phase control. In addition, the phase difference is fixed and no phase switching is necessary. This method increases the channel capacity by 14% and its average is 10.2% compared to the reference.

4. Human head model analysis

As a real in-use environment for the mobile terminals, we place a human head model of a sphere with radius of 100 mm, relative permittivity of 40 and conductivity of 1.4 S/m close to this proposed model as shown in Fig. 9. Using this model, we find the optimum phase difference as the same procedure in the above as shown in Fig. 10. The correlation coefficient takes the minimum at 150-degree with or without this head model. Then, we use the phase difference of 150-degree for the IFA #1 and #2, and -150-degree for the IFA #3 and #4. The radiation patterns for these phase difference are shown in Fig. 11, which shows that the radio wave is not radiated so much to the head side. The channel capacity is shown in Fig. 12, and are compared with the reference model. The channel capacity with the head model is lower than that without the head due to the suppression of radiation to the head side. This also decreases the radiation efficiency by 23%. On the other hand, the channel capacity with phased array is higher than that without phase control, which shows that the phase selection by the correlation coefficient method is effective in the presence of the human head model. This increase of the channel capacity is 17.7% at the maximum and its average of 13.3%.

5. Conclusion

This paper presented two methods to decide the phase difference for the handset antenna applications, and the simulation of a human head model. The phase selection by the complex radiation pattern correlation coefficient improves channel capacity more than the method using the antenna gain. The proposed method does not require the phase shifter and decrease the insertion loss due to the analog phase shifter. In addition, as the real environment for the usage of mobile terminals, we included a human head model close to the antenna arrays, and showed that the proposed method also increase the channel capacity. The experimental verification will be the future problem.

References
Fig. 1 Antenna Geometry, H=110, W=50, D=20
\(d_1=10, \; d_2=15, \; d_3=37, \; \text{Unit [mm]}, \; \delta: \text{Phase difference}\)
Array 1 (\#1 & \#2), Array 2 (\#3 & \#4)

Fig. 2 Propagation model

Fig. 3 Radiation direction
[In the horizontal plane]

Fig. 4 Antenna gain of array 1
[In the horizontal plane]

Fig. 5 Antenna gain of array 2
[In the horizontal plane]

Fig. 6 Channel capacity
[Method using the antenna gain]
Fig. 7 Correlation coefficient for phase difference [Array1 $\delta$, Array2 $-\delta$ in Fig. 1]

Fig. 8 Channel capacity by the correlation coefficient

Fig. 9 Human head model

Fig. 10 Correlation coefficient for phase difference [Array1 $\delta$, Array2 $-\delta$ in Fig. 1]

Fig. 11 V-pol. radiation pattern in the horizontal plane [Array1 150deg, Array2 -150deg in Fig. 1]

Fig. 12 Channel capacity [Human head model analysis]