Optimum phase shift applied to weighted-polarization MIMO antenna in various use scenarios

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Abstract: This paper presents a method to achieve the maximum MIMO channel capacity using a weighted-polarization MIMO antenna. Particular emphasis is placed on the way to adjust the phase shift value between the antenna elements to an optimum value in accordance with the variation of cross polarization power ratio (*XPR*) and the antenna inclination angle. Both the measurement and analytical results show that using the optimum phase shift value, the MIMO channel capacity is increased in comparison with a conventional fixed-phase shift antenna in various conditions.

Keywords: weighted-polarization MIMO antenna, phase shift value, MIMO channel capacity, MIMO-OTA

Classification: Antennas and Propagation

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1 Introduction

Ultra high-speed and high-capacity mobile communication is coming as a result of the development of LTE-Advanced and Beyond 4G cellular systems using multiple-input multiple-output (MIMO) technique [1]. Since a small cell system is taken into consideration in future ultra high-capacity mobile communications [2], the cross polarization power ratio (XPR) in a radio wave propagation environment will vary significantly. Further, the polarization characteristics of a wearable antenna will also change easily due to the antenna inclination caused by the dynamic motion of an operator [3].

In our previous study [4], a weighted-polarization wearable MIMO antenna was proposed, where two of the three antenna elements are combined using weight functions, which considers XPR and antenna inclination angle as key parameters. However, the phase shift value between the two elements was fixed to 90 degrees considering the balance of influence on the received signal power when the antenna inclination angle is varied from -90 to 90 degrees. To achieve the maximum MIMO channel capacity in various use scenarios, the optimum phase shift value needs to be investigated.

This paper presents an investigation of the optimum phase shift value applied to the weighted-polarization MIMO antenna [5]. By adjusting a phase shift value between the antenna elements to an optimum value in accordance with various use scenarios, the MIMO channel capacity is increased significantly in comparison with a conventional fixed-phase shift antenna described in [4].

2 Weighted-polarization MIMO antenna

Fig. 1(a) shows the configuration of the weighted-polarization MIMO antenna [4]. The antenna is comprised of three orthogonal dipole antennas (A_x, A_y, A_z). When the antenna is rotated by an operator, two of the three dipole antennas are selected using two switches (SW_1, SW_2).

The selection of elements is determined by the use scenarios of a tablet terminal, as shown in Fig. 1(b). In the case of the left figure in Fig. 1(b), the element A_y is not selected because A_y remains unchanged in the horizontal

configuration that receives the horizontally polarized component all the time and thus A_y does not have the ability to provide a varied polarized component. In a similar way, the element A_x is not selected in the case of the right figure in Fig. 1(b) because A_x remains unchanged in the horizontal configuration.

The received signals (s_V, s_H) are multiplied by the weight functions (W_V', W_H'). Thus, the signal at the output port (a) of the antenna is expressed by Eqs. (1)–(5).

$$a = \frac{W_V'}{\sqrt{W_V'^2 + W_H'^2}} s_V + \frac{W_H'}{\sqrt{W_V'^2 + W_H'^2}} s_H e^{j\tau} \quad (1)$$

$$W_V' = W_V |\cos \alpha| + W_H |\sin \alpha| \quad (2)$$

$$W_H' = W_V |\sin \alpha| + W_H |\cos \alpha| \quad (3)$$

$$W_V = \sqrt{\frac{XPR}{1 + XPR}} \quad (4)$$

$$W_H = \sqrt{\frac{1}{1 + XPR}} \quad (5)$$

In Fig. 1(a), a variable phase shifter is used in order to realize the phase shift value τ between the two elements, as denoted by Eq. (1). In our previous study [4], the phase shift value τ in Eq. (1) was fixed to 90 degrees considering the balance of influence on the received signal power when the antenna tilt angle α is inclined from -90 to 90 degrees.

However, when the antenna is mounted on a tablet terminal, as shown in Fig. 1(b), the inclination angle α is changed mainly in a range from 0 to 90 degrees, which means that α is not a negative value in this situation. In this case of $\alpha > 0$, the polarization combination mechanism of the weighted-polarization MIMO antenna is limited to the case as shown in Fig. 1(c).

(c) Polarization combination mechanism

Fig. 1. Weighted-polarization MIMO antenna.

In Fig. 1(c), the weighted-polarization MIMO antenna is separated into two crossed dipole antennas, which can be decomposed into vertical and horizontal components, respectively. Thus, the polarization components distributed in the vertical direction are canceled with each other due to the opposite voltages applied to the antenna exciting terminals whereas the polarization components in the horizontal direction are enhanced because of the common voltages. Therefore, the optimum phase shift value between the two elements is investigated in this paper.

If the phase shift value τ is set to 0 degree, the vertical and horizontal polarization component is canceled and enhanced, respectively. Therefore, the radiation pattern of the weighted-polarization MIMO antenna is suitable for the environment where the XPR expressed in decibel is negative. On the other hand, if the phase shift value τ is set to 180 degrees, the vertical and horizontal polarization component is enhanced and canceled, respectively. Therefore, the radiation pattern of the antenna is suitable for the environment where the XPR is positive. Hence, the optimum phase shift value is varied according to different propagation environments of XPR . Based on the abovementioned mechanism, the optimum phase shift value according to XPR and antenna inclination angle can be determined.

3 Radiation characteristics

In our previous study [6], it is found that the average holding angle of a tablet terminal is 55 degrees. Based on this statistical investigation, the measurements of radiation pattern and channel capacity using the weighted-polarization MIMO antenna are carried out in this paper.

Fig. 2(a) shows the configuration of the 2×2 MIMO antenna. Fig. 2(b) shows the photograph of the array antenna in an anechoic chamber. The two orthogonal half-wavelength dipole antennas were arranged as a MIMO array in the y-direction. Based on the method of the element selection described in Sect. 2, the experimental setup comprised of a two-element crossed dipole antenna is used to represent the state when the two elements of the proposed antenna are selected by the switches SW_1 and SW_2 , as shown in Fig. 1(a). The frequency for the measurements was 2 GHz. The distance between the two array elements was set to 7.5 cm.

The signal combining of the two elements based on Eq. (1) is realized by the use of the RF processing unit, which comprises metallic coaxial cables, variable attenuators and a power divider, as shown in Fig. 2(c). The phase shift value τ in Eq. (1) is realized by adjusting the length of metallic coaxial cables. In the measurement, we performed a calibration to compensate the insertion loss of attenuators [7]. Fig. 2(d), (e) and (f) show the radiation pattern in the xy-plane with respect to the variation of phase shift value τ when the XPR in the weight function is set to 10 dB. The blue line indicates the E_θ -component while the red line indicates the E_ϕ -component. We carried out an analytical simulation using the method of moments.

As can be seen in Fig. 2(d), (e) and (f), the measured radiation patterns using the weighted-polarization MIMO antenna are in good agreement with the analytical results as a function of the phase shift value τ . When τ is set to 0 and 180 degrees,

(a) Configuration

(b) Photograph

(c) Setup for realizing the weight function

Fig. 2. Radiation characteristics.

the E_ϕ and E_θ components are enhanced, as shown in Fig. 2(d) and (f), respectively. In this manner, the weighted-polarization MIMO antenna provides appropriate radiation patterns in accordance with XPR , the antenna inclination angle and phase shift value.

4 2×2 MIMO channel capacity

The MIMO channel capacity of a 2×2 weighted-polarization MIMO antenna shown in Fig. 2(b) was measured using a MIMO-OTA (over-the-air) apparatus [8].

Fig. 3(a) shows the measurement setup of the weighted-polarization MIMO antenna, which is placed at the center of the spatial fading emulator.

Fig. 3(b) indicates the measured and analytical results of 2×2 MIMO channel capacity with the phase shift value τ varied from 0 to 180 degrees when XPR is set to 10 dB and the antenna inclination angle α was fixed at 55 degrees. The SNR of the incident wave was set to 30 dB. The incident wave around the MIMO antenna was set to a uniform angular power spectra in the horizontal plane. In a similar way used in the measurement of the radiation pattern mentioned in Sect. 3, a calibration of the MIMO-OTA system was carried out [7]. In Fig. 3(b), the symbol $\bullet$ denotes the measured results of the 2×2 MIMO channel capacity using the weighted-polarization MIMO antenna. The analytical results are calculated by the Monte Carlo simulation [9], as shown by the solid black line.

As can be seen in Fig. 3(b), the measured results are in good agreement with the analytical outcomes. Further, when the phase shift value τ is set to 180 degrees, a 1.9 bits/s/Hz improvement of the channel capacity is achieved in comparison with the conventional 90-degree phase shift antenna. This is because the radiation pattern of the antenna has a large desired vertical polarization component, as shown in Fig. 2(f), and this benefits in a propagation environment when XPR is 10 dB. On the basis of the abovementioned considerations, we conclude that the optimum value of phase shift is 180 degrees when XPR is 10 dB and the antenna inclination angle is 55 degrees.

(a) Measurement setup

(b) Relationship between phase shift value and channel capacity

Fig. 3. 2×2 MIMO channel capacity.

5 Conclusion

This paper presents a method to achieve the maximum MIMO channel capacity using a weighted-polarization MIMO antenna. By adjusting the optimum phase shift value in accordance with various use scenarios, the MIMO channel capacity is increased more than 1.9 bits/s/Hz in comparison with a conventional fixed-phase shift antenna. Future studies include the derivation of optimum phase shift value in accordance with various use scenarios and XPR s.

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