An 8×8 MIMO 3-axis Weighted Polarization Active Antenna for Wearable Radio Applications

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Abstract

This paper presents a 3-axis weighted-polarization active antenna in order to realize ultra high-speed and high-capacity mobile communications. The proposed antenna is comprised of three orthogonal antennas, two of which can be selected according to a weight function in different situations. The weight function is created based on the variation of cross polarization power ratio (XPR) and the inclination angle of an antenna depending on the propagation environment and the human motion. The result shows that a high level of the channel capacity can be obtained even when the variation of XPR and the antenna inclination angle are taken into consideration simultaneously, demonstrating that gigabit high-speed communication can be realized using the proposed antenna.

1. Introduction

Ultra high-speed and high-capacity mobile communication will be coming soon as a result of the development of LTE-Advanced and Beyond 4G cellular systems using multiple-input multiple-output (MIMO) technique. Since a small cell system is planed for realizing ultra high-capacity mobile communications, the cross polarization power ratio (XPR) in a radio wave propagation environment will vary significantly. Furthermore, polarization characteristics of a wearable antenna will also change easily due to the variation in the inclination angle of an antenna caused by the dynamic motion of an operator. Hence, in order to realize a large transmission rate in wearable radio applications, we need to take the variation in the radio wave propagation environment and the antenna inclination angle into account simultaneously.

This paper presents a 3-axis weighted-polarization active antenna. The proposed antenna is comprised of three orthogonal antennas, in which two of the three antennas are chosen adaptively and a weight function is calculated in consideration of the XPR and the inclination angle of an antenna as parameters. Firstly, the radiation pattern of the proposed antenna is calculated using the method of moments. Then, the channel capacity of an 8×8 MIMO system is analyzed using the Monte Carlo simulation when an operator uses a wearable radio terminal with the proposed antenna mounted on the wrist in both browsing and walking situations.

2. 3-Axis Weighted-Polarization Active Antenna

Figure 1 shows the configuration of 3-axis weighted-polarization active antenna. The proposed antenna is comprised of three orthogonal dipole antennas (A_x, A_y, A_z). When the antenna is rotated by the operation of a user, two of the three dipole antennas are selected using two switches (SW_1, SW_2). The received signals (vertical polarization s_V and horizontal polarization s_H) from two selected antennas are combined using the weight function created based on the variation of XPR and the variation in the antenna inclination angle (α) depending on the propagation environment and the motion of an operator.

As shown in Fig. 1, the received signals (s_V, s_H) are multiplied by the weight functions (W_V, W_H). Consequently, the signal at an output port (a) of the proposed antenna is expressed by the following equation:

$$a = W_V s_V + W_H s_H \tag{1}$$

where the weight functions (W_V, W_H) are calculated by the allotment of signal according to the XPR, and are given by:

$$W_V = \sqrt{\frac{XPR}{1+XPR}} \quad , \quad W_H = \sqrt{\frac{1}{1+XPR}} \qquad (2), (3)$$

As can be seen from the equations mentioned above, using the weight functions defined by equations (2), (3), the dominant incoming wave polarization can be extracted in a specific propagation environment where a radio is used. Therefore, an optimum received signal (a) can be obtained whether the antenna exists in an outdoor environment where XPR is large or in an indoor environment where XPR is small.

978-1-4673-5225-3/14/$31.00

Figure 2 shows the situation that the proposed antenna (see Fig. 1) is mounted on the wrist when an operator walks with swinging both arms. The inclination angle of the antenna changes with changing the arm-swinging angle α, leading to the variation of antenna polarization. Therefore, the weight functions (2), (3) are not appropriate for the situation in Fig. 2 when an operator walks. Thus, the following equations are presented:

$$a = W_V^{'} s_V + W_H^{'} s_H e^{j\frac{\pi}{2}} \tag{4}$$

$$W_V^{'} = W_V \left|\cos\alpha\right| + W_H \left|\sin\alpha\right| \ , \ W_H^{'} = W_V \left|\sin\alpha\right| + W_H \left|\cos\alpha\right| \qquad (5), (6)$$

where the weight functions ($W_V^{'}$, $W_H^{'}$) are provided considering both the weight functions defined by the equations (2), (3) (W_V, W_H) and the variation of arm-swinging angle (α). A quadrature phase shift appearing in the last term in Eq. (4) is needed because there is a cancellation between the vertically or horizontally polarized component of a vertical antenna and that of a horizontal antenna when the proposed antenna shown in Fig. 1 is inclined. The inclusion of a 90-degree shift in the weight function for the signal s_H avoids this cancellation phenomenon, and hence the combination of the received signals (s_V and s_H) can be performed properly. As described in this manner, the equations (5), (6) express the method of signal combination which takes into consideration of the variation of antenna polarization characteristics caused by the dynamic arm-swinging motions.

3. Analytical Results

The radiation pattern of the proposed antenna in free space is calculated using the method of moments. Figure 3 shows the radiation patterns in the horizontal plane as a function of the XPR when the antenna inclination angle (α) is fixed at 0 degree. The frequency for the analysis is 2 GHz. The blue lines indicate the E_θ while the red lines indicate the E_ϕ, which denote the electric field directivity of the antenna element for the θ and ϕ components, respectively. As can be seen in Fig. 3, when the XPR is increased, a vertically polarized component in the radiation pattern is large whereas a horizontally polarized component is small. Thus, the weight function works well according to the change of the XPR.

Figure 4 shows the radiation patterns in the horizontal plane as a function of the inclination angle of the antenna when the XPR is 20 dB. The blue lines indicate the E_θ while the red lines indicate the E_ϕ. As can be seen in Fig. 4, when the antenna inclination angle (α) is varied, a vertically polarized component in the radiation pattern is large because the XPR is 20 dB. It is verified from this fact that the weight function also works very well as we expected when the inclination angle of the antenna changes.

Figure 5 shows the structure of a MIMO array antenna arranged in a 2-dimensional configuration. In Fig. 5, an 8-element MIMO array antenna is comprised of 3-axis weighted-polarization active antennas, with 4 elements arranged in column in the z-direction and 2 elements arranged in row in the x-direction. The space between two array elements is set to 9 cm. A vertically aligned MIMO array as shown in Fig. 5 cannot be evaluated using a 2-dimensional channel model. The reason is that there are no scatterers for emulating multipath radio waves from elevation directions. Hence, we used a 3-dimensional channel model to analyze the channel capacity of an 8×8 MIMO system using the 8-element MIMO antenna mounted on the wrist using the Monte Carlo simulation [1].

There are two typical use scenarios for a watch-type terminal, as shown in Fig. 6. One is a browsing situation when an operator watches the display of a terminal, and the other is a walking situation when an operator walks while swinging the arms. In the case of a browsing situation in Fig. 6(a), a watch-type terminal rotates around the arm in the direction of y-axis. Here, the switch SW_1 is connected to the antenna A_y while the switch SW_2 is connected to the antenna A_x. In this case, the antenna A_z (blue antenna in Fig. 6(a)) is not selected because the antenna A_z remains unchanged in a horizontal configuration, meaning that this antenna always receives the horizontal polarization even when the antenna rotates around the y-axis. This fact indicates that the antenna A_z does not have the role of creating the weight function for the allotment of received signals due to the variation of polarizations based on Eqs. (5) and (6).

In contrast, in the case of a walking situation in Fig. 6(b), the left arm swings with the shoulder as the rotation center in the z-x plane. Here, the switch SW_1 is connected to the antenna A_z while the switch SW_2 is connected to the antenna A_x. In this case, the antenna A_y (black antenna in Fig. 6(b)) is not selected because the antenna A_y remains unchanged in a horizontal configuration, meaning that this antenna always receives the horizontal polarization even when the antenna rotates around the y-axis due to the arm-swinging motion. It is understood from the considerations mentioned above that we need three dipole antennas in an orthogonal alignment because an appropriate combination of two dipole antennas should be chosen as a result of the connection of two switches depending on the human motions due to different use scenarios.

Figure 7 shows the analytical results of the channel capacity as a function of the XPR when β=0 degree in a browsing situation. The analyses are carried out in free space excluding the human body effects. The SNR of incident wave is 30dB. The average elevation angle of incident waves is assumed to be 20 degrees with the angular spread of 20 degrees. The black curve indicates the channel capacity of the proposed antenna while the pink curve indicates the channel capacity of the antenna with the weight functions that are identical with each other ($W_V' = W_H'$). The red curve indicates the channel capacity of a watchband antenna, which is mounted on the belt of a watch-type terminal corresponding to A_x in Fig. 6(a).

As can be seen in Fig. 7, using the proposed antenna, a high level of channel capacity can be obtained and maintained in different propagation environments (XPR). The channel capacity of the proposed antenna is improved by 23 bits/s/Hz compared with the watchband antenna while the channel capacity is improved by 7 bits/s/Hz compared with the antenna with the identical weight when XPR=20dB.

Figure 8 shows the analytical results of the channel capacity as a function of the angle of left arm in a walking situation. The angular region of arm-swinging is determined by the statistical measurements of human walking motion and set to be from +40 to −15 degrees [2]. The SNR of incident waves is set to 30dB and the XPR is set to 20dB. The average elevation angle of incident waves is assumed to be 20 degrees with the angular spread of 20 degrees. The analyses are carried out in the presence of the effects of the human body in order to confirm the validity of the proposed antenna in an actual use situation. The blue curve indicates the channel capacity of the proposed antenna with a human phantom while the black curve indicates the channel capacity without a phantom. The pink curve indicates the channel capacity of the antenna with the identical weight functions without a phantom. The red curve indicates the channel capacity of the watchband antenna, which is mounted on the belt of a watch-type terminal corresponding to A_x in Fig. 6(b), without a phantom.

As can be seen in Fig. 8, the channel capacity of the proposed antenna including the phantom is degraded by 4 bits/s/Hz compared with the case in the absence of the phantom. The reason is attributed to the fact that there is a reduction in the radiation pattern caused by the shadowing effects of a human body [2]. Despite this difficulty, a large channel capacity of approximately 65 bits/s/Hz can be obtained and maintained over the entire arm-swinging angle. This fact shows that the 3-axis weighted-polarization active antenna proposed in this paper has the ability to provide an over-gigabit transmission rate for future wearable MIMO applications.

4. Conclusion

This paper presents a 3-axis weighted-polarization active antenna for use in high-speed wearable MIMO terminals. A large channel capacity of 65 bits/s/Hz can be obtained in a situation when the variation of XPR and the inclination angle of the antenna are taken into consideration simultaneously, demonstrating that an over-gigabit communication can be realized using the proposed antenna in wearable radio applications.

Acknowledgments

This work was partly supported by the SCOPE 2013 grant number 135005102.

References

[1] K. Li, K. Honda, and K. Ogawa, "Over-The-Air Assessment for 2-dimensional Arrangement MIMO Array Antennas," to be presented in this conference.

[2] K. Honda, K. Li, and K. Ogawa, "Shadowing-Fading BER Characterization of a BAN Diversity Antenna Based on Statistical Measurements of the Human Walking Motion," IEICE Trans. Commun., vol. E96-B, no. 10, pp. 2530-2541, Oct. 2013.

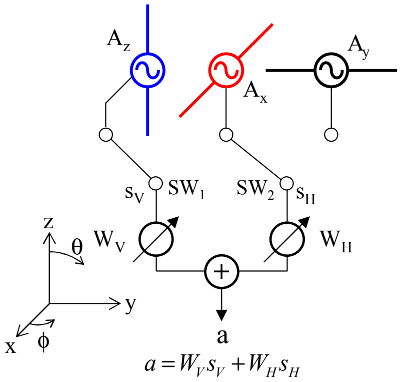


Fig.1 3-axis weighted-polarization active antenna

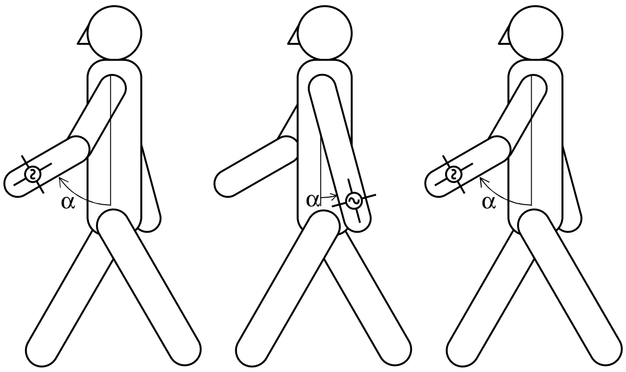
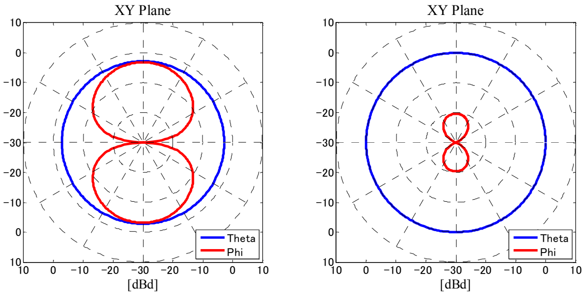
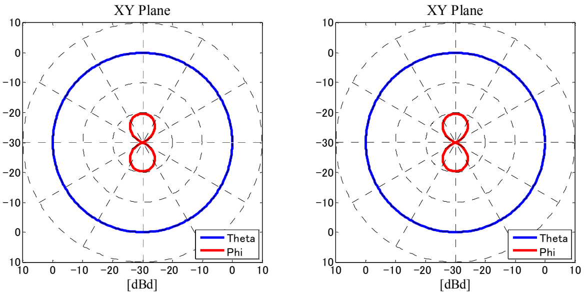


Fig.2 Arm-swinging motion while walking



(a) XPR=0dB (b) XPR=20dB

Fig.3 Radiation pattern (α=0deg)



(a) α=0deg (b) α=90deg

Fig.4 Radiation pattern (XPR=20dB)

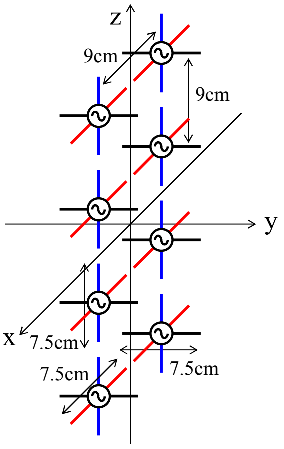
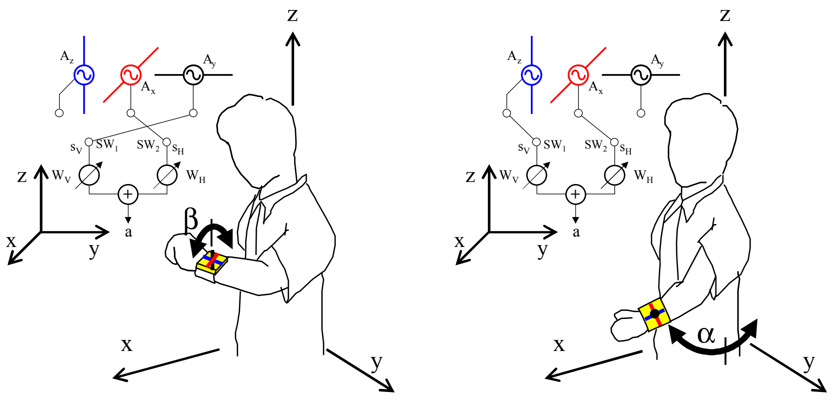


Fig.5 Analytical model



(a) Browsing (b) Walking

Fig.6 Use scenes of a watch-type terminal

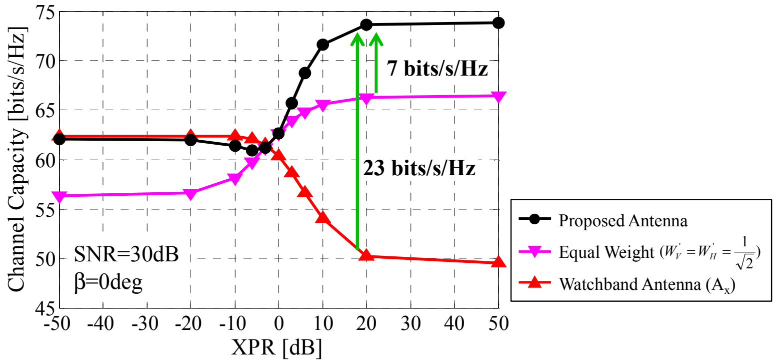


Fig.7 Channel capacity vs. XPR in a browsing situation shown in Fig. 6(a)

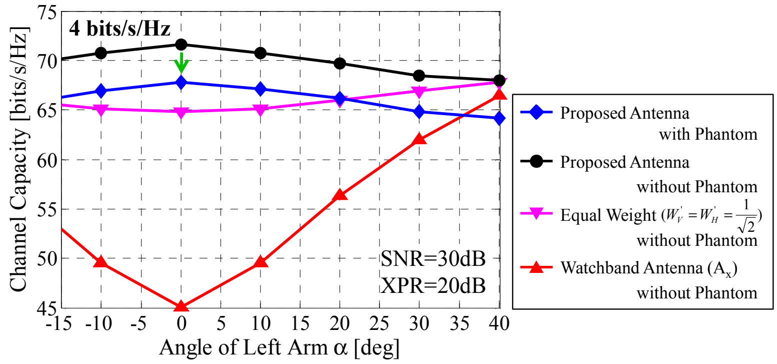


Fig.8 Channel capacity vs. angle of left arm in a walking situation shown in Fig. 6(b)