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On-body Polarization-controlled Active Antenna to Enhance Signal Power in Human Dynamic Channels

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***Abstract* – This paper presents a polarization-controlled active antenna applied to BAN on-body communications. A primal objective is to achieve the enhancement of signal power, not only in downlink but also in uplink dynamic channels, between an access point mounted on the wrist and a sensor module attached to various locations on a human body. Firstly, a dynamic channel model to represent the geometrical relationship between two locations considering arm-swinging motion was proposed. Based on the model, a weight function was derived to control an orthogonal active antenna in an adaptive way for increasing the radiation pattern in desired directions. The analytical results show that a high level of the received signal power can be obtained regardless of the arm-swing angle and antenna placement, confirming the effectiveness of the proposed method for BAN on-body communications.**

***Index Terms* — Body Area Network, on-body channel, dynamic characteristics, human modeling**

I. INTRODUCTION

Due to the dynamic characteristics of human body motion in Body Area Network (BAN) communications, significant signal variations between two terminals mounted on the body is an indispensable subject. Especially, when the access point antenna is located on the wrist, a polarization mismatch due to the dynamic channel fluctuations caused by the arm-swinging motion may result in a severe signal reduction.

This paper presents a polarization-controlled active antenna applied to BAN on-body links to achieve the enhancement of signal power in dynamic channels between an access point mounted on the wrist and a sensor module attached to various locations on a human body. Our proposed method is aimed at achieving a simple RF signal processing without the use of feedback from a baseband LSI, which means that the signal strength can be enhanced not only in downlink but also in uplink channels in BAN wireless systems. This unique feature cannot be attained by using conventional diversity receiving technologies, such as a two-branch selection diversity antenna. Based on a dynamic channel model to represent the geometrical relationship between two antenna locations, the radiation pattern of the proposed antenna was adaptively controlled. The analytical results show that a high level of the received signal power can be obtained regardless of the arm-swing angle and antenna placement, indicating that the proposed antenna can be used for BAN on-body communications.

II. DYNAMIC CHANNEL MODELLING

Fig. 1 shows a two-dimensional dynamic channel model considering the arm-swing motion in BAN on-body links. $P_1(x_1, z_1)$ and $P_2(x_2, z_2)$ indicate the coordinates of a sensor and an access point in *z-x* plane, respectively. θ_2 denotes the arm-swing angle. The height of shoulder is 1.35m while the length from shoulder to wrist is 0.45m. A plane wave with the amplitude *A* arriving at P_2 was assumed. This plane wave can be decomposed into vertical and horizontal polarization components allocated in *z*-axis and *x*-axis. Therefore, the cross polarization power ratio (*XPR*) of the incident wave coming from a sensor to an access point is defined as follows:

$$XPR = \left(\frac{A \sin\theta_1}{A \cos\theta_1} \right)^2 = \tan^2 \theta_1 \tag{1}$$

where θ_1 denotes the angle between *z*-axis and the direction of the incident wave, which can be calculated by the trigonometric function in the following form,

$$\theta_1 = \arctan\left(\frac{x_2 - x_1}{|z_2 - z_1|}\right) \tag{2}$$

According to Eqs. (1) and (2), the *XPR* of the incident wave can be expressed in terms of the geometrical parameters shown in Fig. 1, which is used in a polarization-controlled active antenna, as will be illustrated in section 3.

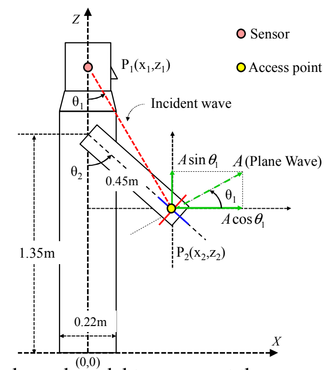

Fig. 1. Dynamic channel model to represent the arm-swinging motion

III. POLARIZATION-CONTROLLED ACTIVE ANTENNA

The polarization-controlled active antenna [1], shown in Fig. 2, is comprised of two orthogonal dipole antennas (A_x, A_z). The received signals (s_V and s_H) from two antennas are combined using a weight function created based on the variations of *XPR* and arm-swing angle (θ_2). The signal at an output port (a) is expressed as:

$$a = \left(\sqrt{\frac{XPR}{1+XPR}}|\cos\theta_2| + \sqrt{\frac{1}{1+XPR}}|\sin\theta_2|\right)s_V + \left(\sqrt{\frac{XPR}{1+XPR}}|\sin\theta_2| + \sqrt{\frac{1}{1+XPR}}|\cos\theta_2|\right)s_H e^{j\frac{\pi}{2}} \quad (3)$$

Eq. (3) shows that only the geometrical parameters are required to control the output signal; this means that the proposed method does not need the information on the state of received signals. Using Eq. (3), the dominant incoming wave polarization can be extracted to obtain the optimum received signal in any relative locations of on-body antennas.

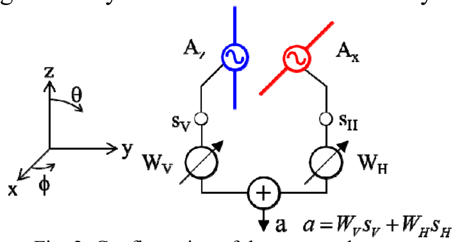

Fig. 2. Configuration of the proposed antenna

IV. ANALYTICAL RESULTS

In this section, the radiation patterns (without human tissue effects) in different use scenarios were analyzed using the method of moments. Fig. 3 indicates the case when a sensor antenna is located at the head and chest, as shown by P_1(0, 1.6m) and P_1(0.12m, 1.3m) in Fig. 1, respectively. The angle of arm θ_2 is fixed to 0 and 65 degrees. Q_1 and Q_2 show the positions on the radiation patterns in the direction of incident wave (θ_1), derived from Eq. (2), that determine the received signal power. It is shown that using the dipole antenna (A_z), the direction of incident waves approaches the null position of radiation patterns in a particular arm-swing angle. However, using the proposed antenna, a strong radiation pattern in the desired directions can be obtained.

Figs. 4 and 5 indicate the received signal power of the access point, normalized to that of an isotropic antenna, as a function of the arm-swing angle from -90 to 90 degrees when the sensor antennas are mounted on the head and chest, respectively. The blue curve shows the result of the dipole antenna A_z while the black curve indicates the proposed antenna. In Figs. 4 and 5, significant degradations more than 35 dB in the received signal is observed when we use the dipole antenna A_z with the arm-swinging motion, as described by the points Q_1 and Q_2 corresponding to those in Fig. 3. However, the proposed antenna can obtain a high and stable level of received signal power regardless of the arm-swing angle and antenna placement, as shown by the black curve, confirming the effectiveness of the proposed method.

It should be noted that although the abovementioned results are described as a receiving antenna, the proposed antenna possesses the function of a transmitting antenna, which means that the signal strength can be enhanced not only in downlink but also in uplink channels.

V. CONCLUSION

This paper presents a polarization-controlled active antenna for BAN on-body communications. The analytical results show that a high level of the received signal power can be obtained regardless of the arm-swing angle and antenna placement, indicating that the proposed antenna can be used to enhance downlink and uplink channels considering dynamic characteristics of the human body.

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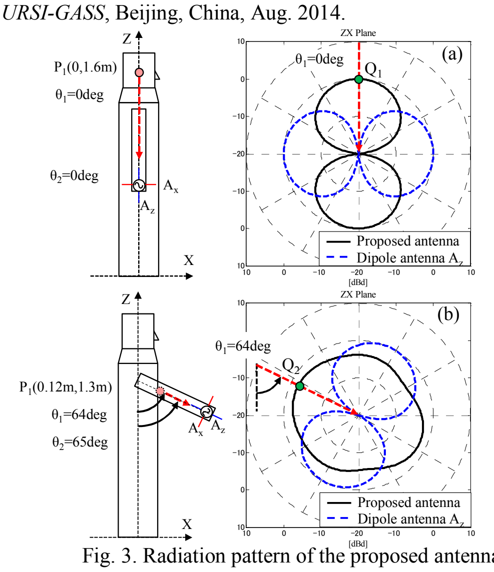

Fig. 3. Radiation pattern of the proposed antenna

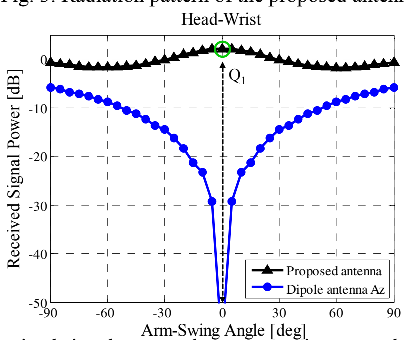

Fig. 4. Received signal power when a sensor is mounted on the head

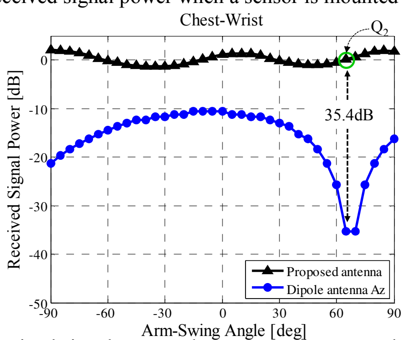

Fig. 5. Received signal power when a sensor is mounted on the chest