

Impact of the Human Walking Motion on BAN Diversity Effects

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Abstract—This paper presents analytical results on the BER degradation of QPSK signals for BAN diversity antennas for the case where the combined outcome of shadowing and multipath fading emerge simultaneously and statistical model of human walking motion is employed in the analysis. The results show that a probability of a low signal level is higher than that for the Rayleigh distribution owing to shadowing caused by the movement of the arms, resulting in the significant impact on the BER performance of body-attached BAN devices. The antenna separation greater than 80 deg. is required for reducing the shadowing effects.

I. INTRODUCTION

The increasing demand for wireless communication has accelerated the development of body area network (BAN) systems that can operate in the immediate vicinity of the human body [1]. The practical applications of BAN systems, which could eliminate the need for wired interconnections, include wearable computers, health monitoring equipment, and entertainment systems.

In BAN systems, the variation of antenna characteristic caused by the motion of the human body is a significant issue [2]-[5]. Not only a shadowing effect caused by the movement of the arms, but also a multiple radio wave propagation environment where the human walks with the BAN diversity antennas mounted at a waist has a significant impact on reception signal level. In addition, it is essential to assess the communication quality, such as signal to bit error rate (BER), which is caused by the combined outcome of shadowing and multipath fading simultaneously. Moreover, the dynamic characteristics, such as swing style and speed, and walking pace and cycle, are not fully examined in previous studies. Hence, a typical analytical model including the arm-swinging and walking motion of human body is also an indispensable point of view in an analysis of BAN diversity antenna.

In the previous study [6], it is shown that the sine-wave model with the angular range of arm-swinging from -15 deg. to +40 deg. is close to an actual human walking motion, and the difference between the triangle and sine-wave models has a serious impact on the BER characteristics for BAN antennas. Hence in this paper, the realistic walking model is used for the analysis of BAN diversity antennas.

This paper presents the analytical results of the BER degradation of QPSK signals for BAN antennas for the case where the combined outcome of shadowing and multipath fading emerge simultaneously and the variation with separation of diversity antennas is also employed in the

analysis. The final objective of this study is to gain useful knowledge about how different separations of diversity antennas have impacts on assessment of the communication quality of BAN diversity antenna system. The results show that a probability of a low signal level is higher than that for the Rayleigh distribution owing to shadowing caused by the movement of the arms, resulting in the significant impact on the BER performance of body-attached BAN devices. The antenna separation which is greater than 80 deg. is required for reducing the shadowing effects.

II. MEASUREMENTS OF THE WALKING MOTION

In the previous studies [6]-[8], a series of video recording was carried out when a person walked in a natural way of swinging over a 18-meter walking distance in a typical classroom of the Toyama University using thirteen 22 to 25-year-old Japanese males. Since our goal is to analyse a BAN diversity antenna mounted on the waist, we focus on the swing motion of the right and left arms through the measured video data including numerous information about the swing style and speed, and walking pace and cycle. The right and left arms are recorded separately for good visibility of the swing motions.

The statistical analysis was carried out using the measured data. A model of the arm-swing which is from +40 deg. to -15 deg. for the forward and backward directions respectively has been selected. The measured swinging wave was similar to a sine wave. The walking pace was set to 70 cm.

III. SHADOWING-FADING COMBINED ANALYSIS

In this section, shadowing characteristics caused by the movement of the arms are shown using the method of moments. The analytical model is shown in Fig. 1.

The model is comprised of the head and body, the right and left arms, all of which are approximated by circular cylinders, and the trapezoidal shoulder located between the head and body. The electrical properties of the model are chosen such that the relative permittivity is 55.8 and conductivity is 0.99 S/m, which are the average values for human muscle at 950 MHz [9]. A diversity antenna, comprising two half-wavelength dipole antennas in vertical orientation, was mounted on the left waist in the symmetrical configuration with respect to the center of the left arm.

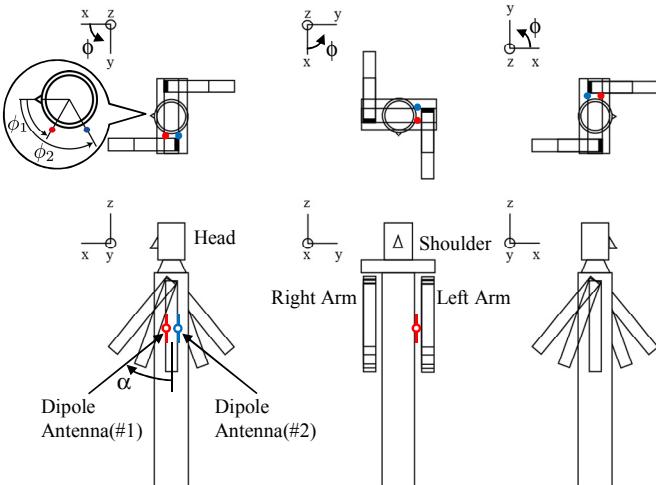


Fig. 1 Analytical model of the diversity antenna

Fig. 2 shows a hybrid model that takes into account both shadowing and fading effects for analysing the arm-swinging dynamic phantom [5] walking in a multipath environment, in which a BAN antenna mounted on the phantom communicates with a wireless access point located at a distance from the operator, i.e., an off-body situation [10]. As shown in the figure, the phantom is surrounded by a uniform distribution of fifteen scatterers ($N=15$) in the horizontal plane, which simulates a large number of radio waves reflected or diffracted by the surrounding objects. Using this model, a Rayleigh propagation channel can be realized by setting a collection of random phases for the scatterers.

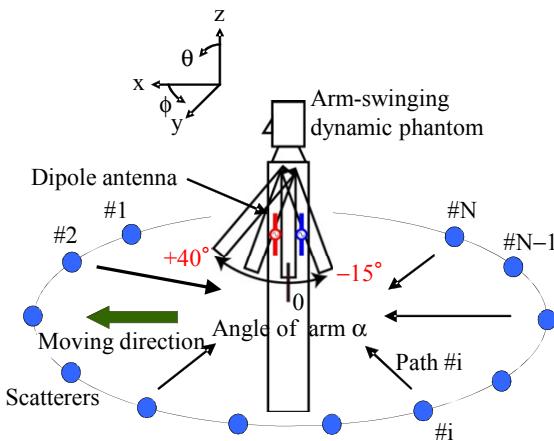


Fig. 2 Shadowing-fading hybrid model for analysing the arm-swinging dynamic phantom

Fig. 3 shows the method of analysis that takes the arm-swinging and walking motions into account simultaneously. In the analysis, the left and right arms swing in the forward ($\alpha=+40$ deg.) and backward ($\alpha=-15$ deg.) directions with respect to the human phantom. A two-way arm swing, corresponding to two paces, is defined as a swing motion that begins from $\alpha=-15$ deg., passing through $\alpha=+40$ deg. status in between, and $\alpha=-15$ deg. at the end of the swing, as shown in Fig. 3.

First, a two-way swing is divided into 22 small angular fragments, with each fragment occupying a 5-degree swing motion, as shown by the blue line in Fig. 3. In all the 5-degree angular regions, the radiation patterns are calculated using the method of moments. Employing a constant-radiation pattern within a 5-degree region, fading signals are created using a Monte Carlo simulation that calculates every snapshot by summing all the paths between the i -th scatterer and a diversity antenna.

The procedure for the Monte Carlo simulation is described in detail in the literature [11]. In the next 5-degree region, the radiation pattern is changed, and fading signals are created in the same manner as mentioned above. The fading signals are continuous between the two successive 5-degree regions because the fading signals are created by giving continuous phase changes to signals of each path caused by the movement of a diversity antenna throughout the walking distance. This process is repeated until the phantom has covered the prescribed walking distance.

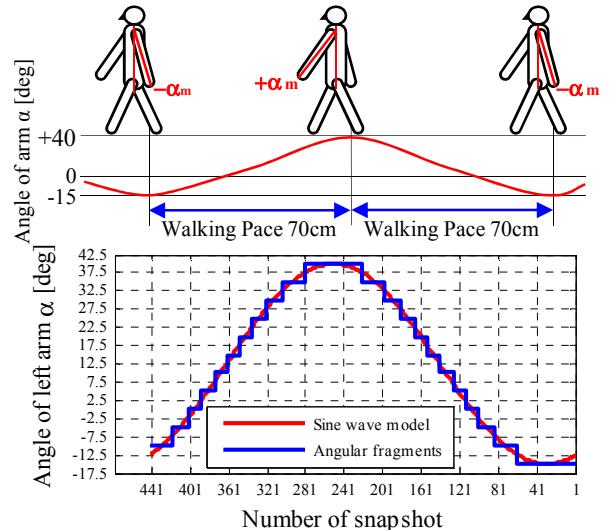


Fig. 3 A method of the analysis considering the arm swinging and the walking motion

Fig. 4 shows the instantaneous response of multipath signals of a diversity antenna with a pace of 70 cm and a walking distance of 140 cm, which is equivalent to 4.43 wavelengths at 950 MHz. Two paces, which are equivalent to a two-way swing, are equal to 140 cm, indicating that there is 1 pace in the designated walking distance. The diversity antenna is mounted at the location $\phi_1=80$ deg. and $\phi_2=100$ deg. The number of snapshots is set to 100 samples per wavelength. The polarization is assumed to be vertical.

Fig. 4(a) shows the instantaneous angle of the left arm when the left arm approaches the branches, as indicated by the horizontal arrows in Fig. 4(a), where the red arrows show the case of branch 1 and the blue arrows show the case of branch 2. The analytical model of the arm is approximated by a circular cylinder with 80 mm in diameter. In the case of $\phi_1=80$ deg. and $\phi_2=100$ deg., the antenna separation is found to be 49 mm, in which the antenna separation is defined as the distance

connecting the two antenna elements with a straight line. Therefore, the left arm approaches both of the branches simultaneously, as indicated by the black arrows in Fig. 4(a).

Fig. 4(b) shows the instantaneous response when the phantom is walking. Two situations shown in Fig. 4(b) indicate the cases where the angular range of arm-swinging is set from -15 deg. to $+40$ deg. and the angle of the left arm α is fixed at 90 deg.: i.e., no arm movement takes place. In the case of fixed arm, there is no shadowing effect, thus the Rayleigh characteristics emerge, as shown by the broken lines in Fig. 4(b). In contrast, in the case of swing arm, periodic deep nulls can be observed in the fading profile, as shown by the solid lines in Fig. 4(b). The location of each nulls coincides with the location where the angle of the left arm α is 0 deg., in which the left arm passes through the immediate vicinity of both of the branches simultaneously, as indicated by the black arrows in Fig. 4(a). The reason for these nulls can be attributed to the fact that the fading signals are overlapped with the shadowing effects due to the movement of the left arm.

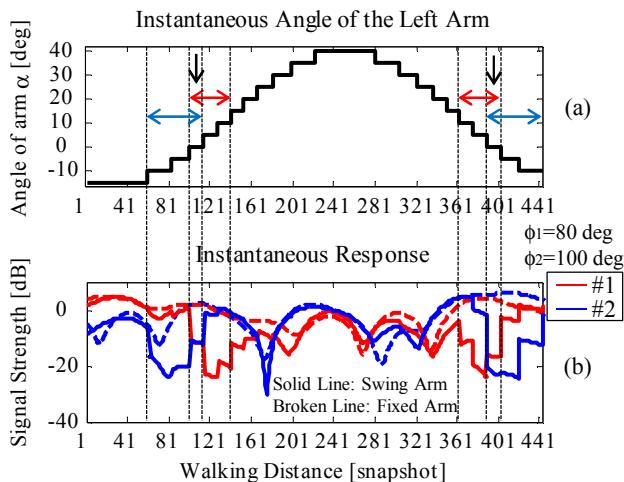


Fig. 4 Instantaneous angle of the left arm and instantaneous response of multipath signals as a function of the walking distance

Fig. 5 shows the cumulative distribution function (CDF) of multipath signals when the phantom walks with a pace of 70 cm over a distance of 16.8 m (53.2 wavelength at 950 MHz) with the location of diversity antenna $\phi_1=80$ deg. and $\phi_2=100$ deg., in which line types used are same as in Fig. 4(b). The green lines in the graph show the case where the selection diversity is used. The theoretical curves for the Rayleigh response are included as the black lines in the graph.

It can be seen that the curves of the two branches for fixed arm coincide with the Rayleigh theoretical curve, and the curve of the diversity for fixed arm coincides with the theoretical curve of the selection diversity. In contrast, the curves of the two branches for swinging arm are plotted on the upper part of the Rayleigh theoretical curve, indicating that a probability of a low signal level appearing for swinging arm is higher than that for the Rayleigh distribution. Hence, the

curve of the diversity for swinging arm is plotted on the upper part of the theoretical curve of the selection diversity.

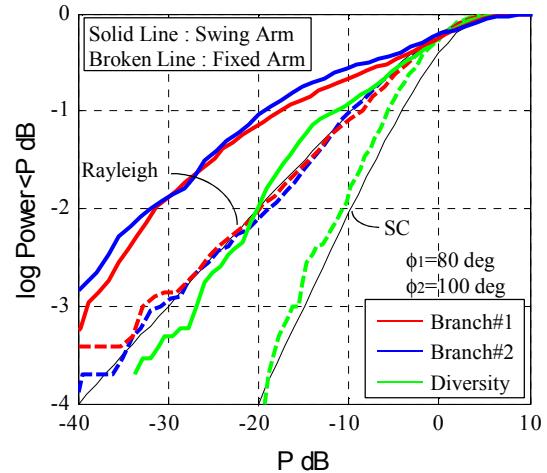


Fig. 5 CDF of multipath signals over a distance of 16.8 m for the location of diversity antenna $\phi_1=80$ deg. and $\phi_2=100$ deg.

In order to eliminate this degradation, the separation of the two branches is increased. Fig. 6 shows the CDF of multipath signals with the location of diversity antenna $\phi_1=50$ deg. and $\phi_2=130$ deg.

As shown in Fig. 6, in the case of swing arm, the CDF curve of branch 2 shown by the blue line is close to the Rayleigh theoretical curve, and the CDF curve of branch 1 shown by the red line eventually coincides with the Rayleigh theoretical curve. The reason is that the arm passing through the vicinity of the branch 2 remains for a longer period of time than the branch 1 due to the use of a sine-wave model, resulting in the degradation of the CDF characteristics. However, compared with the case of $\phi_1=80$ deg. and $\phi_2=100$ deg. shown in Fig. 5, the shadowing effect is reduced. Hence, the curve of the diversity for swing arm coincides with the theoretical curve of the selection diversity. The reason is that since the separation of the two branches increase, shadowing effect does not occur simultaneously.

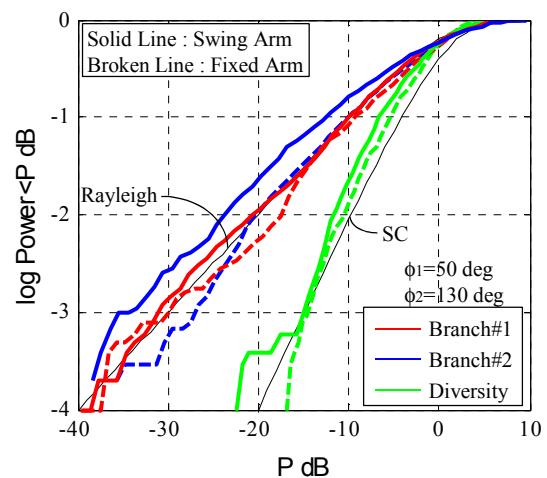


Fig. 6 CDF of multipath signals over a distance of 16.8 m for the location of diversity antenna $\phi_1=50$ deg. and $\phi_2=130$ deg.

Fig. 7 shows the result of BER analysis of QPSK signals with the location of diversity antenna as a parameter, when the phantom walks with a pace of 70 cm over a distance of 16.8 m (53.2 wavelength at 950 MHz) using selection diversity, in which line types used are same as in Fig. 4(b). The theoretical curves for the Rayleigh response are included as the black lines in the graph.

As shown in Fig. 7, there is a significant impact of shadowing effects caused by the arm swinging. In the case of $\phi_1=80$ deg. and $\phi_2=100$ deg., the performance of BER characteristic for swinging arm is degraded by 12 dB compared with the case of fixed arm, as shown by the green lines in Fig. 7. In contrast, in the case of $\phi_1=50$ deg. and $\phi_2=130$ deg., the performance of BER characteristic for swinging arm is degraded by 2 dB compared with the case of fixed arm, as shown by the red lines in Fig. 7, indicating the effectiveness of the diversity antenna. Hence, it is found that the antenna separation greater than 80 deg. is required for reducing the shadowing effects.

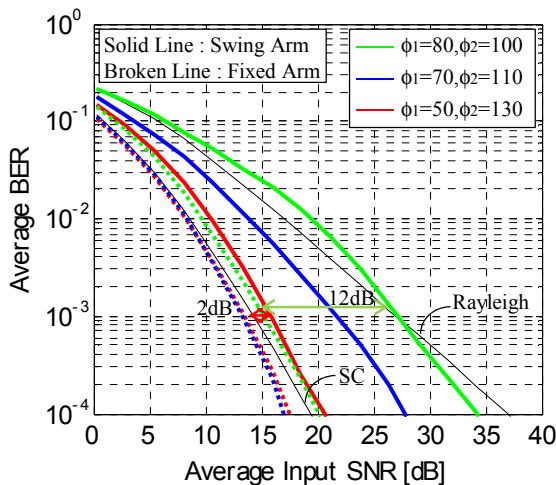


Fig. 7 BER characteristic of QPSK signals with the location of a diversity antenna as a parameter

Fig. 8 shows the correlation coefficient as a function of the antenna separation of diversity antenna. The symbol \square denotes the swing arm. The symbol \circ shows the fixed arm. The Jakes model curve is included as the blue line in Fig. 8.

It can be seen that the correlation coefficient for swinging arm is approximately 0.5, indicating that the correlation coefficient is not the reason causing the degradation of diversity effect. Therefore, the increase of a probability of low signal level shown in Fig. 5 is a major reason for the degradation of diversity effect.

IV. CONCLUSION

In this paper, the shadowing-fading BER characterization of BAN diversity antenna based on a realistic walking model has been conducted. From extensive studies, the increase of a probability of low signal level appearing is a major cause of the degradation of diversity effect. It is found that the antenna

separation greater than 80 deg. is required for reducing the shadowing effects.

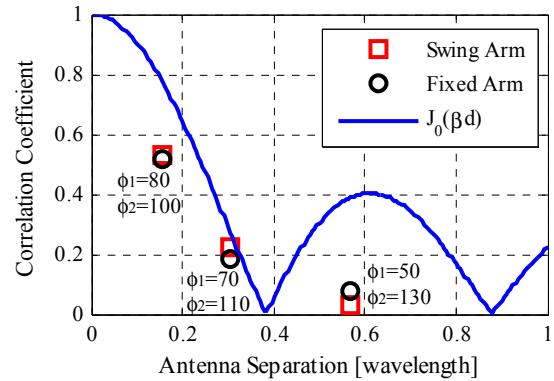


Fig. 8 Correlation coefficient as a function of the antenna separation of diversity antenna

REFERENCES

- [1] P. S. Hall and Y. Hao, *Antennas and Propagation for Body-Centric Wireless Communications*, Artech House, Inc. 2006.
- [2] Z. H. Hu, Y. I. Nechayev, P. S. Hall, C. C. Constantinou, and Y. Hao, "Measurement and Statistical Analysis of On-Body Channel Fading at 2.45 GHz," IEEE Antennas and Wireless Propagation Letters, vol. 6, pp. 612-615, 2007.
- [3] K. Mineok and J. Takada, "Experimental investigation and modeling of shadow fading by human movement on body surface propagation channel," IEEE AP-S Intl. Symp., June 2009.
- [4] M. Gallo, P. S. Hall, Y. I. Nechayev, and M. Bozzetti, "Use of Animation Software in Simulation of On-body Communications Channel at 2.45 GHz," IEEE Antennas and Wireless Propagation Letters, vol. 7, pp.321-324, 2008.
- [5] N. Yamamoto, N. Shirakata, D. Kobayashi, and K. Ogawa, "BAN Communication Quality Assessments Using an Arm-Waving Dynamic Phantom Replicating the Walking Motion of a Human," IEEE International Conference on Communications 2011 Intl. Symp. Digest, WCS-P2, Topics II on Wireless Communications, (ICC 2011, Kyoto, Japan), Jun. 2011.
- [6] K. Li, K. Honda, and K. Ogawa, "Shadowing-Fading BER Characterization of BAN Antennas Based on Realistic Walking Models," ISMCT 2013 Intl. Symp. Digest(Tokyo, Japan), Mar. 2013.
- [7] K. Honda and K. Ogawa, "Shadowing Analysis of a BAN Diversity Antenna Based on Statistical Measurements of the Human Walking Motion," IEICE ISAP Intl. Symp. Digest(Nagoya, Japan), Session 3E1, P0078, Oct. 2012.
- [8] K. Honda, K. Li, and K. Ogawa, "Shadowing-Multipath Analysis of a BAN Diversity Antenna Based on Statistical Dynamic Measurements of the Human Walking Motion," Technical Report IEICE, Antennas and Propagation, Jan. 2013 (in Japanese).
- [9] <http://www.fcc.gov/fcc-bin/dielec.sh>
- [10] K. Ogawa and K. Honda, "BAN Shadowing Properties of an Arm-Waving Dynamic Phantom," The European Conference on Antennas and Propagation (EuCAP 2012, Prague), Intl. Symp. Digest, CP08.1, Mar. 2012.
- [11] K. Ogawa, A. Yamamoto, and J. Takada, "Multipath Performance of Handset Adaptive Array Antennas in the Vicinity of a Human Operator," IEEE Trans. Antennas Propagat. AP-53, No. 8, pp. 2422-2436, Aug. 2005.