K-factor Dependent Multipath Characterization for BAN-OTA Testing Using a Fading Emulator

Kun Li   Kazuhiro Honda   Koichi Ogawa
Graduate School of Engineering, Toyama University
3190 Gofuku, Toyama-shi, Toyama, 930-8555 Japan
m1271031@eng.u-toyama.ac.jp

***Abstract*—This paper presents a new methodology for BAN-OTA Testing using a developed fading emulator with a dynamic phantom. The key to the success of the proposed apparatus is to provide the fading emulator with a proper K-factor that can represent an actual propagation environment under consideration. Firstly, a configuration of the developed fading emulator used for BAN-OTA Testing is shown. Based on the configuration, an analytical investigation of the channel modeling considering K-factor dependent multipath characterization is presented. For getting the knowledge of K-factor, an experiment has been carried out by moving the phantom with different locations of dipole antennas. Finally, a method of calibration by setting the attenuators in fading emulator is also introduced and used in a preliminary experiment for confirming the validity of the proposed channel model. The experimental results show that a variety of K-factors can be controlled in a wide range, which indicates that a realistic BAN radio wave propagation environment can be realized in BAN-OTA Testing using the developed fading emulator.**

Keywords- BAN-OTA Testing, Fading emulator, Rice channel model, K-factor

I. Introduction

OTA (Over-the-Air) Testing is a method that can evaluate the performance of mobile-device more accurately. An OTA Testing to assess a handset MIMO antenna in multipath environments has been developed [1]. However, in Body Area Network (BAN) systems, the OTA technique has not been included in the previous studies. As a next step for future mobile systems, we are aiming at developing an OTA methodology using a fading emulator for the evaluation of BAN systems in this paper.

There are two major differences between an OTA for cellular MIMO and an OTA for BAN radios. The first difference is that in BAN radios we must consider dynamic channel variations, commonly referred to as shadowing, caused by the motion of an operator, such as the arm swinging while walking. The second difference is that since a BAN sensor module may be attached to the head, as shown in Fig. 1, where there is a strong direct wave coming from a sensor module to an access point attached to the waist. This situation creates a Rice propagation environment in cooperation with reflected fields from surrounding objects. To solve the first subject, we have developed the arm-swinging dynamic phantom that can simulate a natural walking style of humans [2]. Using the phantom we can provide a fading emulator with the fading–shadowing combined effects. As for the second difficulty, to get the knowledge of effects caused by the direct path in indoor environments, such as a hospital, is an indispensable subject in the evaluation of BAN radio systems, and this is the core subject of this paper.

Firstly, a configuration of the developed fading emulator used for BAN-OTA Testing is shown. Based on the configuration, an analytical investigation of the channel modeling considering K-factor dependent multipath characterization is presented. For getting the knowledge of K-factor, an experiment has been carried out by moving the phantom with different locations of dipole antennas. Finally, a method of calibration by setting the attenuators in fading emulator is also introduced and used in a preliminary experiment for confirming the validity of the proposed channel model. The experimental results show that a variety of K-factors can be controlled in a wide range, which indicates that a realistic BAN radio wave propagation environment can be realized in BAN-OTA Testing using the developed fading emulator.

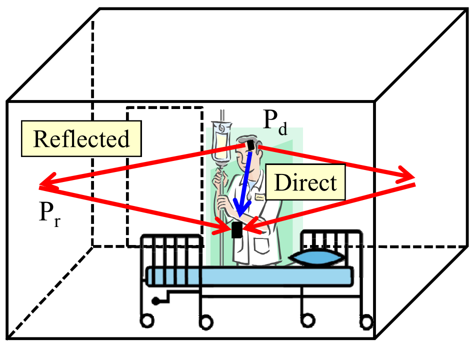

Fig. 1 Typical use scene of BAN radios

II. Configuration of BAN Fading Emulator

A new fading emulator used for BAN-OTA Testing is shown in Fig. 2. The arm-swing dynamic phantom is located at the center of the fading emulator. The phantom can swing both arms to emulate the shadowing effects during scatterers comprised of dipole antennas surrounding the phantom create fading signals at the Doppler frequency of walking. A dipole antenna attached to the head creates direct waves towards a dipole antenna simulating an access point located at waist. The circuit assembly of fading emulator consists of a DA converter, an amplifier, a power combiner, 8 phase shifters, and 8 attenuators. With the control voltage changing from 0 to 10 volts, the phase shifter can change the range of 360 degrees, and the amplitude can change the range of 34 dB, which is sufficient to create the radio waves in different phases and amplitudes as we need in BAN-OTA Testing.

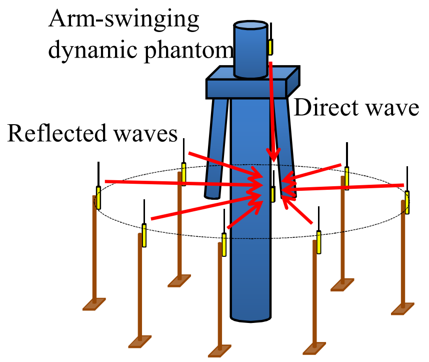

Fig. 2 Configuration of the BAN fading emulator

III. Analytical Investigation of Channel Modeling

Based on the configuration of the BAN fading emulator, an analytical investigation of the channel modeling considering K-factor dependent multipath characterization is presented in this section.

As shown in Fig. 3(a), the average power of reflected waves is obtained as follows:

$$P_r = \frac{1}{S}\sum_{s=1}^{S} |h_s|^2 \quad (1)$$

where h_s indicates the channel response of reflected fields represented as:

$$h_s = \sum_{k=1}^{K} h_k \exp\left\{ j\frac{2\pi d}{\lambda}\cos(\phi_k - \phi_v)\right\} = \sum_{k=1}^{K} h_{kr} \quad (2)$$

Then, the channel response of direct wave can be expressed as:

$$h_d = \sqrt{K_c P_r} \quad (3)$$

where the value K_c is defined as the ratio of P_d and P_r, usually known as the Rice factor or K-factor.

As shown in Fig. 3(b), the signal response of each path can be obtained as:

$$h_{kc} = h_d + h_{kr} \quad (4)$$

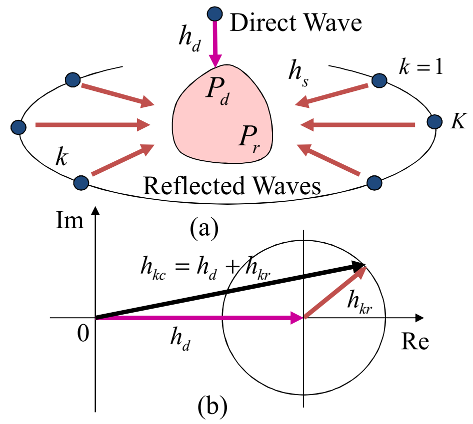

Fig. 3 Channel modeling for BAN-OTA Testing

Therefore, the overall channel response in a Rice environment is expressed as follows:

$$h_{s,c} = \sum_{k=1}^{K} h_{kc} = \sum_{k=1}^{K} (h_d + h_{kr})$$
$$= \sum_{k=1}^{K}\left(\sqrt{K_c P_r} + h_k \exp\left\{ j\frac{2\pi d}{\lambda}\cos(\phi_k - \phi_v)\right\}\right) \quad (5)$$

Using the formulas mentioned above, an analysis can be advanced by calculating the CDF characteristic with different values of K-factor in a Rice propagation environment. As shown in Fig. 4, the CDF curves in different values of K factors as shown by the blue curves agree well with their theoretical curves as shown by the pink curves, indicating the validity of the proposed analytical channel model in BAN-OTA Testing.

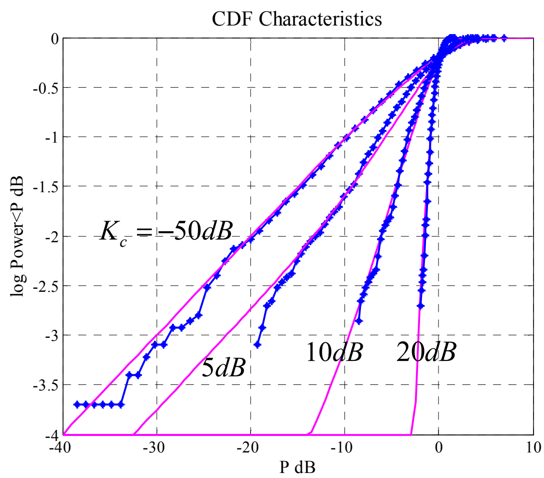

Fig. 4 CDF characteristic with different values of K factor in a Rice propagation environment

IV. Measurement of K-factor

In order to get the knowledge of the actual value of K-factor in BAN situations indoors, a preliminary experiment has been carried out and analytical results are shown for the effects caused by various conditions in BAN situations in this section.

As shown in Fig. 5, a cylindrical phantom with salt water inside, which is close to the electrical property of the human body, was used instead of a real test person. The transmitting antenna was located at the head while the receiving antenna was located at the waist. The frequency for the measurement was 950MHz. The data of received signals were collected and analyzed on the receiving side when the phantom was moved in a distance of 6m, with two dipole antennas attached to the body in an 8m-by-6.5m typical class room in the Toyama University. The experimental results are shown as follows.

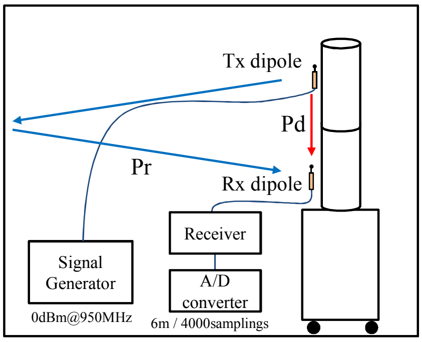

Fig. 5 Measurement setup of K-factor

Fig. 6 shows the cumulative distribution function (CDF) of the received signals. The theoretical curve for the Rayleigh response is also included as the black line. As can be seen, when we use the vertical dipole antenna attached at the waist, the CDF curve approaches the Rayleigh theoretical curve. On the other hand, when we use the parallel dipole antenna, it is found that a large K-factor of 13 dB appears. The reason can be attributed to the fact that the orthogonal alignment has a bad directivity, which causes the direct signal level to reduce to a large extent, leading to a small K-factor.

We have conducted another experiment to examine effects of the relative positions of two sleeve antennas on K-factor in more detail. In Fig. 7, the position of the transmitting antenna is fixed at the left waist, while the location of the receiving antenna varies around the surface of the phantom in a same horizontal plane at 45-degree intervals. It can be seen that the K-factor changes significantly, as indicated by the black line. This observation can be understood from the fact that when the receiving antenna is located on the other side of the transmitting antenna, where the angular difference is 135 degrees, the human body obstructs the direct wave considerably, resulting in a small K-factor.

Moreover, the blue line in the same figure shows the value of path loss between the two dipole antennas calculated by the method of moments. It can be seen that the K-factor decreases as the value of path loss increases. Furthermore, the amount of the variations for the K-factor and path loss coincides approximately with each other, indicating that the K-factor changes mainly due to the variations in the direct wave between the two dipole antennas, rather than the variations in the scattered waves from surrounding objects, such as walls and furniture.

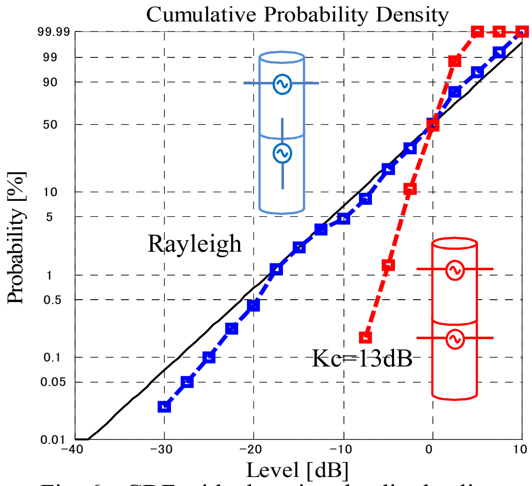

Fig. 6 CDF with changing the dipole alignment

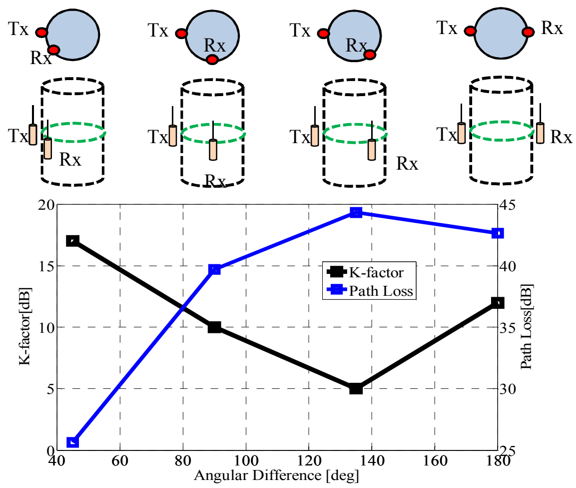

Fig. 7 K-factor and path loss vs. angular difference

V. CALIBRATION IN FADING EMULATOR

Once K-factor in a specified environment is determined as described above, we can calibrate the fading emulator by setting the value of attenuators using Eq. (6) and (7), as follows.

If $Pr > Pd$, *then*

$$ATT1 = 0\ (dB),\quad ATT2 = E[Pr]\ (dBm) - Pd\ (dBm) + Kc(dB) \tag{6}$$

If $Pr < Pd$, *then*

$$ATT1 = Pd\ (dBm) - E[Pr]\ (dBm),\ ATT2 = Kc(dB) \tag{7}$$

where Pd denotes the power of direct wave in dBm. E[Pr] signifies the expectation or average of the scattered signals Pr. The value Kc in Eq. (6) and (7) is defined as the ratio of Pd and Pr, usually known as the Rice factor or K-factor. Knowing the K-factor estimated by the experiment mentioned in Sec. IV, the attenuators in the fading emulator can be set to adjust the power ratio to create a realistic radio propagation environment as we expect.

Then, the method of calibration can be adopted to realize the Rice channel model by a preliminary experiment using the developed fading emulator. As can be seen in the left side in Fig. 8, a sleeve antenna in 950MHz located at the center is used to receive the combined signals, where another sleeve antenna beside it is used to create a strong direct radio wave. Furthermore, 7 scattering units with radio wave absorbers behind them can create Rayleigh fading signals by varying the phases and amplitudes in the control circuit of fading emulator, as shown in the right side in Fig. 8.

Fig. 9 shows the instantaneous response of the combined outcome of the direct and multipath signals of a dipole antenna with a walking distance of 50 wavelengths at 950 MHz in different values of K-factor calibrated by the fading emulator. As can be seen, with the value of K-factor increasing, the deep nulls disappear due to an increase in the power ratio of direct and reflected waves controlled by the fading emulator.

Fig. 10 shows the cumulative distribution function (CDF) of signals created using the channel model mentioned in Sec. III. It can be seen that the CDF curves in different values of K-factor coincide with their theoretical curves, which corresponds to the instantaneous response shown in Fig. 9 and the CDF characteristic shown in Fig. 4, indicating that the Rice channel model in the indoor environment can be realized by adjusting the K-factor using the developed fading emulator in BAN-OTA Testing.

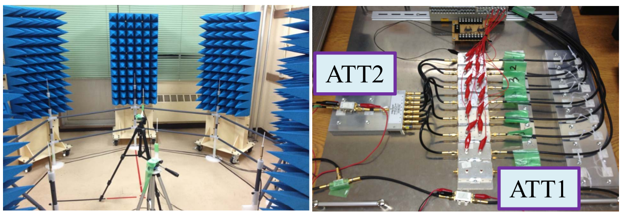

Fig. 8 Multipath measurement with the calibration of different K values using fading emulator

VI. Conclusion

This paper presents a new methodology for BAN-OTA testing using a fading emulator with a dynamic phantom. The key to the success of the proposed apparatus is to provide the fading emulator with a proper K-factor that can represent an actual propagation environment under consideration. Moreover, an analytical investigation of the Rice channel model in BAN-OTA Testing considering K-factor in the multipath characterization has been proposed. In order to confirm the validity of the channel model, a preliminary experiment has been carried out, which indicates that the Rice channel model with a variety of K-factors can be realized by adjusting the K-factor using the developed fading emulator. As a future plan, we will use the dynamic phantom which can swing both the arms to create the shadowing

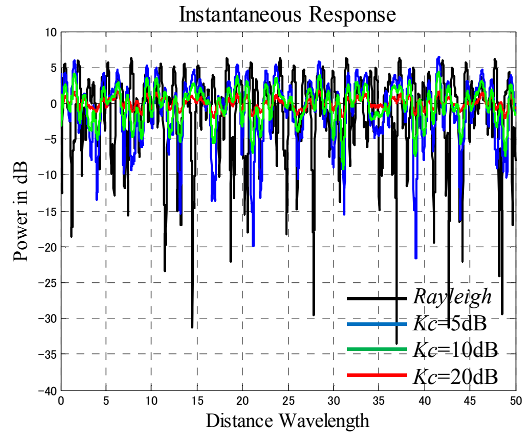

Fig. 9 Instantaneous response of fading signals in different K values

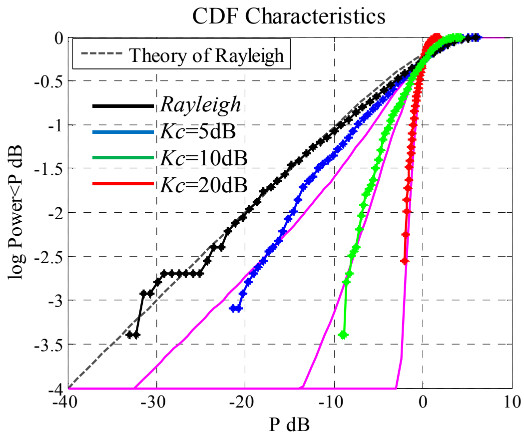

Fig. 10 CDF characteristic of fading signals in different K values

effects for testing the realistic propagation environment considering both on-body and off-body situations in BAN-OTA Testing using the developed fading emulator. The final target is to realize a BAN-OTA apparatus that can make communication quality assessments of commercially available BAN radios. This will be addressed in future studies.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 25420363.

Reference

[1] T. Sakata, A. Yamamoto, K. Ogawa, and J. Takada: "MIMO Channel Capacity Measurement in the Presence of Spatial Clusters Using a Fading Emulator," PIMRC2009 Intl. Symp. Digest (Tokyo, Japan), Session D1 no. 2, Sep. 2009.

[2] N. Yamamoto, N. Shirakata, D. Kobayashi, K. Honda and K. Ogawa, "BAN Radio Link Characterization Using an Arm-Swinging Dynamic Phantom Replicating Human Walking Motion," IEEE Transactions on Antennas and Propagation, Vol. 61, No. 8, pp.***-***, Aug. 2013. (to be published).