Evaluation of channel capacity of millimeter-wave wireless body area network in overcrowded train

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Abstract: Millimeter-wave (mmW) wireless body area network (WBAN) is effective in reducing inter-WBAN interference because of the large attenuation by human body blocking. In this paper, for evaluating the interference power and the channel capacity of mmW WBAN in consideration of the regularity of the arrangement of users, we proposed a user arrangement model which is assumed an actual overcrowded train. In the proposed model, the channel capacity was calculated in consideration of the user's shape, arrangement, and direction in the train. As a result of the computer simulation with the proposed model, it is concluded that the channel capacity of the overcrowded train environment with regularity in user arrangement varies more than that of a random environment.

Keywords: wireless body area network (WBAN), millimeter wave, inter-WBAN interference, human body blocking, wearable node

Classification: Wireless Communication Technologies

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1 Introduction

Wireless body area network (WBAN) is one of the major wireless systems that supports a wide range of applications such as medical, sports, and entertainment with human body area communication [1]. The inter-WBAN interference is one of the serious problems of WBAN which happens among nearby WBANs, especially as the number of WBAN users increases.

The millimeter-wave (mmW) WBAN is effective for suppressing the inter-WBAN interference at user-dense conditions because of their large attenuation of free space loss and human body blocking [2, 3, 4, 5]. We have already shown that mmW WBAN is effective for interference avoidance in crowded environments where users are randomly arranged [4, 5]. Since the attenuation due to the human body blocking is large, the interference power received by one user greatly changes depending on the human density and arrangement. In [2, 4], the human body viewed from above was modeled as a circle. However, for the more accurate evaluation of channel capacity, it needs to come closer to the actual human body by modeling it as an ellipse. Although users were arranged in random directions and positions in [2, 4, 5], it needs to be assumed that users are arranged with some regularity in an actual crowded environment such as an overcrowded train. It is considered that the shape, arrangement, and direction of the users greatly affect the blocking of WBAN, especially in the case of the heavily crowded environment such as in the train.

In this paper, for evaluating the interference power and the channel capacity of mmW WBAN in consideration of the regularity of the arrangement of users, we propose a user arrangement model in a train, which is an actual overcrowded environment.

2 Train model and user arrangement

Figure 1(a) shows the top view of the train model and the position of the evaluation users. This model is a general commuter train in Japan with long seats and four doors on each side. There are two types of users in this model: sitting and standing users. The train capacity is 160 people with 54 sitting people and 106 standing people. The ratio of the number of people to the train capacity is defined as the load factor in this paper. For evaluating the interference power and the channel capacity, we assumed the two types of fixed evaluation users which are indicated with the green ellipse in Fig. 1(a).

Figure 1(b) shows the size and direction of the users assumed in the simulation model. The user model in the left part of Fig. 1(b) shows the top view of the human body and the WBAN node. The WBAN node is assumed which the user is wearing in front. Sitting and standing users have regularity with the positions and directions

(a) Top view of the train model and position of the evaluation users.

(b) Size and direction of the users assumed in the model.

(c) Sample of user arrangements.

Fig. 1. Train model and user arrangement.

as shown in the right part of Fig. 1(b). All sitting users are arranged at the seats shown the gray parts in Fig. 1(a). The sitting users are assumed to face the front with the wall behind. All standing users are assumed to stand in a random position other than the seats. The direction of the standing users is assumed within $\pm 60^\circ$ concerning the long side of train frame because standing people tend to look the window.

Figure 1(c) shows the sample of user arrangements with a number of passengers of 160 people; the top and bottom ones are train and random arrangements, respectively. The train arrangement arranged users according to the above explanation. In the random arrangement for comparison with the train arrangement, the position of the evaluation users is fixed, however the direction and arrangement of the other users are randomly determined.

3 Simulation conditions

In this paper, channel capacity is calculated based on 2-dimensional ray tracing method considering following four-type attenuations: (i) free space loss based on Friis formula L_{free} , (ii) self-body blocking of interfered user (receiver, Rx) L_{Rx} , (iii) self-body blocking of interfering user (transmitter, Tx) L_{Tx} , and (iv) human body attenuation of user standing between Tx and Rx L_{shadow} . The inter-WBAN interference power I [W] is calculated by

Fig. 2. Self-body blocking condition of Rx or Tx.

$$I = \frac{P_{Tx} G_{Rx}^{inter} G_{Tx}^{inter}}{L_{free} L_{Rx} L_{Tx} L_{shadow}}, \quad (1)$$

where P_{Tx} [W] is transmission power. G_{Rx}^{inter} and G_{Tx}^{inter} are Rx and Tx antenna gain for inter-WBAN interference, respectively.

At calculating the interference power, the attenuation of L_{Rx} and L_{Tx} is determined according to the following conditions. Figure 2 shows the self-body blocking condition of Rx or Tx. If a path of interference signal to Rx or from Tx is through within $\pm 60^\circ$ of body direction of Rx or Tx user, L_{Rx} or L_{Tx} is 40 dB from experimental evaluation in [3]. Otherwise, L_{Rx} or L_{Tx} is 0 dB. If there is another user standing between the Tx and Rx nodes, L_{shadow} is 14 dB per each user in between [3]. When there is no other user between the Tx and Rx nodes, L_{shadow} is 0 dB.

The total interference power received by the Rx user I_{total} [W] is the sum of the interference powers I of the Tx users:

$$I_{total} = \sum_{Tx} I. \quad (2)$$

The channel capacity of the intra-WBAN communication C [bit/s] is calculated from Shannon's formula as

$$C = B \log_2(1 + \gamma), \quad (3)$$

where B [Hz] is channel bandwidth of the mmW WBAN system and γ is signal to interference plus noise power ratio (SINR),

$$\gamma = \frac{P_{Tx} G_{Tx}^{intra} G_{Rx}^{intra}}{L_{intra} (I_{Total} + B n_{AWGN} F_{noise})}, \quad (4)$$

where L_{intra} is intra-WBAN propagation attenuation, n_{AWGN} [W/Hz] is white noise power density, and F_{noise} is noise figure (NF) of receiver node. G_{Tx}^{intra} and G_{Rx}^{intra} are Tx and Rx antenna gain for intra-WBAN communication, respectively.

In this computer simulation, we used the following assumed values. Center of radio frequency (RF) is 60 GHz. P_{Tx} is 0 dBm. G_{Tx}^{inter} , G_{Rx}^{inter} , G_{Tx}^{intra} , and G_{Rx}^{intra} are all 3 dBi. L_{intra} is 60 dB. B is 100 MHz. n_{AWGN} at room temperature is -174 dBm/Hz. F_{noise} is 6 dB.

In the case of load factor of 33.8 % or more, *i.e.* the number of users is 54 or more, all seats are occupied because the users are assigned in order from the seats. For calculating interference power, a full load condition is assumed, *i.e.* each node on all users other than the evaluation user (Rx) is assumed to transmit an interference signal. Reflected power is not considered in this simulation. The number of trials is 1,000 per each condition.

4 Evaluation results

Figure 3(a) shows the cumulative distribution function (CDF) of interference power received by the evaluation sitting user. In the case of train arrangement with the load factor of 33.8 % or more, there is a sitting user adjacent to the evaluation sitting user. Thus, the interference power tends to be larger in train arrangements than in random arrangements if the load factor is the same. As the density of standing users increases, the number of standing users facing the evaluation sitting user increases. Therefore, the CDF is steeper for the train arrangement compared to the random arrangement.

Figure 3(b) shows the CDF of interference power received by evaluation standing user. In the case of train arrangement with load factor of 33.8 % or more, all seats are occupied by users. At the load factor of 50 %, the interference power received from the seated user is dominant, so the train arrangement has a steeper characteristic than the random arrangement. At the load factor of 200 %, because the number of the

(a) CDF of interference power (Sitting user).

(b) CDF of interference power (Standing user).

(c) Channel capacity in the case of CDF 0.9.

Fig. 3. Computer simulation results.

standing users who become blocking users standing between evaluation standing user and sitting users increases, the train arrangement tends to have lower interference power than the random arrangement.

Figure 3(c) shows the channel capacity in the case of CDF 0.9. At the evaluation sitting user, the channel capacity that can be ensured by the train arrangement tends to be smaller than that by the random arrangement. However, even in the large interference power condition with a load factor of 200 %, 90 % or more sitting users can ensure a channel capacity of 8.2 Mbit/s or more. On the other hand, the channel capacity that can be ensured by standing user tends to be larger in train arrangement than in random arrangement. A channel capacity of 32 Mbit/s or more can be ensured even in the load factor of 200 %. Therefore, it is shown that the channel capacity of the train environment with regularity in user arrangement varies more than in that a random environment.

5 Conclusion

In this paper, for evaluating the interference power and the channel capacity of millimeter-wave (mmW) wireless body area network (WBAN) in consideration of regularity of the arrangement of users, we proposed a user arrangement model which is assumed an actual overcrowded train. By using the proposed model, the intra-WBAN channel capacity was evaluated in consideration of the user arrangement in the train. As a result of computer simulation, users of over 90 % were ensured channel capacity of 8.2 Mbit/s or more for intra-WBAN communication, even in the overcrowded environment with a load factor of 200 %. Moreover, it is shown that the channel capacity of the train environment with regularity in user arrangement varies more than in that a random environment. Finally, it is concluded that considering the user's shape, arrangement, and direction is important for the accurate evaluation of channel capacity of mmW WBAN with the overcrowded environment.

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