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A Twin Cylinder Model for Moving Human Body Shadowing in 60GHz WLAN

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***Abstract*—As link quality in 60GHz WLAN is significantly affected by moving human body shadowing, it is required to introduce shadowing countermeasures such as diversity and fast session transfer. For performance evaluation of these techniques in various environments, we need a deterministic shadowing model for ray-tracing simulations rather than a traditional empirical shadowing model based on experimental data. With this motivation, this paper proposes a twin cylinder model for moving human body shadowing in 60GHz WLAN, where three knife edges for diffraction loss calculation are derived from geometrical positions of a moving human body, a transmitter and a receiver. It is confirmed that calculated results using the proposed model agrees to measured results.**

***Keywords*— Twin Cylinder, 60GHz; shadowing; moving human body; knife edge**

I. INTRODUCTION

Recently, demand for broadband mobile cellular systems and WLAN (Wireless LAN) have been dramatically increasing to transmit and receive large-volume contents such as high definition TV and video clips in a very short time. To meet these demands for higher transmission rate and capacity, IEEE802.11ad standard for multi-Gbps WLAN using 60GHz band was completed in 2012, and commercial 60GHz WLAN products are under development using advanced RF-CMOS technologies for cost-effective 60GHz WLAN chip set [1]-[3].

As well-known, one of the biggest advantages of 60GHz WLAN is that 9GHz wide spectrum is available for unlicensed use on a world-wide basis however, it has some drawbacks such as large free space loss and severe shadowing loss caused by a moving human body. To solve these problems, high-gain directional antennas must be used to compensate large free space loss in 60GHz and shadowing countermeasures are required to combat severe shadowing loss caused by a moving human body in various environments such as an office, a conference room and an auditorium. Some shadowing countermeasures have been proposed, e.g. fast session transfer (FST) which switches 60GHz WLAN to 2.4/5GHz WLAN, a frequency cooperative automatic repeat request (ARQ) technique based on multiband WLAN using both 60GHz and 2.4/5GHz band, and spatial diversity technique using adaptive beam forming antenna to receive a reflected wave from a wall in case of shadowing [4], [5]. To evaluate performance of these solutions, we need to characterize features of moving human body shadowing in 60GHz.

Moving human body shadowing characteristics such as shadowing period and shadowing depth can be different according to propagation environments, size and moving direction of a human body and positions of a transmitter and a receiver. Measurement results of moving human body shadowing and some human body shadowing models have been reported in the literatures [6]-[8]. However, performance evaluation of the above mentioned techniques needs a deterministic shadowing model for ray-tracing simulations rather than a traditional empirical shadowing model based on experimental results. This is because 60GHz WLAN will be used in various propagation environments according to usage scenarios [9]. It was reported that the calculated results using two knife edges meet the measured results [10]. However, this model can be used only when a human body points to a transmitter and height of a human body is assumed to be infinite. To extend this model, we proposed a cuboid model where three knife edges are assumed according to the position of a human body for diffraction loss calculation, however it does not meet the measured results when the angle between a moving direction of human body and a lone-of-sight (LOS) path is small. [11]. In addition, size difference between a head part and a body part of a human body was not considered.

To improve the moving human body shadowing model, this paper proposes a twin cylinder model for moving human body shadowing in 60GHz WLAN, where three knife edges are derived from geometrical position and size of a moving human body, transmitter and receiver for shadowing loss calculation by knife edge diffraction theory. Calculated results using the proposed model are compared with experimental results in 60GHz to confirm the validity of the proposed model.

II. TWIN CYLINDER MODEL FOR MOVING HUMAN BODY SHADOWING

Fig. 1 shows the proposed twin cylinder model, where a small cylinder representing a head part of a human body is on a large cylinder representing a body part. By using this model, we can derive three diffraction paths and three knife edges according to the geometrical position of a human body, transmitter and receiver based on geometrical theory of diffraction (GTD) for diffraction loss calculation [12].

A. Shadowing loss caused by a body part

Let us suppose that height of a human body is h_p, shoulder width is W_s and thickness of a human body is W_t. As top view of a human body is an oval, W_s is a long axis of the oval, and W_t is a short axis of the oval when a body part of a human body causes shadowing loss. Fig.2 illustrates three diffraction paths and three knife edges, E_1, E_2 and E_3 which are derived from the proposed twin cylinder model.

Fig.3 shows a calculation method to obtain the maximum width of a flat panel with three knife edges. Let us suppose a plane wave comes from the transmitter, TX, is shadowed by a human body, and reaches the receiver, RX. a LOS path is shadowed by a human body and it reaches the receiver, RX. Supposing that center of the oval is the origin point, and Y axis is a moving direction of the human body, we can obtain the coordinates of two symmetrical points $E_1(X,Y)$ and $E_2(-X,-Y)$ by solving the simultaneous equations as given below:

$$\begin{cases} Y = kY + \sqrt{a^2k^2 + b^2} \\ \dfrac{X^2}{a^2} + \dfrac{Y^2}{b^2} = 1 \end{cases}, \tag{1}$$

where $k=tan(\pi/2-\alpha)$, α is the angle between a moving direction of the human body and the LOS path from TX to RX, $0<\alpha<\pi/2$, $a= W_s/2$ and $b=W_t/2$. Finally, the maximum width of a flat panel, h_{max} is given by:

$$h_{\max} = h_1 + h_2 = 2\left|\frac{kx - y}{\sqrt{k^2+1}}\right|, \tag{2}$$

Then, we can obtain one diffraction path, d_1 and d_2, for the knife edge, E_1 and the other diffraction path, d_3 and d_4 for the knife edge, E_2 by h_1 and h_2. As shown in Fig. 3, X and Y are given if the angle α between a moving direction of the human body and the LOS path is given. Actual h_1 and h_2 are obtained according to the position of the center of the oval relative to the LOS path. Another diffraction path, d_5 and d_6 for the knife edge, E_3 is obtained from Fig. 2, and the height of the knife edge, E_3 is given by the following equation:

$$h_3 = h_p - \frac{D_1 h_t + D_2 h_r}{D_1 + D_2}, \tag{3}$$

Diffraction loss for three propagation paths in Fig.2 is calculated by the following equation:

$$J(v) = \frac{\sqrt{[1 - C(v) - S(v)]^2 + [C(v) - S(v)]^2}}{2}, \tag{4}$$

where $C(v)$ and $S(v)$ are Fresnel integral as defined below:

$$C(v) = \int_0^v \cos\left(\frac{\pi}{2}t^2\right)dt, \quad S(v) = \int_0^v \sin\left(\frac{\pi}{2}t^2\right)dt, \tag{5}$$

Each parameter, v_i (i=1~3) for three diffraction paths for Fresnel integral is given by:

$$v_1 = h_1\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1} + \frac{1}{d_2}\right)}, \quad v_2 = h_2\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_3} + \frac{1}{d_4}\right)} \tag{6}$$
$$v_3 = h_3\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_5} + \frac{1}{d_6}\right)}$$

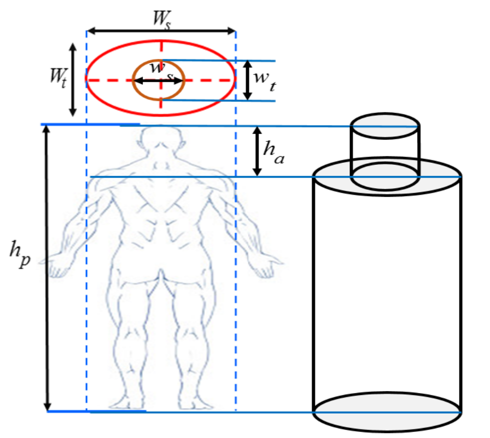


Fig.1 Twin cylinder model for human body shadowing.

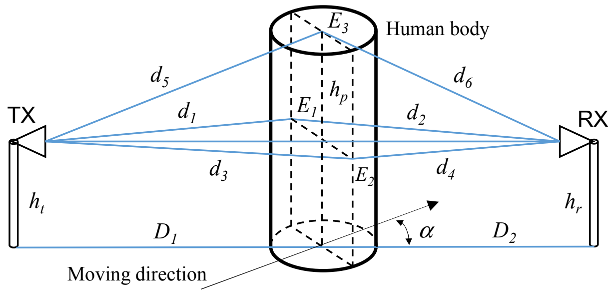


Fig.2 Three diffraction paths and three knife edges, E_1, E_2 and E_3 of the proposed cylinder model

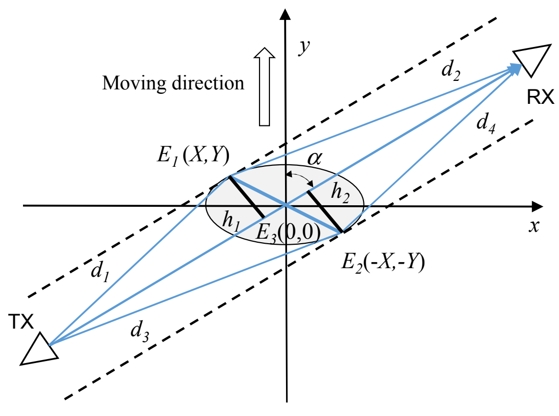


Fig.3 Calculation method of knife edge height in the proposed cylinder model.

Finally, the shadowing loss can be obtained by summing up three diffracted waves as shown below:

$$R = \left| \sum_{i=1}^{3} J(v_i) \exp(-2\pi f \tau_i) \right|, \quad (7)$$

where τ_I (i=1~3) is delay time of each propagation path and is calculated from each path length, d_1+d_2, d_3+d_4 and d_5+d_6.

B. Shadowing loss caused by a head part

As shown in Fig. 1, a small cylinder represents a head part, where h_a is the head height, w_s is the head width and w_t is the head length. Therefore, two flat panels representing a human body and a human head respectively are used according to the cross point of a LOS path.

If LOS path is above the shoulder of the human body at the cross point of the LOS path and the human body, diffraction by knife edges, E_1 and, E_2 is caused by a human head, thus the size of w_t and w_s of a small oval representing a human head is used instead of W_t and W_s to calculate h_{max} by using equations (1) and (2). If the LOS path crosses the shoulder part but not the head part, the height of the shoulder, h_p-h_a is used instead of h_p to calculate h_3 for diffraction by knife edges, E_3 by using equation (3). Note that d_i (i=1~6) needs to be calculated accordingly.

III. COMPARISON OF CALCULATED RESULTS AND MEASURED RESULTS OF MOVING HUMAN BODY SHADOWING

A. Experimental setup

Propagation measurement was carried out to confirm the validity of the proposed shadowing model to calculate shadowing loss caused by a moving human body in 60GHz.

Fig.5 shows experimental setup of moving human body shadowing measurement in a shield room with the size of 6.9m long, 2.9m wide and 3m high. Fig. 6 shows a photo of the experimental set up in the shield room. The distance between a transmitter antenna and a receiver antenna is set at 4m. A directional antenna with half power beam width of 30 degrees is used at both of the transmitter and the receiver. An actual human body sitting on a chair is set on a motor-powered moving table and is moved along the rail way by using a positioner PC which controls the position of the moving table and triggers a network analyzer to measure frequency-amplitude characteristics, $H(f, r)$ according to the position of a human body, r. Network analyzer, Agilent N5227A is used to measure $H(f, r)$ and received power, P_r(r) according to the position, r is calculated by integrating instantanous received power over freqeuncy from f_c-$B/2$ to f_c+$B/2$, as follows:

$$P_r(r) = \int_{f_c-B/2}^{f_c+B/2} |H(f,r)|^2 \, df \cdot \quad (7)$$

B is bandwidth of the received signals and f_c is carrier freqeuncy. Assuming IEEE802.11ad parameters, B is set at 1.76GHz.

We investigated two scenarios, i.e. scenario 1 means that a LOS path crosses the body part of a moving human body and scenario 2 menas that a LOS path crosses the head part of a moving human body. Angle between a LOS path and a

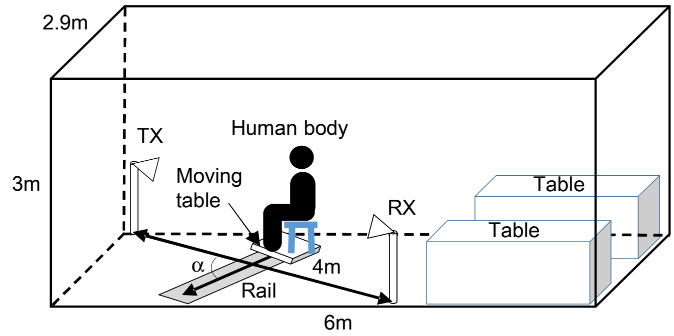


Fig.5 Measurement setup.

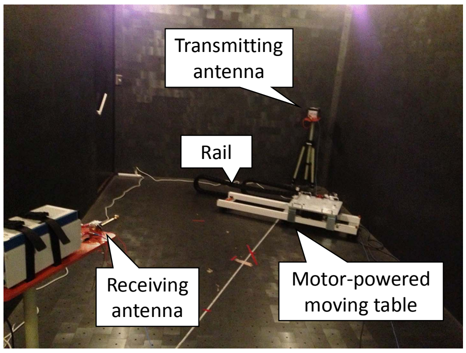


Fig.6 Photo of experimental setup in the shield room.

TABLE I. SIZE OF A HUMAN BODY USED FOR EXPERIMENTS.

Parameters	Size (m)
Head width, w_s	0.2
Head length, w_t	0.2
Body width, W_s	0.5
Body length, W_t	0.25
Body height of a human body sitting on a chair, h_p	1.35
Head height, h_a	0.25

TABLE II. MAJOR EXPERIMENTAL PARAMETERS.

Parameters	Scenario 1	Scenario 2
TX antenna height (m)	1m	1m
RX antenna height (m)	1.5m	1m
Angle, α (degree)	30, 60, 90	0, 15, 30, 60

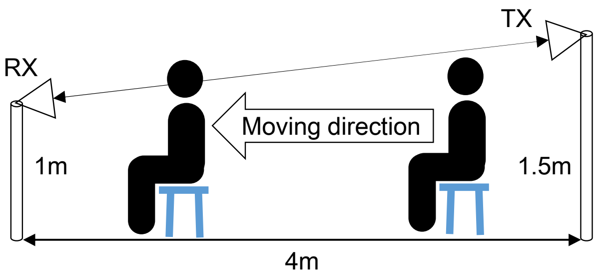


Fig.7 Human body shadowing in scenario 2 with a=0 degree.

moving direction of a human body is α, which is 30, 60 and 90 deg. in scenario 1 and 0, 15, 30, 60 deg. in scenario 2. A real human body was used for experiments and each size of the human body used for experiments is given in Table I, where the human body sat on a chair on a moving table during experiments, thus h_p is as low as 1.35m. Furthermore, we set different TX and RX antenna height for each scenario as shown in Table II. Note that a LOS path is blocked by a body part in scenario 1. As TX antenna height is higher than h_p and RX antenna height is lower than h_p in scenario 2. Fig. 7 illustrates scenario 2 with α=0 where a human body moves from TX to RX. Therefore, a head part mainly causes shadowing.

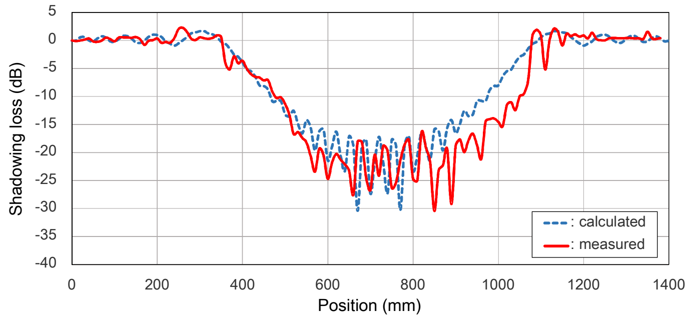
B. Comparison in scenario 1.

The measured results of shadowing loss according to the position of a human body in scenario 1 when α=30, 60 and 90 deg. are shown in Fig. 8, and they are compared with the calculated results using the proposed twin cylinder human body shadowing model. The comparison shows that the calculated results agree to the measured results well in terms of shadowing depth and shadowing duration for any angle, α. It should be noted that the cuboid model we proposed before does not show a good match when α=90 deg., however the twin cylinder model proposed in this paper shows a good agreement.

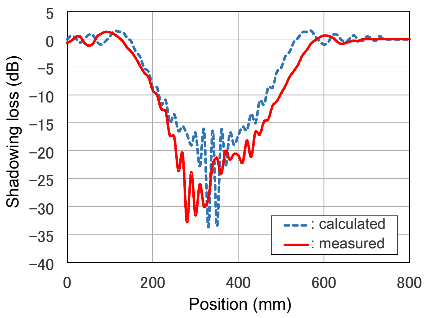
Comparison of shadowing duration and median value of shadowing loss with the measured results in scenario 1 is shown in Fig. 9. Shadowing duration, D_s is defined as the time or distance between the last zero crossing and the first zero crossing after the shadowing event. Median value of shadowing loss, M_s is defined as shadowing loss which gives 50% CDF (Cumulative Probability Distribution Function) during the duration between $1/3.D_s$ and $2/3.D_s$. As shown in Fig. 9, the calculated results of shadowing duration and median value of shadowing loss matches the measured results well for moving direction, α.

C. Comparison in scenario 2.

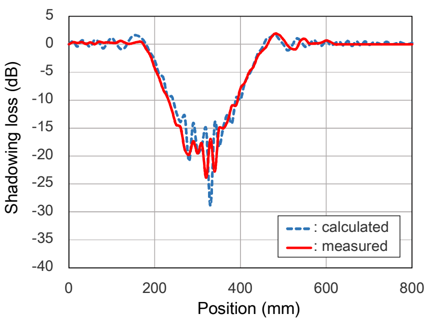
The measured results of shadowing loss according to the position of a human body in scenario 2 when α=0 deg. is shown in Fig. 10, and is compared with the calculated results. The comparison shows that the calculated results matches the measured results very well in terms of shadowing loss and shadowing duration. Due to the limitation of space, the measured results for α=15, 30 and 60 deg. are not shown here, but they also show a good match with calculated results.



(1) α=30 deg.

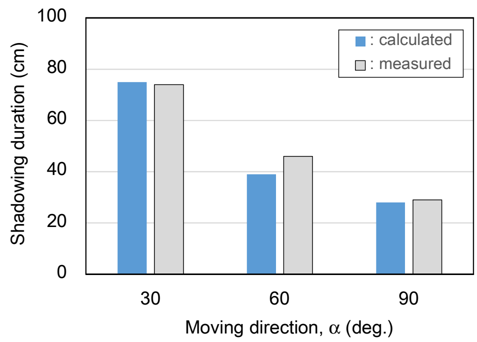


(2) α=60 deg.

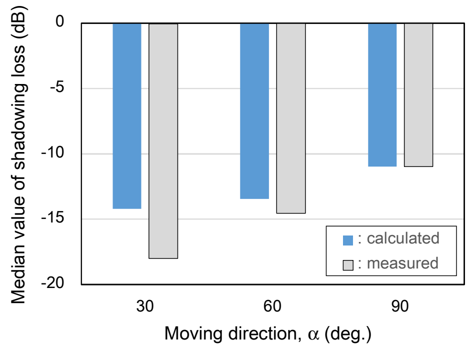


(3) α=90 deg.

Fig.8 Comparison of measured and calculated shadowing loss according to the position of human body when a moving direction, α=30, 60 and 90 deg.



(1) Shadowing duration



(2) Mean values of shadowing loss

Fig.9 Comparison of shadowing duration and mean value of shadowing loss for moving direction, α=30, 60 and 90 deg.

Comparison of shadowing duration and median value of shadowing loss with the measured results in scenario 2 is shown in Fig. 11. As shown here, the calculated results of shadowing duration and median value of shadowing loss matches the measured results well for moving direction, α=0, 15, 30 and 60 deg. If compared with the results in scenario 1 for α=30 and 60 deg., shadowing periods in scenario 2 are about 50cm and 35cm, but shadowing periods in scenario 1 are about 75cm and 40cm since a head part is smaller than a body part. In addition, shadowing loss in scenario 2 is around 7dB which is less than that in scenario 1, i.e.14dB and 10dB. These results seem appropriate as foreseen from the size difference between a body part and a head part of a human body.

IV. Conclusions

This paper proposes a twin cylinder model for moving human body shadowing in 60GHz WLAN, where a small cylinder represents a head part of a human body and a large cylinder represents a body part. By using this model, three knife edges are derived from geometrical positions and size of a moving human body, a transmitter and a receiver for diffraction loss calculation. Propagation measurements have been conducted to validate the proposed model by comparing the calculated results with the measured results in two scenarios. It is confirmed that the calculated results agree to the measured results in terms of the shadowing duration and the shadowing depth. The proposed model will be useful for performance evaluation of shadowing countermeasures by using ray-tracing simulations including human body shadowing.

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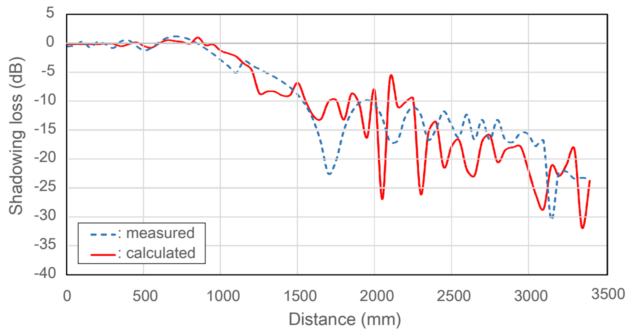
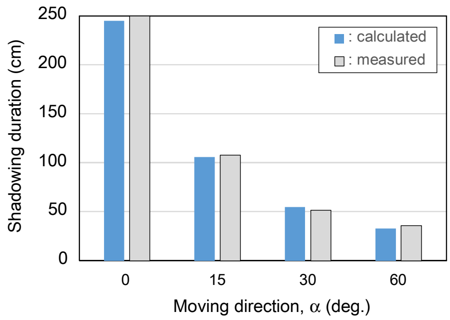
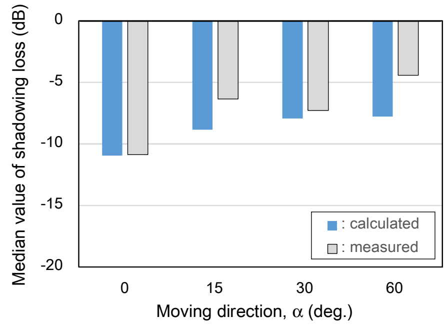


Fig.10 Comparison of measured and calculated shadowing loss according to the position of human body in scenario 2 when a moving direction, α=0 deg.



(1) Shadowing duration



(2) Mean values of shadowing loss

Fig.11 Comparison of shadowing duration and mean value of shadowing loss for moving direction, α=0, 15, 30 and 60 deg

References

[1] IEEE 802.11ad-2012

[2] A.Siligaris et. al., “A 65nm CMOS Fully Integrated Transceiver Module for 60GHz Wireless HD Applications”, ISSCC Dig. Tech. Papers, pp. 160-161, 2011.

[3] N. Saito et al., “A Fully Integrated 60-GHz CMOS Transceiver Chipset Based on WiGig/IEEE 802.11ad With Built-In Self Calibration for Mobile Usage,” IEEE Jounal of Solid-State Circuits, Vol. 48, No. 12, December 2013, pp.3146-3159.

[4] M.Park and H.K. Pan, “A Spatial Diversity Technique for IEEE 802.11ad WLAN in 60 GHz Band,” IEEE Communications Letter, Vol. 16, No. 8, August 2012, pp.1260-1262.

[5] T.Motegi, S.Koike, T.Miyajima, M.Umehira, S.Takeda, K.Kagoshima, “A frequency cooperative ARQ scheme for multi-band WLAN,” IEICE Communications Express, Vol. 4 (2015) No. 2 pp.79-84.

[6] T.V.Nguyen, E.Masry, L.B.Milstein, “Channel Model and Performance Analysis of QAM Multiple Antenna Systems at 60-GHz in the Presence of Human Activity,” IEEE Global Telecommunications Conference (GLOBECOM 2011), 5-9 Dec. 2011, pp.1-6.

[7] M.Jacob, C.Mbianke, T.Kurner, “A dynamic 60 GHz radio channel model for system level simulations with MAC protocols for IEEE 802.11ad,” IEEE 14th International Symposium on Consumer Electronics (ISCE2010), 7-10 June 2010, pp.1-5, Braunschweig.

[8] M.Jacob, et al. “A Ray tracing based stochastic human blockage model for the IEEE 802.11ad 60 GHz channel model,” Proceedings of European Conference on Antennas and Propagation (EUCAP), April 2011, pp.3084 – 3088.

[9] Rob Sun, Yan Xin, Jiamin Chen, Hong Li, “NG 60 Usage Models,” IEEE802.11-14/1185r0, Aug. 2014.

[10] T. Ishimine, K. Sato, “Shadowing of Millimeter Waves due to Human Body,” IEICE Trans. B, vol. J83-B, No.4, pp.615-621, April 2000 (in Japanese).

[11] M.Umehira, S.Takeda, T.Miyajima and K.Kagoshima, “An Extended Calculation Model for Shadowing Loss Caused by a Moving Human Body in 60GHz WLAN,” The 20th Asia-Pacific Conference on Communications (APCC2014), October 1-3, 2014, Pattaya, Thailand.

[12] R.J.Luebbers, “Finite Conductive Uniform GTD Versus Knife Edge Diffraction in Prediction of Propagation Path Loss,” IEEE Trans. on AP, Vo. 32, No.1, Jan. 1984, pp.70-76.