Modeling and Measurement of Human Body Blockage Loss at 28 GHz

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Millimeter-wave (mm-Wave) spectrum is an essential enabler to the fifth generation (5G) wireless technology. Humans are one of the most noticeable blockers that cause temporal variation in indoor radio channels. This paper presents human blockage measurements at 28 GHz, with several humans of different sizes. The effect of the crossing orientations of the human bodies is investigated for three different transmitter heights. A human blockage model based on the Fresnel diffraction scheme is shown to be applicable in estimating the human blockage loss in indoor radio links considering various body sizes, different crossing orientations, and different transmitter heights. The findings reported in this paper could help improve indoor radio channel models at 28 GHz bands for 5G technologies considering the presence of human body blockages.

Keywords: human body blockage; blockage loss; diffraction; millimeter wave (mm-Wave) propagation; fifth generation (5G) networks

1. Introduction

Wireless data traffic is increasing at a significant rate over the past few years, and it is expected to experience a further increase in the coming decade [1]. The currently used sub-6 GHz spectrum is unable to afford this increasing demand on bandwidth and spectral efficiency. Therefore, in order to overcome the global bandwidth shortage, the wireless industry is establishing the fifth-generation cellular technology (5G) that is going to employ the millimeter-wave (mm-Wave) frequency spectrum [2]. The movement toward using the mm-Wave spectrum is expected to tackle the exponential growth of the predicted data traffic capacities [3, 4]. However, as the wavelengths of mm-Wave frequency bands are less by order of magnitude when compared to microwave frequency bands, then the propagation characteristics of those frequency bands are impacted greatly by small obstacles [5-7]. Consequently, the penetrations and diffractions caused by human blockages will suffer from a greater attenuation [8-10]. Therefore, the third-generation partnership project (3GPP) has considered humans to be identified as one of the major obstacles that affect the mm-Wave propagation channel [11]. This requires precise evaluation of the human blockage loss by providing accurate models having low complexity of human body geometrical description and reduced computations.

Several studies are proposed in the literature for determining the blockage loss due to humans based on the shape and dimensions of the body. A detailed survey on models for estimating the human blockage loss and human shadowing effects is presented in [12, 13].

In [12], the authors presented human blockage loss measurements at 28 and 60 GHz, in which a double-truncated multiple knife-edge (DTMKE) model was proposed. The authors in [13] investigated the blockage loss due to a human body at 28 and 32 GHz. The METIS model, the geometrical theory of diffraction (GTD) model, and the Gaussian model were used to simulate the human blockage effects. Measurements at 28 GHz were also performed by the authors in [14] investigating the blockage loss for antenna heights of 1.2m and 1.4m. A 3-D stochastic model to determine the user shadowing is given in [15]. The model is used for the frequency range from 28 to 34 GHz. The user effect is also studied by [16] at 28 GHz. The authors considered the statistical parameters of body loss and coverage efficiency. The measurements were recorded for several users in talk and data modes. Additionally, losses caused by the user's hand at this frequency band were also reported in [17-20]. The authors in [21, 22] presented the effect of human blockages nearby indoor links at 28 GHz for non- Line of Sight (non-LOS) scenarios. The DKED model was proposed in [22], whereas in [21], the street canyon propagation model was proposed.

Although several studies exist on the human blockage loss at mm-Wave frequency bands, deeper investigations on the propagation aspects for the lower mm-Wave bands, such as 28GHz, are still needed [23]. The 28 GHz band is currently available with spectrum allocations of more than 1 GHz of bandwidth. This makes it a valued resource, and it is believed that this could be used for the upcoming 5G mobile cellular networks [2]. Therefore, the Federal Communications Commission (FCC) in the United States issued a Notice of Proposed Rule Making that proposed new flexible service rules for the 28 GHz band [24]. With the announcement from the FCC that the 28 GHz spectrum can now be used for mobile communications, industry has shown great interest in performing further field trials and experiments considering the propagation aspects of the 28 GHz band.

The human blockage models that are available in the literature [12–22] evaluate the loss due to the human blockage by considering the body dimensions and shape. Although these proposed models provide good accuracy at the cost of complexity in the human body geometrical representation and increased computations, these proposed models are not comprehensively validated for different body sizes (height, width, and thickness of the human), orientation (the angle of which the human body blocks the signal), and transmitter antenna height dependence. This information is vital for the design of future mm-Wave communication systems that can overcome the deep fades due to human blockage loss by designing suitable handoff mechanisms and beam steering techniques.

Therefore, the key contributions of this paper can be summarized as follows:

- The human blockage loss measurements based on several humans of different heights and widths along with different crossing orientations at three different transmitter heights are reported.
- A simple yet accurate human blockage model based on the Fresnel diffraction method is proposed and proven to be accurate for different body heights and widths, different orientations, as well as different antenna height operations.

According to the authors' best knowledge, the reported work in this paper is the first study in literature that considers investigating the combination of all the important parameters affecting the human body blockage loss (considering different human sizes and dimensions, different crossing orientations, and different transmitter antenna height combinations). Three different humans were used having heights of 1.66m, 1.73m, and 1.88m, and widths of 0.40m, 0.44m, and 0.48m, respectively. Two crossing orientations were considered, the lateral and frontal crossing of the LOS, and three different transmitter antenna heights of 1m, 1.3m, and 1.6m were used. Regarding the receiver side, the receiver is assumed to be a typical human user equipment, having an average height of approximately 1m above ground, similar to [22, 25, 26]. The proposed theoretical model is validated by comparing the measurement results with the theoretically simulated ones, as well as comparing it with the GTD model. Considering all the above-mentioned parameters, the proposed model can accurately estimate the human blockage loss with an error margin of 2-4 dB.

The remainder of this paper is organized as follows: Section 2 presents the proposed theoretical human blockage model used for estimating the blockage loss. The measurement results for several human blockage losses at 28 GHz and the validity of the proposed theoretical model are provided in Section 3. Finally, in Section 4, the findings are summarized, and conclusions are drawn.

2. Human Blockage Model

Most of the reported literature on determining the human body blockage effect simulates the human body geometry using either a rectangular absorbing screen (based on DKED method) or a perfectly conducting cylinder (based on GTD method). In this paper, we present the use of the Fresnel diffraction method to estimate the effect of the human blockage by considering multiple diffractions.

The proposed human body geometrical model is represented in Fig. 1. The ray going from the Tx to the Rx crosses the plate at a certain point. The shortest distances between the edges of the plate and the ray crossing point are denoted as Hb1 and Hb2 (referring to the human chest width). The distance from the human model to the Tx is denoted as Dtp, whereas the distance to the Rx is defined by Drp. To consider the crossing orientation of the human body blockage, the angle α is used to represent the angle between the LOS and the normal vector to the rectangular plate. It should be noted that the diffraction components from the edges of Hs1 and Hs2 (representing the shoulders of the human) should be considered for antenna heights being higher than the chest of the human body as they are contained within the first Fresnel Zone. Therefore, two methods can be used in calculating the human body shadowing gain. For low antenna heights being less than the chest level of the human, the two verticals edge-diffractions are most dominant. On the other hand, multiple-edge diffractions considering the shoulders' diffractions are used for higher antenna heights.

The Fresnel diffraction method is adopted to describe the mentioned diffraction effect. We focus our study on the First Fresnel Zone, in which the signal propagation

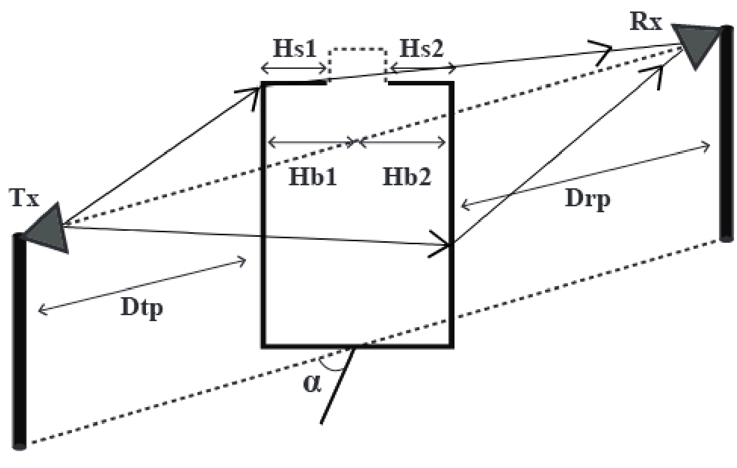

Figure. 1. Geometric model representing the human body.

follows the diffraction theory. Considering a free-space scenario, the Tx transmits radio frequency (RF) signals having a wavelength of λ to the Rx. The Fresnel zones are concentrical ellipses. The boundary of the n-th Fresnel zone is defined as [27]:

$$| TxPn | + | RxPn | - | TxRx | = n\frac{\lambda}{2} \tag{1}$$

Where P_n is a point on the n-th ellipse. The First Fresnel Zone is defined as the innermost ellipse (n=1). Let O be a point on the LoS link between the Tx and Rx, then in general the distance between the Tx and point O and Rx to point O are denoted by d1 and d2, respectively. Thus, the radius of the First Fresnel Zone can be calculated as

$$r_1 = \sqrt{\lambda \frac{d_1 d_2}{d_1 + d_2}} \tag{2}$$

where d_1 and d_2 are referred to Dtp and Drp, respectively as shown in Fig. 1. As approximately 70% of the RF signal energy is transferred via the First Fresnel Zone [28], this implies that diffraction becomes much stronger and more dominant when an object (human body in our case) moves into the First Fresnel Zone. Therefore, such a blockage event will primarily block the energy pathway and the remaining energy bypass the object. Thus, we are interested in discovering how the signal propagation is affected when the human body moves back and forth in the First Fresnel Zone.

By calculating the electric field strength E_d (V/m) at the Rx, the diffraction loss (as compared with free space) is obtained based on the specific Fresnel diffraction parameter ν [29]. The ratio of E_d and the free space field strength E_0 can be computed by summing all the secondary Huygens' sources in the knife edge plane [29,30].

$$\frac{E_d}{E_0} = F(v) = \frac{1+j}{2}\int_V^{\infty} e^{-i\frac{\pi}{2}t^2}\, dt \tag{3}$$

where F(ν) is the complex Fresnel integral and ν is the Fresnel-Kirchhoff diffraction parameter defined in (7).

Therefore, the diffraction gain is expressed as given in [31]:

$$G_l = \frac{1+j}{2}\left\{\left(\frac{1}{2} - C(v)\right) - j\left(\frac{1}{2} - S(v)\right)\right\} \tag{4}$$

where G_l is the Fresnel integral, and the numerical approximation of the Fresnel integration for *C(v)* and *S(v)* are defined as

$$C(v) = \int_0^v \cos\left(\frac{\pi v^2}{2}\right) dv \tag{5}$$

$$S(v) = \int_0^v \sin\left(\frac{\pi v^2}{2}\right) dv \tag{6}$$

where ν is the Fresnel-Kirchhoff diffraction parameter

$$v_{(\theta)} = \theta \sqrt{\frac{2}{\lambda} \frac{d_T d_R}{d_T + d_R}} \tag{7}$$

where θ is the diffraction angle and is expressed as

$$\theta_{(h)} = \tan^{-1}\left(\frac{h}{d_T}\right) + \tan^{-1}\left(\frac{h}{d_R}\right) \tag{8}$$

when the crossing orientation angle α is considered, then the effective height h and distances d_T, and d_R can be calculated as

$$h = h' \cos\alpha \tag{9}$$

$$d_T = Dtp \pm h' \sin\alpha \tag{10}$$

$$d_R = Drp \pm h' \sin\alpha \tag{11}$$

where h' denotes the distances, Hb1, Hb2, Hs1 and Hs2.

In lateral crossing shown in Fig. 2a, the crossing orientation angle α is equal to 0° whereas for frontal crossing (Fig. 2b) the angle α is defined to 90°. In the frontal crossing case, the thickness of the human body will have an impact on the effective height. As a result, the distances d_T, d_R, and the effective height h are calculated as

$$d_T = Dtp \pm Hb1{,}2 \tag{12}$$

$$d_R = Drp \pm Hb1{,}2 \tag{13}$$

$$h = max(h' \cos\alpha, W_T) \tag{14}$$

where the thickness of the human body is defined as W_T. Thus, the total human body shadowing gain is expressed as in [32]:

$$G_{total} = \sum_{l=1}^{n} G_l \tag{15}$$

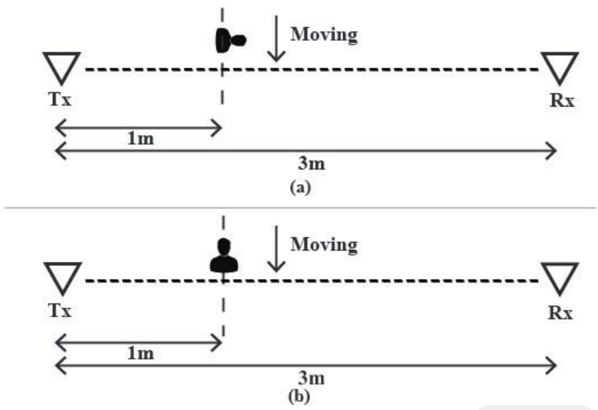

Figure. 2. Illustration of human body crossing (a) Lateral crossing. (b) Frontal crossing. (First Fresnel Zone radius=0.09m).

where n is the total number of diffraction components considered. Note that gain and loss will be used interchangeably throughout the paper as one is simply the inverse of the other [33].

3. Human Blockage Measurements

The measurement system used in this study is identical to the one presented in [22], and this setup has been used by some other researchers as well. Briefly, the system consists mainly of a signal generator (Agilent E8244A) and a spectrum analyzer (Agilent E4448A). Two identical horn antennas (PE9850/2F-20) having 20 dBi of gain, and with a 16.7° vertical and 18.3° horizontal half-power beamwidth (HPBW) are used in both the transmitter and receiver sides of the link. All connections are made using low-loss flexible cables. The measurements were carried out in a large indoor laboratory environment (the RF and Antenna laboratory of Atilim University, Ankara, Turkey). The floor plan of the laboratory is shown in [22, Fig.2]. The communication link was aligned to paunch of a human body using a laser beam. A tiled wall parallel to the link exists at one side of the link. Meanwhile, at the other side, there exist several desks having 0.75m height. The distance from both the wall and the desks to the communication link is 2.4m. At the back of the Tx, there are steel cabinets with high of 2.2m. The cabinets are located 13.5m away from the Tx. A plaster board hanging on a tiled wall is located at 3m behind the Rx. The ceiling height of the laboratory room is approximately 3m.

Some preliminary measurements were performed before the human blockage loss measurements to ensure ideal measurement conditions as described in [22]. Specifically, the effect of multipath signals caused by fixed objects in the laboratory was investigated. Accordingly, it has been concluded that multipath signals can be neglected when considering their positions in the measurement environment. Therefore, the reported results in this paper regarding the blockage loss caused by the human body are independent of the multipath effect.

In the measurement scenario shown in Fig. 2, the Tx and Rx antennas were separated by 3m. Three different Tx antenna heights were used as 1m, 1.3m, and 1.6m. Two different LOS crossing orientations, namely, lateral and frontal crossing were considered. Three different humans having various body dimensions were used in the measurements. The humans' dimensions are given in Table 1. It should be noted that based on several preliminary measurements with multiple human samples, it was observed that humans within similar height ranges, such as 164-167cm, 173-176cm, and 184-188cm, have similar blockage loss. Therefore, humans of height 166cm, 173cm, and 188cm are used in this study to cover a variety of samples in which the blockage loss varies based on height. The humans crossed the LOS path at 1m away from the Tx antenna.

Table 1. Human Dimensions

	Height	**Width (Hb)**	**Thickness (W_T)**	**Shoulder (Hs)**
Human 1	188cm	48cm	22cm	16cm
Human 2	173cm	44cm	22cm	14cm
Human 3	166cm	40cm	24cm	12cm

In the measurements, the human was moving from -1m to +1m by crossing the LOS path (where the position point at 0m refers to the direct path between the Tx and Rx) with an increment of 0.1m. A total of 21 received power values were collected as the person moved toward crossing the LOS. In the measurements, the data at each position was recorded several times, and the average was taken to reduce time-varying fading as well as measurement errors. Moreover, the measurement is repeated over several days to prevent any randomness in the channel and measurement setup. As to be the reference in every measurement, the received power was also recorded when no human blockage is present (free space) to evaluate the effect of the human blockage precisely.

Fig. 3 shows the human blockage maximum loss of the three different humans for lateral and frontal crossings at three different Tx antenna heights. As can be seen, no significant difference in blockage loss is observed for Tx=1m and Tx=1.3m for the same human. However, the height of the human plays an important role when the antenna height increases to 1.6m. For example, Human 1 introduces significant loss (20 to 24 dB). The width along with the height plays an important role at this Tx antenna height. No major difference is observed in frontal crossing when the humans are considered in the case of 1m and 1.3m Tx antenna heights. This could be attributed to the body thickness of the three humans, all are within the range of 22-24cm. Next, the crossing orientation could be studied in detail. As expected, the blockage loss and its duration are higher in lateral crossing when compared to frontal crossing.

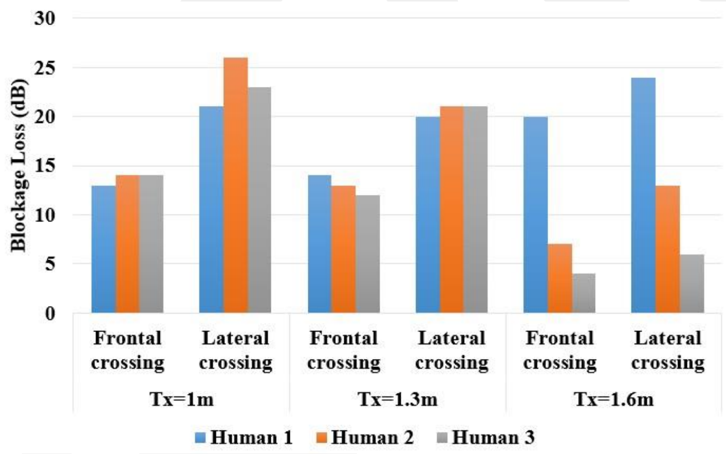

Figure. 3. Blockage loss measurements for three humans and three Tx antenna heights.

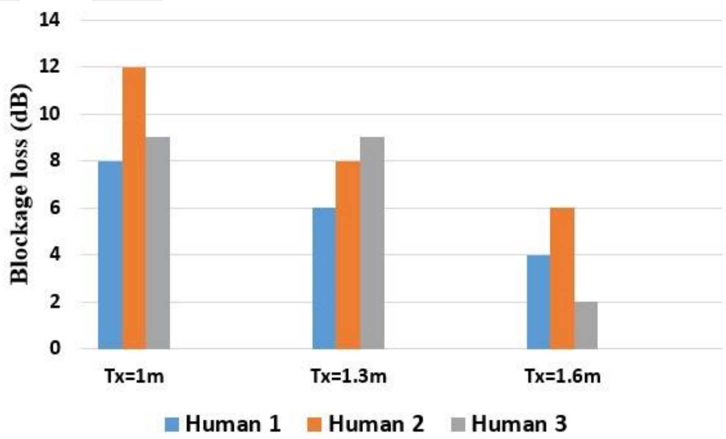

Figure. 4. Difference between lateral crossing and frontal crossing in terms of blockage loss.

Significant blockage loss also exists at Tx height of 1m and 1.3m for average human height as the case in Human 2. The blockage measured results indicate a strong sensitivity to human blockage at those height, as a result of variations in constructive and destructive interference. Only the diffractions from the side edges of the human model 2 exist when the Tx height is at 1m and 1.3m. Therefore, the blockage loss is higher at those heights compared to the Tx height of 1.6m, in which diffraction can also exist from the shoulders of the human body. This effect is similar to the human blockage effect at other mmWave band frequency such as 60GHz and 73GHz, as reported in [12, 34].

Shown in Fig. 4 is the difference between the blockage losses in the case of lateral and frontal crossings. The difference is less significant when the Tx antenna has a height of 1.6m. For Tx antenna height of 1m, the difference of the blockage losses can reach up to 12dB. This difference reduces to a range of 2-6 dB when the Tx antenna height is increased to 1.6m.

Human blockage models based on GTD [35] were already proposed in the literature [36, 37]. The human blockage model presented in the previous section is compared with the measurements as well as the GTD model. The human body shadowing gain, based on Human 2 for Tx antenna height of 1m, along with the GTD model and measurements, is shown in Fig. 5. The proposed human blockage model agrees well with the measurements, especially, for the case of lateral crossing in which the GTD model

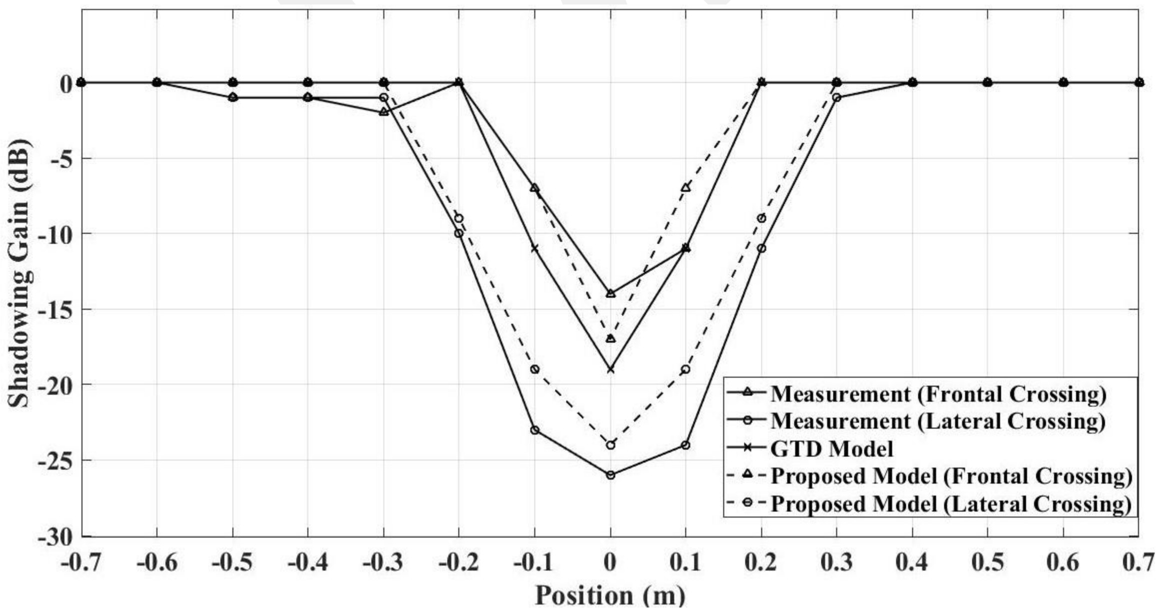

Figure. 5. Human body shadowing gain of Human 2 for Tx height of 1m.

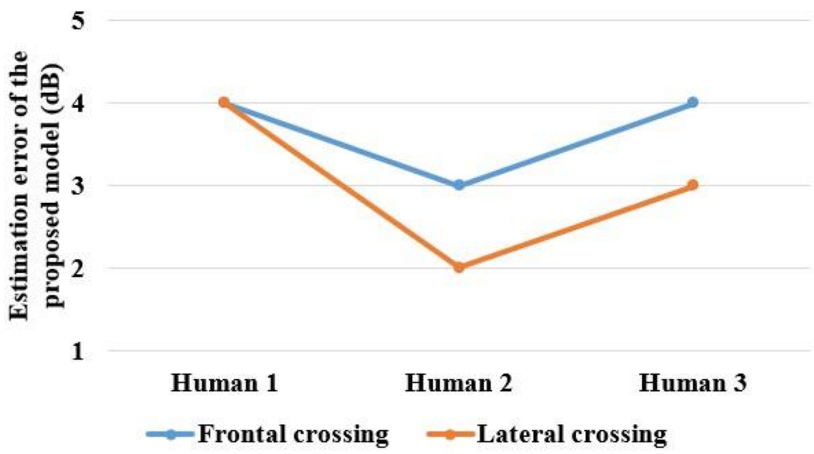

Figure. 6. Difference of blockage loss between the proposed theoretical model and the measurements.

significantly underestimates the gain. This is basically because the GTD model uses simple cylindrical geometry, which is independent of the orientation of the human body, while crossing the link, as well as it ignores geometrical details of the body. Shown in Fig. 6 is the difference of blockage loss between the proposed model estimation and the measurement results. The proposed theoretical model can accurately estimate the human blockage loss with an error margin of 2-4 dB.

4. Conclusion

In this paper, we presented body blockage measurements at 28 GHz considering a variety of humans with various dimensions. The body blockage was studied by considering the crossing orientation along with several Tx antenna heights. A human blockage model based on the Fresnel diffraction mechanism was adapted to predict the body blockage. It was shown that human body height and width along with the crossing orientation are key parameters for the human blockage loss, and they must be considered when developing models, especially, at different antenna heights. The findings reported in this paper could help researchers improve indoor radio channel models at mm-Wave bands for 5G systems. Possible extensions of this work include performance assessments of comparing several human blockage theoretical models with experimental measurements. We leave the analysis of these aspects for future work.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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