Millimeter Wave Channel Models for Human Passing through a Line-of-sight Path

Xiaokang Ye[1], Xuefeng Yin[1], Hua Yan[2], and Antonio Pérez Yuste[3]
[1] School of Electronics and Information Engineering, Tongji University, Shanghai, China
[2] Huawei Technology Company, Chengdu, China
[3] School of Telecommunications Engineering, Technical University of Madrid, Madrid, Spain
Email: {yexiaokang,yinxuefeng}@tongji.edu.cn, yhyanhua.yan@huawei.com, and antonio.perez@upm.es

***Abstract*—Limited by frequency spectrum resources below 6-GHz, millimeter (mm-) wave transmission becomes important in the fifth generation of communication systems for high data rate by utilizing a large available frequency band. In this paper, a recently conducted channel measurement campaign in an indoor environment is introduced for investigating human body's influences on mm-wave propagation from 55 to 65 GHz. We investigate the stochastic behaviors of the duration and angle spread when a human passes through a connection line of two horn antennas. Moreover, the deepest fading depth due to a complete human-body blockage is statistically modeled. The results show that the shadowing caused by human body mainly occurs in the area covered by half-power beamwidth of two antennas.**

I. Introduction

Millimeter (mm-) wave transmission technologies are going to be applied in the fifth generation (5G) of communication systems due to a lack of resources in lower frequency bands, e.g. below 6 GHz. Moreover, the mm-wave transmission can provide a large signal bandwidth to satisfy an increasing demand for a high data rate. These demands are encouraging a large number of researches that focus on characteristics of the mm-wave propagation channel [1]. It is well known that the wideband transmission for 5G with up to 2 GHz bandwidth is expected to be adopted for indoor wireless communications, resulting in a rapid increase of user equipments (UEs) in an indoor environment [2]. A problem arising is that shadow fading and penetration loss caused by a presence of human bodies can significantly influence the mm-wave propagation [3]. This problem urges researchers to construct mm-wave propagation channel models for addressing the human-body influence in indoor environments [4]–[7].

Existing mm-wave channel models for human-body blockage can be categorized into two groups based on the underlying approaches: deterministic and statistical modeling. In terms of a deterministic channel model, a geometry-based model that represents the human body is built by considering human shape, skin and clothing [2], [4], [8]–[10]. Then the attenuation caused by the human body is calculated based on geometrical theory of diffraction and constructed human-body model. However, this kind of modeling cannot generally cover the cases of human bodies with regard to different shapes, clothes or skins. Moreover, human-body model construction as illustrated in [9] involves high computational complexity. Nevertheless, only few parameters are characterized in these deterministic models, e.g. attenuation [2]. Compared to the deterministic modeling, the statistical modeling is more efficient for analyzing the random effect caused by human bodies and the models drawn can provide a broader view of channel characteristics [6], [11], [12].

In this paper, we introduce a channel measurement campaign in an indoor environment within the frequency band from 55 to 65 GHz to extract channel characteristics with a person passing through a Line-of-Sight (LoS) path. The results show that the human body has a considerable impact on the mm-wave channels, and thus needs to be considered in the system design for 5G. We are interested in the stochastic behaviors of three parameters, i.e. fading duration, fading angle and power fading to investigate the influence on mm-wave channels with a human body crossing the LoS path in an indoor environment. Moreover, the behaviors of the shadow fading caused by the objects in a cluttered environment as measured in the indoor hall entrance is discussed to figure out whether the fading is dependent on the frequency. The deepest shadow fading caused by the complete human-body blockage is statistically modeled. Using these models, the variations of the LoS channel when a UE passes through can be generated heuristically.

The rest of the paper is structured as follows. The measurement campaign is described in Section II. Section III elaborates a statistical analysis of the temporal, spatial and power characteristics of mm-wave channel fading. Finally, conclusive remarks are given in Section IV.

II. Measurement Campaign

A. Measurement system

The channel measurement system consists of a Vector Network Analyzer (VNA) with the type of N5227A connected with two horn antennas of same design for transmitting (Tx) and receiving (Rx) respectively, and a laptop computer controlling the VNA as well as storing the transfer functions collected within the frequency ranging from 55 to 65 GHz. A calibration

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Figure 1: The photograph taken during the measurement.

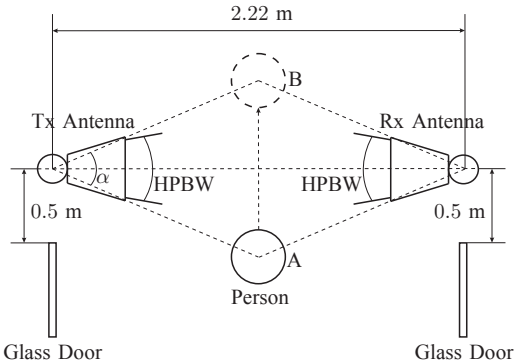

Figure 2: A bird-view sketch map of the measurement scenario.

is applied before the channel measurement to eliminate the responses of the VNA and cables.

B. Measurement scenario and specifications

As showed in Figure 1, a measurement system is fixed and located near a lobby entrance of academic building. The lobby is 10 m in height, the floor is tiled, the ceiling is made of glass plates and the walls are plasterboard. Figure 2 shows the diagram of the measurement scenario, assuming that a person walks from locations "A" to "B" in a perpendicular direction to the LoS path between two antennas. HPBW represents the half-power beamwidth of the horn antenna. The two antennas are about 0.5 meters away from the open glass doors. Specifically, the main lobes of Tx and Rx antennas were right aligned with each other. The LoS path between Tx and Rx antennas existed without human-body blockage in most time during the measurement. Otherwise, the LoS path was blocked when people passed by. During the whole measurement campaign that lasts 3 hours, about 700 persons crossed the LoS path. The detailed settings of the measurement system and scenario are summarized in Table I.

III. Channel Characterization

When a person passes across the LoS path between two antennas, the duration and angle spread caused by the human-body shadowing can be significant in certain area covered by the radiation of two antennas. Moreover, the maximal power loss due to complete human-body blockage is also interesting to study.

Table I: The specifications of the measurement system and scenario.

Parameter	Value
Radio Frequency Range [GHz]	55-65
Number of Sweeping Points	4001
Sweeping Time for the Whole Frequency Range [ms]	400
Transmitting Power [dBm]	10
Antenna Type for Tx and Rx	Directional
Antenna Gain @55-65 GHz [dBi]	Maximum: 24.98 Minimum: 23.73
Antenna Half-power Beamwidth (HPBW) in Horizontal Plane @55-65 GHz [degree]	Maximum: 11.39 Minimum: 9.91
Antenna Polarization	Horizontal
Height of Antennas from Floor [m]	1.15
Distance between Tx and Rx Antennas [m]	2.22

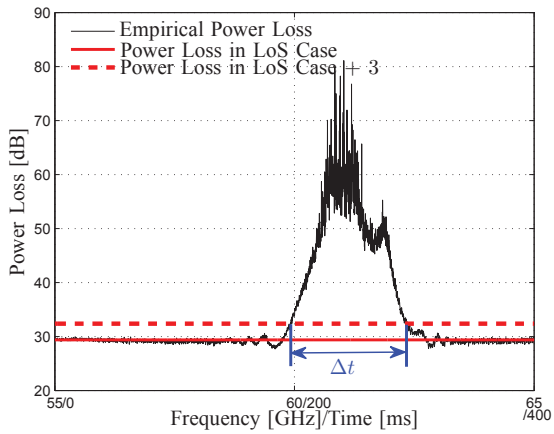

Figure 3: The path loss measured when a person crosses the LoS path.

A. Fading duration

Figure 3 illustrates an example of path loss in dB versus frequency obtained during the time when a person passed by, i.e. the person approached the LoS path, then completely blocked the path, and left the path gradually. It can be observed from Figure 3 that the power experiences a huge attenuation, where the maximal power loss is approximately 50 dB more than the power loss obtained when no human body blocks the LoS path. Moreover, the path loss is observed to contain a "∧"-shaped trajectory, which according to our postulation, is caused by the fact that the person gradually blocks the LoS path with the power decreasing and then leaves it afterwards with the power raising. The trajectory is able to be observed since all 4001 frequency points are swept during a relatively long period of time, i.e. 400 ms, implying that if one person walks in a speed of 1 m/s, the sweeping duration corresponds to a distance of nearly half a meter. Then it is interesting to find out a fading duration for each "∧"-shaped trajectory, i.e. Δt in Figure 3, when the person passes across the LoS

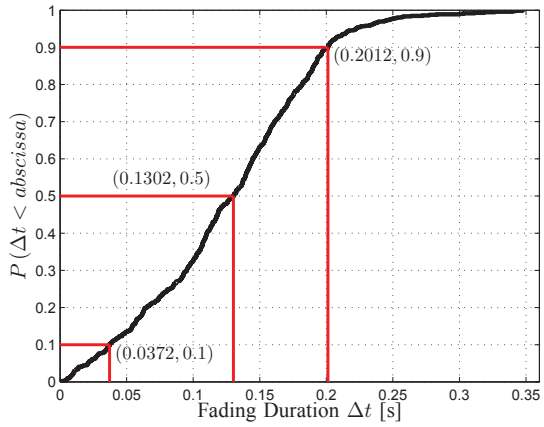

Figure 4: The cumulative distribution function of the fading duration.

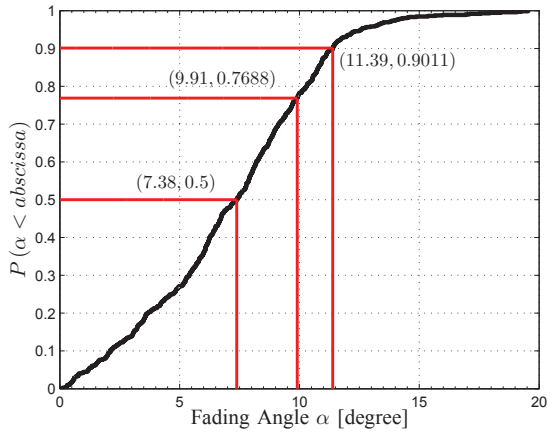

Figure 5: The cumulative distribution function of the fading duration. The minimal and maximal half-power beamwidths are 9.91 and 11.39 degrees respectively as showed in Table I.

path perpendicularly and frontally. The fading duration can be calculated by obtaining the time in which the path loss is higher than the threshold of $PL_{\text{los}} + 3$ dB, assuming that the path loss in LoS case is PL_{los}.

Figure 4 displays a Cumulative Distribution Function (CDF) of the fading duration calculated based on all the "∧"-shaped trajectories during the whole measurement. It can be implied from Figure 4 that some people cross the connection line between two antennas fast during dozen milliseconds while some cross more slowly within nearly half of the whole sweeping time. The fading duration may be related to the distance between two horn antennas, the HPBW of the antennas, and the moving velocity of a person. However, these parameters are fixed and will not be considered in this paper.

B. Fading angle

Based on the calculation of fading duration, a so-called fading angle α illustrated in Figure 2 can be calculated as

$$\alpha = 2 \cdot \arctan\left(\frac{v \cdot \Delta t/2}{d/2}\right) \cdot \frac{\pi}{180}, \tag{1}$$

where $\arctan(\cdot)$ denotes an operator of calculating the angle in radian based on the given argument. We assume that the walking speed v is considered constant during the person walks from locations "A" to "B", and moreover, v is set 1.1 m/s with regard to the whole measurement campaign. The constant d denotes the distance between Tx and Rx antennas, i.e. $d = 2.22$ m.

Figure 5 displays the CDF of the fading angle calculated based on all the observed "∧"-shaped trajectories. It is shown in Figure 5 that the median of fading angle α is 7.38 degrees, which is a bit smaller than the minimal HPBW of 9.91 degrees. The percentages of "∧"-shaped trajectories with fading angle less than minimal and maximal HPBWs are respectively 76.88% and 90.11%, i.e. the percentages of the trajectories are less than 10% for α beyond the maximal HPBW of 11.39 degrees. It implies that the power fades significantly when a person is located in the area covered by the HPBW of two antennas.

C. Shadowing for the LoS path

We assume that the transmitted power experiences the fading P_{avg} derived from the power law in free space, the shadow fading X_{cs} due to the objects in a clutter environment, and the shadow fading S_{h} resulted from human body. It is a reasonable assumption since the reflected rays from the objects in our measurement scenario exist, e.g. from the adjacent glass doors.

First of all, the shadow fading X_{cs} is calculated from the path loss $P_{\text{rx}}^{\text{los}}$ in the case of the unblocked LoS path as

$$P_{\text{rx}}^{\text{los}}(f) = P_{\text{avg}}(f) + X_{\text{cs}}(f), f = [f_1, \cdots f_N] \tag{2}$$

with

$$P_{\text{avg}}(f)|_{d=2.22} = G_{\text{tx}} + G_{\text{rx}} + 20 \cdot \log_{10}\left(\frac{c}{4\pi d f}\right), \tag{3}$$

where G_{tx}, G_{rx} denote the Tx and Rx antenna gains respectively and they are both set 25 dBi in our case. Here, f is the frequency ranging from 55 to 65 GHz and c is the light speed. Totally 5311 samples of path losses are obtained in the LoS case for individual frequencies. For each measured path loss, the shadow fading X_{cs} can be calculated by using (2). Then we obtain the mean value of 5311 samples of shadow fading denoted by $\bar{X}_{\text{cs}}$, as illustrated in Figure 6. A least square method is proposed for fitting the $\bar{X}_{\text{cs}}$ by using a linear function as $\bar{X}_{\text{cs}} = m \cdot f + n$. As illustrated in Figure 6, the fitted line has a pair of $m = 1.59$ dB/GHz and $n = -13.93$ dB. It can be observed that the shadow fading X_{cs} is linearly dependent on the frequency from 55 to 65 GHz.

D. Shadowing caused by human body

To calculate the shadow fading S_h, the influence of X_{cs} needs to be removed. Then S_h can be calculated from the path loss

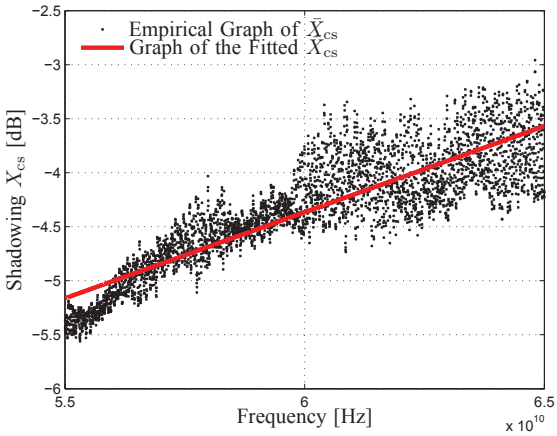

Figure 6: The shadow fading $X_{\rm cs}(f)$ caused by the cluttered environment.

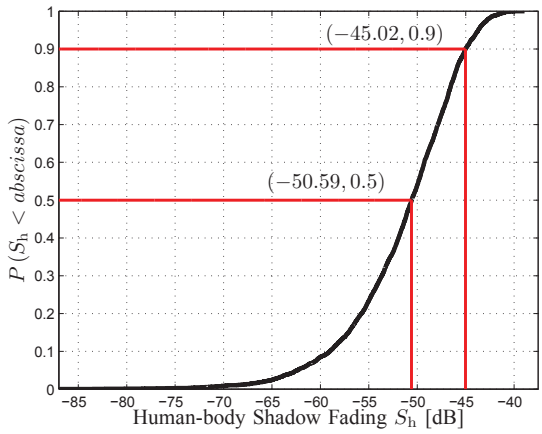

Figure 7: The cumulative distribution function of the deepest shadow fading with human-body completely blocking the two-antenna connection line.

$P_{\rm rx}^{\rm nlos}$ with the LoS path being completely blocked as

$$P_{\rm rx}^{\rm nlos} = P_{\rm avg} + \bar{X}_{\rm cs} + S_{\rm h} \tag{4}$$

Then it is interesting to figure out the distribution of power loss due to the complete human-body blockage to the LoS path during the whole measurement, i.e. the largest fading in the "∧"-shaped trajectory. Figure 7 illustrates the empirical CDF of the deepest human-body shadowing. It can be observed that the percentage of samples with maximal human-body shadowing less than -45.02 dB is 90%, and that the median of maximal shadowing is -50.59 dB.

IV. Conclusions

In this paper, a channel measurement campaign performed in an indoor environment is introduced for investigating an influence of a human body on millimeter wave propagation channel from 55 to 65 GHz. We focus on the measurement scenario that a person approaches the Line-of-Sight (LoS) path, then completely blocks the LoS path, and gradually leaves the path. In this process, a "∧"-shaped trajectory is observed in the measured path loss. The fading duration is used to address the time that lasts when the human walks across the LoS path perpendicularly. The fading angle is defined based on the fading duration to figure out the area where the human shadowing is significantly observed. The statistical results show that the shadowing caused by human body mainly occurs in the area covered by half-power beamwidth of two antennas. The deepest human-body shadow fading in complete LoS blockage has the mean of 51.4 dB and standard deviation of 5.8 dB.

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