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Abstract—In the field of 60 GHz high data rate wireless and Body Area Networks communications, fast computation and accurate analytic models are required to predict the budget link. In this paper, an indoor off-body channel model restricted to TE polarization transmitters and receivers is studied numerically. Some channel properties are extracted and compared to the indoor channel to study the impact of the human body on the 60 GHz propagation.

Index Terms—Off-Body, BAN's, cylinder scattering, millimeter wave communication, 60 GHz, creeping waves, ray-tracing

I. INTRODUCTION

The next emerging technology to realize short-range indoor communication with data rates of a few Gbit/s seems to be the 60 GHz systems [1]. The progress in low-cost mm-wave circuit design and the wide available spectrum around 60 GHz will allow to develop new communication services.Within this framework, the development of 60 GHz Body Area Networks (BANs) (off- and on-body) [2], [3], [4] is important.

In this paper, it is proposed to analytically and numerically implement a 60 GHz indoor off-body channel model. It is assumed that the human body can modeled by a circular cylinder. This assumption has been validated in [4]. The model is based on the solution of the diffraction of a plane wave by a circular cylinder developed in [4]. This solution is well adapted to the standardized indoor channel mode IEEE802.11ad [5].

II. SIMULATIONS

A. Channel Model

In this extended abstract, an indoor off-body channel model is studied numerically. The model is based on the results of the diffraction of a plane wave by a circular cylinder [4], [6] modeling a human body. These diffraction results are implemented in the IEEE802.11ad indoor channel model [5] as proposed in [7].

B. Scenario

The indoor environment studied is based on the *Conference Room* environment of the [5] model. The environment has a size of 4.5m x 3m x 3m. The transmitter antenna is placed at location (1,1.5,1.5). In the simulations, the body turn round
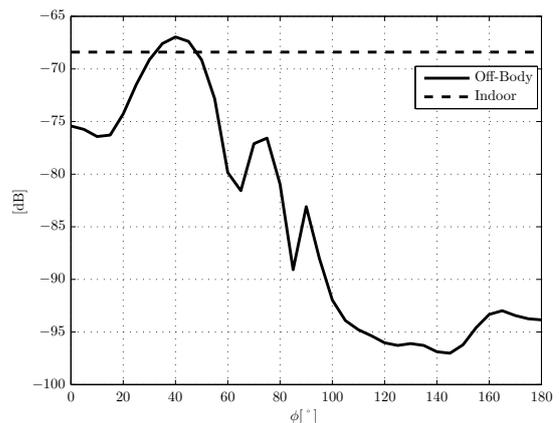
Fig. 1. Channel attenuation for a distance of 2 m. Comparison between indoor and indoor off-body.

with ϕ which is defined with respect to the axis between Tx and the center of the body. The body is placed at a distance $d = 2$ m from the transmitter.80 positions have been randomly chosen (by keeping $d = 2$ m) and 30 channel realizations have been computed for each position. This gives a total of 2430 simulations.

C. Results

In this section, some channel properties are extracted from simulations. A comparison between indoor and indoor off-body is plotted for each property. The parameter of interest is the orientation of the body, therefore all graphs will be studied as a function of ϕ. However, the case without body do not depend on ϕ, the result will always be a constant. The following graphs are presented for a distance between the transmitter Tx and the receiver Rx $d = 2$ m.

a) Channel Attenuation: The channel attenuation is considered as the mean value of the frequency response. It is presented in Fig. 1. This figure shows the influence of the human body regarding its orientation with respect to the transmitter. It can be seen that for most of the orientation,
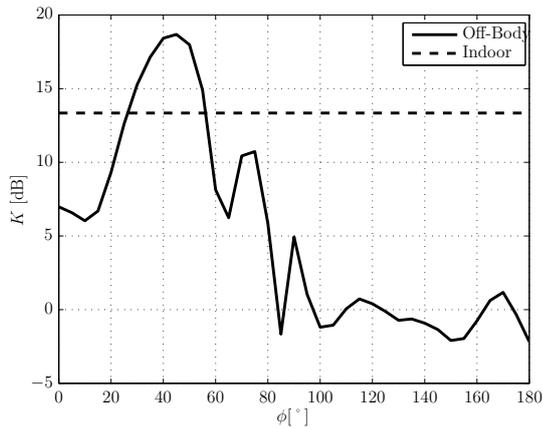
Fig. 2. Rician factor for a distance of 2 m. Comparison between indoor and indoor off-body.

d [m]	Indoor	Lit	Shadow
2	-67.9	-74.5	-93.4
2.2	-68.8	-75.3	-94.0
2.4	-69.6	-76.0	-94.3
2.6	-70.3	-76.7	-94.7
2.8	-70.9	-77.4	-95.2
3	-72.4	-78.8	-93.8

d [m]	Indoor	Lit	Shadow
2	14.98	15.95	1.30
2.2	15.00	15.38	0.72
2.4	14.29	14.85	0.59
2.6	13.61	14.23	0.37
2.8	13.34	13.53	0.05
3	10.80	10.48	0.36

the body created a high attenuation. This attenuation is due to two phenomena. First, the human body is lossy and some of the received power is lost. Secondly, the TE polarization is highly sensitive to mismatch. When the body turns, the orientation of the receiving antenna changes. If this receiving antenna is not completely tangent to the incident plane wave electric field, it will create an attenuation due to this mismatch.

b) Rice Factor: The Rician factor K gives an information about how LOS is the channel. It is calculated by :

$$K = \frac{\max_{(i,k)} \left[\alpha^2_{(i,k)} \right]}{\sum_{(i,k)} \alpha^2_{(i,k)} - \max_{(i,k)} \left[\alpha^2_{(i,k)} \right]} \quad (1)$$

Fig. 2 shows the Rician factor for both indoor and indoor off-body. This comparison allows to compare the power of line-of-sight compared to the multipath. Again it is shown that for some values of ϕ the channel is more LOS than in the case of the off-body channel. In the lit region, most of the multipath is blocked by the human body while the LOS ray is only attenuated due to the body losses.

D. Parameters evolution with the distance

In this section, we study the evolution of the different parameters in function of the distance d. It has been shown that the channel parameters change with the region : lit or shadow. It is proposed to evaluate mean values for each region. In tables I and II, the parameters are presented for the indoor, lit region and shadow region cases. As expected, it can be seen that in case of lit region, the parameters remain close to the indoor case while in the shadow region, the channel is completely different. The communication performances such as the data rate will drastically decrease in the shadow region.

III. CONCLUSION

This paper presents a numerical implementation of an indoor off-body channel. This model is based on the circular geometry assumption for the human body. It has already been shown [2], [4] that for both on- and off-body propagation, the circular geometry shows about 3 dB accuracy even at 60 GHz. Also the algorithm takes advantage of the diffraction by a circular cylinder and the indoor IEEE channel model.

The TE polarization has been presented in this paper. The impact of the human is studied through some channel properties such as attenuation, Rice factor or delay spread. It is shown that the human body creates higher attenuation and decreases the Rice factor. The delay spread is also increased. It has been inferred that these modifications will decrease the data rate in a real communication.

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