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Wideband Measurement and Analysis of Human Blocking on the Indoor Radio Channel at 60 GHz

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Abstract—In millimeter band used for wireless communication systems, there is a strong blocking impact introduced by the human body. At 60 GHz, the coverage of these systems is relatively limited due to high propagation losses. Hence, the use of the beamforming makes it possible to find a reflective path to replace the blocked one. The objective of this work focuses on the impact of a human blocker in a meeting room, to evaluate the blocking losses introduced by the human body at 60 GHz. The results obtained both by calculating the path loss and the impulse response of the channel show that the attenuation due to the human body is between 24 and 26 dB. In addition, the results show that the use of beamforming make it possible to exploit the reflected paths to overcome the cutoff of the radio link due to human blocking.

Keywords—mmWaves, 60 GHz antenna, human blocking, indoor propagation

I. INTRODUCTION

In future wireless communication systems, millimeter waves (mmWaves) will play an important role to meet high data rates. However, due to their short wavelengths, these millimeter waves have high propagation losses and are very attenuated by the blockage, which may be due to the human body.

One of the earliest human blockage measurement studies [1] was conducted at 60 GHz for indoor wireless local area networks (WLAN) with Tx-Rx separation distances of 10 m or less in a typical office environment. The results showed that the signal level decreased by as much as 20 dB when a person blocked the direct path between omnidirectional Tx and Rx antennas, with deep fades reaching 30 dB using directive antennas [2, 3]. In addition to human blockage measurements at 60 GHz, [4] provided a human induced cluster blockage model based on ray tracing [5], a random walk model, and a diffraction model from contributions to 802.11ad [6-7].

The mobile and wireless communications enablers for the twenty-twenty information society (METIS) and 3rd Generation Partnership Project (3GPP) also proposed their own human blockage models [8-10], based on knife-edge diffraction (KED) models for one or multiple edges. Existing studies have used different approaches to model blocking at mmWave bands, taking into account different parameters of the radio link: Tx-Rx position, distance, frequency, antenna gain and antenna height.

In this paper, we present broadband radio propagation measurements at 60 GHz inside a meeting room. The results of these measurements, which relate both to the path loss and to the impulse response of the channel, are analyzed on the one hand, to characterize the impact of the blockage by the human body, and on the other hand, to study the possibility of implementing beamforming as a solution against blocking. The rest of the paper is organized as follows: Section II presents the measurement system and the considered environment. Section III details the scenario studied. Section IV presents the measurement results and their analysis. Finally, Section V gives some conclusions.

II. INDOOR CHANNEL MEASUREMENTS

A. Measurement System

The used measurement system is built around a vector network analyzer (VNA) which performs a frequency sweep over a 2 GHz band centered on the intermediate frequency (IF) of 3.5 GHz (Fig. 1).

The VNA, connected to the transmission (Tx) and reception (Rx) blocks respectively via ports 1 and 2, measures the S21 parameter which makes it possible to calculate the frequency response of the propagation channel in the 59-61 GHz band. The VNA scans the selected 2 GHz frequency band at 401 points with a frequency step of 5 MHz. In [11], more details on the measurement system are given.

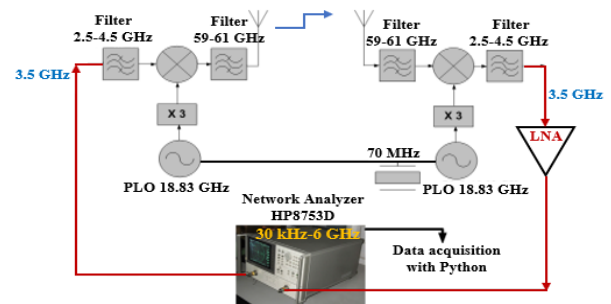


Fig. 1. Measurement system.

An antenna positioning system with a rotational accuracy of 0.02° was used. Its role is to perform antenna rotations by precise steps for a study of the angle of arrival (AOA) of the wave in azimuth. The positioner was used with a mast placed on the motor to support the receiving antenna (Fig. 2).

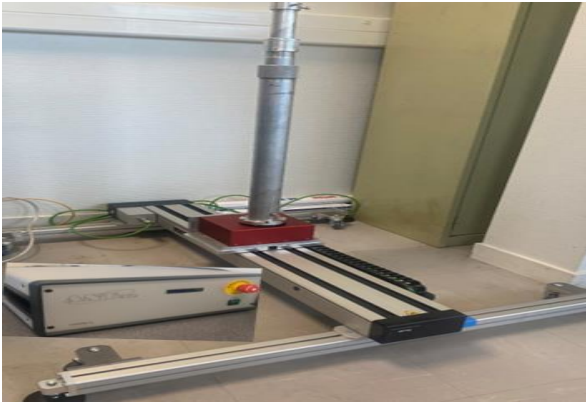


Fig. 2. Antenna positioner.

The VNA and the antenna positioner are controlled by a computer via appropriate interfaces, which allow antenna rotations to be performed using a program developed at IETR INSA and the measurement data to be recorded. Table I summarizes the various parameters of the measurement system. Two RF blocks were used during this measurement campaign, one as IF-to-RF up-converter at the transmitter (Tx) and the other as RF-to-IF down-converter at the receiver (Rx). Two identical horn antennas were used for these measurements.

TABLE I. MEASUREMENT SYSTEM PARAMETERS

Center frequency (GHz)	60
Intermediate frequency (GHz)	3.5
Measurement band (GHz)	2
Number of frequency points	401
Frequency step (MHz)	5
Transmit power (dBm)	0

They have a gain of 22.5 dBi and a -3 dB beamwidth of 13° in azimuth and 10° in elevation (Table II).

Fig. 3 shows a picture of the horn antenna that was used during this measurement campaign.

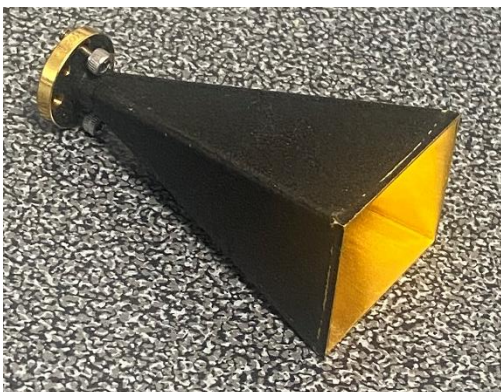


Fig. 3. Horn antenna.

Fig. 4 shows the radiation diagram of the horn antenna.

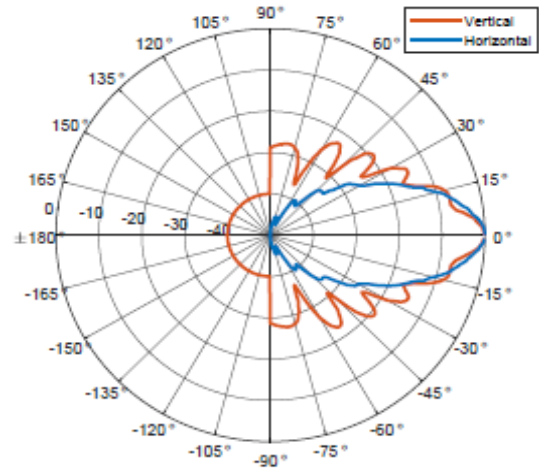


Fig. 4. Horn antenna radiation pattern.

Some characteristics of the antennas such as gain, aperture and polarization are given in the table below.

TABLE II. CHARACTERISTICS OF THE ANTENNAS

Antenna	Rx
Gain	22.5 dBi
HPBW	10°(E) , 13°(H)
Polarization	Vertical

At the beginning of the measurement campaign, the frequency responses of the cables that connect the two RF blocks to the ports of the VNA were eliminated by calibration. On the other hand, in order to measure the frequency response of the channel at 60 GHz, a back-to-back test is necessary to eliminate the frequency response of the two RF blocks.

For this, a 40 dB attenuator is inserted between the transmitter and the receiver (Fig. 5), in order to avoid the saturation of the receiving RF block. Once the frequency response of the RF blocks is obtained, it becomes possible to extract the frequency response of the radio channel, as described in [11].

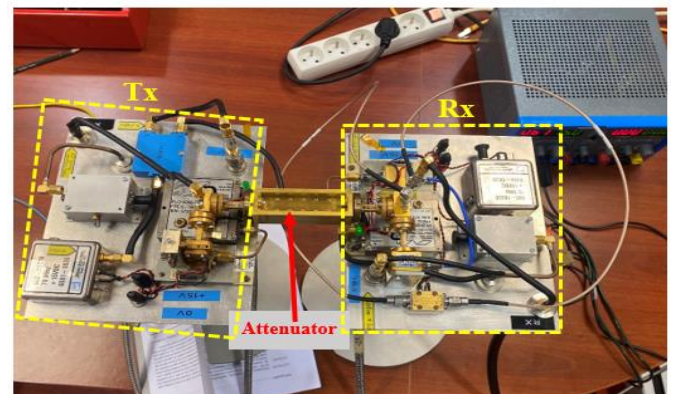


Fig. 5. Back-to-back measurement at 60 GHz.

B. Measurement Environment

The measurements were conducted (realized, performed) in a static environment consisting of a meeting room whose dimensions are: $6.5 \times 2.2 \times 2.5 \text{ m}^3$. Fig. 6 shows a photo of the measurement environment.

In this room, there are two whiteboards of the same dimensions with a length of 2 m and a width of 1.2 m. This room also has a wooden door 2.3 m high and 0.96 m wide (Fig. 7). The door remained closed throughout the measurement campaign.



Fig. 6. Photo of the measurement environment.

In this room, the presence of the chairs and the table does not modify the measurement results, because of the use of very directional antennas.

The measurement environment was static without movement during this measurement campaign

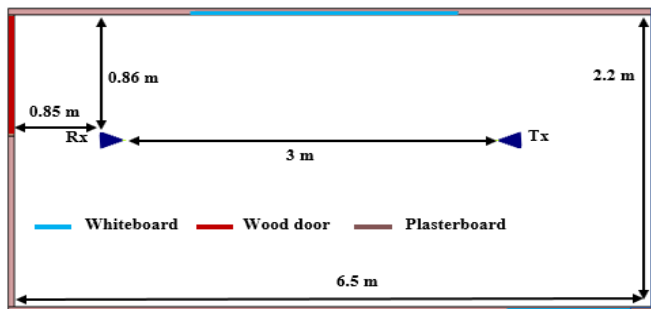


Fig.7. Measurement environment in the meeting room.

III. MEASUREMENT SCENARIO

The measurements were conducted in a meeting room of the IETR laboratory at INSA Rennes. The two antennas were put on supports at the same height of 1.71 m and separated by a distance of 3 m. The height of the two antennas has been chosen so that it corresponds to the middle of the whiteboard. The receiving antenna was placed 0.85 m from the door. Its support is fixed on the positioner, which allows the rotation of the antenna. The whiteboard is at a distance of 1.35 m from the door (Fig. 8).

The two antennas are equidistant from the center of the board and are placed 0.86 m from the board. A human blocker, whose width at the shoulders, thickness and height are respectively 45 cm, 13 cm and 1.72 m, was considered.

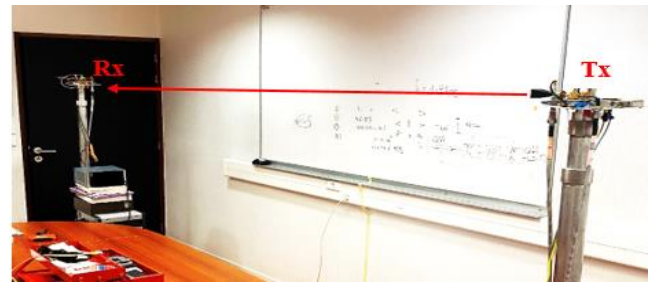


Fig. 8. Measurement scenario in the meeting room.

For this measurement campaign, three different scenarios are considered.

- Case where the antennas are in Line of Sight and oriented towards each other.

Fig. 9 shows the case where the two antennas are in LOS configuration, oriented towards each other.

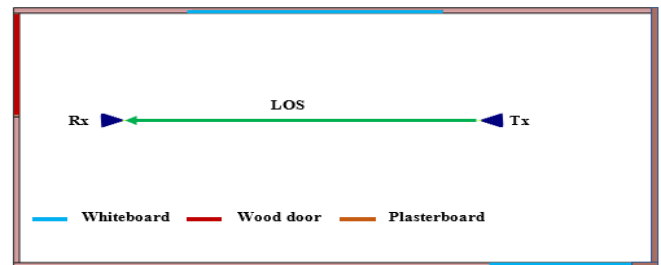


Fig. 9. LOS case.

- Case where the direct path is blocked:

In this case, the blocker was placed in the middle of the Tx-Rx distance and oriented towards the receiver (Rx), without any movement. The height of the antennas corresponds to the center of the blocker's chest, as shown in Fig. 10. For this, the blocker was placed on a support, so that the center of his chest was at a height of 1.71 m. The comparison with the case where the antennas are in LOS makes it possible to estimate the path loss introduced by the human body.

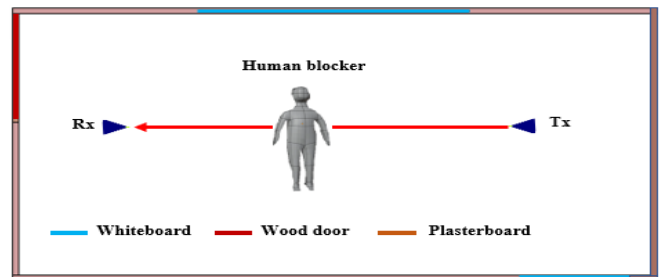


Fig. 10. Blocking the direct path.

- Case with blocking the direct path and depointing of the antennas by 30° towards the whiteboard.

In this case, the two horn antennas have an azimuth pointing angle of 30° with respect to the Tx-Rx line. With this arrangement, the two antennas have been oriented towards the center of the whiteboard (Fig. 11), which allows us to obtain an optimal reflection. In this

configuration, the position and height of the blocker and the antennas have not changed.

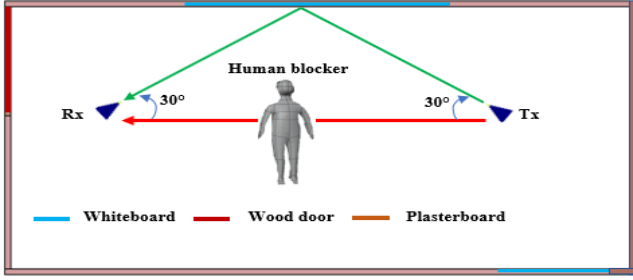


Fig. 11. Case with blocking and depointing of the antennas.

Moreover, in these three cases, the receiving antenna rotates 360° in azimuth using the positioner, with a step of 6° . This choice makes it possible to evaluate the power delay profile (PDP) on these 60 rotation positions for a study of the paths with the delays and the angles of arrival (AOA).

IV. MEASUREMENT RESULTS

The processing of the measurement data was done using a Python program. With this program, we have removed the frequency response of the two RF blocks and the gains of the antennas. This gives the frequency response $H(f)$ of the propagation channel. The average over the 401 frequency points of the module of $H(f)$ allows us to determine the average path loss. We can then represent the evolution of the path loss (PL), with and without blocking, as a function of the angle of arrival (AOA) of the wave (Fig. 12). We also calculated with Matlab the inverse Fourier transform of $H(f)$ to represent the impulse response of the channel, in order to study the different paths with their delays.

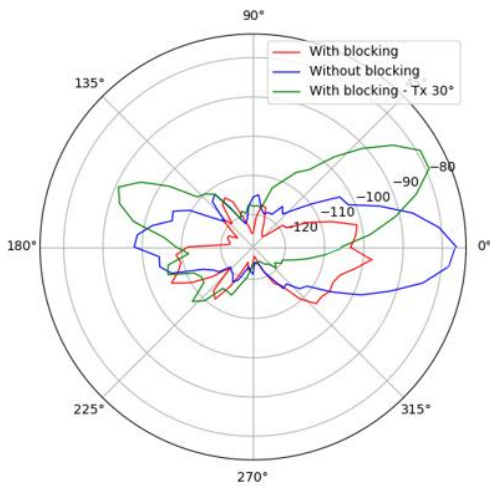


Fig. 12. Evolution of the path loss (PL) according to the angle of arrival (AOA), for the 3 considered cases.

The calculation of the maximum clearance radius of the first Fresnel ellipsoid, at a distance of 1.5 m, gives 0.06 m, which is a value much lower than the distance that separates the Tx-Rx line from the whiteboard and also from the other equipment in the room. We can therefore consider that we are close to the conditions of free space, in the case where the two

antennas are in direct visibility and without the human blocker. The calculation of the path loss in free space gives 77.54 dB. The path loss obtained by measurement in the case of direct visibility (i.e. an AOA of 0°) and without blocking is 77.2 dB (Fig. 12), which is very close to the value previously calculated in free space condition.

With the presence of a human blocker, and taking into account the distances adopted and the beam width of the antennas, it is checked that the main radiation lobe is completely masked by the thorax of the blocker. In this case, when the antennas are pointed towards each other, a path loss of 103 dB is obtained. These results allow us to estimate the losses introduced by the blocker at around 25.8 dB, which is not far from the results presented in [2] at 60 GHz.

The path loss is higher and equal to 105.6 dB in the case where only the transmitting antenna is offset by 30° towards the whiteboard and it becomes equal to 79 dB for the same offset of 30° of the two antennas. This shows that with the blocker, depointing the transmit antenna alone results in an increase in path loss of about 2.6 dB and a decrease of 24 dB if both antennas are depointed 30° compared to the blocked path without depointing. So, the reflected path causes a loss of only 1.8 dB compared to the direct path. This low path loss value can be justified by a very small difference in distance between the direct and reflected paths (0.46 m) and by the fact that the reflection is almost-perfect with the board considered to be metallic. Indeed, a calculation of the difference in losses due to the only difference in paths gives 1.25 dB, which makes it possible to estimate the losses by reflection at approximately 0.55 dB.

On the other hand, the losses introduced by human blockage can be estimated by calculating the channel impulse response on a 2 GHz band. This makes it possible to obtain the relative power delay profile (PDP) for the different scenarios considered.

Fig. 13 shows the relative PDP, i.e. the PDP normalized to the maximum received signal level over all PDPs. The strong main component (0 dB) can be observed in the case where the two antennas are in LOS (blue curve).

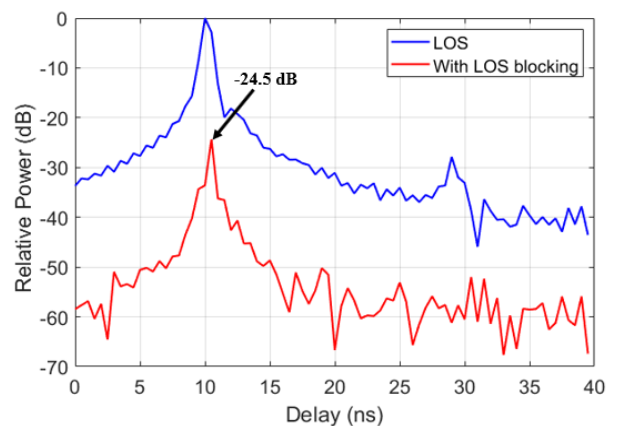


Fig. 13. Relative PDP with and without human blocking.

In this case, the direct path arrives with a delay of 10 ns, which corresponds to the distance of 3 m separating the Tx

and Rx antennas. With the use of a human blocker, we obtain a relative power value of about -24.4 dB with a delay of 10.5 ns (red curve). This delay corresponds to a distance of 3.15 m, i.e. a path difference with respect to the direct path of 0.15 m.

Thus, the human blocking losses of 24.4 dB, obtained by evaluating the relative received power, give a value close to that calculated with the path loss, which is equal to 25.8 dB.

Fig. 14 gives a comparison between the strongest paths in the LOS case and the case where the Tx antenna is oriented 30° towards the middle of the reflective board. This maximum corresponds to the path reflected by the whiteboard. We obtain a relative power value of about -25.3 dB with a delay of 11.5 ns. Compared with the blocked direct path case, a small relative power increase of 0.8 dB is observed. This can be justified by the fact that we used directional antennas and that the depointing of one of the antennas can allow the signal to bypass the blocker.

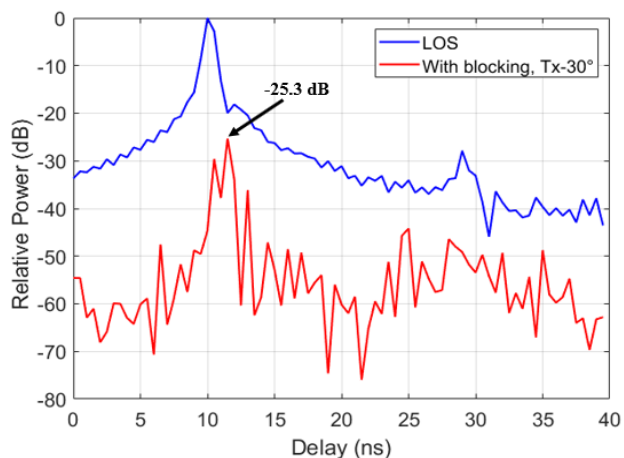


Fig. 14. Relative PDP with blocking and Tx offset by 30° .

The last case is to consider the situation where the transmitting and receiving antennas are both pointed towards the center of the whiteboard, with a 30° offset. This configuration seeks to exploit an alternative path which can replace the direct path when the latter is blocked. Fig. 15 shows the relative PDP of this configuration.

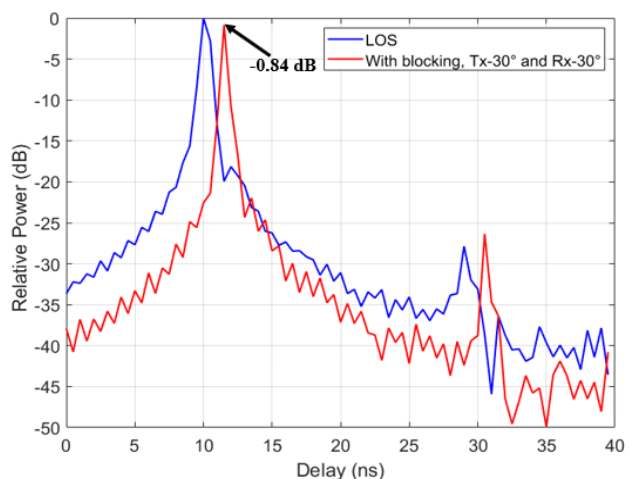


Fig. 15. Relative PDP with blocking and depointing of the two antennas by 30° .

In the case where the two antennas are pointed towards the center of the whiteboard, a reflected path is obtained with a delay of 11.5 ns and a relative power of approximately -0.84 dB. By comparing the received level relative to the direct path without blocking with that received by the reflected path with blocking and depointing, there is a slight decrease of 0.84 dB for a distance difference of 0.45 m. These results are comparable to those obtained with the path loss calculation, where the reflected path gives additional losses of 1.8 dB compared to the direct path, with a distance difference of 0.46 m. This small difference in path loss can be justified by a very small difference in distance between the direct path and the reflected path, and by the fact that the reflection is almost perfect with the whiteboard considered metallic. Therefore, in blocking situations, in order to limit outage times of the radio link, a reflected path can be used as a replacement for the direct path.

V. CONCLUSION

This paper presents the results of a broadband measurement campaign, conducted on the blocking effect by the human body on an indoor radio link at 60 GHz. The obtained results show that, when the antennas are pointed towards each other, the presence of a human blocker introduces additional losses, which are generally between 24 and 26 dB. On the other hand, the calculation of the impulse response of the channel makes it possible to highlight the multipath phenomenon and leads to obtaining the PDPs for the different measurement configurations.

Assuming a search for a new beam on both the transmit side and on the receive side, a beam reflected by the middle of the whiteboard was considered with a 30° misalignment of the two antennas. This reflected path causes low losses compared to the direct path, so the reflected path can be used when the direct path is blocked, using both transmission and reception beamforming.

The considered environment presents very favorable conditions for reflected paths. Other measurement campaigns are planned in environments with less favorable reflection conditions, with other types of antennas and reflective materials (walls, doors, windows, etc.). Other parameters can also be studied such as the location of the blocker, the distance between the antennas or between the Tx-Rx line and the reflector and the height of the antennas.

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