Ray Tracing Technique based 60 GHz Band Propagation Modelling and Influence of People Shadowing

A. Khafaji, R. Saadane, J. El Abbadi, M. Belkasmi

Abstract—The main objectif of this paper is to present a tool that we have developed subject to characterize and modelling indoor radio channel propagation at millimetric wave. The tool is based on the ray tracing technique (RTT). As, in realistic environment we cannot neglect the significant impact of Human Body Shadowing and other objects in motion on indoor 60 GHz propagation channel. Hence, our proposed model allows a simulation of propagation in a dynamic indoor environment. First, we describe a model of human body. Second, RTT with this model is used to simulate the propagation of millimeter waves in the presence of persons in motion. Results of the simulation show that this tool gives results in agreement with those reported in the literature. Specially, the effects of people motion on temporal channel properties.

Keywords—Simulation. 60 GHz band, Ray Tracing Technique, Indoor channel, Propagation, Human Body Model, Level crossing rate,

I. INTRODUCTION

Due to recent developments in digital consumer electronics technology, millimeter bands are becoming more attractive for low cost personal communication applications. Systems operating around millimeter bands are now emerging across a variety of commercial and military applications, including communications, radar, geolocation, and medical. First generation commercial wireless systems millimeter bands based products are widely deployed (in home, hospitals, laboratory, offices,...). This has been fuelled by a demand for high frequency utilization and a large number of users requiring simultaneous multidimensional high data rate access for applications of wireless internet and e-commerce.

Some channel propagation measurements and simulation that dealt with channel parameters have been presented in [1]–[6] and [7]–[9], [16], [17]. Channel modelling is very necessary for wireless communication systems (WCS) conception. Although for millimetric bands propagation the channel is not completely characterized. The well known experimental

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and simulation techniques can be used to investigate the propagation of millimeter waves in indoor environments. In this paper the simulation one is developed, used and compared with experimental results. The advantage of experimental method is that all system and channel parameters affecting the propagation of millimeter waves are accounted for without pre-assumptions. But this method is usually expensive, time consuming, and limited by the characteristics of available equipments. On the other hand, simulation techniques are free from the limitations of experimental approaches but they require more computational time. They also need sophisticated computational resources to carried out simulations.

The main objective of this paper, is to present a characterization based on RTT taking in account the presence of bodies in the propagation environment of millimeter waves namely 60 GHz band. Using this model we have characterized the temporal variation of channel and other channel parameters.

The reminder of this paper is organized as follows. The Section II is presented to a brief description of mathematical channel model and the RTT. In Section III, we recall the previous works dealing on with propagation in the presence on human bodies based on measurements. In section IV we describe our proposed model of human body. In section V we outline the simulation and results analysis. Section VI presents the conclusions of this study.

II. CHANNEL MODEL AND RAY TRACING THEORY PRESENTATION

A. Mathematical model

The indoor channel propagations at millimeter bands constitute a channel with multiple paths. Persons, many obstacles and objects (walls, metallic bar, glass windows, etc...) are present and they, more or less, act as reflective surfaces (generally as obstacles) for the radio waves. Mobile Radio Channels are subject to small and large scale variations. Small scale variations in the channel response are caused by the combination of the multiple paths when the movement range of the receiver or the transmitter (or obstacles in between) is about a few signal's wavelengths. Large scale variations are caused by the losses in open space and the shadowing due to static obstacles or walls when the movement range is about a hundred times of the signal's wavelengths. The received signal at a given location is a function of the signal at the transmitter and the channel impulse response (CIR). In our analysis the antennas response are included in the CIR. To study the small

scale effects, we focus on wireless channels that are commonly described by a linear filter where the received signal is given by:

$$r(t) = s(t) * h(t) + z(t) \qquad (1)$$

where $s(t)$ is the transmitted signal, $h(t)$ is the CIR, and $z(t)$ is the Additive White Gaussian Noise. The CIR can change as a function of time (or as a function of spatial variation) due to the motion of the transmitter or the receiver and/or changes in the physical channel itself. If the channel is assumed to be static over the interval of observation, a time invariant model for the channel can be used [13]:

$$h(t) = \sum_{l=0}^{L-1} a_l \delta(t - \tau_l) e^{-j\theta_l}, \qquad (2)$$

where L the number of paths components, a_l, τ_l, θ_l are the amplitude, delay, and phase sequences, respectively. To characterize the indoor propagation at millimeter waves, designers require detailed understanding of radio propagation, however RTT is used to predict the impulse response, local mean power and τ_{rms} delay spread of an indoor environment.

B. Ray Tracing Theory

1) Ray Tracing description: We present here an efficient three dimensional RTT for prediction of impulse response, path loss, local mean power and τ_{rms} delay spread of an arbitrary indoor environment.

We begin by specifying the transmit and receive points in three coordinates. Each surface of obstacles (wall, ceiling, floor, corner) is modelled as multilayer dielectric. Reflection and transmission coefficients for both polarisations are computed using a recursive algorithm. The sequence of computations begins with the direct path, followed by all paths with one reflection or one diffraction, two interactions (reflection, diffraction), and so on, up two five reflections and two diffractions.

For every path, the distance dependent loss is simply the free space propagation loss, and is proportional to the total length squared. The total path loss is computed as the product of the propagation loss times the reflection losses, the transmission losses, the diffraction losses and the antenna radiation patterns. For an arbitrary path involving multiple reflections, are found by successively reflecting the transmitting antenna coordinates over the sequence of reflecting surfaces defined the path under consideration.

Once the coordinates for the highest order image of the transmitting antenna are known, we can compute the overall path length of the line linking this image to the receiving antenna. Furthermore, the coordinates of all reflection points are computed using geometrical methods (In our work we have adopted the image based one, that we will developed in the next subsection II-B2). Predicted propagation loss does not change more than 1 dB when including five or more reflections. However, the predicted τ_{rms} delay spread is still affected by weak, highly delayed paths, but does not change by more than 3 ns if paths with five or more reflections are not included.

2) Ray tracing algorithm based on image method: This method is also called ray tracing because the ray path is determined when the position of the transmitter, receiver and objects cause propagation phenomenon are known. The image source method consists to simulate the effect of flat surfaces (walls, floor). This method is useful when the number of objects and obstacles is relatively small, like an indoor environment.

The basic idea of this technique is proposed in [10], and illustrated for a simple reflection case see Fig. 1.

The first step is to find the virtual image S' of the source S. Then in a second stage linking the receiver or the point P in the virtual image by a straight line. Finally we determine the intersection point I that is the point of reflection, the result is the whole ray trajectory.

This construction that uses the virtual image and determines the point of reflection on the reflecting surface is valid for multiple reflections of order k and diffraction over a ridge of a corner. The image source method is more accurate than the
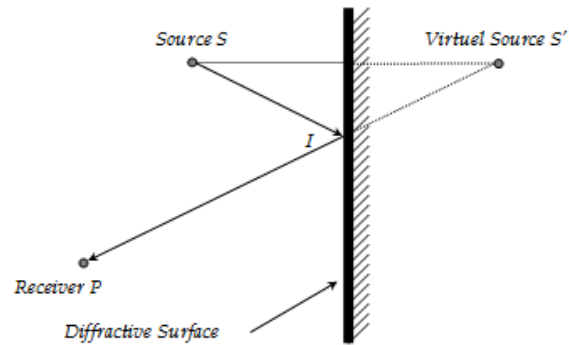

Fig. 1. Ray tracing based on image method for simple reflection.

other methods [11], it can determine all trajectories that can arrive to the receiver. It is also faster because it deals only rays arrived to the receiver. The method source image is one that we have adopted to implement our model ray tracing. It is a method that requires simple geometric methods to be implemented in comparison with direct methods [12], [14], [15]. Fig. 2 shows an example of determination procedure of a trajectory ray with three successive reflections on m1, m2, m3 respectively (M1, M2 and M3 environment composed by three walls), and for three receiver positions P1, P2 and P3. The first step is to generate images of the source S, which are S1, S2 and S3 with respect to Wall 1, Wall 2 and Wall 3 respectively, and the rest of the algorithm is depicted on Fig. 3. For more information the readers are pleased to see the reference [16].

We design locally simulation tool based on RTT where the geometry of the propagation environment is user definable. This tool takes in account different propagation mechanisms like reflection, transmission and diffraction. With model of channel in equation (2) and the effects of persons in movement, the main advantage of our tool is to support the presence of bodies in simulated environment.
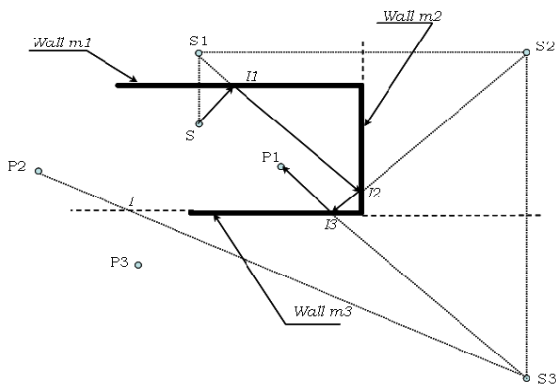
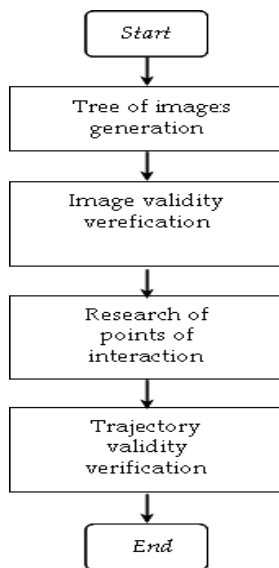Fig. 2.   Ray tracing based on image method for three successive reflections.

Frequency MHz	Permittivity ε_r	Conductivity σ (S/m)
100	77	0.70
200	77	0.71
400	76.9	0.73
800	76.8	0.83
1600	76.5	1.22
3000	75.3	2.50

bodies.In [21], a framework was performed about the effect of human body on the propagation, but the study is done on Ultra Wide Bandwidth. The conclusions show that the human bodies change remarkably the behavior of the channel.

IV.   ENVIRONMENT MODELLING WITH BODIES

The objective of this part is to present our human body model and it's integration in our simulation tool. That will be supported by the RTT. This incorporation of motion aspects in the ray tracing permits to characterize the propagation in realistic environments. Of course, this support different millimeter bands (e.g. 17 GHz, 60 GHz and 94 GHz). In this work, the 60 GHz case is investigated and reported.

A.   Presentation of Human body model

In the literature, the human body is presented physically by cylinders containing salty water. Fig. 4 presents the well known models. The first one says SALTY supposes the cylinder to contain a solution of salty water with a concentration of 1.5 g/L; the cylinder has a 1.7 m height and a diameter of 0.305 m. The second one called Salty-Lite presented in [25] supposes that the solution in partition having a thickness of 0.04 m, the height of the cylinder is 1.32 m and the diameter is identical to the first model. Fig. 5 presents, for a fixed salty water concentration, the behavior of complexes permittivity ε_r versus frequency (In this case the concentration is 1.5 g/L).

Table I summarizes some practical values of the permittivity and conductivity used in to simulate the human body model.
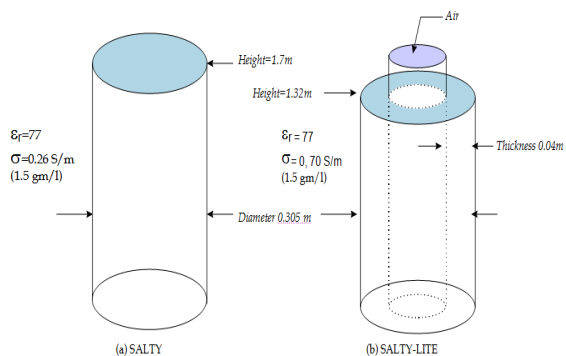

Fig. 3.   Ray tracing algorithm based on image flow.

III.   HUMAN BODIES INFLUENCES ON WIRELESS COMMUNICATIONS

A solid work about the effect of human bodies on the WCS was reported in [1]. This work it is based on channel measurements. These later were conducted at different environments with a variable number of people in motion, these form a typical realistic environments. The main objective of this study was the evaluation of temporal channel variation at 60 GHz band. Also, Hashemi [19] showed and evaluated parameters that can be used to characterize the temporal variation of the channel . These parameters are Level Crossing Rate (LCR) and the Average Fade Duration (AFD). The analysis of Hashimi showed that the LCR and AFD are dependent on antennas separation distance and on the number of people in environment. The influence of HBS has been studied in [2], [18]. The work in [1] presented a detailed study about propagation at 60 GHz. The strong conclusion of the work conduct to a high correlation between the propagation at 60 GHz and the human
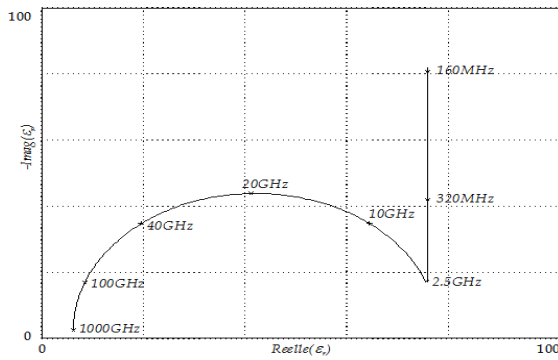

Fig. 4.   Human body Models.

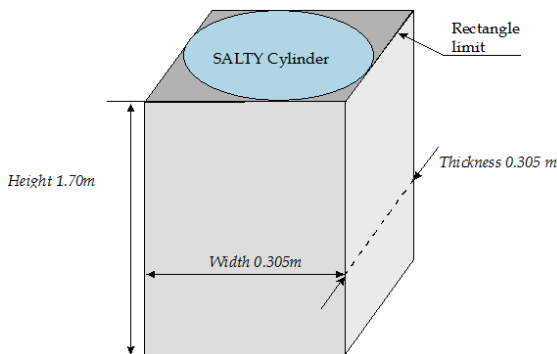Fig. 5.   Relative permittivity of salty water 1.5 g/L.

Fig. 6.   New Human body Model.

B. Used Model

Habitually, one the of human body presented perviously is used in modelling and simulation. Alternatively, we model the humane body by a parallelepiped circumscribed with SALTY cylinder model as RTT deals with plate surfaces. The adopted model is depicted on Fig.6 with its geometrical features.

The persons moving near mobile radio link are modelled by objects having a finished dimensions with a parallelepipeds form, and, characterized by a permittivity ε_r and a conductivity σ. The model assigns to each object a position which will be modified according to the speed and the direction.

V. SIMULATIONS AND RESULTS

A. Simulation specifications

To implement the model described above, we consider a room of dimension 10 m × 20 m, many persons random moving (we change the number voluntary) near around radio link at 60 GHz band. The starting positions of the people are random, speeds are supposed to be constant equal to 0.5 m/s. The positions of transmitter and receiver are indicated in Fig 7 and remain fixed during the simulation. The model representing an abject modelling the human body like a wall with two identical facets, these two facets can reflect wave emitted by Transmitter as they can refract it and transmit it, but for 60 GHz band there are no transmission effect for the human body in our proposed. The series of simulations are

TABLE II
MODEL PARAMETERS

Height of walls	2.8m
Thickness of walls	0.1 m
Relative Permittivity of walls	1.6
Conductivity of walls	0.00105 S/m
Frequency	60 GHz
Polarization	Vertical
radiated power	0 dBm
Gain antenna	0 dBm
Height transmitter/receiver	1 m
Number of reflections for each path	2
Transmission	Deactivate
Diffraction	Activated
Minimal level	−150 dBm
Interval of time computing	0.25 s

TABLE III
MAX AND MIN OF MAGNITUDE (MAG.) FOR DIFFERENT NUMBER OF PERSONS.

Number of Persons	Min of Mag. [dB]	Max of Mag. [dB]
04	−111.5518	−77.4056
07	−114.8184	−78.4006
20	−116.5973	−77.7331

obtained by an automatic change of the positions of the objects modelling the people moving, by respecting their speed of movement and their direction. Simulations are taken with regular time intervals, which makes it possible to compute again the positions of the objects and to make a new calculation of the parameters of the channel.
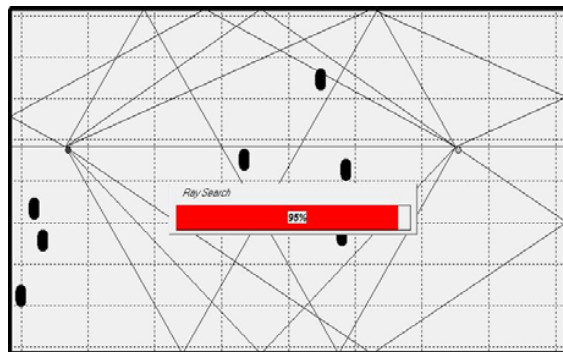

Fig. 7.   Propagation environment for simulation.

The input data for our simulation tool are given by the table II.

B. Analysis of channel at 60 GHz

1) Temporal variations: Fig. 8 shows the results of 60 seconds of simulation and for 04 persons and distance transmitter/receiver of 7 m. This figure shows fast fading and variations around an average value of −82.5582 dB. The maximum depth of fading is of −34.1462 dB for 04 persons. The table III presents the max and min values for different number of persons.

The experiments are carried out during 60 seconds, with a random displacements of people. Figs. 8, 9 and 10 show
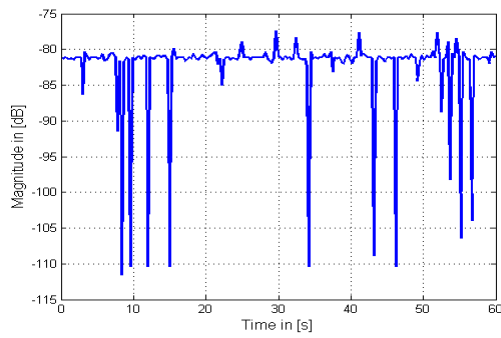
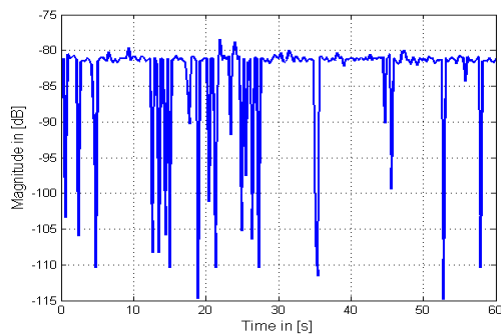Fig. 8. The temporal variations of signal envelope with 4 persons in movement.

Fig. 9. The temporal variations of signal envelope with 7 persons in movement.

the behavior of channel in the presence of persons. From this figures we deduce the impact of persons on the 60 GHz band.

2) Fading and Statistical distributions: To characterize the statistical distribution of the channel magnitude in the presence of people we have compared the simulated channels with theoretical statistical distributions, namely Nakagami, Weibull and Rayleigh. Statistical parameters are deduced directly from simulation. The comparison is performed using Mean Square Error metric. Figs. 11, 12 and 13 illustrate the CDF magnitude
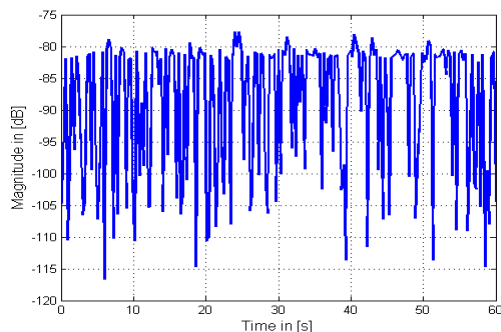

Fig. 10. The temporal variations of signal envelope with 20 persons in movement.

TABLE IV
MEAN SQUARE ERROR OF DISTRIBUTION FOR DIFFERENT NUMBER OF PERSONS.

Distribution	MSE 04	MSE 10	MSE 20
Rayliegh	0.0656	0.0549	0.0462
Nakagami	0.0110	0.0175	0.0295
Weibull	0.0890	0.1290	0.0295

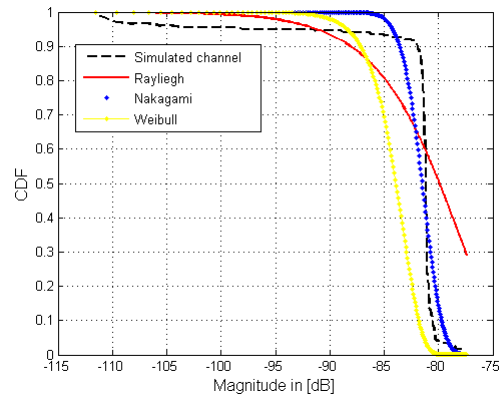of simulated channel and theoretical distributions for different number of persons.

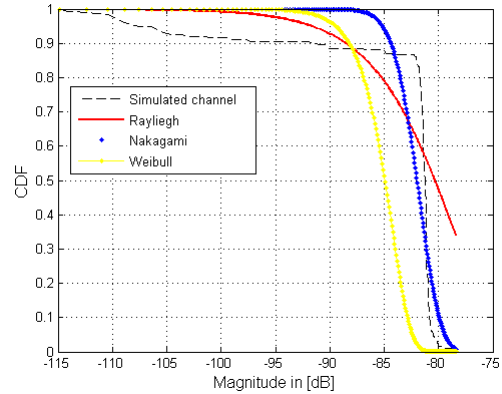Fig. 11. Statistical distribution of the variations (04 Persons).

Fig. 12. Statistical distribution of the variations (07 Persons).

From table IV we observe that the Nakagami distribution presents the best fit of simulated channel for different number of persons. The estimated m-Nakagami parameter is 8.455, 6.6334, and 1.3758 for 4, 7, and 20 persons respectively.

3) Level Crossing Rate analysis: Second order statistics are expressed as the level crossing rate (LCR), defined as the rate at which the envelope crosses a specified level in a positive-going direction, and the average fade duration (AFD), the average time for which the received envelope is below that specified level. This measurement of the frequency of fading if the fixed level represents the sensitivity of the receiver.
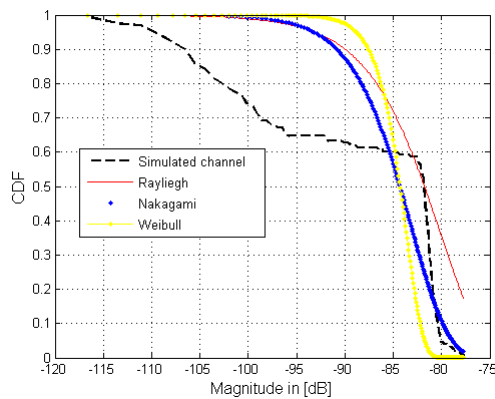
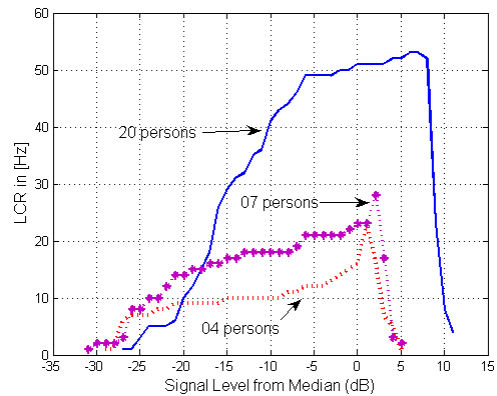Fig. 13. Statistical distribution of the variations (20 P).

Fig. 14. LCR of signal Magnitude.

The LCR allows to estimate the average durations of fading in order to determine the code detecting and correct channel error most suitable. To evaluate the LCR we carried out three recordings of amplitude of the signal with 04, 07 and 20 bodies moving in the simulated propagation environment described above. The LCR is calculated for thresholds varying from -111.5518 dB to -77.4056, from -114.8184 to -78.4006 and from -116.5973 to -77.7331 dB for 04 persons, 07 persons and 20 persons respectively. Compared to the average value of amplitude of the signal and a distance transmitter-receiver up to 7 m.

Fig. 14 shows that, as the number of peoples within the measurement area increased, the maximum LCR also increased. This indicates that, as the number of moving peoples within the simulation area increases, the variations in the received envelope also tend to increase.

4) Average Fade Duration analysis: Fig. 15 illustrates the behavior of spectral envelop of relative signal versus the number of people in the environment. From this figure we observe that the bandwidth increase with the number of people.

The analysis the of the AFD shows that if the number of people increases the AFD increases that means the the channel become unavailable.

5) Delay spread analysis: The temporal variations of the channel also result in a temporal variation of the multipath components of the impulse response. The model of ray tracing makes it possible to predict the impulse response of the channel for given a transmitter-receiver. The temporal variations of the multipath components of the impulse response give place to temporal variations of τ_{rms} delay spread. Pervious simulations make it possible to calculate and trace the variations of this parameter in the form of cumulative distribution Fig. 16. The analysis of the results shows a weak variation of the delay spread τ_{rms} for two cases with 04 and 07 persons which remains less than 08 ns. On the other hand the τ_{rms} varies significantly for the existent of more than 10 people the reader can observe that from Fig. 16 for 20 persons.
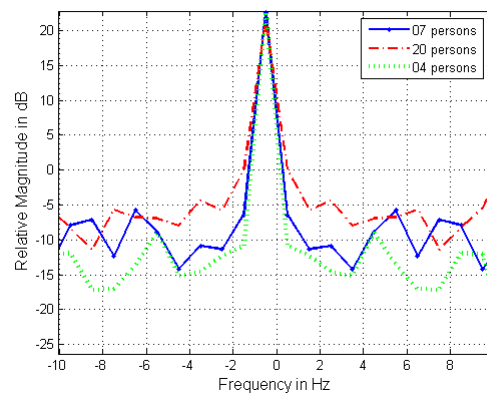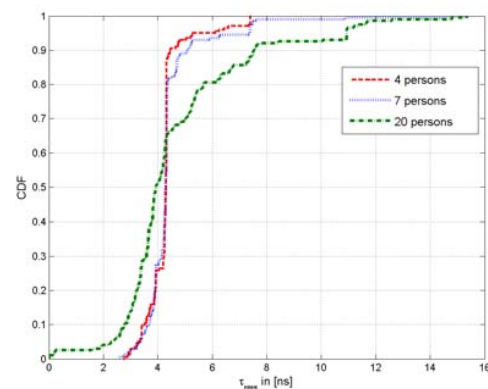

Fig. 15. Magnitude spectral envelop.

Fig. 16. CDF of τ_{rms} for different number of people in environment.

VI. CONCLUSION

This paper exposes the simulation results of indoor radio propagation channel at 60 GHz. The simulations are performed using a tool that we have developed using RTT and simulated model of human body. The results are confirm the impact of bodies on the propagation. The presented results are in agreement with those based on channel measurements in the literature, because we have obtained a high correlation between channel behavior and number of people in environment. The temporal channel variations or fading effects become fast if the number of people increases, this is based on analysis of τ_{rms}, LCR and magnitude behaviors. Finally, this work presents characterization and modelling of a set of channel parameter and show that the RTT can be used to characterize the channel of propagation in a given environment with very knowledge of propagation parameters.

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