# The Influence of People Shadowing on the Modelling of 60 GHz Band Propagation

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## 1. Introduction

The evaluation of performances and the design of communication systems require good knowledge of radio channel characteristics and models. The latter are used to predict power and interference levels and analyze other properties of the radio link. Due to recent developments in digital consumer electronics technology, millimetre bands are becoming more and more attractive for low cost personal communication applications. Systems operating around millimetre bands are now emerging across a variety of commercial and military applications, as well as in communications, radar, geo-location, and medical applications. First generation commercial wireless systems millimetre bands based products are widely deployed (at home, hospitals, laboratory, offices ...). This has been fuelled by a demand for high frequency utilization and by the large number of users requiring simultaneous multidimensional high data rate access for applications of wireless internet and e-commerce systems. A prerequisite for the development of these systems is the availability of propagation models or channel characteristics. In fact, there should be analytical models, which are easily applicable in deterministic channel modelling, e.g. ray-tracing (Khafaji 2008). The latter was demonstrated to provide channel simulation data that is in accurate agreement with measurement results in the mm-wave range and in the 60 GHz band in particular. Moreover, in any communications systems including Narrow Band, Wide Band and Ultra Wide Band systems, the received signal is an attenuated, delayed, and distorted (for millimetric communication systems) version of the transmitted signal affected by the noise present in the propagation environment (Saadane 2004, Saadane 2008). The received and the transmitted signals are linked with each other via the radio channel.
Some mm-wave range channel propagation measurements and simulation that dealt with channel parameters have been presented in the literature. Channel modelling is very

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necessary for the conception of wireless communication systems (WCS). However, the propagation channel for millimetric bands is not completely characterized. The well known experimental and simulation techniques can be used to investigate the propagation of millimetre waves in indoor environments. The advantage of the experimental method is that all systems and channel parameters affecting the propagation of millimetre 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 carry out simulations. In this chapter, we deal with the propagation characterization, modelling, and the influence of people shadowing at 60 GHz. These are used in designing in indoor millimetric communications systems.

The present chapter is organized as follows: the next section presents a review of the literature on 60 GHz Band Propagation characterization and Modelling. It provides a comprehensive summary of used methods for channel characterizations and modelling processes, as well as application systems operating at 60 GHz band. A broader description of ray tracing technique is then provided, also the influence of people shadowing is investigated and discussed. Concluding remarks and suggestions for future work are discussed in section 6.

## 2. Overview of systems operate at 60 GHz

In this section, we give an overview of the concepts, history, and applications of communications at 60 GHz band. After presenting the Federal Communications Commission (FCC)-accepted definition of a 60 GHz communication system, we briefly introduce its history and the current challenges. We also illustrate the characteristics of the 60 GHz system that differentiate it from classical communication systems.

### 2.1 Evolution and Definition

In 2001, the Federal Communications Commission (FCC) set apart a continuous block of 7 gigahertz (GHz) of spectrum between 57 and 64 GHz for wireless communications. A major factor in this allocation with commercial ramifications is that the spectrum is "unlicensed" ;in other words, an operator does not have to buy a license from the FCC before operating equipment in that spectrum. The licensing process is typically very expensive and time-consuming. Until then, less than 0.3 GHz of bandwidth had been made available at lower frequency bands for unlicensed communications.

### 2.2 Communication in the 60 GHz Band

Various applications require high data rates far beyond the capacity of existing WiFi and UWB technology. High quality video signals need data rates more than several Gb/s. This is so because sending uncompressed data greatly reduces power overhead for encoding and decoding video. Digital video cameras and Set-top boxes are noticeable applications for this technology. In general, the need for bandwidth is insatiable, much like the demand for CPU speed, static and dynamic RAM, flash memory, and external hard disk capacity. While new spectrum is available in the low-GHz bands, these bands are likely to be excessively packed full in the near future. Touching up to higher frequency also offers natural isolation from fast switching digital circuitry typical of today's microprocessors, already operating at several GHz clock speed. In addition, the only way to extract more information from a fixed bandwidth at lower frequencies is the application of more complicated modulation schemes. To extract 1 Gb/s from 100 MHz of bandwidth obviously requires 10 bits per Hz, but only 1 bit per Hz from a 60 GHz solution with 1 GHz bandwidth. The 60 GHz system employs a relatively narrowband signal, and low order constellations can be used to transmit and receive the data. The lower GHz system, on the other hand, has to use complicated signal modulation, often placing rigorous demands on the phase noise and power amplifier linearity (particularly for Orthogonal Frequency Division Multiplexing), and this gives rise to a system with less overall sensitivity. Much energy must be consumed in the baseband of these systems to provide FFT and equalization functionality, which will end up consuming additional energy per bit than a mm-wave solution, despite the higher power consumption of the front-end blocks at 60 GHz.

### 2.3 60 GHz Band Applications

There are a large number of multimedia applications requiring broadband wireless transmission over short distances, such as high-speed point-to-point data links and next-generation wireless personal area networking (WPAN). The considered necessary data rate for these applications may be hundreds of Mb/s or even multi-Gb/s. The unlicensed 60-GHz bands (e.g., 59–62 GHz in Europe, USA and Japan) are of special interest for short-range communications within a range of 10m, because the high propagation attenuation in both the oxygen and walls (e.g., 10-15 dB/km in oxygen (Smulders, 2002)) helps to isolate communication cells in a local-area networking environment, enabling multiple channel frequency reuse thanks to the low co-channel interference. In general the availability of low-cost small path silicon mm-wave transceivers leads to the possibility of higher complexity mm-wave systems incorporating dense arrays of transceivers incorporating sophisticated multi-antenna signal processing. For the potential applications of 60 GHz we found as a vital application for imaging the automotive radar operating at 24 GHz and 77 GHz. Today only comfort automobiles are equipped with mm-wave radar technology. This can aid in driving in low visibility conditions, especially in fog, vapour, and in automatic cruise control and even automated driving on a future freeway (Niknejad 2008). Another potential application for mm-wave technology is passive mm-wave imaging. By detecting only the natural thermal radiation of objects in the mm-wave band, images of objects can be formed in a very similar fashion as in an optical system (Niknejad 2008). Other up-and-coming applications for mm-wave technology comprise medical imaging for tumour detection, temperature measurements, blood flow and water/oxygen content measurements. These applications were under powerful investigation in the past two decades but much of the research has discontinued due to the fact that these traditional systems were not capable to compete with existing MRI or X-ray CAT scan systems.

## 3. 60 GHz propagation modelling based on measurements

Millimetre-wave propagation measurements and channel modelling activities have been performed at various European research institutes, in particular at Eindhoven TU/e; see e.g. (Smulders et al. 1995). An elaborated overview of 60 GHz propagation is given in (Smulders et al. 1997). A complementary overview including 27-29 GHz results is provided in (COST

2000). This section will provide a summary of these overviews and will present and elaborate additional results obtained from recent experiments.

### 3.1 Path loss modeling

The specific path loss in the 60 GHz band due to oxygen absorption amounts to 10 – 15 dB per km which is 0.10 to 0.15 dB per 10 m and has, as such, no significant influence on the propagation behaviour in indoor environments. The propagation losses are, therefore, not dominated by the oxygen absorption but by the free space path loss, which is 21 dB higher at 60 GHz when compared with the path loss occurring at 5 GHz.
Recently, path loss measurements have been performed by the Radio communication Group of the TU/e in a room with dimensions 7.2×6×3.1 $m^3$ (George 2001).The sides of the room consist of glass window and smoothly plastered concrete walls whereas the floor is linoleum on concrete. The ceiling consists of aluminium plates and light holders. The transmitting antenna was located in a corner of the room at a height of 2.5 m. This antenna has an antenna gain of 16.5 dBi and produces a fan-beam that is wide in azimuth and narrow in elevation. Its beam was aiming towards the middle of the room. A similar fan-beam antenna was applied at the receiving station, which was positioned at various places in the room at 1.4 m above the ground. For comparison, additional measurements have been performed with the fan-beam antenna at the receiver replaced by an omnidirectional antenna.
Figure 4-1 in (George 2001) shows the received power normalised on the transmitted power (NRP) in dB measured in the 58-59 GHz band as function of the separation distance between transmitter and receiver. The upper solid curve in this figure shows the NRP in case the beam of the receiving antenna is pointing exactly towards the transmitting antenna. The dotted curve represents the situation in which the fan beam at the receiver has an azimuth pointing deviation of 35°. ….

### 3.2 Antenna Beamwidths at 60 GHz

For 60 GHz band we have found that high directivity antennas in a scattering environment lose gain when compared to the omnidirectional antennas. In the literature this is regarded as antenna GRF (gain reduction factor). Also, directive antennas amplify only some propagation rays, others are attenuated and therefore multipath components are lost that results in a loss of power, loss of diversity, and reduced rank for MIMO systems that reduces spatial multiplexing gains. Furthermore, omnidirectional antennas amplify all rays evenly, in most cases. So, in path loss calculations, nominal (advertised) antenna gain determined in an anechoic chamber has to be reduced by GRF. Concerning the propagation in indoor and outdoor environments, we deduce from the available literature that indoor environments experience more scattering than outdoor environments, potentially resulting in larger GRF. In our viewpoint this subject needs more and further investigation. Manabe et al. in (Manabe et al. 1995) investigated the LOS delay profiles, for different antenna beamwidths at 60 GHz. They show that with decreasing antenna beamwidth, the LOS component is amplified and reflected components are attenuated by the antenna pattern.

## 4. Ray tracing approach for channel modelling and characterization

### 4.1 Ray Tracing description

We present here an efficient three dimensional RTT for the prediction of impulse response, path loss, local mean power and $\tau_{rms}$ delay spread of an arbitrary indoor environment.

We begin by specifying transmit and receive points in three coordinates. Each surface of obstacles (wall, ceiling, floor, and 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). Predicted propagation loss does not change more than 1 dB when including five or more reflections. However, the predicted $\tau_{rms}$ 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.

### 4.2 Ray tracing algorithm based on image method

This method is also called ray tracing because the ray path is determined when the positions of the transmitter, receiver and objects causing the propagation phenomenon are known. The image source method consists of simulating 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 (John et al. 1991) and illustrated for a simple reflection case see Figure 1. The first step is to find the virtual image S0 of the source S. Then in the 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 other methods (Falsafi et al. 1996) 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 (Smulders 1993), (Turin et

al. 1972), (Yang et al. 1994). Figure 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 Figure 3. For more information the readers are pleased to see the reference (El Abbadi et al. 2003).
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.

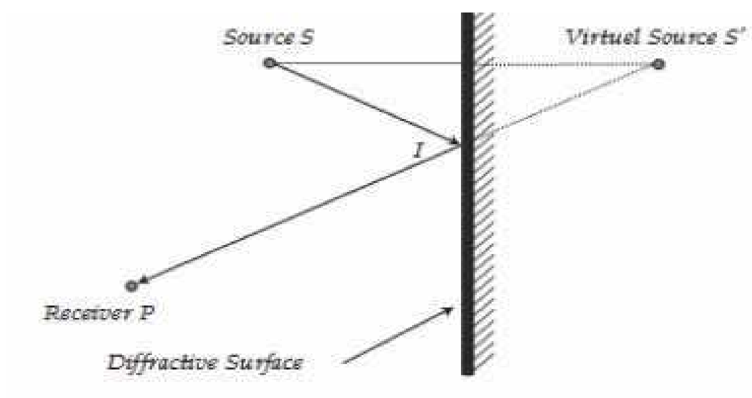


Fig. 1. Ray tracing based on image method for simple reflection.

## 5 Effects of human bodies on wireless communications (60 GHz band)

A solid work about the effect of human bodies on the WCS was reported in (Collonge et al., 2004). 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 typical realistic environments. The main objective of this study was the evaluation of temporal channel variation at 60 GHz band. Also, Hashemi (Hashemi, 1993) 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).

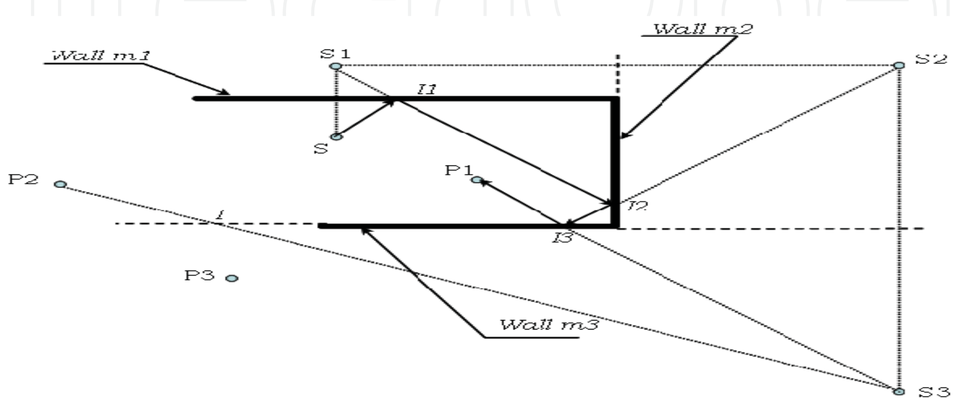


Fig. 2. Ray tracing based on image method for three successive reflections.

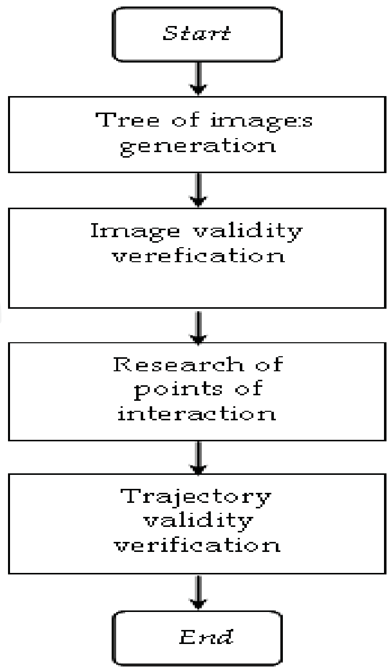


Fig. 3. Ray tracing algorithm based on image flow.

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 (Sato & Manab 1998), (Lim, 2007). The work in (Collonge et al. 2004) 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 bodies. In (Siwiak 1995), 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 human bodies remarkably change the behaviour of the channel.

## 6 Environment modelling with bodies

The objective of this part is to present our human body model and its 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.

### 6.1 Human body models

In the literature, the human body is presented physically by cylinders containing salty water. Figure 4 presents the well known models. The first one named 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 (Siwiak 1995) 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. Figure 5 presents, for a fixed salty water concentration, the behaviour of complexes permittivity $\varepsilon_r$ versus frequency (In this case the concentration is 1.5 g/L).

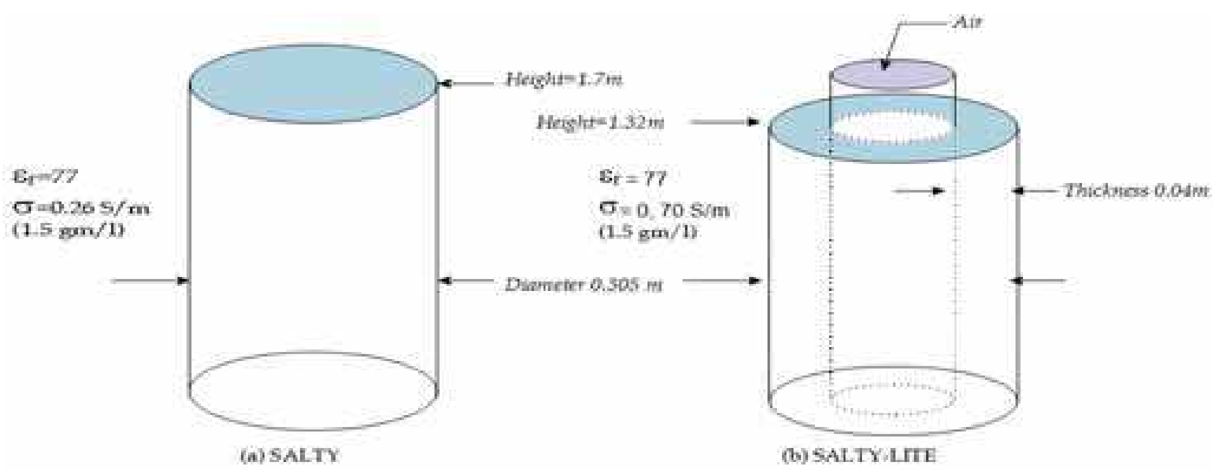


Fig. 4. Human body Models.

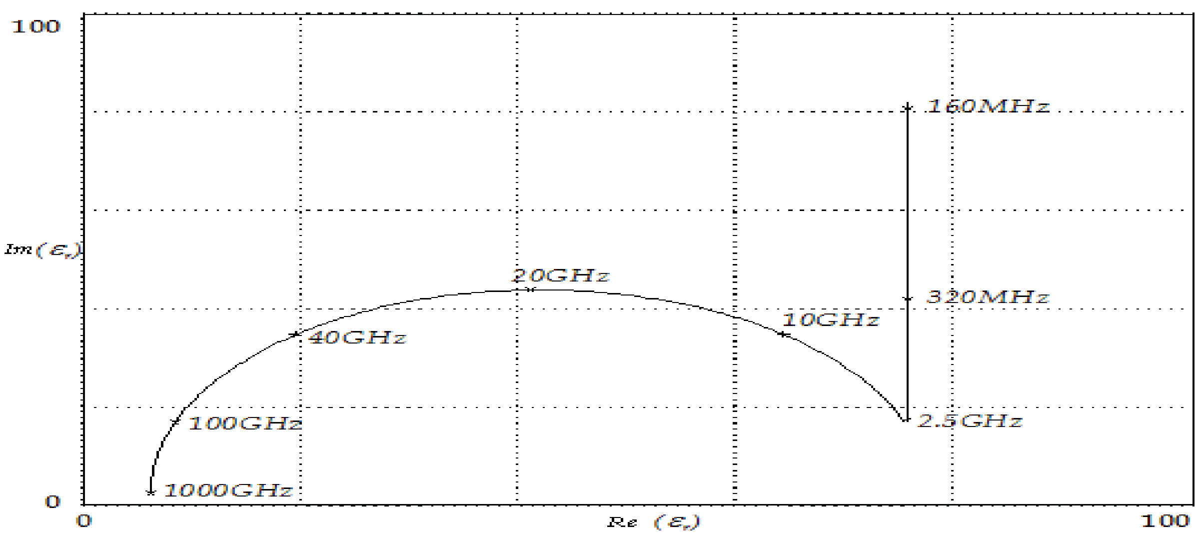


Fig. 5. Relative permittivity of salty water 1.5 g/L.

### 6.2 Used Model

Habitually, one of the human body models presented previously is used in modelling and simulation. Alternatively, we model the human body by a parallelepiped circumscribed with SALTY cylinder model as RTT deals with plate surfaces. The adopted model is depicted on Figure 6 with its geometrical features. The persons moving near mobile radio link are modelled by objects having finished dimensions with a parallelepipeds form, and, characterized by permittivity $\varepsilon_r$ and conductivity $\sigma$. The model assigns to each object a position which will be modified according to the speed and the direction.

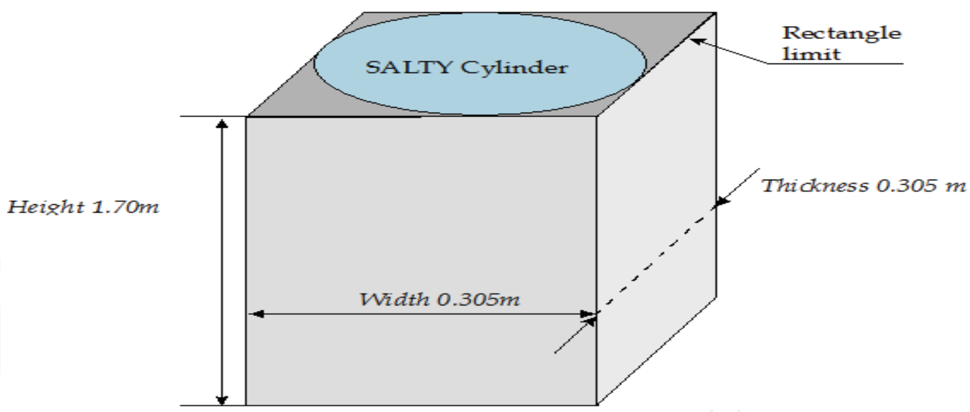


Fig. 6. New Human body Model.

## 7 Results Analysis

### 7.1 Simulation setup

To investigate the model described already in the previous paragraphs, 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, with constant speed (0.5 m/s). The positions of transmitter and receiver are indicated in Figure 7 and remain fixed during the simulation. The presented human body above is used to simulate the human activities in the propagation environments.
The series of simulations are obtained by an automatic change of the positions of the objects modelling the people moving, by respecting their speed and their direction of movement. Simulations are taken with a regular time interval, which enable us to compute again new positions of objects and other parameters of the channel. The specifications on environment for our simulation tool are given in the table 1.

| | |
|---|---|
| Frequency | 60 GHz |
| Height of walls | 2.8m |
| Thickness of walls | 0.1 m |
| Relative Permittivity of walls | 1.6 |
| Conductivity of walls | 0.00105 S/m |
| Antennas | Horn gain=11 dB |
| Polarization | Vertical |
| High of antennas | 0.9 m |
| Radiated Power | 0 dBm |
| Antenna gain | 0 dBm |
| Height transmitter/receiver | 1 m |
| Reflection order | 2 |
| Transmission | Not active |
| Diffraction order | 2 |
| Threshold (minimum level) | −150 dBm |
| Interval of time computing | 0.25 s |

Table 1. Model parameters

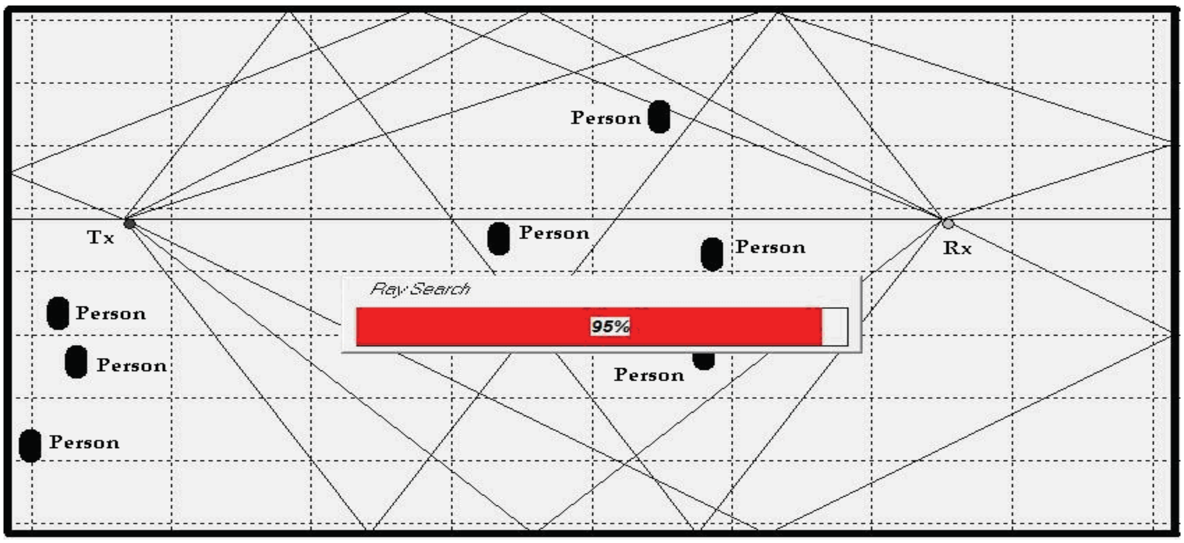


Fig. 7. Propagation environment for simulation for 07 persons.

### 7.2 60 GHz band analysis

#### 7.2.1 Temporal behaviour of channel at 60 GHz

Figure 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 2 presents the max and min values for different number of persons. The experiments are carried out during 60 seconds, with random movement of people. Figs. 8, 9 and 10 show the behaviour of channel in peopled environment. From this figures we concluded the impact of persons on the 60 GHz band propagation.

#### 7.2.2 Fading Statistics

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, illustrates the CDF magnitude of simulated channel and theoretical distributions for 04 persons.

From table 3 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 04, 07, and 20 persons respectively. The Figure 15 shows the evolution of the min of signal magnitude versus the number of persons.

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

Table 2. Max and min of magnitude for different numbers of persons.

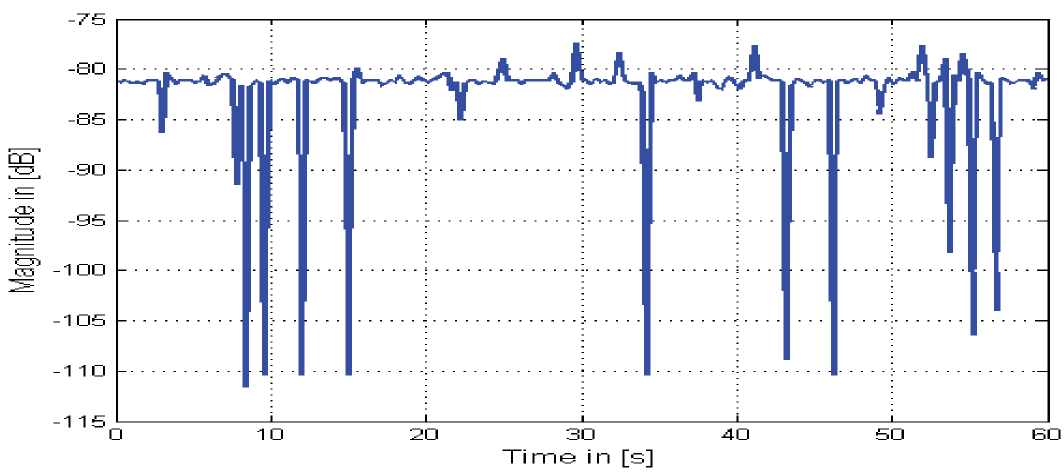

Fig. 8. The temporal variations of signal envelope with 04 persons in movement.

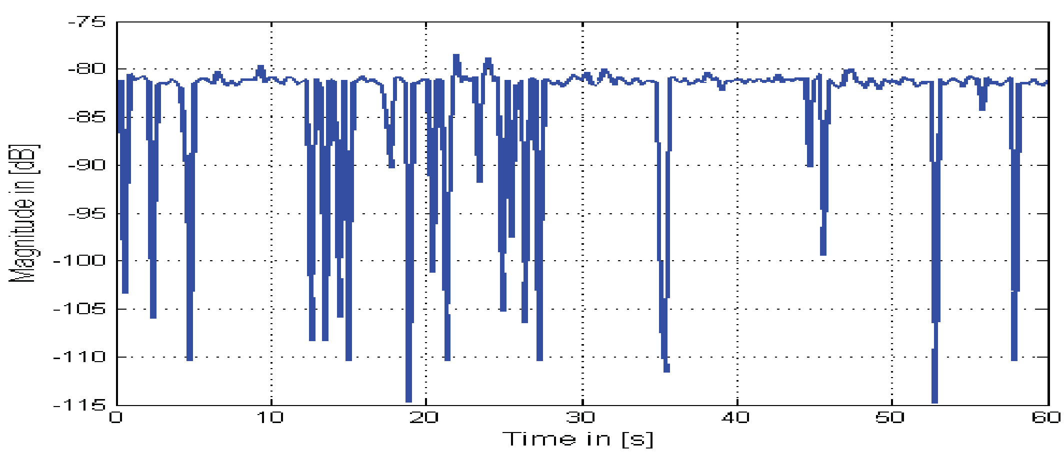

Fig. 9. The temporal variations of signal envelope with 07 persons in movement.

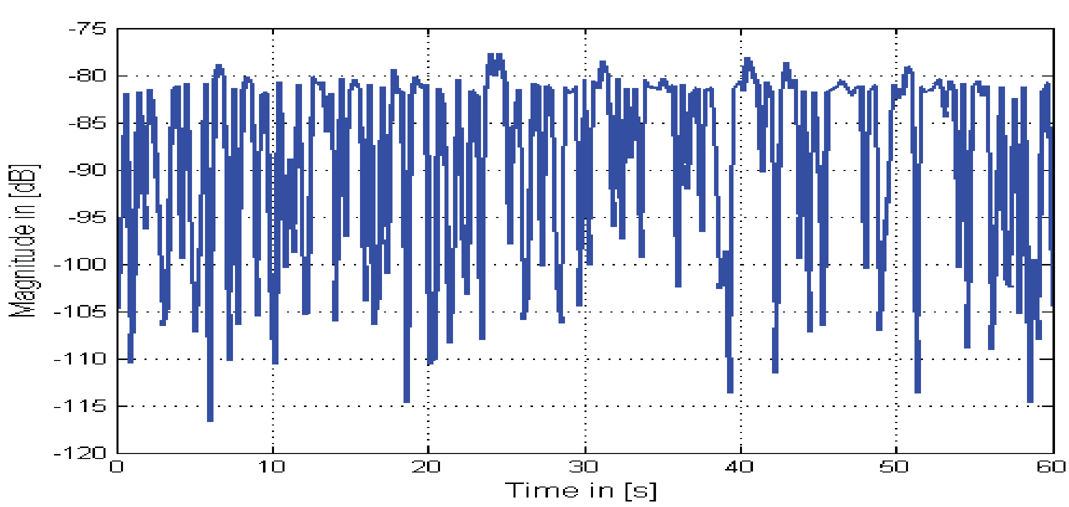

Fig. 10. Temporal variations of signal envelope with 20 persons in movement.

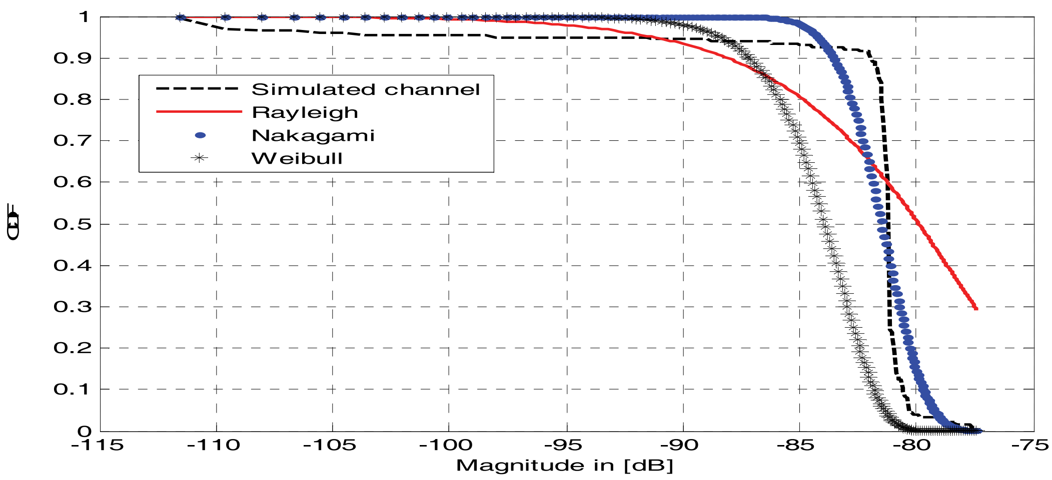

Fig. 11. Statistical distribution of the variations (04 Persons).

| Distribution | MSE 04 | MSE 10 | MSE 20 |
|---|---|---|---|
| Rayleigh | 0.0656 | 0.0549 | 0.0462 |
| Nakagami | 0.0110 | 0.0175 | 0.0295 |
| Weibull | 0.0890 | 0.1290 | 0.0617 |

Table 3. Mean square of error of distribution for different number of persons.

### 7.2.3 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. 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 dB, from −114.8184 dB to −78.4006 dB 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. Figure 12 shows that, as the number of people within the measurement area increased, the maximum LCR also increased. This indicates that, as the number of moving people within the simulation area increases, the variations in the received envelope also tend to increase.

### 7.2.4 Average Fade Duration analysis

Figure 13 illustrates the behaviour of spectral envelope of relative signal versus the number of people in the environment. From this figure we observe that the bandwidth increases with the number of people.

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

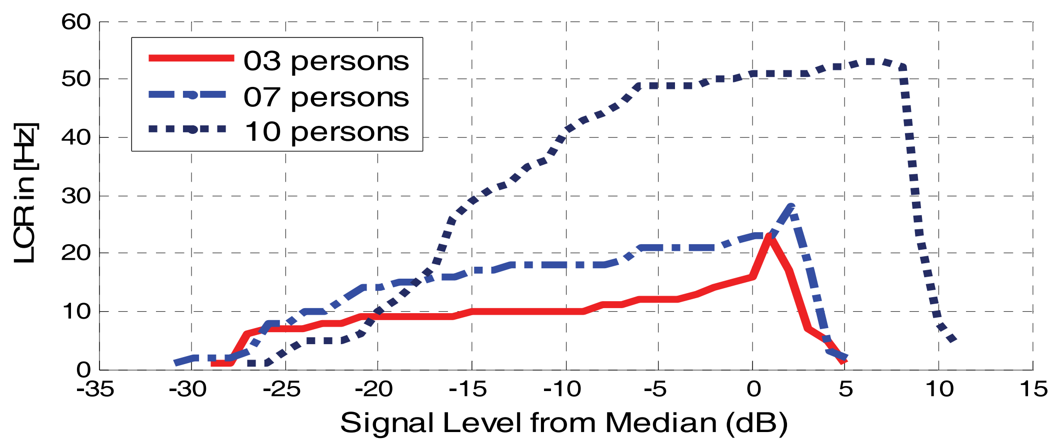


Fig. 12. LCR of signal Magnitude.

**7.2.5 Delay spread analysis***:*

The temporal variations of the channel also result in a temporal variation of the multipath components of the impulse response (Turin et al 1972). 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 $\tau_{rms}$ delay spread. Pervious simulations make it possible to calculate and trace the variations of this parameter in the form of cumulative distribution Figure 14. The analysis of the results shows a weak variation of the delay spread $\tau_{rms}$ for two cases with 04 and 07 persons which remains less than 08 ns. On the other hand $\tau_{rms}$ varies significantly for the existence of more than 10 people. The reader can observe that from Figure 16 for 20 persons.

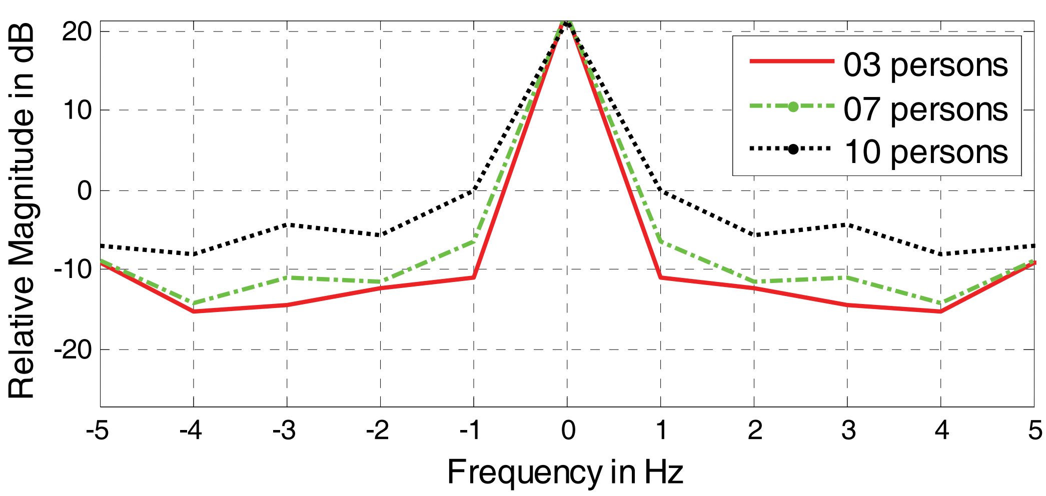


Fig. 13. Magnitudes spectral envelope.

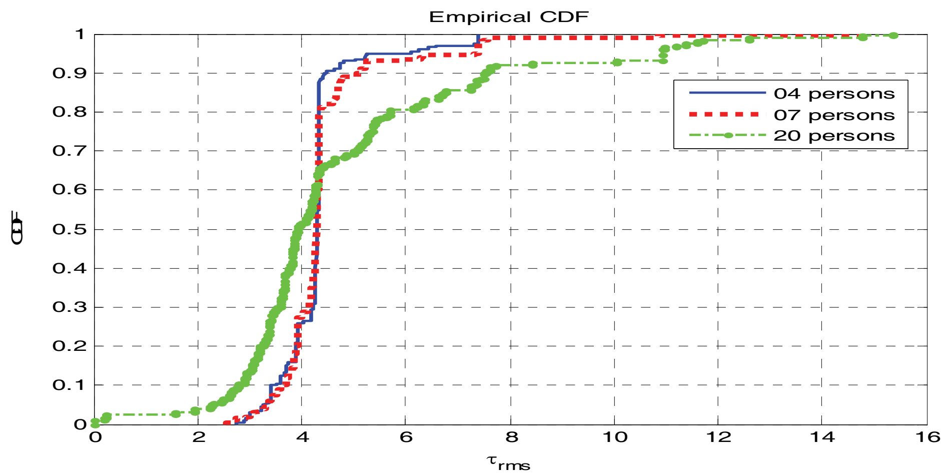


Fig. 14. CDF of $\tau_{rms}$ for different numbers of people in environment.

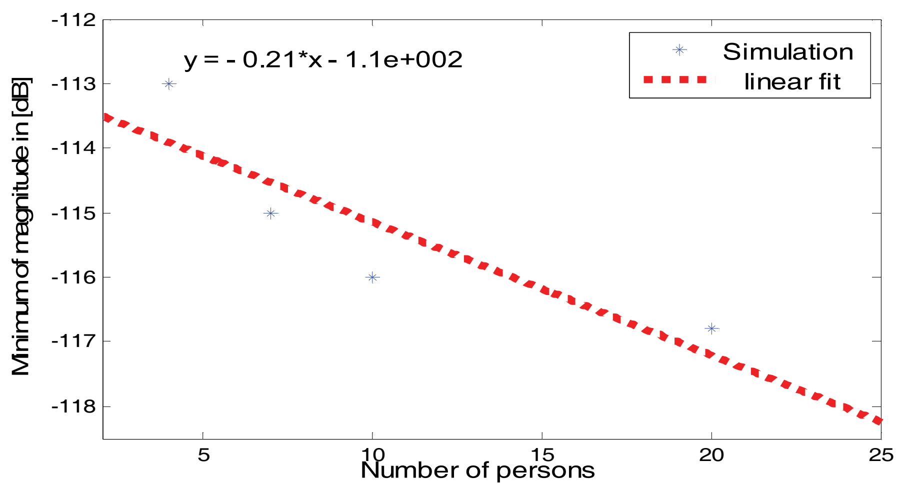


Fig. 15. Evolution of the min of signal magnitude versus the number of persons

## 8. Conclusion

In this chapter we discussed the characterization and modelling techniques in 60 GHz band communication channels in cases in which people are available in the propagation environment. We have discussed the history of 60 GHz band communication. However, 60 GHz band is still an ongoing research topic, and there is interest in improving its spectral efficiency. After, we have investigated the propagation channels at millimetric band, and established a statistical model that describes the behaviour of the channel in term of magnitude and delay spread parameters. The study is based on Ray tracing Theory. The simulations are performed for 60 GHz by using the developed tool. Our results are confirming the impact of bodies on the propagation. The temporal channel variations or fading effects become fast if the number of people increases; this is based on analysis of delay spread $\tau_{rms}$ , LCR and magnitude behaviours. Finally, this chapter presents characterization and modelling of a set of channel parameters and show that the RTT can be used to characterize the channel of propagation in a given realistic environment with knowledge of propagation parameters.

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