Body-centric Wireless Communications at 94GHz

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1. Introduction

Wireless applications where both receivers and transmitters are located on the human body, also known as Wireless Body Area Network (WBAN) applications, have been extensively investigated in the past few years [1] with commercial products already available [2].

WBANs are relevant to different applications, both in civil and military fields, such as vital signs monitoring, augmented reality, and interactive entertainment. Mainly, frequencies up to X band have been considered so far [1], but the interest of research activity is progressively moving towards higher frequencies, namely V and W bands, covering 50 to 75 GHz and 75 to 110 GHz respectively, as demonstrated by the release of the 60 GHz Wireless Personal Area Network Standardization within IEEE 802.15.3c [3]. In addition to the obvious advantages of potentially higher data rates and more compact devices, necessary for high speed data communication in WBANs, such frequencies do not suffer from the overcrowding that is present at lower bands, where a multitude of applications coexist. Moreover, it is also easier to confine the radiated energy around the body, because of the possibility to design directive but compact antennas and the higher free space attenuation. Finally, the reduced penetration depth due to the characteristics of human tissues at such frequencies mitigates the concerns for the interaction between signals and biological tissues.

One of the main issues in designing reliable and efficient WBANs at V and W bands is the modelling of the communication channel. The human body is a dispersive and dissipative medium, and its typical dimensions, with respect to the wavelength, are extremely large at the considered frequencies. So far, the Finite Differences in Time Domain (FDTD) method has been widely used up to X band [7], but the computational burden at millimetre-wave frequencies suggests considering the use of different, more efficient techniques, such as Ray Tracing (RT) in combination with the Uniform Theory of Diffraction (UTD).

The aim of this paper is to evaluate the reliability and accuracy of the above mentioned method at W band by comparing the results of numerical simulations and on-body measurements at 94GHz. The simulations have been performed by means of the commercial software XGTDv2.5 by Remcom [5], where a digital phantom with dimensions similar to the subject has been imported.

2. Simulation

As mentioned above, at the here investigated frequency of interest, the dimensions of the human body are extremely large compared with the wavelength. Therefore, the numerical modelling and simulation of a body-centric scenario at 94 GHz is computationally inefficient when performed by using traditional full-wave numerical techniques such as Finite Element Method (FEM), Method of Moments (MoM) or Finite Difference Time Domain (FDTD). Indeed, although the mentioned methods allow describing completely the electromagnetic problem in terms of propagation and field distribution, they are required to solve problems characterized by a huge number of mesh elements. In order to overcome this limit and to be allowed to study electrically large models, high frequency techniques, based on the ray-tracing algorithm, have been applied and the obtained data have been compared with the measured ones.

The software used to analyse propagation on a body-centric scenario in W band is RemCom XGTD$^{v2.5}$ which implements a combination of Geometrical Optics and Uniform Theory of Diffraction [1].

The performed analysis can be summarized in several steps as follows:

- Import of the numerical model of male human subject;
- Assignment of the electromagnetic properties;
- Import of the measured antenna pattern;
- Placement of the transmitter and receivers for two different links.

The investigated numerical model represents a male human body and it has been obtained from the Google SketchUp free Library. The model consists of a 3-dimensional surface composed by facets; moreover the geometrical accuracy of the model takes into account the shape of the clothes. The numerical model is shown in Fig. 1 for different views.

Figure 1: numerical model of the male human body for different views

In order to take into account and to assign the electromagnetic properties of skin and clothes, a layered structure has been considered in the model. Considering the small penetration depth, at the investigated frequency, the body has been assumed as having the dielectric characteristics of dry skin. In particular, according to the location of the clothes, it is possible to distinguish three different areas of the body. As indicated in Fig. 2, the skin layer is associated to the uncovered areas, such as the head and the hands, a skin layer plus a layer of cotton are associated to the areas where the shirt is present and finally a layer of skin and two layers of different types of cotton are associated to the areas covered by the jacket and the shirt. A proper thickness has been associated to each layer according to the physical properties of the tissues and fabrics.

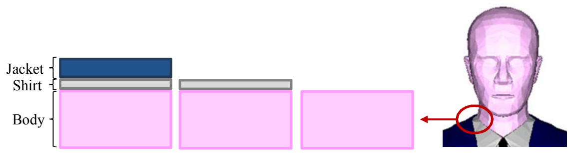


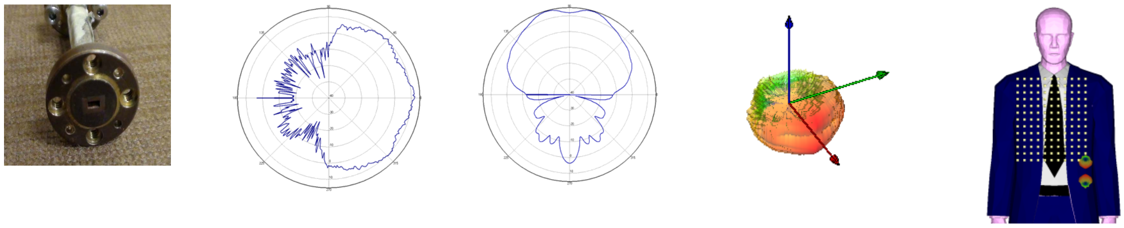
Figure 2: layered structure associated to the model

The dielectric permittivity and the electric conductivity of the skin and the fabrics at 94GHz [5][6], are summarized in Table 1 together with the thickness associated to each layer.

Table 1: Electromagnetic properties and thickness of skin and fabrics layers

Material	Dielectric permittivity	Electric conductivity[S/m]	Thickness [mm]
Dry skin	5.79	39.18	30
Shirt	2	0.01	1
Jacket	2	0.1	5

Subsequently, the radiation pattern of the antennas has been taken into account in the XGTD environment. Two flanged standard rectangular waveguides WR-10 (Fig. 3a) have been used both as transmitter and receiver. The patterns on the E-plane and H-plane, shown in Fig. 3b and c respectively, have been measured in anechoic chamber then imported and interpolated in XGTD in order to obtain the 3-dimensional one (Fig. 3d). The obtained 3D pattern has been assigned to the transmitter and the receivers placed in several different reciprocal positions in proximity of the human body. In particular the path loss for the link belt-chest has been evaluated. In this case the transmitter has been placed on the left side of the belt and a grid of receivers has been placed in the torso area. The two antennas have been aligned according to the polarization of the electric field. In Fig. 3e the investigated link and the reciprocal position of the two antennas have been shown.



(a) (b) (c) (d) (e)

Figure 3: WR-10 used for measurements (a), Radiation Pattern on E-plane (b), on H-plane (c) and 3D pattern (d) and belt-chest link (e)

In order to achieve a good trade-off between computational effort and numerical accuracy, in addition to the direct ray, the contribution of reflected rays have been considered until the third order, moreover the diffraction has been taken into account.

3. Measurements setup

In order to compare the path loss obtained by means of simulation, a campaign of measurements has been carried on a human subject for the two investigated links. For the sake of clarity let us consider the measurement setup shown in Fig. 4. A Continuous Wave (CW) generator has been used to generate a signal at 10.4 GHz which represents the input for the frequency multiplier. The signal at 94 GHz, obtained as output from the multiplier, is decoupled by a 20 dB directional coupler which provides the feeding for the transmitting antenna WR-10 and for the Mixer. This module extracts the 9^{th} harmonic of the 94 GHz signal and combines it with the signal at 10.4 GHz generated by the Local Oscillator (LO) in order to provide, as input for the Vector Network Analyser (VNA), a referring signal at 20 MHz. On the receiving path, the flanged waveguide WR-10 is remote controlled by a mechanical scan which allows to move it over a vertical plane with a precision of 0.1 mm. The received signal at 94 GHz is combined in the Mixer with the one generated by the LO at 10.4 GHz to obtain a signal at 20 MHz. Finally, in order to obtain the path loss in terms of S_{21}, both the referring signal and the received one are compared in the VNA.

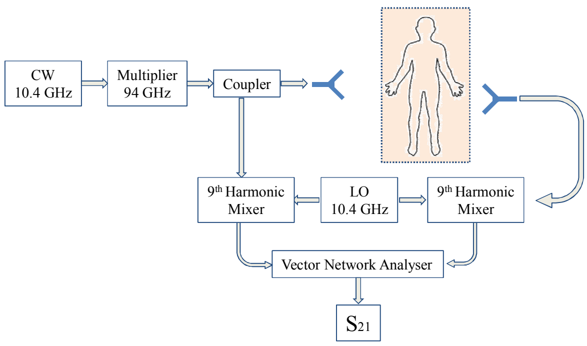


Figure 4: Measurement setup

4. Results

In order to validate the accuracy and the reliability of the investigated procedure, the data obtained by applying the high frequency method as mentioned above, have been compared with measured ones. Due to the sensitivity of the instruments, path loss greater than 80 dB have not been considered in the analysis and have been assumed completely shadowed.

For what concerns the belt-chest link, the simulated and measured Path Loss (PL) has been shown in Fig. 5a and b respectively.

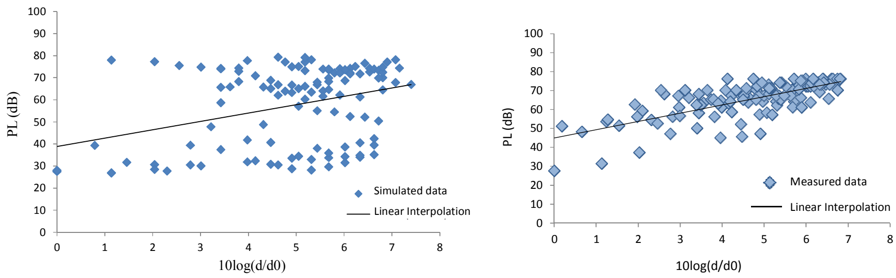


Figure 5: Simulated (a) and measured (b) Path Loss for the belt-chest link

By referring to the previous figure, the path loss has been evaluated as function of the logarithm of the distance between the transmitter and the receiver normalized to the minimum one d_0 of 10 cm. According to the semi-empirical formula for evaluating the path loss [7][8], the propagation channel has been evaluated in terms of path loss exponent; to this aim both the simulated and measured data have been analysed by using a linear interpolation. For what concerns the simulated data, the path loss exponent is 3.79 and for the measured data it is 4.36 showing a good agreement between the two set of data. However, the higher variance of the simulated data (17.8) respect to the measured one (6.4) is probably due to the large number of small facets which compose the model and which introduce small variation that make the data more scattered.

5. Conclusions

The analysis of a body-centric environment at W band has been investigated in this paper. Simulations of a male human body numerical model have been performed by using a combination of GO/UTD implemented in the commercial software RemCom XGTD. Measurements have been carried out on a human subject in order to prove the effectiveness of the methodology used in this study. Finally the comparison of the results, obtained by simulation and by measurements for the head-shoulder link, shows a good agreement between the set of data.

Acknowledgments

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