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Antennas and Propagation for Body Centric Wireless Communications

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Abstract: In this paper, on-body propagation modelling has been investigated applying various numerical computational techniques. Propagation measurements with body-worn antennas have been carried out at 2.4GHz inside and outside an anechoic chamber respectively for narrowband communication channel characterisation. Both simulation and measurement results have been also obtained at the UWB (Ultra Wide-Band) band.

Keywords: On-body channel, Finite-Difference Time-Domain (FDTD), Narrowband, Ultra Wide Band (UWB)

1. Introduction

Wireless body-Centric Networks consist of a number of nodes and units placed on the human body or in close proximity, such as on everyday clothing. Such networks are aiming to provide systems with constant availability, re-configurability, unobtrusiveness and true extension of a human's mind [1] [2]. They have distinctive features in comparison to other available wireless networks and that is due to the rapid changes in communication channel behavior on the body during the network operation. This raises some important issues regarding the propagation channel characteristics. There are potentially many communication paths in an on-body network. In addition the dynamic nature of the body and hence the path geometry make propagation characterisation and antenna optimization difficult to specify in a deterministic way. In this paper, we present initial modelling of on-body propagation using the conformal Finite-Difference Time-Domain (FDTD) method and also applying the Finite Element Method (FEM) and Finite Integral Technique (FIT) for cross evaluation by means of commercial packages. Detailed description of the measurement campaign performed in order to obtain sufficient path variation data for acceptable characterization of the on-body channels for both narrowband channels (2.4 GHz) and UWB channels are presented. Comparison between on-body channels using different UWB antennas is also discussed. The constant presence of the body during the measurement could assist in providing deterministic channel models that can provide great assistance to system designers.

2. On-body Propagation Channel Modelling

Since radio propagation on human body is quite a complex electromagnetic problem, numerical simulation tools will provide physical insight into the propagation mechanisms present and enable its prediction in far more complex environment. Accurate and fast theoretical modeling by Finite-Difference Time-Domain (FDTD) method [3] on large size conformal human bodies mounted with antennas is seen as the most valuable method; however it is constrained by computational power and memory resorting to inefficient staircase orthogonal meshes on curved surfaces. Local distorted nonorthogonal FDTD (LN-FDTD) method [5] was developed such that only those cells close to the curved boundary are distorted and processed with the nonorthogonal FDTD (NFDTD) algorithm; others remain as Cartesian cells. The in-house conformal FDTD modelling software was used to evaluate on-body propagation channels. The human body grid, shown in Fig 1a, was given the following parameters for correct modelling at 2.4 GHz; the relative permittivity and conductivity for dry skin are 38.1 and 1.441 S/m; those for muscle which is used dominantly over the whole body are 52.7 and 1.705 S/m; those for lungs which is of large volume in upper body are 34.5 and 1.219S/m. Bones and other organs are not taken into consideration because of their relatively small volumes. The path loss was found to be 44.2 dB. This value is

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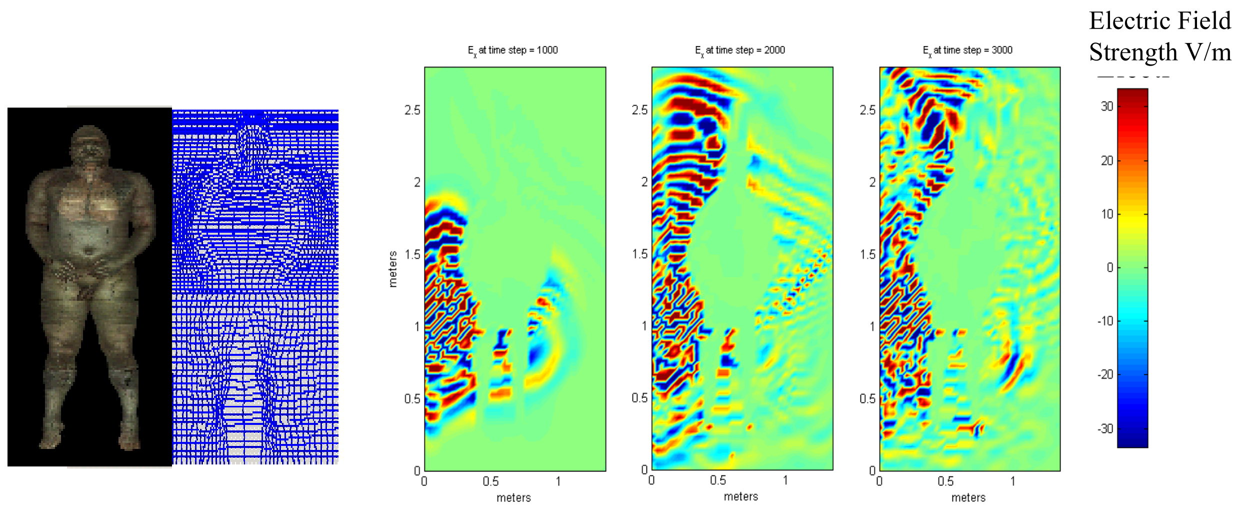

a) b)

Fig. 1. a) Human grid based on US visible human project, b) Electric field (E_x) distribution around the human body and on the body surface at a cut inside the body

comparable to the measurement value (approximately 44 dB) obtained for the monopole-loop case for the trunk-to-trunk scenario when body standing straight up. Figure 1b presents the electric field distribution around and on the surface of the human body at different time steps. The waves are initially travelling to the opposite side across the waist, since it is the shortest path and then along the human body surface with human body attenuation and shadowing is apparent in later time steps with electric field being stronger at the source side of the body in comparison to the opposite side.

The High Frequency Structure Simulator (HFSS®), provided by Ansoft Corp., was applied to model the propagation channel on human arm with two microstrip patch antenna (patch size: length 3.4 cm and width 3.95 cm and substrate permittivity of 3 and thickness of 0.1524 cm was used) placed on the arm and resonating at 2.4 GHz. The total antenna ground plane size is 10 cm x 10 cm and the free space distance between the antennas is 28 cm. The arm model has a total length of 48 cm. Human skin (dry) were used as the dielectric material for the arm. The same configuration was also used for in CST Microwave Studio® based on FIT [4]. The use of one human tissue property as the dielectric material proved adequate due to the fact that the skin depth at the frequency of interests is very small and the transmission power in consideration is of very low values. Figure 2 shows a comparison between the S21, transmission loss, results for measurement, HFSS and CST when the arm is away from the body (Perpendicular to the upper human body). Excellent comparison is achieved with differences of maximum 1 dB produced. Initial investigations were also carried out characterise on-body UWB channel using time domain techniques, mainly FIT applied by CST®. However, the complex human structure and the dispersive property of different human tissues were found to be computationally intensive and only small parts of the UWB band were modelled at different stages. As a main issue in characterising any propagation channel, different antenna orientations for both transmit and receive nodes would affect the path behaviour. The Planar Inverted Cone Antenna (PICA [7]), was modelled in CST and two antennas were placed at 0.5 meter distance form each other. Changing the orientation of one of the pair with respect to the first antenna, the path loss variations were observed.

3. Characterisation of On-body Communication Channel

2.1 On-body Propagation Channel at 2.4 GHz

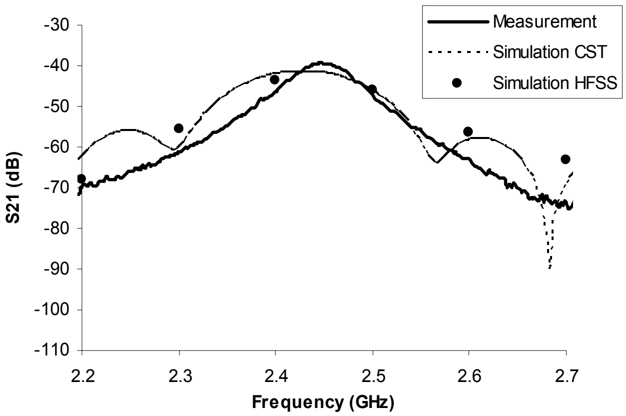

Fig. 2. Path loss comparison between HFSS/CST modelling and measurement results for on-arm propagation

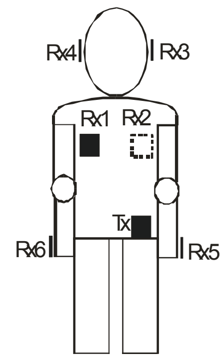

Fig. 3. Antenna positions on body for measurement

Propagation path loss of an on-body channel was measured using a vector network analyser (VNA). Two 8.6 dBi patch antennas were positioned on the body at a number of positions and orientations, Fig. 3, and connected to the calibrated VNA by two 5 m long flexible coaxial cables. For each antenna placement setup, S_{21} response was then measured every second while the person wearing the antennas assumed various body positions changing them every 20 seconds. Each measurement set was made inside an anechoic chamber and outside, in the laboratory. Figure 4 presents some of the measurement results for scenarios when both antennas are on the trunk of the body. In all the presented measurements the transmit antenna was placed on the belt on the left front side of the body and polarised either vertically or horizontally. Comparing the results taken in the anechoic chamber and in the laboratory, we have shown a noticeable increase in signal variability outside the anechoic chamber due to multipath fading. Variations due to breathing and/or other small body movements are no more than about 4 dB. Spread of values due to changing body positions, on the other hand, reaches a maximum of 26, 36 and 44 dB, respectively, for the trunk-to-trunk, trunk-to-head and trunk-to-hand measurements in the anechoic chamber. The corresponding values for the measurements outside the chamber are 30, 37 and 40dB, respectively.

2.2 UWB On-body Communication Channel

Frequency-domain measurements were performed in the range 3 GHz to 9 GHz for UWB on-body communication channels. VNA was also used here in addition to two pairs of different UWB antennas (PICA [7] and Horn Shaped Self –Complementary Antenna (HSCA) [8]) to measure channel frequency response. Two sets of measurements were performed in the anechoic chamber to account for deterministic channel characteristics

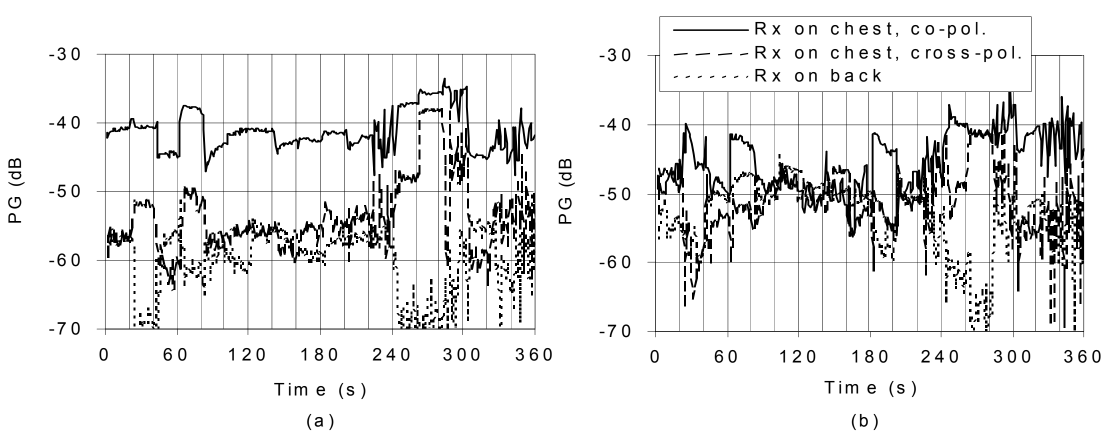

Fig. 4. Trunk-to-Trunk measurements (a) in the anechoic chamber (b) in the lab

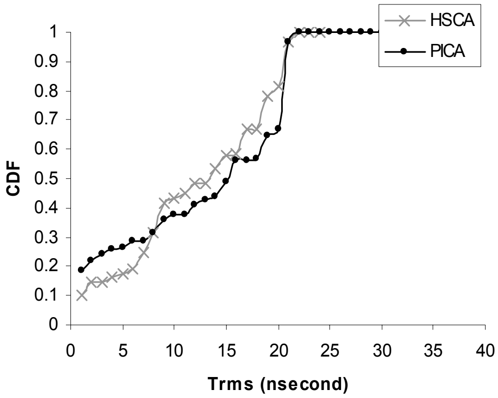

Fig. 5. CDF of RMS delay spread for both HSCA and PICA measurements

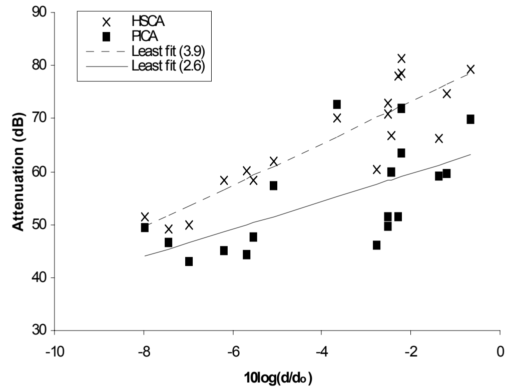

Fig. 6. Path loss for the on-body channels (measured and modelled) for both antenna cases (PICA and HSCA)

due to the human body for both antenna types, which resulted in 710 frequency responses for different body positions, Fig. 3. Figure 5 shows the probability (CDF) distribution of RMS delay spread for both measurement cases. Time domain parameters of the measured channels were then obtained from the power delay profile. The path loss of the channel is calculated directly from the measurement data using averaging over the measured frequency transfers at each frequency points. Figure 6 presents the measured values and modelled path loss for both antenna cases. The two types of antennas give different path loss exponents, for the HSCA case 3.9 and 2.6 for the PICA. These high exponent values are due to the non-reflecting environment in the anechoic chamber.

4. Conclusion

Modelling and characterisation of on-body propagation channels were discussed and presented for narrowband (2.4 GHz) and UWB communication systems. Time domain electromagnetic computational technique (specifically conformal FDTD) proved to be the most suitable choice for initial modelling of propagation channel on complex structures such as the human body. For narrowband propagation, the channel was shown to exhibit high variability caused by relative movements of the body parts. For UWB channel characterisation, reduction in mean RMS delay spread were noticed for cases where surface waves were dominant in the wave travelling along the human body using printed HSCA. In contrast, when PICA was used in the same scenarios, the main radiation cone was perpendicular to the body and mean spread delays were higher due to free space wave domination.

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