Stochastic Dosimetry for the Assessment of the Fetal Exposure to 4G LTE Tablet in Realistic Scenarios

Emma Chiaramello (1), Marta Parazzini (1), Serena Fiocchi (1), Paolo Ravazzani (1), Joe Wiart (2)
(1) Istituto di Elettronica e di Ingegneria dell’Informazione e delle Telecomunicazioni, CNR, Milano, Italy
(2) Télécom ParisTech, LTCI University Paris Saclay, Chair C2M, Paris, France

Abstract

In this study, we used stochastic dosimetry, a promising approach that combines electromagnetic computational techniques and statistics, to assess the exposure of a fetus at 9 months of gestational age to a 4G LTE tablet in realistic scenarios characterized by variability. In particular, we analyzed how the exposure changes when moving the tablet in a range of positions representative of realistic exposure scenarios. Polynomial chaos theory, applied to build surrogate models of Specific Absorption Rate (SAR), permitted a fast estimation of the variability of the exposure due to the variation in the tablet position.

1. Introduction

In the approaching era of the Internet of Things, the development of new devices and new infrastructure for the creation of smart environments based on wireless communications will lead to a pervasive use of new Radio Frequency devices [1]. This contributes to the growing up of public concern toward the exposure to Radio- Frequency Electromagnetic Fields (RF-EMF) and highlights the need of conducting appropriate health risk assessment in order to reveal possible health risks correlated to the exposure to these new RF technologies. This is especially true for fetuses, newborns and babies, who are early exposed to RF-EMF due to the indirect use of RF devices by adults and to the direct use by the baby him/herself [2].

One of the major steps of this health risk assessment process is the evaluation of the level of exposure to RF-EMF, considering the emissions of new generation devices in real exposure scenarios. Among the new generation devices it is important to consider the exposure induced by both infrastructures (e.g. base stations, femtocells) and devices close to the body (e.g. mobile phones and PC tablets).

The assessment of the exposure in real scenarios is a challenging task, due to the intrinsic variability of the parameters that influence the exposure (e.g., the source design, the morphology and posture of the subject exposed) [3]. Classical electromagnetic computational techniques, also called deterministic dosimetry, typically involve highly time-consuming simulations, making almost impossible to characterize how the exposure changes in variable conditions.

A promising approach to overcome this challenge is given by the stochastic dosimetry [4], a method that combines electromagnetic computational techniques and statistics to build surrogate models able to replace the heavy numerical simulations by analytical equations. Among the statistical approaches that could be used to build surrogate models in stochastic dosimetry, the polynomial chaos (PC) theory [5], has already been used to study the exposure to low frequency (LF) and RF sources, resulting in an efficient tool to assess the variability of the EMF [6-7].

In this study, we will use stochastic dosimetry based on the PC theory to evaluate the exposure of a fetus at 9 months of gestational age to RF-EMF due to a 4G LTE tablet in realistic scenarios. The exposure will be characterized in terms of Specific Absorption Rate (SAR). A PC expansion will be built for the SAR induced in each specific tissue of the fetus, to assess the variability of the exposure with the change of the tablet position.

2. Materials and Methods

Figure 1 shows the exposure scenarios of the fetus to the 4G LTE tablet. To describe the reciprocal position between the tablet and the fetus, we considered five spatial coordinates: the translation along the axis x, y, z, the rotation \( \alpha \) around the x-axis in the yz-plane and the rotation \( \varphi \) around the axis z in the xy-plane. All ranges of variability of the input parameters are reported in Figure 1. Similarly to the experiment described by Tateno et al. [8], we considered only three possible screen orientations of the tablet, corresponding to values of \( \varphi \) equal to 0°, 180° and 270°.

We evaluated the fetal exposure in terms of the Specific Absorption Rate (SAR) for different positions of the tablet using surrogate models based on Polynomial Chaos expansions.

The Polynomial Chaos is a spectral method and consists in the approximation of the system output \( Y \) in a suitable basis \( \Psi(X) \) made of orthogonal polynomials [9]:

\[
Y = M(X) = \sum_{0}^{P-1} \alpha \psi_j(X) + \varepsilon \quad (1)
\]

where \( Y \) is the system output, \( X \) is the random input vector made of the input parameters \( x_i \), \( \psi_j \) are the polynomials belonging to \( \Psi(X) \), \( \alpha \) are the coefficients to be estimated, \( \varepsilon \)
is the error of truncation and $P$ is the size of the polynomial basis $\Psi(X)$.

The random input vector $X$ is composed by four independent input parameters, representing the spatial coordinates of the reciprocal position of the 4G LTE tablet and the exposed fetus (as shown in Fig. 1). All the input parameters $x_i$ are supposed to be uniformly distributed, allowing using the Legendre polynomials as polynomial basis [10].

The system output $Y$ we modelled by PC is the Specific Absorption Rate (SAR). More specifically, we estimated the SAR in each specific fetal tissue, analyzed in terms of both whole-tissue SAR (SAR WT) and peak SAR averaged on 1 g of tissue (pSAR 1gT).

To apply the LAR algorithm to obtain a proper surrogate model, we need a set of observations of the quantity that has to be modelled. In this case, the observations $Y_0$ of the SAR have been estimated through deterministic dosimetry (Finite Time Domain Method (FDTD) applied to an input vector $X_0$ describing $N = 60$ possible positions of the tablet in the space. We used a high resolution pregnant woman model at 9 months of gestational age (GA), based on the model “Ella” of the Virtual Family [14]. The dielectric properties in each tissue have been assigned on the base of the data available in literature [15].

We used a numerical tablet model designed and validated within the Fp7 European LEXNET Project [15]. The simplified model was built respecting the physical characteristics of current commercial tablets and it is composed of the frame, the display, the battery, the printed circuit board (PCB) and four different antennas, all located on the upper side of the tablet. In this study we used the 4G LTE antenna working in the 800 MHz frequency band. The input power was set equal to 250 mW.

Once all the PC models have been built for the SAR in each specific tissue for both SAR WT and pSAR 1gT, 10,000 different positions for both tablet exposure have been randomly selected, calculating the SAR values through the PC expansions. A statistical analysis has been performed to assess the variability of the exposure due to the position of the tablet with respect to the fetus, in terms of coefficient of variation (CV), calculated as the ratio of the standard deviation to the mean value.

### 3. Results

Figure 2 shows the SAR WT values (figure 2(a)) (mean values and standard deviation) and the corresponding CV values (figure 2(b)) obtained in 10000 random positions of the tablet, considering the screen orientations corresponding to $\phi$ equal to 0°, 180° and 270°. Across the 26 tissues, mean values of SAR WT found for the screen orientation corresponding to $\phi$ equal 180° were always higher that those found for the other two screen orientations. In particular, for $\phi$ equal to 180°, five tissues, i.e. adrenal gland, gallbladder, kidney, ovary and uterus, had mean values of SAR WT equal or higher than 2 mW/kg. On the contrary, for $\phi$ equal to 0° and 270° the mean values of SAR WT for all the tissues were below 2 mW/kg, with the highest values for adrenal gland, kidney, ovary and uterus.

The variability of the fetal exposure in terms of SAR WT due to the position of the tablet was high for all the considered screen orientations, as shown by the CV values represented in figure 2(b). The screen orientation with the highest CV values across the 26 tissues was the one corresponding to $\phi = 270°$, with CV values ranging from 63% for the esophagus to 94% in the eye tissues (eye vitreous humor and eye lens). For the remaining screen orientations, i.e. $\phi = 0°$ and $\phi = 180°$, we found CV values ranging from 44% for the esophagus to 83% in the eye lens and from 38% for the brain white matter to 75% in the kidney, respectively.

Figure 3 shows the pSAR 1gT values (figure 3(a)) (mean values and standard deviation) and the corresponding CV values (figure 3(b)) obtained in 10000 random positions of the tablet, considering the screen orientations corresponding to $\phi$ equal to 0°, 180° and 270°. Analogously to what previously observed for SAR WT, also pSAR 1gT values found for the screen orientation corresponding to $\phi$ equal 180° were higher that those found for the other two orientations.
Figure 2. (a) SAR\(_{WT}\) values (mean values and standard deviation) obtained in each fetal tissue 10000 random positions of the tablet and (b) corresponding CV values. SAT is the acronym for Subcutaneous Adipose Tissue.

Figure 3. (a) pSAR\(_{1gT}\) values (mean values and standard deviation) obtained in each fetal tissue 10000 random positions of the tablet and (b) corresponding CV values. SAT is the acronym for Subcutaneous Adipose Tissue.

In particular, for \(\phi\) equal to 180°, skin, small intestine and muscle were the tissues showing the highest pSAR\(_{1gT}\) mean values, equal to 11.3 mW/kg, 9.97 mW/kg and 7.38 mW/kg, respectively. Also for the other screen orientations skin, small intestine and muscle were the tissues showing the highest pSAR\(_{1gT}\) mean values, equal to 5.1 mW/kg, 4.25 mW/kg and 3.34 mW/kg, respectively, for \(\phi = 0^\circ\), and equal to 4.9 mW/kg, 2.7 mW/kg and 3.4 mW/kg, respectively, for \(\phi = 270^\circ\).

The variability of the fetal exposure in terms of pSAR\(_{1gT}\) due to the position of the tablet was high for all the considered screen orientations, as shown by the CV values represented in figure 3(b). The screen orientation with the highest CV values was \(\phi = 270^\circ\) for all the tissues except for spleen and Subcutaneous Adipose Tissue (SAT), in which the orientation corresponding to \(\phi = 180^\circ\) showed the highest CV values. More specifically, for \(\phi = 0^\circ\) we found CV values ranging from 37% for the pancreas to 83% for eye lens; for \(\phi = 180^\circ\) we found CV values ranging from 42% for the brain white matter to 94% for the spleen; for \(\phi = 270^\circ\) we found CV values ranging from 52% for the cerebrospinal fluid to 94% for the eye vitreous humor.

4. Discussion and Conclusions

In this study, we assessed the exposure of a 9-months GA fetus to RF-EMF due to a 4G LTE tablet in realistic scenarios using stochastic dosimetry based on polynomial chaos theory. The combined use of deterministic dosimetry and polynomial chaos theory allowed obtaining a complete description of the level of exposure in 10000 possible positions of the tablet.

Among the three screen orientations of the tablet considered, the highest values of SAR induced in the fetal tissues, were found for \(\phi = 180^\circ\), i.e. when the antenna was nearest to the womb of the pregnant woman. This result, well expected, was in accordance with previous findings by Tateno et al. [8], in which the authors found that the induced SAR in male and female adults was higher when the antenna was nearer to the human body.

All the SAR values we found for the three screen orientations in the fetal tissues were significantly below the limits of the International Commission of Non-Ionizing Radiation Protection (ICNIRP) guidelines [17], for the general public exposure (0.08 W/kg).

The variation of the position of the tablet influenced significantly the exposure of the 9-months fetus, resulting in high CV values, both for SAR\(_{WT}\) than for pSAR\(_{1gT}\). This finding, confirming that also a small variation in the RF-EMF source location is influential for the induced SAR in the fetus, supported the need of providing descriptions of fetal exposure to RF-EMF in realistic scenarios affected by high variability. The polynomial chaos theory applied in this study to build surrogate models of SAR permitted a fast estimation of the variability of the exposure due to the variation in the tablet position. Therefore, the combined use of deterministic dosimetry and surrogate models was confirmed to be a powerful tool to evaluate the influence...
of the variation of the input parameters in a realistic exposure scenario, overcoming the problems of the high computational costs faced by deterministic dosimetry alone.

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7. References


