Statistical Study of SAR under Wireless Channel Exposure in Indoor Environment

Etude Statistique du DAS sous Exposition d'un Canal sans Fils en Environnement Intérieur

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Abstract

The development of wireless technologies led to the birth of numerical dosimetry for non-ionizing radiation. In another hand, studies of the wireless communication channel improve the knowledge of the electromagnetic environment. This paper studies the impact of wireless channel modelling, especially the cluster concept, on the exposure of a body model. An analytical expression of Whole Body Specific Absorption Rate SAR_{WB} mean and its standard deviation are developed and evaluated with different conditions of exposure in order to do a statistical study of SAR_{WB}. The point is to identify the parameters of the Wireless Channel which led to significant SAR_{WB} variations.

1 Introduction

The study of whole-body exposure to electromagnetic fields emitted by mobile terminals and base stations led to the development of standards and guidelines proposed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1]. Nowadays, numerical dosimetry took an important place into assessing compliance with these guidelines. Specific Absorption Rate (SAR) calculation is a target of numerical dosimetry. The improvement of human body models and the development of numerical methods taking into account accurate propagation modeling have fostered this domain of research. A deeper understanding of the electromagnetic environment emerged in the last decade in parallel with the emergence of high performance wireless systems. This knowledge enables to finely simulate the wireless channel parameters which define the exposure conditions. In the first part of this paper the wireless channel model in indoor environment will be presented. An analytical study will be developed in order to evaluate the SAR_{WB}. The analytical method will be presented and tested on a cylindrical body model. The parameters of the wireless channel which lead to significant variation of SAR_{WB} will be highlighted.

2 Wireless Channel Modelling in Indoor Environment

In [2], a Multi-Input Multi-Output (MIMO) indoor channel model is described. It is based on experimental data and identification algorithms. The algorithm of identification detects one by one the channel MultiPath Components (MPCs); the measurements are then statistically analyzed in order to define a stochastic channel model. This model, as the other state-of-the-art channel models, is based on the cluster concept: it has been proven that MPCs propagate as bundles named clusters. Inside each cluster, the MPCs are grouped together in the angular and delay domains (see figure 1). Only azimuthal angle is taken into account in our model. All waves are supposed to arrive in an azimuthal propagation plane as we can see in figure 1, which is a good first approximation in indoor environment.

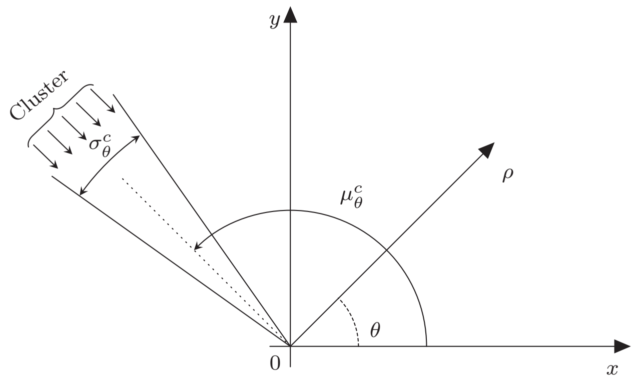

Figure 1: A cluster arriving at the origin of (x, y) axis system

The total electric field can be developed in terms of the MPCs:

$$E_{tot} = \sum_{c=1}^{N_c} \sum_{l=1}^{N_{MPCs}} E_{c,l}\left(\alpha_{c,l}, \theta_{c,l}, \varphi_{c,l}\right) \tag{1}$$

with N_c the number of clusters, N_{MPCs} the number of MPCs in each cluster and, respectively, $E_{c,l}$ the electric field, $\alpha_{c,l}$ the amplitude, $\theta_{c,l}$ the angle of incidence and $\varphi_{c,l}$ the phase of l-th MPC of c-th cluster. The amplitude follows a standard complex normal probability distribution.

$$\alpha_{c,l} \sim \sqrt{\frac{P_{cl}^c}{2N_{MPCs}}}(\mathcal{N}(0,1) + j\mathcal{N}(0,1)) \tag{2}$$

With $\mathcal{N}(0,1)$ a standard normal probability distribution and P_{cl}^c the power of the cluster. The Uncorrelated Scattering (US) assumption is made, based on the fact that the MPCs arriving from different directions are supposed to be uncorrelated:

$$\langle \alpha_{c,l}\alpha_{c',l'} \rangle = \frac{P_{cl}^c}{N_{MPCs}} \delta_{c,c'}\delta_{l,l'} \tag{3}$$

With $\langle \bullet \rangle$ the expectation of the random variable. The angles of incidence of MPCs are defined thanks to the angular spread and the angle of incidence of the cluster. The angles of incidence of MPCs, $\theta_{c,l}$, follows a normal distribution.

$$\theta_{c,l} \sim \mathcal{N}(\mu_\theta^c, \sigma_\theta^c) \tag{4}$$

The definition of a cluster requires that the number of MPCs must be significant otherwise the cluster has no sense (typically 20 MPCs in each cluster).

3 Analytical Study

The conditions of exposure are defined from the cluster model, which is stochastic. In that situation, the analysis of the exposure of a body must be done in a statistical sense. In the following development, all the clusters are made of the same number of MPCs, with random complex amplitude. The total field absorbed by the body can be split into its random part and its deterministic part:

$$E_{tot} = \sum_{c=1}^{N_c} \sum_{l=1}^{N_{MPCs}} \mathcal{E}_l(\rho, \theta, \theta_{c,l})\alpha_{c,l} \tag{5}$$

$\mathcal{E}_l$ represents the normalized electric field (deterministic part) due to the l-th MPC, ρ and θ are the cylindrical coordinates. In order to evaluate the mean of SAR_{WB} and his standard deviation:

$$|E_{tot}|^2 = \sum_{c,d}^{N_c} \sum_{l,m}^{N_{MPCs}} \mathcal{E}_l(\rho, \theta, \theta_{c,l})\mathcal{E}^*_m(\rho, \theta, \theta_{d,m})\alpha_{c,l}\alpha^*_{d,m} \tag{6}$$

$$\langle|E_{tot}|^2\rangle = \sum_{c,d}^{N_c} \sum_{l,m}^{N_{MPCs}} \mathcal{E}_l(\rho, \theta, \theta_{c,l})\mathcal{E}^*_m(\rho, \theta, \theta_{d,m})\langle\alpha_{c,l}\alpha^*_{d,m}\rangle \tag{7}$$

Under US assumption:

$$\langle|E_{tot}|^2\rangle = \sum_{c=1}^{N_c} \sum_{l=1}^{N_{MPCs}} |\mathcal{E}_l(\rho, \theta, \theta_{c,l})|^2 \frac{P^c_{cl}}{N_{MPCs}} \tag{8}$$

So, the mean value of whole body SAR is given by

$$\langle SAR_{WB}\rangle = \frac{1}{m}\sum_{c=1}^{N_c} \frac{P^c_{cl}}{2N_{MPCs}} \sum_{l=1}^{N_{MPCs}} \int_V \sigma|\mathcal{E}_l(\rho, \theta, \theta_{c,l})|^2 \mathrm{d}V \tag{9}$$

Its variance is given by

$$\sigma^2_{SAR_{WB}} = \langle {SAR_{WB}}^2\rangle - \langle SAR_{WB}\rangle^2 \tag{10}$$

It is necessary to determine $\langle {SAR_{WB}}^2\rangle$, hence $\langle|E_{tot}|^4\rangle$:

$$\langle|E_{tot}|^4\rangle = \sum_{c,d,e,f}^{N_c} \sum_{l,m,n,p}^{N_{MPCs}} \mathcal{E}_l(\rho, \theta, \theta_{c,l})\mathcal{E}^*_m(\rho, \theta, \theta_{d,m})\mathcal{E}_n(\rho, \theta, \theta_{e,n})\mathcal{E}^*_p(\rho, \theta, \theta_{f,p})\langle\alpha_{c,l}\alpha^*_{d,m}\alpha_{e,n}\alpha^*_{f,p}\rangle \tag{11}$$

Under US assumption, $\langle|E_{tot}|^4\rangle - \langle|E_{tot}|^2\rangle^2$ becomes

$$\langle|E_{tot}|^4\rangle - \langle|E_{tot}|^2\rangle^2 = \sum_{c,d}^{N_c} \sum_{l\neq n}^{N_{MPCs}} |\mathcal{E}_l(\rho, \theta, \theta_{c,l})|^2|\mathcal{E}_n(\rho, \theta, \theta_{c,n})|^2 \left(\frac{P^c_{cl}}{N_{MPCs}}\right)^2 \tag{12}$$

So that

$$\sigma_{SAR_{WB}} = \frac{\sigma}{2m}\sum_{c,d}^{N_c} \frac{P^c_{cl}}{N_{MPCs}} \left[\int_V \sum_{l\neq n}^{N_{MPCs}} |\mathcal{E}_l(\rho, \theta, \theta_{c,l})|^2|\mathcal{E}_n(\rho, \theta, \theta_{d,n})|^2 \mathrm{d}V\right]^{\frac{1}{2}} \tag{13}$$

It is worth noting that results (9) and (13) do not depend on $\alpha_{c,l}$.

4 Cylindrical Body Model

In order to study the impact of the cluster concept on the SAR a simple body model has been chosen. It is made of three homogeneous cylinders which play the role of a trunk and two arms. This cylindrical body model is represented in figure 2 in two dimensions and seen from the top. The cylindrical body model is exposed to a TM^z electric field incident from x axis. The complex electric permittivity is defined by

$$\tilde{\varepsilon}_r = \varepsilon_r - j\frac{\sigma}{\varepsilon_0\omega} \tag{14}$$

with ε_0 the free space permittivity and ω the angular frequency. The physical and electrical properties of the cylindrical body model are presented in table 1 [3]. The study was done at frequency $f = 2.45$ GHz.

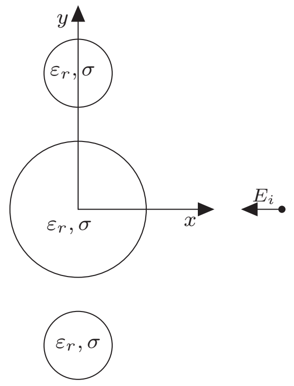

Figure 2: Cylindrical body model exposed to an incident electric field

Table 1: Physical and Electrical properties

Trunk length (m)	1.80
Trunk radius(m)	0.15
Arms length (m)	0.80
Arms radius (cm)	3.6
Distance arm-trunk (cm)	6.0
Density (kg/m^3)	523.4
Relative permittivity	38.57
Conductivity (S/m)	1.27
Relative Permeability	1

The electric field inside the body model was computed by using an iterative method described in [4].

5 Results

5.1 Scenarios

In order to analyse the impact of the wireless channel parameters on the SAR_{WB} two different cases are considered. They are described in table 2. In both cases, the body model is exposed to a cluster, its power is set to one watt.

Table 2: Different configurations for studying channel parameters impact

	Case 1	Case 2
$\alpha_{c,l}$	random	random
μ_θ	fixed to 0°	from 0° to 90°
σ_θ	from 5° to 40°	fixed to 5°
$\theta_{c,l}$	fixed	fixed

5.1.1 Case 1

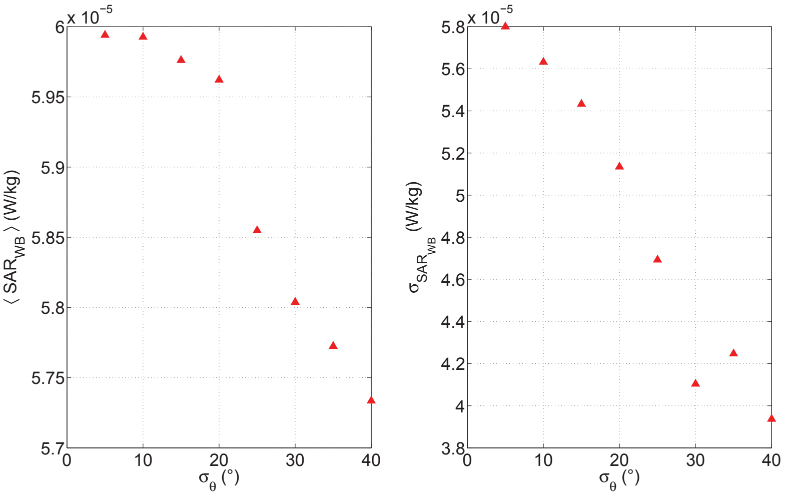

Figure 3: $\langle SAR_{WB} \rangle$ and his standard deviation as a function of the cluster angular spread

As seen in Figure 3, the mean SAR_{WB} and its standard deviation are found to be decreasing while the angular spread increases. The fact that the level of exposure is high when the angular spread is small is due to constructive interference of the MPCs on average in that case. The order of magnitude of standard deviation and mean are the same, meaning that the stochastic nature of exposition cannot be neglected.

5.1.2 Case 2

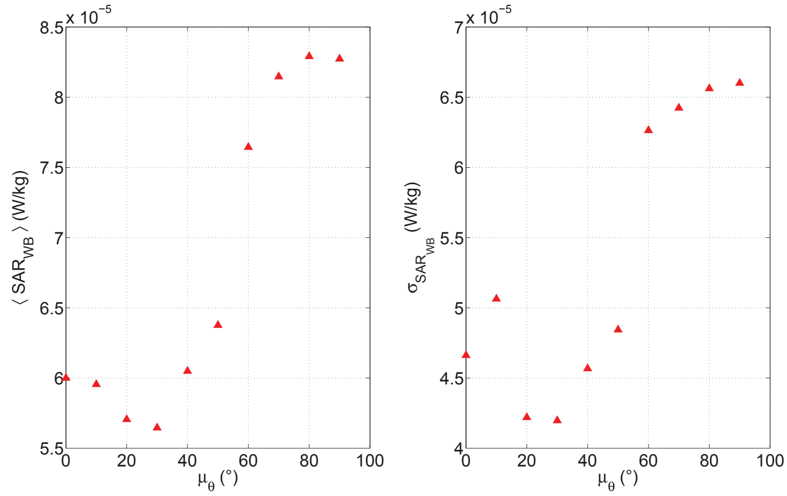

Figure 4: $\langle SAR_{WB} \rangle$ as a function of the cluster angle of incidence

It can be observed in figure 4 that the $\langle SAR_{WB} \rangle$ and his standard deviation increases when the angle of incidence increases for an angular spread fixed to 5°. The worst case of exposure is at 90° because the entire cluster is absorbed by the arm. We can also notice that the second case lead to significant fluctuation of $\langle SAR_{WB} \rangle$ and its standard deviation.

6 Conclusion

In this paper, firstly, analytical expressions of $\langle SAR_{WB} \rangle$ and its standard deviation has been derived. The impact of wireless channel parameters has been studied and led to significant variation on $\langle SAR_{WB} \rangle$.

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