STATISTICAL INDOOR PROPAGATION ANALYSIS FOR BROADBAND PERSONAL AREA NETWORKS

Ph. De Doncker(1), M. Hélier(2), W. Tabbara(3)

(1) ***Université Libre de Bruxelles, CP 165/51, Av. Roosevelt 50, 1050 Bruxelles, Belgium, pdedonck@ulb.ac.be***

(2) ***Supélec/DRE, Plateau de Moulon 91192 Gif-sur-Yvette, France, Marc.Helier@supelec.fr***

(3) ***As (2) above, but tabbara@lss.supelec.fr***

ABSTRACT

To study the indoor propagation in the framework of BPANs located inside a single furnished and populated room, a statistical approach has been developed to take into account the variability in the geometry of the transmission channel and in the location and orientation of the transmitter. The numerical method used in this study is hybrid in the sense that near-field diffraction has been computed thanks to the MoM while the propagation inside the room has been carried out thanks to a ray-tracing algorithm. Statistical results have been obtained concerning on the one hand the transmission channel characteristics and on the other hand the optimization of the receiver localization and orientation.

INTRODUCTION

With the emergence of 3G communication systems, the future of wireless networks is more and more conceived in a hierarchical way: depending on the mobility and on the data rate needed, the user will connect either on a Broadband Personal Area Network (BPAN), on a Local Area Network or on the UMTS network.

The BPANs form a class of wireless networks aiming to provide very high data rates ($>$ 100 Mb/s in the near future) at short distances (a few meters). Typically, in an indoor environment the range of a BPAN will be of the order of the dimensions of a room. The user will connect to the BPAN thanks to his GSM, PDA or laptop and in each room, a base station will be placed in order to insure the management of the local BPAN. In this case the electromagnetic propagation between the transmitter and the receiver inside a single room is difficult to simulate for two reasons:

1. Two orders of magnitude exist: on the one hand the user antenna is always located near an important obstacle like the body of the user or the screen of a laptop, and on the other hand the typical room dimensions are always much greater than the wavelength of the transmitted signal. Consequently it is necessary to use an hybrid method: near the user antenna the Method of Moments (MoM) must be considered to estimate the influence of the obstacles and far from this antenna an asymptotic method like the GTD can be applied.
2. The geometry of the transmission channel is very complex since a room always contains several kind of obstacles: tables, cupboards, or people for instance. Moreover the distribution of these obstacles is different in each room and a propagation simulation for a given environment will only give very partial information on the transmission channel. A statistical approach must then be considered: the propagation parameters have to be determined in a statistical way thanks to simulations done on a very important number of cases.

We propose to use an hybrid MoM/Ray-tracing method to carry out a statistical analysis of the indoor propagation in a single furnished and populated room in the framework of BPANs.

THE STATISTICAL METHOD

In a first step, the effects of near-field obstacles on the radiated fields are taken into account thanks to a potentials based Method of Moments [1]. The antenna is supposed to be a vertical $\lambda/2$ electric dipole and two kinds of obstacles are considered: the user body (modeled by an homogeneous cylinder) and the screen of a laptop. In our approach, the effect of the near-field obstacles must be computed only once since the relative position of the antenna and of these obstacles is always the same. The reaction of the obstacles on the antenna has been considered as a second order effect and it has not been taken into account in the computation of the radiated fields.

Once the fields diffracted by the near-field obstacles are known, the user antenna and these obstacles are considered as one entity whose radiated fields are the sum of the antenna original fields and of the diffracted fields. Then, the actual propagation inside the room is computed thanks to a ray-tracing algorithm based on the image theory [2]. At this stage, three kinds of far-field obstacles are introduced: tables, cupboards located along the walls and people. To maximize their influence, the tables and cupboards have been assumed to be perfectly conducting and the people have been modeled by perfectly absorbing cylinders.

To obtain statistical results, the location of the obstacles inside the room is randomly fixed (for a chosen maximum total number of obstacles: tables, cupboards and people). The position of the receiver is then chosen and the transmitter (the user antenna) is randomly positioned and oriented inside the room. Thanks to the radiated fields computed with the MoM, the ray-tracing algorithm determines the direct field and the reflected fields on the walls and on the obstacles. All these rays are summed up at the receiver (assumed to be a $\lambda/2$ electric dipole) and the broadband parameters of the transmission channel are determined, namely the impulse response $h(t)$ defined by

$$h(t) \;=\; \sum_{k=1}^{N} a_k \, e^{j\theta_k} \, \delta(t - t_k) \tag{1}$$

if the receiver gets N rays of amplitude a_k, phase θ_k and arrival time t_k, and also the delay spread Δ given by

$$\Delta \;=\; \sqrt{\frac{\sum_k \,(t_k - \tau_m - t_1)^2 a_k^2}{\sum_k \, a_k^2}} \tag{2}$$

where τ_m is the mean excess delay:

$$\tau_m \;=\; \frac{\sum_k \,(t_k - t_1) a_k^2}{\sum_k \; a_k^2} \tag{3}$$

The computation is then restarted for another environment and/or another position of the transmitter. To obtain stable statistical results, a minimum of 10.000 simulations have to be carried out for a fixed position of the receiver or for a fixed maximum number of obstacles and to speed up the ray-tracing process, a maximum of three reflections have been considered but no diffraction.

RESULTS

Numerous statistical results have been obtained concerning on the one hand the distributions of the room impulse response, of the delay spread and of the coherence bandwidth and on the other hand the distributions of the path-loss and of the received power, both as a function of the receiver position and of the number of obstacles. In all our simulations, a room of dimensions (6m,4m,3m) has been considered with walls of thickness 10 cm and relative permittivity 5.2-j0.3. The ceiling and the floor have been supposed to be 20 cm thick with a relative permittivity 7.9-j0.9 and one wall has been supposed to be made of glass of thickness 0.5 cm and relative permittivity 4. The receiver has been placed at 50 cm of the wall $x = 0$, at $y = 2m$ and with various heights. The transmitter is a $\lambda/2$ electric dipole either alone or near the user body or the screen of a laptop. It emits at 2.45 GHz.

The main goal of our work was to study which is the exact effect of furniture and people on the transmission channel simulation for indoor propagation. Fig. 1 shows for instance two typical room impulse responses obtained either in the empty room or in the furnished and populated room. It is clear that the furniture effect is to empower certain rays so that

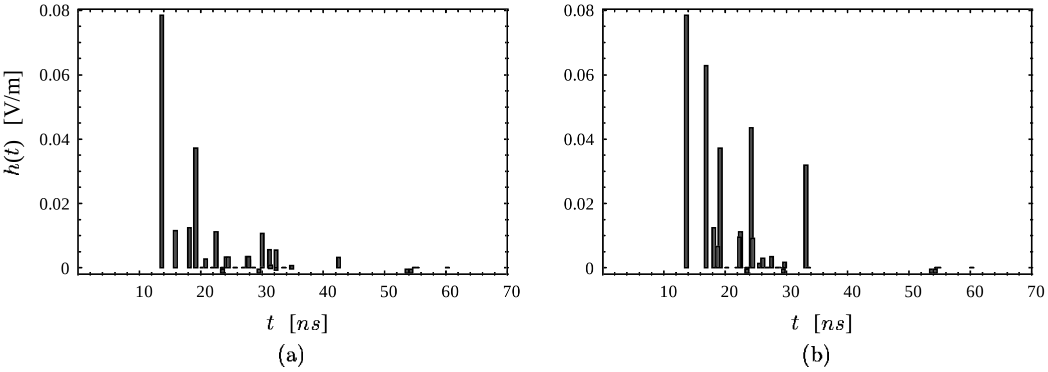

Figure 1: Typical impulse response (a) empty room (b) furnished room

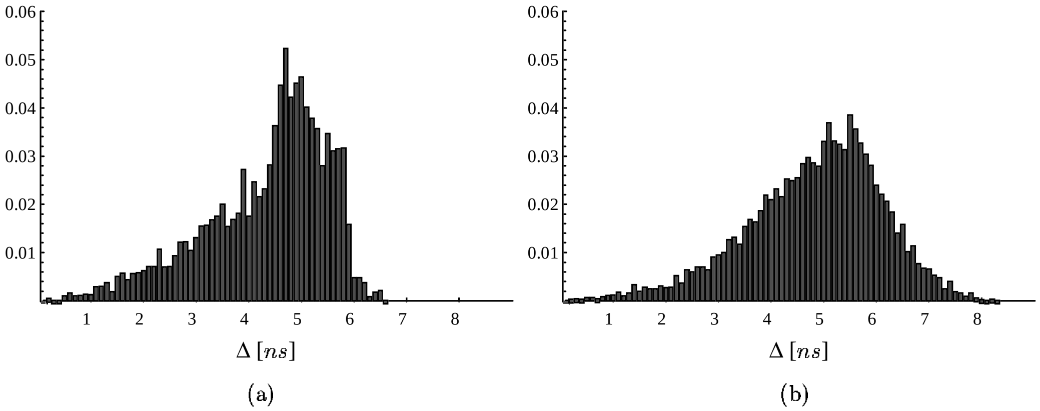

Figure 2: Statistical distribution of the delay spread (a) empty room (b) furnished room.

even if the obstacles block part of the rays, the delay spread of the channel is increased in this case by about 35% due to the presence of the metallic cupboards. On Fig. 1 for instance Δ varies from 4.2 ns for the empty room to 6.3 ns for the furnished one.

Fig. 1 only shows one example, and to draw more general conclusions, the delay spread has been computed for a random position of the transmitter inside the room (located at heights between z =1 and 2 m) for a receiver located at $z = 1.4$ m either in the case of the empty room or in the case of a randomly furnished and populated one. Fig. 2 shows the statistical distribution of Δ in both situations. The 98th quantile of these distributions are respectively 6.2 ns and 7.4 ns, a difference of about 15%. The propagation simulations neglecting the obstacles must hence be corrected by this factor to obtain satisfactory results.

It was also interesting to see if the receiver position and the amount of furniture have an impact on the delay spread of the transmission channel. Fig.3 shows the quotient χ of the 98th quantile of Δ for the empty room and of the 98th quantile of Δ for the furnished room as a function of the relative amount of furniture placed inside the room called F_r. If the receiver is located below the furniture level, it is possible to see that the furniture effect on the transmission channel is very important and that it must be taken into account in the simulations. On the other hand, if the receiver is located above the level of furniture, quite surprisingly, Δ is rather constant whatever the amount of furniture. In practical applications, it seems hence most important to locate the receiver as near as possible to the ceiling. Once this position chosen, the receiver orientation influence must still be studied. Fig. 4 shows the 2nd quantile of the received power and the 98th quantile of the delay spread as a function of the orientation of the receiver (angle θ of the receiver with respect to the vertical axis). The receiver has been assumed to be a lossless, perfectly matched $\lambda/2$ electric dipole located at a height of 2.7 m, and the transmitter is a vertical $\lambda/2$ electric dipole (ERP=5mW, f=2.45 GHz) located on the back of a laptop. It is

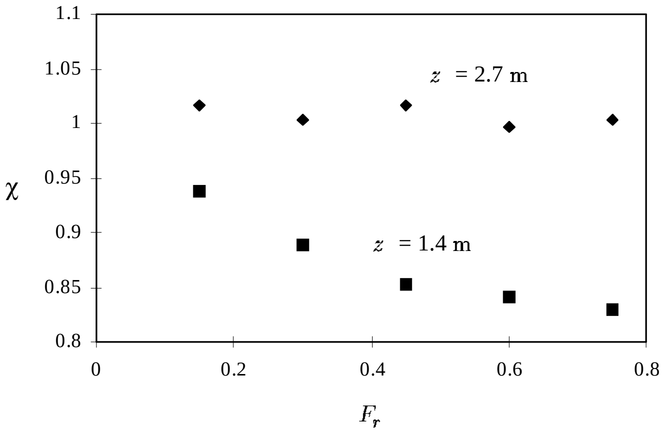

Figure 3: penalty coefficient χ vs. the relative amount of furniture inside the room for two receiver locations.

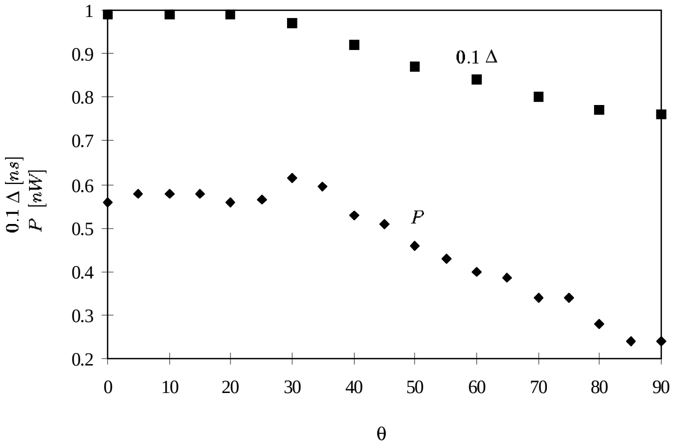

Figure 4: 2nd quantile of the received power P and 98th quantile of the delay spread Δ as a function of the orientation of the receiver (angle θ of the receiver with respect to the vertical axis).

possible to see on this figure that to reduce the delay spread, the receiver has to be tilted. On the other hand, to enhance the received power, the receiver has to be placed vertically. A compromise can be found by choosing θ around 30 or 40 degrees and the best receiver orientation seems very sensitive to the transmitter orientation.

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