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Study of rows of seats effects on indoor propagation at 2.4 GHz

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Abstract— **The need of new functions to optimize train or building management in term of energy consumption, comfort or people information is increasing and then Wireless Sensor Network (WSN) can be a low cost solution. Indeed, WSN can be implemented without great changing in the infrastructure and some technologies are low energy. The goal of this paper is to study the seats effects on the propagation of a 2.4GHz signal inside a train or a building. In order to analyze the effect of rows of seats, a first measurement campaign has been deployed in a corridor. In this paper, experimental results are compared to simulation ones using geometrical Optics. Various parameters have been studied such as seats absorption or wave-guide effect of the corridor. Statistical analysis of the measurement is also done in order to find the distribution law characterizing such channel.**

Index Terms— **WSN; Channel Propagation; Indoor Environments, Path loss; Geometrical Optics**

I. INTRODUCTION

Now a day, the Wireless Sensor Networks (WSN) are increasingly deployed for more and more applications in building and industry for energy management, building safety, etc...

Wireless communication systems are based on electromagnetic waves as transmission medium. During the propagation between the transmitter and the receiver, the waves interact with all elements present in their environment.

In building [1,2] or in transport, especially trains, metro, buses, aircraft [3,4], etc., there are indoor configurations which can be represented by parallelepiped containing obstacles like rows of chairs. These obstacles can have a great impact on the emitted signals quality. For these reasons, before deploying WSN in this kind of environment, preliminary studies based on simulation and measurements are essential to determine the risks of electromagnetic disturbances on electronic equipments or the coexistence between radio systems. In the literature, several propagation channel estimation methods are proposed. Many types of simulation model exist like deterministic models, statistical models and hybrid models.

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The deterministic models are based on a precise description of the propagation environment in order to take into account the obstacles effects [5]. Two methods can be proposed to achieve this description: a classical approach and an asymptotic one. The classical approach is based on the resolution of Maxwell's equations. Then, various methods can be used like the Finite Difference Time Domain (FDTD) or the Method Of Moment (MoM) [6].

The asymptotic approach can be used when the wavelength is small compared to the obstacles dimensions or when small obstacles can be neflected. In that case, the wave propagation can be studied as optical propagation and then various method can be used like Geometrical Optics (GO) and Geometric Theory of Diffraction (GTD) or Uniform Theory of Diffraction (UTD). Thus, the deterministic models allow to consider the entire geometrical and electrical complexity of the system in order to provide precise results. However, for their implementations, deterministic methods require the use of powerful computer and lot of times of calculations to model an environment.

In this paper, we characterize the propagation channel inside a corridor. The purpose of this study is to see the impact of the rows of seats on the signal propagation at 2.4 GHz. For this, we have carried out a measurement campaign and compared the obtained results with simulation ones based on geometrical optics.

II. THEORETICAL BACKGROUND

A. Geometrical Optics

Geometrical Optics allows calculating the electromagnetic field issued from a source (E) and received at a point (R) using the ray tracing. This technique can be used when the obstacles present in the vicinity of the rays are greater than the wavelength λ = c / f with c the celerity of the light and f the signal frequency. As an example Fig.1 shows few rays between the source (E) and the receiver (R) .

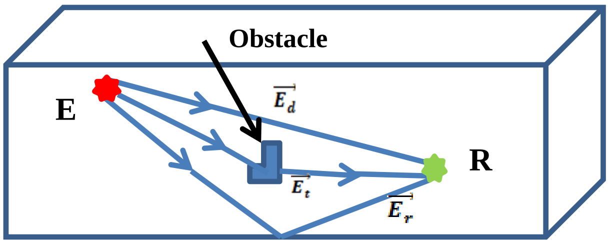

Fig. 1. Synoptic of few rays between transmitter and receiver

The received electric field $\vec{E}$ is the vector addition of the line of sight field, the reflected fields, the transmitted fields and hybrid fields (combining transmission and reflection) and can be expressed (1) :

$$\vec{E} = \vec{E}_d + \Sigma \vec{E}_t + \Sigma \vec{E}_r + \Sigma \vec{E}_{rt} \quad (1)$$

Where

$\vec{E}_d$ is the line of sight field

$\Sigma \vec{E}_t$ the vector sum of the transmitted fields

$\Sigma \vec{E}_r$ the vector sum of the reflected fields

$\Sigma \vec{E}_{rt}$ the vector sum of the hybrid fields (reflected and transmited fields) .

B. Reflected and transmitted fields

First, let us consider only one plane of reflection. The plane of incidence is defined by the ray and a vector normal to the plane of reflection. Then, an electric field vector $\vec{E}$ can be decomposed into two vectors relative to this plane of incidence (2):

$$\vec{E}_i = \vec{E}_{i\perp} + \vec{E}_{i//} \quad (2)$$

Where

- $\vec{E}_{i//}$ is the component of the field in the plane of incidence.

- $\vec{E}_{i\perp}$ is the component of the field normal to the plane of incidence.

And then the refleted $\vec{E}_r$ and transmited $\vec{E}_t$ fields can be also decomposed in the same way (Fig.2).

$$\vec{E}_r = \vec{E}_{r\perp} + \vec{E}_{r//}$$
$$\vec{E}_t = \vec{E}_{t\perp} + \vec{E}_{t//} \quad (3)$$

Fig.2 shows two configurations of reflected and transmitted fied. The first one (a) when the field $\vec{E}$ is normal to the plane of incidence and the second when the field $\vec{E}$ is in the plane of incidence. The reflection coefficient can be given by (4):

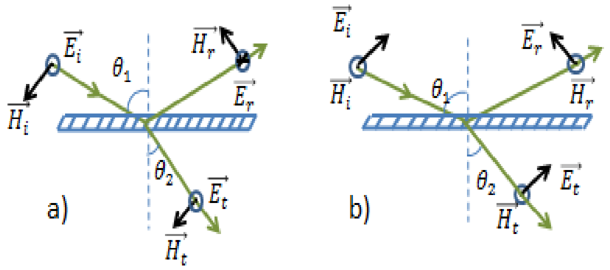

Fig. 2. a) E field normal to plane of incidence

b) E field in the plane of incidence

$$R = \frac{E_r}{E_i} \quad (4)$$

And the transmission coefficient by (5)

$$T = \frac{E_t}{E_i} \quad (5)$$

When the field $\vec{E}$ is normal to the plane of incidence (Fig.2-a) the reflection coefficient and transmission coefficient are given by (6), (7) ,[7],

$$R_{E\perp} = \frac{\cos\theta_1 - \sqrt{\varepsilon_r^* \quad \sin 2\theta_1}}{\cos\theta_1 + \sqrt{\varepsilon_r^* \quad \sin 2\theta_1}} \quad (6)$$

$$T_{E\perp} = \frac{2\cos\theta_2}{\cos\theta_2 + \sqrt{\varepsilon_r^* - \sin 2\theta_1}} \quad (7)$$

Where θ_1 is the angle of incidence and θ_2 the angle of refraction(Fig.2).

When $\vec{E}$ is parallel to the plane of incidence (Fig.2-b), the reflection and transmission coefficients are given by (8),(9), [7].

$$R_{E//} = \frac{\varepsilon_r^* \cos\theta_1 - \sqrt{\varepsilon_r^* \quad \sin 2\theta_1}}{\varepsilon_r^* \cos\theta_1 + \sqrt{\varepsilon_r^* \quad \sin 2\theta_1}} \quad (8)$$

$$T_{E//} = \frac{2\cos\theta_2 \quad \sqrt{\varepsilon_r^*}}{\varepsilon_r^* \cos\theta_2 + \sqrt{\varepsilon_r^* \quad \sin 2\theta_1}} \quad (9)$$

Where ε_r^* is the complex relative permittivity of the reflection medium (10) [8]

$$\varepsilon_r^* = \varepsilon_r - i\frac{\sigma}{\omega\varepsilon_0} \quad (10)$$

ε_r and σ are respectivily the relative electric permittivity and the conductivity of the medium and ε_0 the electric permittivity of the vaccum.

In the next paragraphs, we will consider the set of reflections on all obstacles in the measurement vicinity.

C. The simulation tool SimuEM3D

The simulation has been realized with simuEM3D [7] tool, developed by a staff of IEMN laboratory of the University of Lille (France) which allows simulating the electromagnetic fields in 3D. This platform uses Geometrical Optics. For our application, the diffraction effect was not simulated, since, in the corridor, diffraction phenomena are negligible compared to the others (line of sight or reflected). The main algorithm of SimuEM3D software allows to calculate the received signal as a vector sum of finite number of rays from a source S; to simulate the experimental environment in 3D, it takes into account the material properties such as the conductivity and the permittivity of each element present in the scenario. The position and frequency informations are also considered for the transmitter and the receiver. The radiation patterns of the antennas are not taken into account in our application, but it can be easily introduced as an antennas factor function of the angle of the considered ray.

III. Methodologie

D. Measurement Setup

To characterize the seat effect on the radio channel in indoor environment at 2.4 GHz, we have used a frequency measurement with Vector Network Analyzer (VNA) between one biconical antenna and a monopole.

For this experiment, the measurements were carried out in corridor environment with length L = 18m , width l = 2.8m and height H = 2.5m. The walls of the corridor are in concrete. To determine the rows of seat effects, we have placed the chairs in the corridor as presented in Fig.3 and Fig.4 . In this scenario, the transmitter is located at 2.18m from the corridor entrance at a height H=2m. The received power was measured every 10cm along four lines Pr0, Pr1, Pr2 and Pr3 as illustrated in Fig.4:

-Pr0 the receiver is moving each 10 cm in the passage.
-Pr1 the receiver is moving each 10 cm very close to the right wall
-Pr2 the receiver is moving each 10 cm between the left chairs
-Pr3 the receivers is moving each 10 cm very close to the left wall.

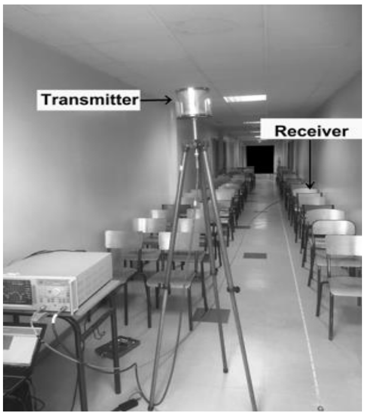

Fig. 3. Scenario of this experiment

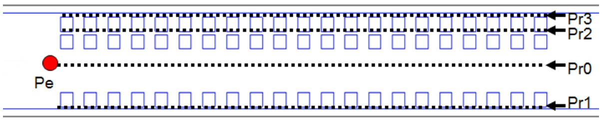

Fig. 4. Measurements Plane

E. Simulation Setup

Fig.5 shows the simulation environment and all the considered rays in a 3D view and a top view. The environment is constituted by a the corridor with concrete floor, brick walls and ceiling board. The corridor is modeled by rectangular parallelepiped of length L=18m width l=2.8m and height H=2.5m. Inside the corridor three rows of chairs are placed. Each chair is represented by two perpendicular slabs of wood. The vertical slab dimensions are length L=42cm and width l=36 cm and thickness t=0,5 cm. The horizontal slab dimensions are length L=36cm and width l=36 cm and thickness t=0,5 cm. Table I shows the characteristics of the different objects of the scenario.

Material	Relative permittivity	Conductivity S/m at 2.4GHz
Corridor Floor	5.31	0.0662
Corridor Wall	3.75	0.012
Corridor Ceiling	1.5	0.0215
Chairs	1.99	0.012

TABLE I. Material characteristics @ 2.4 GHz [9]

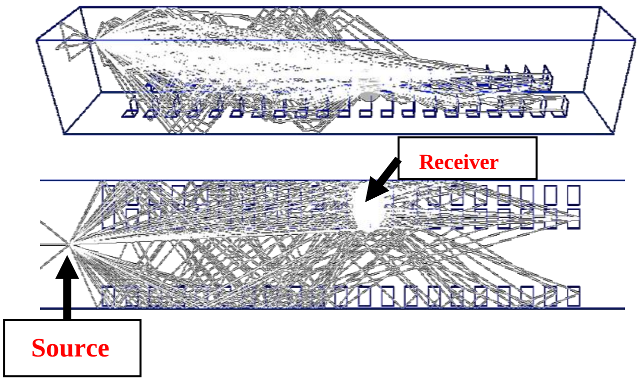

Fig. 5. Modeling SimuEM3D and example of ray paths between a source S and a receiver Results

IV. Results and Comparaison

Fig. (6, 7, 8) show respectively the comparison between measurements of the received power at the considered position Pr1, Pr2 and Pr3 and the simulation in the same configurations. Table II shows the mean values and standard deviations of each position.

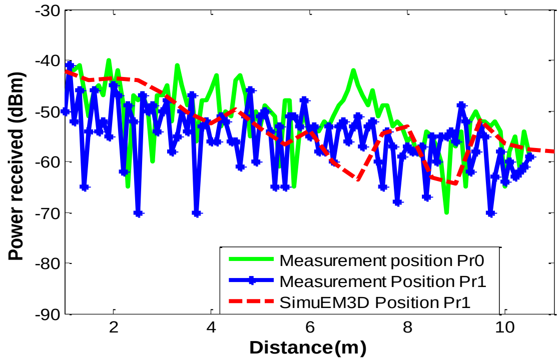

Fig. 6. Measurement Pr0 vs Pr1 vs SimuEM3D Pr1

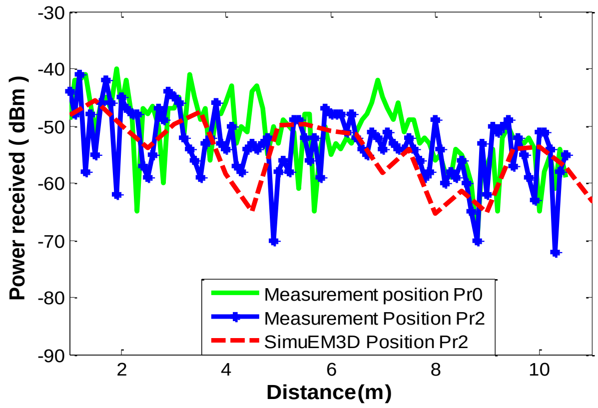

Fig. 7. Measurement Pr0 vs Pr2 vs SimuEM3D Pr2

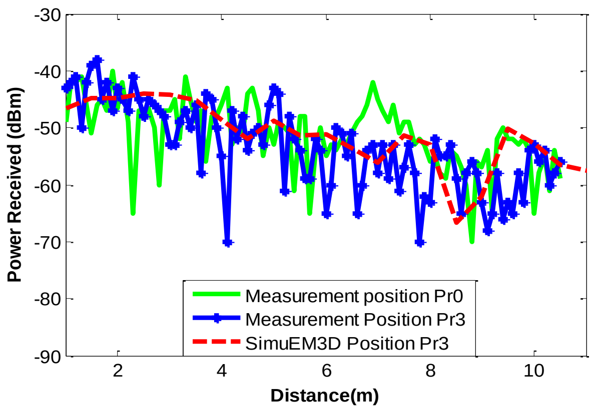

Fig. 8. Measurement Pr0 vs Pr3 vs SimuEM3D Pr3

Scenario	Mean Pr (dBm)	Deviation σ(dB)
Pr1	-55.35	5.91
Pr2	-53.34	5.75
Pr3	-53.26	7.40

TABLE II. Statistical results of Scenario

Fig.9 shows the superposition of the measurements of all positions Pr0, Pr1, Pr2, Pr3. The comparison of the curves shows a very small variation in the received power as a function of the distance between position Pr0, Pr1, Pr2, Pr3. Whatever the position of receiver (Pr0, Pr1, Pr2, Pr3) the received power curve is similar. Thus we can confirm that the seats have a negligible effect on the received signal.

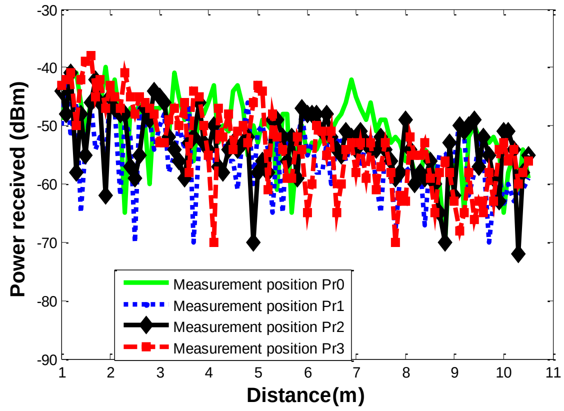

Fig. 9. Measurement Pr0 vs Pr1 vs Pr2 vs Pr3

The comparison of simulation values with the measured values for each position (Fig.6, Fig.7, Fig.8) shows a consistency between the simulation and the measured values. Then we can say that the parameters used in the simulation are good and the measurement environment is well modelled.

Fig.10 shows the result of comparison of received power between the simulations Config1, Config2, Config3,and Config4.

-Config1 represents the simulation results in an empty corridor without chair.
-Config 2 represents the simulation results in corridor with two symmetrical rows of chairs.
-Config3 represents the simulation results in corridor with four rows of chairs with two rows on each side.
-Config 4 is that shown in Fig.2.

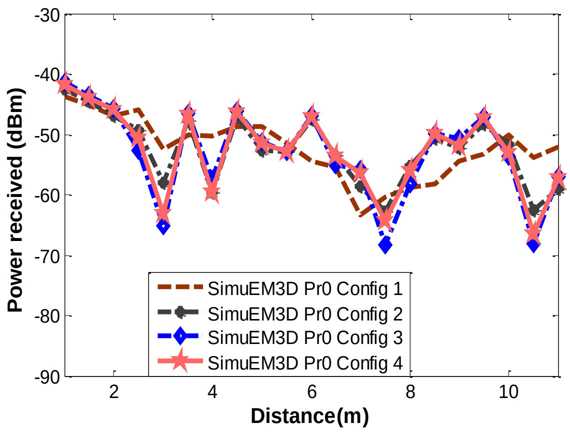

Fig. 10. SimuEM3D Config1 vs Config2 vs Config 3 vs Config4

The comparison between the curves in Fig. 10 shows that they are nearly the same whatever the presence or not of chairs in the corridor. Also, if there are two, three or four rows in the corridor the results are the same. The bows that we see on the curves are due the signal resonance on the corridor walls because the bows are also present in Config1. This comparison allows us to confirm that the rows of seats have negligible effects on the received signal compared to the wave guide effect of the corridor.

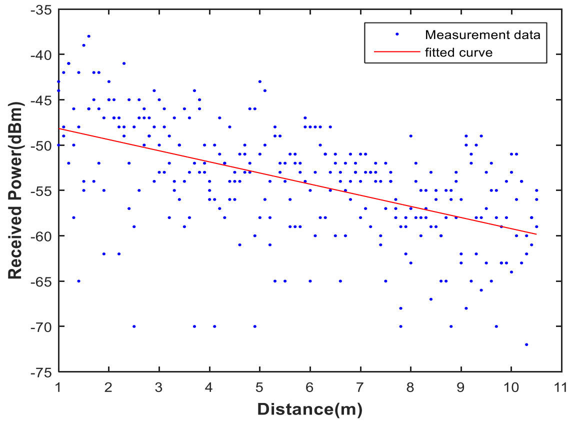

Fig. 11.Received power with regression fited curve

Fig.11 shows the cloud of points measured in the corridor for all measurements. We can consider that these measurements are randomly. However, the random phenomena generally follow statistics laws. In the literature, Probability Density Function (PDF) can be used to model or predict the signal received in indoor or outdoor environment [10].

Fig.12 shows the histogram standardized of all measurements (dBm) compared to a Log Normal distribution.

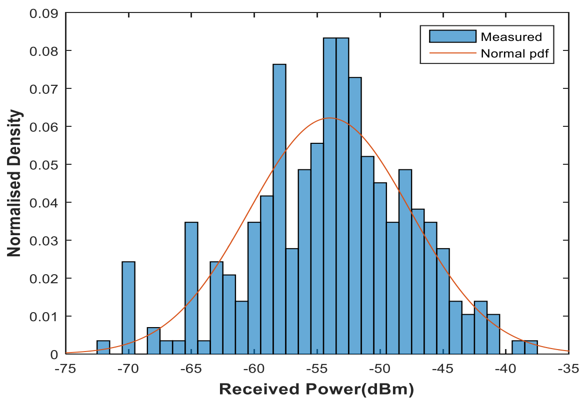

Fig. 12.Received power distribution

PDF of the Log Normal distribution is defined by (9):

$$f(x) = \frac{1}{x.\sigma\sqrt{2.\pi}} e^{\frac{(\ln(x) \quad \mu)^2}{2.\sigma^2}} \qquad (9)$$

Where x is vector mesurements range values, μ is the mean value of this vector and σ the standard deviation.

Log Normal distribution is plotted using the average and the standard deviation obtained from the measurements. From the statistical study, we obtained mean μ = -54 dBm and standard deviation σ = 6.45 dB. It may be noted that the mean and standard deviation of the measurement values are calculated in linear (mW) and then reconverted into dB and display. We can see that the measurements follow the normal law. For more accuracy on this statistical analysis, it would be necessary to get more measurements.

V. Conclusion

The results presented in this paper have been demonstrated the capability to simulate the propagation inside a corridor with an optical approach; indeed simulation results are similar to measured ones. The study can be extended to various environment without measurement, using the simulation tools. In the studied configuration, it has been demonstrated that the wave-guide effect of the corridor is more important than the absorption or reflection of seats on the signal propagation. A statistical analysis of the measurements has shown that the received signal along the corridor is following Log Normal law. The next steps will be the measurement inside a train or a tram in order to compare the results with this preliminary results. The measurements campaign in classroom could be also interesting because the wave guide will be reduced. The study of human body impact on the propagation in these configuration could be also interesting.

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