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Outdoor to Indoor Propagation - An Analysis of Location Variability at 2600 MHz

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Abstract – The paper presents an analysis of the RF signal transmitted from an outdoor base station (BS), in order to find its spatial distribution for an indoor location, based on measurements data and a Matlab simulation developed by the authors.
Keywords: indoor measurements, prediction.

I. INTRODUCTION

A lot of technical papers are consecrated to the behavior of the electromagnetic fields propagating in micro-cells and indoor locations, with signal variations both in time and in space (for a relative displacement). The variations recorded in different moments of time are determined by the variant character of the propagation path, by movement of people or objects that interact with electromagnetic wave (cars, elevators, doors) in the observation point [1]. The signal variations due to the changing position of the receiver from transmitter can be divided in two categories, depending on the distance covered by receiver relative to wavelength. For distances larger than a few ten of wavelengths, signal fading is generic named large scale fading, is distance dependent, and can be statistically modeled by a log-normal distribution. For small distance displacements, signal variation is called small scale fading and is the result of combination of several waves, arrived in the reception point on different paths due to multiple diffractions and reflections. In this kind of situations, the signal power can vary above 20 dB for a relative displacement of a few wave lengths [2]. Usually, the small scale fading is statistically modeled with Rayleigh probability density functions.

The indoor propagation scenario is more “unfriendly” comparative to the outdoor case, and the RF signal variations due to multipath propagation are strong. The goal of this study is not to develop an indoor propagation model, but to verify the RF signal spatial distribution, identifying the factors that influence the signal strength inside a building, when the transmitter is outside, in line of sight (LoS) with the building.

II. PREMISES OF THE STUDY

This study started from the previous one whose purpose was to determine through measurements, the path loss ‘gain’ that appears due to the increase of receiver height, when the receiver is placed at different floors of a building. The building where the measurements were made is a three-storied offices building. The RF signal came from a mobile communications BS operating at 2630 MHz, with 35 dBm transmitted power and a 17 dBi antenna gain. The BS antenna was at 15 m height from the ground and about 130 m (straight line) from building (Fig. 1).

If the measurements are made inside a building at different floors with various configurations of the offices (different positions and dimensions of the separating walls, furniture, etc.), the question was which is the proper position of the receiver inside an office, in order to have measurements

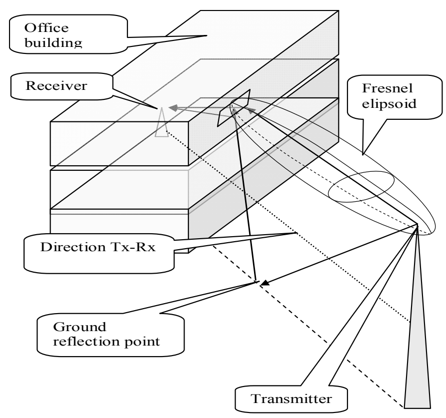

Fig.1. The geometry of the measurement site

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reproducibility and compare the measurements for establish a height gain.

At high frequencies, small displacements and receiver relative position change means, especially for indoor locations, a dramatic change of the propagation conditions.

The empirical or semi-empirical propagation models have different approaches in the attempt of establish the path loss median attenuation. Usually it starts from simplifying hypothesis related to the radio wave interaction with the obstacles along the propagation path.

The COST 231 model [3] for instance considers that the radio waves penetrate the walls found in line of sight with the BS. On the other hand, in [4] it presumes that the received power is the sum of two rays arrived on different paths, suffering diffractions and reflections along the propagation path.

Our hypothesis was similar with the idea found in [5]. We presumed that a large percent of the received electrical field into a point inside an office is the result of wave propagation through building openings. In our case, the outside walls of the building had large windows.

III. EXPERIMENTAL RESULTS

A. The measurements

The presumption that the window is the main source of radiation inside the office, as an aperture equivalent antenna, was first investigated measuring the RF signal distribution into an area inside an office. That area was placed somewhere in the middle of an office situated at the third floor of the building. The geometrical dimensions of the office: 5.5 m × 4 m, 2.3 m height, with 5.5 m – the length for the outside wall, and a window of 4 m × 1.4 m, at 1m from the floor and 0.5 m from the ceiling. Measurement antenna was placed at 1.3 meters about the floor, and was moved in two orthogonal directions, with respect to the window: one direction is normal to the window surface and the other, parallel to it, intersecting each other in a ‘middle’ point situated at 2 m from the window, chosen in the middle of the window. The displacement of the antenna was made from 10 to 10 cm, on a distance of 1.2 m (12λ), resulting 13 measurement points on each direction. Also, measurements were made in the imaginary corners of a square with the two measurements lines in the middle (Fig. 2).

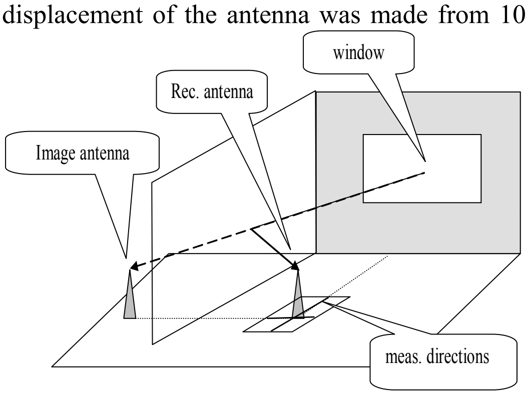

Fig. 2. The measurement site

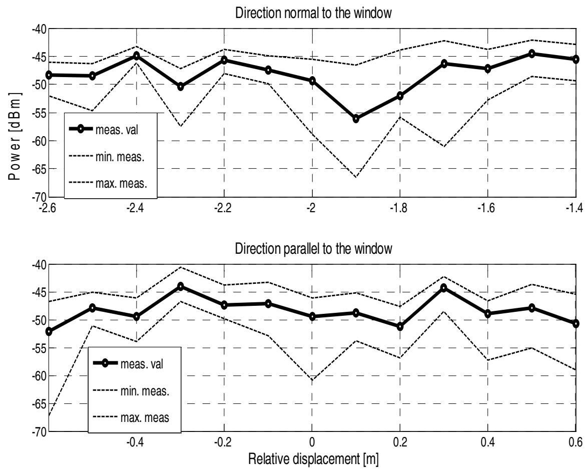

Fig. 3 The measurements (averaged, minimum and maximum) values

The measurements were made using a handheld spectrum analyzer and a omni-directional antenna, 3 dBi gain. Every measurement point has been monitorised for several tens of second, in order to record the time-fading. The averaged measurements values are given in Fig. 3. Along with the averaged measured data, are represented the minimum and maximum signal values (a dynamic range of signal fluctuation), obtained in the measurements over time in each point.

B. The simulation data analisys

In the Matlab simulation development we tried to have as many similarities with the real propagation scenario as we could. Based on the site geometry, the assumption was that the signal coming from the transmitter is a sum of a direct wave, a reflected wave by the ground and diffracted by the window walls. Further, inside the office, the signal is reflected by the inside walls. We have considered that in the receiver point arrive four different waves, on four different paths: a direct, diffracted ray, a reflected by the ground and diffracted ray and the previous rays, diffracted and reflected by the inside walls (Fig. 2).

The equation (1), shows the r.m.s electrical field calculus used in the simulation.

$$\overline{E}_{tot} = \frac{E_0}{{d_1}^p} \cdot \left| F(\nu_1) \right| \cdot e^{-jkd_1} + \\ + \frac{E_0}{{d_2}^p} \cdot R_{grnd} \cdot \left| F(\nu_2) \right| \cdot e^{-jkd_2} + \quad (1)$$

$$+R_{wall}\cdot\left(\begin{array}{l}\dfrac{E_0}{d_3^{\;p}}\cdot\left|F(\nu_3)\right|\cdot e^{-jkd_3}+\\[2ex]+R_{gnd}\cdot\dfrac{E_0}{d_4^{\;p}}\cdot\left|F(\nu_3)\right|\cdot e^{-jkd_4}\end{array}\right)$$

where:

- $E_0=\sqrt{30\cdot P_t\cdot G_t}$ - the r.m.s of the electric field of the transmitted wave;
- $F(\nu_i)$ is the Fresnel function for diffraction calculus;
- d_i – propagation path distances for the four rays;
- p – the path loss exponent;
- R_{gnd}, R_{wall} – reflection coefficients for the ground and wall reflections.

The model implemented in Matlab uses for the diffraction attenuation calculus, the Fresnel integrals, calculating the Fresnel first ellipsoid radius and his obstruction due to the window opening.

Simulation was made in order to obtain the received power in an area similar with the square where the measurements were made. For a compare between the simulated and measured results, the measurements for the two directions were interpolated along with the values measured in the corners of the square and further interpolated using cubic method. The resulting surface was compared with the surface obtained in the simulation (Fig. 4).

In Fig. 5 and 6, are represented the averaged values of the measured signal in every point (similar with Fig. 3), and the corresponding 'mode' value (by 'mode' – we express the statistical parameter that can be obtained from probability distributions), but interpolated using the 'spline' method, in order to have the same number of points both on the simulation and measurement characteristics. The simulation data were also processed, with the purpose of expressing the average values for the variations that appear due to multipath propagation.

The processing was made averaging data on a spatial window with the length equal with one wavelength.

In [6] is presented an algorithm developed to compare two sets of data, and put them in an objective and comprehensible form, named Feature

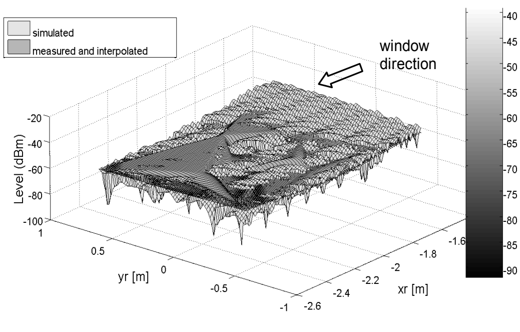

Fig. 4. The measurements and simulation surfaces

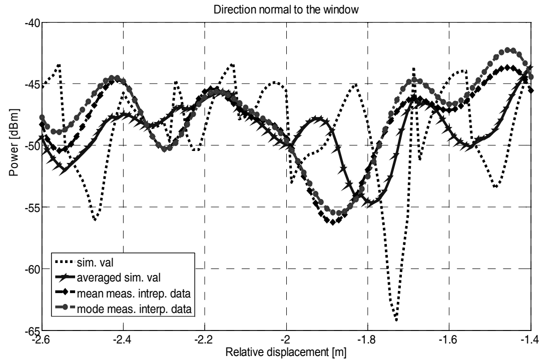

Figure 5 – The measurements and simulation data, for the direction normal to the window

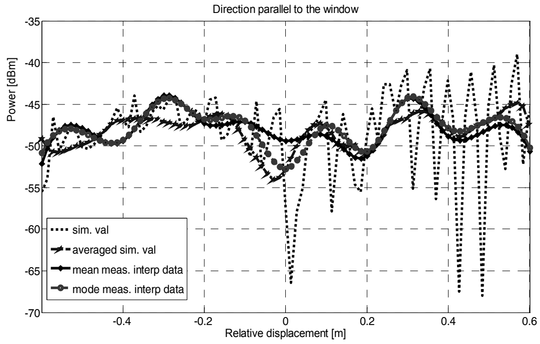

Fig. 6. The measurements and simulation data, for the direction parallel to the window

Selective Validation. The FSV offers three figures of merit of the comparison of two data sets: ADM (Amplitude Difference Measure) and FDM (Feature Difference Measure). These are available as numerical values and can be converted to a natural language descriptor in a six level scale: excellent, very good, good, fair, poor, very poor, and are combined to give the GDM (Global Difference Measure), an overall single figure goodness-of-fit between the two data sets being compared. Using this feature, to compare the interpolated measurements set and the averages simulation data set, we obtained Fig. 7 and 8.

Comparing the FSV analysis for the pair data simulation-measurements, we can see a good conformity between them. This conformity is expressed also by statistics given in Table 1.

Table 1 - Statistics

	Parallel direction	**Normal direction**
Meas. average	-48 dB	-48.27 dB
Meas. std	1.85 dB	3.19 dB
Sim. average	-48.3 dB	-48.8 dB
Sim. std	1.91 dB	2.37 dB

In Table I, by '*std*', we express standard deviation from the mean.

For the model developed in Matlab, an important and sensitive parameter is path loss exponent. In terms of electrical field r.m.s, we obtained p = 2.11, meaning that, in terms of signal power, p = 4.22, a value close to the values reported by other studies [7].

A further confirmation of the model results, and also verification for the measurements

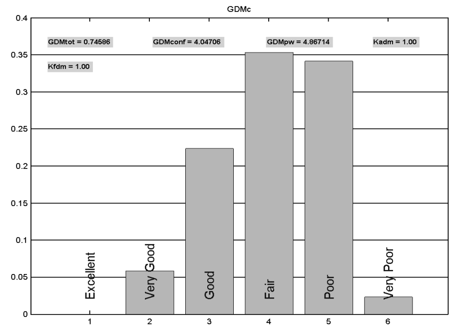

Fig. 7. The FSV - GDM analysis for the normal direction measurements

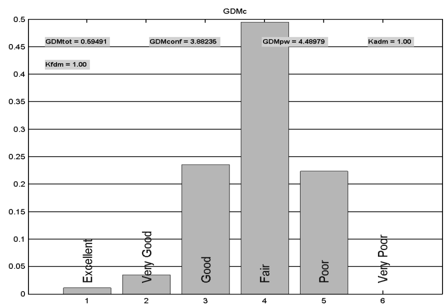

Fig. 8. The FSV - GDM analysis for the parallel direction measurements

reproducibility principle, was made using another set of measurements in the same office (Fig. 9).

The measurements made in the corners of the office (at about 0.5 m from the walls) and also in the middle of it, can confirm the hypothesis of considering the window as an equivalent aperture antenna. P4 for instance, have the smallest value (all are averaged values), due to the strongest obstruction by the window walls. Instead, the P2 is in the position of a very small obstruction of the Fresnel ellipsoid.

IV. CONCLUSION

From this study several important conclusions can be drawn. First, the measurements shows that the hypothesis of considering a window as an aperture equivalent antenna that radiate the RF signal inside the building is correct. This is confirmed also by the simulation results. Further, it shows how we can choose the measurement points

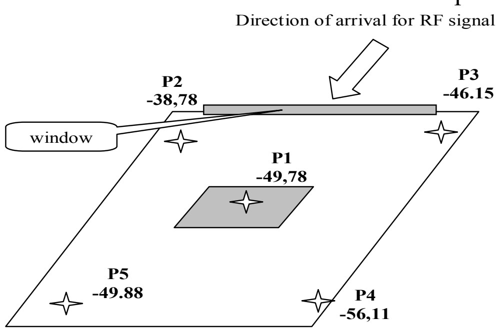

Fig. 9. Measurements in several points in the office

in order to compare the received signal at different floors, for establishing the 'height gain': the measurement points have to be placed in the same relative position with respect to the window.

The simulation results are well correlated with measurements data, and the model developed is suitable to be used in other similar applications and studies. The simulations show that the geometrical dimensions of the window influence the signal strength inside the office, idea confirmed also in [7].

The imperfections due to the use of theoretical models for reflections and diffractions calculus in the simulation program are corrected by the path loss exponent. This is a sensitive parameter of the model and can be used to calibrate the model using prior measurements. Its value, obtained in our study, is close to the values found in [8].

The fading due to multipath propagation can be eliminated by averaging the measured data for a receiver movement on a distance from 20λ to 40λ [9]. This study shows that, at least for the 2600 MHz, is enough an averaging distance of 10λ.

The office where the measurements were made was on the LoS side of the building. As a further study, it is interesting to find if the same behavior is recorded in the offices from NLoS side of the building.

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