700 MHz (4G) Indoor Propagation - Measurement and Correlation with Different Numerical Methods

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Abstract **─** This article details the comparison of three different approaches of indoor propagation modeling – Ray Tracing, Dominant Path Model and the empirical Multi-Wall, the latter based on the COST-231. These methods are implemented inside the Altair Winprop suite, and are correlated with measurements taken at the frequency of 700 MHz. The choice of this frequency is due to its future use as LTE (4G) for applications in public security services.

Index Terms **─** Indoor Wave Propagation, Propagation Measurements, Ray Tracing, Wave Propagation Modeling.

I. INTRODUCTION

The importance of indoor propagation has become relevant not only due to the widespread use of wireless communication systems but also due to the wide deployment of IoT (Internet of Things) devices [1, 2]. The efficient use of the crowded electromagnetic spectrum depends on careful planning, due to its use by different services. Numerical prediction can then help plan the use of the spectrum, obtaining the maximum output from a given channel. Since propagation measurements might not always be possible for each and every case, confidence in numerical prediction tools is advantageous to use the existing hardware with full capacity. Nevertheless, empirical formulations based on a comprehensive set of measurements are still useful and adequate for first-order addressing of propagation in indoor/office spaces [2].

This paper compares three different numerical approaches - Ray Tracing (RT), Dominant Path Model (DPM) and Multi-wall (MW), in descending order of complexity. They are presented applied to an indoor measurement site, at the frequency of 700 MHz, chosen because of its possible assignment use by 4G (Long Term Evolution), particularly by the Police, enabling data and video transmission. A short description of the numerical methods is presented, followed by the measurements and finally, conclusions are shown regarding the performance of the three approaches.

II. NUMERICAL METHODS

Three different numerical methods were tested against measurements. In order to keep a neutral approach, each one of the methods did not have its settings changed, they were left as default.

The RT method is a deterministic model, which follows the wave propagation in a similar way to a light ray. It is a time-consuming method since it computes for each point the complex sum of all the arriving rays, under certain energy thresholds (for instance after a certain number of diffractions or reflections the ray might be discarded due to its low amplitude). A ray can reach its destination by four different physical mechanisms – line of sight (LOS), refraction, diffraction and scattering [3]. Fig. 1 shows a basic scheme of an RT propagation – four different rays, indexes 1 to 4 are launched from the antenna. They propagate in straight lines, and upon facing a reflection (rays 1 and 4) they are computed accordingly (generating rays 1a and 4a). The ray 3 undergoes a knife-edge type diffraction and generates the 3a ray, whereas ray 2 goes through a window – its amplitude will be reduced as it goes out (2a). All these propagation mechanisms follow analytical formulations, whose respective parameters might be further adjusted by the user. Unlike the basic scheme of Fig. 1, the real simulation sweeps the whole 3D space with different rays emerging from the transmitter site [4]. RT offers the possibility of computing further propagation parameters, such as impulse response and angle of arrival, unlike empirical methods. It is a method sometimes too demanding for outdoor prediction, but adequate for indoor environments [3, 5]

Submitted On: November 2, 2018
Accepted On: December 2, 2019

and has been applied even to address the reception of medical implants inside human bodies [6].

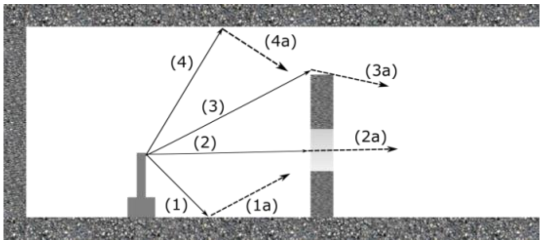

Fig. 1 Ray tracing idea, lateral view.

The DPM chooses before effectively launching the simulation only the ray paths which reach the receiving points with the strongest amplitudes [7,8,9]. As Fig. 2 shows, the rays which undergo multiple diffractions or reflections and which present large losses are discarded. Therefore by choosing only the dominant path a substantial shorter processing time can be obtained, in contrast to the RT. Besides that, geometrical description of the model and their material description errors impact less on the final result, because DPM minimizes this error by focusing on the rays with the most energy only.

On Fig. 2 a top view of an indoor environment is shown, where three rays reach the receiver from the transmitter. Only the red trace will be considered for this case, since it undergoes fewer reflections and refractions, thereby reaching the RX point with higher energy. This reasoning is applied to every receiver site on the simulation domain, and it allows gains in terms of computational time and resources. Winprop particularly uses only one ray for the DPM approach, the one with reaches the receiving point with the most energy [10].

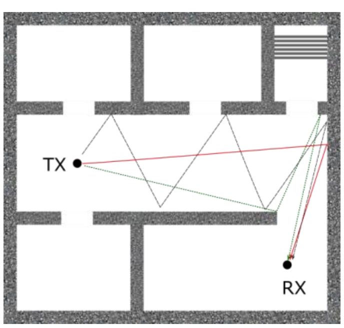

Fig. 2. DPM Dominant Path Model, top view of the propagation rays.

The third method hereby analyzed is the so-called Multi-Wall, based on an adaptation of the COST-231 regulation (idealized for small cells [11]) and originally based on [12,13]. It analyzes only the direct connection between the transmitter and receiver. This ray has its loss computed as the sum of the Free space propagation loss (by Friis formula) and an additional loss term relative to the number of walls and floors that the ray goes through until it reaches the receiving point [14,15]. The factors acting on the wall/floor propagation loss are taken from empirical measurement sets. Fig. 3 depicts a simple application – only the direct ray is taken into account, though there is not a line of sight between the two points the loss is computed from analytical formulations. Though apparently simple the method has the advantage of its fast simulation time and the small dependency on the geometrical and material model accuracies, in contrast to the RT and DPM alternatives. It does not take into account diffraction (therefore becomes more pessimistic as the receiving point moves further away from the transmitter) [10].

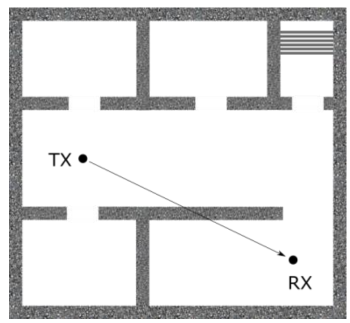

Fig. 3 Multi-Wall Method basic schematic.

Fig. 4. Spectrum analyzer used as receiver, with telescopic antenna, measuring the environment noise floor.

III. MEASUREMENTS

Measurements took place on the seventh floor of a concrete building in the UFABC Campus, with walls made out of concrete and plaster, mainly occupied by research laboratories and data centers. A spectrum analyzer connected to a telescopic antenna sampled the electric field on the receiving sites. The transmitter was set to 700 MHz and with its maximum amplitude (20 dBm), also using a telescopic antenna. Figure 4 shows the spectrum analyzer set as a receiver, displaying the ambient noise floor, without the generator powered on - visually there is no RF power on the vicinity of 700 MHz, only a carrier at 788 MHz. The antennas were kept with vertical polarization all along. A set of 12 points were taken, seven of them inside the lab and the other outside, spread on the common hall connecting the different laboratories.

Fig. 5. Blueprint of the measurement site with the transmitter and receiver points. The gray area on the top is shown in detail on the inferior part.

Figure 5 shows the indoor environment with the respective receiver (in red) and transmitter (blue) points. According to Fig. 5, there is a maximum (straight) distance between the transmitter and the furthest point (number 5) of about 35 meters. Points 1 up to 5 are outside the laboratory; the other ones are inside (i.e. the signal does not have to go through walls or door, only subjected to diffractions on the furniture). The maximum distance taken for the measurement was set by the spectrum analyzer sensitivity - points further away do not result in accurate received power measurements since they are on the same level as the ambient noise floor. The measurements were taken with both spectrum analyzer and signal generator kept at floor level; condition consistent to the simulation.

Figure 6 shows both the transmitter site and its position just across the door, with the generator shown in detail with the actual operational settings. It can be seen that it is positioned just across the wood door, kept closed throughout the test, and close to a metallic power distribution box (not considered in the simulation).

IV. NUMERICAL PREDICTION

The virtual model is constructed from the scratch based on an uploaded blueprint, which contains the information necessary to draw the walls and apertures (windows and doors) and contains the reference for distances. Materials are assigned in a proper way (concrete, wood, and glass). Furniture was not included, for the sake of simplification, and it is, therefore, an error source - affecting all numerical methods to different degrees according to the observed in Section II. The antennas were considered to be omnidirectional, for the sake of simplicity – they were positioned against varied walls, doors, metallic frames, etc as they were moved along the measurement points, thereby distorting their patterns. Figure 7 shows the three predicted power plots, along with the CAD model that describes the scenario. It can be seen that in general the DPM prediction pattern is smoother, without the acute lower amplitude areas from RT and MW, located on the lower half of the area. MW also, in particular, predicts a more pessimist coverage (i.e. with lower amplitudes) in the areas further from the transmitter (right half of the respective plot figure). In terms of computing time and resources, DPM took 2 seconds and approximately 0.8 Mbytes; Multi-Wall 1 second and 0.1 Mbyte and RT 15 seconds with 87 Mbytes.

Fig. 6. Transmitter site and the generator shown in detail.

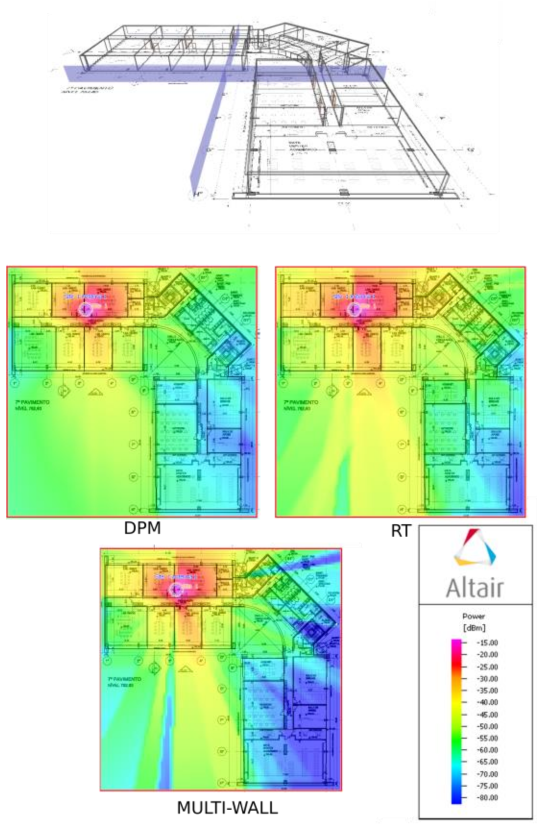

Fig. 7. Predicted results from the three different numerical methods; on top the CAD model used by the simulation.

Taking into account the measurements, Fig. 8 shows their correlation with the predicted sets, for the three numerical methods. The points are presented following the convention in Fig. 5 - i.e. they are not organized in ascending order of distance.

The largest discrepancy with the measurement took place with point number 2; 17 dB for the worst (DPM) case. It can be inferred that this specific spot, on the wall in front of the lab where the transmitter is located, is subjected to a strong spatial field amplitude variation (visualized in Fig. 7), so that it is more sensitive to the receiver position. All three methods generated, for this specific point, poor correlation, so an error on the actual measured position might be possible.

Another correlation parameter is the Mean Square Error, hereby called E, for each one of the numerical methods, as (1) shows:

$$E_{method} = \frac{\sum_{i=1}^{N}(p_{i,predicted} - p_{i,measured})^2}{N}, \qquad (1)$$

where E_{method} is the error associated with the specific method; N the total number of sampled points and $p_{predicted}$ and $p_{measured}$ the respective computed and measured individual power values. Table 1 summarizes the parameter for the three different methods. The subscripts indicate which method the error parameter refers to.

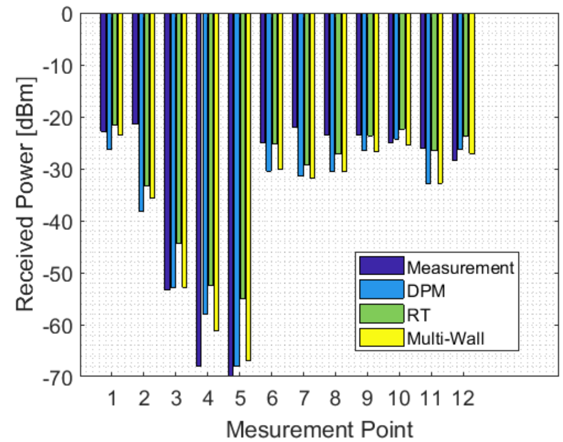

Fig. 8. Comparison between the three different numerical methods and measurements.

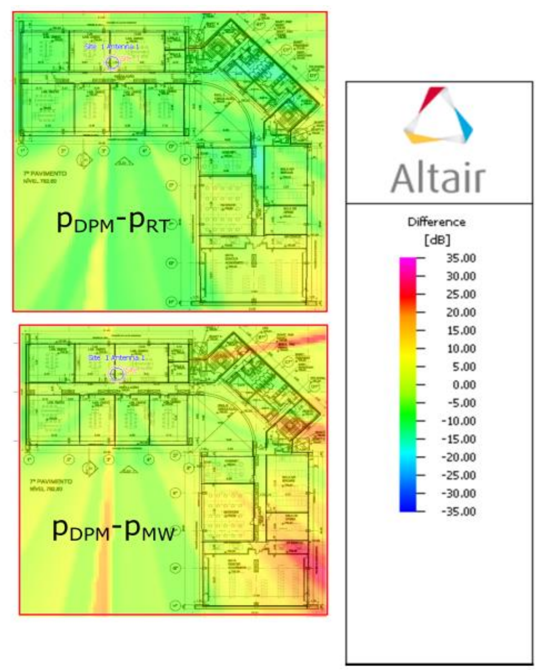

Fig. 9. Plots of the difference between predicted received powers from sets of two different methods.

Table 1: Error parameter

E_{DPM}	52.41
E_{RT}	65.36
E_{MW}	40.78

It can be seen that for the points in question the Multi-Wall method provided the smaller overall error, with Ray Tracing showing the worse performance. It needs to be stressed that if the points were distributed further away from the transmitter it is likely that the Multi-Wall results would be farther from the measurements, since it generates more pessimistic values for these cases as Fig. 7 showed. The concentration of measured points near the transmitter, due to the spectrum analyzer sensitivity, helped MW in relation to DPM and RT methods.

The subtraction of the predicted received power values across the simulation plane is shown in Fig. 9. Both differences are shown with the same scale, so that it is apparent that the DPM has a larger similarity with the RT method than the Multi-Wall, notably as the distances from the transmitter increase.

Similar study, used for address the Lora protocol at the frequency of 865 MHz in an office building concluded that the Multi-Wall method, though less precise, offers advantages mainly due to the fact of being less demanding in terms of a precise virtual model of the building [14], in comparison to the Ray Tracing method.

V. CONCLUSION

This paper presented the comparison between measurements and simulations, using three different numerical methods, on an indoor scenario at 700 MHz. It was shown good correlation with the measurement set, and characteristics of each method were pointed out. It was seen that the empirical method Multi-Wall based on the COST-231 regulation generated closer results to the measurements, due to the fact the sampled points were distributed at distances not far from the transmitter site.

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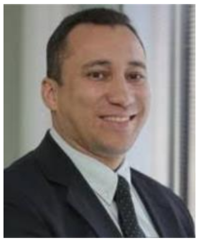

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