Heuristic UTD Coefficients for Radiowave Coverage Prediction in a Urban Scenario

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***Abstract*—This paper presents a comparison of three heuristic coefficients for the Uniform Theory of Diffraction (UTD), used to characterize the radiowave scattering in typical urban scenarios. The coefficients were implemented in a propagation model based on ray-tracing techniques based in image theory. In order to evaluate each coefficient we analyze the statistical behavior of the mean and standard deviation of the absolute errors between the estimated values and the measured data of path loss in a large number of receptor points provided in the literature. Finally, we show the path loss prediction for each UTD coefficients proposed.**

Keywords—Heuristic diffraction coefficients, ray tracing, image theory, uniform theory of diffraction.

I. INTRODUCTION

The continued technological evolution of wireless communication systems, particularly in urban environment, leads to investigate methods to estimate, with high precision, the multipath propagation of wide-band radio channel in order to minimize the error with respect to on-site measurements. In recent years, methods based on ray tracing and UTD have shown accuracy and efficiency in the simulation of path-loss in complex environments. This accuracy depends mainly on the ray physical model in realistic environments and the numerical model used for estimating the scattered field. Therefore, the choice of the diffraction coefficients is important to accurately predict the signal amplitude obtained from the diffraction process.

Many heuristic solutions have been proposed to simulate the diffraction by wedges with finite conductivity. Initially, UTD coefficients were developed for perfectly conducting wedges [1]. Then, Luebbers established heuristic diffraction coefficients for lossy conducting wedges [2]. Luebbers' contributions have triggered a large number of studies to improve the accuracy of the heuristic coefficients. Among the most recent researches, Schettino et al [3] proposed a heuristic UTD coefficients combining features of previously investigated heuristic coefficients [2, 4-6],ensuring reciprocity and providing superior performance in arbitrary source and observer locations. Guevara et al [7] used Luebbers' coefficients in union with a physical technique that model the edge where diffraction occurs to obey reciprocity. Previous work has shown that Luebbers, Schettino and Guevara coefficients are suited to estimate path loss with high accuracy in outdoor environment. Among them stands[8], in that work is used a 3D ray-tracing model based in “brute force” algorithm for ray-launching. The results show high accuracy in the path loss prediction in the city of Valencia, Spain. Therefore, it’s important to mention that in this paper we will verify the usefulness of these coefficients using a different propagation model, it’s based on ray-tracing by image theory to simulate the multipath and so to evaluate the precision of path loss prediction for each coefficient with respect to measurements in a distinct urban environment, which is provided in [9].

The paper is organized as follows: in section II we describe the heuristic UTD coefficients used for the comparison, in section III we describe the channel modeling process, in section IV we mentioned the characteristics of the propagation and the outdoor scenario, in section V we discuss the results obtained and in section VI conclusions and further work.

II. HEURISTIC UTD COEFFICIENTS

The UTD electric field at the observer (see Fig. 1) is defined as [1]:

$$E_d(O) = E_i(W) \cdot \bar{D} \;\; A(s_d) e^{-jks_d} \qquad (1)$$

where $E_i(W)$ is the incident electric field at the wedge, $A(s_d)$ is the amplitude factor, s_d is the distance between wedge and observer, and $\bar{D}$ is the dyadic diffraction coefficient. Adopting the classical notation of [1], these dyadic soft and hard are given by:

$$\bar{D}^{s,h} = G_0^{s,h}\left[D_2 + R_0^{s,h}(\alpha_0) D_4\right] + G_n^{s,h}\left[D_1 + R_n^{s,h}(\alpha_n) D_3\right] \qquad (2)$$

where D_i, for $i = 1, \ldots, 4$, are the UTD diffraction coefficients, G_0 and G_n, are grazing incidence factors, R_0 and

R_n are Fresnel reflection coefficients, for the 0 and n faces, respectively. This paper implements three heuristic UTD coefficients used for the characterization of the radio channel:

1) Luebbers' coefficients [2]: It introduced the Fresnel reflection coefficients in the UTD diffraction coefficients, defining incidence and reflection angles according to the incident and diffracted rays. However, it presents difficulties associated with reciprocity and deep shadow regions, because they were derived for forward scattering analysis (assuming $\varphi_i < \varphi_d$).

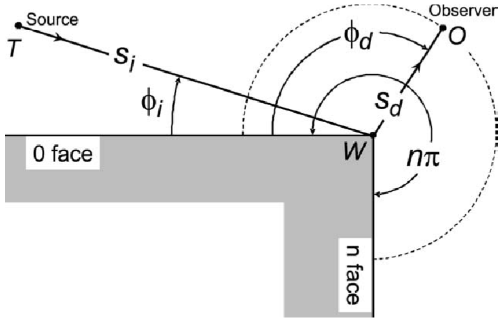

Fig. 1.Geometry and variables for diffraction on the wedge.

2) Schettino's coefficients [3]: It proposed a heuristic UTD coefficients mainly based on Holm's formulation [4], with angular definitions for α_0 and $\alpha_n$based on [5, 6]. It ensures reciprocity and providing superior performance in arbitrary source and observer locations.

3) Guevara's coefficients [7]: It based in [2] and the application of a physical technique in order to obey reciprocity and specification of permittivity for building materials. This technique allows modeling the diffraction from side edges of each building.

III. CHANNEL MODEL

We have used a quasi-3D ray-tracing model in a urban model supported in C++. Previous work has shown that this model is suited to estimate multipath parameters with high accuracy and fast processing [10-12]. The quasi-3-D model is based on the image theory. It considers reflections over streets and the buildings faces, and diffractions on the buildings edges. Neither reflections nor diffractions at the building tops are considered. However, this is not a concern in this particular case study, as the transmitter and receiver antennas heights are much smaller than the building's heights [9]. The number of iterations for multipath rays is limited to five reflections and two diffractions. Due to the number of interactions increases the computational complexity and processing time in order to obtain sufficient accuracy with respect to measurements, the experience has shown that around to five reflections and two diffractions are sufficient [13].

It's important to characterize the electromagnetic constitutive parameters of materials (i.e. permittivity and conductivity) to ensure high accuracy in the path loss estimation. According to the electromagnetic properties, for reflections and diffractions from buildings we assumed (εr=7, σ=0.2 S/m) and for reflections from streets (εr=15, σ=0.05 S/m) [14].

IV. OUTDOOR SCENARIO AND PROPAGATION CHANNEL

In order to demonstrate the accuracy of the ray-tracing model for the mentioned UTD coefficients, two case studies will be presented, the Bank St. case and de Laurier St. case, in a common environment. The outdoor scenario adopted corresponds to the downtown core of Ottawa City, Canada [9]. Such scenario has a measured data available for comparison purposes.

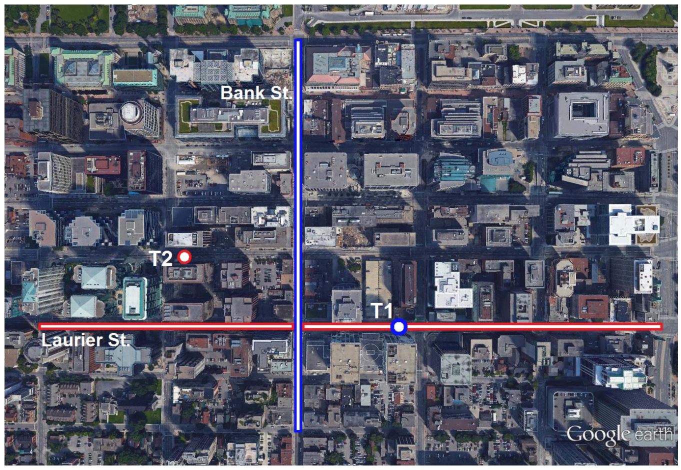

Fig. 2.Downtown core of Ottawa City, Canada from Google Earth.

Fig. 2 shows the scenario for simulation and the measurement routes (see Fig. 2, blue line for Bank St. case and red line for Laurier St. case). This scenario has a 0.6 km x 0.9 km area, with complex building architecture, where it is provided a radio signal at 910 MHz. This signal is supplied by a transmitter (Tx) located on the street at 8.5 m height (see Fig. 2, blue point for Bank St. case and red point for Laurier St. case). The measurements characterized the propagation loss in the selected routes, which is composed by receptors points located on the street at 3.5 m height with LOS and NLOS localizations. For Bank St. case was obtained in total 291 measurement points and for Laurier St. case 452 measurement points.

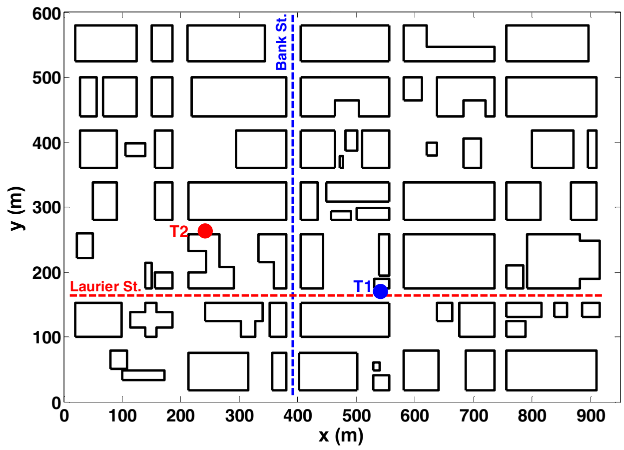

Fig. 3.The 2D urban model of Ottawa, Canada.

The Fig. 3 shows the 2D urban model of the Ottawa city. This model allows characterize the streets and buildings by flat polygons, and in order to take into account the effects of diffraction on the channel response, we model the buildings edges as points positioned at the vertices of each polygons. Also, the Fig. 3 shows the measurement routes located along the street for each case study. The measurements obtained in these routes were used to evaluate the propagation model using the heuristic UTD coefficients.

V. Analysis And Results

For the analysis and evaluation of the three heuristic coefficients, we obtained the channel response for each one. Figures 4 and 5 show the path loss prediction at the receiver locations, where results obtained by the heuristic UTD coefficients presented in Section II are compared with measurements. The comparisons show that the coefficients present a close response, thus the path loss prediction is very approximate but not identical in some reception points.

Fig. 4 shows the comparison for the Bank St. case. It presents some regions where the coefficients provide a high accuracy in the measurement route (i.e. receiver position from 100 to 200, 270 to 300, among others). On the other hand, the Fig. 5 shows the comparison for the Laurier St. case, which presents a strong variation in the channel response with respect to measurement. However, it provides an approximately response with respect to measurements behavior in receiver positions from 200 to 500.

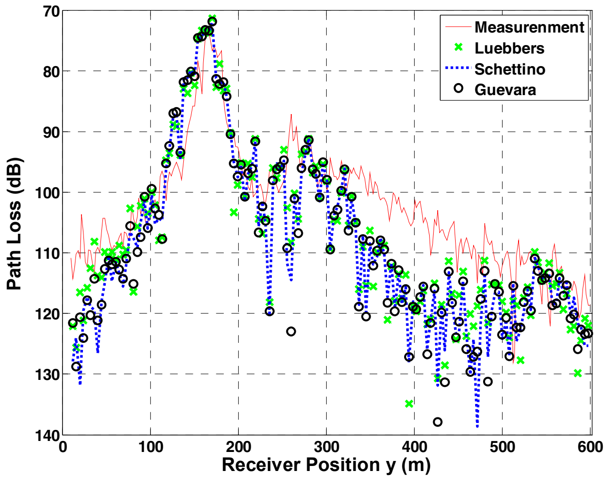

Fig. 4. Path loss prediction comparison between the heuristic UTD coefficients and measurements (red line) for Bank St. case.

In order to evaluate which one is more accurate, we calculate the mean and standard deviation of the absolute errors. These statistical results are summarized in Table I for the Bank St. case and Table II for the Laurier St. case.

Statistical analysis shows that for Bank St. case, Luebbers' coefficients [2] provide slightly better results, with a standard deviation of 5.77 dB and mean absolute error of 7.41 dB. The others formulations, Schettino's coefficients [3] and Guevara's coefficients [7] present a close statistical result. The standard deviation difference with respect to Schettino's coefficients [3] is +0.43 dB (approx.7%variation), while that the difference with Guevara's coefficients [7] is +0.58 dB (approx. 10% variation).

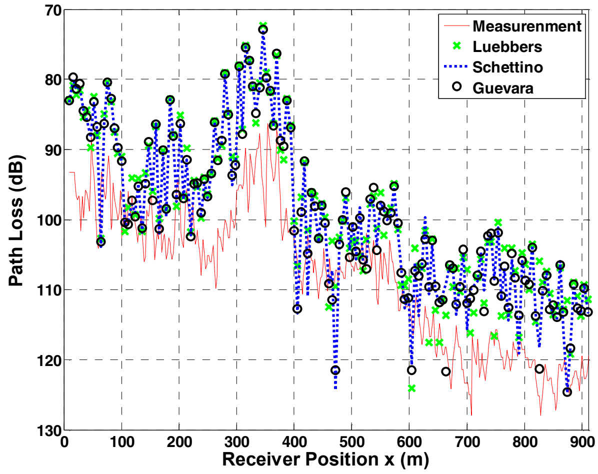

Fig. 5. Path loss prediction comparison between the heuristic UTD coefficients and measurements (red line) for Laurier St. case.

The results corresponding to Laurier St. case show that Schettino's coefficients [3] provide the better results; with a standard deviation of 5.17 dB, predicted value that indicate high accuracy; and a mean absolute error of 9.48 dB. However, the standard deviation difference with respect to Guevara's coefficients [7] is small (+0.02 dB, variation less than 1%), while that the difference with Luebbers' coefficients [2] is considerable (+0.92 dB, approx. 42%variation).

TABLE I. Statistical Summary of Path Loss Prediction for Bank St. Case

UTD Coefficients	Mean absolute error (dB)	Standard Deviation (dB)
Luebbers	7.41	5.77
Schettino	8.33	6.20
Guevara	8.27	6.35

TABLE II. Statistical Summary of Path Loss Prediction for Laurier St. Case

UTD Coefficients	Mean absolute error (dB)	Standard Deviation (dB)
Luebbers	9.94	6.09
Schettino	9.48	5.17
Guevara	9.51	5.19

VI. Conclusions

This work presented the application of UTD coefficients to analyze radiowave scattering in a real-life urban scenario. The results show that Luebbers', Schettino's and Guevara's coefficients present a high accuracy to predict path loss in the two cases studies proposed. Also, we verify that Schettino's and Guevara's coefficients overcome the inaccuracies in deep shadow regions presented in Luebbers' formulations for Laurier St. case and, consequently, suited to predict the radiowave propagation in complex scenarios with a large number of receptor points. As further work, we propose the implementation in others realistic scenarios.

Acknowledgment

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