Comparison of Heuristic UTD Coefficients in an Outdoor 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 3D ray-tracing techniques for a Digital Video Broadcasting (DVB) service. 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 in an outdoor scenario.**

Index Terms—**Heuristic diffraction coefficients, ray tracing, uniform theory of diffraction.**

I. INTRODUCTION

The continued development of wireless technologies, particularly in urban environment, leads to investigate methods to estimate, with high precision, the propagation parameters of wide-band channels 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.

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 [8] used Luebbers' coefficients in union with a physical technique that model the edge where diffraction occurs to obey reciprocity and adopt two types of permittivity to characterize the building materials.

These two studies estimated propagation path loss in urban scenarios and compared them with measurements. Since the results indicated a good accuracy, this paper will present a comparison between these and the Luebbers' formulation in a common scenario. For this purpose, we use a 3D ray-tracing model based on optic rays to simulate the multipath propagation and so to evaluate the UTD in a realistic scenario that has been previously validated in [8].

The novelty in this paper is the implementation of three heuristic UTD coefficients applied to predict path loss in the realistic outdoor environment in order to evaluate the precision of the 3D ray-tracing model with respect to measurements.

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, the simulated outdoor scenario and the measurement campaign, 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]:

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

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 $\overline{D}$ is the dyadic diffraction coefficient. Adopting the classical notation of [1], Luebbers' soft and hard heuristic diffraction coefficients are given by:

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

where D_i, for $i = 1, \dots, 4$, 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, as defined in [2]. The angular definition α_0 and α_n, used to calculate R_0 and R_n respectively, are given by:

$$\alpha_0 = \min[\varphi_i, n\pi - \varphi_i], \ \alpha_n = \min[\varphi_d, n\pi - \varphi_d] \qquad (3)$$

where, φ_i is the angle of the incident wave, and φ_d is the angle of the diffracted wave, both with respect to face 0, and $n\pi$ is the wedge exterior angle (see Fig. 1). Luebbers'

coefficients present difficulties associated with reciprocity and deep shadow regions, as they were derived for forward scattering analysis (assuming $\varphi_i < \varphi_d$).
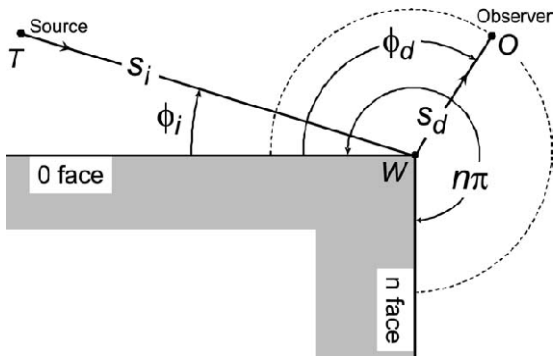

Fig. 1.Geometry and variables for diffraction on the wedge.

The heuristic diffraction coefficients of [3] are mainly based on Holm's formulation [4], with angular definitions for α_0 and α_n based on [5, 6]. When only one of the wedge faces, 0 or n, is illuminated, the angular definitions proposed in [6] are adopted. When both faces are illuminated, the angular definitions of [5] proved to be more appropriate. These coefficients were simulated and validated with measurement in a downtown core of Ottawa City, Canada [7].

The heuristic diffraction coefficients of [8] are based on Luebbers' formulation [2] and the application of a physical technique in order to obey reciprocity and specification of permittivity of the building materials. This technique allows modeling the diffraction from the top and side edges of each building. Besides, it also allows characterizing the structure of the buildings into two different classes: building walls and building roofs, with common dielectric material parameters for each one.

III. CHANNEL MODEL

We have used a 3D ray-tracing model in combination with a 3D urban model supported in game engine and Graphics Processing Unit (GPU). Previous work has shown that these models are suited to estimate multipath parameters with high accuracy and fast processing [8-10]. The 3D ray-tracing model was used to obtain the channel impulse response, given as:

$$h(t,\tau) = \sum_{n=1}^{N} A_n e^{-j\varphi_n} \delta(t - \tau_n) \qquad (4)$$

where, N in the total number of multipath components, A_n is the amplitude, φ_n is the phase and τ_n is the delay for each component. Thus, the channel model is represented as a power delay profile (PDP) taking the spatial average of $|h(t,\tau)|^2$ over a local area, and is able to estimate path loss. The number of iterations is limited to five combinations in total. The number of diffractions is limited to two and the number of reflections considered is five. 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 a number of five wave interactions (reflection and diffraction) are sufficient [11].

It's important to characterize the electromagnetic constitutive parameters of materials (i.e. permittivity, permeability and rugosity) to ensure high accuracy in the path loss estimation. According to the electromagnetic properties, the structure of the buildings and streets are classified into 3 different classes with common dielectric material parameters for building walls, building roofs and street pavement. Specifically, we assumed brick (εr=7-j0.3, μr=1) for all building walls; a first type of dry concrete (εr=5.3-j0.25, μr=1) for all building roofs; and a second type of dry concrete (εr=7-j0.3, μr=1) for street pavement. Finally, we assume that brick and the two types of dry concrete have a similar rugosity factor (σr=1 mm.) [12].

IV. OUTDOOR SCENARIO AND MEASUREMENT CAMPAIGN

The simulated and analyzed scenario was a sub-urban macrocell in the main campus of the Universitat Politècnica de València (Spain) [8]. Fig. 2 shows the scenario for simulation and the measurement route (green line). This scenario has a 2 km x 2 km area, with slightly tilted roads and complex building architecture around the campus, where it is provided a Digital Video Broadcasting (DVB) service. This service is supplied by a transmitter (Tx) located on the top of the building inside of the main campus at 24 m height (see red point in the Fig. 2), thus providing a medium coverage; the EIRP of all transmitters is 36.01 dBm. The transmitter has two panel antennas oriented 114° and 316° azimuth. The antennas are vertically-polarized panel antennas with 62° half-power beam-width in the horizontal plane and 28°in the vertical plane and 12.15 dBm gain.

Fig. 2. Universitat Politècnica de València scenario from Google Earth.

The measured data was obtained by a measurement campaign that consisted in the collecting of the the power received in the streets, inside and outside of the campus and around the transmitter. The power of the DVB signal on 496 MHz is measured by the receiver system within a bandwidth of approximately 8 MHz. The receiver system consists of a Teamcast professional receiver composed by a vertical quarter-wave length monopole, a GPS and software to collect and store the measured data. This system is in the test car used for the drive test, with the receiver antenna positioned above a metallic

plate fixed on the top of the vehicle. The radio channel measurement characterized the propagation loss in the selected routes, which include localizations with LOS and NLOS. It was obtained in 1380 measurement points for the drive test. The acquisition time was 1 ms and the transmitter antenna power is monitored throughout the measurement campaign to control the stability of the transmission.
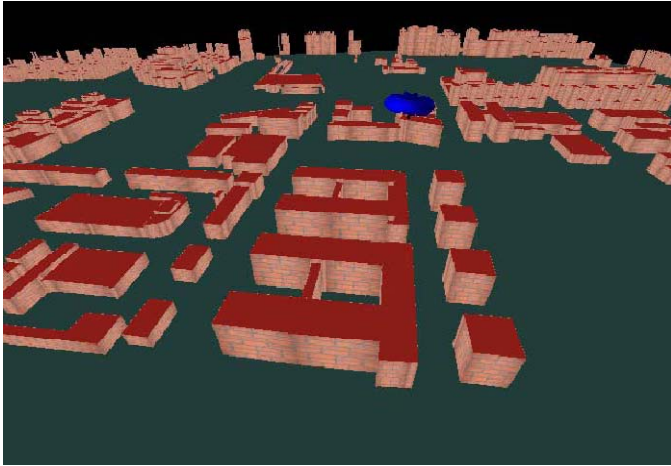

Fig 3. The 3D urban model around of transmitter (blue bounding) using the game engine.

Fig. 3 shows the 3D urban model, based on a 1m resolution ASCII raster for the Digital Terrain Models (DTM) of Valencia city. This DTM was recreated using Java Monkey Engine (jME v. 2.0), allowing characterize the streets, roofs and walls by spatial geometries, so we represent the external surfaces of buildings (walls and roofs) and streets using flat polygons, and in order to take into account the effects of diffraction on the channel model, we model the buildings edges (vertical and horizontal) using the bounding volume technique, hence cylinders were used to represent edges.
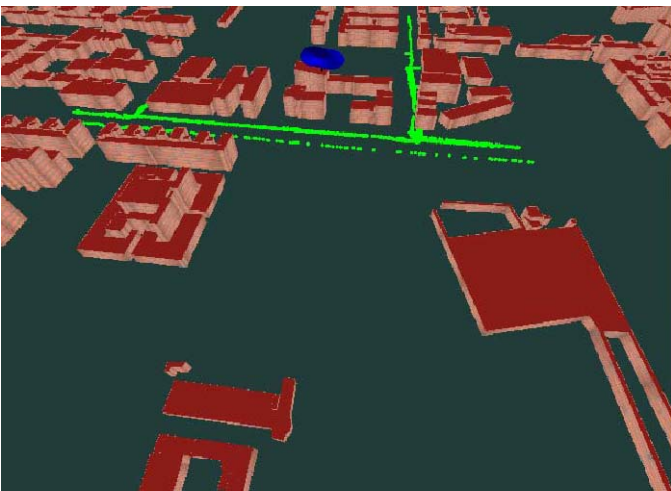

Fig 4. Localization of the receiver points with LOS and NLOS (green spheres) and the transmitter (blue bounding).

Finally, Fig. 4 shows the measurement route identified by the green spheres, which represent each reception point located in the middle of the streets. The measurements obtained in this route 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 5, 6 and 7 show the path loss at the receiver locations, where results obtained by the heuristic UTD coefficients presented in Section II are compared with measurements. The comparisons show some regions where Guevara's and Schettino's coefficients provide a high accuracy in the measurement route (i.e. location numbers from 75 to 300, 1100 to 1200, among others). Moreover, these two coefficients show a close response with minor differences in some points of reception, then the Figs. 6 and 7 present an approximate prediction but not identical.
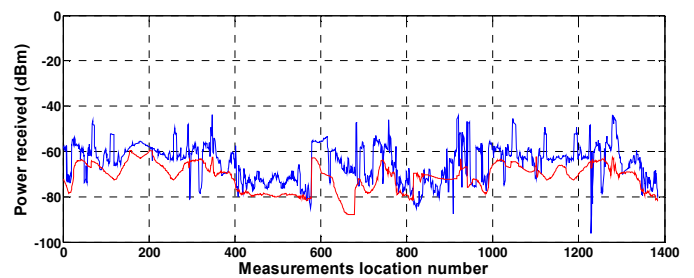

Fig. 5. Power prediction comparison between ray tracing using Luebbers' coefficients (blue line) and measurements (red line).
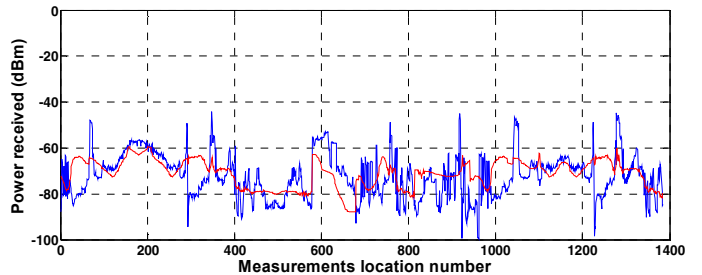

Fig. 6. Power prediction comparison between ray tracing using Schettino et al coefficients (blue line) and measurements (red line).
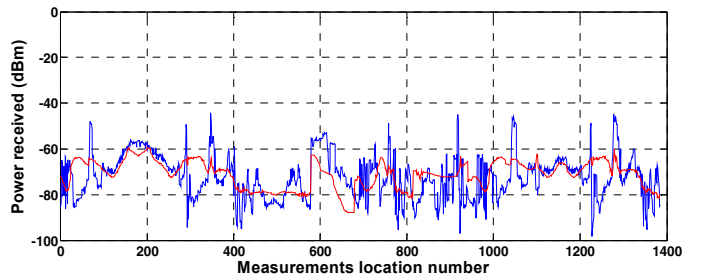

Fig. 7. Power prediction comparison between ray tracing using Guevara et al coefficients (blue line) and measurements (red line).

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.

Statistical analysis shows that for this scenario, Guevara's coefficients [8] provide the greatest accuracy, with a mean absolute error of 4.79 dB and a standard deviation of 5.95 dB. However the difference with respect to Schettino's coefficients [3] is small, while the difference with Luebbers' coefficients [2] is significant.

TABLE I.   STATISTICAL SUMMARY OF PATH LOSS PREDICTION

UTD Coefficients	Mean absolute error (dB)	Standard Deviation (dB)
Luebbers	5.51	7.96
Schettino	5.08	6.02
Guevara	4.79	5.95

In this study, Guevara's coefficients provide slightly better results with respect to previous results published in [8], this improvement is due to the assumption of permittivity optimized values mentioned in [12].

VI.   CONCLUSIONS

This work presented the application of UTD coefficients to analyze radiowave scattering in a real-life urban scenario. The results show that Guevara's and Schettino's coefficients present higher accuracy to predict path loss in the proposed scenario. Thus, we verify that these researches overcome the inaccuracies presented in Luebbers' formulations and, consequently, suited to handle 3D complex scenarios with a large number of receptor points.

The use of the 3D ray tracing technique is very effective and useful to compare different heuristic UTD coefficients in the proposed scenario; therefore as further work, we propose the implementation in others realistic urban scenarios.

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