Abstract - Complex computer based wireless propagation models are tested by field measurements. Unfortunately, the measured quantities cannot be related to the physical models embedded into the theoretical computer algorithm. This difficulty is overcome by considering scaled models of actual urban environments and making measurements inside anechoic chambers. In this way, since the geometrical and electrical parameters of the environment under study are all known, it is possible to relate the physical models to the measurements and make appropriate modifications, if necessary. Anechoic chamber measurements can therefore play an important role in the verification of complex computer based propagation models before actual field measurements. In this work, several experiments to validate the accuracy of a propagation method are discussed, both for frequency and time domains.

I. INTRODUCTION

Propagation prediction models have existed since the invention of the radio. Because of the complexity of the propagation environment, the data for the deployment of the first personal communication networks were gathered through field measurements, such as those reported in [1].

With the growing interest in propagation prediction models, many researchers started developing different prediction theories. In particular, the number of technical papers about propagation prediction models (both for outdoor and indoor propagation) started to increase significantly around the time personal computers were introduced. One of the first computer based prediction models was presented in [2]. Since then, many computer based propagation prediction models have been developed [3-6]. Propagation prediction models are still developed because of the strong interest in reliable and accurate theoretical ways of helping the planning of cellular networks [7]. Among propagation prediction models, those that provide the most significant results exploit the geometrical and electrical parameters of the environment under study and are based on ray-tracing techniques [5, 6].

After the development of a propagation prediction model, field measurements are usually made to verify its predictions. Propagation prediction models usually account for different possible physical mechanisms that are likely to act together in the study of a complex environment. Unfortunately, since too many factors are involved in an actual situation, it is not possible to clearly relate the measurements with the theoretical predictions.

Therefore in this work it is presented a method to obtain feedback between measurements and the theoretical predictions. This feedback should be used to verify the accuracy of the theoretical model before carrying out actual field measurements.

The measurements discussed in this work are conducted on scaled models of urban environments inside an anechoic chamber. The advantages of this experimental setup are twofold. First, the anechoic chamber provides a controlled environment where disturbances are negligible. Second, the geometrical and electrical parameters of the scaled model are totally known. Therefore, it is possible to conduct experiments to verify the effectiveness of one of the physical mechanisms that are part of the computer model. The latter is obviously not possible with field measurements. The last statement simply means that it is not possible to derive from field measurements a clear feedback about what needs to be modified to improve a computer based propagation prediction model. Nevertheless, field measurements will always be the method to determine the accuracy of a propagation prediction technique.

Propagation prediction computer models are extremely complex and it is very important to find ways to determine their accuracy. The originality of this work consists in suggesting an experimental technique that can be used to verify complex computer models, an area of growing interest in engineering. This work is relevant to the EMC community because it suggests a new application for anechoic chambers.

This work describes measurements that were made to verify the accuracy of the propagation prediction simulator developed by Erricolo and Uslenghi [8]. This is a two-dimensional propagation model, therefore it is first described the experimental setup to approximate the two-dimensional assumption. Then various frequency domain experiments are described to emphasize the mechanisms that account for reflection and diffraction, particularly from double wedge structures. The result of the application of the simulator developed in [8] to a realistic two-dimensional environment is given. Finally, time-domain experiments are also discussed.

II. EXPERIMENTAL SETUP

The propagation prediction simulator described in [8] assumes that rays propagate in the vertical plane that passes through the transmitter and the receiver antennas. The purpose of the simulator is to compute the path-loss experienced by the signal while
propagating, in the vertical plane, above building obstructions such as those shown in Fig. 1. In order to reduce the influence of external factors, the measurements were performed in the anechoic chamber of the University of Illinois at Chicago. Since the experiments had to satisfy the 2D assumptions of the propagation simulator, the antennas had to satisfy the directivity requirements described below.

Referring to Fig. 2, in order to experimentally emphasize only those trajectories that are contained in the vertical plane, such as Tx-P-Q-Rx, the patterns of both the antennas in the horizontal plane must be narrow and directed along the line connecting the two antennas. This directive pattern in the horizontal plane has also an additional reason. Even though, in the theoretical model, the buildings are infinitely large in the transverse direction, the actual scaled models must be truncated at some point. The termination introduces a disturbing contribution by allowing trajectories to propagate around the buildings, such as for the trajectory Tx-D1-D2-Rx of Fig. 2. Hence, the additional advantage of having a strong directivity in the horizontal plane is the capability of reducing the contribution of undesired trajectories that propagate around the scaled buildings. The antennas used for the experiments described in the following are two high gain sector antennas BCAH90-250 provided by Andrew Corporation, Orland Park, IL, USA.

The scaled models are made of copper to strengthen the effects of reflections. The geometrical size of the scaled models is determined mainly by the dimension of the anechoic chamber; within these limits their width was chosen to reduce the contributions from undesired trajectories propagating around scaled models. Moreover, absorbing material was wrapped around corners and edges to further reduce unwanted contributions. In the following, some results obtained from anechoic chamber measurements at the frequency of 25GHz are discussed. The results are given for two different polarizations: soft and hard. The terms soft and hard come from acoustics. Soft polarization corresponds to the electric field parallel to the diffracting edges (Dirichlet boundary condition), while hard polarization corresponds to the electric field perpendicular to the diffracting edges (Neumann boundary condition).

III. EXPERIMENTAL RESULTS

Fig. 2 shows one of the scaled building models that were considered in the experiments. Let us consider some examples of how anechoic chamber measurements help obtaining feedback about the assumptions made in the theoretical model used for path-loss prediction. Referring to Fig. 2, the field diffracted past this simple building obstruction could be computed using a ray formulation based on (1) single wedge diffraction coefficients [9] or (2) double wedge diffraction coefficients [10-11]. Anechoic chamber measurements clearly show that if diffraction mechanisms are accounted for by single wedge diffraction coefficients then the path-loss prediction is not correct, as shown in Fig. 3 for the case of soft polarization. Therefore, the simple test just described clearly shows the difference between the two formulations, see also [12].

Another feature that can easily be tested inside an anechoic chamber is the effect of the reflection from the ground. This topic is still investigated in some theoretical models, for example in [7]. Referring to Fig. 4, the effect of reflections from the ground is particularly evident for lower positions of the receiver.
Fig. 4: Propagation with Tx below rooftop level. Hard polarization case: mean error: 1.12 dB; standard deviation: 1.23 dB. The computation made using only the first order UTD coefficients fails to predict the field correctly in the shadow zone.

Fig. 4 also shows that the prediction made using single wedge diffraction coefficients is not correct in the shadow zone for the geometry under study. A comparison of Fig. 4 with Fig. 5 evidences that if reflections from the ground are neglected the oscillations of the received field disappear.

Fig. 5: Propagation with Tx below rooftop level. Hard polarization case with no ground reflection: mean error: 0.75 dB; standard deviation: 0.56 dB. Compare with Fig. 4 and observe that the oscillations of the measured field have practically disappeared for lower positions of the receiver.

Removing the contribution of ground reflections is very easily accomplished inside an anechoic chamber, but would be a more challenging task during field measurements.

A challenging physical situation for a ray-tracing propagation method, based upon the uniform theory of diffraction, occurs when considering diffraction past buildings of equivalent height under grazing aspects of at least one between incidence and observation. Anechoic chamber measurements allow for the verification of the accuracy that is achieved by the theoretical prediction under this condition. The inset of Fig. 6 shows the geometry of two scaled buildings of equivalent height under grazing incidence and observation aspects. For this measurement the receiver is vertically moved at increments of \( \lambda/10 \) and one can observe that the prediction is close to the measured values, as proven by a mean error of 0.59 dB and a standard deviation of 0.50 dB. Therefore, since the diffraction situation shown in the inset of Fig. 6 was computed using the double wedge diffraction coefficients [10-11] then one concludes that they should be included in the theoretical prediction model. Similar experiments were conducted on the more complex model shown in Fig. 7. For this case too, close agreement between the theoretical prediction and the measured values is observed.

Fig. 6: Propagation with Tx below the rooftops and almost at grazing incidence with an incidence angle of 1.34°. Hard polarization case. The mean error is 0.59 dB and the standard deviation is 0.50 dB.

The results shown in Figs. 3-7 give a close agreement between the theoretical method of [8] and the anechoic chamber measurements. This close agreement is possible since the experiments are carefully designed to match the assumptions of the theoretical model. Once the method is pre-validated in this way, the final verification is provided by comparisons with actual field measurements. In this case, one should not expect the same close agreement just found, since not all the features of the real world are included in the theoretical model and accurate data may not be available.
The field verification is now discussed with the comparison of the 2-D polygonal line simulator developed in [8] with measurements taken in the area of Hjørringvej, Denmark, at the frequency of 970MHz. This area satisfies the requirement of being sufficiently uniform in the direction transverse to the direction of propagation under exam to justify the application of a propagation model with trajectories contained in the vertical plane. Figure 8 shows a comparison among the 2-D simulator, measurements, and the integral equation (IE) method discussed in [13]. Assuming a perfect electric conductor (PEC) terrain, the 2-D simulator prediction for the path-loss follows quite closely the measurements, considering that the altitude profile was introduced at intervals of 500m. Additional comparisons are provided in [15].

The comparison between measurements and the theoretical prediction obtained superimposing the contributions 1), 2), 3) at the receiver is given in Fig. 10. One observes that the main peak is correctly predicted in terms of both amplitude and time; the prediction of the secondary peaks are also close to the measured values, which are summarized in Table I. Additional results for these time-domain measurements are given in [18-19].

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<th>Trj</th>
<th>Measurements</th>
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<tr>
<td></td>
<td>Delay(ns)</td>
<td>Attn(dB)</td>
</tr>
<tr>
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<td>10.655</td>
<td>-35.40</td>
</tr>
<tr>
<td>3</td>
<td>10.934</td>
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The results presented so far are about (narrow band) frequency measurements; see also [16-17]. One could also perform time-domain (wide-band) measurements to investigate, as an example, that trajectories predicted by the theoretical method actually contribute to the measured field. This requires separating each trajectory contribution from the others. This separation is possible in the time-domain since different trajectories are usually associated with different times of arrival. Fig. 9 shows the positions of the antennas used to measure the time-domain shape of the pulse measured at the receiver that is due to the superposition of different multipath components originated from a single pulse emitted by the transmitter. In this experiment, the transmitter sends a band limited impulse that has components in the frequency range from 19GHz to 27 GHz. The theoretical prediction for this case finds that the first three trajectories, sorted according to their length, are:

1) $Tx \rightarrow A \rightarrow B \rightarrow C \rightarrow D \rightarrow Rx$
2) $Tx \rightarrow A \rightarrow B \rightarrow C \rightarrow D \rightarrow K \rightarrow Rx$
3) $Tx \rightarrow H \rightarrow A \rightarrow B \rightarrow C \rightarrow D \rightarrow Rx$

Fig. 9: Configuration of the Tx and Rx with respect to the profile of two scaled buildings with the same height. The dimensions are referred to the wavelength at the frequency of 25GHz.
Fig. 10: Comparison of the 2D propagation simulator prediction (black line) and measurements (blue line) for the case of hard polarization.

IV. CONCLUSIONS

Field measurements to verify the accuracy of complex computer models for radio propagation prediction have the drawback that it is practically impossible to relate the measured quantities with the physical models embedded into the theoretical computer model. Measurements of scaled urban environments inside anechoic chambers provide a way to overcome this difficulty because the geometrical and electrical parameters of the environment under study are all known. The results of some anechoic chamber measurements were discussed to evaluate the accuracy of the 2-D propagation prediction simulator described in [8]. Specifically, it was shown 1) the quantitative effect of applying simple wedge diffraction coefficients [9] instead of double wedge diffraction coefficients [10-11]; 2) the quantitative contribution of reflections from the ground plane; 3) the accuracy of the results computed using double wedge diffraction coefficients [10-11] for path-loss prediction with buildings of equivalent height under grazing aspects of incidence and observation; 4) the accuracy of time-domain predictions to evaluate multipath parameters. Comparisons with real world measurements were also provided. Additional details are found in [14-17].

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VI. REFERENCES


