

# Path loss measurements on scaled models and comparison with propagation predictions in urban environments

Giuseppe D'Elia, Danilo Erricolo, Piergiorgio L.E. Uslenghi

University of Illinois at Chicago, Department of EECS  
851 South Morgan Street, Chicago, IL, 60607, USA.  
E-mail derricol@eecs.uic.edu

*Abstract*— Scaled models of simple 2D urban environments are considered to investigate propagation along a vertical plane. Path loss measurements are taken for different positions of the transmitting and receiving antennas at 25 GHz. Measurement results are compared with theoretical predictions computed by a ray-tracing polygonal line simulator. The measurements indicate a very good agreement between the ray-tracing model and the experiments.

## I. INTRODUCTION

Path-loss estimates in complex urban environments are usually made using ray-tracing methods. Even with ray-tracing methods, a full 3D investigation is very difficult to achieve and, therefore, a simpler 2D problem is examined here. The 2D problem assumes that propagation occurs above building obstructions and that the main contributions come from trajectories contained in a vertical plane passing through the transmitting and receiving antennas. The theoretical path-loss estimates are made using a polygonal line simulator that is based on a ray-tracing method [1], [2], [3]. This work shows the accuracy of the polygonal line simulator by comparing its theoretical predictions with measurements on scaled models of simple buildings. The measurements emphasize the importance of correctly reproducing almost ideal two-dimensional conditions to validate the theoretical method.

## II. THE EXPERIMENTAL SETUP

First of all, in order to reduce the influence of external factors, the measurements are taken inside the anechoic chamber facility at the University of Illinois at Chicago. The experiments consist of the measurement of the propagation path-loss due to the presence of scaled models of buildings between the transmitting and receiving antennas. In particular, the trajectories considered by the polygonal line simulator are contained in a vertical plane. As a consequence,

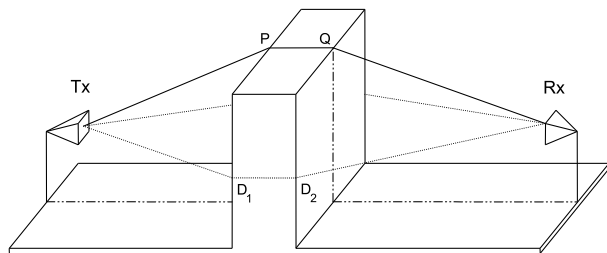


Fig. 1. Example of three-dimensional propagation. The trajectory  $T_x \rightarrow P \rightarrow Q \rightarrow R_x$  that is contained in the vertical plane is of interest for the experiments; however, the trajectory  $T_x \rightarrow D_1 \rightarrow D_2 \rightarrow R_x$  is an undesired one.

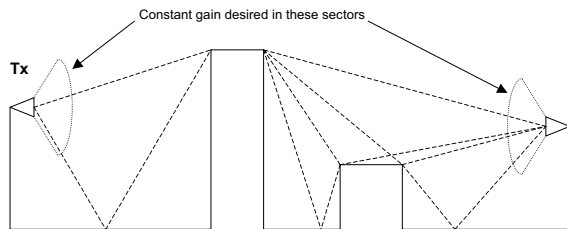


Fig. 2. Example of the angular sectors within which the directive gain must be as constant as possible to guarantee that all trajectories of interest are equally weighted.

in order to experimentally emphasize only those trajectories, such as trajectory  $T_x \rightarrow P \rightarrow Q \rightarrow R_x$  of Fig. 1, the patterns of both antennas in the horizontal plane must be narrow and directed along the line connecting the antennas. Furthermore, for both antennas the directivity patterns in the vertical plane must be isotropic, so that the contributions from all possible trajectories are equally weighted. At least within the angular sector of interest shown in Fig. 2, the directivity gain must be reasonably constant. The scaled models are made of copper to obtain a perfect electric conductor behavior that strengthens the effects of reflections. The geometrical shapes of the scaled models are simple but effective to test the performance of the polygonal line simulator. The following shapes are examined: single-building profile,

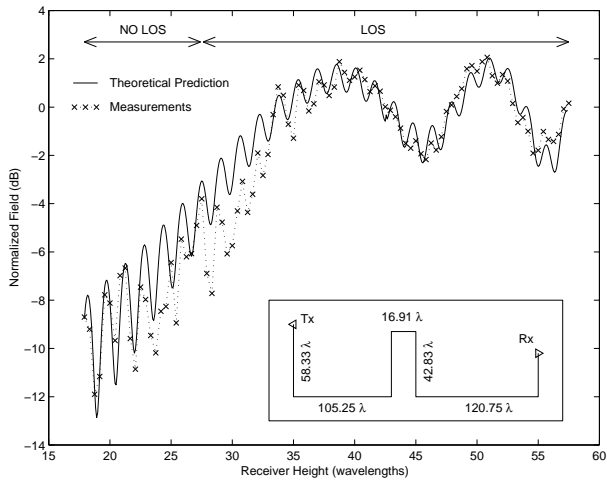


Fig. 3. Propagation with Tx above rooftop level. Hard polarization case: mean error: 0.87 dB; standard deviation: 0.82 dB.

two-building profile, and three-building profile. Preliminary results of this investigation were given in [4], [5].

### III. SINGLE-BUILDING PROFILE

The single-building profile is the simplest approximation of a building obstruction along the path joining the transmitter to the receiver. Because of its rectangular shape, there are two diffracting edges at the top of the building model. Even though this appears to be a very simple case, the field diffracted past these two edges cannot be computed using only first order diffraction coefficients, but at least second order diffraction coefficients must be applied. To prove this statement, three different configurations classified upon the position of the transmitter are examined. In all these configurations, the transmitter is kept at a constant height, while the receiver is moved vertically at small increments of a fraction of the wavelength  $\lambda$ .

The first configuration has the transmitter at a constant height above the rooftop level. The measurement results are shown in Fig. 3 and 4 for hard and soft polarization, respectively. For both polarizations, two wide oscillations are observed in the line-of-sight (LOS) region. They are the consequence of the interference between the ray that goes directly from the transmitter to the receiver and the ray reflected on the rooftop of the building. The oscillations seen in the shadow region are due to the interference between the trajectories containing reflections from the ground with the trajectories containing only diffractions by the edges of the building.

The second configuration considers the transmitter below the building rooftop. The results for the hard polarization case are shown in Fig. 5, which also shows the theoretical prediction obtained by computing the field using only first order uniform theory of diffraction (UTD) coefficients [6]. It is evident that,

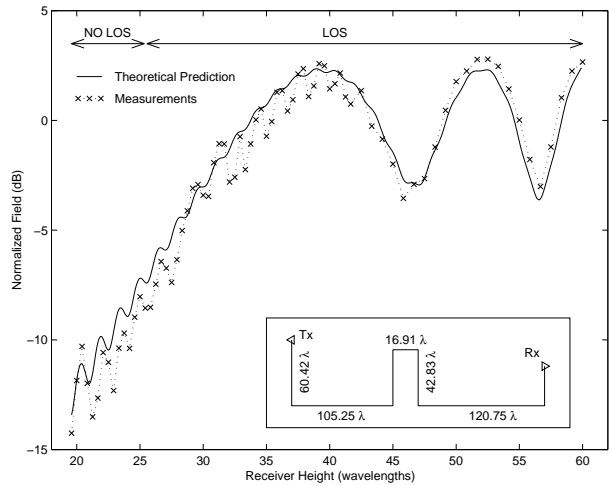


Fig. 4. Propagation with Tx above rooftop level. Soft polarization case: mean error: 0.79 dB; standard deviation: 0.58 dB.

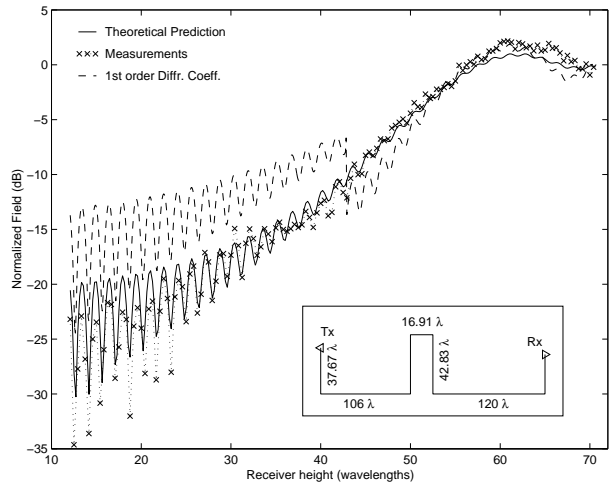


Fig. 5. Propagation with Tx below rooftop level. Hard polarization case: mean error: 1.12 dB; standard deviation: 1.23 dB. The computation made using only the first order UTD coefficients fails to predict the field correctly in the shadow zone.

even in this simple geometrical configuration, a first order UTD theory is not sufficient to provide correct results. The results for the soft polarization case are shown in Fig. 6. In this figure, the result computed using the first order UTD coefficients is also shown. It is clear that, as soon as the receiver enters the transition zone between the LOS region and the shadow region, the prediction is no longer correct.

The third configuration is the case of grazing incidence and observation aspects, shown in Fig. 7. Here the transmitter, due to its non-negligible size, is positioned slightly below the rooftop level to guarantee that no direct ray illuminate the receiver. The receiver is moved vertically at small increments of  $0.08\lambda$ . This case is challenging for the application of the ray theory because the ray approximation of the diffracted fields is not correct within the transition zones. Nevertheless, the application of the second or-

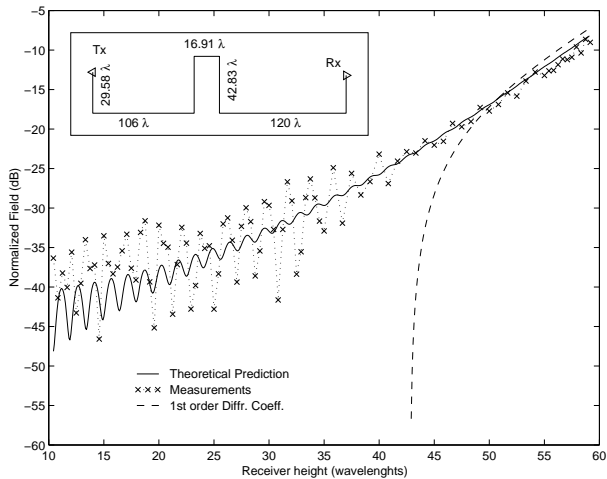


Fig. 6. Propagation with Tx below rooftop level. Soft polarization case: mean error: 2.90 dB; standard deviation: 2.59 dB. Notice that the field predicted using the first order UTD theory is not correct in the shadow zone.

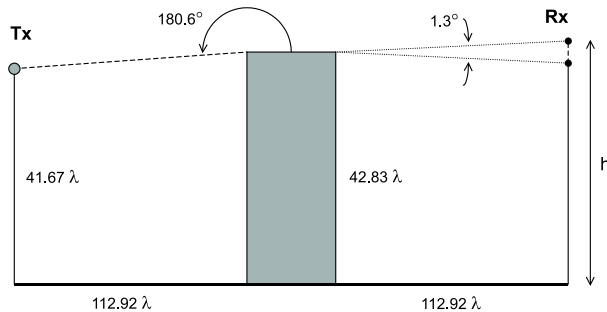


Fig. 7. Geometry for a rectangular building obstacle at almost grazing incidence and observation aspects

der UTD theory provides a close agreement for both polarizations as shown in Fig. 8.

#### IV. TWO-BUILDING PROFILE

The two-building profile may be regarded as the simplest case of multiple rows of buildings having nearly uniform height, which is a situation of practical interest, especially in suburban areas. The case of two buildings of almost equivalent height is challenging for any ray-tracing method. Referring to the inset of Fig. 9, the challenge comes from the trajectories that are in the transition zone of the edges. In particular, the most difficult case occurs when the transmitter is below the building rooftop, since the field at the receiver is only due to diffraction mechanisms, which have to be carefully computed.

This experiment considers the transmitter located below the level of the buildings' rooftops, while the receiver height varies from near the ground up to the line-of-sight region. The hard polarization case is examined in Fig. 9. The agreement is very good, but one notices stronger differences around the transition between the lit and shadow zone. These differences are explained on the basis that at grazing incidence the transmitter and the receiver are aligned

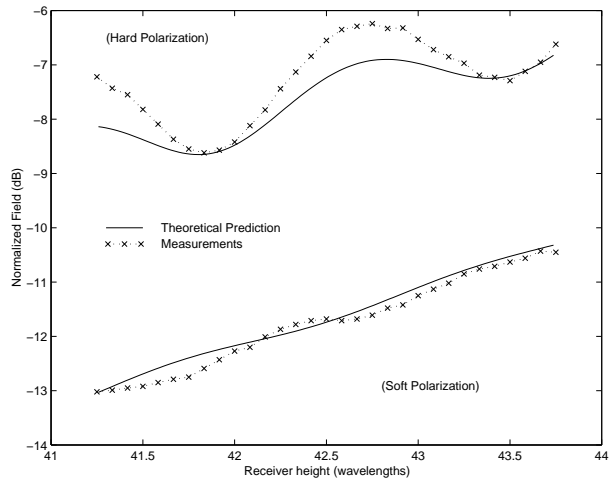


Fig. 8. Propagation at grazing incidence. Soft polarization case: mean error 0.14 dB; standard deviation 0.08 dB. Hard polarization case: mean error 0.36 dB; standard deviation 0.27 dB.

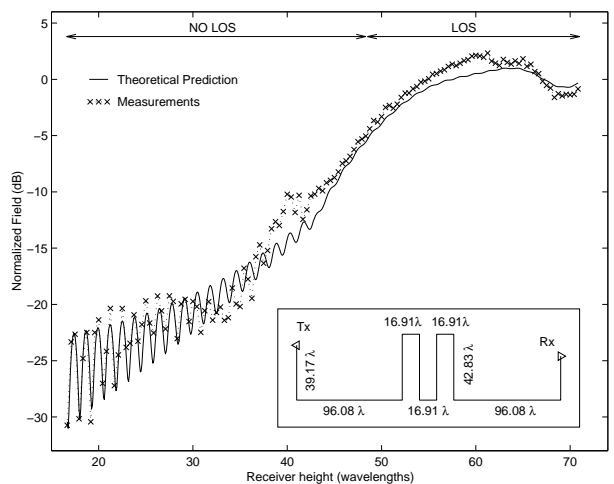


Fig. 9. Propagation with Tx below rooftops. Hard polarization case: mean error: 1.14 dB; standard deviation: 0.85 dB. The incidence angle is  $2.18^\circ$ .

with the four edges of the two buildings. This situation requires a diffraction coefficient of order higher than the second; however, the polygonal line simulator uses only the second order diffraction coefficients described in [7] that, nevertheless, perform very well.

The soft polarization case is examined for the configuration in Fig. 10. Even though the predicted field results slightly exceed the measurements in the shadow zone, the comparison still shows a very good agreement. Incidentally, a similar profile has also been considered, but only theoretically, using the parabolic equation method in [8].

#### V. THREE-BUILDING PROFILE

The third profile contains buildings of different height and shape and is shown in the inset of Fig. 11. The purpose of this profile is to investigate propagation mechanisms more complex than those found with the previous two profiles as well as to prove that the

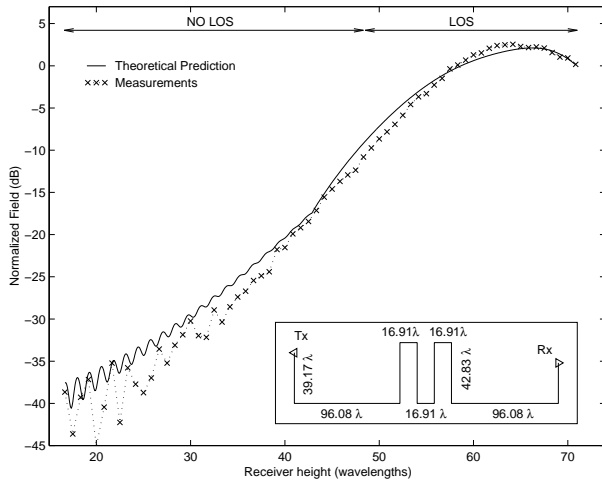


Fig. 10. Propagation with Tx below rooftops. Soft polarization case: mean error 1.53 dB; standard deviation 1.45 dB.

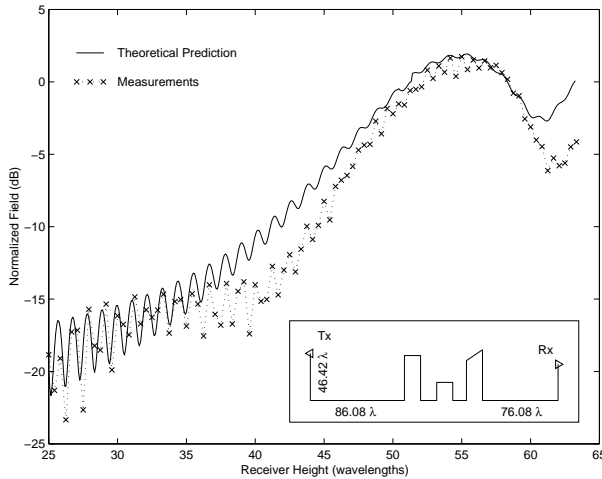


Fig. 11. Propagation with Tx above rooftops. Hard polarization case.

polygonal line simulator can account for more complex situations. The comparison for the case of hard polarization is shown in Fig. 11, while the soft polarization case is considered in Fig. 12. For both cases, we can conclude that the agreement with the theoretical predictions is excellent.

## VI. CONCLUSIONS

The authors have presented experimental results conducted inside an anechoic chamber at the frequency of 25 GHz to further verify the simulator described in [1], [2], [3]. The comparisons show a very good agreement between theory and measurements.

The importance of this research is the comparison of the theoretical method with measurements inside a controlled environment. This allows for a validation of the theoretical method, without the influence of external parameters that are unavoidable in the case of open field measurements. To the best of the authors' knowledge there is only another study [9] describes

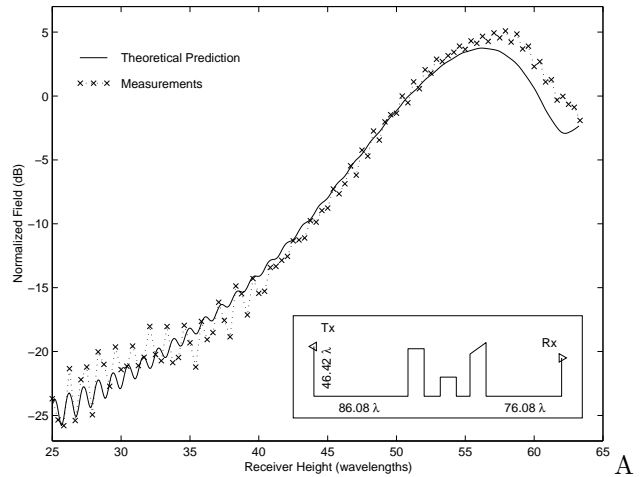


Fig. 12. Propagation with Tx above rooftops. Soft polarization case

measurements on a scaled model. The analysis presented herein is followed by the one given in [10].

## VII. ACKNOWLEDGMENTS

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