Proceedings of the IEEE 46th Vehicular Technology Conference, Atlanta, USA, April 1996, pp. 859-863.

PROPAGATION IN URBAN MICROCELLS WITH HIGH RISE BUILDINGS

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Abstract—In this paper 2D and 3D ray-tracing-predictions based on UTD are compared to measurements in urban microcellular environments characterized by an irregular mixture of building heights due to the presence of relatively high rise buildings. It is shown that the 2D ray-tracing underestimates the measurement in area far from the transmitter. The theoretical study and the preliminary comparisons with measurements in Rotterdam (NL) showed that the 3D backward diffraction by high rise buildings might account for the propagation in area far from the transmitter and overcome the limitation of the 2D model in these areas. Trees were found to influence heavily the 2D prediction. Taking into account the same 3D contributions becomes even more important when there are obstructions such as trees in the 2D plane. A reasonable agreement with measurement can be obtained with a combined 3D and 2D (considering the absorption effects of trees) predictions.

I. INTRODUCTION

Accurate path loss predictions in urban microcellular environments are required to improve the planning of emerging high capacity cellular networks. Two dimensional (2D) ray-tracing for propagation prediction in microcells simplifies the environment by considering infinitely high buildings, and thus leads to relatively fast computation at the expense of neglecting the effects of propagation over the rooftops [1]. At some distance from a base station, comparisons between measurements performed in a microcellular environment (transmitter below rooftops) in Bern (Switzerland) and 2D ray-tracing predictions showed that the computed 2D contributions (reflection and diffraction) underestimate the measurements. The missing contributions are expected to come from scattering on building walls or more probably from over rooftop propagation. Maciel, Bertoni and Xia [2] used the multiple half screen approach to account for the energy traveling forward over rooftops from the transmitter to the receiver. Cichon, Kurner and Wiesbeck [3] applied the Uniform Theory of Diffraction (UTD) to account for the propagation in the vertical and transversal planes containing the transmitter and the receiver. Outside these two planes, only first order scattering contributions were accounted for. In this paper 2D and 3D ray-tracing-predictions based on UTD are investigated. Up to third order combinations of reflections by vertical building walls and diffractions by horizontal building wedges are considered in the whole 3D space, i.e., not only in the vertical plane containing the transmitter and receiver as in [3]. As opposed to [2] this paper studies over rooftop propagation in environments with an irregular mixture of building heights.

The 2D and 3D ray tracing methods used here are briefly presented in section II. Section III presents a theoretical investigation of over rooftop propagation in microcellular environments. The measurements are described in section IV. Comparison between around buildings (2D) and over rooftop (3D) predictions and measurements are presented in section V. Finally section VI draws conclusions on some propagation phenomena in microcells.

II. MODEL DESCRIPTION

The 2D ray tracing algorithm investigated accounts for all combinations of reflected rays by building walls and diffraction by building corners up to a certain predetermined order. Arbitrary layout of buildings can be handled. The absorption effects of trees are also considered in the model as described in section V.

The 3D ray tracing package we are using (FiPre) is a UTD based propagation prediction tool of Technical University of Eindhoven. It was originally developed for application in Satellite communication systems for determining site shielding effects [8-9]. Later on it was developed further in cooperation with KPN Research for application to terrestrial mobile systems [10]. In this work we are using a subset of FiPre prediction, i. e., the over rooftop component. Thus our 3D package accounts for combinations of reflected and diffracted rays in the 3D space up to an order of three. Reflections occur on the vertical building walls. Reflections by building rooftops are not considered. Arbitrary layout of flat rooftop buildings can be handled. In this paper, since we are only interested in over rooftop contribution, we do not consider the diffraction by the vertical wedges of buildings. At least one diffraction is involved in any ray path.

In both the 2D and 3D algorithms reflected wave fields are computed according to the well known formula for the Fresnel reflection coefficient for vertical polarization. The depolarization effects are neglected. The heuristic extension of the UTD valid for a wedge with impedance faces [5] is used to account for the diffraction. In the 3D algorithm, a slope diffraction [6] component is considered when double diffraction occurs on the same building rooftop. The electrical parameters attributed to the building walls in both the 2D and 3D predictions were 5 for the relative permitivity and 10^{-3} [S/m] for the conductivity. These values, reasonable for building material, were found to give a good fit between predictions and measurements in Bern [1] and Fribourg in Switzerland.

In the 2D predictions all combinations of reflected and diffracted rays are accounted for up to nine reflections and one diffraction per path. The order of reflection was fixed to ensure that a higher order of reflection will not change the result of the predictions.

III. THEORETICAL INVESTIGATION OF OVER ROOFTOP PROPAGATION

This section focuses on the two scenarios shown in Fig. 1. The two scenarios illustrate an example of backward and forward propagation by a high rise building. The term forward propagation denotes the mechanism in which the energy travels in the vertical plane containing the transmitter and the receiver in a forward way from the transmitter to the receiver as studied in [2]. The term backward propagation denotes any other mechanism in and outside the vertical plane containing the transmitter and the receiver. The mechanism depicted in Fig. 1(a) is an example of backward propagation in the vertical plane. Obviously, many other backward propagation scenarios could exist in a real environment.

Over rooftop propagation when buildings have the same height or when the transmitter is at the same as the buildings is not considered in our study since the UTD formulas considered here cannot be applied when successive diffractions occur in the transition region.

At least two diffractions are involved in each of the scenarios shown in Fig. 1. The diffractions occur at angles where it was rather difficult to derive a simple accurate analytical expression to account for the over rooftop loss considering all the geometrical parameters describing the environment. Instead, we performed predictions in the two scenarios illustrated in Fig. 1 considering different geometrical parameters for the environment. Based on these predictions, a qualitative analysis of the influence of the different geometrical parameters describing the environment is given below.

For the backward propagation scenario shown in Fig. 1(a) six geometrical parameters are required to compute the path loss at the receiver L_{Rx}: d1, d2, h_{av}, Δh_{bld}, Δh_{Tx} and w. For the forward propagation scenario shown in Fig. 1(b) another parameter w_{bld} is also required. We consider the variation of: a) the relative height of the high rise building Δh_{bld} from 3 to 30m, b) the average building height h_{av} from 10 to 25m and c) the distance between the transmitter and the receiver d2 from 100 to 1000m. Two street widths w 10 and 20m were considered. The relative base station height Δh_{Tx} is set to 5m and d1 to 15m. For the forward propagation case a Δh_{Tx} equal to 2m was also considered. Triple diffraction does not occur in the transition region for the parameters considered. Fig. 2 shows an example of the results. The observed trend of the field strength at the receiver L_{Rx} due to backward and forward diffraction by a high rise building are summarized in Table 1.

Table 1 The observed trend of the field strength at the receiver L_{Rx} due to backward and forward diffraction by a high rise building in terms of the geometrical parameters of the environment (Fig. 1)

Parameters of the env.	*Variation of L_{Rx}*	*Comments*
h_{av} ↗: 10 - 25m	↘ 6dB	the angle β (Fig. 1) becomes less favorable
Δh_{bld} ↗ : 3 - 30m	↘ 6dB (see note below)	the diffraction by the high rise building becomes lower
d2 ↗ :100 1000m	↘~15-25dB	
Δh_{Tx} ↗: 2 - 5m	no variation	
w ↗: 10 - 20m	no variation	

Note: In the forward propagation scenarios the influence of the high rise building becomes greater for a high average building height (h_{av} ↗) and when the transmitter is located near the transmitter (d2 ↘).

In all the computed backward propagation scenarios the dominant ray was the ray doubly diffracted by the high rise building and then by either wedge P or P' shown in Fig. 1.

In most of the forward propagation scenarios computed the dominant ray was the triple diffracted ray over the high rise building and then by either wedge P or P' shown in Fig. 1. When the high rise building is at less than 50 m from the street in which the receiver is located the double diffracted and then reflected once becomes dominant. It is expected that further than 50 m and up a to certain distance the double diffracted and then double reflected ray will dominate over the triple diffracted ray. The triple diffracted ray will only dominate in the area far form the transmitter. However, our 3D software does not account for rays with an order greater than 3.

The UTD predicts the contribution of the forward diffraction to be about 15 dB less than the backward diffraction as seen from Fig. 2.

When applying the 3D algorithm to a real environment as in section V we will see that other scenarios of backward propagation by high rise buildings could exist leading to less attenuation than the backward scenario shown in Fig. 1(a).

IV. MEASUREMENTS

The measurements were performed by KPN Research in August 94 in three main cities of the Netherlands: Rotterdam, the Hague and Amsterdam. The measurements used three different transmitter heights: 8, 11 and 15 m. The frequency was 945 MHz. A sector averaging was applied on the measurement every 10 m. In Fig. 3 the measurements in Rotterdam are shown as a function of the distance to the transmitter on a log-log scale. The transmitter height is 8 m. The dependency on the distance is not obvious especially in the area near the transmitter (distance<500m). Although not shown here, it was observed that the dependency on the distance is weaker in Rotterdam which presents a more irregular mixture of building heights than the Hague. The weak dependency on the distance in both cities shows that more deterministic model than the conventional empirical single or dual slope models are needed to accurately predict the coverage in urban microcells.

V. Comparison with Measurements in Rotterdam

This section presents a comparison between our 2D and 3D predictions and some measurements in Rotterdam for a transmitter height of 8m. The map of the area considered in Rotterdam and the observation route are shown in Fig. 4. The black dots represent the 300 measurement points. The point numbers are shown every 5 points. The distance between two successive measurement points is about 10m. The prediction area is 800x800m^2 and contains about 400 buildings. The total number of building walls is 3400. A rough layout of the trees is also shown.

The 2D predictions with and without considering trees are compared to measurements in Fig. 5. The 2D predictions without considering trees overestimates the measurements along all the measurement road even in the line of sight of the transmitter (measurement point numbers 120-140 and 260-280 in Fig. 4). The overestimation is most probably due to the trees surrounding the transmitter. In fact, a rough map of the tree locations was introduced in the 2D ray tracing algorithm as shown in Fig. 4. In the literature, trees are reported to have an absorption [6] and scattering [7] effects. None of these references was applied to microcellular propagation. Here only the absorption effect is considered. The reference [6] reports an average absorption loss of 1.8 dB per meter for trees with foliage at a frequency of 900 MHz. However in [6] the study considered a relatively short path through trees: from 2 to 15 m. In a microcell environment the passage of the ray through trees could vary from a few meters to a few hundred meters. The following approximation of the tree loss L_{tree} was found to adequately correct the error due to trees:

$$L_{tree} = 1.8 + 12\log(d_{tree})\ [\text{dB}], \qquad d_{tree} \geq 1\text{m}$$
$$L_{tree} = 1.8\ [\text{dB}], \qquad d_{tree} < 1\text{m}$$

where d_{tree} is the passage of the ray through trees. This expression fits the results reported in [6] for short passage through trees but does not increase as rapidly for $d_{tree} > 15$m. When trees are considered in the 2D predictions, an obvious improvement is noticed in the line of sight (measurement point numbers 120-140 and 160-180 in Fig. 4) and in vertical streets (e. g., measurement point numbers 1-35 and 50-75 in Fig. 4). Fig. 5 shows clearly the effects of vegetation on microcellular propagation. Further investigation is needed to determine how the absorption varies in term of tree kind and the level of details in which trees have to be described.

In Fig. 6 the 3D contribution is added to the 2D prediction considering the trees. In Fig. 6 the 3D contribution was only computed on the measurement points: 35-45, 75-115 and 140-220. The remaining points lie either in the line of sight or in vertical streets. In these areas the 2D contribution is expected to account for the propagation phenomena and thus there is no need to consider the 3D contribution.

Comparison between the 2D predictions attenuated by the trees (thick black line in Fig. 5) and the combination between the 2D predictions considering trees and 3D predictions (thick black line in Fig. 6) shows that on the measurement points 35-45, 75-115 and 140-180 the measurements are better matched by the 3D predictions that the 2D ones. Thus, the 3D propagation is found to account for the propagation where the 2D contribution is too low. In Rotterdam, trees has led the 2D contribution to vanish already in the first parallel street (measurement points number 140-160).

The remaining divergence between measurements and the 3D contribution, when it dominates (e. g., measurement point numbers 140-180 in Fig. 4), could be due to the limited order (three) used in the 3D computation. In fact, as mentioned in section II, the order of reflection must be chosen to ensure that a higher order will not change the result of the predictions. Unfortunately our 3D software cannot account for contributions with an order of reflection higher than three. However, on the measurement points 35-45, 75-115, 140-180, the noticeable improvement observed of the prediction when the reflection order was increased from 2 to 3 (not shown here for lack of space) tends to show that a higher order is needed. The 3D predictions are then expected to be higher on measurement points 35-45, 75-115 and 140-180 and thus would be closer to the measurements. On measurement points 180-220 an order higher than 3 is not expected to change the 3D prediction, which already fits the measurement, as the two and three-order-predictions were found to be close to each other.

On measurement points 180-220 the 2D and 3D contribution are similar and both fit the measurements. When the transmitter is neither located in the line of sight nor in a vertical street nor in the first parallel street (in case of low density of trees, otherwise in any parallel street) both 2D and 3D contribution have to be computed and the strongest contribution has to be considered. The 3D contribution becomes more important when there are obstructions in the 2D plane such as trees.

Fig. 4 shows the dominant 3D ray for three chosen locations. Thus, the mechanism of 3D propagation is thus better understood. It is shown that the backward propagation, as defined in section III, is the dominant mechanism. This mechanism is somewhat similar to the 2D mechanism in the sense that reflections by building walls are replaced by diffractions by the horizontal wedges of buildings. When the horizontal wedge on which the diffraction occurs is higher than the average building height, i. e., when it occurs on relatively high rise buildings, the energy is not obscured by other buildings and thus reaches areas far form the transmitter with relatively low attenuation.

VI. Conclusions

In this paper over rooftop propagation in environments with an irregular mixture of building heights due to the presence of relatively high rise buildings was investigated. The theoretical study and the preliminary comparisons with measurements in Rotterdam showed that the backward diffraction mechanism by a high rise building, as defined in section III, might account for the propagation in areas far from the transmitter and therefore overcome the limitation of

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the 2D model in these areas. Taking into account the 3D contribution becomes even more important when there are obstructions in the 2D plane such as trees. The theoretical investigation considering canonical scenarios, predicts the contribution of the forward diffraction to be less important than the backward diffraction. Further comparisons between higher order 3D predictions and measurements are needed to determine under which conditions the backward or forward propagation dominates in a real environment. The influence of combined horizontal/vertical wedge diffractions, not considered in this study, needs also to be investigated.

Trees were found to influence heavily the 2D prediction. Taking into account the tree absorption effects improved the 2D predictions. A reasonable agreement with measurement can be obtained with combined predictions using both 3D and 2D (including the absorption effects of trees) predictions.

Acknowledgment

The authors acknowledge the kind permission of Prof. dr. G. Brussaard of the Technical University of Eindhoven given to us for using FiPre in this collaborative research. The first author would like to thank KPN Research for providing a three months internship during which the major part of this work was carried out.

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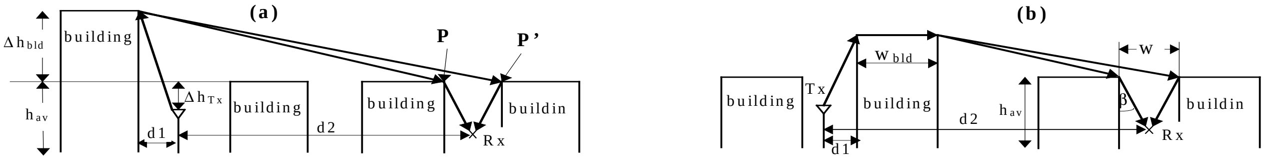

Fig. 1. Two scenarios of over rooftop propagation in a Microcellular environment due to a high rise building: (a) backward and (b) forward diffraction

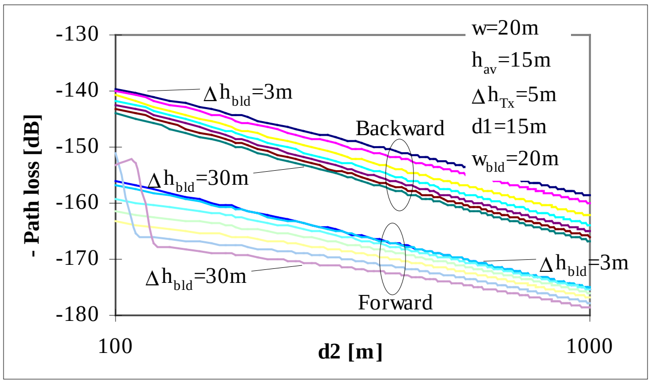

Fig. 2. Variation of the path loss due to backward and forward diffraction by a high rise building in terms of the relative height of the high rise building Δh_{bld} and the distance between the transmitter and the receiver d2 (see Fig. 1).

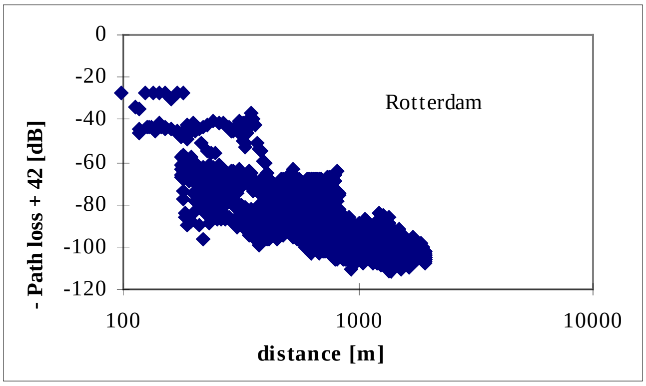

Fig. 3. Measured sector averages signal (dots) versus the distance to the transmitter in Rotterdam (Netherlands)

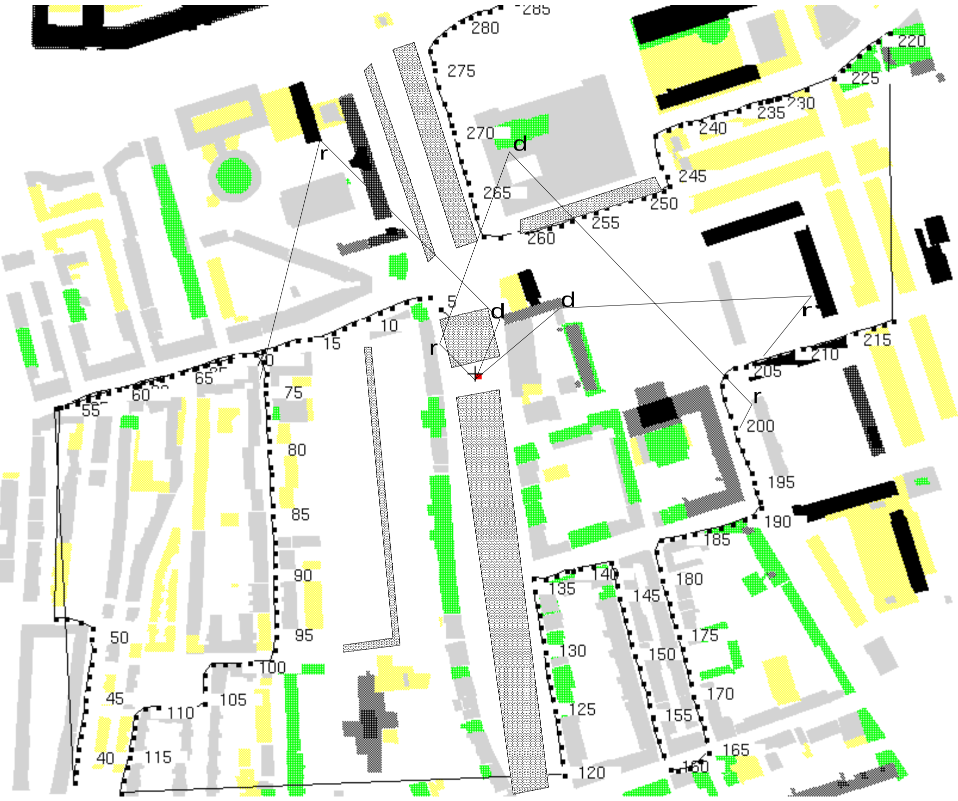

Fig. 4. Map of Rotterdam. The cross indicates the positions of the transmitter. The square dots indicate the 300 measurement locations numbered by steps of 5. The hatched polygons represent the trees. The six building gray levels indicate six levels of building heights: from up to 10m (light) to more than 35m (dark). The dominant ray in the 3D prediction is shown on three observation points. The letters **r** and **d** denote reflection and diffraction

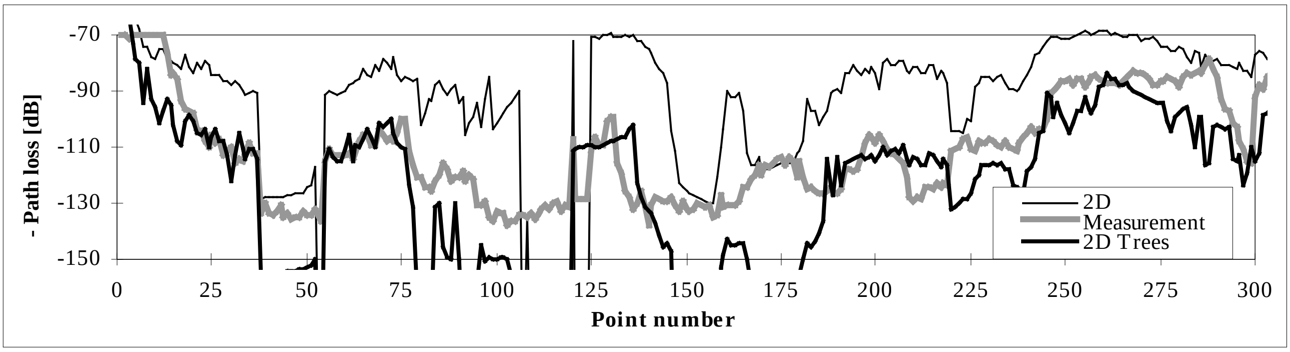

Fig. 5. Comparison in Rotterdam between measurements and the 2D predictions with and without tree effects

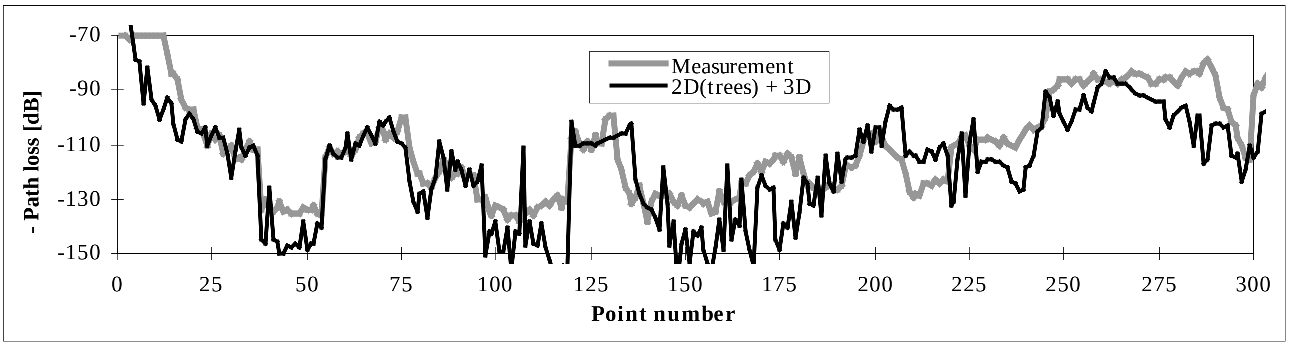

Fig. 6. Comparison in Rotterdam between measurements and combined 2D predictions considering tree effects and 3D predictions.