Verifying path loss and delay spread predictions of a 3D ray tracing propagation model in urban environment

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Abstract— **In this paper path loss and delay spread predictions of a 3D ray tracing software are compared to wideband radio channel measurements made in Helsinki city center. Measurements were carried out in the 2 GHz band by using a wideband radio channel sounder, which gives out complex channel impulse responses. Reference delay spreads were obtained from power delay profiles, and path losses were available after appropriate cable calibration measurements. Comparisons between measurement and propagation predictions were made in cases where a realistic directional BS antenna was placed a) slightly below the rooftop level and b) slightly above the rooftop level. For propagation modeling a fully 3D ray optical model was used.**

Keywords— path loss prediction, delay spread, ray tracing, wave propagation modeling.

I. INTRODUCTION

A. Radio network planning

The performance of wireless communication systems depends in a fundamental way on the mobile radio channel. As a consequence predicting the propagation characteristics between two antennas belongs to the most important tasks for the planning of cellular mobile communication systems. According to the growing number of subscribers, the size of cells had to be reduced from radii in the order of tens of kilometers within rural and suburban environments (macro-cells) down to a few hundreds of meters in urban scenarios (micro-cells). With decreasing size of the cells the importance of wave propagation modeling within urban scenarios increases with regard to the extension of present and the deployment of future systems. This paper verifies a 3D ray tracing software with minimized computational complexity [1] by comparisons to path loss and delay spread measurements in Helsinki city center.

B. Mobile radio channel

The mobile radio channel is characterized by a multipath situation. The signal transmitted by the base station – if only the downlink is considered here – will travel along different paths to the receiving antenna of the mobile station. In many cases there is no direct line of sight and the only signals reaching the receiver have undergone reflections and diffractions at a number of different obstacles. Consequently the field strength in a radio cell shows small-scale fading.

While deterministic ray-based propagation models are able to compute the small-scale fading, planning tools for the prediction of field strength levels will generally provide only mean or median values, as small-scale fading is adequately represented by Rayleigh- or Rice-distributions.

C. Data bases for urban scenarios

Data bases used with radio propagation models contain information on the kind of obstacles between the transmitter (base station) and the receiver (mobile station) and are a compulsory requirement for using the more sophisticated prediction tools. While rural propagation models are generally based on terrain and morphological data in pixel format, urban data bases contain information on the location of buildings and are generally vector oriented. In the vector format, the shape of every building is defined by its corners and its height. All buildings are consequently represented by cylinders with a polygonal plan view. Figure 1 gives an overview of the inner city of Helsinki, the scenario under investigation within this paper.

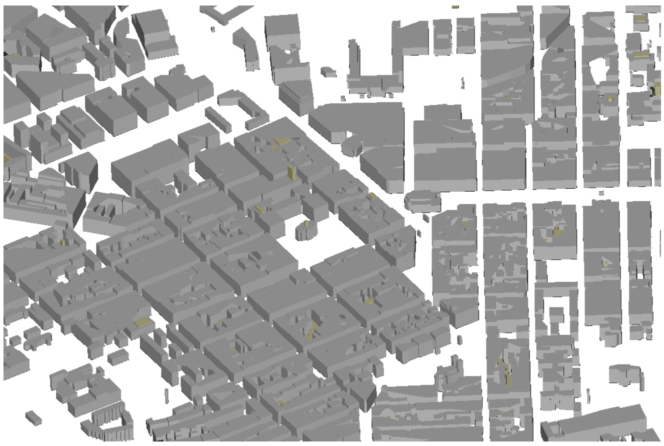

Figure 1. Data base describing the considered environment.
(Data base © FM-Kartta Oy [2])

II. Description of the Measurement Campaign

Channel measurements were performed in the city center of Helsinki. Helsinki downtown area has rather a uniform building height profile without significant high-rise buildings, and the average building height is approximately 20-25 meters from the ground level (see Figure 1). The terrain profile is reasonably flat. Although attenuation due to vegetation objects is also possible to take into account in ray optical modelling [1], it was not considered significant in this urban environment.

Measurements were carried out in the 2125 MHz carrier frequency by using PropSound wideband radio channel sounder (of Nokia Research Center, built by Elektrobit AG [3]). A PN-sequence of length 127 and chip rate of 5 Mchips/s was used as a wideband channel sounding signal. In post-processing phase the complex impulse responses of the channel were obtained by cross-correlating the received signal with the replica of the original PN-sequence. With the parameters given above the maximum complex impulse response delay window is 25.4 µs, and the maximum theoretical dynamic range 42 dB.

Figure 2. Path loss measurements for “low” BS antenna.

Figure 3. Path loss measurements for “high” BS antenna.

The MS with omnidirectional antenna was placed on the roof on a van approximately 2.5 meters above ground level. Two base station antenna locations were considered. In a) "low" position the antenna was placed 5 meters below the rooftop of a 30-m high building. That cannot be considered a clear micro-cellular installation, since the BS was not completely below, but rather at the rooftop level of the surrounding buildings. The (x,y) coordinates for the b) "high" antenna position were same than for the "low" case, but the height was 1.5 m above the rooftop, i.e. 6.5m higher that in the "low" case, and clearly above the neighbouring buildings. The BS was equipped with directional antenna with 11 dBi gain in the mainlobe direction, and 3-dB beamwidth of 120º in the horizontal and 18º in vertical plane. The antenna was mechanically downtilted by 7º.

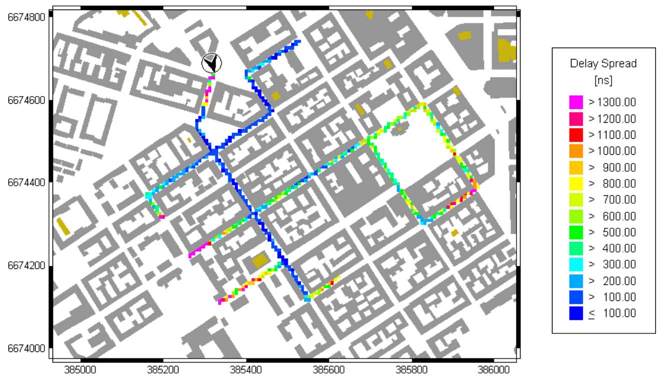

Figure 4. Delay spread measurements for “low” BS antenna.

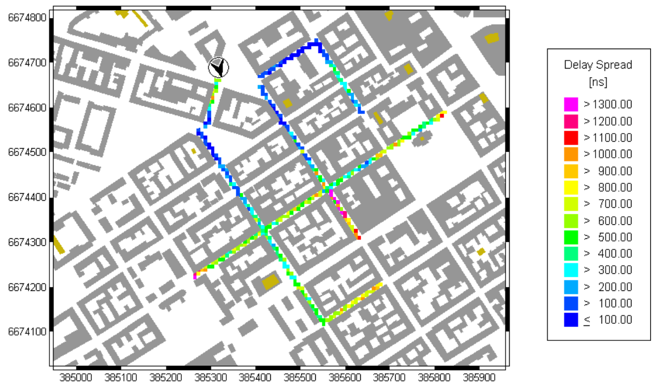

Figure 5. Delay spread measurements for “high” BS antenna.

In case b) the over rooftop propagation plays an important role whereas in a) the street canyon effects are becoming more important. Therefore, the ray tracing model must be capable of treating fully 3D rays in order to capture different propagation mechanisms. Also because in this study the both BS locations were more of macro-cellular nature, vector database accuracy with respect to the building heights and rooftop edges plays a more significant role than in clear micro-cellular modelling. In macro-cellular scenarios also rays over buildings carry significant amounts of energy, and therefore rooftop profiles must be accurately enough modelled. In the vector database used in this study the building height profile was taken into account and height differences greater than 2-3 meters were modelled.

The reference measurement data consist of 3.7 kms routes for the "low", and 2.7 kms for the "high" BS position, measured along streets and open areas. The maximum distance from the BS was 700 meters in both the cases.

Figures 2 and 3 present path loss measurements, and measurements of the delay spread are visualized in Figs. 4 and 5 for both the BS antenna placements.

III. Description of the Wave propagation Model

A. Deterministic modeling

Deterministic propagation models are generally based on ray optical techniques where different rays emitted by the transmitting antenna are subject to reflection, scattering and diffraction at walls and edges of buildings and similar obstacles. The computations are performed with help of the universal theory of diffraction (UTD) or with empirical diffraction models [4]. The most time-consuming part of a prediction based on ray-optical algorithms is the determination of all the relevant paths from transmitter to receiver. For this purpose either a ray tracing or a ray launching algorithm is used [5]. While empirical models for urban scenarios assume a dominant propagation from the transmitter to the receiver above the rooftops, deterministic models consider the physical propagation paths. As a consequence, deterministic models cope with effects such as wave guiding in street canyons, offer excellent accuracy and are able to provide additional parameters such as small-scale fading or delay spread.

B. 3D Ray-optical model based on preprocessing

The main disadvantage of the deterministic prediction models is their excessive computation time (in the order of hours). Different authors presented ideas to accelerate the path finding and some of them lead to considerable acceleration factors. However, these approaches consider only the propagation in two dimensions or in two perpendicular planes (horizontal and vertical plane). In contrast to this a rigorous 3D approach is presented in this paper.

For radio network planning a lot of different transmitter locations are evaluated concerning the overall network performance. As the database of the considered buildings remains the same and only the position of the transmitter changes, the overwhelming part of the different rays remains unchanged, only the rays between the transmitting antenna and primary obstacles or receiving points in line-of-sight are changing if different transmitter locations are compared.

This is the basis for a “Data Base Preprocessing”. In a first step the walls of the building (or other obstacles) are divided into tiles (reflections and penetrations) and the edges (diffractions) into horizontal and vertical segments. After this, the visibility conditions between these different elements (possible rays) are determined and stored in a file (as indicated in Fig. 6). The result of this preprocessing can be represented in the shape of a “visibility tree” (see Fig. 7). For a different transmitter location only the uppermost branches in this tree must be computed again, i.e. determining which elements are in line-of-sight to the transmitter. Consequently all other relations have to be computed only once, which can be done prior to optimizing the location of the transmitter. The remaining computation time after the preprocessing is many orders of magnitude lower than that needed for the conventional analysis without preprocessing. As a consequence 3D deterministic models with their supreme accuracy can be utilized for all practical applications with computation times in the order of those found with empirical models.

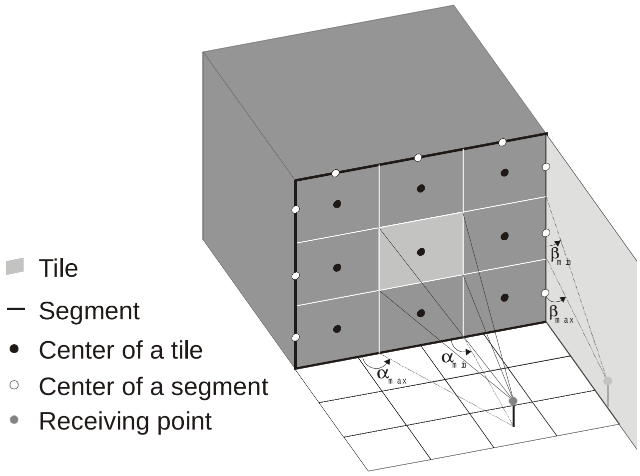

Figure 6. Tiles and segments of a wall (discretization).

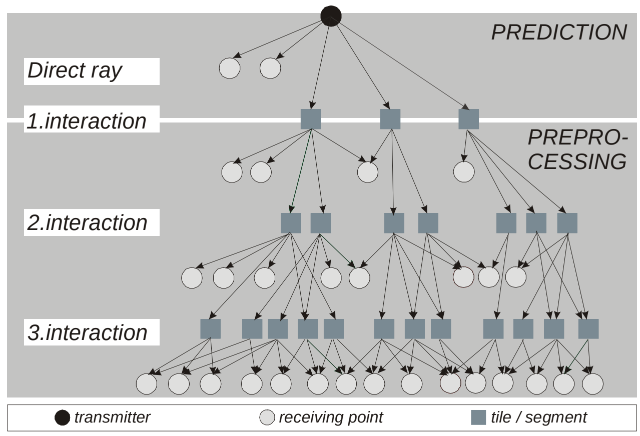

Figure 7. Resulting tree structure of the visbility relations.

IV. Results

The ray tracing propagation model used in this study is fully three dimensional [1], i.e. ray propagation is not limited to vertical and horizontal planes (2x2D). Therefore the 3D ray tracing computes all rays with max. three interactions (triple reflections and double diffractions in arbitrary combinations).

The dependency of the achievable accuracy on the number of interactions (and types of rays: reflections and/or diffractions) has shown that consideration of double diffractions in 3D modeling is very important and leads to the best accuracy. The results shown in this paper are obtained with the consideration of all rays with max. three interactions (max. two diffractions and up to three reflections in arbitrary combinations). Additionally the multiple diffracted ray in the vertical plane between transmitter and receiver is determined for each pixel to include at least the propagation over the rooftops for each pixel (according to the COST 231 Walfisch-Ikegami model) [1],[4]. This additional ray increases the accuracy of the path loss and delay spread predictions.

Table 1 shows the prediction times of the different scenarios used in this paper for a total area of 1.8 km x 1.1 km (resolution 8 m) with more than 1150 buildings. The preprocessing is required only once for the whole database and reduces the prediction times significantly.

TABLE I. COMPUTATION TIMES OF THE 3D RAY TRACING MODEL (1 GHZ PENTIUM® III)

Scenario Helsinki Downtown	
No. of buildings	1150
Area	2 km^2
Resolution	8 m
Database preprocessing (only once)	312 min
Prediction time: Tx above rooftop	20 s
Prediction time: Tx below rooftop	10 s

With this ray tracing algorithm a prediction of path loss, delay spread, angular spread, angle of arrival and channel impulse responses are possible [1]. The focus within this paper is the evaluation of the path loss and delay spread predictions in a typical urban environment (downtown Helsinki, Finland).

A. *Evaluation of the path loss*

Path losses were calculated from sounder measurements in a wideband sense, i.e summing the mean absolute tap powers of the complex impulse responses. In ray optical simulations also mean powers of rays (without phase information) were considered for path loss calculations.

Figures 8 and 9 show 3D path loss predictions for both the low as well as the high transmitter case, indicating a 9 dB increased overall coverage for the high BS antenna.

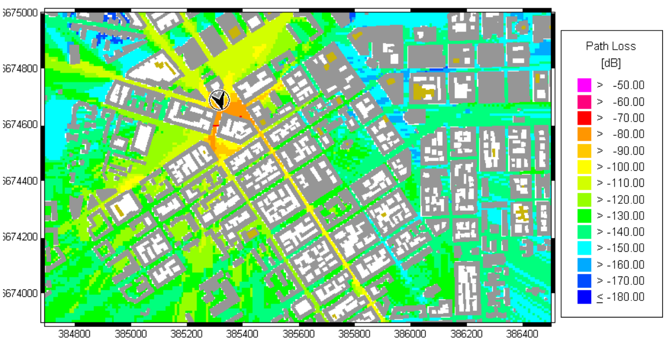

Figure 8. Path loss prediction for “low” BS antenna.

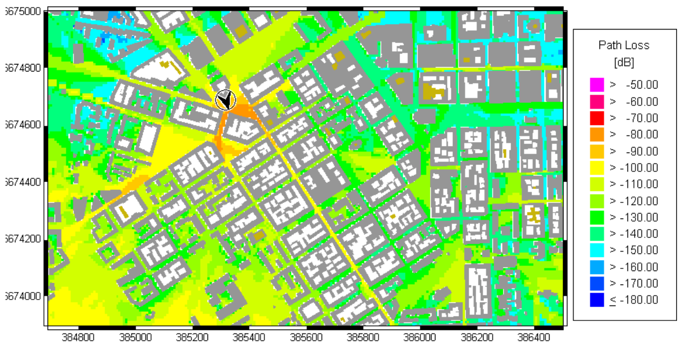

Figure 9. Path loss prediction for “high” BS antenna.

In Fig. 10 differences between predictions and measurements are visualized. For both BS locations a similar behaviour can be observed, i.e. the error of the prediction does not depend on the absolute predicted value. Table II presents the statistical values of the comparisons between predictions and measurements. In both cases the mean value is close to 0 dB and the standard deviation is around 8 dB. This accuracy is also achieved in other scenarios [6].

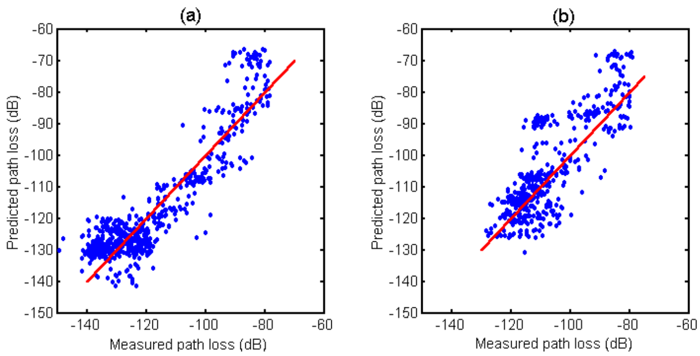

Figure 10. Measured path loss versus predicted pathloss for (a) "low" and (b) "high" BS position. Red line denotes the exact match for reference.

For the predictions the terrain topography was additionally considered but it influenced the accuracy only slightly because the terrain profile of Helsinki is nearly flat.

TABLE II. ACCURACY OF THE 3D RAY-OPTICAL MODEL FOR PREDICTIONS OF PATH LOSS IN AN URBAN SCENARIO.

Scenario Helsinki	Mean Error	Std. Deviation
Low BS antenna	0.8 dB	7.7 dB
High BS antenna	0.1 dB	8.7 dB

B. *Evaluation of the delay spread*

In calculating the predicted delay spread values the impulse responses obtained by ray optical model were first filtered to match the sounder chip rate of 5 Mchips/s. Figures 11 and 12 show predictions of the delay spread for both the low as well as the high transmitter case indicating somewhat larger delay spreads for the higher BS antenna. This corresponds also to the measurements presented in Figs. 4 and

5. However the number of interactions for the ray-optical approach has a strong influence on the accuracy of the delay spread prediction (as reported also in [5]) e.g. in the low transmitter case where some outer regions are reached by a limited number of rays.

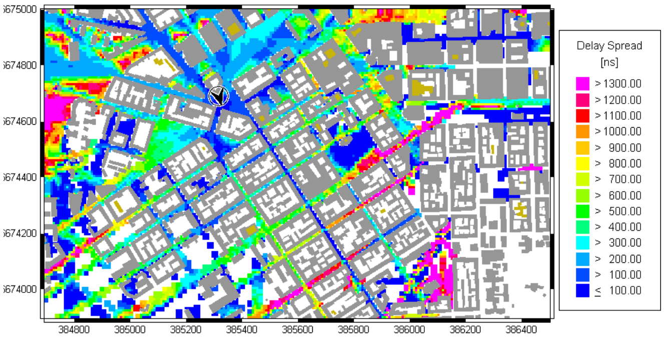

Figure 11. Delay spread prediction for "low" BS antenna.

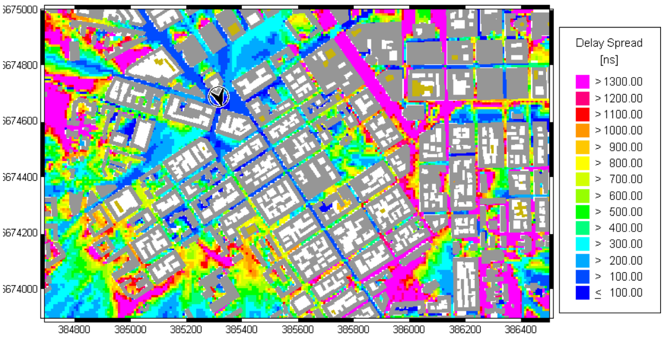

Figure 12. Delay spread prediction for "high" BS antenna.

In Figure 13 differences between predictions and measurements are visualized, and Table III presents the statistical values of the comparison between predicted and measured delay spreads. In both cases the mean error value is below zero which means that the predicted delay spread is underestimated. The reason for this might be the limited number of interactions, and also the limited number of obstacles included in the building database (small non-building obstacles will increase the number of rays and lead to higher values of the delay spread). Also no big obstacles (tall buildings) in large distances (outside the prediction area) are considered, which might be responsible for some significant reflections and contributions to the resulting signal.

TABLE III. ACCURACY OF THE 3D RAY-OPTICAL MODEL FOR PREDICTIONS OF DELAY SPREAD IN AN URBAN SCENARIO.

Scenario Helsinki	Mean Error	Std. Deviation
Low BS antenna	-52 ns	428 ns
High BS antenna	-106 ns	375 ns

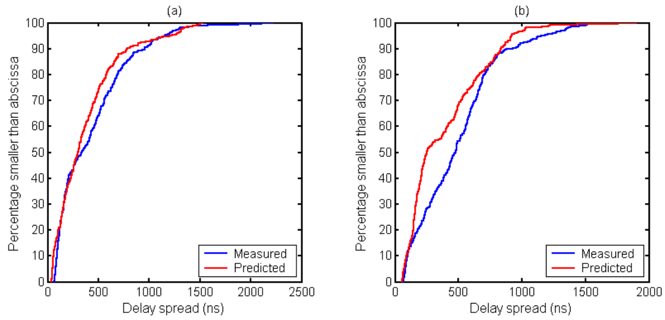

Figure 13. Cumulative distributions of delay spreads for (a) "low" and (b) "high" BS position.

V. SUMMARY

In this paper path loss and delay spread predictions were compared against data from wideband radio channel measurements. With the ray-optical model presented in this paper, path loss and delay spread predictions in urban macro-cellular propagation environment gave reasonable accuracy in very short simulation times.

Especially delay spread comparisons are generally rather seldom reported results due to for example the difficulties related to the sensitivity of the parameter to measurement setup and postprocessing, as well as its dependence on number of rays in the ray-optical model and the extent of the available data base. The selected comparison scenarios in this study were challenging in the sense that (nearly) macro-cellular BS locations require accurate modelling of fully 3D propagation. Also the database quality is a more critical parameter than in pure micro-cellular scenarios, because building heigth profile has greater impact on prediction accuray. Moreover, in this study a realistic directional antenna was used in the BS, whereas normally in ray tracing verifications omnidirectional antennas are used, as in this way errors related to sector antenna orientation can be eliminated.

ACKNOWLEDGEMENTS

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