Accelerated Ray Optical Propagation Modeling for the Planning of Wireless Communication Networks

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Ray optical modeling of wave propagation is often used for the prediction of the field strength (and delay spread) in wireless mobile communication networks. However, the practical use of these deterministic models is limited due to their high computational demands. For large areas in urban or indoor scenarios the computation times are in the range of hours which is too long for the planning of mobile radio networks.

A new method for the acceleration of ray optical models is presented in this paper. It is based on a single intelligent preprocessing of the database in which the mutual visibility relations between the walls and the edges of the buildings are determined. The propagation model is implemented for urban and indoor scenarios and comparisons with measurements show the gain in computation efficiency as well as in achieved prediction accuracy.

I. Introduction

Ray optical 3D propagation modeling has become a widely discussed technique for the prediction of the field strength (and also of the delay spread) in indoor and urban scenarios [1]. This kind of wave propagation modeling is very accurate because it considers waveguiding effects in street canyons (urban) or corridors (indoor) and it includes also diffraction at corners.

There are two basic approaches to searching ray optical propagation paths in an arbitrary vector oriented building database: ray tracing and ray launching [2].

Ray tracing computes valid rays for each receiver point individually and guarantees the consideration of each wall as well as a constant resolution. This individual computation is more time-consuming than the ray launching approach, where the rays are launched from the transmitter into all relevant directions discretized into small angular increments. There are problems, however, with considering diffracted rays. In ray launching an edge could be neglected because it is located between two rays, additionally the diffraction multiplicates the number of launched rays. Different approaches to solve the problems with ray launching were presented in the last years [3], but the ray launching has still kept the disadvantage of a variable resolution depending on the distance to the transmitter.

Generally the field strength is computed using Fresnel equations for the reflection and GTD/UTD for the diffraction [4]. On the other side empirical diffraction models are available, because they can be calibrated with measurements [5].

Ray optical models are very time-consuming, because all possible rays must be determined and therefore many reflections and diffractions have to be computed. Especially 3D models generate a large number of rays, but only few of them deliver an important contribution to the received electromagnetic energy. Therefore implementations for 2D are also available, but they have a limited accuracy and the computation times are still in the range of hours on a standard PC. Several approaches to accelerating these models were presented in the last years and lead to acceleration factors up to 10 [5]. But the computation times of these ray optical models (2D and 3D) are currently still in the range of hours if many prediction points (large prediction areas) and many interactions are taken into account.

II. Preprocessing of the Database

The visibility relations between walls and edges of the buildings stored in the database are independent of the position of the basestation. Based on this consideration it is possible to accelerate the time consuming process of path finding by a single intelligent preprocessing of the database. This preprocessing is the basic idea of our new approach.

To this end all walls of the database are subdivided into tiles, all edges of the database are subdivided into segments and also the prediction area is subdivided into a grid of receiver points as shown in figure 1.

The discretization of the database leads to a reduction of identical operations, because the ray tracing algorithm

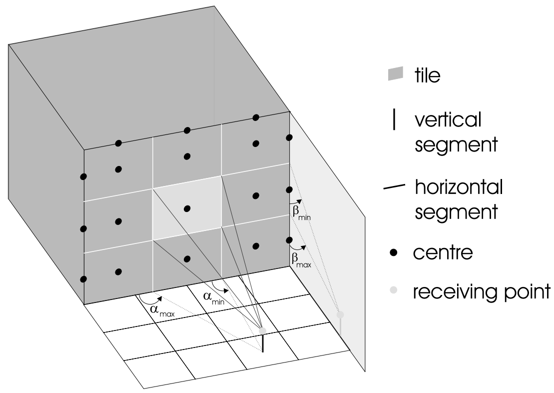

Fig. 1: Tiles and segments of a wall and receiver points

determines nearly the same rays for neighboring prediction points and for all these points the same computations are necessary (reflection and diffraction points lie on the same walls and edges [2]).

After discretizing the database the visibility relationships between all tiles, segments and receiver points are determined in the preprocessing. The visibility relations are given by the line of sight criterion between the centers of the tiles (or segments). This leads to a simplification of the problem of path finding, i.e. possible interaction points are the centers of the tiles and segments, only.

If there is e.g. line of sight between a tile and a receiver point (see figure 1), the four connecting straight lines from the receiving point to the corners of the tile are considered. By projecting these four lines into two perpendicular planes, four angles are determined which give an adequate description of the visibility relation. Similar computations for the visibility relations between tiles and tiles, tiles and segments, segments and segments and between segments and receiving points are performed in the following steps and are also stored in a file.

The projection of the connecting straight lines is very important, because by this operation a range of possible reflection (or diffraction) angles for the illuminated tile (or segment) is defined. Also the angles continue on the neighboring tile respectively segment, so a very accurate computation of the rays is possible even if the tiles or segments are large (up to 5 or 10 meters, depending on the database) [2].

Tables I and II show the memory requirements for different urban scenarios and different sizes of the tiles and segments. The computation times given in table III are smaller than the computation time needed for a single prediction for the same area with the standard ray tracing (see table V), because each visibility relation is only computed once in the *preprocessing* while in the *prediction* the visibility relation might be considered and be computed for many prediction points.

Area	400 m x 400 m	600 m x 600 m	800 m x 800 m	1000 m x 1000 m
Nancy	1.2 MB	3.1 MB	6.7 MB	10.4 MB
Stuttgart	1.0 MB	2.8 MB	6.2 MB	10.1 MB

TABLE I: Memory requirements depending on the size of the preprocessed urban database

Resolution	5 m	10 m	20 m
Nancy	37.9 MB	10.2 MB	3.6 MB
Stuttgart	36.7 MB	9.8 MB	3.4 MB

TABLE II: Memory requirements for the preprocessing of an area 600 m x 600 m of an urban database depending on the resolution of tiles and segments (in all cases 5 m resolution for the receiving points)

Area	400 m x 400 m	600 m x 600 m	800 m x 800 m	1000 m x 1000 m
Nancy	1 min	3 min	7 min	15 min
Stuttgart	1 min	4 min	8 min	17 min

TABLE III: Computation times for the preprocessing of databases

Table IV presents the dependency of the computation time on the size of the tiles and segments.

Further information about the preprocessing, the subdivision of the buildings and the parameters for the computation of the visibility relations are given in [2].

III. Prediction with a preprocessed database

If the visibility relations described are determined in the preprocessing, the only remaining visibility relations to be computed in the prediction are the visibility relations from the transmitter to the tiles, segments and receiver points.

Figure 2 shows schematically the visibility relations determined in the preprocessing. Only the relations in the first layer of the tree structure must be computed in the prediction, all other relations are determined in the preprocessing and can be read from a file.

The stored visibility relations in the tree structure (all layers except the first layer) are independent of the transmitter location and can be used for all predictions with the same database. Only the relations in the first layer of the tree are depending on the location of the transmitter and must be computed in the prediction process for each transmitter location. Due to the small number of visibility relations in the first layer of the tree, the computation times are very small.

Resolution	5 m	10 m	20 m
Nancy	74 min	18 min	6 min
Stuttgart	83 min	19 min	6 min

TABLE IV: Computation times for the preprocessing of an area 600 m x 600 m of an urban database depending on the resolution of tiles and segments (in all cases 5 m resolution for the receiving points)

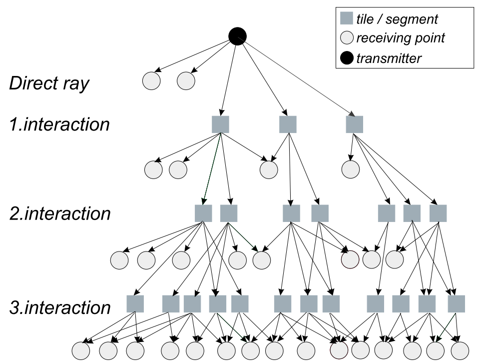

Fig. 2: Tree structure of the visibility relations

The number of interactions influences the computation time because each new interaction corresponds to a further layer in the visibility tree. Very good results are achieved with a maximum of six interactions (reflections and diffractions in different combinations with a maximum of two diffractions in each ray).

In contrast to the urban propagation model, the indoor model considers also the penetration of walls. For this purpose the path loss of each tile is stored together with the visibility relation in the preprocessed file, so the algorithms for the prediction in the two different scenarios are nearly similar.

Area	400 m x 400 m	600 m x 600 m	800 m x 800 m	1000 m x 1000 m
Nancy	*2 s* 2743 s	*8 s* 4607 s	*12 s* 11232 s	*47 s* 29548 s
Stuttgart	*2 s* 3127 s	*6 s* 5134 s	*11 s* 13428 s	*21 s* 33541 s

TABLE V: Computation times for the field strength prediction with *preprocessing* of the database (written in *italic*) compared to the conservative 3D ray tracing

The computation times for different urban scenarios in comparison with a conservative 3D model [5] are presented in table V. They are gained with a maximum of 4 interactions (all combinations of reflections and diffractions with a maximum of two diffractions). Indoor scenarios are computed with similar acceleration factors.

The new approach combines the accuracy of ray tracing with the idea of ray launching. Like with ray launching, the new model follows all rays from the transmitter to the receiver points. But in contrast to ray launching, the accuracy and the resolution are very high, because all rays and their points of interaction are determined in the *preprocessing* similar to ray tracing.

IV. Hybrid prediction models

Ray optical propagation models are characterized by a large number of reflections and diffractions that have to be considered. Owing to the fact that PC-memory is limited, it may happen, that – particularly far away from the transmitter – not all prediction points are hit by rays. In this case empirical wave propagation models are utilized to complement the prediction. For urban scenarios the Walfisch-Ikegami-COST231 model is implemented [6] and for indoor environments the model of Motley-Keenan is used [7].

In order to provide a smooth transition between the empirical prediction and the ray optical prediction a special weighting function is introduced [5], [8].

V. Transition between urban and indoor models

When different databases are used for the indoor and urban scenarios, a very simple interface can be implemented for the prediction model, because the tiles of the walls surrounding the building define the interface between the two databases.

If the transmitter is placed *outside* the buildings, all rays and their angles of incidence are stored for each tile on the surrounding walls of the building. The following computation of the indoor propagation is very easy with the indoor tool, because it uses the information of the incident rays on the surrounding tiles and follows these rays on their way through the indoor visibility tree.

If the transmitter is placed *inside* the building, all rays reaching the tiles of the surrounding walls are stored and followed up later with the urban tool on their way through the urban visibility tree.

VI. Comparison to measurements

A comparison with measurements shows the performance of each propagation model. Many measurements in different scenarios (indoor and urban) were used for the analysis of the performance [1], [2].

A. Urban scenarios

To show the accuracy, an often used scenario in Munich (Germany) is utilized [1]. Figure 3 shows a prediction for this scenario.

Table VI shows the accuracy of the propagation model with the hybrid computation mode (as mentioned

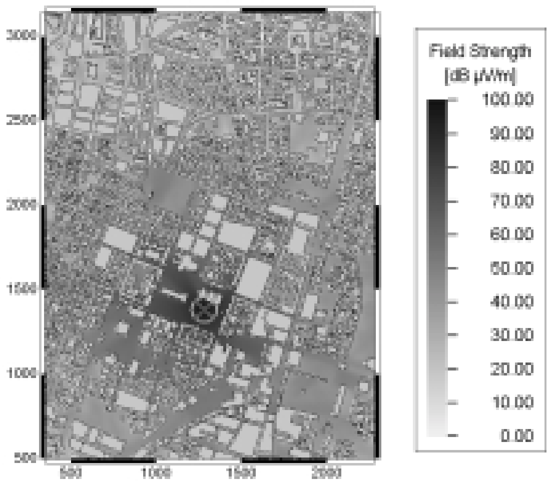

Fig. 3: Prediction in Munich with ray tracing

	Mean Error	Standard-deviation
Route 0	1.3 dB	6.7 dB
Route 1	0.8 dB	5.0 dB
Route 2	-0.2 dB	6.8 dB

TABLE VI: Accuracy of the prediction in Munich

above). The total area (2000 x 2500 meters) is computed in less than 300 seconds on a standard PC [8]. Compared to other approaches [6], very fast and accurate predictions are possible. Further comparisons for the city of Stuttgart (Germany) [2] and Nancy (France) [5] confirm these results.

B. Indoor scenarios

For indoor environments different benchmarks with measurement campaigns were used in different types of buildings. New office buildings like those of the University of Stuttgart [9], older office buildings like those of the University of Vienna [9] and very old buildings like the Marconi-Villa in Bologna were used for the comparison. The results concerning accuracy and performance are similar to those of the urban scenarios.

VII. Conclusions

A very fast and efficient ray optical propagation model is presented in this paper. The new approach combines the advantages of both ray tracing and ray launching and neglects their disadvantages. The comparison with measurements shows a very high accuracy of the new model. An empirical model, implemented in a hybrid approach, improves the accuracy and leads to even better results.

A very simple interface between indoor and urban propagation models is defined using the visibility information of the preprocessed databases.

With this new prediction model it is possible to reduce the computation times for the planning of mobile radio networks to a few minutes and to increase the accuracy of the computation because more interactions can be considered with ray optical models.

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