Fast and Enhanced Ray Optical Propagation Modeling for Radio Network Planning in Urban and Indoor Scenarios

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With the increasing number of subscribers in mobile communications there is a growing interest in propagation models for the mobile radio channel in urban scenarios and inside buildings. Because of the increasing transmission rates propagation models should be able to predict the field strength coverage as well as the wideband properties for these scenarios.

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. Therefore the computation time is reduced to a few minutes on standard PCs. 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 [1].

1. Introduction

The increasing number of subscribers in mobile communications forces network operators to utilize economical frequency planning. An adequate solution to cope with the growing capacity demands is the reduction of the cell size. Especially in densely built up areas with high traffic rates microcellular or picocellular networks are used very often.

The planning of these networks requires highly sophisticated propagation models. Depending on the parameters of the base station (location, frequency, transmitting power and characteristic of the antenna) the propagation models give information about the quality of service in the area taken into account. The field strength level is still considered as the most significant parameter for describing the coverage. However, with the increasing number of digital communications other parameters that characterize the radio channel, such as delay spread and impulse response, become more and more important.

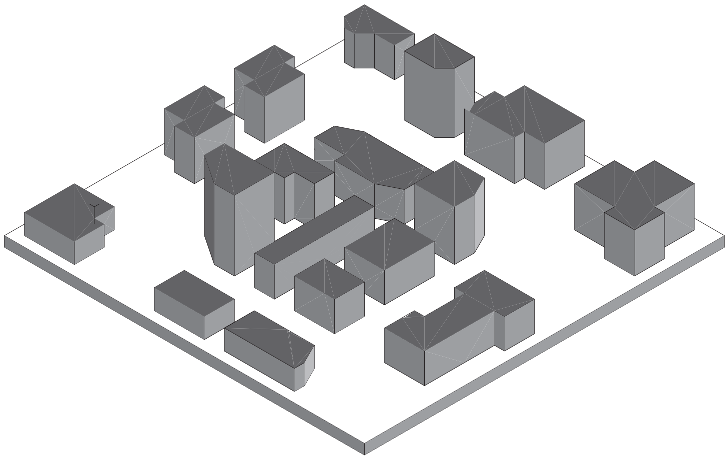

Fig. 1: Building database for urban areas

The basis for any propagation model is a database which describes the propagation environment. As microcells are planned to increase the network capacity in cities, it is obvious to use building oriented databases for urban areas. In order to get a more accurate description of wave propagation, the building data are stored in a vector format. Every building is modelled as a vertical cylinder with polygonal ground plane and an uniform height above street level. With this approach only vertical walls and horizontal flat roofs are considered. Additionally, the material properties of the building surfaces can be taken into account. Figure 1 shows an example of a building database for urban areas.

For indoor sceanrios the building data are stored in a 3D-vector format including all walls, doors, and windows. All elements inside the building are described in terms of plane elements. Every wall is represented by a plane and its extent and location is defined by its corners. As mentioned above, for each element individual material properties can be taken into account. With respect to an efficient use it is also possible to import dxf-files, a very common data format of CAD–software used in architecture.

2. Propagation Models

There are basically two approaches to the prediction of wave propagation in urban and indoor environments which differ in computational effort and accuracy of the prediction [2].

The so called empirical models (e.g. the model according to Walfisch/Ikegami for urban areas or the Multi–Wall–Model for indoor [3]) consider only the propagation in a vertical plane which contains transmitter and receiver (see fig. 2). For the field strength prediction significant parameters have to be extracted from this vertical section (e.g. average building height or number of penetrated walls). Finally equations containing these parameters have to be optimised and fitted to numerous measurements in order to get a prediction model which is applicable in different propagation environments. The main advantage of empirical models is their short computation time. However, their prediction accuracy is limited due to the fact that only a small number of parameters is taken into account and the influence of the distance from the transmitter is over-emphasised. Additionally, waveguiding effects in streets or along floors cannot be considered with this empirical approach.

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 [4]. This kind of wave propagation modeling is very accurate because it considers waveguiding effects in street canyons (urban) or corridors (indoor) and additionally includes diffraction around corners.

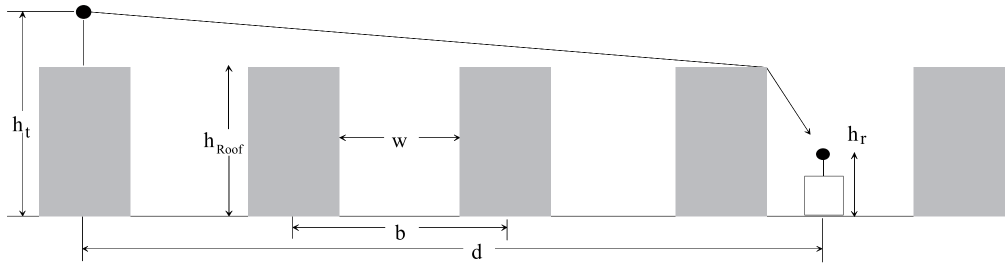

Fig. 2: Empirical approach for wave propagation in urban areas

There are two basic approaches to searching ray optical propagation paths in an arbitrary vector oriented building database: ray tracing and ray launching [5]:

Both of them have their individual advantages and disadvantages. 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 in the middle 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 [6], but the ray launching has still kept the disadvantage of a variable resolution depending on the distance to the transmitter.

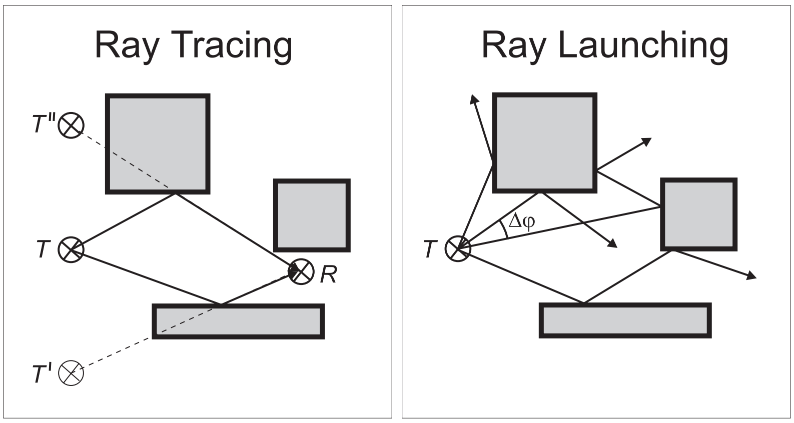

Fig. 3: Different approaches to the search of ray optical propagation paths

Generally the field strength is computed using Fresnel equations for the reflection and transmission and GTD/UTD for the diffraction [7]. On the other side empirical diffraction models are available, because they can be calibrated with measurements [8].

Ray optical models are very time-consuming, because all possible rays must be determined and therefore many reflections, transmissions 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 [8]. 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.

3. Intelligent Preprocessing of the Building 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. For this purpose 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 4.

The discretization of the database leads to a reduction of identical operations, because the ray tracing algorithm 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 [5]).

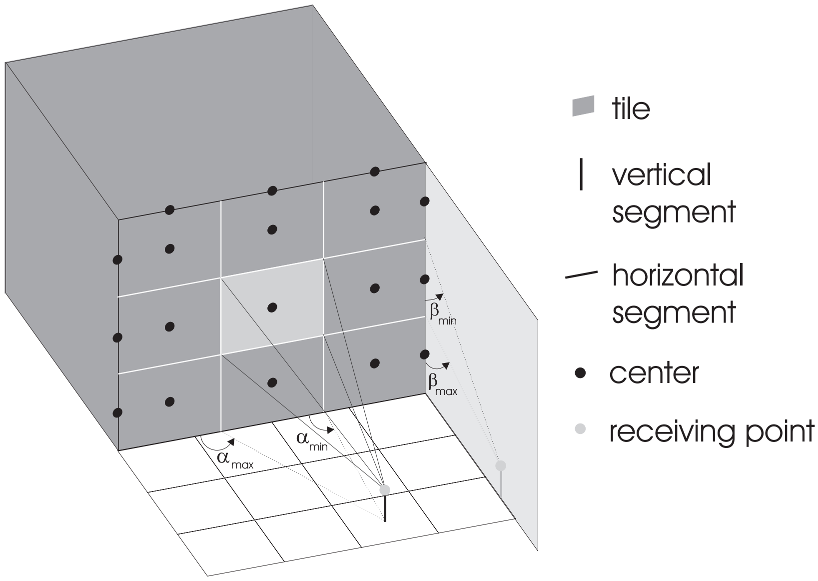

Fig. 4: Tiles and segments of a wall and receiving point

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 path finding problem, 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 receiving point (see figure 4), 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) [5].

Tables 1 and 2 show the memory requirements and computation times for different urban scenarios and different sizes of the tiles and segments. The computation times are smaller than the computation time needed for a single prediction for the same area with the standard ray tracing (see table 3), because each visibility relation is only computed

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 1 min	3.1 MB 3 min	6.7 MB 7 min	10.4 MB 15 min
Stuttgart	1.0 MB 1 min	2.8 MB 4 min	6.2 MB 8 min	10.1 MB 17 min

TABLE 1: Memory requirements and computation times for database preprocessing depending on the size of the urban database

Resolution	5 m	10 m	20 m
Nancy	37.9 MB 74 min	10.2 MB 18 min	3.1 MB 3 min
Stuttgart	36.7 MB 83 min	9.8 MB 19 min	2.8 MB 4 min

TABLE 2: Memory requirements and 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)

once in the *preprocessing* while in the *prediction* the visibility relation might be considered and be computed several times for different prediction points.

4. Prediction after Database Preprocessing

The result of the preprocessing of the building database is a tree structure containing tiles, segments and receiving points of the prediction area, as indicated in fig. 5. In this tree every branch symbolizes a visibility relationship between two elements. For the prediction only the tiles, segments and receiving points, which are visible from the base station have to be determined. Additionally, the angles of incidence for the visible tiles and segments have to be calculated. Subsequently path finding can be done similar to the Ray Launching algorithm by recursively processing all visible elements and checking if the specific conditions for reflection or diffraction are fulfilled. The ray search is stopped, if a receiving point or a given maximum number of interactions is reached. Finally the field strength is summed up at all potential receiving points. Preprocessing the building database reduces the time consuming path finding to the search in a tree structure. A comparison between the number of branches in the first layer (determined in the prediction) with the number of branches in the remaining layers (determined in the preprocessing) in the tree structure given in fig. 5 indicates the relation between the computational effort in the prediction and the computational effort in the preprocessing.

Figure 6 shows the situation of a single reflected ray between the base station and an arbitrary receiving point. Both the transmitter and the indicated receiving point are visible from the center of the bright tile. Therefore, only the conditions expressed in equations (1) and (2) for the different angles have to be verified (see fig. 6). If they are fulfilled, a single reflected ray between the base station and the receiving point exists and its interaction point is assumed to lie in the centre of the tile considered.

The stored visibility relations in the tree structure (all layers except the first layer) are independent of the transmitter

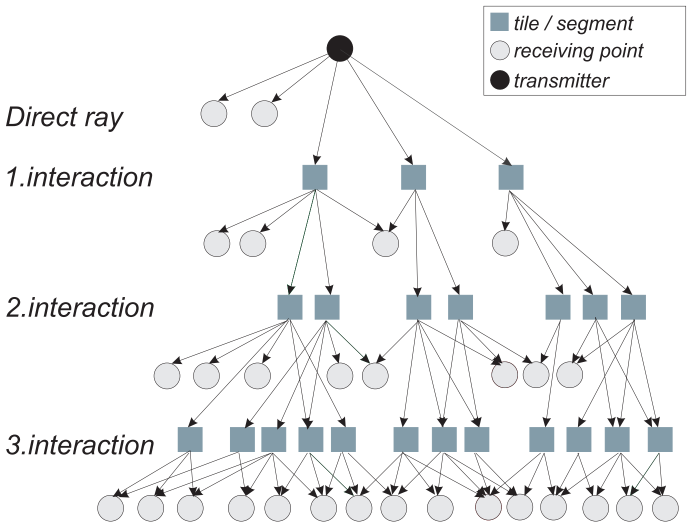

Fig. 5: Tree structure of the visibility relations

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.

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).

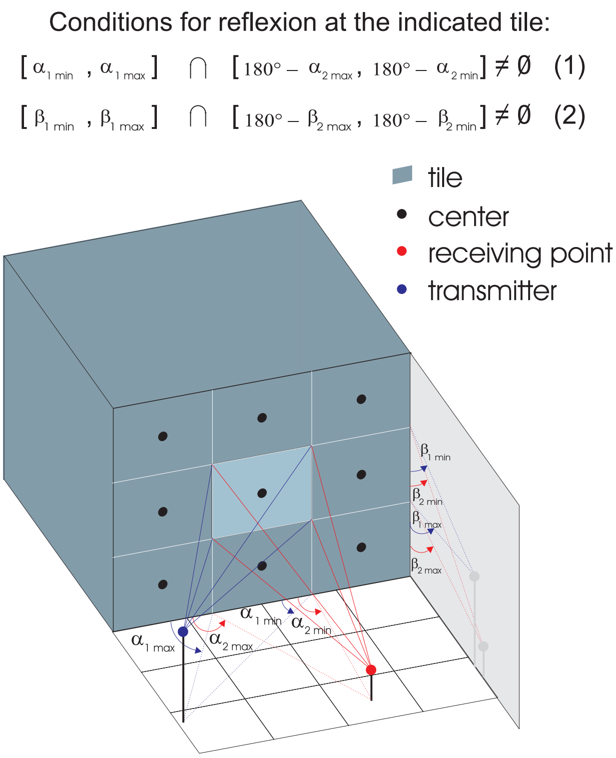

Fig. 6: Example for path finding: Single reflected ray between transmitter and a receiving point

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 3: 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 [8] are presented in table 3. 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.

5. 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 can be used as 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.

6. Comparison to measurements

In order to show the accuracy of the new prediction approach, comparisons with field strength measurements are presented. As underlying test scenario, part of the city center of Stuttgart is chosen with two transmitting stations operating at 900 MHz. The transmitter antennas were mounted at 6 m respectively 5 m height, well below rooftops, which is a typical microcellular environment. Different measurement routes with both LOS and NLOS conditions are considered (see fig. 7 and fig. 9).

Figure 7 shows the differences between prediction and measurement for the first transmitter. The distribution of the differences shown in fig. 7 is presented in fig. 8. The mean error is 0.3 dB and the standard deviation is 5.8 dB. The prediction considers all classes of ray paths shown in table 4. For the discretization of the building database the

Fig. 7: Difference between the new prediction approach and measurements in Stuttgart

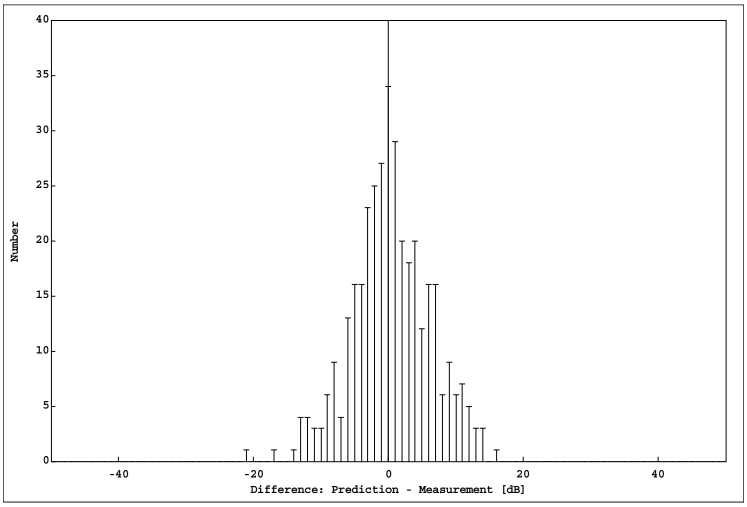

Fig. 8: Distribution of the differences shown in fig. 7

class	ray paths
1	direct ray
2	single reflexion
3	double reflexion
4	single diffraction
5	triple reflexion
6	single reflexion + single diffraction
7	double diffraction
8	double reflexion + single diffraction

TABLE 4: Calculated types of ray paths

parameters shown in table 5 have been selected.

In fig. 9 the differences between prediction and measurement for another transmitting station are presented. Figure 10 shows the distribution of these differences. The prediction has been calculated with identical parameters. In this

Max. horizontal extension of the tiles	10 m
Max. vertical extension of the tiles	40 m
Max. extension of the vertical segments	10 m
Max. extension of the horizontal segments	10 m
Resolution of the receiving points	10 m

TABLE 5: Selected parameters for the discretization of the building database

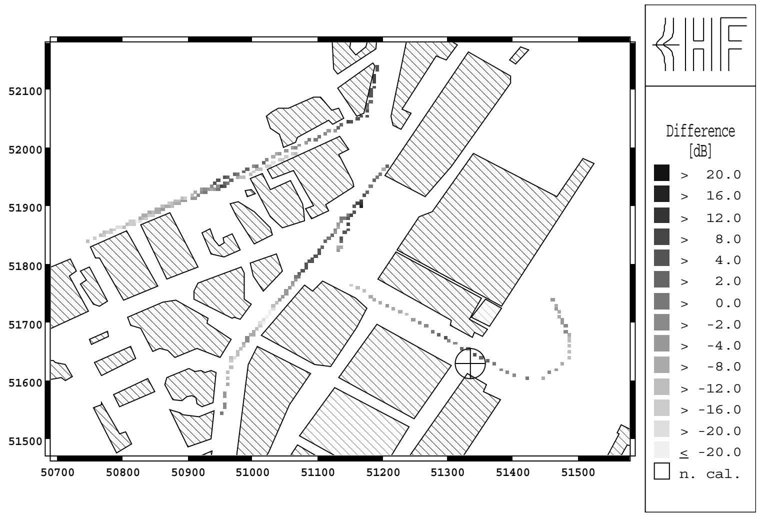

Fig. 9: Difference between the new prediction approach and measurements in Stuttgart

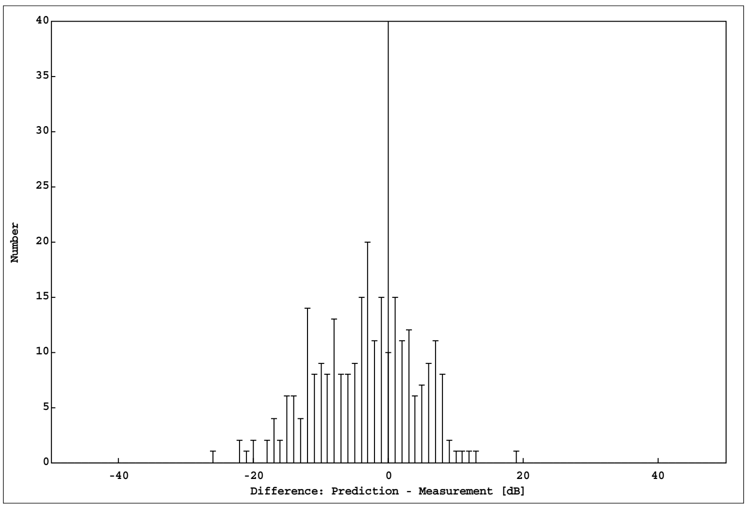

Fig. 10: Distribution of the differences shown in fig. 9

case the mean error is -3.5 dB and the standard deviation is 7.4 dB.

These first comparisons between the new prediction approach and field strength measurements indicate that the same accuracy as with the standard 3-D Ray Tracing can be obtained. With this new approach the delay spread and the impulse response can also be predicted.

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], and other kinds of office buildings were used for the comparison. The results concerning accuracy and performance are similar to those of the urban scenarios.

7. Conclusions

In this paper a fast and efficient ray optical propagation model for the planning of wireless communication networks is presented. The new approach consists of a single preprocessing of the building database. Therefore, the database must be discretized first and then the visibilitiy relations between the resulting elements must be computed and stored in a file. This process reduces the computational effort of the deterministic path finding considerably. The comparison to measurements shows a good agreement of the new model. The new deterministic approach with intelligent preprocessing of the database combines the short computation times of empirical models with the accuracy of ray optical modelling. Additionally, it is possible to define a very simple interface between indoor and urban propagation models by using the visibility information of the preprocessed databases.

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