Consideration of Topography for Wave Propagation Modeling in Urban Scenarios

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Abstract — **Deterministic 3-D modeling of wave propagation in urban areas has become a widely discussed technique for the planning of microcells. The preprocessing of the building database enables the practical use of these deterministic models by combining the accuracy of the ray optical approach with the short computation times of an empirical approach. In the preprocessing the mutual visibility conditions between the walls and edges of the buildings are determined and stored. This paper presents an extension to this ray optical propagation model in order to consider the terrain profile of the urban area taken into account.**

I. Introduction

With the continuing evolution of mobile radio communication systems network operators are forced to utilise economical frequency planning. An adequate solution to cope with the growing capacity demands is the reduction of the cell sizes. Especially in densely built up areas with high traffic rates microcells are used very often (see fig. 1).

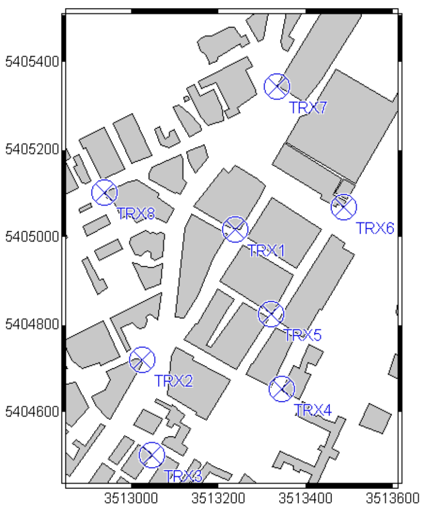

Figure 1: Microcellular network

The planning of these microcells 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 considered area. The practical use of such 3-D modeling can be seen mainly in urban environments where for example waveguiding effects of streets, the shadowing by discrete obstacles or the knowledge of impulse responses is important.

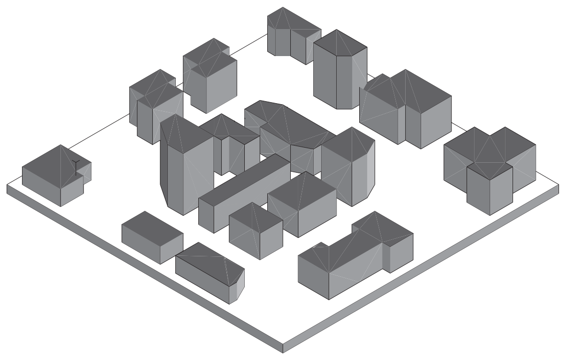

Figure 2: Building database

The basis for any propagation model is a database which describes the propagation environment. In order to get a more accurate description of wave propagation, the building data are stored in a 3-D 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 2 shows an example of a database for buildings.

Recalling the influence of database information on prediction accuracy, also the terrain profile should be considered for the propagation modeling if the evaluated urban area is not flat. The criterion taken into account is the standard deviation of the terrain heights in comparison to the standard deviation of the building heights in the considered area. For large standard deviations of the terrain heights databases in pixel format are required with resolutions of about 20-30 m, i.e. higher resolution than for the terrain or macrocellular propagation models.

II. Propagation Models

There are basically two approaches to the prediction of wave propagation in urban areas which differ in computational effort and accuracy of the prediction.

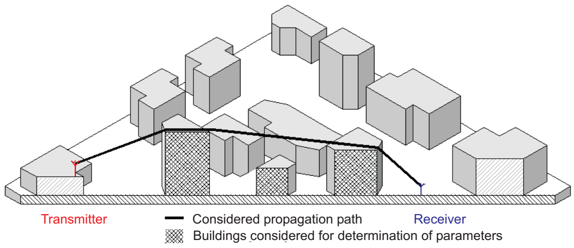

Figure 3: Principle of empirical models in urban areas

The so called empirical models (e.g. the model according to Walfisch/Ikegami, or COST 231 respectively) consider only the propagation in a vertical plane which contains transmitter and receiver (see fig. 3). For the field strength prediction significant parameters have to be extracted from this vertical section (e.g. average building height). 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 [1]. However, their prediction accuracy is limited due to the fact that only a small number of parameters is taken into account and waveguiding effects in streets cannot be considered.

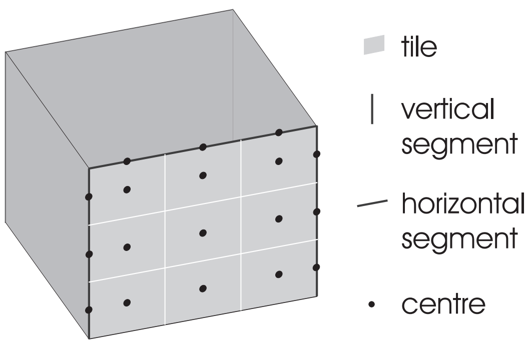

Figure 4: Discretization of the database into tiles and segments

The wave propagation in urban areas is dominated by reflected and diffracted rays [2]. Therefore, a lot of attention has recently been drawn to deterministic modeling, based on ray optical path finding in combination with diffraction theory (UTD). There are two basic approaches to searching propagation paths in an arbitrary vector oriented building database.

The so called 'Ray Launching' approach launches rays from a fixed transmitting antenna in all relevant directions, discretized into small angular increments [3]. These rays are inspected by their way through the building database and the field strength is summed up at all potential receiving points. The determination of paths is stopped, if either the energy is below a minimum or a given maximum number of interactions is reached. Ray Launching is basically an area oriented algorithm and therefore well suited to an area prediction. There are problems, however, with the consideration of diffracted rays due to the multiplication of rays. Additionally the different resolution of the rays depending on the distance between transmitter and receiver has to be considered.

An alternative technique is the 'Ray Tracing' algorithm. This method looks for valid ray paths between the base station and a fixed receiving station. Therefore, Ray Tracing is basically a point to point algorithm. For coverage calculations, the receiver has to be moved all around the prediction area. Obviously the computation time increases with the number of receiving points (i.e. the dimension of the prediction area). In addition, there is an exponential dependency between the number of buildings and the number of interactions considered in the calculation. The disadvantages of the Ray Launching concept do not occur, but there is a higher computational effort.

Owing to the high computational complexity of the ray optical approachs, many authors have tried to reduce the effort of path finding in arbitrary geometrical structures by restriction to two dimensions, the subsequent application of the two dimensional approach to orthogonal planes, or the consideration of rectangular structures only. Such reductions of the complexity always lead to reduced accuracy in comparison to a rigorous 3-D modeling [2].

III. Preprocessing of the Building Database

In order to cope with the excessive computation times for the 3-D ray optical models a single preprocessing of the database for buildings has been introduced. In a first step, as indicated in fig. 4, the walls of the buildings will be divided into tiles and the edges into horizontal and vertical segments.

After this discretization of the database the visibility relationships of the different elements are determined and stored in a file (see fig. 5). For this process all elements are represented by their centers. This leads to a simplification of the problem of ray path finding, i.e. possible interaction points are only the centers of the tiles and segments [4].

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. 6 in an example. In this tree every branch sym-

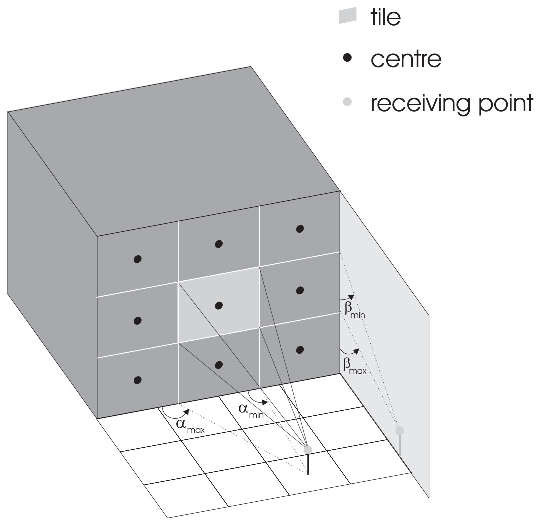

Figure 5: Visibility relation between a tile and a receiving point

bolizes 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. After this 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 [4].

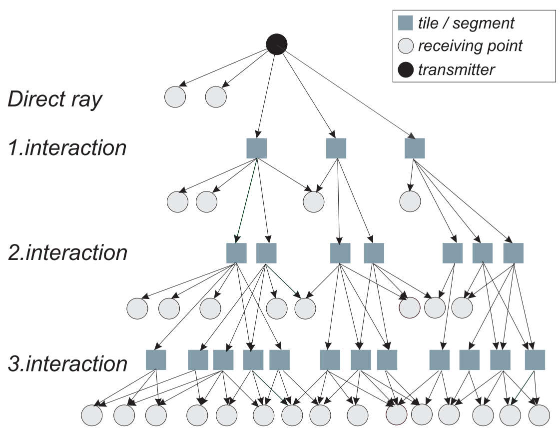

Figure 6: Determination of ray paths by searching in a tree structure

IV. Consideration of the Topography

Almost all of the known applications of 3-D modeling assume flat terrain scenarios with no or negligible topographical effects. In contrast to this assumption it is shown in [5] that even moderate valleys or hills along streets may have a considerabel impact on the actual path loss. Depending on the specific terrain profile the consideration of the topography might be very important for radio network planning in urban scenarios. Therefore the deterministic and empirical models have been extended according to this problem.

Generally the topography is given in raster format containing the elevation for each pixel. A smooth modeling of the terrain can be done by subdividing the ground surface into triangular elements. During the path finding process all triangles are treated as potential obstacles.

In order to consider the topography in an efficient way concerning the computation time, the extensions have been made for the deterministic propagation model, which is based on the above mentioned preprocessing of the building database. The topographical data is taken into account at this preprocessing in order to enable afterwards predictions of the field strength coverage in urban microcells including topography.

Finally an approach has been developed for the consideration of the topography in the empirical COST 231-model according to Walfisch/Ikegami.

A. Approach for the consideration of the topography in the deterministic model

The consideration of the terrain profile for the deterministic wave propagation model is implemented by including the topographical data in the discretized model, which determines if there is line of sight between two different points. This model was originally integrated in order to reduce the computation time for the preprocessing of the building database. The algorithm implemented in this model subdivides the preprocessing area in small elements (pixel with one square meter) whose values represent the height information of the corresponding points in the building database (see fig. 7).

When the topography is included the building height values are replaced by the terrain values in the following manner: If the pixel is inside a building, the sum of the building height and the topographical height for the center of gravity of the considered building is stored. If the pixel is outside all buildings, the corresponding elevation value is taken into account.

Additionally the terrain profile is approximated by triangles in order to provide the topographical information also for the function, which determines the line of sight relations in a more analogue way. This function is more accurate in comparison to the discretized

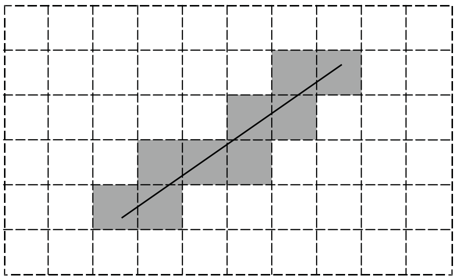

Figure 7: Investigated pixel in the discretized model for the line of sight check

model and therefore investigated for the determination of the elements visible from the transmitter at the prediction. In contrary to the discretized model this function determines the intersection points between the walls of the buildings and the considered ray by solving the equations of the corresponding straight line. The triangles ensure a steady run of the terrain curve (see fig. 8). In order to generate these triangles the height values out of the file with the topographical pixel data are evaluated, i.e. each pixel of the terrain input data generates two triangles.

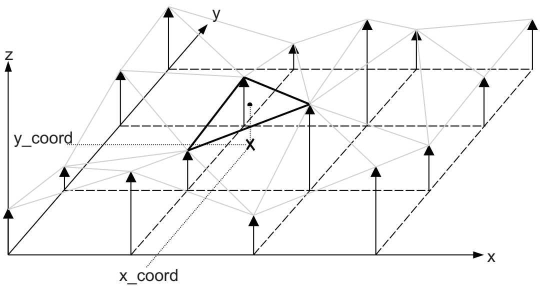

Figure 8: Modeling of the terrain profile by triangles

In order to verify the effect of the terrain profile on the prediction results computed with deterministic and empirical models the scenario of Stuttgart shown in fig. 9 was chosen. The terrain profile of the considered area was approximated by pixel data with a resolution of 30 m. The base station was located five meters above the ground. Fig. 10 and fig. 11 oppose field strength predictions without topography and including topography.

For both predictions the ray optical model based on the preprocessing of the database has been applied, taking into account rays up to double diffraction and triple reflection. Because of the elevated transmitter location there are many receiver pixels in LOS to the transmitter, which results in a more optimistic prediction when including the topography. Additionally there are a lot of receiving points which are reached by rays with less interactions, e.g. single diffraction instead of double diffraction.

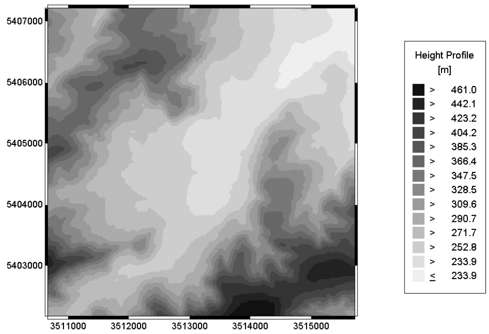

Figure 9: Topography in the vicinity of Stuttgart

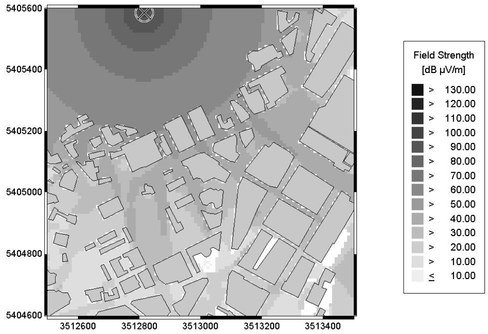

Figure 10: Ray optical prediction without topography

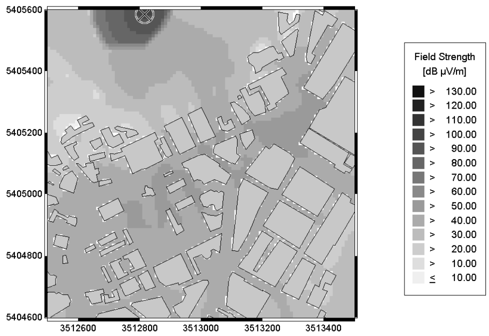

Figure 11: Ray optical prediction including topography

B. Approach for consideration of the topography for the empirical model according to COST 231 and Walfisch/Ikegami

In the well known empirical COST 231 model according to Walfisch/Ikegami the terrain profile is not considered for the computation of the field strength in urban areas. An extension to this empirical model have been investigated in order to include the topography.

For the prediction with the empirical COST 231 model the vertical intersection of the building database is evaluated. Therefore all intersected buildings and their rooftop heights are determined (see fig. 3).

In order to consider the topography directly within this model it is possible to define the lowest elevation along the terrain profile as new reference level. The heights of all relevant objects out of this vertical intersection are changed taking the new reference level into account, i.e. transmitter height, receiver height and the rooftop heights of the buildings. If the COST 231 model is applied considering the shifted objects the topography is included implicitly in the prediction.

Figure 12 describes the principle of this new approach. Generally the transmitter and receiver heights are increased when using this approach because of the new reference level. While the range of possible transmitter heights (< 50 m) and receiver heights (< 3 m) is limited in the empirical COST model, its topographical extension is only valid if these requirements are fulfilled after shifting the transmitter and receiver according to the new reference level. If the considered terrain profile is very rough with large elevation differences an approach according to multiple knife edge diffraction might be better suited. But for urban environments this extension leads to reasonable results.

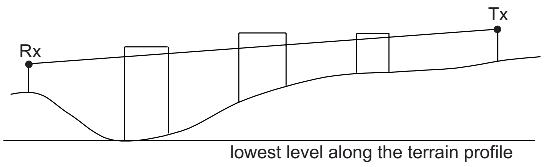

Figure 12: Determination of the reference level along the terrain profile

Fig. 13 and fig. 14 oppose field strength predictions without topography and including topography. The effect of the acceding terrain around the inner city is obvious, which leads to higher prediction values.

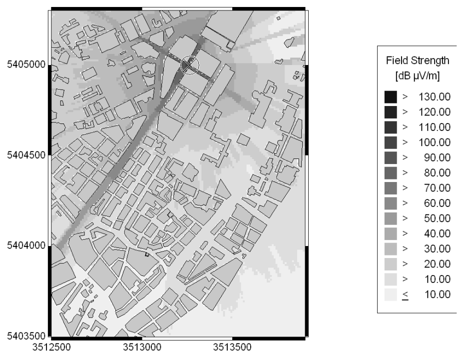

Figure 13: Empirical prediction without topography

V. Conclusions

In this paper an topographical extension to the fast 3-D Ray Tracing which is based on a single preprocessing of the building database is presented. Another approach considers the topography in the empirical model according to Walfisch/Ikegami and COST 231.

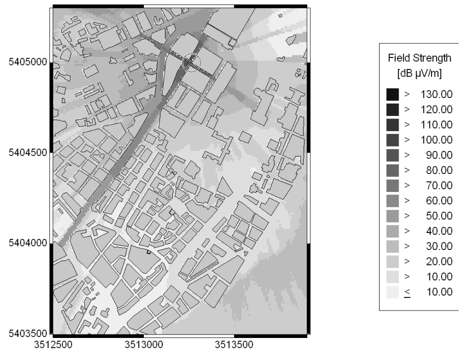

Figure 14: Empirical prediction including topography

The combination of both models provides an efficient tool for the radio network planning in urban environments [6], taking into account the waveguiding effects in street canyons as well as multiple knife edge diffraction describing the propagation above the rooftops for receiver locations far away from the transmitter. With the presented methods also the terrain profile of the urban area might be considered.

VI. References

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