ADVANCED RAY-OPTICAL WAVE PROPAGATION MODELLING FOR URBAN AND INDOOR SCENARIOS

F. M. Landstorfer and R. Hoppe

Institute of Radio Frequency Technology, University of Stuttgart
Pfaffenwaldring 47, 70550 Stuttgart, Germany, E-mail: hoppe@ihf.uni-stuttgart.de

ABSTRACT

Ray-optical propagation models are often utilized for the prediction of the field strength (and delay spread) in mobile radio networks. However, the practical usage of these deterministic models is limited due to their high computational demands. A new method for the acceleration of ray-optical models is presented in this paper. It is based on a single 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.

INTRODUCTION

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 still belongs to the most important tasks for the design and installation of cellular mobile communication systems [1]. According to the growing number of subscribers during the last years, the size of cells had to be reduced from radii in the order of tens of kilometres within rural and suburban environments (macrocells) down to a few hundreds of metres in urban scenarios (microcells) and even further down to some 10 m with indoor applications (picocells). With decreasing size of the cells the importance of wave propagation modelling within urban and indoor scenarios increases with regard to the extension of present and the deployment of future systems. This paper introduces a new approach for modelling wave propagation within these scenarios in an accurate way with minimized computational complexity.

The 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, scattering 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, as described later, 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 [2].

Data Bases for Buildings

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.

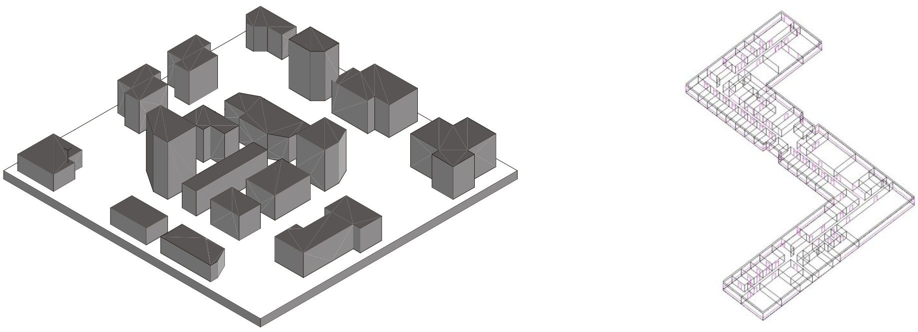

Fig. 1: Data bases describing urban (left) and indoor (right) environments, respectively

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 (see Fig. 1). Indoor data bases are 3D and include all walls, doors, windows and possibly furniture. All elements inside the building are described in terms of plane elements. Every wall is e.g. represented by a plane and its extent and location is defined by its corners (see Fig. 1). For each wall individual material properties can be defined.

WAVE PROPAGATION MODELS

While other wireless communication networks, like e.g. directive radio links, operate under line-of-sight (LOS) conditions and can use a simple free space propagation model, mobile communication, as outlined above, is generally non-line-of-sight (NLOS) and requires more sophisticated approaches. Most of the widely employed methods for the prediction of field strength in different scenarios are based on empirical equations. Consequently these models offer short computation times but on the other hand less accuracy in comparison to deterministic approaches [3].

Deterministic Models

Deterministic propagation models are generally based on ray optical techniques. Their common idea is to describe wave propagation by different rays that travel from the transmitting to the receiving antenna and 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). The most time-consuming part of a field-prediction based on this method is finding all the relevant paths from transmitter to receiver. For this purpose either the ray tracing or the ray launching algorithm is used (as indicated in Fig. 2). While empirical models [4] assume straight propagation from transmitter to receiver, regardless of any obstacles such as buildings or walls, deterministic models consider the physical paths along which the transmitted waves propagate. 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. Their main disadvantage consists in their sometimes prohibitively large computation time.

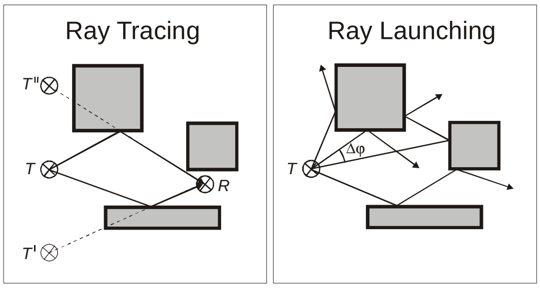

Fig. 2: Algorithms for path finding

Advanced Ray-Optical Model based on Data Base 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 [5][6]. However, these approaches consider only the propagation in two dimensions or in two perpendicular planes (horizontal and vertical plane). In contrast to this our approach is rigorously three dimensional.
One of the major applications of propagation models is to evaluate the degree of coverage that can be achieved in a radio cell depending on the position of the base station. As the data base of the considered building 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 change [7].
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. 3 on the left). The result of this preprocessing can be represented in the shape of a “visibility tree” (see Fig. 3 on the right). 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 optimising 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 [8].

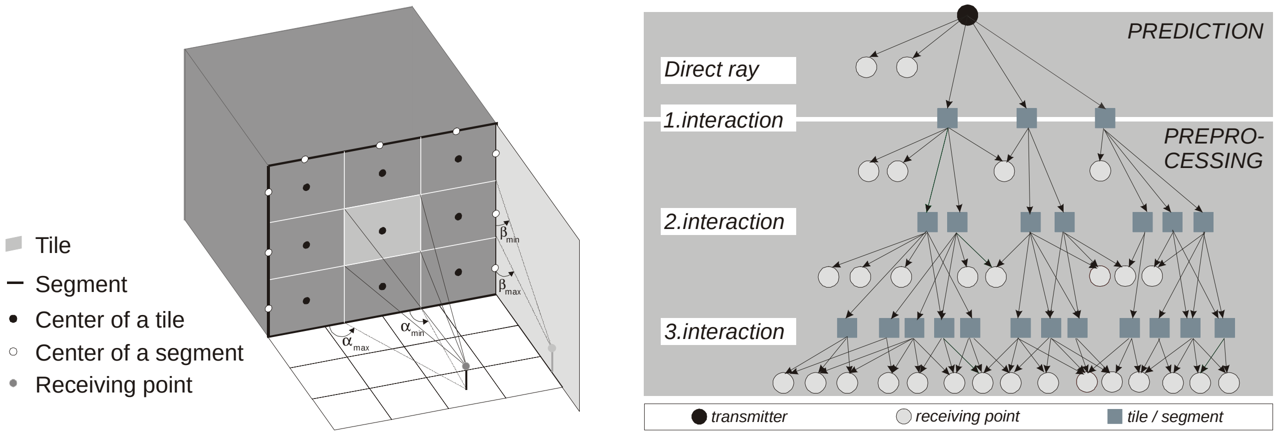

Fig. 3: Tiles and segments of a wall (left), and resulting tree structure of the visibility relations (right)

Results

The performance when utilizing this advanced ray-optical method for the wave propagation modelling within urban and indoor scenarios is shown in the following. Table 1 indicates the memory requirements and computation times for two different urban scenarios. These values depend on the size of the database (number of buildings, size of considered area) as well as on the resolution for the discretization of the database. They are gained with a maximum of three interactions (all combinations of reflections and diffractions with max. two diffractions), while the resolution of the prediction has been 10 *m*.

Table 1: Performance of the advanced ray-optical method

Database	No. of buildings	Area	Preprocessing time	Preprocessing file	Prediction time
Stuttgart	303	5,0 km^2	19 min	18 MB	85 s
Munich	2040	8,2 km^2	258 min	75 MB	237 s

In order to analyse the performance of the advanced ray-optical method many measurements in different scenarios were evaluated. To show the accuracy of the new model within urban environments, the well-known scenario in Munich (Germany) is utilized [4]. Fig. 4 presents the prediction for a GSM transmitter (900 *MHz*) as well as the difference between the prediction and the measurements for the same scenario. Table 2 indicates the statistical values for the comparisons between predictions and measurements for three different routes, which have been provided by [4].

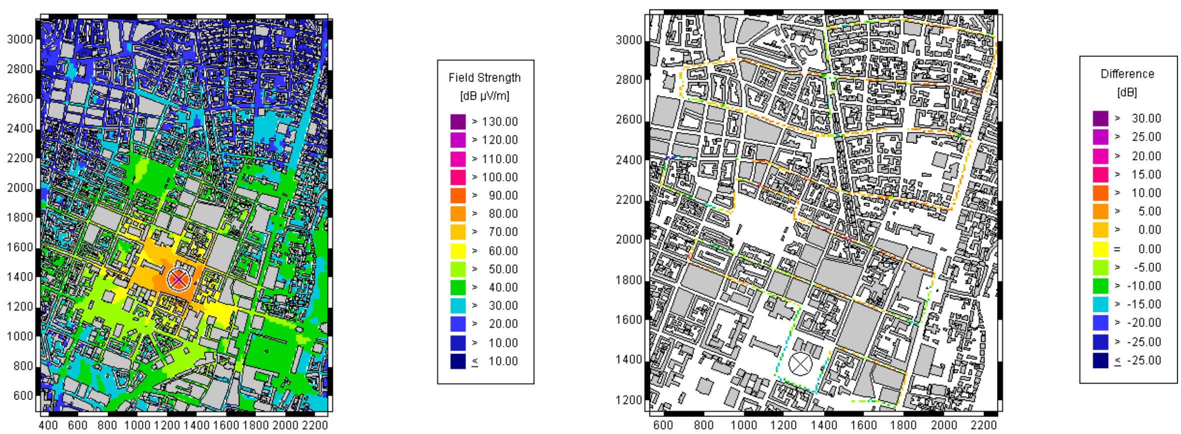

Fig. 4: Prediction for the scenario in Munich (frequency 900 *MHz*) and comparison to measurements

Table 2: Accuracy of the advanced ray-optical method for predictions of field strength in an urban scenario

Scenario	METRO 200		METRO 201		METRO 202	
Munich	Mean: 0.6 dB	Std.: 6.7 dB	Mean: -0.2 dB	Std.: 7.2 dB	Mean: -0.8 dB	Std.: 7.0 dB

In contrast to the urban model, the indoor model includes also the penetration of walls. But with this exception the same algorithms can be used for urban and indoor modelling. Indoor scenarios are computed with similar acceleration factors compared to rigorous 3D ray tracing models. Measurements of field strength and delay spread have been evaluated in order to verify the accuracy of the new approach for the prediction of the mobile radio channel inside buildings. The building taken into account for the verification has already been presented in Fig. 1 and is a modern type office building with floor and ceiling made out of reinforced concrete. The outer walls are made out of plastic and cement asbestos respectively with large windows, while the inner walls are mostly wooden. Fig. 5 shows a field strength prediction with the new approach after preprocessing of the building database. This prediction indicates a typical behaviour of a ray optical modelling including wave guiding along the corridor. The difference between prediction and measurement for another transmitter location is also presented in Fig. 5.

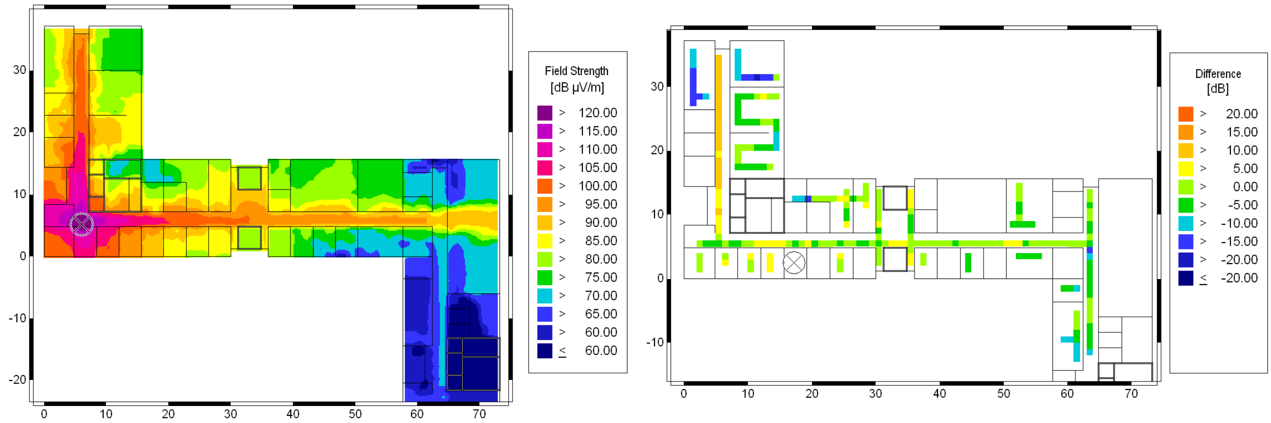

Fig. 5: Prediction for the indoor scenario for Tx 1 and comparison to measurements for Tx 2 (frequency 1800 *MHz*)

In order to minimize the mean error and the standard deviation ray paths with up to five interactions (reflections, diffractions and transmissions) are considered if the transmitter is located in the corridor. For transmitter locations inside rooms seven interactions are necessary. Table 3 shows the statistical values of the comparisons between predictions and measurements for different transmitter locations. While the locations Tx 2 and Tx 3 (located at 51.2, 15.1) are inside a room, Tx 1 and Tx 4 (located at 63.8, 5.8) have been installed in the corridor. For the predictions visualised here a resolution of 1.5 *m* for the discretization of the building has been selected. With the new propagation model it is also possible to predict the delay spread. Because of the ray optical approach all waves impinging on the receiver are calculated separately (up to a maximum number of interactions). In comparison to existing ray optical methods more interactions can be considered, which improves the accuracy of the delay spread predictions.

Table3: Accuracy of the advanced ray-optical method for predictions of field strength in an indoor scenario

Scenario	Tx 1		Tx 2		Tx 3		Tx 4	
Mod. office	Mean: 0.6 dB	Std.: 5.2 dB	Mean: 1.0 dB	Std.: 5.9 dB	Mean: -0.2 dB	Std.: 6.1 dB	Mean: 2.8 dB	Std.: 5.7 dB

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