Requirements for Indoor Building Databases to increase the Accuracy of the Propagation Results

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Abstract – **Currently, for the planning of wireless networks (e.g. WLAN) in indoor scenarios either empirical (direct ray), semi-deterministic or ray-optical propagation models are used. In this paper two different model approaches are used to investigate the impact of database inaccuracies to prediction results. Therefore a fast Ray Tracing model using a preprocessing of building vector data is used, as well as a semi-deterministic Dominant Path Model. This paper focuses on different inaccuracies in indoor building databases: Time variance due to doors or windows which are closed or opened causes Slow Fading and has thus significant influence to the prediction results. The accuracy of models is also influenced by missing objects in the building database, such as furniture or walls. The impact of adjacent buildings is also investigated.**

Index Terms **– wave propagation, indoor, ray tracing, dominant paths, empirical, measurements, time variance**

I. INTRODUCTION

The planning of wireless communication networks in indoor scenarios must be based on accurate propagation models for the prediction of the path loss between fixed base station antennas (e.g. WLAN access points) and mobile terminals. Many different approaches have been investigated during the last years to obtain accurate and fast propagation models. Today either statistical/empirical models or ray-optical models are used. For the ray-optical models significant accelerations are available leading to computation times in the range of empirical models [1].

Sophisticated propagation models used with accurate building databases provide highly accurate prediction results. A restriction is that the databases are often very complex as they come from 3D CAD data generated by architects. Often, many objects are included which are not relevant for the wave propagation. Moreover, these objects influence the prediction in a negative way. Another point is the time variance in indoor environments. Slow Fading occurs due to opened or closed doors and windows and will also have significant influence on the prediction quality.

Two different model approaches, a 3D Ray Tracing model with preprocessing of building data and a Dominant Path Model, which focuses only on the dominant propagation paths are used to investigate the impacts of database inaccuracies and time variant effects. References to other publications are given, in which the accuracy of the models used here were investigated.

II. INDOOR PROPAGATION MODELS

A. Accelerated 3D Ray Tracing Model

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, walls, and similar obstacles. The computations are performed with help of the Uniform Geometrical Theory of Diffraction (UTD) [2]. The most time-consuming part of a prediction based on this method is finding all the relevant paths from transmitter to receiver. For this purpose a Ray Tracing algorithm is used [3]. Ray tracing computes all rays for each receiving point individually and guarantees the consideration of each wall as well as a constant resolution. 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.

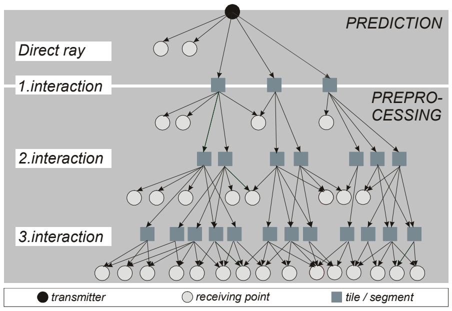

Fig. 1: Resulting tree structure with visibility relations.

Their main disadvantage consists in their sometimes prohibitively large computation time. A huge acceleration can be achieved with the following approach: As the database of the considered building remains the same and only the position of the transmitter changes for different indoor cells, 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 (LOS) change [4]. This is the basis for a “database 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. Additionally, the prediction grid is subdivided into receiving points. After this, the visibility conditions between these different elements (possible rays) are determined and stored in a file. The visibility relations between all tiles, segments and receiving points in the database are computed in this preprocessing, because they are independent of the transmitter location. For this purpose all elements are represented by their centres, which leads to the discretization of the problem of path finding.

The result of this preprocessing can be represented in the shape of a "visibility tree" (fig. 1). Each branch of this tree represents a visibility relation between two different elements. For a different transmitter location only the uppermost branches in this tree must be computed again, i.e. determining which elements are in LOS 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. With such a tree structure 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 and diffraction are fulfilled. The ray search is stopped, if a receiving point or a given maximum number of interactions is reached.

The 3D Ray Tracing model was validated by a comparison from predicted path loss values to several measurement campaigns [5]. The accuracy is quite good.

B. *Dominant Path Model*

In the upper picture of fig. 2 the principle of ray-optical propagation models is shown. Up to hundreds of rays can be computed for each receiver. The contributions of all rays are superposed to obtain the received power. But in most cases only 2 or 3 rays are contributing more than 98% of the energy, i.e. by focusing on these dominant rays the accuracy would be sufficient [6]. A second disadvantage of ray-optical models is their high dependency on small inaccuracies in the databases. As angular criteria are evaluated during the ray-optical prediction, the orientation of walls is extremely important.

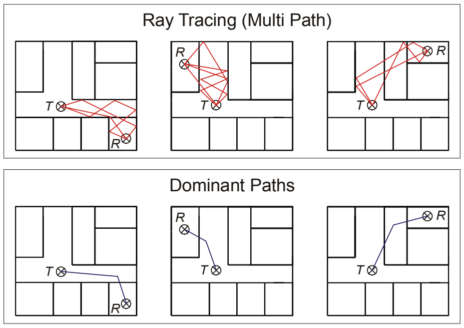

Fig. 2: Comparison of different model approaches: Ray-optical models (upper picture) consider hundreds of rays in contrast to the Dominant Path model, which considers only the most relevant ray.

After analyzing the restrictions of deterministic ray optical models, the requirements for a new model can be formulated: A new model should focus on the dominant path between transmitter (T) and receiver (R), as this path carries most part of the energy. The algorithm of the Dominant Path Model can be subdivided into two steps: Determination of the dominant paths (geometry) and prediction of the path loss along the paths. In the first step, the dominant paths are determined. Fig. 3 shows a scenario where the transmitter T is located in a corridor. The information about the arrangement of the walls is used to determine the types of corners. The dominant path from T to R must lead via convex corners to the receiver. For the determination of the path, a tree with all convex corners is computed. All corners visible from the examined corner are new branches in the tree. As shown in fig. 3 (right side), the corner-tree starts with the corners visible from T. The receiver R is also included in the tree. Each time the receiver is found in the tree, the corners along the path can be determined by following the branches back to T. Fig. 3 shows that more than one path between T and R exists.

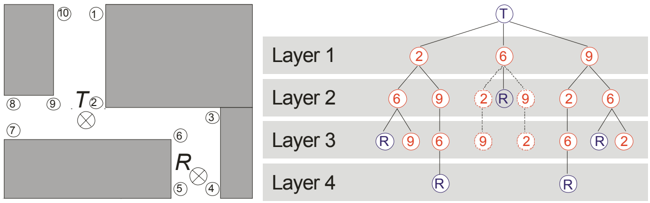

Fig. 3: Scenario with walls, transmitter and receiver (left) and tree structure built by algorithm (right).

After computation of the tree, the algorithm has to decide which path is the best one. This is done by comparing the path losses of the different paths to each other. The prediction of the path loss along the path is done by using the following equation:

$$L = 20\log\left(\frac{4\pi}{\lambda}\right) + 10p\log(l) + \sum_{i=1}^{n} f(\varphi,i) + \sum_{j=1}^{m} t_j - \Omega$$

L is the path loss in dB of a path with a length l (in meters). λ is the wavelength and Ω the waveguiding factor (see below). $f(\varphi,i)$ is a function which determines the interaction loss in dB, i.e. the loss when changing the direction of propagation. The angle between the former direction and the new direction of propagation is φ. The loss increases linearly with the angle, starting with an offset α_1. The linearity ends at angle φ_1 and the loss will be constant (at level α_2) for angles above φ_1. i is the number of the interaction, i. e. i=2 means the second interaction on this propagation path. The number of the current interaction is important, because not all interactions are weighted in the same way. Interactions with higher indices i lead to reduced losses compared to interactions with smaller indices i. This is considered because the wave is becoming more and more diffuse after each interaction and the more options for interactions occur the more diffuse the wave will be (more options means less total loss). Losses due to horizontal and vertical changes in the direction of propagation are determined independently.

The factor p depends on the visibility between the current pixel and the transmitter. Adapting p to the situation allows different path loss exponents and individual breakpoints depending on the LOS, OLOS (Obstructed Line of Sight) or NLOS (Non Line of Sight) condition.

The waveguiding factor Ω is described in [7]. The reflection loss of the walls along the path, as well as their distance to the path, influence α. The smaller the reflection loss and the closer the wall to the path, the higher the waveguiding factor. The gain due to waveguiding is determined for each pixel before the prediction starts. During the prediction this gain is accumulated along the propagation path. In close street canyons or in small corridors this gain is higher than in open areas. For the determination of the path loss in indoor scenarios, transmissions through walls have to be considered additionally. t_j means the transmission loss of wall number j, i.e. t_2 is the transmission loss of the second wall penetrated by the dominant path.

A validation of the Dominant Path Model was also made by comparing predictions to measurment campaigns [8]. The comparison shows a good accuracy of the model.

III. REQUIREMENTS FOR INDOOR DATABASES

A. *Impact of Time Variance*

Real indoor environments are time variant. Due to the opening and the closing of doors or windows, Slow Fading occurs. Movements of chairs or tables tend also the Slow Fading. Regarding ray-optical propagation models, this means new propagation paths will arise or existing propagation paths will no longer be valid. Points for reflections, diffractions or penetrations will change from time to time.

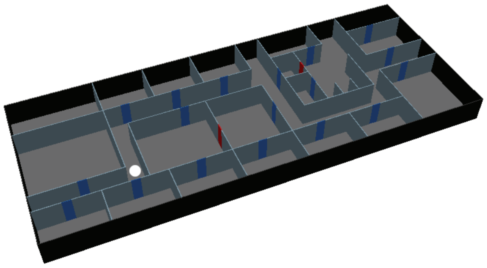

Fig. 4: 3D view of modern office building used for investigations. Transmitter location is marked with white sphere. The red colored doors are considered as time variant.

Fig. 4 shows a floor plan of an office building. A transmitter (f=2000 MHz) is placed inside the building (white sphere) and the red colored doors are considered as time variant for this example here. At first predictions with the two models are accomplished with both doors closed and afterwards the doors are in 'open' state and again the predictions are computed. The results (difference from prediction with opened doors minus prediction with closed doors) are depicted in fig. 5.

Analyzing the results presented in fig. 5 shows clearly the different model approaches: As the Dominant Path Model (fig. 5 upper picture) considers only diffractions and no reflections, the differences between both predictions are mainly in the areas, which can be reached with diffractions. The results of the Ray Tracing differ in the complete right area of the building, as this model considers reflections additionally.

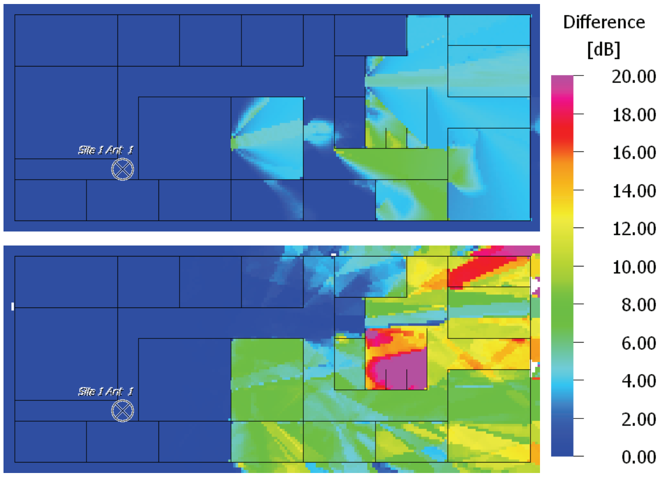

Fig. 5: Differences from predictions with closed doors minus predictions with opened doors for Dominant Path Model (top) and 3D Ray Tracing.

The results shown above are presented to show the intention of the investigations only. In the final version of this paper, not only results for one transmitter location and two time variant doors are presented, but results will be available more general. This means different indoor building databases, transmitter location and propagation situations will be used to derive a general statement concerning time variant objects. The goal is to get an idea of the significance of time variance in indoor environments.

B. *Impact of Furniture*

In most cases, furniture is not included in indoor building databases. Depending on transmitter location, size and type of furniture, the prediction quality would be influenced by additional objects, such as sideboards, cabinets, tables or cupboards. Especially large and tall objects made of metal would have significant influence on the prediction results.

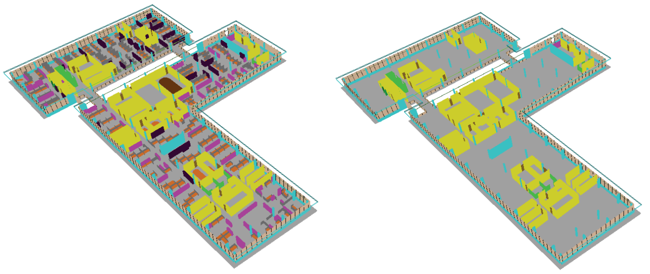

Fig. 6: Database of modern office building with furniture (left) and without.

An example for a building database of a modern office block is shown in fig. 6. Among others, this database is used to investigate the impact of furniture. In the left image of fig.

6, the database contains furniture. In the right picture all furniture objects (tables, desks, chairs and dividers) have been removed.

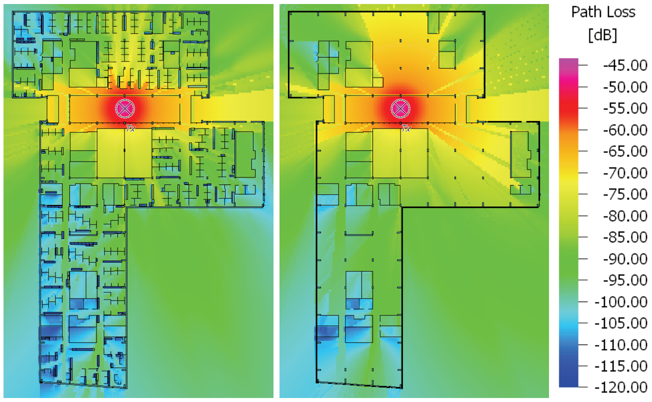

Fig. 7: Prediction using the Dominant Path Model in a modern office with furniture (left) and without any furniture.

Fig. 7 shows exemplarily two predictions computed with the building databases of fig. 6. In the final version of this paper, the influence of furniture will be described in detail. Conventions for the handling of furniture in indoor environments will be derived from the results.

C. *Impact of Adjacent Buildings*

In the planning of wireless networks, adjacent buildings are in most cases not considered. Fig. 8 shows a scenario, where the adjacent buildings have influence on the predicted field strength distribution in the major building. Especially Ray Tracing models computing reflections and diffractions on all walls are influenced by adjacent buildings.

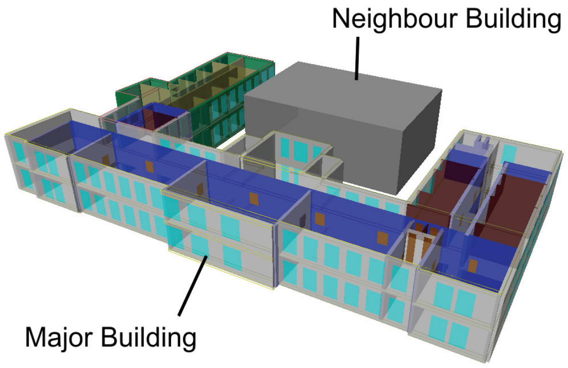

Fig. 8: Database of a historical office building (major building) with adjacent office block (neighbour building).

A demonstration of the influence is shown in fig. 9. The transmitter (*f*=3500 MHz) is located on the 2nd floor and the prediction is computed for the 1st floor. The right image shows the field distribution considering the adjacent building. In the left image, the adjacent building was neglected, so no reflections can occur outside the major building. This leads to a more pessimistic prediction result on the 1st floor (see fig. 9 left).

An analysis of more than one scenario with adjacent buildings will be presented in the final paper. A general statement about the influence of adjacent buildings will be derived from all prediction results.

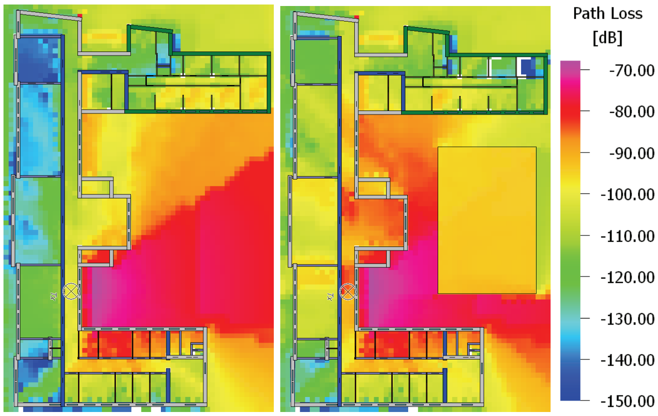

Fig. 9: Prediction using 3D Ray Tracing in a historical office building considering adjacent building (right) and neglecting adjacent building.

IV. CONCLUSIONS

In this paper, two sophisticated prediction models for indoor scenarios are presented. The models do not rely on the direct ray only, but either use many rays (Ray Tracing) or use the dominant ray (Dominant Path Model) to predict the field strength. The models are used to analyse the impact of time variance and furniture in databases and the influence of adjacent buildings to the prediction quality inside buildings.

The results shown in this paper are only exemplarily to demonstrate the influence of different effects (time variance, furniture) to the prediction results. In the final version of this paper general statements derived from the investigated scenarios will be presented.

V. REFERENCES

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