Dominant Path Prediction Model for Indoor Scenarios

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Abstract— **Currently, for the planning of wireless networks (e.g. WLAN) in indoor scenarios either empirical (direct ray) or ray-optical (ray tracing) propagation models are used. In this paper both approaches are compared to one another and to measurements in different (multi-floor) buildings. Additionally a new concept - which is called Dominant Path Model - is presented in this paper. This new concept does not focus only on the direct ray (like empirical models) and it does not consider hundreds of rays for a single pixel (like ray tracing), but it focuses on the dominant path(s) between transmitter and receiver. The parameters of these dominant paths are determined (e.g. path length, number and type of interactions, material properties of objects along the path, etc.) and are used for the prediction of the path loss between transmitter and receiver. Thus the computational effort is far below ray tracing and in the range of empirical models. But the accuracy of the new model in very complex environments (where multiple interactions occur) is even higher than the accuracy of ray tracing models (because of their limitations in the number of interactions considered). This very high accuracy is shown with the comparison to measurements in different buildings.**

Keywords—wave propagation, indoor, ray tracing, dominant paths, measurements.

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 [1].

Nowadays 3D vector databases of buildings are available and can be used without any restrictions. These databases provide a high accuracy, but errors in the material definitions or in the coordinates lead to significant errors if ray-optical propagation models are used (see figure 3). So there is a demand for models which are fast and consider multiple interactions (e.g. diffractions) – but which are not relying on each detail of the vector database. In this paper such an approach is presented and compared to empirical and ray-optical propagation models as well as measurements.

II. INDOOR DOMINANT PATH MODEL

A. *Current status*

Figure 1 shows the problem of empirical propagation models in indoor scenarios. They are based on the direct ray between transmitter and receiver. However, this ray is not always dominant and very often this path is highly attenuated.

Focusing a model on this path must lead to errors in nearly all scenarios where this path has only a minor contribution to the total received signal power.

In figure 2 the principle of a ray-optical propagation model is shown. Up to many hundreds of rays are computed for each receiver location. The contributions of each ray are superposed to obtain the received power. In most cases only 2 or 3 rays are contributing more than 95% of the energy, i.e. by focusing on these dominant rays the accuracy would be sufficient.

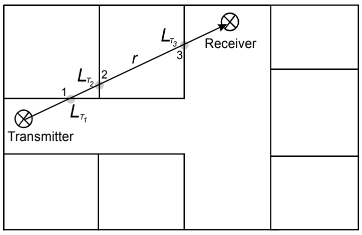

Figure 1. Empirical propagation models in indoor scenarios

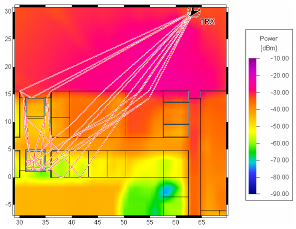

Figure 2. Ray-optical prop. models in a university office building

A second disadvantage of ray-optical models is shown in figure 3. Small inaccuracies in the databases lead to totally different prediction results. As angular criteria are evaluated during the ray-optical prediction, the orientation of walls is extremely important. Unfortunately building databases with this very high accuracy incl. a very detailed description of the material properties are very difficult to obtain at reasonable costs.

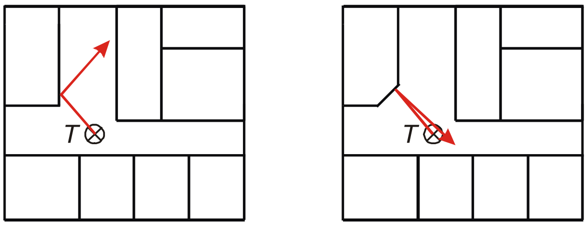

Figure 3. Accuracy of building databases

B. *Requirements for a new model*

After analyzing the status of the models currently available, the requirements for a new model can be defined:

- Model should not depend on each micro-detail in the vector database (see figure 3).
- Focusing on the dominant paths (see figure 4) and not computing hundreds of irrelevant paths.
- Simple calibration possible with reference data (e.g. measurements).

With these requirements the dominant path model was defined.

C. *The Dominant Path Model*

The Dominant Path Model can be subdivided into two steps:

- Determination of the dominant paths (geometry)
- Prediction of the path loss along the paths

Determining the dominant paths is a very complex task [2], [3]. Figure 4 shows an example for dominant paths in indoor scenarios.

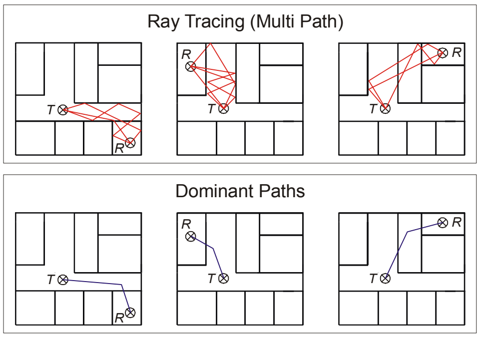

Figure 4. Dominant paths in indoor scenarios

By adjusting the weights described in [3], different paths can be obtained (small number of interactions, short paths, small number of transmissions, etc.). Obviously more than one path can be computed for each pixel if several runs with different weighting factors are computed and the contributions of the paths are superposed. In this paper the single path approach is used, i.e. only one path is determined per pixel. This reduces the computation time as each new set of weighting factors leads to a new computation of the paths, i.e. 5 different sets lead to a 5 times longer computation time compared to the single path approach.

It should also be mentioned that the path search algorithm works either in 2D or in 3D. In multi floor indoor environments the model can work in rigorous 3D. 2D is sufficient for most single floor applications.

The prediction of the path loss along the path is done with the following equation:

$$L = 20 \cdot p \cdot \log(d) + \sum_{i=1}^{n} f(\varphi, i) + \sum_{j=1}^{m} t_j - \alpha$$

L is the path loss in dB after a path length of d (in meters). α is the waveguiding factor (see below). $f(\varphi,i)$ is a function which determines the loss in dB due to an interaction, i.e. changing the direction of propagation. The angle between the former direction and the new direction of propagation is φ_i. The loss for an interaction increases linearly with the angle, beginning with an offset β_1. The linearity ends at angle φ_2 and the loss will be constant at β_2 for the remaining angles larger than 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 smaller losses in contrast to interactions with smaller indices i. This is reasonable because after multiple interactions the wave is very diffuse and so multiple options for interactions occur and thus the loss is not so high.

The waveguiding factor α is described in [4]. The reflection loss of the walls along the path as well as their distance to the path influence the value. The smaller the reflection loss and the closer the wall to the path, the higher the waveguiding factor will be. As described in [4], the factor is determined in dB. Figure 5 shows an example for the waveguiding factor in a university building [2].

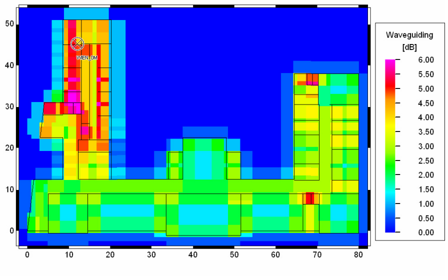

Figure 5. Waveguiding factor in a university building

The model could be improved with more details to increase the accuracy. But if an automatic calibration (e.g. linear regression) of the parameters should be possible, the dependency should not be too complex – otherwise the automatic calibration will not be feasible.

The exponent p for the path loss is set to fit the indoor requirements (i.e. this factor is higher than the value in the urban case). In addition to that, the factor is adapted to the current state of the propagating wave, thus different factors for LOS, OLOS (obstructed LOS) and NLOS (non-LOS) areas can be realized.

For the determination of the path loss, transmissions through walls have to be considered. t_j means the transmission loss for wall number j, i.e. t_2 is the transmission loss of the second wall, which was penetrated by the propagating wave.

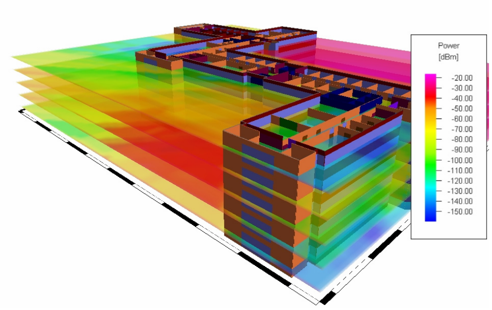

Figure 6. Prediction of received Power with multiple layers

As mentioned above, the algorithm works also in a 3D mode, which is very useful for multi floor buildings (see figure 6). If the rigorous 3D algorithm is used for computation, the dominant paths are determined over several layers, which leads to very accurate results especially in multi floor buildings.

III. BENCHMARKS

A. General

To demonstrate the performance of the Dominant Path Model in indoor environments, measurement campaigns in different types of buildings were used. New office buildings like the University of Stuttgart [5], older office buildings like the University of Vienna [2], [6] as well as buildings with multiple floors like the Instituto de Telecomunicações in Lisbon [7] were used for the comparison. The results concerning accuracy were compared to a 3D ray tracing model (IRT) and the well known Multi Wall model (MW).

B. Modern office building

One measurement campaign was conducted in a modern office building at the University of Stuttgart, which is mainly built of concrete and glass. The database of a single floor of the building contains 108 planar objects with more than 130 subdivisions (windows, doors…).

The campaign includes 20 different transmitter locations and many measurement routes for each location. Two of the transmitter locations are presented in this paper. The comparison of further measurement routes and transmitter locations can be found in [5]. The results of the prediction for transmitter site 8 with different prediction models are presented in figures 7 to 9. The path loss measurements obtained in this building were performed with a CW signal. The carrier frequency was 1800 MHz and the transmitter output power was 20 dBm.

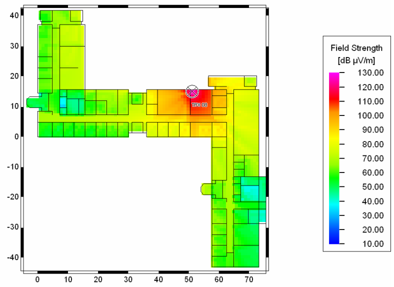

Figure 7. Prediction for site 8 with Dominant Path Model

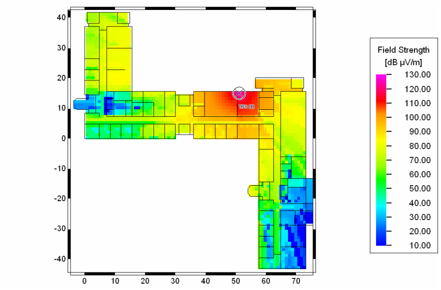

Figure 8. Prediction for site 8 with the 3D ray tracing (IRT) model [1] with 6 transmissions, 4 diffractions and 5 reflections in multiple combinations

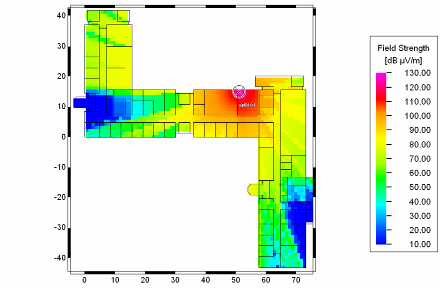

Figure 9. Prediction for site 8 with Multi-Wall Model

The results of the prediction with the Dominant Path Model are more realistic compared to the results of the other two models. Especially after multiple diffractions and large distances, the fieldstrength of the ray tracing and the Multi-Wall Model are too pessimistic (table I and figures 8 and 9). This can be explained with the fact, that the ray tracing considers 4 diffractions and 5 reflections in this case, in contrast to the Dominant Path Model, which has no limit for the number of interactions. The accuracy of the Multi-Wall Model is even worse, which is obviously a consequence of the fact that it considers only the direct ray and does not consider reflections and diffractions.

Figures 10 and 11 show the difference between predictions performed with the Dominant Path Model and measurements for transmitter sites 2, 6, 8, and 12. The differences between prediction and measurement are good as shown in table I.

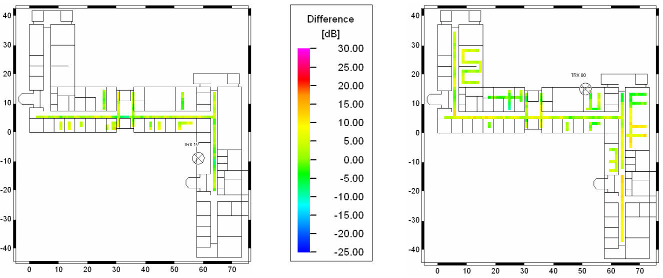

Figure 10. Difference between prediction and measurement for the Dominant Path Model, Site 12 (left) and Site 8 (right)

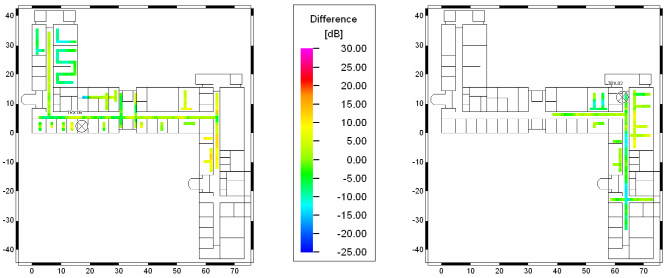

Figure 11. Difference between prediction and measurement for the Dominant Path Model, Site 6 (left) and Site 2 (right)

Table I shows the difference between predictions and measurements for the Dominant Path Model as well as for the ray tracing and Multi Wall models.

TABLE I. COMPARISON TO MEASUREMENTS

Site	**Difference (Predictions – Measurements) in dB**					
	IRT		**Dominant Path**		**Multi Wall**	
	Mean value	***Std. Dev.***	***Mean value***	***Std. Dev.***	***Mean value***	***Std. Dev.***
TRX 2	1.25	6.04	-1.73	5.12	-4.31	5.82
TRX 6	-2.94	11.31	-0.19	5.81	-9.62	16.86
TRX 8	3.99	9.30	3.69	4.39	1.54	16.55
TRX 12	6.68	7.13	2.42	3.48	3.21	8.97

C. *Old office building*

Figures 12 and 13 show the predictions for two transmitter locations in a building of the Institute of Communications and Radio-Frequency Engineering in Vienna [2], [6]. This building is mainly built of brick and wood – so it represents the older office buildings. The database of a single floor of the building contains 107 planar objects.

The carrier frequency for the measurements was 1800 MHz. A detailed description of the measurement equipment and campaign can be found in [2].

In figure 13 some propagation paths are presented. For each receiver location only one set of weighting factors for the determination of the paths is used. Each diffraction and each transmission causes an additional attenuation along the propagation path. The computation is made in 2D as the transmitter and the receiver are located on the same floor.

The comparison between the predictions of the different models and measurements can be found in table II. Also in this scenario the Dominant Path Model shows a very good accuracy.

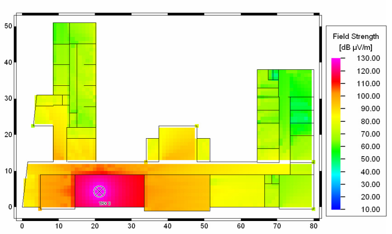

Figure 12. Prediction for Dominant Path Model, Site 3

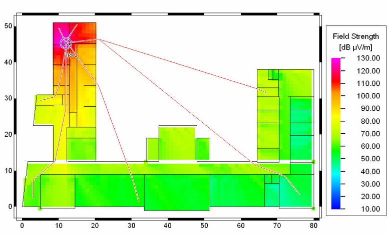

Figure 13. Prediction for Dominant Path Model with some propagation paths, Site 0

TABLE II. COMPARISON TO MEASUREMENTS

Site	**Difference (Predictions – Measurements) in dB**					
	IRT		**Dominant Path**		**Multi Wall**	
	Mean value	***Std. Dev.***	***Mean value***	***Std. Dev.***	***Mean value***	***Std. Dev.***
TRX 0	-0.85	12.11	-3.11	5.85	-1.93	11.39
TRX 3	2.18	7.23	-0.87	6.36	-3.96	9.83
TRX 7	-0.85	9.76	-2.86	5.64	0.60	6.04

D. *Multi-floor building*

The considered multi-floor building is the office building of the Instituto de Telecomunicações (Instituto Superior Técnico, IST) in Lisbon, Portugal. It is mainly built of concrete and glass – so it represents a typical modern office building. The multi floor building database of this building contains 355 planar objects. A three dimensional view (without external walls) of this scenario is given in figure 14.

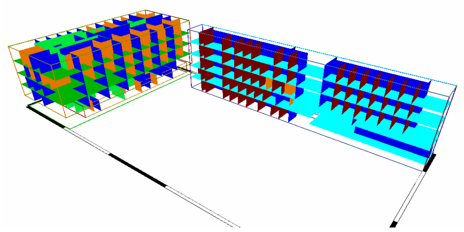

Figure 14. Three dimensional view of modern multi-floor office building in Lisbon

In this scenario the transmitting antenna is located on the top of the building [7]. Measurements and predictions were made in the building below the antenna and in an adjacent building (see figures 15 and 16).

The carrier frequency for the measurements was 950 MHz. As in this scenario the mobile station and the base station antenna are located on different floors (height of antenna: 20.5 m, height of prediction: 15.4 m, 5th floor), the 3D mode of the Dominant Path Model was used for the computation. When using the 3D Dominant Path Model, not only one prediction plane (at receiver height) is used, but several layers between transmitter and receiver are used in order to improve the result. The differences between predictions and measurements are presented in table III. All measurements together with a detailed description of the equipment can be found in [7].

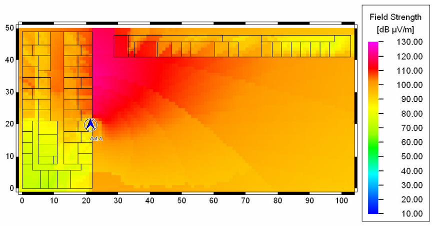

Figure 15. Prediction for Dominant Path Model (3D mode), Site A

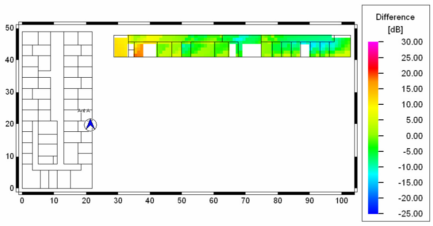

Figure 16. Difference between prediction and measurement for Dominant Path Model (3D mode), Site A

The result of the Dominant Path Model for this scenario is good (considering the complexity of the scenario). Table III shows the difference to measurements for the compared prediction models.

TABLE III. COMPARISON TO MEASUREMENTS

Site	**Difference (Predictions – Measurements) in dB**					
	IRT		**Dominant Path**		**Multi Wall**	
	Mean value	***Std. Dev.***	***Mean value***	***Std. Dev.***	***Mean value***	***Std. Dev.***
Antenna A, Building 2, Floor 5	2.79	5.37	-1.25	6.45	0.68	8.46

E. *Computation times*

The computation times of the Dominant Path Model are in the range of those of the Multi Wall Model, i.e. less than 1 s on standard PCs (AMD Athlon 2800+ CPU) for the scenarios described in sections III.B and III.C.

For the scenario described in section III.D, the 3D mode of the Dominant Path model was used as multiple floors had to be considered (see also section II.C). Therefore, the computation time for this scenario was longer (31 s) on the PC described above.

Ray tracing models have much longer computation times, especially if a sufficient number of interactions is computed. Even the accelerated Intelligent Ray Tracing Model [8] based on the preprocessing of the building data [1] does not reach the computation times of the Dominant Path Model. Additionally, the time for preprocessing that is needed for these Ray Tracing Models has to be considered.

IV. CONCLUSIONS

A new approach for propagation modeling in indoor scenarios based on vector databases is presented in this paper. The approach is based on the fact that not all rays between transmitter and receiver contribute a similar part of the energy. Some paths are dominant and by determining only these dominant paths, the computation time is reduced without influencing the accuracy.

The new indoor propagation model is compared to measurements performed in different indoor environments. In comparison to results of ray tracing predictions it is shown that the new propagation model reaches the accuracy of ray tracing models or even exceeds it. The computation times are in the range of empirical models and therefore very short, especially compared to those of ray tracing models. No preprocessing of the building data is needed.

As the models compute the dominant ray paths, also wideband properties of the channels (channel impulse response, delay spread) could be computed with statistical channel models. This will be the object of further studies.

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