WIDEBAND PROPAGATION MODELLING FOR INDOOR ENVIRONMENTS AND FOR RADIO TRANSMISSION INTO BUILDINGS

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***ABSTRACT* – With the introduction of wireless broadband services in indoor environments there is a growing interest in propagation models for the mobile radio channel inside buildings. Because of the increasing transmission rates propagation models should be able to calculate the field strength coverage as well as the wideband properties for these indoor scenarios. This paper presents a new ray optical approach, which enables the prediction of field strength, delay spread and impulse response within a very short computation time. Additionally, simulation results gained with the new model are compared to measurements of the different wideband channel parameters.**

I. INTRODUCTION

Wireless broadband transmission inside buildings as well as into buildings is getting more and more important in future mobile communication systems [1], e.g. the wireless local area networks according to the different HIPERLAN standards or the decreasing cell sizes in UMTS.

The mobile radio channel in indoor scenarios is characterised by a multipath situation (see fig. 1). The signal transmitted by the base station will propagate along different paths to the receiving antenna of the mobile. In many cases there is no line of sight and the only signals reaching the receiver have undergone reflections and diffractions at a number of different obstacles. Consequently the field strength in such scenarios shows small scale fading and a time-dispersive characteristic [2].

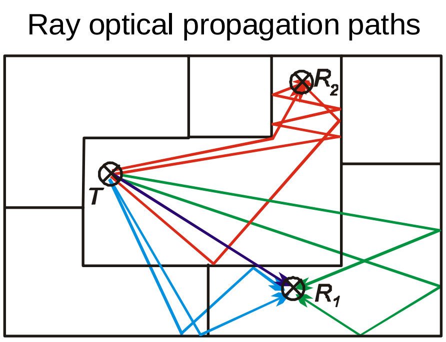

Fig. 1: Multipath situation

II. PROPAGATION MODELLING APPROACH

A. 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 3D-vector format including all walls, doors, and windows. 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. 2). Additionally, 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 in architecture [3].

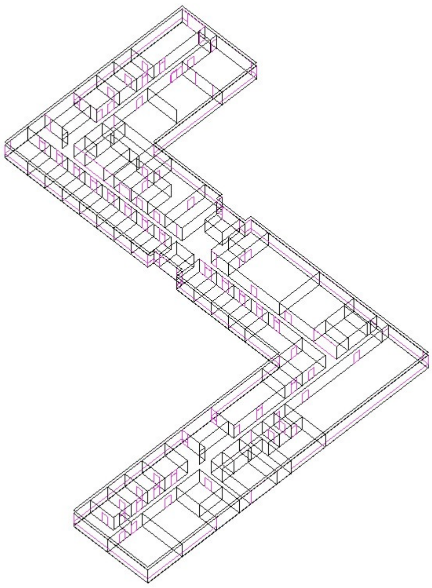

Fig. 2: Example for an indoor database

B. Ray Optical Models

Ray optical propagation models are often used for the prediction of field strength within indoor and urban scenarios, because they consider wave-guiding effects in street canyons (outdoor) or corridors (indoor) and they include diffraction at corners.

There are two approaches to ray optical modelling: ray tracing and ray launching (see fig. 3). Both have their individual advantages and disadvantages. Ray tracing computes all rays for each receiving point individually and guarantees the consideration of each wall as well as a constant resolution.

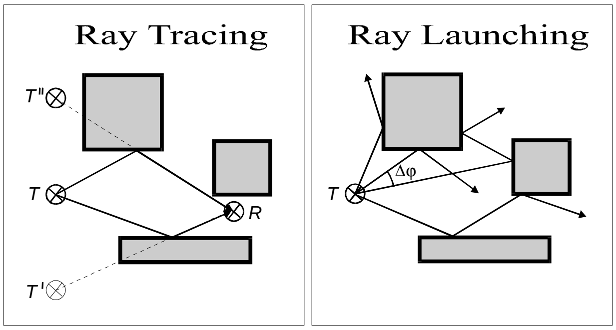

Fig. 3: Deterministic propagation models

This individual computation is more time-consuming than the ray launching approach, where the rays are launched from the transmitter with a constant angular increment. However, with ray launching several problems occur, such as “ray-multiplication” as a result of diffraction cones and decreasing resolution with growing distance from the transmitter.

With the increasing transmission rates in future mobile communication systems propagation models should be able to predict the field strength as well as the impulse response.

In general ray tracing tools are adequate for predicting the total received power, but not very successful in describing the impulse response or the delay spread of the mobile radio channel. The reason therefore is that indoor environments require many reflections and diffractions to accurately predict the situation and the resulting high number of interactions is too time consuming to apply.

C. New Approach

Ray optical models are very time consuming, because all possible rays must be determined. A new approach to the acceleration of ray optical models reduces the computation time to that of empirical models. This new method combines the advantages of both ray optical models and neglects their disadvantages [3][4]. It is based on a single preprocessing of the database.

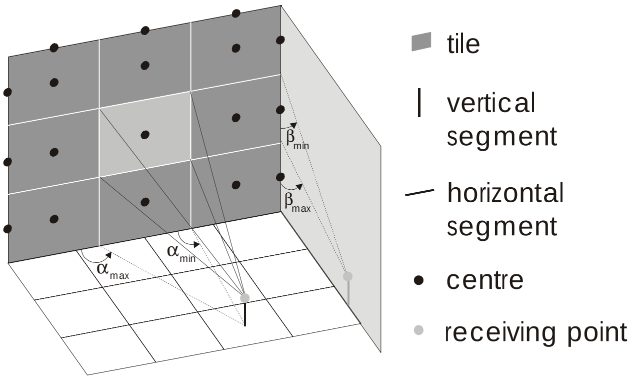

Fig. 4: Tiles and segments of a wall

All walls of the considered building are subdivided into tiles and all wedges are subdivided into segments (see fig. 4). The visibility relations between all tiles, segments and receiving points in the database are computed in the 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.

Fig. 5 illustrates the visibility relations computed in the preprocessing in the shape of a “visibility tree”. Only the relations in the first layer of the tree must be computed at prediction time which can be done very fast, all other relations are determined in the preprocessing and can be read from a file. The stored visibility relations (except the first layer) can be used for all predictions with the same database.

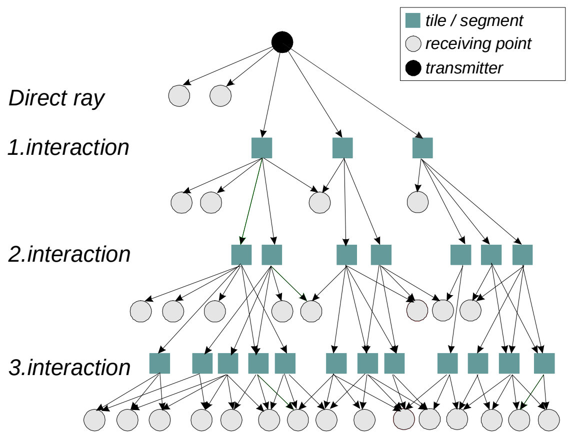

Fig. 5: Tree structure of the visibility relations

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.

For transmission into a building this preprocessing can be done for the outdoor (contains the description of the outer walls of all buildings) as well as for the indoor database (contains the outer and inner walls of the building taken into account for the indoor prediction). The tiles at the walls surrounding the selected building define the interface between the two databases.

Table 1: Preprocessing time, size of the preprocessed file and prediction time for the building shown in fig. 2

resolution for the discretization	preprocessing time	size of the preprocessed file	prediction time
1 m	7212 s	51.6 MB	110 s
1.5 m	1835 s	24.9 MB	100 s
2 m	1095 s	12.2 MB	67 s
2.5 m	680 s	7.3 MB	16 s
3 m	457 s	3.2 MB	1 s

Table 1 presents the dependencies of the preprocessing time, size of the preprocessing file and the prediction time for different resolution values used for the discretization of the building database shown in fig. 2, i.e. extension of the tiles and segments while the resolution of the receiving points remains constant at 1 m (on a PC Pentium II 350 MHz with 128 MB RAM). An exponential increase of memory requirement and computation time can be observed when reducing the extension of the tiles and segments.

III. MEASUREMENTS

In order to characterize the mobile radio channel inside buildings and to verify the propagation models several measurement campaigns with different transmitter locations have been carried out at the building presented in fig. 2.

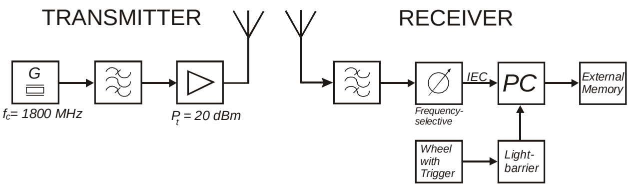

Fig. 6: Equipment for CW-measurements

For the determination of the field strength the simple measurement equipment shown in fig. 6 has been used. A CW-signal is generated and transmitted with a quarter wavelength monopole. The receiver (containing another λ/4-monopole and a spectrum analyser) is mounted on a trolley, which can be moved inside the building. The distance between the measurement points is always 0.8 λ. In order to eliminate the fast fading for each measurement point the median value of the field strength is computed with an interval of 15 instantaneous values, corresponding to a distance of 12 λ. Figure 7 shows the median values of the field strength for transmitter TRX 1 with 0.1 W operating at 1800 MHz.

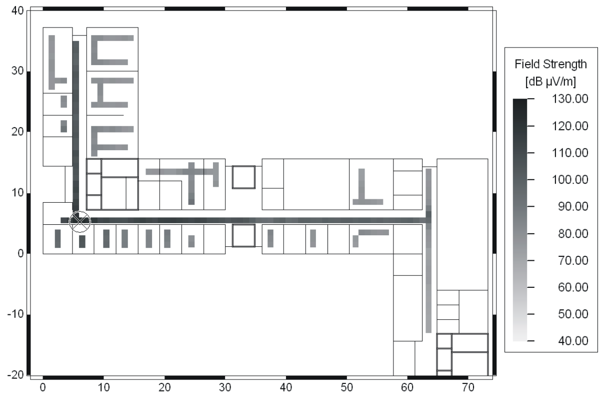

Fig. 7: Measured field strength for transmitter TRX 1

Additionally, a high resolution channel sounder was developed and used for the determination of the channel impulse responses within buildings. A pseudo random binary sequence (PRBS) is generated in the transmitter unit and modulated with a sinusoidal carrier. The principle of the transmitter is shown in fig. 8. For the measurements presented in this paper a bit rate of 220 MBit/s was chosen, which leads to a resolution of 4.45 ns in the time domain [5].

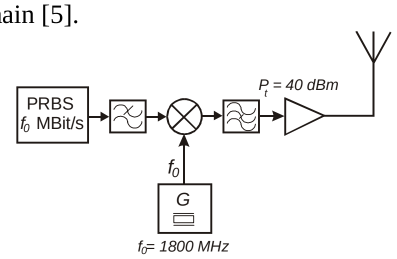

Fig. 8: Transmitter of the channel sounder

The received signal is converted to the base band with a two-step demodulator and split into I and Q parts (see fig. 9). A sliding correlation technique based on the principle of Cox [6] is used for the determination of the channel impulse response. Further information about the measurement equipment and the performance of the channel sounder is given in [7].

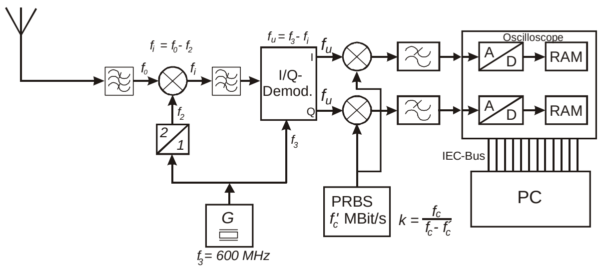

Fig. 9: Receiver of the channel sounder

Figures 10 and 11 show two measured impulse responses for line of sight (LOS) and no line of sight (NLOS). Many thousands of impulse responses were measured with different transmitter and receiver positions in different scenarios.

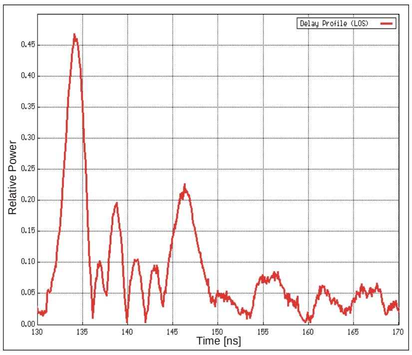

Fig. 10: Measured impulse response (LOS)

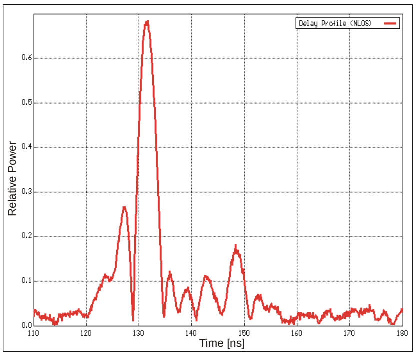

Fig. 11: Measured impulse response (NLOS)

The delay spread of each impulse response was computed and fig. 12 shows the measured delay spread for the indicated transmitter location TRX 2.

Fig. 12: Measured Delay Spread for transmitter TRX 2

IV. VERIFICATION OF THE NEW MODEL WITH MEASUREMENTS

Measurements of field strength, delay spread and impulse response with the above introduced equipment 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. 2 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. Only around the elevators also reinforced concrete is used.

A. Field Strength

Fig. 13 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. Differences between prediction and measurement for other transmitter locations are presented in fig. 14 and 15.

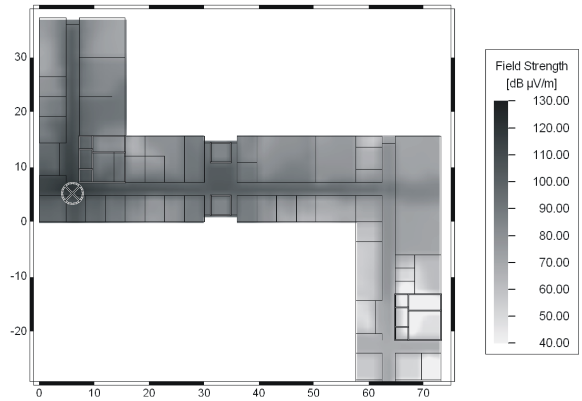

Fig. 13: Field strength prediction with the new approach for TRX1 (transmitting power 0.1 W at 1800 MHz)

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 (see fig. 14 and 15) seven interactions are necessary. Table 2 shows the statistical values of the comparisons between predictions and measurements for different transmitter locations. In every case the transmitting power has been 0.1 W at 1800 MHz. While the locations TRX 2 and TRX 3 are inside a room, TRX 1 and TRX 4 have been installed in the corridor.

Fig. 14: Difference between prediction and measurement (mean = 1.0 dB, std. dev. = 5.9 dB) for TRX 2

Fig. 15: Difference between prediction and measurement (mean = -0.2 dB, std. dev. = 6.1 dB) for TRX 3

Table 2: Comparison between field strength predictions and measurements

transmitter location	mean value	standard deviation
TRX 1	0.6 dB	5.2 dB
TRX 2	1.0 dB	5.9 dB
TRX 3	-0.2 dB	6.1 dB
TRX 4	2.8 dB	5.7 dB

While for the predictions taken into account in this paper a resolution of 1.5 m for the discretization of the building database has been selected it is possible to increase this resolution to some extent without loosing accuracy. As confirmed by measurements from other buildings, the mean error is generally in the range between 0 and 3 dB, while for the standard deviation values around 5-6 dB are reached.

B. Delay Spread

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 (see fig. 16).

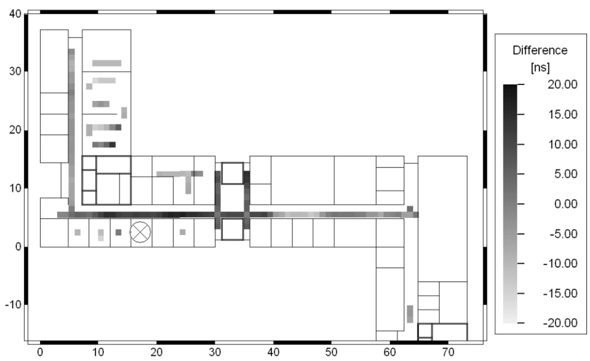

Fig. 16: Difference between prediction and measurement (mean = 0.3 ns, std. dev. = 8.2 ns) for TRX 2

Table 3: Comparison between delay spread predictions and measurements

transmitter location	mean value	standard deviation
TRX 1	1.5 ns	7.5 ns
TRX 2	0.3 ns	8.2 ns
TRX 3	2.0 ns	8.5 ns

With the same settings as for the field strength predictions (i.e. five interactions for transmitters located in corridors and seven interactions for transmitters inside rooms) the statistical values presented in table 3 have been achieved. In general for the delay spread predictions mean errors lower 5 ns with standard deviations around 8 ns are reached.

C. Impulse Response

Additionally, the impulse response of the radio channel in indoor scenarios can be predicted with the new approach (see fig 17). In order to compare the predictions to the measurements of the power delay profile (carried out with the channel sounder) the individual dirac-impulses have to be convoluted with a triangle impulse.

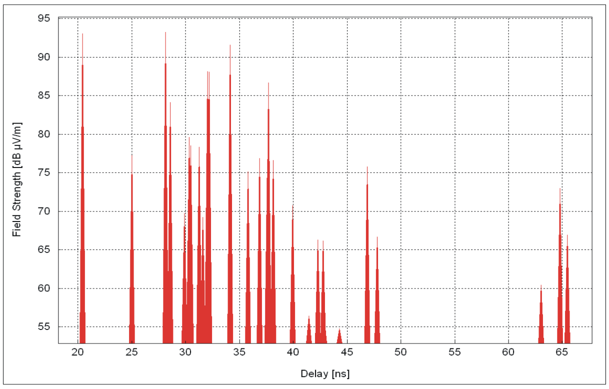

Fig. 17: Predicted impulse response for TRX 1 inside a room (NLOS, receiver at 11.5, 3.5)

The sum of the different contributions represents the power delay profile. Fig. 18 presents the comparison in a LOS-case, which indicates only slight differences.

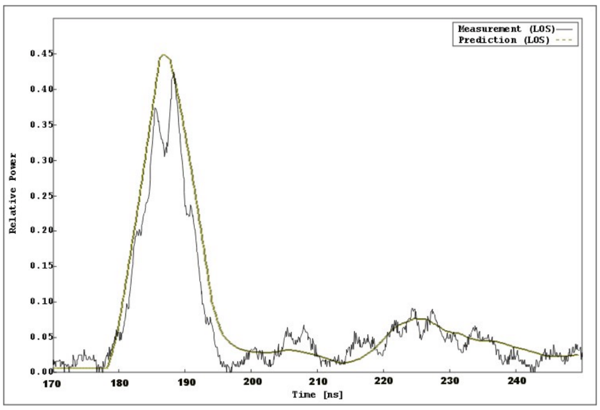

Fig. 18: Measured and predicted power delay profile for TRX 1 in the corridor (LOS, receiver at 61.5, 6.0)

V. CONCLUSIONS

In this paper a new approach to the prediction of the mobile radio channel including wideband properties inside buildings is presented. In order to achieve very short computation times the developed method is based on a single preprocessing of the building database. For the verification of the model measurements of field strength, delay spread and impulse response were compared to the simulation results, which leads in general to a good agreement.

VI. REFERENCES

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