

RADIO NETWORK PLANNING AND PROPAGATION MODELS FOR URBAN AND INDOOR WIRELESS COMMUNICATION NETWORKS

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INTRODUCTION

Radio network planning for the frequency range between 500 MHz and 5 GHz requires accurate prediction models. For large cells (macrocells) and urban scenarios (microcells) different models were already published [6]. Especially for urban scenarios ray optical models are used very often because they consider waveguiding effects in contrast to empirical models like the COST231 model [4]. In the last years different approaches to the acceleration of ray optical models were presented - so today these models are very accurate and very fast [1].

But there are still some limitations and restrictions for the ray optical models. Even with the newest approaches [3] not all prediction pixels in an urban scenario are predicted with the model (because only a limited number of interactions is considered). So hybrid models combining ray optical and empirical models are implemented to guarantee the prediction of the total area. But the transition between ray optical and empirical models is not smooth.

In most prediction tools the contribution of each ray to the total field strength is computed with the GTD/UTD (diffractions) and with the Fresnel equations (reflections/transmissions). These equations require a detailed and exact description of the electrical properties of the material of the buildings. But for most applications this description is not available. So there is a very high demand for a simple reflection/diffraction model to be calibrated with measurements by the user.

EMPIRICAL MODELS

The simplest approach to the prediction of the field strength in urban scenarios are empirical models. They are based on the direct ray between transmitter and receiver. The following parameters are considered in these models [5]:

- length of the direct ray (i.e. distance between transmitter and receiver)
- number (and perhaps material) of obstacles intersecting the direct ray between transmitter and receiver
- offset for attenuation (used for calibration)
- location of the transmitter and receiver antenna (height and local environment/obstacles)

The prediction of the field strength is based on these few parameters. Therefore empirical models are very fast but they are not very accurate because they do not consider waveguiding effects [1].

Urban Scenarios

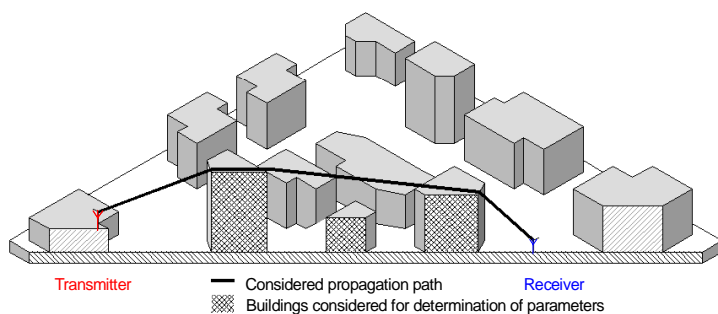


Figure 1: Vertical plane of an urban data base

In urban scenarios the direct ray represents the propagation over the rooftops as shown in figure 1. This ray includes multiple diffractions. If the antenna is mounted at or below roof top level and if the prediction pixel is far away from the transmitter, this ray is very often the only one to reach the receiver pixel.

Empirical models analyse the vertical plane between transmitter and receiver and the parameters of the model are gained from the properties of the buildings in this vertical plane. The model most often implemented is the COST 231 Walfisch-Ikegami model [4]. The main equations of this model are given in figure 2.

The predicted path loss depends on

- height of the buildings between transmitter and receiver
- If the buildings have no uniform height, the medium height is used.

- distance between the buildings

If the distance is not homogenous, the mean distance is used.

- street width

If the width of the street varies, the mean width is considered,

- transmitter and receiver height

All parameters are determined in the vertical plane between transmitter and receiver. So the parameters must be computed individually for each receiver pixel and they are different even for neighbouring pixels.

Further correction factors are introduced but they have only a very limited influence on the result of the prediction [4]. Different software packages are already available using this prediction model [6]. In most cases the COST 231 model is an alternative model if the pixel is not reached with ray optical models. In this paper a new approach is presented combining the prediction results of ray optical and empirical models.

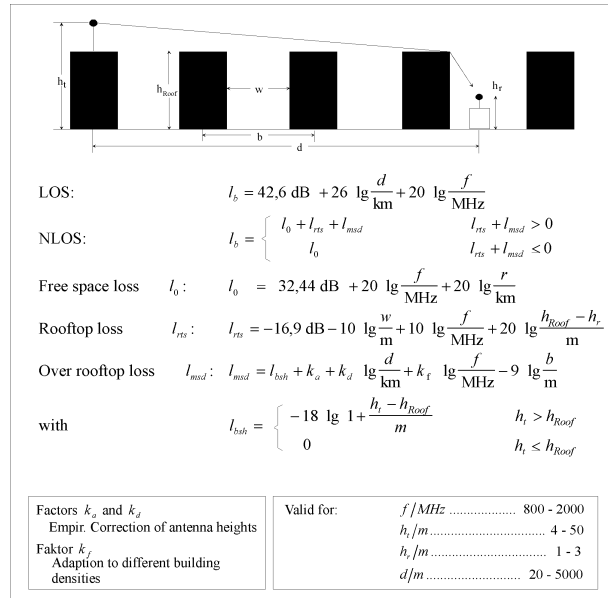


Figure 2: Equations of COST 231 Walfisch-Ikegami

Indoor Scenarios

The models for indoor scenarios are presented in a further paper in this proceedings [5] so only a brief summary is given here. The model of Motley-Keenan or the Multi-Wall-Model [4] are both used in commercial products [6]. They consider the distance between transmitter and receiver and the material of the walls penetrated by the direct ray between transmitter and receiver. Predictions with these models are not very accurate because the direct ray is very often highly attenuated and the waves are guided in corridors - an effect which is not included in these models [5].

RAY OPTICAL MODELS

Principle

Ray-optical models are based on a determination of the rays between transmitter and receiver. Multiple reflections and diffractions are considered as well as the penetration of walls. The contribution of each ray is determined with the Fresnel equations for the transmission/reflection and with the equations of the GTD/UTD for the diffraction.

One of the main disadvantages of these models were their very long computation times. But in the meantime different approaches were presented to accelerate the computation time up to a few seconds on a standard PC for the prediction of a micro- or picocell (coverage area smaller than 3km x 3km [1], [6]). The algorithm leading to this very short computation time is presented in [5].

Problems

Today the remaining two problems are

- the dependency on the accuracy of the data base and the influence of the material properties.

A calibration of ray optical models is very complicated because the dependency of the attenuation on the material properties in the Fresnel equations or in the GTD/UTD is non-linear and therefore a convergence or improvement during the calibration process is nearly impossible.

- the limited coverage area.

Prediction points far away from the transmitter can be reached only with a high number of interactions. So in most cases only the area around the transmitter is predicted with ray optical models. If empirical models (COST 231) are used for the remaining pixels, a inhomogenous transition between the two models leads to confusing results.

For both problems new solutions are presented in this paper. Together with these improvements ray optical models are an excellent alternative for the planning of mobile communication networks in urban and indoor scenarios.

EMPIRICAL DIFFRACTION MODEL FOR RAY OPTICAL MODELS

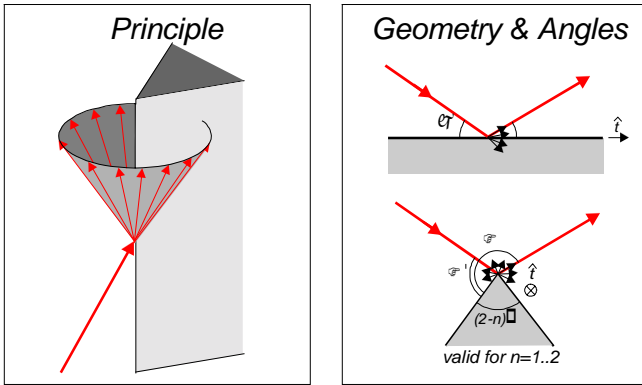


Figure 3: Geometry for diffraction

In most propagation models the attenuation of the signal along the ray paths is computed with the Fresnel equations for reflection/transmission and with the GTD/UTD for diffraction. These equations require a very accurate description of the material of the buildings. But in most data bases only a very vague information about the material of the buildings is available. If enough measurements in similar cities or buildings are available, the user is interested in a calibration of the propagation model. Unfortunately the dependency of the attenuation on the material properties in the GTD/UTD is very complicated and highly non-linear. So a calibration leading to reasonable results and an improvements of the accuracy are nearly impossible.

Therefore a new empirical diffraction model was developed to allow a very simple calibration of ray optical propagation models with measurements. Figure 3 shows the geometry of the diffraction. The wedge, the rays, and the angles are shown. The equations for the computation of the diffraction loss L_{diff} are very simple in given in equations (1) to (5):

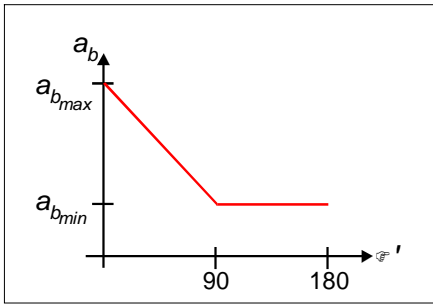


Figure 4: Plot for equation (2)

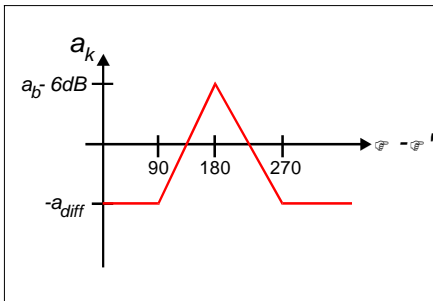


Figure 5: Plot for equation (3)

$$\Psi = \Phi - \Phi' \quad (1)$$

$$a_b = \begin{cases} a_{b \max} + \frac{a_{b \min} - a_{b \max}}{90^\circ} \Phi' & \Phi' < 90^\circ \\ a_{b \min} & \Phi' \geq 90^\circ \end{cases} \quad (2)$$

$$a_d = \begin{cases} 0 & \Psi \leq 90^\circ \\ (a_b - 6 \text{ dB} + a_{diff}) \left(\frac{\Psi}{90^\circ} - 1 \right) & 90^\circ < \Psi \leq 180^\circ \\ (-a_b + 6 \text{ dB} - a_{diff}) \left(\frac{\Psi}{90^\circ} - 3 \right) & 180^\circ < \Psi \leq 270^\circ \\ 0 & \Psi > 270^\circ \end{cases} \quad (3)$$

$$a_k = a_d - a_{diff} \quad (4)$$

$$L_{diff} = a_b - a_k \quad (5)$$

The diffraction model presented in this figures and equations allows a calibration by manipulating $a_{b \max}$, $a_{b \min}$, and a_{diff} (all values in dB). Different implementations of ray optical models include the GTD/UTD and this new model for the computation of the attenuation of diffracted rays. So a comparison between the results of the two diffraction models is possible with free sample data bases and demo versions for the same scenario and the same rays [6].

The default values $a_{b \max} = 15$ dB, $a_{b \min} = 8$ dB, and $a_{diff} = 5$ dB led to very accurate prediction results in several European cities (Stuttgart [3], Munich [1], Nancy [3],...) when compared to measurements. If the material of the different buildings in a city is not homogenous, the three default values can be adjusted to the special material properties of the individual buildings or they can be calibrated with measurements.

The building data base used for the prediction presented in figure 7 had a homogenous description of the material properties (concrete walls). The prediction based on the new diffraction model (with given default values) increased the accuracy compared to the GTD/UTD model: The mean error was reduced from -3 dB to -2 dB and the standard deviation from 9 dB to 7 dB.

TRANSITION BETWEEN EMPIRICAL AND RAY OPTICAL PREDICTION MODEL

For large prediction areas in city centres many of the prediction points far away from the transmitter are not reached with ray optical models or only a few rays (1,2 or 3 rays with very small contributions) lead to very pessimistic predictions. In most cases only rays with more than five interactions or more than two diffractions reach these points. But most of the prediction models are limited to less than five interactions and to less than three diffractions[6].

As already mentioned in this paper, empirical models are an alternative for the prediction of these pixels. But the predicted field strength of the empirical models is much higher than the prediction of the ray optical model for the neighbouring pixels, because the ray optical prediction is only based on one or two rays (or no ray).

Therefore a smooth transition between the ray optical model and the empirical model must be implemented. For each pixel the ray optical value and the empirical value are computed. If the ray optical value is higher, waveguiding is

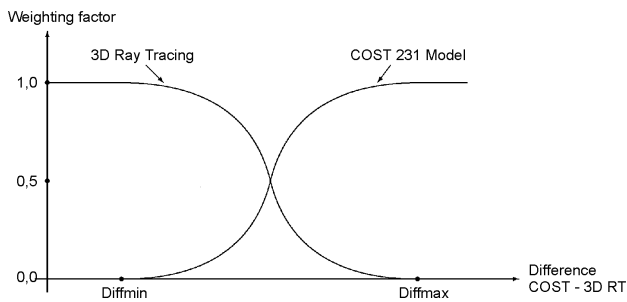


Figure 6: Transition betw. ray optical and empirical model

assumed and only the ray optical value is used. If the empirical value is higher the ray optical model has considered not enough interactions and so only the empirical value is used. To get a smooth transition between the two models, a function for the definition of the weighting factors is used as shown in figure 6. Depending on the difference between the two predictions, different weights for the two models are computed and the predicted value represents the sum of the two weighted values. For the weighting functions \sin^2x and \cos^2x were used, because their sum is always equal to 1.

RESULTS

Figure 7 shows a prediction for a GSM 900 network in Stuttgart. The empirical diffraction model and the smooth transition were used for this prediction. Two diffractions and max. three reflections (and arbitrary combinations with max. two diffractions and three reflections) were computed. The accuracy was very high (mean error 0 dB and standard deviation 5 dB). Further results for the test scenario in Munich (GSM 900) [2], [4] confirm these results [1].

CONCLUSIONS

A new empirical diffraction model and a hybrid extension with an empirical prediction model were presented for ray optical propagation models. The empirical diffraction model allows a simple calibration and the hybrid extension improves the accuracy.

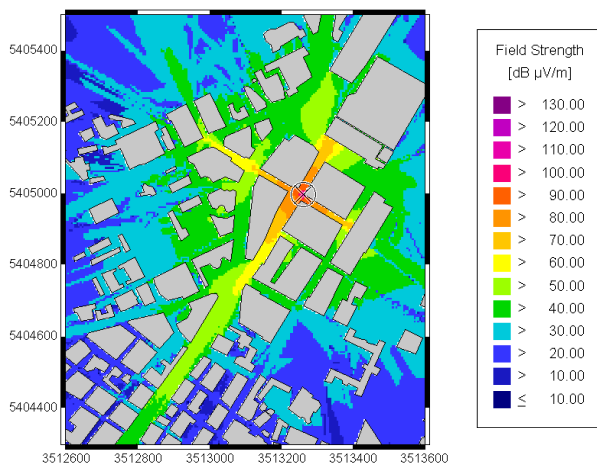


Figure 7: Prediction for GSM 900 in Stuttgart

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