PREDICTION OF WIDE-BAND PARAMETERS OF MOBILE PROPAGATION CHANNEL

Martin Klepal, Pavel Pechač, Zdeněk Hradecký

Czech Technical University in Prague, Department of Electromagnetic Field
Technická 2, 166 27 Prague 6, Czech Republic
E-mail: klepalm@fel.cvut.cz

ABSTRACT

Wireless communications services are becoming ubiquitous and the main area of interest is now partly shifting from low performance wireless wide area networks to high performance local wireless networks using picocells and high data rates. In order to facilitate proper design of such networks appropriate simulation tools based on accurate signal propagation prediction are required. A semi-deterministic approach called Motif Model was developed to provide an accurate and computationally efficient way for indoor radio propagation prediction. Up to now model parameter have been based on heuristic values derived from propagation measurements. In order to increase accuracy of the model, an approach for parameter optimisation using evolutionary computation techniques is also presented in this paper and the improved accuracy is assessed.

INTRODUCTION

The boom of wireless personal communication over the last few years has brought about an increasing demand for sufficient signal coverage also inside buildings. If a signal penetration from outdoor cells into buildings is not sufficient then, in the case of cellular systems such GSM and UMTS, the design of indoor picocells system is required. Additionally, the popularity of Wireless Local Area Networks (WLAN) is increasing and with the implementation of new high-speed radio technology a boom of indoor wireless systems is inevitable. Such progress brings about the necessity for an appropriate design of wireless systems, which requires accurate signal propagation prediction.

Two conventional approaches to indoor propagation modelling exist: empirical and deterministic. For brief introduction of their advantages and disadvantages see ref. [1]. The proposed Motif Model attempts to avoid the disadvantages and combines the advantages of the conventional models by employing a stochastic description of the environment. The principles of the proposed Motif Model will be described and issues associated with the indoor propagation environment description will be highlighted. We will then discuss how the new model addresses those issues. Afterwards the models performance is assessed with optimisation of stochastic model parameters and a comparison of results will be presented.

DESCRIPTION OF THE MOTIF MODEL

The Motif Model was first introduced in [1] as a combination of advantages of empirical and deterministic approaches: wide-band channel measures, high site-specific accuracy, short computation time and easy-to-obtain input data. The main idea behind the model is based on a ray launching technique, the Monte Carlo method and general statistics. When a new "motif concept" is used, all the electromagnetic effects, including diffuse scattering, are taken into account while complicated calculations of reflection and diffraction can be avoided.

Algorithm

The fundamentals of the model algorithm are shown in Fig. 1. A simple bitmap of a floor plan serves as the main input data. Filled pixels represent walls, partitions and obstacles. Different colours distinguish different materials. Propagation prediction is calculated in all empty elements at once. The size of the pixel is predetermined to be equal to one wavelength of the carrier frequency of the radio system under consideration.

Rays are launched from a transmitter antenna according its radiation pattern using a fast pixel graphics algorithm. When the ray hits a filled element its neighbourhood elements are separated into a matrix called "motif". According to this motif and an angle of the incoming ray, the probability radiation pattern is taken from the database (Fig. 2). Then, based on a random number the ray behaviour of a next step is determined, e.g. next direction or possible ray absorption. When the ray is absorbed in the motif or reaches the boundary of the bitmap a new ray is launched from the transmitter location.

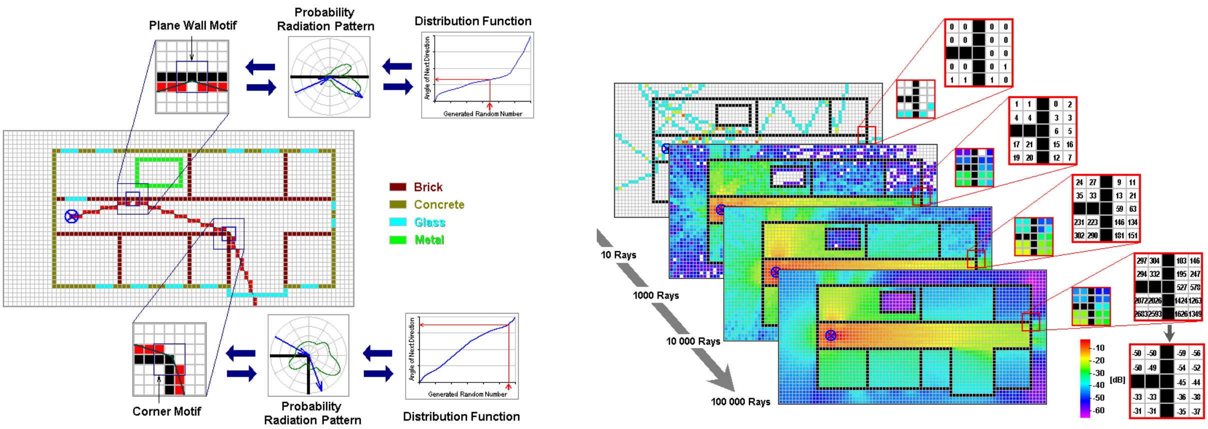

Fig. 1. Fundamentals of the Motif Model algorithm

Motifs

The probability radiation pattern of each motif could be calculated by either an exact calculation using the Uniform Theory of Diffraction (UTD) for example or by a stochastic description. The best way depends on the application of the Motif Model. If a precise site-specific description and parameter characterisation of all obstacles is available, e.g. light propagation inside exactly defined structures, an exact propagation prediction is feasible. On the other hand if it is not possible to exactly define the environment under investigation, the stochastic description is preferred.

It can be seen from the "plain wall" motif (Fig. 1) that the specular reflection and direct transmission through the wall are the most probable cases. In fact the probability radiation pattern could ensure that other phenomena - non-specular reflection, diffuse scattering, absorption - are also taken into account and fully modelled, which is not the case in classical optical models.

Prediction

The signal strength is predicted in each empty element of the bitmap by recording the number of passed rays. As is illustrated in Fig. 1b. a sufficient number of rays must be launched and traced to yield results with adequate precision. The wide-band output such as the impulse response and the angle of arrival are very easily obtained in each empty element by recording the length and the angle of arrival of all passing rays. An example of the Motif Model outputs is displayed in Fig. 2.

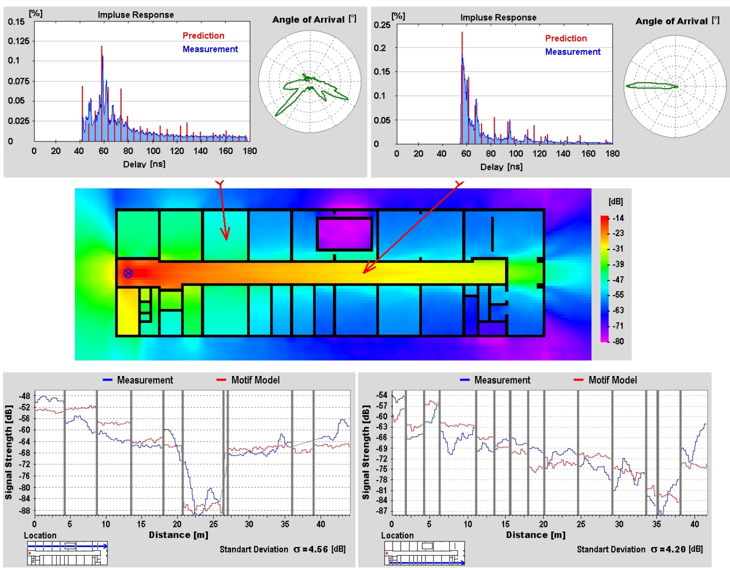

Fig. 2. Sample of the communication channel parameters prediction by Motif Model

OPTIMISATION OF MOTIF MODEL PARAMETERS

The accuracy of the Motif model is directly proportional to appropriate shapes of probability radiation patterns and ray absorption of motifs (motif behaviour). If the motif behaviour could be characterised by a straightforward calculation using for example UTD and parameters of real obstacles, the accuracy of Motif Model reaches only the accuracy of deterministic models. As was mentioned earlier, the accuracy of deterministic models rapidly decreases if some significant obstacle cannot be included in the input database. However in indoor scenarios it is often not possible to describe every obstacle, which has a non-negligible influence on signal distribution inside a building. That is why the use of UTD or other deterministic approaches is not the best way to predict indoor signal strength distribution.

For example, assume a common wall inside a building (Fig. 3), which is illuminated by the incident wave. We usually do not just find a bare wall, but we also typically find furniture or moving persons close to the wall. All of those have a significant influence on electromagnetic wave propagation.

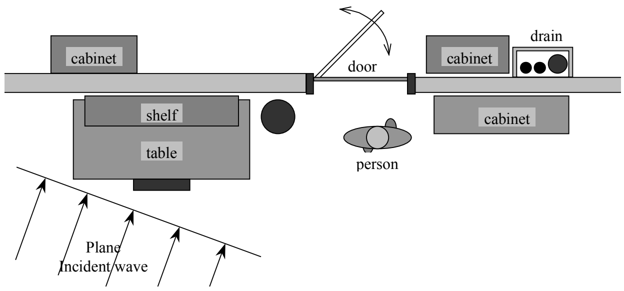

Fig. 3. Common situation - a wall surounded by many other undefined obstacles

Precise prediction of incident wave scattering using deterministic models requires every obstacle (at least those bigger than the wavelength) and their electrical parameters included in the database. The approach presented here describes walls and other vague obstacles by a semi-deterministic approach, which considers walls together with other nearby smaller obstacles as a cluster of obstacles. Such a general clusters can then be described by stochastic scattering parameters, which are used in the Motif Model to increase the prediction accuracy. For accurate prediction using stochastic scattering parameters, the parameters need to be optimized for a particular environment.

Gathering of Stochastic Scattering Parameters

The stochastic scattering parameters could be gathered either from a measurement campaign or by calculation of incident wave scattering on randomly distributed obstacles surounding the wall (Fig. 4). The input parameters of the second solution should be real parameters of obstacles, however their definition is uncertain. The output is an overall stochastic radiation pattern, which is obtained after sufficient number of randomly generated clusters is analyzed. There will be presented the first method of gathering of stochastic scattering parameters from measurements to define radiation pattern.

As is from the Motif Model description obvious Motif Model can be based on the probability of ray absorption in clusters and on the stochastic probability radiation pattern of clusters. Their shapes are influenced a lot by many parameters. The dominant parameter is the incident angle of incoming wave. Every others are for static scenario constant. From the observation of different patterns is evident, that their shapes are possible approximated by easy defined mathematics functions. For example the Motif Model uses the cosine function powered by n to approximate main lobes. Diffraction and diffusion can be also by means of other mathematics functions easy described.

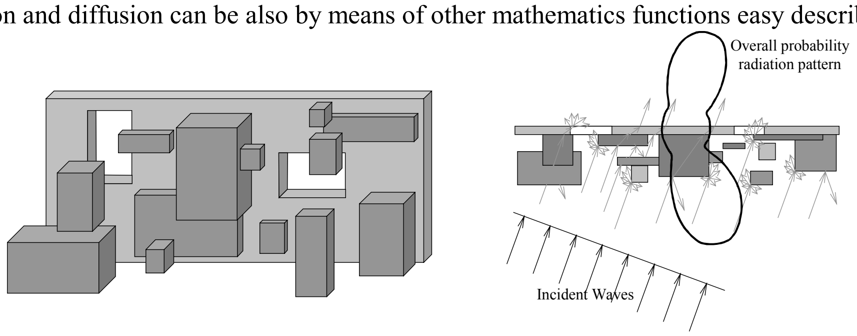

Fig. 4. Example of a wall fraction with randomly distributed obstacles and the overall stochastic probability radiation pattern concerned incident wave

The Motif Model prediction algorithm presented here uses seven basic coefficients to define the probability radiation patterns. These coefficients are unique for different kinds of walls and to achieve a better approximation could also be unique for different motifs. If four different kinds of walls are assumed, 28 parameters are necessary to define them. If different motifs are also required the overall number of parameters will rise to 228. The way to identify the best values for such an amount of parameters from measured signal strength distribution is by optimization.

Chosen Optimization Technique

Application of the stochastic cluster description gives lots of advantages. On the other hand it is necessary to carry out many measurement campaigns with different settings and environments to produce a table of stochastic parameters that represent a wide range of building variety. The similar calibration process is often used in other models, where exact calculations are also infeasible because of exact data is missing.

A stochastic approach avoids impossible characterization of all obstacles, but the optimization of 28 or 228 parameters (in Motif Model) is also quite intricate and an appropriate selection of an optimization technique is crucial. The standard deviation σ of the difference between measurement and prediction is commonly used as indicator of the signal strength prediction accuracy. σ is changing together with the alteration of the Motif Model parameters to produce a fitness landscape containing many sub-optimal solutions with similar fitness as the optimal solution. In such cases conventional optimization approaches such as the basic Down Hill Simplex method or the exact Conjugate Gradient method are incapable to find the optimal solution. The optimization problem is in fact such that evolutionary computation techniques are best suited to finding the optimal parameter setting for the Motif Model.

Description of Evolutionary Computation Techniques

The two best-known evolutionary computation methods are Genetic Algorithm [2] and Evolution Strategies [3]. Many books and articles describe their features in detail and therefore we will only give a summary of the main points related to their application in the Motif Model optimization.

- The fitness function (cost function) is given by the combination of standard deviation and mean error of a difference between prediction and measurement.
- Both crossover and mutation techniques are used in different forms in GA.
- The most efficient ES algorithm from point of view the minimization of number of fitness function evaluation was the (1+l)-ES. Its successful convergence was strongly dependent on the selection of appropriate heuristic parameters. Consequently the others ES algorithms combined by different self-adaptation techniques were investigated too.
- Others modifications are used to find an optimal solution and to accelerate the convergence of the algorithms

Detailed results and an assessment of the optimization will be introduced in the presentation.

CONCLUSION

The basic principles of the Motif Model, which is based on a novel propagation prediction algorithm, were introduced. The Motif Model can predict the radio signal strength and other parameters of communication channels such as impulse response and angle of arrival at high speed and with simple input data. None of the electromagnetic wave propagation phenomena is neglected. From this point of view the Motif Model can be considering more deterministic than optical models.

The key aspect of prediction accuracy inside buildings is the incorporation of all significant obstacles to the model input. Reasons for preferring the stochastic description of obstacles instead of the exact description in case of indoors propagation were discussed. Possible ways of stochastic parameter gathering were mentioned. Model parameter optimisation based on broad measurement data using evolutionary computation techniques to create the table of stochastic parameters were presented. The results and an assessment of the performance of the model using different optimisation techniques will be presented in the final paper.

ACKNOWLEDGMENTS

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