RAY-TRACING FOR VEHICLE-TO-VEHICLE COMMUNICATIONS

Jürgen Maurer, Werner Sörgel and Werner Wiesbeck

Institut für Höchstfrequenztechnik und Elektronik (IHE)
Universität Karlsruhe (TH), Kaiserstr. 12, D-76131 Karlsruhe, Germany
Phone: +49-721-608 7678, Fax: +49-721-691865, E-mail: Juergen.Maurer@ihe.uka.de

ABSTRACT

A comprehensive model of the transmission channel between moving vehicles in realistic environments is presented in this paper. The approach consists of tree major parts: the modelling of the road traffic, the modelling of the environment adjacent to the road and the actual modelling of the wave propagation between the vehicles. A ray-tracing approach is used for the wave propagation, which allows for wide-band as well as narrow-band analyses of the channel. Characteristic time series of impulse responses of the inter-vehicle transmission channel can therefore be calculated for link level simulations. Simulation results are compared to wide-band channel measurements at 5.2 GHz, yielding a good agreement.

I. INTRODUCTION

Future vehicles will be equipped with inter-vehicle communication (IVC) systems, providing the driver with specific route dependent information [1]. This includes mobility-relevant information (e.g. the actual traffic conditions on the whole route) as well as safety-relevant information (e.g. detailed information about the road and traffic conditions in the vicinity of the vehicle). Thereby, the primary goal is to improve the traffic flow, avoid accidents and shorten journey lengths. Moreover, the increasing demand for mobile computing will have the automobiles being supplied with high data rate access to the internet. Various multimedia applications, such as video on demand, games, email, etc. will be available.

A detailed knowledge about the vehicle-to-vehicle (v2v) transmission channel is necessary for the design and optimisation of IVC systems. The basis for these investigations are typical high resolution time series of impulse responses (IRs) of the physical radio channel between automobiles. A comprehensive IVC channel model is therefore presented in this paper, which is able to provide realistic time series of IRs in a quasi-continuous manner. The model can be divided into three major parts consisting of a realistic dynamic road traffic model, a comprehensive model of the environment adjacent to the road, and an accurate model for the multi-path wave propagation between the transmit and receive vehicles. Since typical road traffic environments are very complex and rich of different scatterers (e.g. vehicles, buildings, trees, etc.), special care has to be taken to account for all relevant wave propagation effects. Hence, ray-tracing is used to determine the various multi-path components.

The three different parts of the model are discussed in this paper. Finally, comparisons with measurements of typical traffic environments at 5.2 GHz are presented, showing a good agreement.

II. ROAD TRAFFIC MODEL

For a realistic modelling of road traffic, the implementation of a dynamic traffic model is necessary. Currently, two major approaches that differ in their level of resolution are available. They are termed "macroscopic" and "microscopic" traffic models [2]. As only microscopic models consider the motion of single vehicles they are more suitable for the integration of the proposed channel model. Microscopic models generate realistic time series (snapshots) of instantaneous positions and velocities of individual vehicles that interact with each other (e.g. braking and overtaking), which is essential for an accurate characterisation of the time variance of the channel. This leads to a microscopic model being used for the description of the dynamic road traffic. The so-called *Wiedemann* traffic model [3] is implemented in the proposed IVC channel model, which ensures a realistic description of road traffic under various conditions.

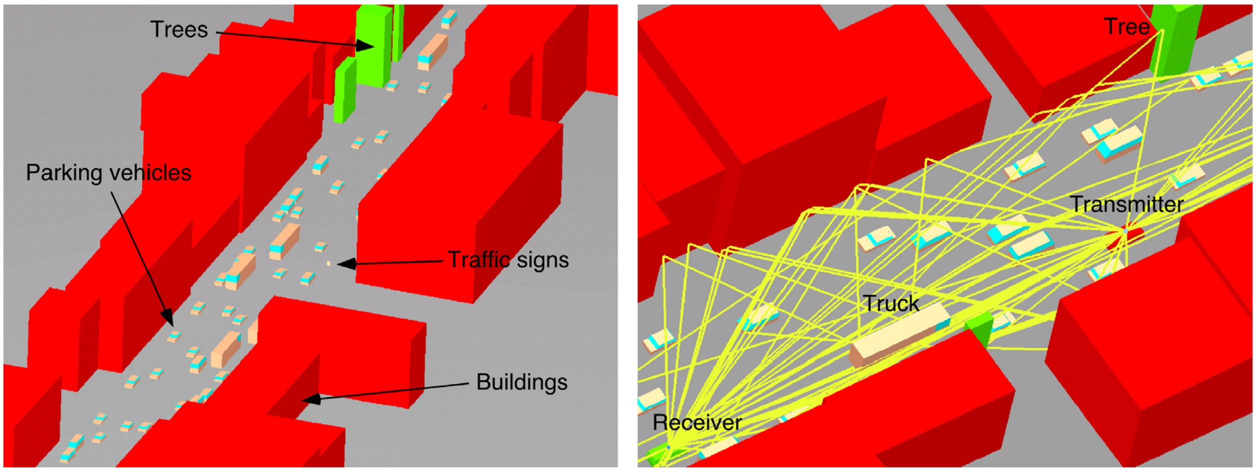
Different types of vehicles are taken into account. They are categorised into five types of cars, e.g. vans, compact cars, etc. and trucks. Cars are modelled using two stacked boxes of different size. The side plates of the upper box, which represent the windows, are inclined with different angles. The corresponding constitutive material parameters are that of a perfect electrical conductor (PEC) for the car's body and that of glass ($\varepsilon_r = 6 - j0.006$, $\mu_r = 1$) for the windows. Trucks are composed of one metal (PEC) box with a windscreen and two side windows made of glass.

III. ENVIRONMENT MODEL

The environment adjacent to the road is in general very complex and one can find a variety of different characteristic objects (e.g. buildings, parked vehicles, trees, etc.). Depending on the area different objects occur with different probabilities. E.g. in the surrounding of motorways probable objects are crash barriers, trees or bridges, whereas in urban areas buildings and parked cars are more likely.

The proposed approach to model the environment next to the road is therefore based on stochastic positioning of different typical objects. Various morphographic classes are defined and implemented, e.g. urban, suburban, highway or motorway. Based on a comprehensive set of typical objects such as buildings, trees, parked cars, bridges, traffic signs, etc. each class is assigned a different set of probabilities of occurrence for all these objects. Several values for the object probabilities of different morphografic classes can be taken from literature [4]. For the remaining ones reasonable assumptions are made. During the generation of the environment the objects are placed randomly adjacent to the road lane with respect to their probability of occurrence. Furthermore, the size and the relative position to the lane of certain objects (e.g. buildings and trees) are varied randomly within certain limits.

Fig. 1(a) shows the result of a stochastically generated urban environment. The road consists of two lanes in each direction filled with cars and trucks generated by means of the traffic model. Buildings, small traffic signs, parked cars and trucks as well as some trees are positioned randomly adjacent to the road according to the urban morphographic class. Buildings are modelled as large single boxes. As can be seen in Fig. 1(a) their absolute size and distance to the lane is varying randomly within certain limits. It is assumed that on average all buildings have constitutive parameters of dry concrete ($\varepsilon_{\mathrm{r}} = 5 - j0.1$, $\mu_{\mathrm{r}} = 1$). The surface roughness is set to $\sigma = 1\,\mathrm{mm}$. Traffic signs are modelled as perfect electric conducting (PEC) metal plates of different size. Their distance to the road lane is fixed and depends on the type of the road. Trees are simply described by boxes. No distinction between the crown of the trees and the trunk is made. In order to characterise the scattering behaviour of the trees, a certain radar cross section σ^0 is assigned to each tree (cf. Sec. IV). As for the buildings the size of each tree and its distance to the lane are drawn stochastically. The material parameters of the road's surface are chosen to be that of concrete with $\varepsilon_{\mathrm{r}} = 5 - j0.1$ and $\mu_{\mathrm{r}} = 1$. The corresponding surface roughness is set to a reasonable value of $\sigma = 0.4\,\mathrm{mm}$ [5].



(a) Urban traffic scenario

(b) Ray-tracing result

Fig. 1. Stochastically generated urban traffic scenario and result of ray-tracing

Fig. 1(a) shows that the proposed approach to model the environment adjacent to the road together with the dynamic road traffic model delivers a comprehensive description of typical traffic scenarios. The resulting time series of realistic traffic situations serve as input data for the ray-tracing, which is described in the next section.

IV. WAVE PROPAGATION MODEL

Ray-tracing provides an adequate means to model the multi-path wave propagation in the aforementioned traffic scenarios. The propagation phenomena taken into account in the IVC-channel model are combinations of multiple reflections, diffractions and scattering from trees. The modified Fresnel reflection coefficients, which account for slightly rough surfaces, are used to model the reflections. Diffractions are described by the uniform geometrical theory of diffraction (UTD) and the corresponding coefficients for wedge diffraction. Scattering from trees is considered to be totally incoherent, i.e. no distinct specular component is present. This assumption holds, if the wavelength λ is smaller than the dimensions of the randomly distributed leaves and branches. Distinct scattering components resulting from tree trunks are neglected. To describe scattering from trees, the surface of the tree model (box) is divided into small squared tiles. Depending on the energy, which is incident on the surface of the tree, each tile gives rise to a Lambertian scattering source [6]. The amount of scattered energy per tile can be derived from measured normalised radar cross sections σ^0. At the frequency $f_{\mathrm{c}} = 5.2\,\mathrm{GHz}$ used for the verification of the channel model, average values of $\sigma^0_{\mathrm{Co}} = -10\,\mathrm{dB}$ and $\sigma^0_{\mathrm{X}} = -16\,\mathrm{dB}$ are assumed for co- and cross-polarisation respectively [7].

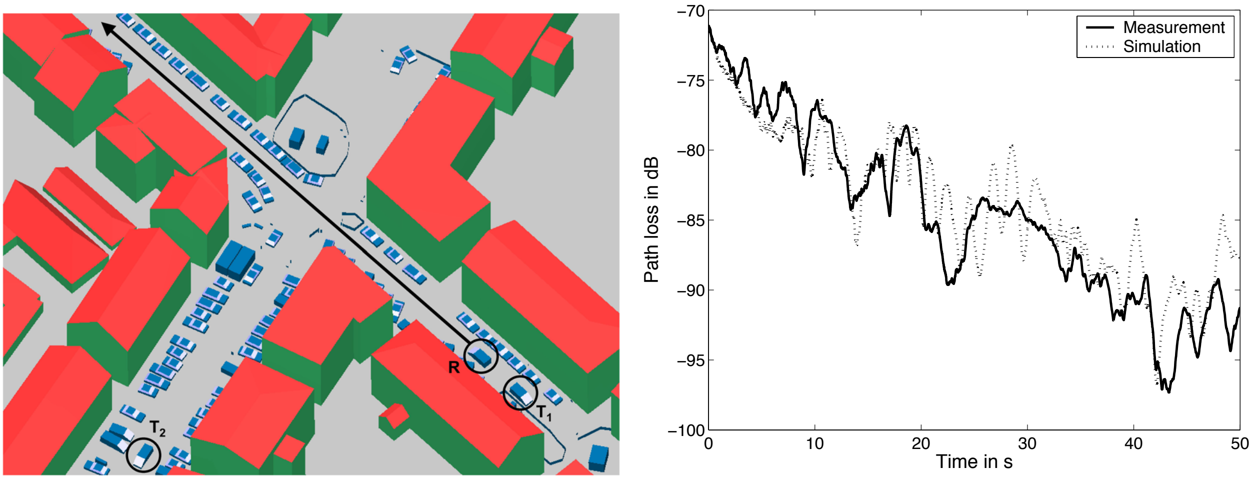
Depending on the propagation phenomena, different approaches of ray-tracing exist. In order to trace pure reflection paths, the method of image transmitters (image theory) is implemented. Since the proposed propagation model supports full 3D diffraction, Fermat's principle is used to determine the diffracted ray paths. For mixed paths image theory and Fermat's principle are combined. As only single scattering from trees is taken into account, the scattering paths are defined by the position of transmitter and receiver and the position of the central point of the tiles, in which the tree model is subdivided.

Fig. 1(b) shows the result of the ray-tracing for one snapshot of an urban road traffic scenario. Receiver and transmitter are positioned on two consecutive cars with a truck in between resulting in a NLOS condition. In order to keep track of the result, only the 30 strongest propagation paths are indicated (bright lines). It can be clearly seen that part of the transmitted energy is diffracted around the truck. Since there are many buildings next to the road, the expected street canyon effect arises. Scattering from single trees contributes to the received signal as well.

V. VERIFICATION

Wide-band v2v propagation measurements are performed at the centre frequency of $f_{\mathrm{c}} = 5.2\,\mathrm{GHz}$ to verify the proposed ray-tracing approach. The RUSK ATM vector channel sounder is used as measurement platform [8]. It consists of a signal generator with an output power of 33 dBm and a receiver unit, which enables real-time measurements of the complex channel transfer function. The measurement principle is based on the transmission of a multi-carrier signal with a total bandwidth $B = 120\,\mathrm{MHz}$. Two vehicles (vans) are equipped with the transmitter and the receiver unit, respectively. As transmit and receive antenna $\lambda/4$-mono-poles are used. The antennas are mounted approx. 20 cm above the centre of the rooftop of each vehicle.

The measurements are performed in an urban environment in the city of Karlsruhe, Germany. In order to verify the absolute behaviour of the ray-tracing model, the distinct measurement scenario is reconstructed and simulated in a deterministic way. A comprehensive model of the measurement environment including all relevant objects, such as buildings, parked vehicles, road signs, etc. is implemented for the simulations and shown in Fig. 2(a). The buildings are taken from an already existing data base, whereas all other objects are recorded and implemented manually right before the actual measurement. All parking vehicles occurring in the scenario are divided into the car models, which are available in the channel model (cf. Sec. II). A road construction around the junction, involving objects such as metal (PEC) containers, piles of bricks, etc., further increases the complexity of the scenario and is taken into account as well. The material parameters of brick are set to $\varepsilon_{\mathrm{r}} = 5 - j0.1$, $\mu_{\mathrm{r}} = 1$ and $\sigma = 0.5\,\mathrm{mm}$.



(a) Measurement scenario

(b) Average path loss

Fig. 2. Measurement scenario and measured and simulated average path loss for transmitter position T_1

Only the receiver is moving during the measurements. The transmitter is kept stationary and no other moving vehicles are located in the scenario as well. The reason is that it is impossible to keep track of several moving vehicles with reasonable effort and to reconstruct their exact movement for the simulation. In order to measure LOS and NLOS conditions, two different transmitter positions are chosen, denoted T_1 and T_2 (cf. Fig. 2(a)). The receiver vehicle (R) is moved along the indicated line with a velocity $v_{\mathrm{R}} = 10\,\mathrm{km/h}$ for both transmitter positions. While moving, the receiver records the complex channel transfer function with a sample frequency of 100 Hz. The total measurement time for each transmitter position is 50 s, which corresponds to a route of approximately 140 m in length.

Fig. 2(b) shows the measured and simulated path loss over the measurement time for transmitter position T_1. A very good agreement between both curves is recognised. Similar results are obtained for transmitter position

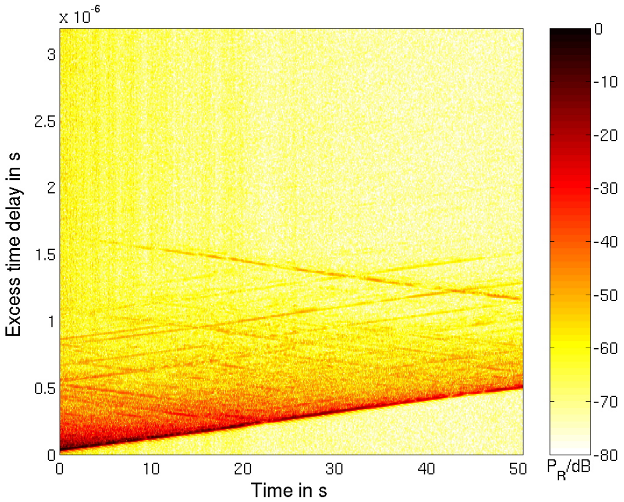
T_2. In order to quantify the deviation between measurement and simulation, the corresponding mean errors μ_E and standard deviations of the error σ_E are listed in Tab. I. Especially the low standard deviation for both, LOS and NLOS scenario, show the excellent quality of the wave propagation model.

TABLE I

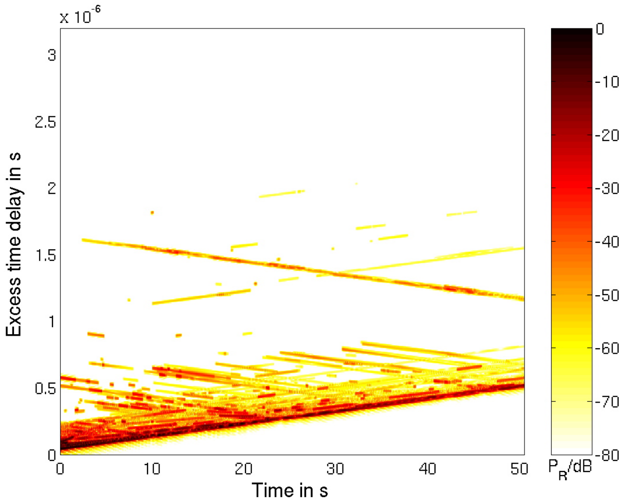
MEAN ERROR AND STANDARD DEVIATION IN dB

Transmitter pos.	μ_E	σ_E
T_1	-0.8	2.8
T_2	-0.3	2.9

For the comparison of the wide-band behaviour of the channel Fig. 3 shows the time-variant measured and the simulated PDP over the measurement time for T_1. The gray scale of the plots indicates the normalised received power level. By means of the PDP one can recognise the excess time, at which each multi-path component arrives at the receiver. Each line in the plots is associated with at least one propagation path. The slope of the lines is directly related to the variation of the corresponding path length during the measurement. Comparing both plots one can see that the major propagation paths in the measurement are found in the simulation as well.



(a) Measurement



(b) Simulation

Fig. 3. Measured and simulated time-variant PDP for transmitter position T_1

VI. CONCLUSION

A new IVC channel model is proposed in this paper, which is based on ray-optical wave propagation modelling in realistic traffic scenarios. Comprehensive wide-band channel measurements in an urban scenario are preformed for the verification of the approach. The comparison between measurement and simulation presented in this work indicates that the implemented ray-tracing model delivers an excellent coincidence with real IVC channels in terms of the narrow-band and wide-band behaviour.

References

[1] W. Enkelmann, "Fleetnet - Applications for Inter-Vehicle Communication," in *Proceedings of the IEEE Intelligent Vehicles Symposium 2003*, Columbus, OH, USA, June 2003, pp. 162–167.

[2] D. Helbing, "Traffic and Related Self-Driven Many-Particle Systems," *Reviews of Modern Physics*, vol. 73, no. 4, pp. 1067–1141, 2001.

[3] J. Maurer, T.M. Schäfer, and W. Wiesbeck, "A Realistic Description of the Environment for Inter-Vehicle Wave Propagation Modelling," in *Proceedings of the 54th IEEE Vehicular Technology Conference, VTC2001-Fall*, Atlantic City, NJ, USA, Sept. 2001, pp. 1437–1441.

[4] M. Döttling, *Strahlenoptisches Wellenausbreitungsmodell und Systemstudien für den Satellitenmobilfunk, (in German)*, Ph.D. thesis, Forschungsberichte aus dem Institut für Höchstfrequenztechnik und Elektronik der Universität Karlsruhe, 2000.

[5] R. Schneider, D. Didascalou, and W. Wiesbeck, "Impact of Road Surfaces on Millimeter-Wave Propagation," *IEEE Transactions on Vehicular Technology*, vol. 49, no. 4, pp. 1314–1320, July 2000.

[6] G.T. Ruck, D.E. Barrick, W.D. Stuart, and C.K. Krichbaum, *Radar Cross Section Handbook*, Plenum Press, New York, London, 1970.

[7] F.T. Ulaby and M.C. Dobson, *Handbook of Radar Scattering Statistics for Terrain*, Artech House, Norwood, 1989.

[8] R.S. Thomä, D. Hampicke, A. Richter, G. Sommerkorn, and U. Trautwein, "MIMO vector channel sounder measurement for smart antenna system evaluation," *European Trans. on Telecom., Special issue on smart antennas*, vol. 12, no. 5, pp. 427–438, Sept. 2001.