Wave Propagation Inside and Around Vehicles in Dynamic Time Variant Scenarios

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***Abstract*–With the growing demand for wireless communication systems, a wireless concept for the data exchange between different system components inside a vehicle and also between vehicles becomes interesting. In order to describe and thus assess the mobile radio channel in and around the vehicle, simulations are required. For low frequencies, full wave simulations using the Method of Moments are adequate means. For higher frequencies, those models get inadequate because of their computational effort. Systems employing high frequencies are also used for car-to-car communication systems. The main aspect in such applications is the time variance of the scenario, as the vehicles move continuously and thus the channel impulse response is time-variant. This paper discusses the demands for models to describe the radio channel inside and around vehicles at high frequencies and presents an appropriate ray tracing approach.**

***Index Terms*–Automotive, Vehicles, Multimedia in Vehicles, Time Variant Scenarios, Ray Tracing, Car-to-Car Communication**

I. INTRODUCTION

After the great success of wireless communications used in land mobile radio systems, wireless communications inside vehicles and between vehicles becomes more and more interesting.

The steadily increasing demand for multimedia applications in modern cars requires looking for new wireless concepts for the planning of wireless in-car systems.

To increase driving safety, assistance systems exchanging data using wireless channels between two or more vehicles will be introduced during the next years. Such a wireless system is the Dedicated Short-Range Communications Standard (DSRC) which is a short to medium range wireless protocol specifically designed for automotive use. It offers communication between vehicles and roadside equipment. This technology is working in the 5.9 GHz band. The main aspect in such applications is the time variance of these scenarios, as the positions of vehicles change continuously.

II. MODELING INSIDE VEHICLES

A. Current Status

In the automotive sector, simulations by using full wave approaches (e.g. Method of Moments [1]) have been established to e.g. optimize antenna positions in the vehicle under consideration of EMC problems and electromagnetic field exposure of the user. Therefore several software packages are available, such as FEKO [2], Microwave Studio [3] or XFDTD [4].

The frequency range available and suitable for wireless links in and around vehicles will be above 450 MHz and might go up to several GHz. At those frequencies, an approach with full wave methods still requires an enormous computational effort and very large memory recources. However, with increasing frequency ray optical approaches can be used alternatively, if the dimensions of the objects are much larger than the wavelength [5].

B. Description of the new Approach

Ray optical propagation models are well known in the domain of urban radio network planning [6]. In the last years, these models have become more and more important also for indoor scenarios because of their high accuracy [7]-[9]. Therefore, a 3D Ray Tracing model was used as a basis for the described approach. Some improvements (e.g. higher resolution of the databases, handling of curved surfaces, consideration of a very large number of polygons) were made to the Ray Tracing model, so that the algorithm can deal with vehicle databases and fits to the needs of such scenarios.

As the 3D Ray Tracing propagation model allows the vector-oriented definition of an arbitrary number of polygons with different material properties, a vehicle with all details can be modeled easily. The vehicles in fig. 1 are built up of more than 50,000 polygons with individual material properties, such as permittivity, permeability and conductance.

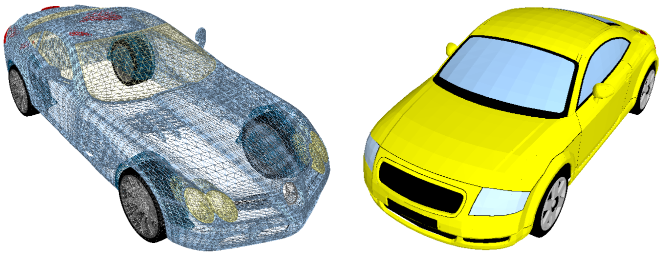

Figure 1: Vector oriented databases of vehicles: Wire frame (left) and with filled polygons (right).

The determination of interaction losses along each ray is based on the Uniform Geometrical Theory of Diffraction (UTD) for diffractions and on the Fresnel coefficients for reflections and transmissions [10]. Due to the material properties of objects used in vehicles, the consideration of diffractions is much less important than the consideration of reflections and transmissions/penetrations, (as diffractions lead to higher attenuations). Thus, propagation paths with diffractions are highly attenuated and nearly irrelevant if many reflected ray paths for one pixel are superposed.

In urban and indoor environments, the position of walls and buildings are usually rather inaccurate. Therefore the (deterministically determined) phase of the signal contributions of each propagation path is not considered for these environments, as the geometrical inaccuracies could be in the range of several wavelengths. So radio network planning tools only accumulate the power contributions (i.e. incoherent superposition) [11]. For vehicles, very accurate CAD data is available. This makes it possible to compute the individual ray path contributions with consideration of the phases. This is very important, as a large number of interactions must be taken into account due to the low reflection losses of the materials utilized in vehicles [12]. The extreme multipath propagation is shown in figure 2.

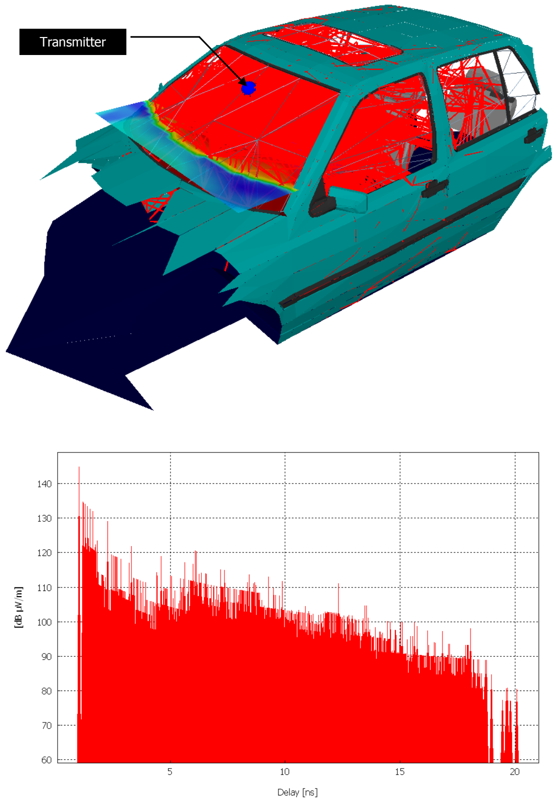

Figure 2: Propagation paths (top) and channel impulse response (bottom) for one receiver pixel.

Another point is the movement of objects inside the vehicle. Objects like the engine, the wheel suspension or parts of the steering are not stationary and move or vibrate. High frequent vibrations lead to Doppler shift of the propagation paths and must be considered in the computation.

C. Comparison of Approaches

For a comparison between two different approaches, namely the Method of Moments (MoM) and the 3D Ray Tracing (3D RT), a scenario with an engine compartment was chosen. The MoM is included in the software package FEKO [2].

In the left picture of figure 4 the database used for the computations is shown. The transmitter (40 dBm) was placed near the battery. The frequency used was 433 MHz. At this frequency the conditions for ray optical models are not completely fulfilled, so this is a worst-case scenario for the ray tracing model. Nevertheless, the results of both simulation approaches are nearly similar (fig. 3 and fig. 4). The deviations between the results can be traced back to the differences in the treatment of the material properties.

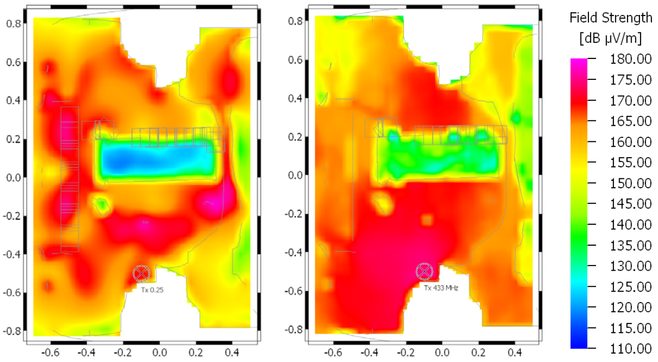

Figure 3: Comparison of prediction results of Method of Moments (left) to 3D Ray Tracing (right).

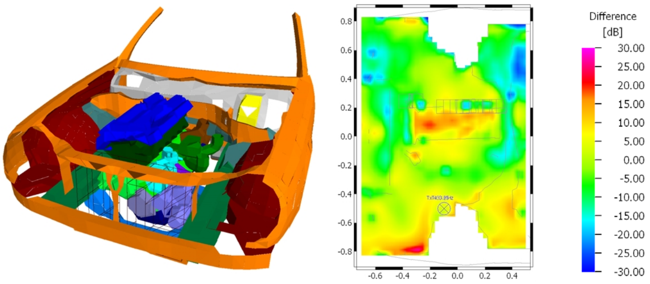

Figure 4: Database used for computation (left) and difference between prediction with Method of Moments and 3D Ray Tracing (right).

The horizontal area predicted for this comparison was about 1.3m x 1.7m. The resolution used was 3 cm. The computation time for the 3D RT is much shorter than the time needed by FEKO, using the MoM approach. Even more, the 3D RT needs less memory for the computation. See table **I** for the values. In the computation four reflections, four diffractions and four transmissions are computed.

Table I: Comparison between FEKO and the 3D RT approach (3 GHz CPU, 1.5 GB RAM)

Approach	Computation Time	Memory needed
MoM (FEKO)	some hours	about 1 GB
3D Ray Tracing	some seconds	about 100 MB

D. Example Application

Figure 5 shows an example of a prediction of a wireless communication system inside a vehicle operating at 433 MHz. The transmitter (40 dBm) is located at the mirror beneath the windshield and the prediction layer is above the dashboard. Only the relevant parts of the vehicle (no wheels, rims, lights) are used for the computation.

The database of the vehicle is preprocessed once, before the prediction. This takes several hours of time on a standard PC. The computation time of the prediction itself for arbitrary transmitter locations is below than one minute, even if two diffractions, two reflections and an arbitrary number of transmissions for each propagation path are allowed.

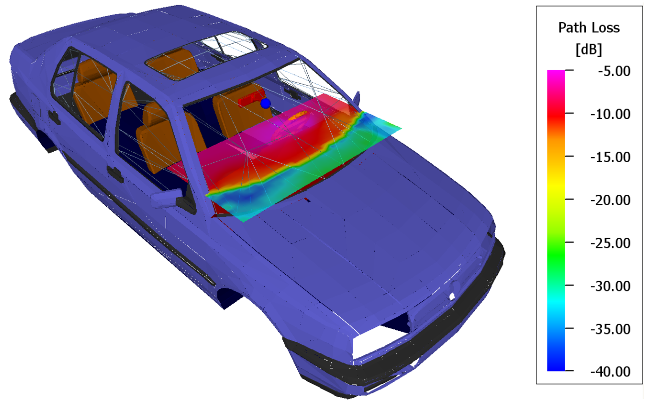

Figure 5: Prediction of path loss for an in-car communication scenario.

III. MODELING AROUND VEHICLES

A. *Time-variant Scenarios*

In real traffic situations, many objects influence the propagation of waves around vehicles. One example is shown in fig. 6, where a car-to-car communication scenario is depicted. Buildings, vegetation, guard rails and other vehicles have a significant influence on the received channel impulse response (CIR).

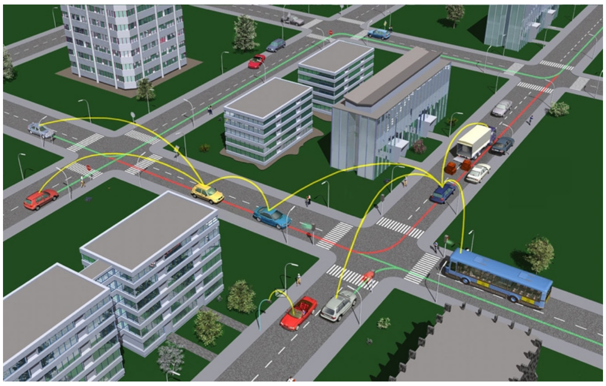

Figure 6: A car-to-car communication scenario [13].

A new software module was developed to create and edit time-variant scenarios. The basis of the databases are planar polygons, like in ordinary indoor databases. Each element in the database can be either stationary (not moving) or non-stationary (dynamic). Translation and rotation vectors, as well as a scalar value for the velocity are assigned to dynamic objects for the definition of their behavior in the scenario, depending on the time. Predictions are then accomplished for arbitrary defined timestamps.

An example for a modeling of a time-variant scenario is shown in the pictures of fig. 7. The scenario contains a highway, guardrails, buildings and several cars. For each car a route was defined. The cars are built up of very simple databases in contrast to the vehicle databases in fig. 1, as for computations around vehicles highly accurate CAD databases are not required to achieve accurate results.

For the prediction of the scenarios, a 3D Ray Tracing model was used. The algorithm supports an arbitrary number of reflections, diffractions and transmissions/penetrations for each ray path. It was adapted to the needs of dynamic scenarios, e.g. the consideration of the Doppler Shift was added.

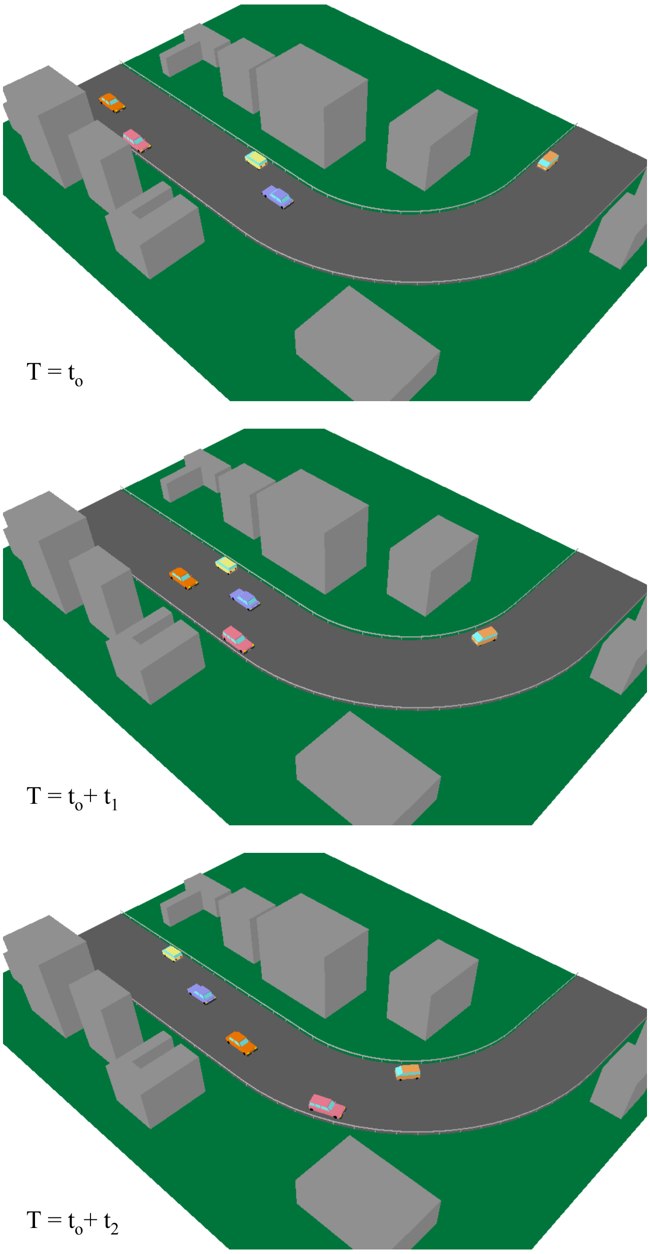

Figure 7: Example of a dynamic database with several cars for different timestamps. The time is increasing from the upper to the lower picture.

B. *Example Prediction*

Figure 8 presents a result of a car-to-car communication scenario with the most important propagation paths for one snapshot. The computation time is below one minute on a standard PC. The transmitting antenna (ideal omni antenna) is located at the mirror of a vehicle as well as the receiving antenna. For the prediction a maximum of two reflections, one diffraction and zero transmissions for one propagation path are computed. More interactions do not improve the accuracy significantly. Therefore they have been neglected. All elements in the database with their individual material properties (buildings, streets, guardrails, vehicles) are considered for the computation.

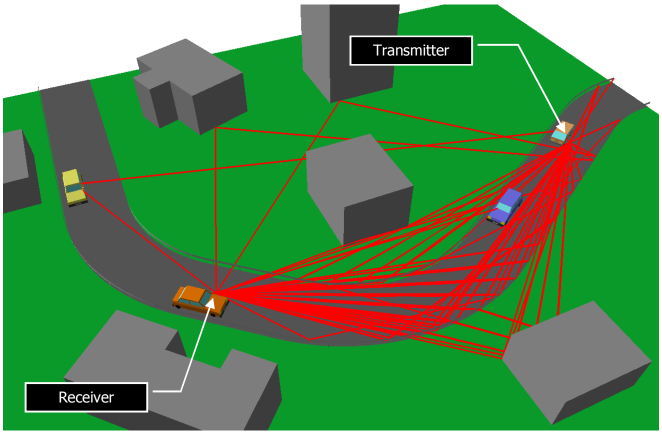

Figure 8: The most relevant propagation paths in a dynamic car-to-car-communication scenario.

C. *Using RCS for the Modeling of complex Objects*

As already mentioned above, the vector-oriented databases of the vehicles consist of a lot of polygons. Hence, the usage of ray optical models for scenarios shown in figure 6 is no longer possible, as memory restrictions exist and computation time should be limited. New methods to define complex objects (like cars) must be found.

One method is to use simpler databases of vehicles, which do not have so many polygons and are a rough approximation of the cars as described above in the previous section. Another method is to substitute complex objects with their bistatic radar cross sections (RCS). A relation between each incident and each scattered ray/angle to an object is defined, usually with attenuation and phase shift. RCS data has to be measured or computed [14].

The Ray Tracing algorithm does not consider polygons of objects defined by RCS data for reflection and diffraction. The polygons are only considered for transmission/ penetration losses in the scenario, as reflections and diffractions are defined by the RCS data assigned to an object.

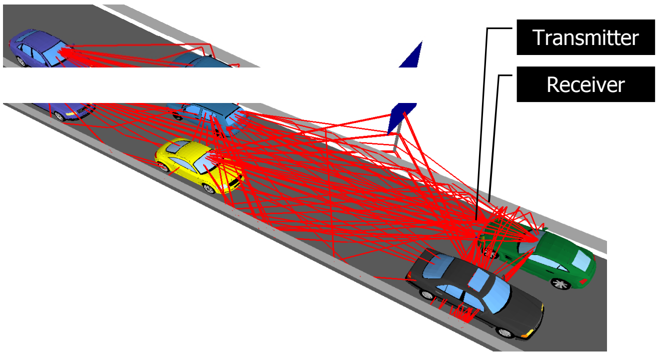

Figure 9: Propagation paths in a dynamic scenario where all vehicles are defined by RCS data.

An example for a prediction including RCS data is shown in fig. 9. As shown in the figure, all propagation rays are concentrated in the center of the vehicles, as the RCS data was defined for this point.

IV. CONCLUSIONS

In this paper the requirements for modeling the radio channel inside vehicles as well as for large time variant scenarios are described. A ray tracing approach for the propagation modeling in such scenarios is presented and a concept for the modeling of large scenarios is shown.

Until now costly measurement campaigns are needed to determine the CIR in time variant scenarios. Simulations now offer the possibility to modify a time variant scenario and re-simulate the CIR within short time intervals instead of carrying out time-consuming measurement campaigns.

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