WAVE PROPAGATION MODELLING FOR INTER-VEHICLE COMMUNICATIONS

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ABSTRACT

A new model to analyse the wave propagation between moving vehicles 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 lane and the actual modelling of the wave propagation. A realistic traffic model is used to generate time series of instantaneous positions and velocities of vehicles on a predefined road. Several specific characteristics of the vehicles and their drivers are taken into account. It is therefore possible to create complex traffic scenarios without the need of having detailed and extensive traffic data of selected roads. Additionally the environment of the road is generated stochastically, depending on morphographic data. The result is a proper traffic scenario, which serves as input data for wave propagation simulations. A ray optical approach is used to model the actual wave propagation. Thus, wideband as well as narrowband analyses are possible. Channel parameters such as delay spread, Doppler spread, coherence bandwidth, etc. can be derived.

I. INTRODUCTION

In recent years the road traffic density has been increasing drastically and it seems that this trend has not yet come to an end. The large number of vehicles on the streets leads to congestion and many accidents, which cause long delays, immense costs as well as injury and sometimes death. It is therefore a challenging task to cope with all this traffic.

A necessary step to solve the problem is the provision of user specific information i.e. any driver will be able to get just the information he needs, depending on his individual route. This includes mobility-relevant information (e.g. online information about the actual traffic conditions) as well as safety-relevant information (e.g. detailed information about the road conditions ahead). Thereby, the primary objective is to improve the traffic flow, avoid accidents and shorten journey lengths.

To get all the information to its destination, i.e. to the vehicles, a wireless communication system is necessary. Existing mobile systems like GSM (Global System for Mobile communications) or the upcoming UMTS (Universal Mobile Telecommunication System) may be used for this purpose to some extent. However, in cases of high traffic density, where hundreds of vehicles are within one cell, it is not possible for all drivers to make a connection to the base station at the same time, due to the limited capacity of the system.

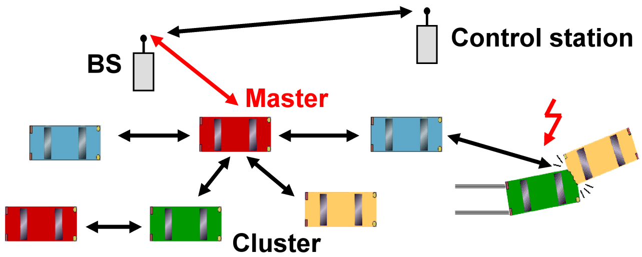


Fig. 1. Concept of inter-vehicle communications

A solution would be a more efficient use of the system's resources. This can be achieved by utilising adaptive mobile ad-hoc networks, where a randomly arranged group of vehicles, a so-called cluster, forms a secondary communication cell [1] (cf. Fig. 1). A cluster preferably consists of vehicles (drivers) with the same intentions, e.g. a similar destination. All participants within a cluster are able to communicate with each other, and each vehicle may serve as a transceiver in the system. One of the participants serves as the master or router and keeps connection to a higher level communication system such as GSM or UMTS. The master collects all information requests from the vehicles in the cluster and forwards them to the higher level communication system, which establishes a connection to some kind of traffic information database. In turn, the master receives the desired information from the database and distributes it to its destinations in the cluster.

Since only one connection to the base station is required, a substantial reduction of the transmission of control data is achieved in the system. Furthermore, the repeated transmission of the same information can be avoided. This enhances the efficiency of the system significantly, which makes it possible to use existing mobile communication systems such as GSM or UMTS for the above mentioned purposes.

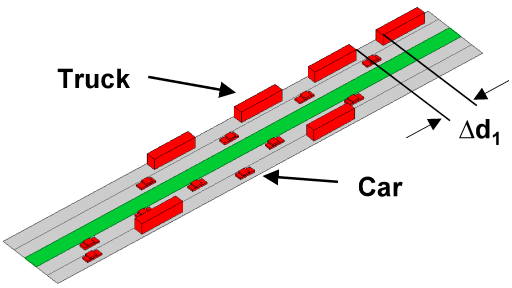
Inter-vehicle communications can also be used for the mutual exchange of status data or sensor information between vehicles [2]. For example, if an accident happens, the vehicle concerned will be able to send a distress-signal to surrounding vehicles to warn them without a delay (cf. Fig. 1). These vehicles could then be automatically slowed down in time. The same holds for vehicles approaching a traffic jam. In a similar way, sensor information such as the road condition may be detected and distributed by the vehicles.

In order to design mobile-to-mobile communication systems for vehicles and to set up proper transmission schemes, it is essential to perform narrowband as well as wideband analyses of the propagation channel, i.e. typical time series of channel impulse responses, Doppler spread, delay spread and the received power. A new wave propagation tool is therefore presented in this paper, which is able to perform these calculations.

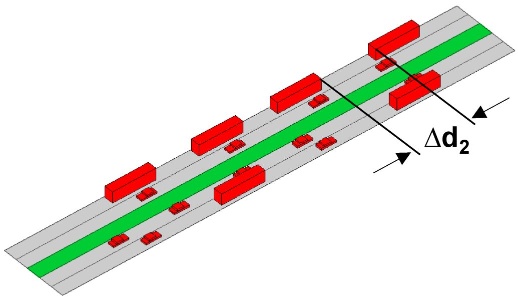
II. DYNAMIC ROAD TRAFFIC MODELLING

In order to simulate realistic road traffic behaviour, the use of a dynamic traffic model is necessary. Dynamic models are able to generate realistic time series of the simulation scenario, which is essential for a proper characterisation of the transmission channel. The so-called "Wiedemann" road traffic model is implemented [3], [4]. It takes into account the individual driving behaviour, which is influenced by several internal and external factors. Firstly, each single vehicle gets a statistically generated set of intrinsic parameters, such as acceleration and braking power, driving characteristics and motivation, reaction time and desired speed. These parameters characterise the type of the individual vehicle and its driver. Then, the vehicle interacts with external influence factors such as road condition, weather (rain, fog, snow, etc.), traffic regulations and especially other vehicles. For example, on crowded roads it might be not possible to drive at a desired speed. If overtaking of slower vehicles is not possible, the driver has to slow down and adjust his speed to that of the others.

The "Wiedemann-Model" delivers time series of instantaneous positions and velocities of individual vehicles that interact with each other and their environment. Fig. 2 shows two snapshots of a four-lane motorway with vehicles moving in both directions. Two different kinds of vehicles are chosen for this example: trucks and cars. Each truck is represented by a single large box, whereas each car is composed of two stacked boxes.



(a) Snapshot 1



(b) Snapshot 2

Fig. 2. Two snapshots of a traffic simulation

It can be seen that the relative position between the vehicles is changing within the two snapshots, which is caused by the different velocities of the vehicles. For example the distance between the upper two trucks is getting larger ($\Delta d_1 < \Delta d_2$).

As a second part of the project, a model for the vehicle's vicinity is implemented. This model is discussed in the next section.

III. MODELLING OF THE VEHICLE'S VICINITY

A detailed description of the vehicle's vicinity is essential for a proper wave propagation model. This includes the moving vehicles themselves, the lane and the environment adjacent to the lane. The movement of the vehicles is generated by the dynamic traffic model described in the previous section.

For system design purposes, statistical information about the transmission channel [5] and its time variant behaviour is necessary. In order to obtain sufficient statistics, a large number of time series of the wave propagation situation in different scenarios has to be generated. As it is very difficult, or even impossible, to get sufficiently detailed data about roads and their surroundings, a stochastic model of the environment is chosen. This includes the stochastic generation of the path that the road follows and the stochastic positioning of objects (e.g. buildings, trees, etc.) adjacent to the road. The stochastic modelling of the environment is described in the following subsections.

A. Modelling of the Road Lane

The number and width of the road lanes can be chosen arbitrarily for each direction. The street plan may be composed of straight and curved (circular) sections (cf. Fig. 3). In contrast to curved sections, straight sections can also have slopes. For wave propagation calculations the material of the street (asphalt, concrete etc.) and the layers underneath (stones, sand etc.) are important, especially for steeply impinging waves [6]. These features are therefore taken into account.

B. Modelling of the Road Surrounding

Depending on the environment, in which the scenario is located, different objects occur in the vicinity of the vehicle with a certain probability. For example, on a motorway possible objects are crash barriers, bushes, bridges, tunnels, etc., whereas in an urban or a suburban area houses and parked cars are most probable. In suburban areas single trees have to be taken into account as well. Forested regions consist of different kinds of vegetation. The occurrence of buildings is quite unlikely here.

A variety of morphographic classes are defined and implemented for different environments, e.g. urban, suburban, rural, motorway, etc. Each class includes several objects such as buildings, vegetation, parked cars, bridges, tunnels, traffic signs, trees, crash barriers, etc. Different probabilities of occurrence are assigned to each object, depending on the class. Examples for different sets of probabilities of occurrence for several objects are given in [7]. For the generation of the environment the objects are placed randomly, with respect to their probability of occurrence, adjacent to the lane. Furthermore, the relative position to the lane and the size of certain objects (e.g., buildings, trees, etc.) are set randomly within certain limits.

Fig. 3 shows the result of a stochastically generated suburban environment. The road consists of one lane in each direction. It is composed of two curved and three straight sections. The straight sections have different gradients. Next to the lane, buildings, parked cars and single trees are positioned randomly according to their morphographic class. The buildings are modelled as single boxes, whereas the cars are composed of two stacked boxes of different size. The trees are described by a cylindrical trunk and a sphere, which models the tree-top. The moving vehicles are modelled as indicated in Fig. 2.

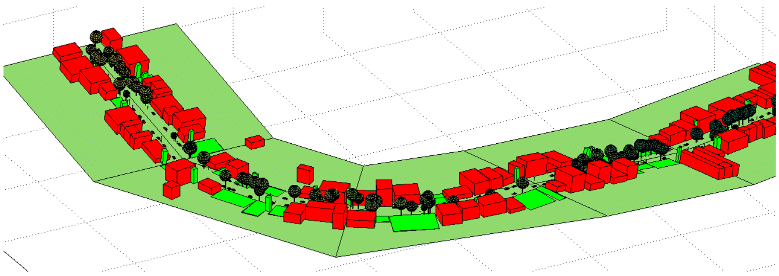


Fig. 3. Stochastically generated view of a road in a suburban environment

The generated scenarios together with the moving vehicles serve as input data for the wave propagation simulation, which is described in the next section.

IV. MODELLING OF THE WAVE PROPAGATION

Since narrowband as well as wideband analyses are required for an accurate characterisation of the inter-vehicular transmission channel, ray-optical methods are used for the wave propagation modelling [6]. The main problem

with ray optics is the determination of the different propagation paths. A common method for the path search is the image theory [8], which is implemented in the simulation tool. For the initial calculations, only single and multiple reflections are taken into account. This is applicable at higher frequencies, where diffraction effects can be neglected. As far as scattering at rough surfaces is concerned, the concept of modified Fresnel reflection coefficients is applied [6], [9]. At present, scattering caused by trees and other vegetation is not included.
Fig. 4 shows the result of the path search for a snapshot of an urban road traffic scenario. The environment is composed of a four lane road, buildings of different size, parked cars and moving vehicles. Receiver and transmitter are both positioned on vehicles. Reflections up to the fourth order are taken into account. The black lines in the graph indicate the different propagation paths. Since there are a lot of buildings next to the road, the expected street canyon effect arises.

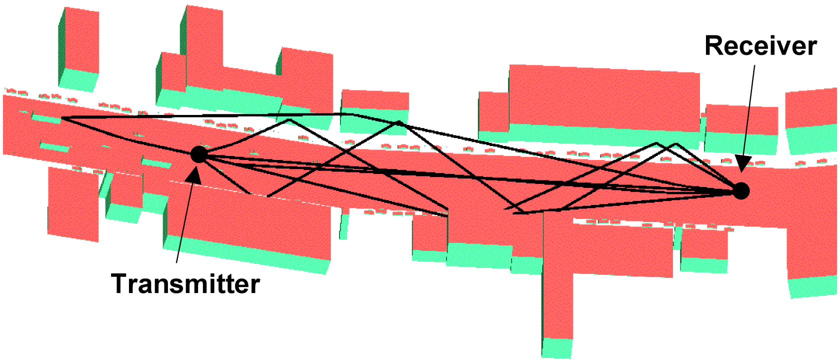


Fig. 4. Reflection paths up to the fourth order

The transfer function of the according propagation channel is completely defined by the propagation paths. Various channel parameters, such as received power, delay spread, Doppler spread, angular spread, etc. can be derived [5] . The dynamic character of the model allows to generate realistic time series of the inter-vehicle channel transfer function, which is the basis for a statistical characterisation of the channel. Probability density functions for the different channel parameters can be derived.

V. Conclusion

In a new inter-vehicle wave propagation tool, the "Wiedemann-Model" is used to generate realistic traffic scenarios including all relevant factors for individual driving behaviour. The superposition of all these individual driving actions (braking, accelerating, overtaking) yields typical dynamic variations of traffic density and therefore provides a realistic model of road traffic. Additionally the moving vehicles (cars and trucks) are embedded in different scenarios such as cities, forests, motorways, etc. A complete description of the propagation environment is therefore obtained with this tool. The wave propagation model itself is based on ray-optical methods. Thus, wideband as well as narrowband analyses are possible. Furthermore, the dynamic character of the model enables it to generate time series of simulations. Parameters such as delay spread, average fade duration or level crossing rate can then be derived.

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