# Ray-Tracing in a Virtual Drive for Mobile Communications

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***Abstract*— The availability of mobile communications from and to vehicles is becoming a major criterion for the market success of future cars. Presently the required antenna installations are tested by road driving, a time and money consuming adventure. This paper proposes a *Virtual Drive*, by which not only the test but also an optimization of the car-integrated antenna systems can be performed. This is achieved by electromagnetically modeling the complete scene, i.e. driving the electromagnetically modeled antennas on the car through a coverage predicted by Ray-tracing. The obtained results are the complex output voltages at the different antennas, which allow for evaluating the antenna system suitability for communications applications with Diversity and MIMO techniques.**

## I. Introduction

Mobile automotive communications, including broadcast, is one of the fastest growing areas in communications. Mobile phone, Wireless LAN, data transfer, radio, TV, in the future mobile to mobile (C2C, C2X …), and many other candidates require the installation of numerous antennas on vehicles. To overcome the typical fading of the received signal at moving receivers, most services require multiple antennas for Diversity or MIMO operation, which multiplies the number of antennas by a factor of 2 to 4. This runs the number of antennas on a car easily up to 12 to 15. The design, placement and test of these antennas require enormous efforts in manpower, time and cost. The solution to overcome this is *Virtual Drive*. Presently antennas and antenna systems are integrated in vehicles and then the systems are tested in different environments like urban, rural, free-way, and so on. This procedure is quite time and cost intensive, as it requires that the vehicles are ready to drive and furthermore the tests have to be carried out in different environments. In case of a negative result the procedure has to be started again. In the *Virtual Drive* the test of the communications antenna system can be performed by the computer as soon as the body of the vehicle and its material composition are known. The idea is very simple and intends to model the system electromagnetically. This procedure has the following steps:

- model the complex, vehicle integrated antennas
- model the environment where to drive the vehicle
- model the vectorial coverage (wavefront distribution) from the communication transmitter
- let the vehicle virtually drive through the covered area and sample the received complex voltages of all antennas

## II. Modeling Approach

The modeling of the vehicle-integrated antennas requires the knowledge of the vehicle structure and material composition. The antennas have to be integrated in their intended positions. The calculation of the complex antenna characteristic may be performed by standard EM tools or better by hybrid tools, because of the vehicle size. These hybrid tools combine the Method of Moments e.g. with Ray-tracing [1].

The computed antenna characteristic (see Fig. 1) has to be 3D, complex and polarimetric. This is required because the waves from the transmitter may arrive after line of sight propagation, reflections, scattering and diffractions from the whole upper hemisphere with arbitrary polarizations. The phase information is required for the later evaluation in diversity or MIMO systems.

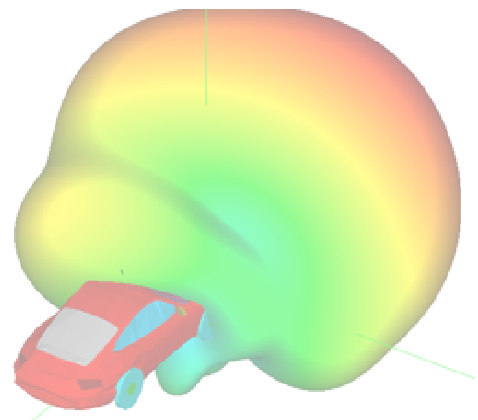

Fig. 1 Example of a car integrated 3D antenna characteristic

In the next step the wavefront distribution at the receiving antenna has to be calculated. The ideal tool for this purpose is a propagation simulator based on Ray-Tracing [2]. The environment for the *Virtual Drive* has to include all relevant objects in the corresponding area, e.g. urban, suburban, rural, free-way, hilly areas, snow areas:

- road surface, road vicinity
- moving vehicles
- trees, buildings, bridges

The whole modeling has to be prepared with respect to the intended Ray-tracing simulation for the determination of the coverage. Special care has to be taken in modeling the vehicles and roadside metallic objects like traffic signs and so on. For roads with trees on the sides these trees are advantageously modeled as volume scatterers [3]. For the vehicles on the road four types showed to be sufficient: medium size cars, small trucks, trucks and buses [4]. A further detailing improves the results. Fig. 2 shows a typical traffic scene.

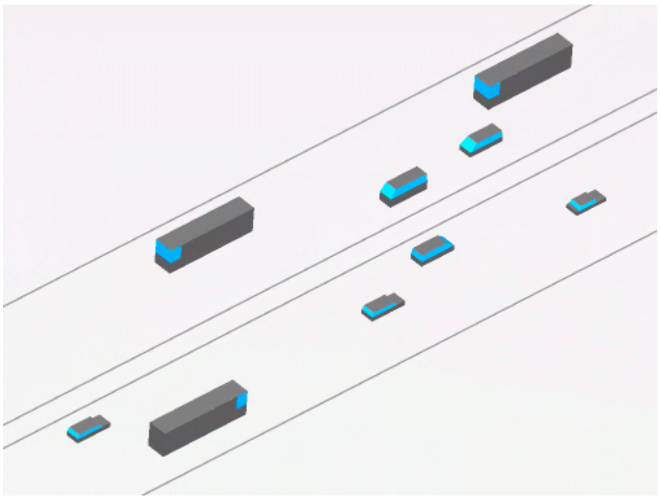

Fig. 2 Typical modelled traffic scene

The coverage prediction for the environment has to be complex and polarimetric, including the direction of wave propagation, i.e. the complete wavefront distribution at the position of the receiving antenna has to be recovered. For this purpose Ray-tracing is best suited. It renders the direction of the propagation and the field-strength with amplitude and phase for all signal components. As the calculation of the coverage prediction cannot be arbitrarily dense it has to be decided where and how the reference points are placed. Two cases offer a reasonable computational load:

- calculation in a regular grid, with grid point spacing from 5 λ to 10 λ, λ being the communication signal wavelength.
- calculation in the middle of the road, again with grid point spacing from 5 λ to 10 λ

While the first procedure is recommended for urban areas, the second one is more suitable for rural communications. A typical coverage prediction for 3G communications is shown in Fig. 3.

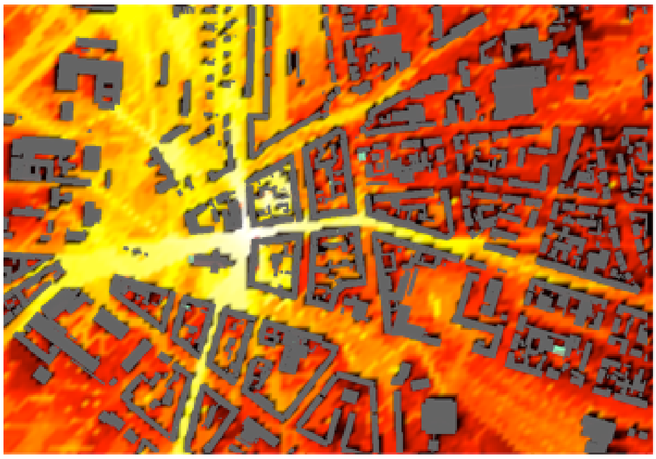

Fig. 3 Typical coverage prediction for 3G communications

If all information regarding the coverage and the car antenna system is available, the vehicle is driven virtually over the road in the Ray-tracer [5], see Fig. 4 for a car to car communication scenario.

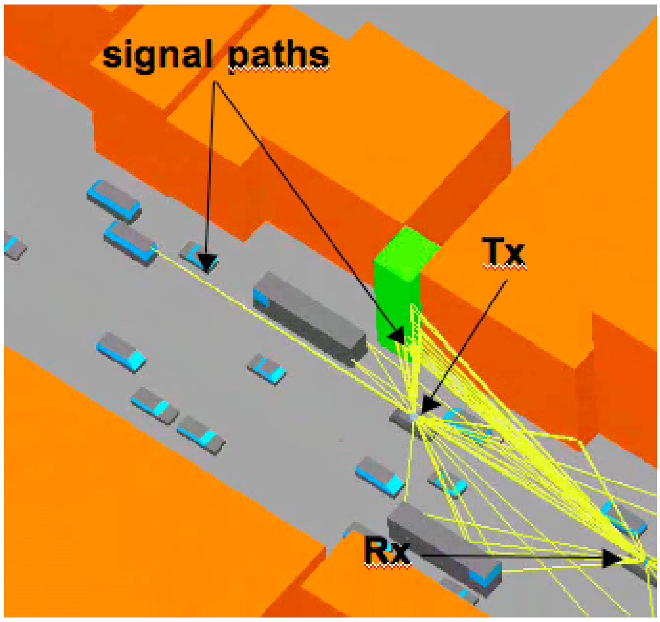


Fig. 4 Ray-tracing in a virtual scenario, here C2C communications

In Fig. 5 the propagation paths determined by the Ray-tracer are shown for a mobile communication to a fixed base station.

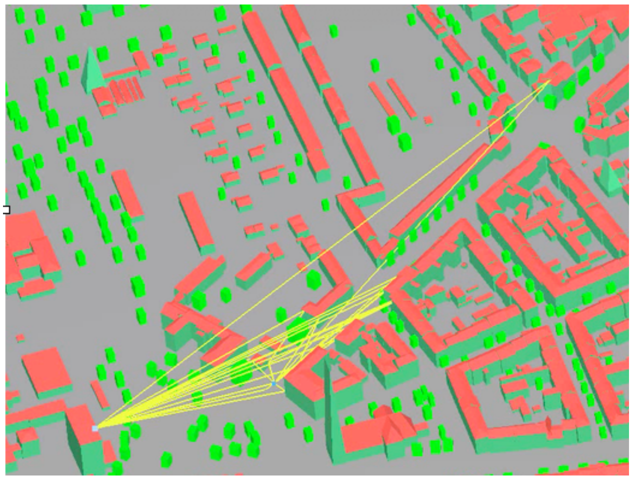

Fig. 5 Ray-tracing in a virtual scenario, here C2 base station

As usually the reference points do not match the different antenna positions, the rays, carrying plane waves, are extrapolated to the antenna positions. This has to be done in a vectorial computation for all rays. The spacing between the reference points should again be between 5 λ and 10 λ. The extrapolation is shown in Fig. 6 for one wave, which is extrapolated from the reference point to one antenna.

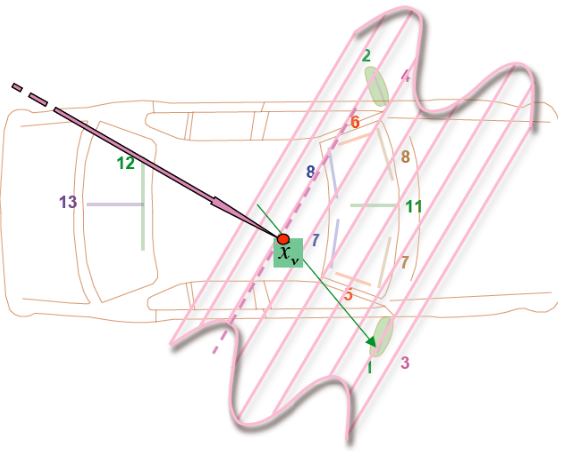


Fig. 6 Extrapolation of a wave from a reference point to one antenna

This makes the complex antenna signals available during the *Virtual Drive*. At each position the channel impulse response $h$ is determined for each path:

$$h^{LP}\left(\Omega_{Tx},\Omega_{Rx},\tau,t\right)= \sum_{n=1}^{N(t)} A_n(t) e^{-j2\pi f_c \tau_n(t)} \delta\left(\tau-\tau_n(t)\right)\delta\left(\Omega_{Tx}-\Omega_{Tx,n}(t)\right)\delta\left(\Omega_{Rx}-\Omega_{Rx,n}(t)\right) \quad (1)$$

It results for each antenna the information of

- amplitude $A_n$
- phase $\varphi_n$
- delay time $\tau_n$
- Doppler shift $f_{Dn}$
- direction of departure $\Omega_{Tx}$
- direction of arrival $\Omega_{Rx}$

Thus they can be compared for optimal antenna positions or be applied for Diversity or MIMO processing. For the upcoming MIMO systems the correlation of the received signals is a major factor of interest. This correlation can be easily determined from the virtual drive [6].

## III. Conclusion

This whole procedure allows the test and optimization of communication antennas before the vehicle is finally built. It saves time and improves the results. It has to be noted that the virtual drive, like a real drive, is for a specific environment. It requires a minimum length in order to render statistically relevant data. As the coverage data can be used for multiple types of cars and antenna arrangements, it is recommended to perform the complex, polarimetric coverage prediction at the reference points for a number of uncorrelated scenarios like urban, rural, free-way and for different weather conditions, like summer and winter scenes. In total this may result in ten to twelve scenarios to be computed.

The major obstacles to overcome are:

- modeling of the car integrated antennas
- modeling the mobile environment
- determining all signals received by each antenna

Ray-tracing is an absolutely necessary tool for this procedure. It is recommended to model more antennas integrated in the car than will be realized later in order to be able to determine the optimum combination of the antennas with respect to

- signal strength
- correlation
- interference

For mobile communications this should be the tool to provide the expected data rates and bit error rates required in the future.

## References

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