Short Paper:
Vehicle Shadowing Distribution Depends on Vehicle Type: Results of an Experimental Study

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***Abstract*—Simulations play a fundamental role for the evaluation of vehicular network communication strategies and applications' effectiveness. Therefore, the vehicular networking community is continuously seeking more realistic channel and reception models to provide more reliable results, yet maintaining scalability in terms of computational effort. We investigate the effects of vehicle shadowing on IEEE 802.11p based communication. In particular, we perform a set of real world measurements on a freeway and study the impact of different obstructing vehicles on the received signal power distribution. Different vehicle types not only affect the average received power, but also its distribution, suggesting that the attenuation characteristics of the simulation model need to be tailored to the type of vehicle that obstructs the communication path. Based on these observations, we propose a novel way to compose shadowing and fading models to reproduce the observed effects.**

I. INTRODUCTION

Research in Inter-Vehicular Communication (IVC) involves all layers, from the application down to the physical layer, as the entire network stack had to be designed to properly support vehicular networking applications [1], [2]. This led to the emergence of new protocols including the DSRC/WAVE protocol stack, built on the IEEE 802.11p standard [3].

Simulations are the primary tool for performance evaluation in IVC, and there is a continuous effort to make them more realistic and efficient [4]. In order to achieve this goal, network phenomena such as topology dynamics and physical layer effects have to be modeled. The key question regarding channel modeling is: Which physical effects have a major impact on signal propagation and, therefore, have to be considered in simulations?

The faithful reproduction of such effects is indeed crucial to obtain realistic simulation results. Despite the fact that the vehicular networking community is actively working on this since a decade, the community is still investigating diverse possibilities to model the complexity of real world phenomena. Several models for representing effects of shadowing and multipath fading have been proposed and are employed in modern IVC simulators [5]–[7] and the community continues to strive to obtain more precise, but still computationally feasible models to be employed in simulation [8], [9]. The goal of this paper is to understand, based on experimental evidence, the effects of shadowing in Non Line of Sight (NLOS) scenarios due to different vehicle types obstructing the line of sight for two vehicles driving on a freeway.

One application where this study is of particular interest is platooning [10], [11]. In platooning, IVC complements local sensors such as radar in order to control a large number of vehicles that make up a *road train*. For the simulation and the evaluation of such a system from a networking perspective, the channel model between specific car pairs is fundamental to obtain valid results, and this requires understanding how different interfering vehicles affect this channel.

Other examples include intersection warning systems, emergency electronic brake lights, coordination and management of virtual traffic lights, or green light speed advisory systems. Shadowing can seriously harm these applications, especially when big trucks obstruct the Line of Sight (LOS).

To gain more insights on shadowing phenomena, we performed a measurement campaign on a freeway in Tyrol, Austria, where different types of vehicles obstructed the line of sight between two cars. The results discussed in this paper clearly show how different obstacles affect the received signal power distribution; in particular, we show that not only the average power is affected by the type of vehicle, but also its distribution and variance. Our results pave the way towards a new generation of more fine-grained shadowing models that are especially important if microscopic behavior of safety applications is to be investigated.

II. RELATED WORK

In vehicular networks, the channel model must encompass path-loss, shadowing, and fading, combining together all the effects they were designed to reproduce [12].

Path loss models compute the average attenuation a signal is subject to due to propagation distance. The most simple – and still the one most widely used in vehicular network simulations – is the *Free space model* [13], but recently more sophisticated versions taking into account the contribution of the ground reflected ray have been investigated and implemented into simulators [13], [14].

Shadowing models reproduce the additional attenuation induced by obstacles, such as buildings or vehicles. This can be modeled either stochastically, in particular with a log-normal distribution [12], or geometrically [5]–[7], taking into account the objects that the direct ray has to traverse. The latter approach requires at least a rough geometric description of the scenario, but modern simulators include means of specifying geometries, or are capable of importing real world maps [15].

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Figure 1. Measurement scenario showing the two cars employed. In the picture, one car drives before and one drives after a truck obstructing their Line of Sight (LOS).

Fading models capture the fluctuations of the received signal power caused by multi-path effects. Like for shadowing, this effect can be reproduced either geometrically by means of ray tracing [16], [17], or stochastically. As ray tracing models are in general either too coarse grained or too computationally expensive, stochastic models are usually preferred in vehicular simulations. Examples are Rician, Rayleigh, and Nakagami fading [12]. The choice of one of these models (and related parameters) depends on the simulated environment (freeway, highway, urban, rural, etc…).

A stochastic model which takes into account both shadowing and fading effects is the Suzuki distribution [18]. It combines log-normal and Rayleigh distributions. Being completely stochastic, it is clearly not able to exploit geometric representations of the scenarios provided by modern simulators.

A step towards a more realistic model has been done in [19], where the authors model three kind of communication links, namely LOS, where two-ray ground path-loss is applied, NLOS due to buildings, and NLOS due to vehicles. The model exploits the geometric knowledge of the environment within the simulator, and adds stochastic components to account for fading. Yet, no different vehicle types have been considered.

In this paper, we investigate the impact of shadowing and fading in an experimental setup. Our main objective is to validate and to improve available signal propagation models being used for IVC simulations that have to cover shadowing caused by other vehicles in addition to fading effects.

III. MEASUREMENT SETUP

The measurement setup is the A12 freeway west of the city of Innsbruck, Austria, with the two cars depicted in Figures 1 and 2. While driving, we continuously sent data frames back and forth between the two vehicles at different distances, while logging information such as signal power and GPS position. A sketch of the measurement scenario is shown in Figure 3.

We made experiments having either perfect LOS conditions or NLOS conditions with obstacles of different type in between, in particular a car, a van, and a truck. The obstructing vehicle was driven by one of the authors (car, van), or we relied on volunteers such as helpful truck drivers.

We were also interested in considering different distances between the two cars. As minimum distance we chose 80 m as it is quite close, but still permits a truck to drive in between while maintaining a safe distance. We then tried to perform the same experiments at distances of 120 m, 160 m, and 200 m.

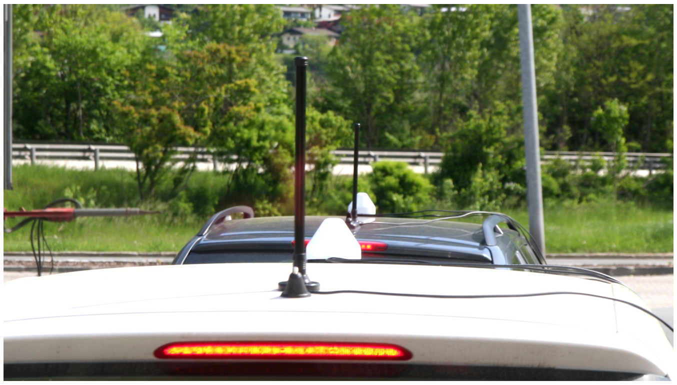


Figure 2. Placement of radio antenna (black) and GPS antenna (white) on the rooftops.

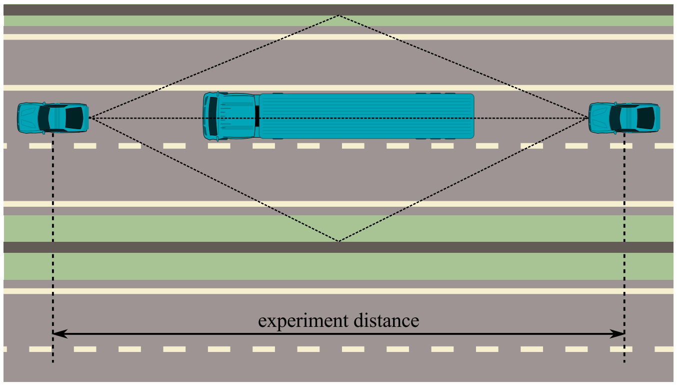


Figure 3. Sketch of the scenario with a truck as obstacle.

The majority of these tests had to be aborted for two reasons. With high distances, the first problem comes from the fact that on a public freeway it is impossible to prevent other vehicles to interfere with the experiment. The second is due to the topology of the road that is never really straight, so as soon as it slightly bends, the vehicles get in LOS. This was clearly a problem, as the aim of the analysis was to study LOS and NLOS condition separately. Due to this, we had to limit experiments to 80 m and 120 m, with the exception of the obstruction by a car with 120 m of distance, which had been made impossible because of other vehicles interfering.

To perform the measurements we employed two Cohda MK2 devices, which are fully IEEE 802.11p compliant. We disabled the diversity combining feature and configured them to decode the frame using the signal of a single antenna. Prototype antennas for vehicular communications have been developed but it is still unclear which type will be adopted, since antenna characteristics, as well as vehicle roofs, considerably affect communication performance [20]. Due to this, we decided to use omni-directional high-gain antennas in order to get rid of these effects as much as possible. We employed Mobile Mark ECOM9-5500 dipole antennas with 9 dBi of gain. As GPS antennas we employed two Mobile Mark MGW-303. We placed them in the rear part of the rooftop, in the middle of the car. The positioning of the antennas on the rooftop of the

Parameter	Value
Beacon frequency	20 Hz (single direction, 40 Hz bidirectional)
Center frequency	5.89 GHz
Bandwidth	10 MHz
Modulation	BPSK R = ½ (3 Mbit/s)
Transmission power	20 dBm
Driving speed	≃ 90 km/h

Table I
EXPERIMENT PARAMETERS.

cars is shown in Figure 2.

Table I summarizes the parameters used during the experiments. To maximize the probability of frame reception and gather as many samples as possible, we employed 20 dBm transmission power and BPSK R=½ modulation and coding scheme. For each measurement, we collected 5000 samples per car (so 10 000 in total) and took note of events interfering with the experiments to be able to filter data during the analysis.

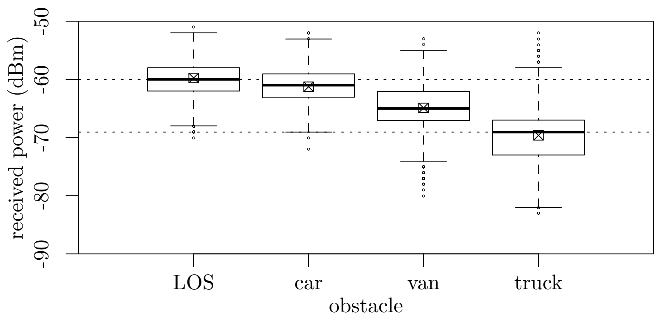
Prior to performing the experiments, we tested the two IEEE 802.11p in a controlled environment in order to calibrate reported power value. In particular, we connected via cable the two devices to a Unex DCMA-86P2 transceiver, sending messages in both directions and recording received signal strength. We found out that the two devices report received signal powers with slightly different offsets for which we compensate during data pre-processing.

IV. RESULTS AND DISCUSSION

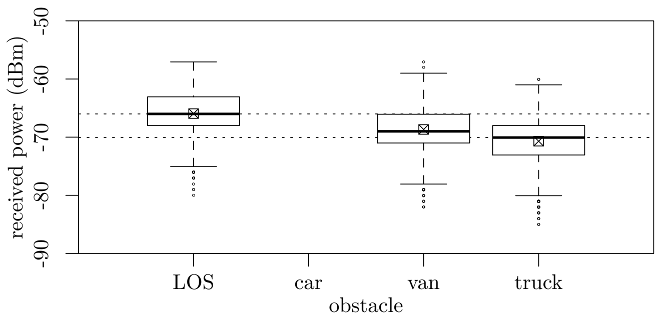
In order to evaluate the measurement results we post-processed the data to remove obviously incorrect values, for example when a vehicle was interfering with the measurements, or when the actual distance between the two vehicles was deviating too much from the experiment distance. We kept the data where the actual GPS distance (which should be accurate to within 2.5 m with 90 % accuracy [21]) was within ±5 % of the experiment distance. The average distance for any experiment was then found to be within ±2.5 % and ±0.8 % of the target 80 m and 120 m, respectively. In NLOS experiments we also removed points collected while being in temporary LOS due to road topology in order to isolate the effects.

We start the analysis by focusing on average received power. Figure 4 shows the box plots of received power for each type of obstacle, for 80 m and 120 m experiments. For each data set, a box is drawn from the 25 % to the 75 % quantile; the thick line is the median. Additional whiskers extend from the edges of the box towards the minimum and maximum of the data set, but no further than 1.5 times the interquartile range. Data points outside the range of whiskers are drawn separately. Additionally, the mean value is depicted as a small square.

For the experiment at 80 m (Figure 4a) the effect of different LOS/NLOS conditions was as expected and can be seen by looking at the average received power. In particular, the difference between LOS and NLOS caused by a truck is as high as 10 dB. In the 120 m scenario (Figure 4b), the difference is less pronounced. The difference between LOS and the truck measurements is in the order of 5 dB. This is in line with the results shown in [22], where the impact of different obstructions decreases as the distance between sender and receiver increases. Note that the experiment with the car is missing: it was not possible to drive at this distance on a public freeway without other cars changing into the carefully maintained gap.



(a) 80 m



(b) 120 m

Figure 4. Boxplots of received power for Line of Sight (LOS) and for different obstacles between sender and receiver.

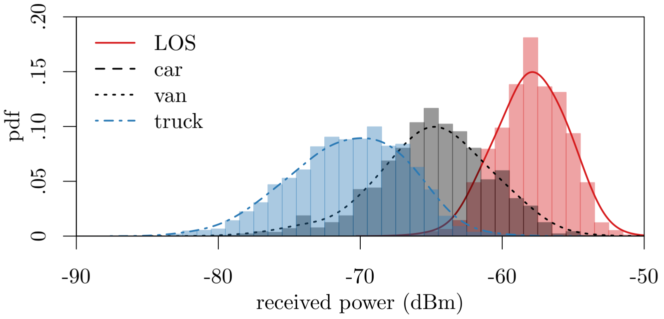
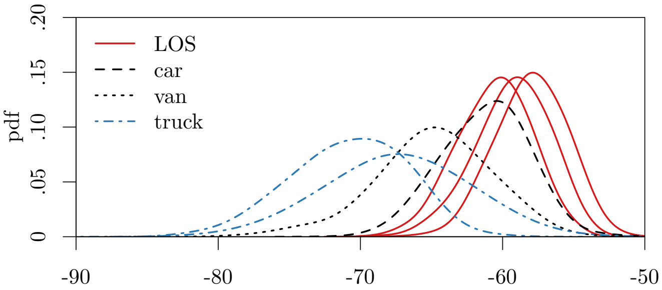


Figure 5. Histogram of received power for a subset of the 80 m experiments with overlaid estimated probability density function.

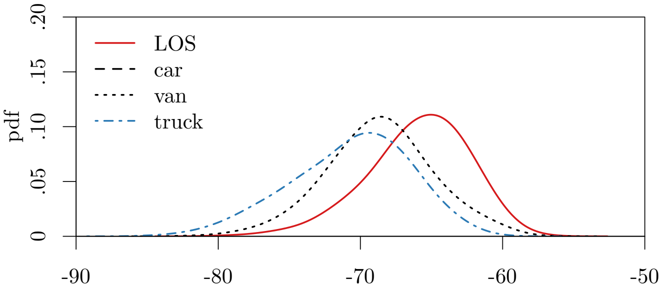
As clearly depicted in Figure 4, however, not only the average value must be considered, as the received power spans over a particular range. We therefore investigate the individual distributions of received power per experiment and compare them by means of kernel density estimates using a Gaussian smoothing kernel, as illustrated in Figure 5.

Figure 6 shows the resulting estimated probability density functions for the received power, for 80 m and 120 m. Here repetitions of the same experiment have been analyzed separately. For the 80 m experiment (Figure 6a) it can be seen that not only the average received power is affected by different obstacle types, but also its distribution. In particular, the "bigger" the obstacle, the higher the variance. This suggests that different received power distribution parameters should be employed in simulations when different types of vehicles obstruct the LOS.

This phenomenon becomes less pronounced for 120 m but this might be an artifact of the experiment. Increasing the



(a) 80 m



(b) 120 m

Figure 6. Probability density functions of the received power.

distance clearly reduces received power, and for the truck NLOS experiments this value gets as low as -85 dBm. This is close to the limit for correctly decoding packets, but still well above the specified sensitivity level of the Cohda MK2 devices used.

Existing vehicle shadowing models can be extended to reproduce the analyzed effects. For instance, the model described in [22] takes into account the height of the vehicles obstructing the LOS to compute the additional attenuation induced by the obstacle. The same information could be used to decide the distribution (and relative parameters) to be used in order to extract a randomized attenuation value.

V. CONCLUSION AND FUTURE WORK

This work reports results from a measurement campaign on a freeway performed to gain better insights on the effects of different vehicles on shadowing, by analyzing the received power distribution. We show that not only the average power is affected by the type of vehicle, but also its distribution, opening up the way for the development of more realistic channel models for Inter-Vehicular Communication (IVC) simulations. Further measurements should, however, be performed before a model can be derived. In particular, it is important to consider more fine-grained distances to understand the relationship with power distribution. Moreover, the impact of multiple vehicles between sender and receiver should also be assessed. Even if a more focused and in-depth analysis still needs to be performed, we think that this work paves the way towards more realistic channel models for vehicular simulations.

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