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Shadowing or Multi-Path Fading: Which Dominates in Inter-Vehicle Communication?

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***Abstract*—We aim to resolve a long standing dispute in the vehicular networking community when it comes to modeling the physical layer most accurately. Essentially, two major groups have formed: one believes that shadowing is the most important source of signal attenuation (and fading can essentially be ignored); the other argues that the exact opposite is true. So, depending on the simulation study, either accurate shadowing models have been used – or the focus was on multi-path fading. Thus, we conducted specific measurements in the field, collecting extensive experimental data, to explore the dominance of one or the other aspect and resolve this dispute. Our aim was to define a set of models to be used in simulation that most realistically represents the signal attenuation in Inter-Vehicular Communication (IVC), while also preventing unnecessary complexity (and, thus, unnecessarily long simulation times). In brief, we can show that neither of the two effects is dominant over the other, and that both affect the received signal power considerably. As the most interesting result, we show that the distribution of the received signal power due to multi-path fading even depends on the amount of shadowing.**

***Index Terms*—inter-vehicle communication, shadowing, fading, DSRC/WAVE, IEEE 802.11p**

I. Introduction

Research in vehicular networking encompasses all layers, from application down to physical, as the entire network stack had to be redesigned to properly support vehicular networking applications [1]. This led to the emergence of completely new protocols including the DSRC/WAVE protocol stack, built on the IEEE 802.11p protocol [2].

As simulation is still the primary tool for performance evaluation of new research techniques and algorithms in this field, the area of simulation and modeling has likewise seen many new developments to make simulation results more realistic [3]. In order to model networking phenomena such as topology dynamics, nowadays simulation in vehicular networks encompasses road traffic and network simulation [4]. Research on channel modeling is aiming to even more accurately capture the effects the environment causes on signal propagation.

The faithful reproduction of such effects is indeed crucial for obtaining realistic simulation results. Despite the fact that the vehicular networking community is actively working on this since a decade, a final answer has still to be provided because of the complexity of phenomena caused by real world environment.

Several models for resembling effects of shadowing and multi-path fading are employed in modern IVC simulators [5]–[8]. Nowadays, however, the community is still working to obtain more precise and computationally feasible models to be employed in simulation.

Thus, the aim of this paper is to understand, based on experimental evidence, the combined effects of shadowing due to vehicles obstructing the line of sight and multi-path fading, for two vehicles driving on a freeway. Essentially, we want to resolve the long lasting dispute in the community, whether shadowing or fading has more impact on signal attenuation in IVC scenarios.

One advantage would be to disable either fading or shadowing models during simulation to gain speed without losing precision when the effects of one are dominant with respect to the effects of the other. Our working hypothesis was that shadowing is dominating, yet, we will show that results from our measurement campaign tell that this is not entirely true.

Our main contributions can be summarized as follows:

- We present results of an extensive measurement campaign on a freeway in Tyrol, Austria, where different types of vehicles obstructed the line of sight between two cars.
- We show that none of the two effects is dominant over the other, and that both affect the received signal power considerably.
- We also show, as a very interesting result, an interdependency: The distribution of the received signal power due to multi-path fading depends on the amount of shadowing.

II. Related Work

The main effect of radio propagation is the attenuation in power due to the distance. The most well-known model employed to reproduce this effect is the *Free space model* [9], which computes the attenuation experienced by a single, unobstructed ray, depending on distance and wavelength. This model is clearly too simplistic to reproduce the effects which are typical of a vehicular environment. As shown

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).

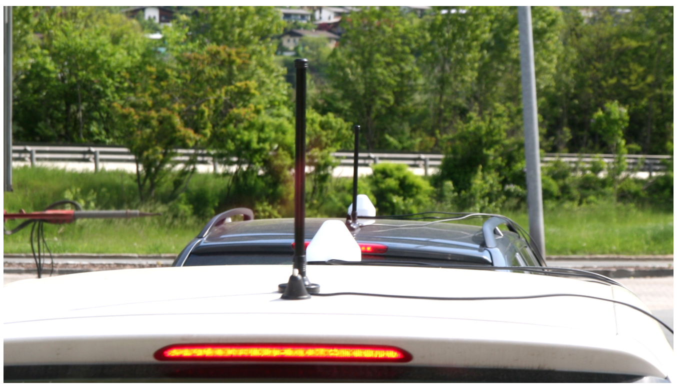


Figure 2. Placement of radio antenna (black) and GPS antenna (white) on the rooftops.

in [10], [11], the *Two-Ray interference model* captures the non-marginal effect that the radio signal is also being reflected by the ground. This second Non Line of Sight (NLOS) ray either amplifies or attenuates the total signal power by adding up constructively or destructively with the direct Line of Sight (LOS) ray.

Other effects include shadowing caused by obstacles, either fixed ones (such as buildings), or moving ones (like other vehicles). It has been shown that shadowing by vehicles can be captured by a multiple knife edge diffraction model [12] and that vehicular networking protocols do well to address the high topology dynamics this can cause in freeway and urban scenarios [13]. Regarding buildings, several papers analyze the effects and try to model the attenuation a ray is subjected to when traveling through one or more walls [5]–[8]. The models work by either considering the number of intersections/corners that are in between the direct communication line of two vehicles [6], by considering a simplified representation of an intersection [8], or by using information about real building shapes taken from online maps such as *Open Street Map*[1] [7].

In environments that are typical for vehicular networks, also multi-path fading plays a major role. The signal emitted by a transmitter's antenna gets to each receiver by traveling multiple paths, via reflections by one or several surfaces (e.g., buildings, the ground, or other vehicles). Similar to considerations of a ground reflection in the Two-Ray interference model, the components might sum up constructively or destructively.

[1]http://www.openstreetmap.org/

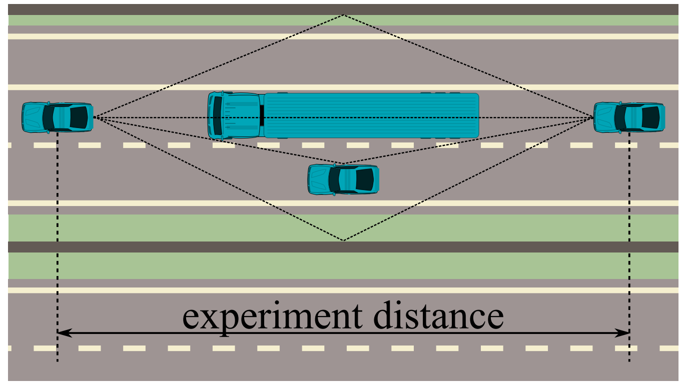


Figure 3. Sketch of the scenario with a truck as obstacle.

To model such effects, two methods can be found in the literature. The first is ray tracing where, by geometrically computing all the paths traveled by the electromagnetic wave, it is possible to estimate the power of the signal at the receiver. Such a method clearly requires a detailed geometrical description of the simulation environment, as well as a huge amount of computational power, but it is very accurate. Some examples of these models can be found in [14]–[18].

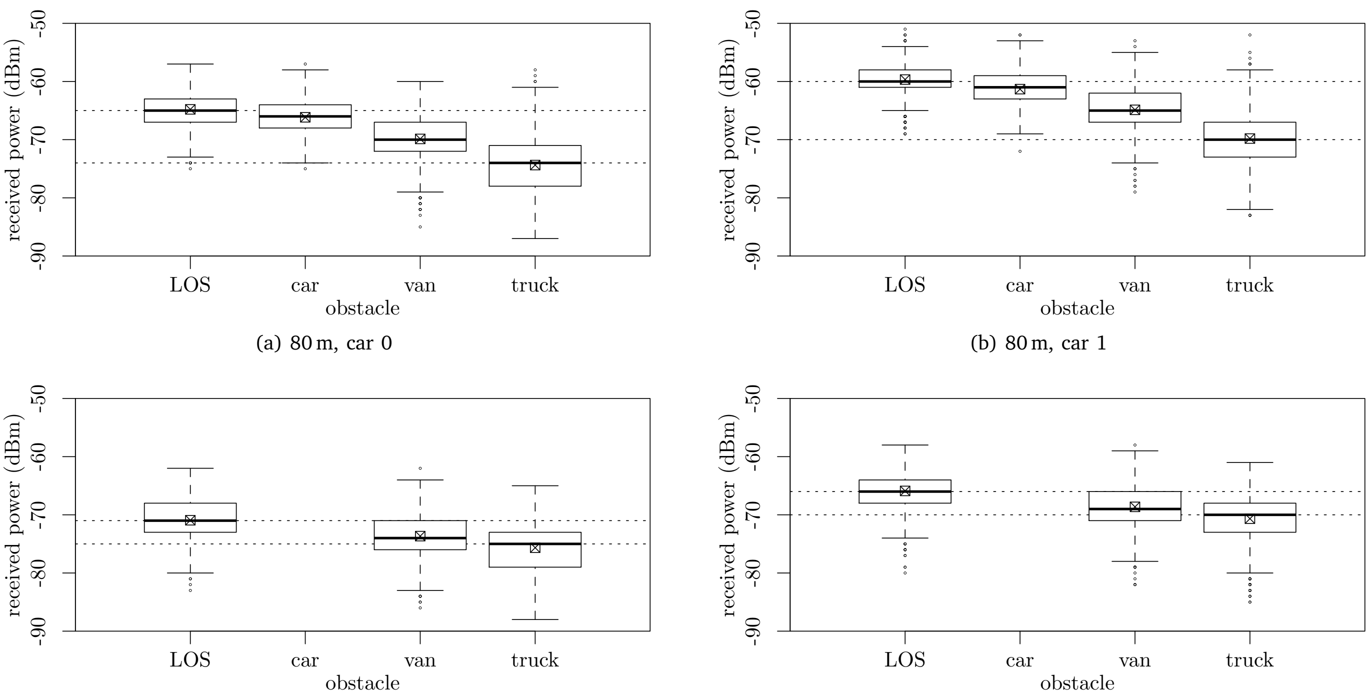
The second method employs statistical distributions. After computing the attenuation due to path loss and shadowing, a random value (either positive or negative) is added in order to account for multi-path fading effects. These distributions include the Rayleigh distribution [19] (employed when no LOS exists), the Rice distribution [19] (employed when there is a strong contribution of the LOS ray), and the Nakagami m-distribution [20], a more general model which can be tuned by adjusting the m parameter to reproduce different fading intensities [21].

III. Measurement Setup

During our freeway scenario measurements we drove on 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.

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



(a) 80 m, car 0

(b) 80 m, car 1

(c) 120 m, car 0

(d) 120 m, car 1

Figure 4. Boxplots for received power as function of the obstacle.

between while maintaining a safe distance. Then we tried to perform the same experiments at distances of 120 m, 160 m, and 200 m. The majority of these tests had to be aborted for two reasons. With such high distances, the first problem comes from the fact that on a public freeway it is almost impossible to prevent other vehicles to interfere with the experiment. The second is instead due to the topology of the road which is never really straight, so as soon as the freeway slightly bends, the vehicles immediately get in LOS. 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 IEEE 802.11p compliant devices[2]. For radio communication, we employed Mobile Mark ECOM9-5500 dipole antennas with 9 dBi of gain. As GPS antennas we employed two Mobile Mark MGW-303. The positioning of the antennas on the rooftop of the cars is shown in Figure 2.

To maximize the probability of frame reception and gather as many sample points as possible, we employed 20 dBm of transmission power and BPSK $R=1/2$ as 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 phase.

[2]http://www.cohdawireless.com/product/mk2.html

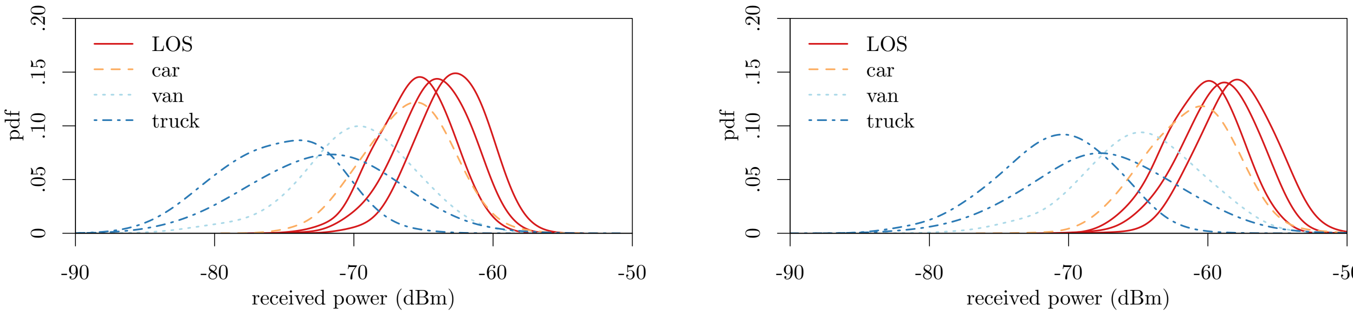
IV. Analysis

In order to perform the analysis we needed to post-process the data to get rid of 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 was within ±5 % of the experiment distance. As result, the average distance was in the interval from 79 m to 82 m for the 80 m experiment, and in the interval from 120 m to 121 m for the 120 m experiment.

A. Shadowing

The first effect we analyze is shadowing. To this purpose, Figure 4 shows a boxplot and the average for the received power for each type of obstacle. We plot them for 80 m and 120 m and split between first and second car. The reason is that the Cohda devices we own always report different quantitative levels for received signal power. The power reported by the devices shows the same trend, but with a difference of roughly 5 dB.

When considering 80 m distance (Figures 4a and 4b) the results show a clear decrease in the received signal strength due to the different obstacles. The difference is only slightly noticeable when the obstacle is a car, but it is substantial for the van and the truck. When considering 120 m instead (Figures 4c and 4d), this difference becomes less relevant. In particular, the difference between LOS and the experiment with the truck is lower than 5 dB at 120 m, while being as high as 10 dB at 80 m. Note that for 120 m the experiment



(a) Car 0

(b) Car 1

Figure 5. Probability density functions of the received power for the 80 m experiments.

with the car is missing: it was not possible to perform it without interference from other vehicles.

What Figure 4 suggests is that the effects of shadowing get smaller as distance increase. This conclusion needs however to be verified, for example by performing experiments at smaller distances. The effects of shadowing should then become more noticeable.

B. Fading

In order to analyze the effects of fading, we consider the distribution of received power for each experiment instance. The probability density functions for the 80 m experiment are shown in Figure 5. As can be seen, we made three repetitions for the LOS experiment, one repetition for car and van each, and two repetitions for the truck. The first thing that can be noticed is that fading effects are very evident, and they are not negligible with respect to shadowing. This suggests that, in this particular scenario, considering fading when performing simulation is crucial in order to obtain realistic simulation results. Furthermore, the plots show that shadowing impacts on multi-path fading behavior. The variance of the received power indeed increases with the size of the obstacle. We can then conclude not only that in such a scenario none of the two effects is dominant with respect to the other, but that they are not even independent from each other. This means that, in order to faithfully reproduce realistic channel behaviors in short-range communications, a model considering different fading distributions depending on the amount of shadowing might be needed.

V. Conclusion

In this report we perform a measurement campaign on a freeway in order to understand the relationship between shadowing and fading in different LOS conditions. We show that, for this particular scenario (i.e., with distances between 80 and 120 m), none of the two effects is dominant with respect to the other. We instead show that there is an interdependence between the two. In particular the amount of shadowing impacts on fading distribution.

Further investigations are in any case needed in order to develop a model able to reproduce such effects. For example we might need to perform the same measurements with smaller distances. This could either confirm what we discovered for the 80 m experiments or show that with close following one effect becomes negligible with respect to the other.

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