Propagation Channel in a Rural Overtaking Scenario with Large Obstructing Vehicles

Kim Mahler, Wilhelm Keusgen, Fredrik Tufvesson, Thomas Zemen and Giuseppe Caire

***Abstract*—An overtaking warning system depends on a reliable connectivity between the involved vehicles. We investigate the 6 GHz propagation channel between oncoming vehicles with five different types of large obstructing vehicles in a poor scattering environment. The presented channel gains emphasize the advantages of different antenna positions and the difference between a straight road and curved road. We conclude that connectivity ranges on a straight road are close to the minimum distance required by a warning system. We furthermore conclude that the channel gain of antennas mounted inside the vehicle is usually higher compared to antennas mounted on the roof, which can increase the connectivity range significantly.**

***Index Terms*—Radio propagation, Multipath channels, Channel models, Intelligent transportation systems,Vehicular and wireless technologies.**

I. Introduction

VEHICLE-to-vehicle communication is envisioned as an additional vehicular sensor, complementary to radar, video and laser sensors. Radio communication holds the unique capability to detect other vehicles even if they are out of sight, which is of particular relevance for collision avoidance systems at urban intersections or during an overtaking maneuver on a rural road. An example for the latter application could be a video-based overtaking assistant, where the overtaken vehicle transmits video-messages to the overtaking vehicle [1] [2] [3]. Alternatively, the vehicle to be overtaken is exchanging cooperative awareness messages (CAM) with the vehicles driving in the opposite direction [4]. If traffic of both directions is queueing, the vehicles leading these queues have the best opportunities to achieve line-of-sight (LOS) communication and should warn the vehicles following them. However, if the leading vehicle is not equipped with radio communication sensors, an apparent overtaking application alternative is simply the exchange of CAM between the overtaking vehicle and the vehicles driving in the opposite direction. In any of the above mentioned application scenarios, large obstructing vehicles are most relevant since they block the view of the driver and possibly also radio waves.

There is some literature on vehicle-to-vehicle (V2V) communication in rural environments. Work in [5] covers connectivity ranges based on measurements with an 802.11p transceiver, where one of the transceivers is kept stationary. The LOS obstruction in the measured rural environment scenarios is due a steep crest between the communicating vehicles or to the vegetation in a curved road scenario, with connectivity ranges of up to 160 m. The power delay profile and the Doppler spectral density of an overtaking scenario is described in [6], where both transmitter (Tx) and receiver (Rx) drive in the same direction with an obstructing truck between the measurement vehicles. The same setup is measured in [7], where the authors indicate power losses of 5-10 dB if the LOS is obstructed by a truck. Similar measurements are conducted by [8], however in these measurements some of the antennas are placed at different locations within the vehicle. Compared to the antenna mounted on the roof center, the inside antennas yield to a gain of up to 20 dB for the obstructing truck scenario. To the knowledge of the authors, no paper has been published on the propagation channel of a rural overtaking scenario with the communicating vehicles driving in opposite directions.

The contribution of this paper is an analysis of channel measurements relevant to this scenario with five different types of large obstructing vehicles. The measuring vehicles are equipped with antennas mounted on the edge of the roof and also inside the vehicle. We investigate the difference of these antenna positions in terms of channel gain and also emphasize the difference of the propagation condition between the so-called curved road scenario and the straight road scenario. The results provide an indication on achievable channel gains and connectivity ranges for a rural overtaking warning application under the given conditions.

II. Measurements

A. Measurement Equipment

The HHI Channel Sounder, developed at the Fraunhofer Heinrich Hertz Institute, is a wideband measurement device with a bandwidth of 1 GHz at a carrier frequency of 5.7 GHz [9]. It comes with 2x4 fully parallel frontends (two at transmitter, four at receiver) to allow simultaneous testing of different antenna positions. The measurement device can be installed in regular passenger vehicles and deployed in any traffic scenarios. The position of the measuring vehicles is recorded with a highly accurate positioning system and the measurements are accompanied by video cameras mounted on the roof of both vehicles. For this measurement campaign, we use an Audi Avant as a Tx vehicle and a Renault Scenic as Rx vehicle. Both vehicles are equipped with omnidirectional and vertically polarized antennas mounted on the roof at the left

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Fig. 1. Antenna placement at both transmitter and receiver vehicle

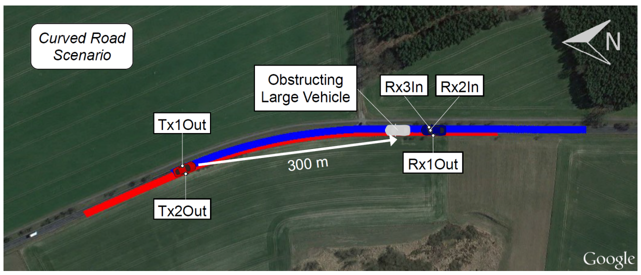

Fig. 2. Overview of the measurement conducted on a curved road section

and right edges of the vehicle. Probably due to the bended shape of the roof of a Renault Scenic, the antenna on the right edge of the Rx vehicle did not collect valid channel data and had to be omitted for further analysis. In addition to the antennas mounted on the roof, we installed two vertically polarized antennas at different locations inside the receiver vehicle as shown in Fig. 1. The purpose of this experiment was to find out whether aftermarket transceivers with an in-cabin antenna serve their purpose and to evaluate which antenna location is more suitable in terms of a reliable connectivity.

B. Measurement Environment

In order to evaluate a worst case scenario, we searched for rural roads with a poor scattering environment. The rural road we selected is named Potsdamer Chaussee and located south of the village Seeburg near Berlin (N52.504, E13.123). Buildings of the close-by village are too distant for relevant scattering and the surrounding vegetation is expected to result in diffuse multipath components only. The selected road can be separated into two parts: a section with a straight road and a section with road bending of approximately 25 ° (see Fig. 2 and Fig. 7). We conducted measurement runs for these two kind of scenarios: a curved road scenario and a straight road scenario. In total we executed 7 runs with different obstructing large vehicles: 1 truck, 2 coaches, 1 large caravan, 2 site vehicles of type Mercedes-Benz Actros 4146 and 1 van of type Volkswagen Type 2 (T3). The distance between the obstructing vehicle and the following measurement vehicle was in the range of 5-20 m. Depending on the traffic situation, the average speed of the measurement vehicles ranged 60-100 km/h.

III. Curved road scenario

An overview of the curved road scenario is depicted in Fig. 2. The Rx vehicle is driving at an average speed of 82 km/h behind a site vehicle of type Mercedes Actros 4146 at distances of around 10-20 m, while the Tx vehicle is driving at an average speed of 83 km/h in the opposite direction. Visual inspection of multipath tracking results revealed that no significant multipath components could be observed, i.e. paths are either LOS or diffuse. Apparently, the path of the antenna mounted on the roof of the Rx vehicle (Rx1Out) bypasses or diffracts around the obstructing vehicle and establishes a specular path from both antennas of the Tx vehicle. In this measurement run, we observe that for distances between 450 m and 150 m the antennas mounted inside the vehicle yield to a higher channel gain, as can be seen in Fig. 3. In addition to this, the outside antennas experience a significant energy drop at distances around 300 m. Hence, we can conclude that at most relevant distances in terms of a corresponding warning application antennas mounted inside the vehicle would perform better with gains of up to 10 dB.

Although the channel sounder has a temporal resolution of 1 ns, multipath caused by two-ray ground-reflection with antenna heights of 1.5 m can only be resolved at distances below 15 m. We computed from the measured time-variant channel impulses the Rician K-factor $K = 10\log_{10}(P_s/P_r)$, where P_s is the power of the strongest path and P_r is the sum of the power of all paths except for the strongest path. The results in Fig. 4 indicate that the energy drop at a distance of 300 m is indeed due to the destructive ground-reflection. The antenna at the rear-mirror yields to a progression similar to the roof antenna, yet with a smoother change of the K-factor and a less severe energy drop. The antenna mounted on the dashboard is apparently not affected by the ground-reflection and moreover has the highest channel gain.

Additional examples where inside antennas yield to a gain are observed in two measurement runs conducted at this curved road section. As in the previously described run, the Rx vehicle is driving behind the obstructing vehicles, which are in this case a large truck and a large coach. Different to the previously described scenario, the driving direction of both measurement vehicles changed, i.e. the Tx vehicle is driving northbound at an average speed of 60 km/h (or 90 km/h in the second measurement) and Rx vehicle is driving southbound at an average speed of 65 km/h. Since the results of these two measurements are very alike, we computed the average channel gain over distance of both measurements. As can be seen in Fig. 5, at distances of around 500 m the channel gain of all antennas is above -105 dB and reaches values of around -100 dB at distances of 350 m, with a slight gain of the inside antennas. After a minor energy drop for all antennas at distances around 300 m, the differences between the antennas become apparent. At distances of 200-250 m, the channel gain of the antennas mounted inside the vehicle rise to values of around -90 dB, whereas the roof antenna energy stays at roughly the same level and then even falls again below -100 dB. One might assume that this effect is due to the transition from a right-curved road to a straight road and that a stronger

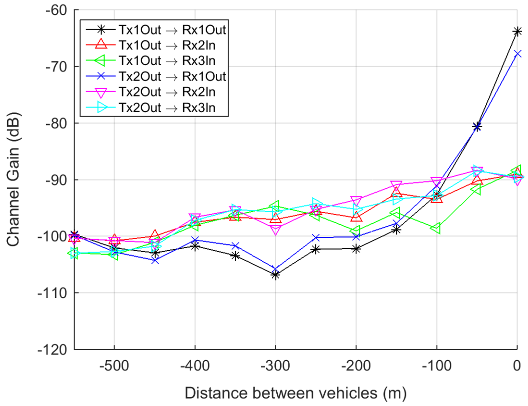

Fig. 3. Channel gain of different antenna combinations on a curved road

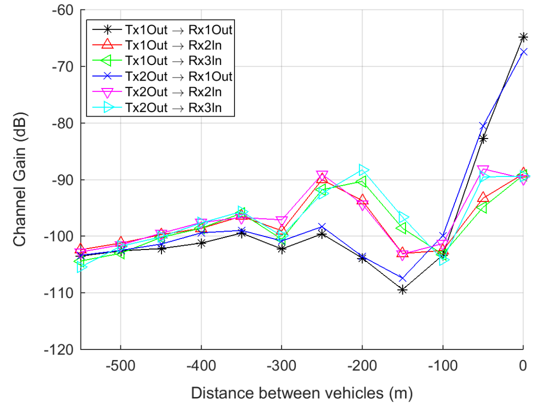

Fig. 5. Averaged channel gain of two measurements on a curved road

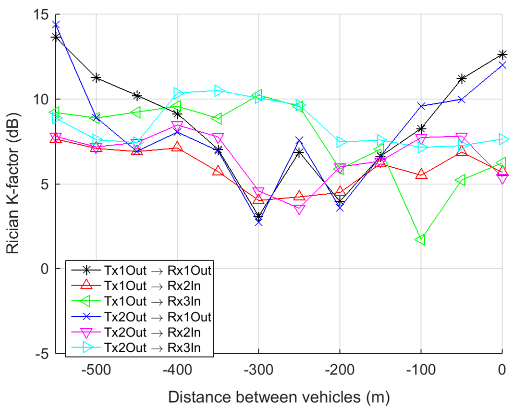

Fig. 4. Rician K-factor for different antenna combinations on a curved road

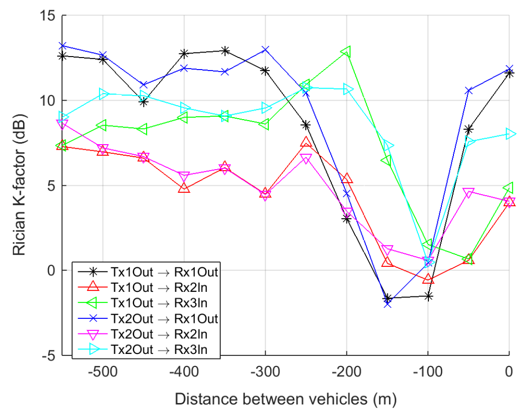

Fig. 6. Averaged Rician K-facto of two measurements on a curved road

obstruction of the Rx1Out antenna occurs because it is placed on the left hand side of the vehicle. Indeed, the starting point of the severe K-factor drop in Fig. 6 is in good accordance with the position of the antennas in terms of left and right position: the drop of the Rx1Out antenna mounted on the left edge of the roof starts at 250 m, the drop of the Rx2In antenna mounted at the rear-mirror starts at 200 m and the drop of the Rx3In antenna mounted on the right hand side of the dashboard starts at 150 m. Also we notice that the K-factor curves of the inside antennas raise just before they decline, which might be due to the obstructing vehicle acting as a specular scatterer at the transition from a curved road to a straight road. This explains also the significant energy gain of the inside antennas at a distance of 200-250 m. At a distance of 150 m, the higher channel gain of the Rx3In antenna is clearly due to its position on the right hand side, which can be concluded from the higher K-factor values at this distance. At distances around 100 m the obstruction is at its peak and values of both channel gain and K-factor are very similar for all antennas. We can conclude that on the curved road section the channel gain is often above -100 dB and that inside antennas usually yield to a higher channel gain at distances relevant for an overtaking warning application.

IV. Straight Road Scenario

Now, we study the scenario on a straight road section as depicted in Fig. 7. The obstructing vehicle drives at an average speed of 96 km/h and a distance of around 10 m in front of the Tx vehicle, while the Rx vehicle drives at an average speed of 71 km/h in the opposite direction. Although the obstructing vehicle in this run, a van of type Volkswagen Type 2 (T3) (see Fig. 8), is clearly not as large as the obstructing vehicle in the previously described results in Fig. 3, the obstruction effect in this case is far more severe. Results in Fig. 9 demonstrate that at a distance of 300 m the channel gain reaches values of around -110 dB only. On the other hand, we can observe that the antenna mounted on the left edge of the Tx enables a channel gain of nearly -100 dB at distances of 500 m. This is due to the fact that the measurement run starts as a curved road scenario and becomes a straight road scenario at a distance of around 300 m. This transition from obstructed LOS to LOS can be verified by corresponding K-factor curves and is the cause for the 10 dB channel gain drop of the Tx1Out antenna, as shown in Fig. 9. The large truck next to the van in Fig. 8 drove around 350 m ahead of the Rx vehicle and appears to have nearly no effect on the channel gain. We can conclude that a channel gain of -100 dB can only be reached at distances around 200 m and that inside antennas experience on average

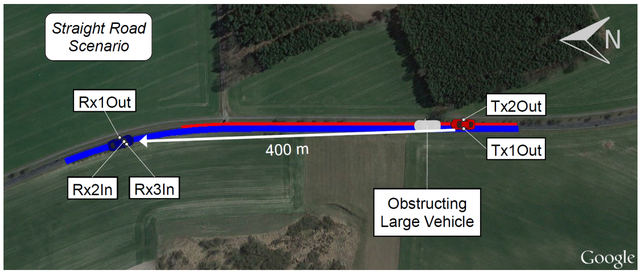

Fig. 7. Overview of the measurement conducted on a straight road

Fig. 8. Video capture of the measurement conducted on a straight road

a slightly higher channel gain.

Four measurement runs on this straight road section with different obstructing vehicles returned very similar channel gain progressions. In order to make a more general statement on achievable channel gains in this scenario, we computed the average of these runs, where the obstructing vehicle drove twice in front of the Tx vehicle and twice in front of the Rx vehicle. The obstructing vehicles were a large caravan, a large coach, a site vehicle of type Mercedes Actros 4146 and the Volkswagen Type 2 (T3) in Fig. 8. The distance between the obstructing vehicle and the following measurement vehicle is the range 5-15 m, whereas the average speed of the measurement vehicles ranges 70-95 km/h. As we clearly can observe in Fig. 11, the channel gain reaches a level of -100 dB not until a distance of 100 m. After the vehicles passed by each other, the channel gain differences can be explained with the fact that the antenna Rx1Out on the roof does not experience any obstruction, whereas the antenna Rx2In mounted at the rear-view mirror and even more the Rx3In antenna mounted on the dashboard (see Fig. 1) experience obstruction from various objects within the Rx vehicle.

A. Delay and Doppler spread

In order to examine the frequency and time dispersion of the measured channels, we extracted the RMS delay spread and the RMS Doppler spread for all 7 measurement runs and found that the delay spread is low with maximum values of around 20 ns. The only exception to this observation is the measurement run pictured in Fig. 8, where the delay spread is significantly higher as shown in Fig. 10. This can only be explained with multipath components from other attendant vehicles, e.g. the site vehicle visible left of the van in Fig. 8. The delay spread of the channel at antenna Tx1Out reaches its peak at a distance of 150 m, whereas for antenna Tx2Out the maximum value is found at a distance of 100 m. Also, it can be observed that the delay spread values for inside antennas are significantly higher compared to outside antennas with values up to 90 ns. The values of the RMS Doppler at distances above 400 m are usually below 100 Hz, while they can reach values of up to 400 Hz at smaller distances.

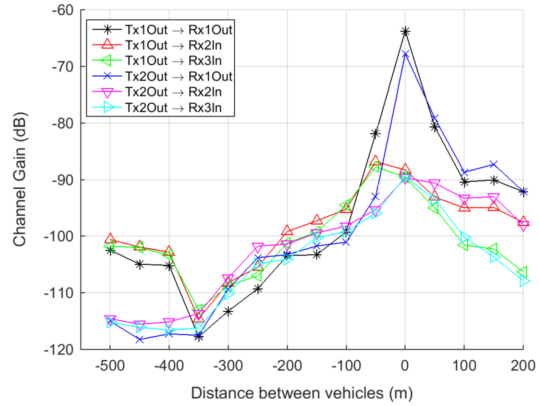

Fig. 9. Channel gain of different antenna combinations on a straight road

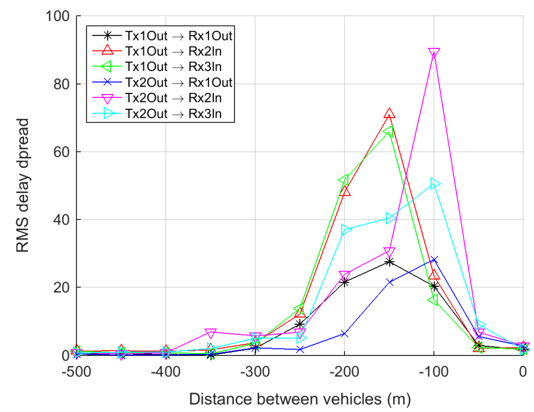

Fig. 10. RMS delay spread of different antenna combinations

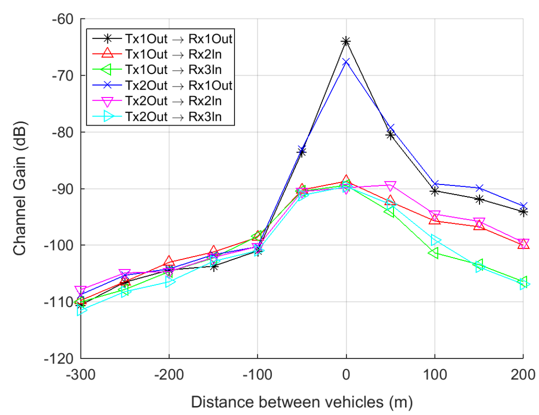

Fig. 11. Averaged channel gain of four measurements on a straight road

V. Conclusions

Before drawing conclusions on the presented results, we give some preliminary considerations to an overtaking warning application. Assuming a relative speed of 180 km/h of vehicles heading in opposite directions and furthermore assuming a reaction time of 2 s required for an overtaking warning system to work (see [4]), the V2V communication has to be established at a minimum distance of 100 m. If we also take into account that the maximum transmit power of an IEEE 802.11p transmitter is 23 dBm (see page 31 in [10]) and that the minimum sensitivity is -82 dBm for a modulation and coding scheme of 6 Mbit/s with 10 MHz channel spacing (see page 1612 in [11]), we can conclude that communication can only be established if the channel gain is above around -100 dB. Based on these considerations and the results presented in this paper, we can draw some conclusions on the connectivity range for different measurements and antenna positions.

The channel gain of the inside antennas in Fig. 3 achieve the aimed threshold of -100 dB at a distance of 400 m, whereas the antennas mounted on the roof cross this threshold only at a distance of 150 m. The gained distance of 250 m is significant and makes an advantage of antennas mounted within the vehicle apparent. Similarly, the results in Fig. 5 demonstrate that the channel gain of inside antennas is above the threshold of -100 dB at a distances between 400 m and 150 m, whereas the channel gain of the roof antennas at these distances barely touches this threshold. We can conclude that for a curved road scenario in a rural environment, antennas mounted at the rear mirror or on the dashboard can significantly increase the connectivity distance and hence fulfill the prerequisites of a rural overtaking warning application.

For the measurement results in Fig. 9, where the vehicles change from a curved road scenario to a straight road scenario, we could observe the advantage of antennas mounted on the edge of the roof. However, the channel gain of the Tx1Out antenna still doesn't achieve the threshold of -100 dB. We therefore conclude that in this case connectivity would start at distances between 200 m and 100 m. When looking at the averaged results from four straight road scenario measurements, we can clearly observe that on average and under the given measurement conditions none of the antenna position reaches the channel gain threshold of -100 dB at a distance of 150 m. This distance is very close to the previously estimated minimum distance of 100 m and leaves little time for a corresponding warning system.

Our results show that in the 6 GHz band only very little energy can be exchanged between obstructed vehicles on a straight road and that it is not recommended to count on the connectivity under the given conditions. This weakness should be significantly eased for frequencies of 700 MHz, as published work in [12] indicates. Nevertheless, different antenna positions can mitigate the obstruction effects. If the road is not perfectly straight, antennas mounted on the edge of the roof can diffract around the obstructing vehicle and increase the channel gain by around 10 dB. Furthermore, antennas mounted inside the vehicle do not suffer as much from the destructive effect of two-ray ground-reflection and can therefore increase the connectivity range significantly. Also noteworthy, the inside antennas never experience a disadvantage in terms of channel gain compared to antennas mounted on the roof. Therefore, aftermarket solutions with an integrated antenna mounted on the rear-mirror or the dashboard are a serious alternative.

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