On the Impact of Antenna Patterns on VANET Simulation

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***Abstract*—Although the level of realism in vehicular network simulation is constantly increasing, antenna radiation patterns have only rarely entered the picture. In this paper we investigate the impact of these antenna patterns on the outcome of a city-wide simulation with hundreds of cars as well as an isolated intersection collision avoidance scenario. We show that in both cases pronounced differences can be observed: Compared to idealistic isotropic antennas, using realistic antennas changes the distribution of angle of arrival, affecting network topology dynamics. In collision avoidance applications, the antenna radiation pattern can make the difference between a crash and a successful emergency brake, strongly indicating that antenna characteristics should find more consideration in vehicular network simulation.**

I. Introduction

Simulation has become an essential part for the evaluation of vehicular networking protocols, applications, and properties [1]. Starting from simplistic random way point models, substantial efforts have been undertaken to make vehicular simulations more realistic and thereby their results more meaningful. Current simulators take into account various effects and components to approximate a realistic environment while still maintaining performance that allows to investigate networks consisting of thousands of vehicles. The availability of models for the entire protocol stack [2], including detailed MAC [3] and PHY [4] layers, combined with realistic traffic mobility [5] allows for holistic examinations of future Vehicular Ad-Hoc Networks (VANETs).

A key aspect in the evaluation of any wireless network is the consideration of the wireless channel itself. Due to the required level of simulation detail and processing power, studies usually rely on packet-level simulations instead of accurate ray-tracing methods. Commonly, an AWGN channel is assumed to compute a reception probability for each packet which is based on its Signal-to-Interference-plus-Noise Ratio (SINR). The SINR compares the power levels of the received packet P_r with that of the background noise plus any interfering packets. For this, P_r can be determined by computing $P_r = P_t + G_t + G_r - \sum L_x$, where P_t is the transmit power, G_t and G_r are sender and receiver antenna gains, and L_x are different path loss and fading components.

These path loss and fading components have received much attention lately, as they allow to deterministically model the impact of distance, buildings [6], other cars [7], and reflection from the road surface [8] on the received signal. Additionally, probabilistic fading models such as Nakagami-m [9] and log-normal shadowing [10] have found wide application in the vehicular networking community.

Considering the level of detail found in these models, it is surprising that most simulators used in vehicular network simulation do not consider the impact of different types of antennas, the actual interface of vehicle and wireless channel. Antennas are usually modeled as omnidirectional with no gains, even though real antennas used in vehicular networks were shown to be anything but omnidirectional [11]. A slight change in angle can have considerable impact on the received signal strength, and thereby also on the transmission range. This might not be a significant factor in the simulation of general wireless networks with random mobility and uniformly distributed angles. In the scope of vehicular networks, however, some scenarios (e.g., on highways) predominantly require communication with vehicles in front and behind. Conversely, applications like intersection collision avoidance rely on information received from crossing traffic instead.

In this paper, we want to investigate the impact of different antenna patterns on the outcome of vehicular network simulation. We take a look at macroscopic effects in large-scale simulations [12] as well as isolated collision avoidance situations, where failed transmissions can have severe consequences. We model different antennas found in the literature and implemented a 2D antenna model for the open-source vehicular network simulation framework Veins.[1] In summary, we want to answer the question if and when antenna characteristics have to be taken into account when simulating vehicular networks.

II. Related Work

The importance of antenna radiation patterns for vehicular communication has been understood from the very beginning. In 1985, Jesch [13] presented extensive measurements and found that not only the antenna itself, but more so its position on the car and the existence of sirens and lights on the roof can have significant effects on the radiation pattern of the antenna. Similarly, Reichardt et al. [14] investigated the effects of antenna placement on car-to-car communication. Using ray tracing simulation, they found that the receive signal power heavily depends on the antenna position causing differences in received power of up to 30 dB. The authors

[1] http://veins.car2x.org/

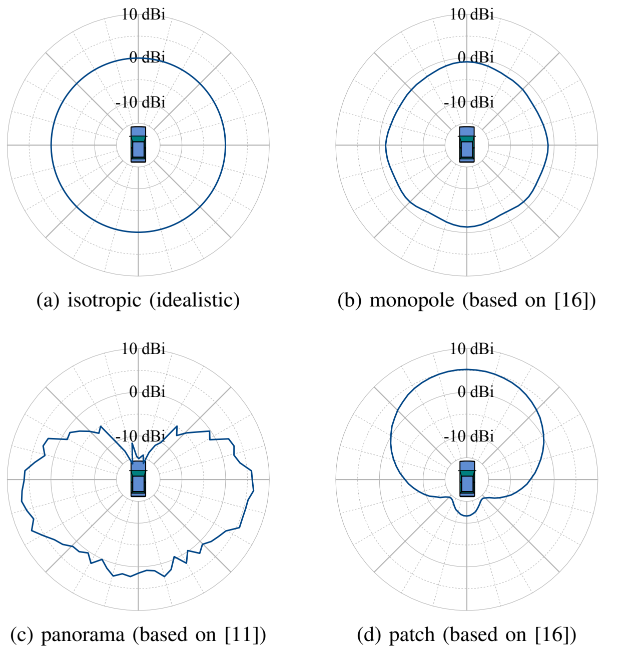


Figure 1. Sample antenna types considered in this study. Shown is the gain in dBi in the azimuth plane (i.e., top view). Drawn with vehicle facing north.

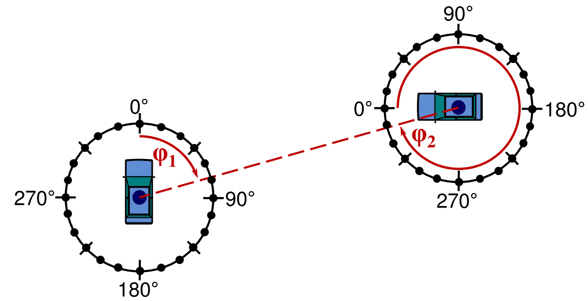


Figure 2. Angles considered for the computation of gain and attenuation between two vehicles.

conclude that a combination of diverse antenna locations would be advantageous. Karedal et al. [15] showed in real-life measurements that not only the antenna pattern but also the layout of the intersection have a significant impact on the receive power level, further emphasizing on the need for more realistic simulation models.

Kwoczek et al. [11] investigated the effect of panorama glass roofs on the antenna radiation pattern. They observed a significant negative impact due to reflections inside the glass. This causes a considerably reduced forward transmission range. Their work is based on measurements in the 5.9 GHz frequency band as used by the IEEE 802.11p standard. We use the presented antenna pattern as template for an antenna type in our simulation study. Additionally, we make use of the measured patterns presented by Kornek et al. [16].

Focusing now on applications, extensive studies of vehicular safety applications can be found throughout the literature. For example, Farnoud and Valaee [17] compare broadcast strategies for vehicular safety messages with regard to packet error rates and delays. Ma et al. [18] use simulations to analyze the performance of safety broadcast schemes under the consideration of fading channel conditions and detailed MAC layer functionality. Likewise, in an earlier article, we evaluated the effect of buildings on safety applications and afforded reaction times [6].

Reflecting on this related work, it becomes clear that, while the studies of safety applications pay particular attention to the level of realism provided by their simulation environment, none of them consider antenna radiation characteristics. Conversely, the simulations focusing on radiation patterns do not investigate possible effects on safety or other applications. However, the various antenna radiation patterns found in the literature suggest that the angle dependence potentially affects safety applications, particularly under Non-Line-of-Sight (NLOS) conditions, where transmission ranges are already low. This paper tries to illustrate this effect and quantify it to an extent.

III. Antenna Patterns

In wireless communication the characteristics of the used antennas play an important role. When there is no distinct angle dependence of the envisioned use case, ideally, the used antenna would also be angle-independent, radiating equally in all directions. This could be assumed for vehicular networks: they cover a large range of applications; ranging from traffic safety, to traffic efficiency, to comfort applications. Achieving an almost omnidirectional vehicular antenna, however, is challenging due to the strong influence of antenna placement [13] and also the fact that modern vehicles follow certain aesthetic design guidelines, including the design and shape of the antenna. Therefore vehicular antennas often show strong angle dependence, significantly attenuating the emitted signal in some directions.

Figure 1 shows the radiation patterns in the 2D plane of the four different antennas which are used throughout this paper. The reference isotropic antenna is angle-independent and shows no gain or attenuation at all. The monopole antenna [16] comes closest to being perfectly omnidirectional and shows no prominent angle dependence. The *panorama* antenna shows significant attenuation in the forward direction. The patch antenna placed at the side mirror [16] amplifies the signal in forward direction, but has a heavily reduced transmission range to the rear.

Support for directional antennas was implemented within the Veins simulation framework. We then equidistantly sampled the radiation patterns shown in Figure 1, so that each angle is associated with a positive or negative gain. Values in-between samples are interpolated. Sender and receiver gains for each sent packet can then be computed using angles φ_1 and φ_2 as illustrated in Figure 2. We argue that for many cases in vehicular networks, in particular car-to-car communication, vertical angles between sender and receiver antenna are likely to be small. Therefore in this work we only consider gains and attenuation in the 2D plane.

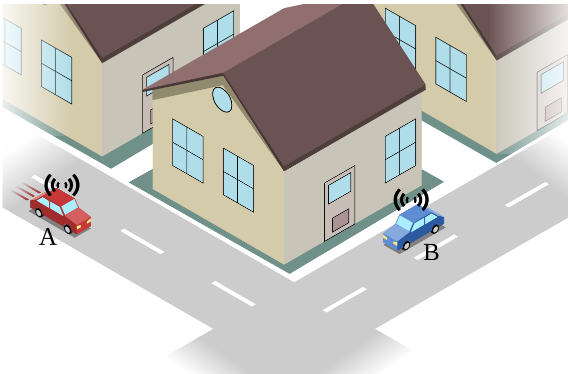


Figure 3. Intersection Scenario: A vehicle with a distracted driver (A, red) disobeys the right of way to potentially collide with the ego vehicle (B, blue). Buildings obstruct the line of sight, affecting communication between the vehicles.

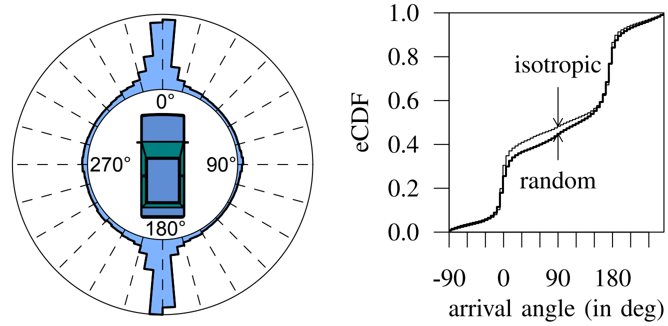
IV. Simulation Setup

We analyze the impact of radiation patterns on vehicular communication in two simulation scenarios, a city-wide scenario and an isolated intersection.

In both cases, vehicles were configured to periodically send beacon messages using IEEE 802.11p with a power of 20 mW and each recipient logged the angle of arrival. Receiver sensitivity was set to −89 dBm, resulting in a maximum line-of-sight transmission range of approximately 500 m. In the interest of determinism, following the fully deterministic model in [6] we configure the impact of shadow fading of obstacles in the line of sight to $\beta = 9\,\mathrm{dB}$ per wall and $\gamma = 0.4\,\mathrm{dB/m}$. We also abstract away from all fast fading effects that would introduce noise in the data.

The city-wide simulations are based on the LuST scenario [12], which models realistic traffic in the city of Luxembourg. As a reference setting, we equipped all vehicles with isotropic antennas, representing the status quo in packet-level vehicular network simulation. We compare this to a setting where each vehicle is randomly assigned one of the other three radiation patterns illustrated in Figure 1.

To get a better understanding of the impact of antennas on safety, we also set up a second, isolated simulation. Figure 3 shows this simple, fully deterministic intersection collision avoidance scenario. Two vehicles were driving towards a junction on orthogonal roads. The ego vehicle is 1000 m away from junction, driving at 14 m/s (approx. 50 km/h) and equipped with a wireless receiver. A vehicle with a distracted driver (ignorant of the presence of the ego vehicle and of any traffic rule) drives on the orthogonal leg of the junction and is equipped with a wireless transmitter sending periodic beacons. It drives at a fixed speed chosen from 4 m/s to 28 m/s, with a position offset that will guarantee that both vehicles will reach the junction center at precisely the same time. We assume that the channel is otherwise empty, so that the message can be decoded if the received signal strength is above the sensitivity threshold. A building positioned 1 m away from the roads severely attenuates radio transmissions.



(a) histogram (isotropic antenna) (b) comparison of distributions

Figure 4. Number of packets received from a given angle.

This, as well as our parameter choices, surely does not allow quantitative insights into application performance, but this is not our goal; instead, we are interested in qualitative differences depending on antenna types. To this end, both vehicles are equipped with the same antenna, choosing for each simulation one of the types shown in Figure 1.

V. Results

Figure 4 shows the distribution of received frames over different angles of arrival in the Luxembourg scenario in the form of a histogram and an eCDF. We observe a dominance of angles around $0\,\mathrm{deg}$ and $180\,\mathrm{deg}$, showing that most packets were received from vehicles in the front or in the back, that is, vehicles on the same street or even lane. Compared to the isotropic antennas, vehicles with realistic antenna patterns received noticeably fewer packets from these directions (Figure 4b), caused by the strong angle-dependent attenuation of the patch and panorama glass roof antennas. Not visible in the figure is another effect; we observed that using a random mix of the presented antenna types, the number of received beacon messages was about 15 % to 20 % lower compared to simulating isotropic antennas, depending on the traffic density. This clearly indicates that simulations using only isotropic antennas overestimate transmission ranges and thereby connectivity. This potentially leads to changed network topology dynamics.

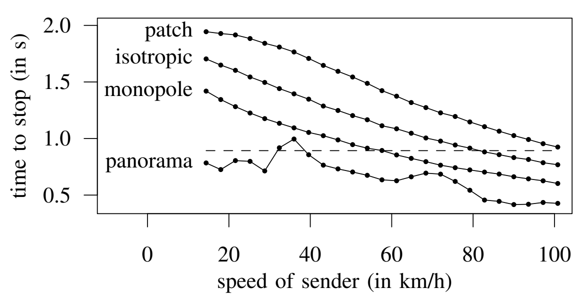


Figure 5. Time left after receiving the first warning message until a receiver traveling at 14 m/s (approx. 50 km/h) reaches the center of a junction. A building blocks the direct line of sight. Plotted for different speeds of the sender vehicle and for different antenna types. A horizontal line is drawn at time approx. 0.9 s, the deadline for starting to brake, assuming 12.5 m of stopping distance.

Figure 5 shows the results of our experiments for the collision avoidance scenario. We measure the advance warning time, that is, the time between receiving the first message from the distracted driver and both vehicles reaching the center of the intersection. We also mark an indication of a likely advance warning time required for the ego vehicle to brake to a complete stop before reaching the center (assuming an optimistic 12.5 m stopping distance).

Moving from the obvious to the interesting, Figure 5 shows that a faster opponent leaves less time for the ego vehicle to react; in some cases less time than would be needed to stop before reaching the center of the intersection.

The longest reaction time is afforded by the *patch* antenna reported by Kornek et al. [16], which trades less antenna gain at angles further than 60° from the driving direction for more gain at angles towards the front.

Closer inspection of the speed vs. reaction time relation also reveals that, depending on the antenna type, the trend is not strictly linear. In fact, for the *panorama* antenna reported by Kwoczek et al. [11], it is even reversed for some speed relations: A collision scenario with one car going 14 m/s (approx. 50 km/h) and the other car going 10 m/s (36 km/h) leaves much more time to react than any scenario where the other car is going either slower or faster. Indeed, under the parameters of this simplistic scenario, it is the only speed range where a collision could be avoided.

VI. Conclusion and Future Work

In this paper we have demonstrated the impact of antenna radiation patterns in vehicular networks. Although these patterns are well understood and thoroughly measured, they have not yet found wide application in packet-level vehicular network simulations.

As a first step, we implemented support for directionality of radio transmissions in a computer simulation model. We make this model available as open source, as part of the Veins simulation framework. We then sampled three antenna patterns found in the literature and evaluated their impact in a city-wide scenario as well as an intersection scenario, where one vehicle disobeys the right of way.

We found that modeling antenna patterns in VANET simulations has a direct impact on their outcomes. We further observe that typical antenna designs (coupled with urban street and building layouts) yield network topologies dominated by line-of-sight communication along the main axis of cars' movement. Typical antenna patterns [16] exhibit a high gain precisely along this axis, compounding this directionality effect. This opens up interesting avenues of research.

When investigating safety applications, in particular collision avoidance with crossing traffic at an intersection, we showed that antenna patterns can make the difference between crash and no crash. The strong angle dependence, especially of the investigated antenna behind a panorama glass roof, can render other vehicles invisible to car-to-car-based warning systems until moments before the accident.

Future work includes adding support for more dimensions, i.e., polarity and 3D antenna patterns to investigate sender and receiver antennas at different heights, e.g., when vehicles communicate with infrastructure such as traffic lights.

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