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Cooperative Awareness At Low Vehicle Densities: How Parked Cars Can Help See Through Buildings

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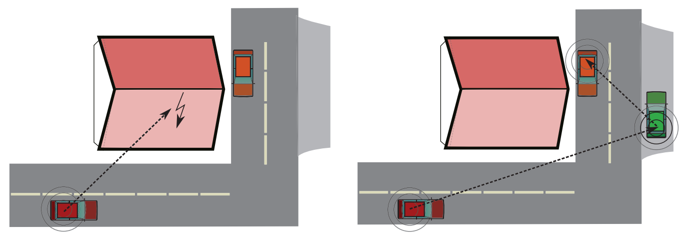
***Abstract*—Many safety applications in Intelligent Transportation Systems (ITS) require vehicles to be aware of the presence of nearby cars, but – especially in urban and suburban regions – buildings and other obstacles may block radio transmissions. In the literature, multi-hop relaying by neighboring cars has been demonstrated to perform well at disseminating safety broadcasts in the presence of obstacles. At night, in areas with low traffic density, or when the penetration rate of Car-2-X devices is low, however, there are likely to be too few relaying cars available. This again leads to the problem that vehicles which are not in line-of-sight frequently cannot be sensed either. To the best of our knowledge, we are the first to help overcome this problem by utilizing parked cars as relay nodes. We study the effectiveness and the necessity of this approach with the help of extensive simulative studies and real life experiments. We show how, for scenarios with few equipped cars, the utilization of parked cars proves crucial to support safety applications. When disseminating safety critical events in a realistic scenario, parked cars can increase cooperative awareness by over 40 % in total.**

I. Introduction

In 2009 the European Transport Safety Council reported over 1.3 million traffic accidents in the European Union, with a total of approximately 36 000 citizens killed. Efforts to reduce accidents and casualties include the design of safer vehicles and roads, both of which will also likely rely on Car-2-X technology [1].

Vehicles will be equipped with on-board devices connected to different automotive subsystems to access information like speed and GPS data. This information can then be shared with other cars equipped with, e.g., Vehicular Ad Hoc Network (VANET) technology and over a wireless channel. Currently, the IEEE 802.11p/DSRC protocol stack for wireless communication in vehicular networks is being standardized to ensure that all equipped vehicles can communicate with each other [2]. Those vehicles will then periodically broadcast beacon messages including their current state (information such as speed, position, and heading) to all nodes in their vicinity to inform them about their presence. These messages are called Cooperative Awareness Messages (CAMs). Many safety applications rely on these beacons and are envisioned to assist the driver with helpful instructions or information in order to reduce the possibility of a traffic accident [3]–[5].

The earlier a vehicle knows about the presence of nearby cars, the earlier it can inform the driver. When relied upon, late or missing information (caused, e.g., by lost messages) can lead to severe accidents.



(a) safety message blocked by house (b) 2-hop relaying using parked car

Figure 1. Utilization of parked cars as relay nodes can increase cooperative awareness in vehicular safety applications.

There are several reasons why the transmission of a safety message to neighboring cars might fail. First, antennas commonly have directionality characteristics and will not emit the signal in all directions with uniform strength. Secondly, a signal can be interfered with by another signal, rendering it undecodable. Finally, radio propagation effects can significantly reduce the theoretical transmission range of vehicles.

In this paper, we concentrate on the third aspect, and particularly on signal loss due to shadowing caused by obstacles. In metropolitan areas the line of sight between vehicles is often blocked by obstacles such as buildings, vegetation, or parked and moving vehicles [6], [7]. This does not necessarily result in packet loss but still leads to a considerable attenuation of the signal. Dependent on the material of the obstacle, the theoretical transmission range of a node will thus not be reached [8]. Other nodes, although they are within transmission range, may not sense emitted beacons of a node until both nodes move closer to each other. The time it takes for both nodes to get into communication range constitutes an additional delay that can have a negative influence on the benefit of safety applications.

To overcome this problem, multi-hop beaconing has been proposed [3], [5]. Vehicles will not only broadcast their own state but also retransmit received beacons from other nodes. With a high enough penetration rate and traffic density, this approach could be shown to be effective and improve the cooperative awareness among all nearby nodes. However, in the early stage of Car-2-X technology, only a small percentage of all nodes will be equipped with on-board devices – thus reducing the likelihood of other equipped cars being around a broadcasting car. Furthermore, there will always be low traffic density spots in suburban regions where the assistance of other driving vehicles is not possible. Finally, during off-peak hours and at night even in the city center, the car density can be expected to drop substantially.

We therefore propose the utilization of parked nodes as relay nodes to route around obstacles as depicted in Figure 1. Parked vehicles will not transmit their own beacons informing other cars about their position and state, but only retransmit overheard beacons from moving vehicles. The use of parked cars has a number of advantages with only one negative impact: parked cars are not energy-autonomous. We show that in different scenarios cooperative awareness can be significantly improved. Thus, the safety of vehicles using such Car-2-X applications is positively impacted. To the best of our knowledge, we are the first to help overcome the aforementioned problems by making use of parked vehicles for safety applications.

In this paper we focus on studying the influence of parked cars as relay nodes. We examine whether and to what extent the usage of parked cars as additional nodes in Intelligent Transportation Systems (ITS) can increase the safety of nearby vehicles. We do not want to present a specific relay strategy or a power management scheme, although we acknowledge that intelligent algorithms would have to be applied in order to optimize the overall system behavior. The main focus of this work is to give an answer to the question whether parked cars should participate or stay silent when it comes to safety applications in urban areas.

The remainder of this paper is organized as follows. In Section II, we discuss related work in this field of research. Subsequently, we present our approach in Section III. This is followed by an evaluation of the approach based on extensive simulative studies (Section IV). We conclude the paper with a short summary and an outlook on future work.

II. Related Work

There have been several publications on safety applications and cooperative awareness using periodic beacon messages [9]–[11]. All those systems concentrate on moving cars only. In the following, we briefly introduce the state of the art of safety-related broadcasting applications.

Ros et al. proposed a beacon-based protocol to increase reliability of VANETs while minimizing the number of beacon retransmissions [12]. In their approach, local position information is used by cars to determine whether they belong to a connected dominating set and subsequently reduce waiting periods before retransmissions. A similar approach, extended to 2-hop neighborhood, was presented by Khan et al. [13]. They further exploit geographic location, speed, and direction information. Based on this information, nodes will produce retransmission strategies for periodic beaconing. 3-hop connectivity was investigated in the scope of the FleetNet project [14]. It has been shown that the available capacity on the wireless channel is sufficient to support safety protocols on these connections.

The idea of placing Stationary Support Units (SSUs) in order to strengthen connectivity between moving nodes has also been discussed in literature. Lochert et al. studied the impact of connected SSUs to improve the performance of VANET applications in the roll-out phase [15]. They found that those static units can significantly improve connectivity between nodes. Furthermore, Ding et al. presented SADV, an approach that utilizes static nodes at road intersections in order to improve data dissemination in VANETs [16]. They use a store-and-forward algorithm to overcome problems in scenarios with low vehicle density.

Our approach, in contrast, does not rely on the deployment of additional SSUs. Instead, it uses parking cars, which are already placed in advantageous positions – along urban streets. We will show that safety applications greatly benefit from this approach, especially in the transitional phase, i.e., when Car-2-X communication devices and SSUs are starting to be deployed in the market. The listed related approaches could also be substantially improved by parking car relay nodes.

III. Utilizing Parked Cars

A detailed study of parking behavior in the area of Montreal, Canada offers some quite interesting numbers [17]: in 2003, out of 61 000 daily parking events, 69.2 % of all parked cars were parked on streets while only 27.1 % were parked on outside parking lots. A minority of 3.7 % was parked in interior parking facilities. On average the duration of one parking event was about 7 h. The study furthermore shows that parking vehicles were widely distributed throughout the whole city, which means there is a high possibility that a parking node is within transmission range of a moving car. Other studies have stated that, on average, a vehicle is parked for 23 h a day [18].

We therefore conclude that the use of parked cars as relays in vehicular networks can prove to be very helpful in supporting message exchange – at any given time, most cars are parking; of these, most are parking on streets.

The general advantage of vehicles is that they are energy-autonomous: as vehicles move, their battery is continuously recharged. However, parking nodes do not have this virtually unlimited supply of power as their battery does not recharge while the engine is turned off – this might actually change in future electric car scenarios. It is therefore obligatory that on-board devices of parked vehicles do not discharge the battery power below a point where the car cannot be started again. There must always be enough power left for the ignition and other mandatory functions of the vehicle. Basically, there are two possibilities to overcome this problem. Either the on-board device knows about the battery level and can switch itself off accordingly, or the device is equipped with a second battery that is also recharged when the car moves again. For the remainder of this paper we assume that, without loss of generality, all cars have an infinite amount of energy.

In collaboration with Audi AG, we performed several real life experiments with IEEE 802.11p hardware, which conclusively demonstrated that shadowing in urban and suburban areas is indeed a critical problem – even at short communication ranges. Figure 2a shows how communication can fail even though both cars are near each other. Each line depicts one measurement of signal attenuation, taken by using high-gain

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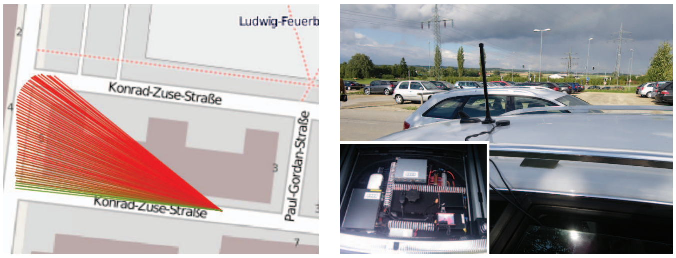


(a) measured attenuation values (b) IEEE 802.11p radio and antennae

Figure 2. Real world experiments with IEEE 802.11p hardware showed that even at distances of 30 m between vehicles communication can fail due to shadowing effects.

omni-directional antennae and radio hardware operating at full power, both shown in Figure 2b. Indicated by the lines' colors are their associated attenuation values (green: low, red: high). The end points of the lines trace the position of our test cars: one car moved around the building while the other one was standing. As can be seen, communication with the driving car experienced very high attenuation until it was almost on the same street as the standing car. Using conventional antennae or moderate transmission power, communication would only have been possible on the same street. More detailed results of this study can be found in [8].

A benefit of parked cars is their parking position itself. Along the street and often near obstacles they offer a promising possibility to relay beacon messages of driving cars in order to bypass obstacles. This idea is shown in Figure 1. Conceptually, parked vehicles represent a set of dynamic SSUs, participating in the VANET, e.g., to optimize safety applications. We see a major benefit in the ubiquitous availability of such parked cars in comparison to SSUs.

Assuming that each moving car periodically emits beacon messages with its position and speed, parking nodes will overhear these messages. A parked car will rebroadcast this beacon message so that other moving cars (which might not receive the original broadcast due to shadowing) will then pick up the beacon. Conceptually, we extend previous work on safety applications and check the influence of parked cars on the success rate of such safety beacons. To cope with the broadcast storm problem and to keep channel load low, we limit the relaying of messages to 2-hop transmissions, i.e., a maximum of one relay node.

IV. Evaluation

We performed extensive simulations to show the effectiveness of using parked cars to support VANETs. In order to produce meaningful results, the underlying model has to be chosen very carefully. We investigated our scheme with the help of our simulation environment Veins [19], [20], which is based on two dedicated simulation toolkits for road traffic and network traffic simulation (SUMO and OMNeT++), both well established in their respective domain. With the main goal of reducing the effect of obstacle shadowing, a realistic obstacle and radio propagation model has to be used: the overhead of ray-tracing simulation for large VANETs is prohibitively expensive, therefore we decided to use the model presented in [8]. The attenuation of a signal is dependent on the line-of-sight intersection with a building outline and furthermore on the number of penetrated walls. When line-of-sight communication can be established, free-space propagation is used. This approach, while admittedly simplistic, has been shown to match real world measurements very well.

A. Simulation Setup

We investigate two different scenarios: a synthetic Manhattan Grid scenario and a realistic suburban scenario.

The Manhattan Grid scenario, true to its name, is based on regularly spaced vertical and horizontal two-way streets forming $270\,\text{m} \times 80\,\text{m}$ blocks; this block size is inspired by downtown Manhattan. We model blocks as homogeneous obstacles, allow vehicles to park at arbitrary points on the curbside around them, and turn off all traffic lights.

The realistic suburban scenario is based on real geodata for the city of Ingolstadt, Germany. We imported this geodata (i.e., road and building geometry, speed limits, right of way, one way streets, etc.) from OpenStreetMap, and adapted the data to reflect realistic intersection management (correct turning lanes, coherent traffic light phases). Based on satellite data, we also added parking areas, distributing vehicles according to the size of the parking area.

In the simulation of these scenarios, cars were allowed to park anywhere in these areas, their locations following a random uniform distribution. Driving vehicles used the *Krauss* microscopic driver model implemented in SUMO and followed all traffic regulations. These vehicles were generated by randomly selecting Origin/Destination pairs, describing the departure location and route destination of vehicles, and iteratively applying dynamic user assignment [21], until the algorithm reported a stable, optimal distribution of flows.

In our evaluation, we focus on the $1.5\,\text{km}^2$ Region of Interest (ROI), which contains a typical mixture of high- and low-capacity roads, traffic lights, and unregulated intersections, as well as high- and low-density areas. To avoid border effects, we simulated traffic in in the whole city of Ingolstadt, but only investigate nodes driving within the ROI. We thus believe that this traffic is sufficiently realistic in order to obtain meaningful simulation results.

In both scenarios all moving vehicles (but no parking vehicles) emit CAMs (i.e., beacons) once every second. The beacons could then be relayed in a 2-hop fashion by nodes in the immediate neighborhood – depending on the simulated configuration either by driving cars only, parked cars only, or both. In order to reduce collisions on the wireless channel, we configured relaying nodes to re-transmit beacons only after a short random back-off time, but did not apply further strategies to avoid collisions or to save power as this was not within the focus of this paper.

Measuring the level of safety that the ITS application affords at a global scale is, in general, a difficult task. One would have to identify certain classes of constellations between vehicles,

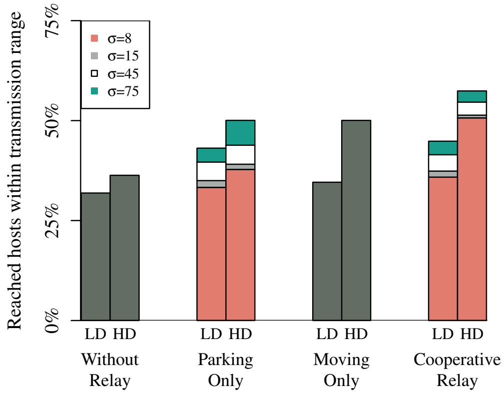
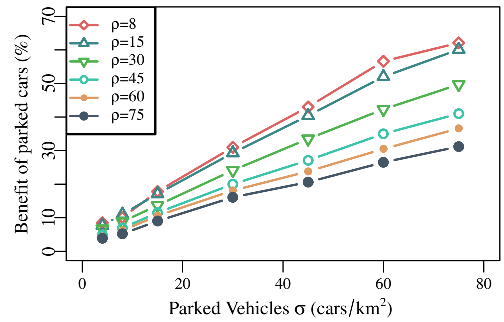
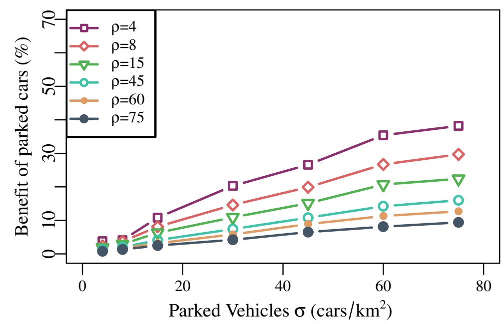


Figure 3. Comparison of beacon relay approaches in two suburban scenarios: low density (LD) and high density (HD). The x-axis depicts which nodes relay messages. Cooperative relay means that both parking and moving vehicles participate as relay nodes.



(a) Manhattan Grid



(b) Realistic Scenario

Figure 4. Message delivery success increase when additionally using parked nodes as relay nodes.

obstacles, and parked cars in order to give an absolute insight whether safety has improved or not. The classification of these cases, however, is very hard and a 100 % coverage of all cases cannot be guaranteed.

Therefore, we chose as the primary metric in our simulation the ratio between the number of potential neighbors in a theoretical maximum transmission range (assuming a unit disc radio propagation model) and the number of such nodes that a beacon message actually reached. We thus obtain a ratio describing the *reachability* of nodes in the network. The maximum unobstructed transmission range of a node was configured to be 400 m, as we believe that nodes further away do not play an important role for safety applications in urban environments. Please note that we only use this theoretical transmission range to measure the benefit gained from beacon-relaying parked vehicles. For computing signal attenuation, we used the obstacle model described above.

For easy reference, Table I gives an overview of parameters and terminology used in the following discussion of results.

B. Results

First, we compared 1-hop and different 2-hop broadcast approaches in the realistic suburban scenario. Figure 3 illustrates how obstacles reduce the number of reached hosts drastically: without relaying (1-hop) the percentage of reached hosts was far below 40 % in both the low density (LD, $\rho = 15\,\mathrm{cars/km^2}$) and high density (HD, $\rho = 75\,\mathrm{cars/km^2}$) scenario.

Table I
Parameters and terminology

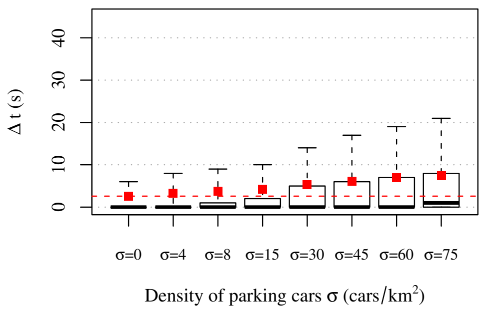
Density of moving cars	ρ cars/km^2
Density of parked cars	σ cars/km^2
Time by which moving vehicles encounter each other earlier when using broadcast relay	Δt
Beacon interval	1000 ms
Theoretical transmission range	400 m
ROI size	1.5 km^2

This is in line with other findings demonstrating a minimum rate of equipped vehicles for successful ITS operation [9]. Enabling broadcast relay on moving nodes improved this ratio only marginally for the low density scenario, but helped when traffic density was high.

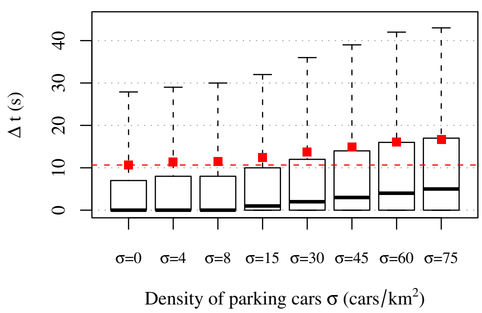
For the core of this work, the use of parking cars, we were able to reveal a more complex relationship. In networks with few moving vehicles, parked car assistance can clearly outperform regular VANET 2-hop broadcasting. We observe that when the number of parked cars equals the number of moving cars ($\sigma = \rho$) slightly more cars could be reached within the transmission range. This means that parked cars, due to their by nature strategical placement along streets and near obstacles, are better suited for relaying broadcast messages than their moving counterparts.

By enabling relay functionality on both parking and moving nodes, we can even further increase the level of cooperative awareness. The two outer right bars show that the gain when adding parked cars is higher in a low density scenario than for the high density scenario. We can clearly see that the set of nodes additionally reached with the aid of parking vehicles is not a subset of the nodes reached with moving vehicles.

In a next step, we wanted to further investigate the gain achieved by employing parked cars as relay nodes. As a metric we used the amount of previously unreachable cars that could be reached when additionally using parked vehicles as relay nodes. Simulations were repeated until the standard deviation of the data set was below 5 %; for the very sparse densities ($\rho = 4$, $\rho = 8$) the standard deviation was about 7.5 %.

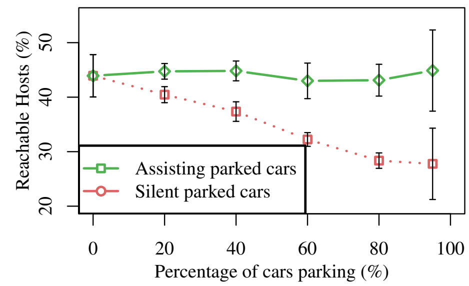


(a) Manhattan Grid

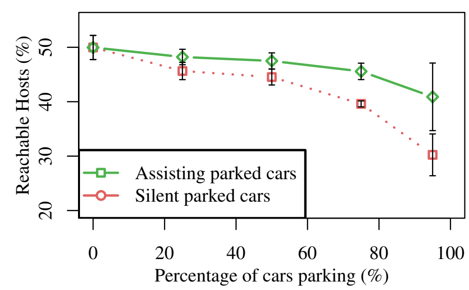


(b) Realistic Scenario

Figure 5. Temporal improvements (Δt is the number of seconds cars encounter themselves earlier compared to a non-relay approach) in a low-density scenario ($\rho = 22$). The boxes reach from the 25 % to the 75 % quartile while the whiskers extend to the 90 % quantile. The bold line within the box marks the median while the red squares show the mean.



(a) Manhattan Grid



(b) Realistic Scenario

Figure 6. Percentage of hosts reached within the maximal theoretical transmission range plotted for a typical day-night-scenario. While the density of active nodes in the scenario is invariant ($\rho + \sigma = 90$), the ratio of moving to parking vehicles ($\frac{\rho}{\sigma}$) decreases. Error bars visualize the standard deviation of the dataset.

Figure 4 shows our measurements for the Manhattan Grid (Fig. 4a) and the realistic suburban (Fig. 4b) scenario, respectively. It is apparent that in both graphs the benefit of parked cars is considerably higher in sparser scenarios than in denser ones. The gain seems to grow linearly with the amount of parked cars in the scenario, although the slope becomes smaller when increasing ρ. The gain of parked cars in the Manhattan Grid scenario is observably higher than in the realistic one, because every parked car is located on a strategical good position, that is, next to an obstacle.

We conclude from this that in areas with few equipped vehicles the aid of parked cars can considerably boost cooperative awareness (up to 60 % for Manhattan Grid), while in suburban regions the aid of parked cars is not necessarily needed if a sufficient number of equipped vehicles is available.

When measuring cooperative awareness, not only the amount of cars reached by a broadcast message is relevant, but also how early vehicles are aware of the existence of a nearby car. As a further metric, we thus measured the number of seconds by which cars encountered each other earlier (compared to a non-relay approach).

We investigated both the Manhattan Grid and the realistic suburban scenario with a fixed low density of $\rho = 22$. The results are displayed in Figure 5a and Figure 5b, respectively, in the form of box plots (as the distribution of the recorded data was heavy-tailed, we also plot the mean of recorded values in addition to the median, but do not plot individual values).

In both scenarios we observe that for 50 % of all cars there is no improvement when allowing only moving nodes to relay messages ($\sigma = 0$). For the realistic scenario this also holds when a very low number of parked cars is added to the scenario ($\sigma \leq 8$). However, adding more parking vehicles to the scenario results in a clear temporal improvement. With $\sigma \geq 45$ over 50 % of all moving vehicles encounter each other 4 s and more earlier. Moreover, it can be seen that for 25 % of all nodes, Δt is clearly higher than 10 s.

The effect is not so obvious for the Manhattan Grid Scenario. However, it is not less valuable. As the immense obstacles block a large percentage of all communication, cars are bound to encounter each other later than in the realistic scenario with its non area-wide buildings. We observed that only a short time before a possible collision, cars can decode beacon messages from other vehicles. From this, we follow that only a small increase of this time period can be decisive when it comes to accident prevention. With adding $\sigma \geq 8$ parking vehicles we can achieve this for about 25 % of all driving nodes – giving the driver valuable extra seconds to react.

In a last step, we wanted to examine a typical day-night-scenario where the amount of moving vehicles constantly decreases in the evening and reaches a minimum sometime in the night. Those vehicles, however, may still be parking along the street and can therefore be used as relay nodes in a VANET. In our setup, the amount of total vehicles $\rho + \sigma$ was therefore invariant, but the ratio $\frac{\rho}{\sigma}$ varied.

Our findings are presented in Figure 6a and Figure 6b, respectively. For the realistic scenario, we observe that we cannot quite keep the level of hosts reached within transmission range when the number of moving nodes decreases. However, without parking cars as relay nodes, this curve drops considerably faster. In the synthetic Manhattan Grid scenario, the effect of aiding parked cars is again clearer. Although the density of moving vehicles ρ got smaller and smaller, the lack of relaying moving nodes could be completely compensated by parked cars. The percentage of reachable hosts within transmission range only varied marginally (green line) when moving vehicles further participated in the VANET as parking ones. In contrast to that, the level of awareness considerably dropped when this was not the case (dashed red line). When 80 % of vehicles were parking, under 30 % of all vehicles within transmission range could decode a beacon message from another vehicle.

However, cooperative awareness is particularly important at night, when lighting conditions might be bad yet drivers more inclined to drive faster on the now almost empty streets. With the help of parked cars, vehicles can experience the same level of cooperative awareness at night, as if there were still many more moving vehicles on the street.

Independent from day and night, we furthermore conclude that with parked cars we can achieve the same level of cooperative awareness in sparsely populated areas as we would have in those with many moving vehicles.

V. Conclusion and future work

The benefit of safety applications in VANETs heavily relies on the number of equipped vehicles participating in the network. However, there are also cases where such vehicles may not be able to communicate correctly due to effects like shadowing, caused by obstacles such as buildings.

We propose the use of parked cars as relay nodes for the periodically emitted Cooperative Awareness Messages (CAMs) of moving vehicles. This alleviates both problems, providing more nodes that are able to participate in the network, which is particularly important when penetration rates of equipped vehicles are still low.

We showed that especially (but not exclusively) in low density areas, where parked cars are readily available, the amount of nodes that can be reached with CAMs can be significantly increased. We furthermore showed that vehicles can encounter each other considerably earlier when additionally using parked cars as relay nodes. This extra time for drivers to respond could help prevent accidents. Lastly, we found that, with the aid of parking cars, the loss of cooperative awareness due to the decreasing number of moving vehicles at night can be completely countered in a Manhattan Grid scenario, and substantially reduced in a realistic suburban environment.

Future work includes the design of more advanced beacon relay algorithms for parked cars and investigations on 3-hop-broadcasting in such scenarios.

References

[1] S. Biswas and F. Dion, "Vehicle-to-Vehicle Wireless Communication Protocols for Enhancing Highway Traffic Safety," *IEEE Communications Magazine*, vol. 44, no. 1, pp. 74–82, January 2006.

[2] IEEE 802.11 Working Group of the IEEE 802 Committee, "802.11p/D10.0 - Amendment 7: Wireless Access in Vehicular Environments," Tech. Rep., February 2010.

[3] G. Korkmaz, E. Ekici, F. Özgüner, and Ü. Özgüner, "Urban Multi-Hop Broadcast Protocol for Inter-Vehicle Communication Systems," in *First ACM Workshop on Vehicular Ad Hoc Networks (VANET 2004)*. Philadelphia, PA: ACM, October 2004, pp. 76–85.

[4] R. K. Schmidt, T. Leinmüller, E. Schoch, F. Kargl, and G. Schäfer, "Exploration of adaptive beaconing for efficient intervehicle safety communication," *IEEE Network Magazine*, vol. 24, no. 1, pp. 14–19, January 2010.

[5] F. Farnoud and S. Valaee, "Reliable Broadcast of Safety Messages in Vehicular Ad Hoc Networks," in *28th IEEE Conference on Computer Communications (INFOCOM 2009)*, Rio de Janeiro, Brazil, April 2009.

[6] M. Boban, T. Vinhosa, J. Barros, M. Ferreira, and O. K. Tonguz, "Impact of Vehicles as Obstacles in vehicular Networks," *IEEE Journal on Selected Areas in Communications (JSAC)*, July 2010, to appear.

[7] D. Dhoutaut, A. Régis, and F. Spies, "Impact of radio propagation models in vehicular ad hoc networks simulations," in *3rd ACM International Workshop on Vehicular Ad Hoc Networks (VANET 2006)*. Los Angeles, CA: ACM, 2006, pp. 40–49.

[8] C. Sommer, D. Eckhoff, R. German, and F. Dressler, "A Computationally Inexpensive Empirical Model of IEEE 802.11p Radio Shadowing in Urban Environments," in *8th IEEE/IFIP Conference on Wireless On demand Network Systems and Services (WONS 2011), Poster Session*. Bardonecchia, Italy: IEEE, January 2011, pp. 84–90.

[9] O. K. Tonguz, N. Wisitpongphan, and F. Bai, "DV-CAST: A distributed vehicular broadcast protocol for vehicular ad hoc networks," *IEEE Wireless Communications*, vol. 17, no. 2, pp. 47–57, April 2010.

[10] P. Muhlethaler, A. Laouiti, and Y. Toor, "Comparison of Flooding Techniques for Safety Applications in VANETs," in *7th International Conference on ITS Telecommunications (ITST'07)*, June 2007, pp. 1–6.

[11] C. Sommer, O. K. Tonguz, and F. Dressler, "Adaptive Beaconing for Delay-Sensitive and Congestion-Aware Traffic Information Systems," in *2nd IEEE Vehicular Networking Conference (VNC 2010)*. Jersey City, NJ: IEEE, December 2010, pp. 1–8.

[12] F. J. Ros, P. M. Ruiz, and I. Stojmenovic, "Reliable and Efficient Broadcasting in Vehicular Ad Hoc Networks," in *69th IEEE Vehicular Technology Conference (VTC2009-Spring)*. Barcelona, Spain: IEEE, April 2009, pp. 1–5.

[13] A. Khan, I. Stojmenovic, and N. Zaguia, "Parameterless broadcasting in static to highly mobile wireless ad hoc, sensor and actuator networks," in *22nd International Conference on Advanced Information Networking and Applications*, Okinawa, Japan, March 2008, pp. 620–627.

[14] A. Festag, H. Fussler, H. Hartenstein, A. Sarma, and R. Schmitz, "FleetNet: Bringing Car-to-Car Communication into the Real World," in *11th ITS World Congress and Exhibtion*, Nagoya, Japan, Oct. 2004.

[15] C. Lochert, B. Scheuermann, M. Caliskan, and M. Mauve, "The Feasibility of Information Dissemination in Vehicular Ad-Hoc Networks," in *4th Annual Conference on Wireless On demand Network Systems and Services (WONS 2007)*, Obergurgl, Austria, January 2007, pp. 92–99.

[16] Y. Ding, C. Wang, and L. Xiao, "A Static-Node Assisted Adaptive Routing Protocol in Vehicular Networks," in *4th ACM International Workshop on Vehicular Ad Hoc Networks (VANET 2007)*, Montréal, QC, Canada, September 2007, p. 68.

[17] C. Morency and M. Trépanier, "Characterizing Parking Spaces Using Travel Survey Data," *CIRRELT*, May 2008.

[18] T. Litman, "Parking management: strategies, evaluation and planning," *Victoria Transport Policy Institute*, vol. 25, 2006.

[19] C. Sommer, Z. Yao, R. German, and F. Dressler, "Simulating the Influence of IVC on Road Traffic using Bidirectionally Coupled Simulators," in *27th IEEE Conference on Computer Communications (INFOCOM 2008): IEEE Workshop on Mobile Networking for Vehicular Environments (MOVE 2008)*. Phoenix, AZ: IEEE, April 2008, pp. 1–6.

[20] C. Sommer, R. German, and F. Dressler, "Bidirectionally Coupled Network and Road Traffic Simulation for Improved IVC Analysis," *IEEE Transactions on Mobile Computing*, vol. 10, no. 1, pp. 3–15, Jan. 2011.

[21] C. Gawron, "Simulation-based traffic assignment - computing user equilibria in large street networks," PhD Thesis, Univ. of Cologne, 1999.