# The Feasibility of Information Dissemination in Vehicular Ad-Hoc Networks

Christian Lochert*, Björn Scheuermann*, Murat Caliskan‡, and Martin Mauve*

*Institute of Computer Science, Heinrich Heine University, Düsseldorf, Germany
{lochert, scheuermann, mauve}@cs.uni-duesseldorf.de

‡Volkswagen AG, Wolfsburg, Germany
murat.caliskan@volkswagen.de

***Abstract*— In this paper we consider information dissemination in vehicular ad-hoc networks (VANETs) in city scenarios. Information dissemination is an important building block of many proposed VANET applications. These applications need a certain dissemination performance to work satisfactorily. This is critical during the rollout of VANETs, when only few cars participate. After analytical considerations, we focus on simulations using a detailed model of a whole city. We assess the dissemination performance depending on the amount of equipped vehicles on the road. For few equipped vehicles, we show that dissemination speed and coverage will not be sufficient. Therefore, we propose to use specialized, but simple and cheap infrastructure, Stationary Supporting Units (SSUs). If a small number of SSUs is installed in a city and connected via some backbone network, the dissemination performance improves dramatically, especially during the VANET rollout phase. Thus, SSUs allow for a faster and earlier rollout of working, dissemination-based VANET applications.**

## I. INTRODUCTION

In the context of vehicular ad-hoc networks (VANETs), a number of safety and convenience applications have been proposed. Many of them rely on distributing data, e. g., on the current traffic situation, or on free parking lots. Often, the data needs to be distributed over long distances, for example to allow a driver to choose between different arterial roads when driving into the city center. Typically, the applications are based on some form of proactive information dissemination. Although a variety of optimizations is possible, the basic idea of such a dissemination scheme is that every node maintains a knowledge base, where it stores known information, e. g., on road conditions or parking lot occupancies. The nodes periodically broadcast all or parts of their knowledge to their neighbors. Upon reception, the nodes integrate new or updated information into their knowledge base. Step by step a local overview of the total scenario emerges.

In this paper, we tackle a fundamental question, which is highly relevant for all such applications: is the required data dissemination feasible at all, and what requirements need to be fulfilled to make it work? While it is fairly obvious that information dissemination will work well when all or nearly all vehicles participate in the vehicular ad-hoc network, this is not at all self-evident during the early rollout of VANETs, where the number of equipped vehicles is small.

The focus of this paper is on city scenarios, where the environment is rather complex and many of the proposed application types are particularly useful. While, e. g., up-to-date traffic information on the comparatively small number of highways could also be collected at a central point and distributed via wireless infrastructure, like UMTS or satellites, the detailed, geographically small-scale, and continuously updated information that is necessary for city environments may stress centralized approaches beyond their limits.

We use a specialized simulation environment for an inner-city VANET scenario, in order to evaluate the performance that a dissemination protocol can achieve. In particular, we look on upper bounds for metrics like the speed and efficiency of the information dissemination, depending on the number of equipped vehicles on the road. By means of an idealized stub dissemination protocol, we are able to evaluate the general feasibility, independent from a specific protocol or application. Because our simulation scenario is closely modeled after a real city, it allows us to give concrete numbers on the necessary amount of vehicles provided with car-to-car communication equipment in order to achieve a certain performance. Our results demonstrate that, in particular during the initial rollout of VANET technology, information dissemination is not practically feasible without the use of supporting infrastructure. On the other hand, however, we also show that a limited amount of simple and cheap infrastructure can be the critical factor that improves the situation significantly, and allows for working dissemination-based applications.

The remainder of this paper is structured as follows. In Section II we review related work. Following that, in Section III, some theoretical considerations are presented, leading to general insights on how information dissemination happens in an inner-city VANET, and where the limiting factors are. The simulation environment used for the evaluation is described in Section IV, results of our simulation study are presented in Section V. In Section VI, we show how these results can be significantly improved by infrastructure support when only few cars are equipped. Finally, we conclude our paper in Section VII.

## II. RELATED WORK

In recent years, increasing research effort has been put into the area of VANETs. Most of this research deals with network-centric aspects like, e. g., routing. However, also a number of applications has been proposed that use vehicular ad-hoc communication to increase driving comfort or safety. In particular convenience applications often use information dissemination. Thus, in their context, our contributions here are of immediate relevance. For example, in [1] and in [2] the authors present VANET-based traffic information services. Road conditions and information on traffic jams are disseminated, and can then be used for navigation and early warning. Although both concentrate on highway scenarios, a similar service can also be envisioned for city environments. The authors of [3] and [4] focus on how to guide a car to the most convenient parking lot in a city using information disseminated in a wireless multihop network. Communication protocols for data dissemination in cities have been proposed in [5]–[8].

There also exist performance analyses of general information dissemination. These, however, deal only with highway scenarios. The situation on a highway cannot be directly compared to an inner-city environment, because highways are practically one-dimensional, while in a city the number of junctions and intersections is typically high. Moreover, the driving speed and the traffic pattern are also largely different, which can severely influence the dissemination speed.

In [9], the authors study information dissemination in VANETs depending on the number of cars in a scenario. However, they analyze only unidirectional traffic along a single road. A study of a one-dimensional highway scenario is presented in [10]. The authors assess the network utilization analytically, and conduct simulations regarding this aspect as well as the dissemination performance. In particular, they focus on the question whether oncoming traffic should be used for information transport or not.

## III. CONNECTIVITY IN VANETS

Let us consider an application for VANETs that uses proactive data dissemination in a city environment. We now look at the connectivity that can be expected if the density of equipped vehicles is low. The network connectivity is a limiting factor for information dissemination. A low connectivity of the network may have serious effects on the dissemination speed, and thus on the up-to-dateness of the information. It also determines how long it takes for a vehicle entering the VANET until it meets other participating vehicles and receives any information at all.

Data can be passed on from vehicle to vehicle by wireless communication, or it can be carried around by a car, and is thus transported with the car's locomotion. Both ways allow the information to reach different network areas, and in practice both will coexist. However, the possible dissemination speed is much higher for wireless communication.

Data transport via locomotion happens at the car's speed, in cities typically at most 50 km/h. The propagation speed via wireless communication along a chain of equipped vehicles, where each one is within the communication range of its predecessor, can be approximated as follows. Let us consider a number of equipped vehicles driving at distances in the order of a typical radio communication range between two consecutive cars, like 250 m. Before newly arrived information is propagated further by a car, there will be some delay. This delay mainly occurs because it takes some time until the next broadcasting interval has elapsed, but other factors like, e. g., backoff times also add up to this. The transmission time itself is negligibly small in comparison. Even if we estimate the delay pessimistically to be one second, we get a data propagation speed along the chain of one radio range per second, which is 900 km/h.

Furthermore, in contrast to data dissemination by locomotion, wireless propagation is possible in and against the driving direction. This becomes relevant when taking into account that cars are particularly interested in information on the areas ahead of them. Considering cities, there are often asymmetric traffic situations, where many vehicles are driving in the same direction, e. g., towards the commercial quarters in the morning rush hour, while the oncoming traffic is relatively sparse. So, few cars drive in the more important dissemination direction, and thus data transport by locomotion will work particularly bad.

These simple reflections demonstrate that the formation of chains of equipped vehicles, each driving within the radio range of its respective predecessor, is essential for a satisfying dissemination performance. Thus, we are now interested in the probability that such a chain of equipped vehicles exists on a road. Assume that the distances between equipped cars are exponentially distributed and pairwise independent. This is a standard assumption [11]. It is optimistic in the case of city scenarios, as will soon become clear, but it serves well for a best-case estimation.

Let $r$ be the radio communication range, and let $\rho$ denote the average number of equipped vehicles per radio range of road. We call $\rho$ the *equipment density*. Let $d_i$ be exponentially distributed, pairwise independent random variables. $d_i$ stands for the distance between the $i$-th equipped vehicle and its successor. The parameter $\lambda$ of the exponential distribution of the $d_i$ is chosen as $\lambda = \rho$, so the expected equipment density of our chain matches $\rho$. The probability that $n$ consecutive equipped vehicles drive at distances of less than $r$, can now be calculated as

$$P_v(\rho, r, n) = \prod_{i=1}^{n-1} P(d_i \le r) = \left(1 - e^{-\rho r}\right)^{n-1}.$$

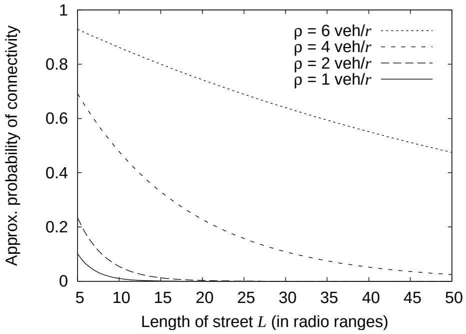
For disturbed traffic, which is common in cities, cars tend to form clusters on the road. Consider for example a traffic light, where a number of cars queue and then continue driving closer together, in a cluster. In this case the assumption of exponentially distributed inter-arrival times does not apply. Then, the above estimation tends to be too optimistic: at the same average equipment density, the formation of clusters means that longer gaps—between the clusters—become more probable. Therefore, a non-connected situation can be expected to be even more likely.

Assuming a sufficiently long road segment of length $L$ and a sufficiently large equipment density $\rho$, the number of equipped cars on the road segment can be approximated as $\rho \cdot L$. Again for exponentially distributed inter-vehicle distances, the probability $P_c$ that radio connectivity exists and thus fast dissemination by multihop wireless communication over the whole distance $L$ can happen at some time instant is then

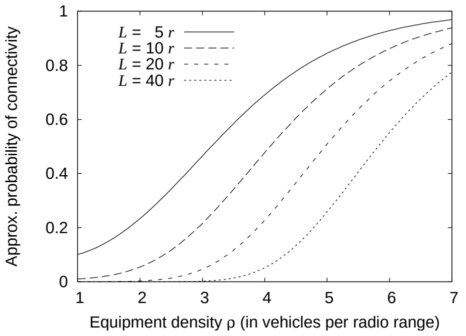
$$P_c(\rho, r, L) \approx \prod_{i=1}^{\lfloor \rho L \rfloor} P(d_i \leq r) \approx \left(1 - e^{-\rho r}\right)^{\rho L}.$$

This means that the probability of continuous connectivity decreases exponentially over an increasing distance $L$. Therefore, multihop radio transport alone will *not* be sufficient, and data transport via locomotion is an important additional factor, as long as the equipment density does not become very high. The interplay of the two ways of data transport determines the achievable performance of data dissemination in a city environment.

The effects of these characteristics are depicted in Figure 1. It is quite obvious that information dissemination solely by chains of equipped vehicles is far from sufficient at equipment densities as they occur during VANET rollout.



(a) Connectivity over street length.



(b) Connectivity over equipment density.

Fig. 1. Approximated probability of radio connectivity dependent to the street's length and equipment density.

## IV. SIMULATIVE EVALUATION METHODOLOGY

In the following, we present a simulation study on the feasibility of information dissemination in a city environment. It is carried out using a VANET simulation environment. We now introduce this environment as well as a stub application that we have used.

### A. *Simulation Environment*

The simulation environment has originally been presented in [12]. It combines specialized simulators for the simulation of vehicle movements on the one hand, and for the simulation of the wireless network on the other hand. The simulators exchange data continuously and interactively, so each of them can react to events from the other one.

Vehicular movements are generated by the microscopic traffic simulator VISSIM [13]. It includes, for example, multi-lane traffic, traffic lights, and different types of vehicles. It also takes driver-specific behavior into account. We use a traffic model of the extended downtown area of Brunswick, Germany, covering a geographical area of about 250 km$^2$, with more than 500 km of roads and up to 10 000 vehicles. The vehicular traffic in the model is based on extensive measurements taken by the city of Brunswick for the purpose of traffic planning. It models the time between 6:00 am and 10:00 am. VISSIM is coupled with the well-known network simulator ns-2 [14] in version 2.29. The combination of VISSIM and ns-2 allows for a detailed simulation of both, vehicle movements and network events.

In ns-2, we use the two-ray ground propagation model with a communication range of 250 meters and a carrier sense range of 550 meters. The network simulator is enhanced with an obstacle modeling that does not allow radio signals to propagate through the walls of buildings. IEEE 802.11 is employed as the MAC protocol.

### B. *Equipment Density*

Since we are interested in the influence of the amount of car-to-car enabled vehicles on the protocol performance, the question arises which metric one should use to describe this factor. The *penetration ratio* (or *market penetration*) is commonly used. It is defined as the percentage of equipped vehicles, out of all vehicles.

We, however, consider the penetration ratio inappropriate for our purposes. The number of cars on the road changes largely over time. In the night it can be orders of magnitude lower than during rush hour. This means that a protocol can work very well at a low penetration ratio during rush hour, since still many equipped cars are on the road. On the other hand, even a very high penetration ratio can be insufficient if the traffic volume is low. Therefore, we use the *equipment density* $\rho$. It is, as defined above in Section III, the number of vehicles participating in the VANET per radio range of road. The equipment density is independent from the total traffic volume.

In the Brunswick model, a penetration ratio of 100 % with a radio communication range of 250 meters corresponds to an average equipment density between 2.25 and 5 $\frac{\text{vehicles}}{\text{radio range}}$, depending on the simulated time of day. However, the inhomogeneous distribution of vehicles has to be considered, so the local equipment density at some point can be higher or lower.

### C. *Considered Application*

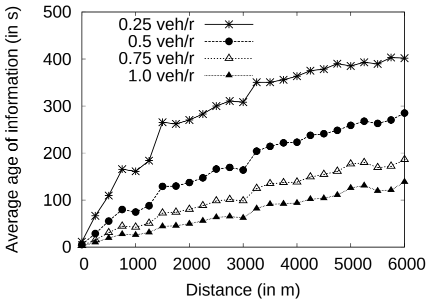
We consider a simple stub dissemination application for our simulations. Whether information on one single data source or on many of them is disseminated influences the amount of information that is redistributed, and thus the necessary network bandwidth. It does not, however, affect the network connectivity. Regarding the utilized network bandwidth, many optimizations, e. g., by using data aggregation strategies, are possible. Optimizing the network connectivity by means of protocol design is not as easily possible. This is why we concentrate on the latter aspect here. Consequently, for our purposes, it is sufficient to use only one single data source.

We place this data source in the city center of the scenario. Each car passing by will measure the current “value” of this data source, which is simply a timestamp. This information is then proactively disseminated by periodic broadcasting, as described above. The vehicles use a periodic broadcasting interval of one second, the broadcasted packets have a size of 1 KB. Whether information is available in which vehicle at which point in time, and how old this information is, allows us to draw conclusions on how well information can be disseminated in a vehicular ad-hoc network.

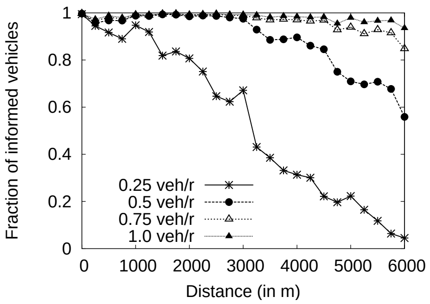
## V. RESULTS

For the evaluation of information dissemination in VANETs, we have performed simulations over a wide parameter range. Figure 2(a) shows the average age of information available in a vehicle as a function of the distance from the data source. It can be seen that the age of the information grows approximately linearly with the distance. The propagation speed rises significantly with increasing equipment density. This is because the probability of the formation of long chains increases with growing equipment density. This in turn means that data transport via wireless communication becomes more and more predominant, while the importance of transport via locomotion decreases.

At a low equipment density, the average duration for the dissemination of information to the outer areas can reach a value as high as 400 s. But a low equipment density has an even more serious influence on the probability of a vehicle knowing anything about the data source *at all*. This statistic, after 500 s of simulation time, is depicted in Figure 2(b). The probability to obtain information at an increasing distance decreases rapidly. The main reason for this trait is that it takes some time after a vehicle starts its trip from a residential area, a parking lot, etc., until it meets another car from which it can obtain information. From the results it can be seen that a relatively high equipment density is necessary for sufficiently reliable information dissemination. Consequentially, the rollout phase of a VANET application, where only a low equipment density is available, is highly problematic.



(a) Average age of information.



(b) Fraction of informed cars.

Fig. 2. Dissemination without infrastructure support.

In order to gain more information on the exchange of information within a VANET, we evaluated in which geographical regions the highest number of successful information transfers happen. A successful information transfer takes place whenever a car receives a broadcast that contains more up-to-date information than it already had in its knowledge base. Figure 3 shows the city of Brunswick on the x- and z-axis. The small-scale density of successful information transfers is plotted on the y-axis. Because only the relative heights of the peaks are relevant here, we have left out the axis labels, keeping the figure concise. It can be seen that, apart from the inner city where the information originally stems from, most successful information transfers occur in few, geographically limited areas. These are located mainly at the ends of and along the main arterial roads. It is here where cars with different knowledge meet. We therefore call these areas *communication market places*. They are vital for successful information dissemination.

## VI. STATIONARY SUPPORTING UNITS

The results presented above clearly show that during the rollout of VANET technology some kind of support is needed. Otherwise, many envisioned applications are unlikely to work until a large fraction of vehicles participates. We therefore

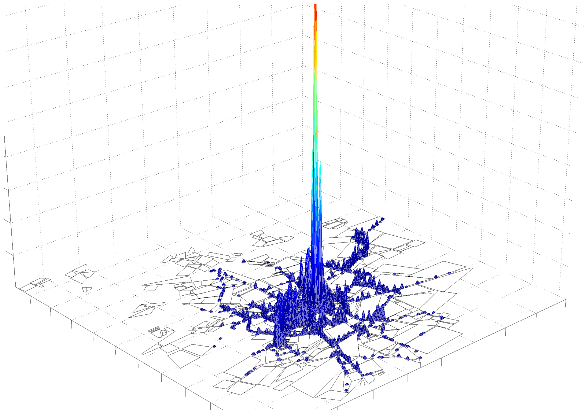


Fig. 3. Geographical distribution of successful information transfers.

propose to install cheap, stationary devices at strategic positions. These *Stationary Supporting Units (SSUs)* participate in the VANET. They collect and redistribute information, thereby leveraging the dissemination in the network. The SSUs may either be stand-alone units, or they can be connected over some backbone network. The computational and memory resources needed for an SSU and therefore their hardware costs are very limited. While stand-alone SSUs are particularly cheap, networking them implies additional expenses for the backbone connection, which might be realized, e. g., via wireless infrastructure networks like WiMAX or UMTS. Because of the higher cost per SSU the possible number of networked SSUs is much more limited than that of the non-networked variant.

Just like the cars themselves, SSUs receive information from the VANET and periodically rebroadcast their knowledge. The most important difference to vehicles is that SSUs do not move. Besides that, networked SSUs share a common knowledge base. This means that information learned by one SSU is rebroadcasted by all of them.

### A. Positioning of SSUs

A central question that now arises is where to position the SSUs, in order to allow for a best-possible support of the VANET. In the following, we analyze different heuristics of the positioning of SSUs, and we assess whether networking the SSUs is worth the additional effort, i. e., whether few networked or many non-networked SSUs perform better.

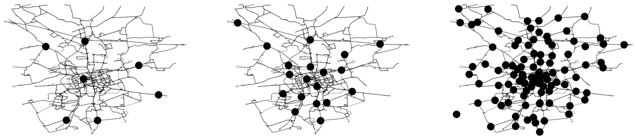
We concentrate on three possible strategies for positioning the SSUs:

*1) At market places:* The identification of communication market places led us to the idea to install the SSUs there. Since many cars learn new information at the market places, in particular networked SSUs promise to achieve that the information is as up-to-date as possible. There is a small set of clearly predominating communication market places. So, in our first strategy, the very limited number of seven SSUs is installed. One is located in the city center, the others at the most predominant information market places in the periphery. We assess SSUs at communication market places both stand-alone and networked.

*2) At high traffic density areas:* The communication market place strategy is based on the observed communication pattern in the network. It is also possible to select strategically promising positions based directly on the vehicular traffic pattern. In our second strategy, SSUs are installed at high traffic density areas, along the main roads. There, typically relatively few successful information transfers happen, but SSUs might assist to bridge gaps between chains of vehicles by storing the information and passing it on when the next vehicles arrive. Since the high traffic density areas outnumber the communication market places, this strategy uses more supporting units. We use 19 SSUs in our simulations, and again simulate them stand-alone and networked.

*3) Randomly distributed:* As a last heuristic we have placed 100 SSUs randomly within the road network. A that high number of SSUs can potentially improve the connectivity of the network significantly. However, the effort of installing that many SSUs is only feasible without a backbone connection for each one. So, this strategy is simulated only for non-networked SSUs.

The positions of the supporting units in Brunswick's road network for all three positioning strategies are depicted in Figure 4.



(a) At market places.

(b) At high traffic density areas.

(c) Randomly distributed.

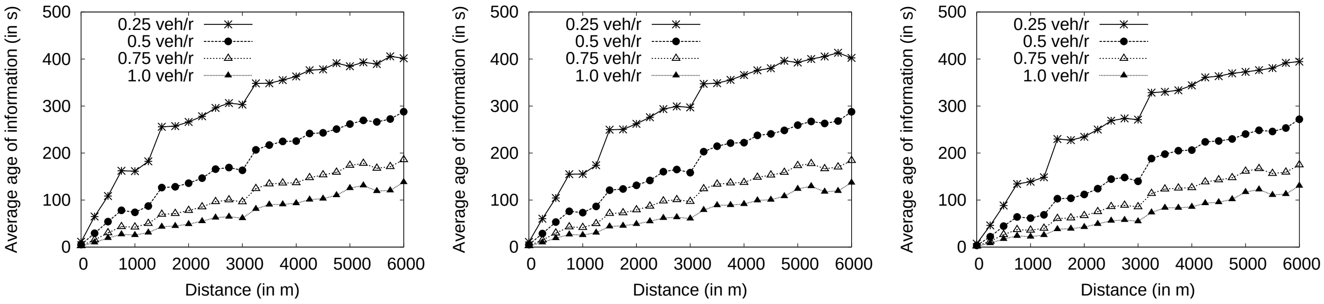
Fig. 4. Positioning of stationary supporting units.

### B. Simulation Results

Figures 5 and 6 show the results of the simulations with stand-alone SSUs. In comparison to the results without any supporting units, the information age and the number of informed cars improve only slightly, even for the very high number of SSUs in the random positioning heuristic.

In contrast, Figures 7 and 8 show the advantages of networked supporting units. Compared to the results without or with stand-alone SSUs, a significant improvement can be achieved, especially in regions far away from the information source. The improvement is also large for low equipment densities and few SSUs. In particular, as depicted in Figures 7(b) and 8(b), the fraction of informed cars increases dramatically. During the rollout phase this can make the difference between a well-working and a non-working service.

All of the figures presented so far present the results in dependency of the distance from the data source, but they do not show the geographical distribution of the information age. In Figure 9, the information age after 500 s of simulation time at each point of the scenario is depicted. The figure is a Voronoi diagram, i. e., each point is colored according to the closest vehicle. The same shade indicates the same age of

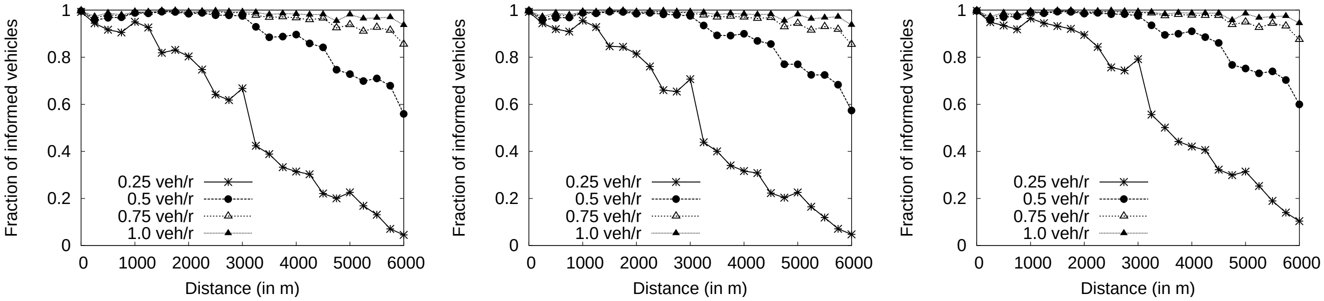


(a) At market places.

(b) At high traffic density areas.

(c) At randomly chosen locations.

Fig. 5. Stand-alone stationary supporting units—Average age of information.



(a) At market places.

(b) At high traffic density areas.

(c) At randomly chosen locations.

Fig. 6. Stand-alone stationary supporting units—Fraction of informed cars.

information. The darker an area is, the more up-to-date is the available information. White areas indicate that no information is available. The positions of the supporting units, according to Figure 4, can easily be spotted in Figure 9(c). The most current information can be found in their vicinity.

In these plots, the strong dependency of the age of information on the equipment density is once again visible. Equipment densities of approximately $0.25\,\frac{\text{vehicles}}{\text{r}}$ without stationary supporting units show an acceptable coverage only of the downtown area. In regions further away, the information becomes more and more outdated, and more and more vehicles are completely uninformed. Stand-alone supporting units cannot improve this situation significantly, so the insights of the above presented results are confirmed.

It is evident that networked SSUs influence the up-to-dateness of information beneficially. This is even true if the equipment density is low, and if only very few SSUs are used. With both analyzed positioning strategies, but in particular with the slightly higher number of SSUs at high traffic density areas, the cars can be informed quickly and accurately.

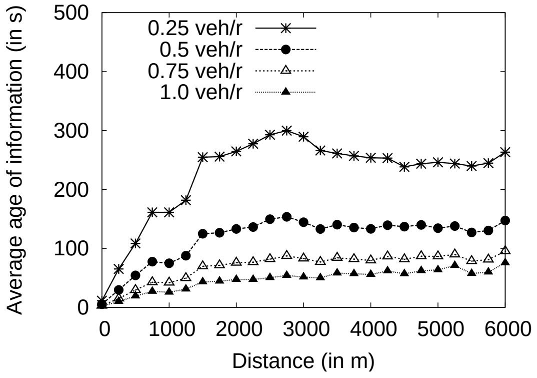
Figures 9(f)–9(j) underline that at higher equipment densities the information dissemination starts working much better. However, the dissemination is still largely improved by networked SSUs.

## VII. CONCLUSION

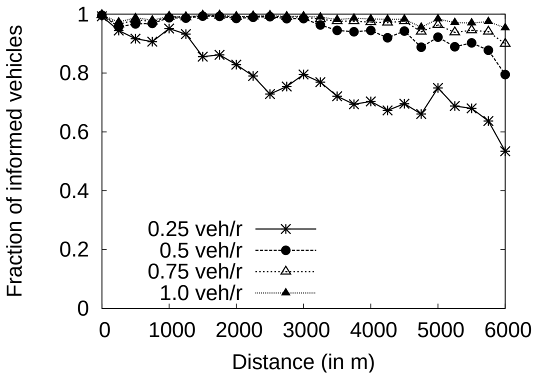
The theoretical results as well as the simulation results presented in this study deal with the information dissemination of VANETs in a city environment, and show general limitations of the approach. The simulation results of a city scenario indicate that a dissemination application can operate satisfactorily starting from equipment density averages of around $0.25\,\frac{\text{vehicles}}{\text{radio range}}$. In the examined scenario this corresponds to a penetration ratio of approximately 5 % during rush hour (at 8:00 am), with a radio range of 250 m.

We identified the formation of chains of equipped vehicles as a vital mechanism to ensure fast information dissemination. Along these chains, information can be transmitted much faster than by carrying the information in a vehicle. With rising equipment density the probability for the formation of long chains, and thus their effectiveness, increases.

During VANET rollout, stationary supporting units can be used to facilitate the information dissemination, in particular for data transport against the main direction of traffic. To achieve this goal, the SSUs need to be networked, sharing a common knowledge base. Then, they achieve both a higher probability to receive information at all, and more up-to-date information.

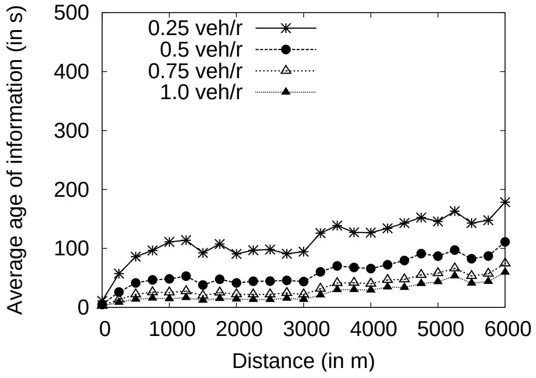


(a) Average age of information.

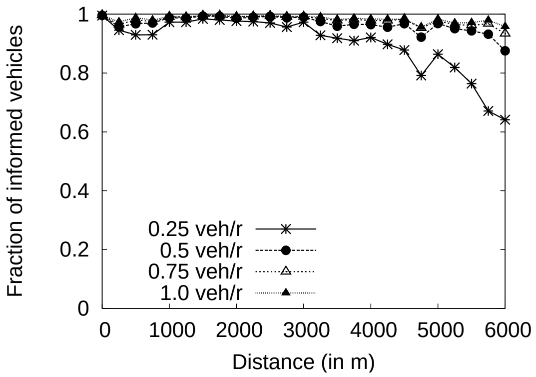


(b) Fraction of informed cars.

Fig. 7. Networked stationary supporting units at information market places.



(a) Average age of information.



(b) Fraction of informed cars.

Fig. 8. Networked stationary supporting units at high traffic density areas.

## REFERENCES

[1] L. Wischhof, A. Ebner, H. Rohling, M. Lott, and R. Halfmann, "SOTIS—A Self-Organizing Traffic Information System," in *VTC '03-Spring: Proceedings of the 57th IEEE Vehicular Technology Conference*, vol. 4, 2003, pp. 2422–2446.

[2] T. Nadeem, S. Dashtinezhad, C. Liao, and L. Iftode, "TrafficView: traffic data dissemination using car-to-car communication," *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 8, no. 3, pp. 6–19, 2004.

[3] P. Basu and T. D. Little, "Wireless Ad Hoc Discovery of Parking Spaces," in *Workshop on Applications of Mobile Embedded Systems (MobiSys 2004)*, June 2004.

[4] M. Caliskan, D. Graupner, and M. Mauve, "Decentralized Disovery of Free Parking Places," in *VANET '06: Proceedings of the 3rd ACM International Workshop on Vehicular Ad Hoc Networks*. Los Angeles, California, USA: ACM Press, Sept. 2006.

[5] H. Wu, R. Fujimoto, R. Guensler, and M. Hunter, "MDDV: a mobility-centric data dissemination algorithm for vehicular networks," in *VANET '04: Proceedings of the 1st ACM International Workshop on Vehicular Ad Hoc Networks*. Philadelphia, PA, USA: ACM Press, Sept. 2004, pp. 47–56.

[6] G. Korkmaz, E. Ekici, F. Özgüner, and Ü. Özgüner, "Urban multi-hop broadcast protocol for inter-vehicle communication systems," in *VANET '04: Proceedings of the 1st ACM International Workshop on Vehicular Ad Hoc Networks*. Philadelphia, PA, USA: ACM Press, Sept. 2004, pp. 76–85.

[7] M. Saito, M. Funai, T. Umedu, and T. Higashino, "Inter-vehicle Ad-hoc Communication Protocol for Acquiring Local Traffic Information," in *Proceedings of the 11th World Congress on ITS*, 2004.

[8] S. Goel, T. Imielinski, and K. Ozbay, "Ascertaining viability of WiFi based vehicle-to-vehicle network for traffic information dissemination," in *Proceedings of the 7th International IEEE Conference on Intelligent Transportation Systems*, 2004, pp. 1086–1091.

[9] H. Wu, R. Fujimoto, and G. Riley, "Analytical models for information propagation in vehicle-to-vehicle networks," in *VTC '04-Fall: Proceedings of the 60th IEEE Vehicular Technology Conference*, vol. 6, 2004.

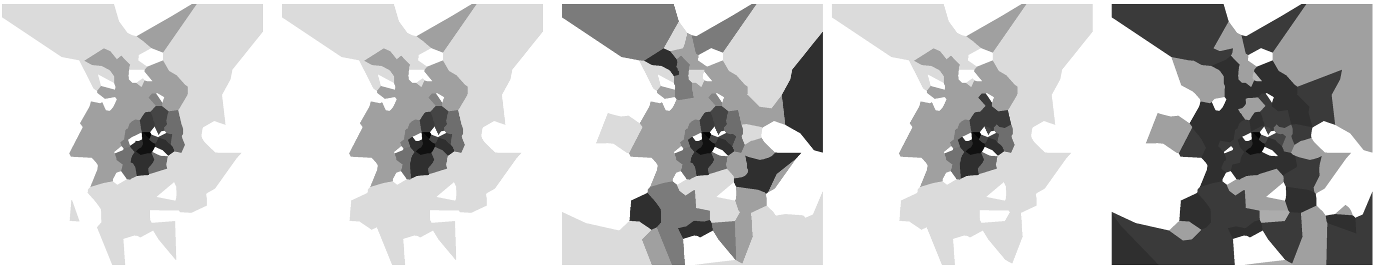
[10] T. Nadeem, P. Shankar, and L. Iftode, "A Comparative Study of Data Dissemination Models for VANETs," in *MobiQuitous '06: Proceedings of the Second Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services*, July 2006.

[11] M. Rudack, M. Meincke, and M. Lott, "The Dynamics of Ad-Hoc Networks for Intervehicle Communications," in *ICWN '02: Proceedings of the International Conference on Wireless Networks*, 2002.

[12] C. Lochert, M. Caliskan, B. Scheuermann, A. Barthels, A. Cervantes, and M. Mauve, "Multiple Simulator Interlinking Environment for Inter Vehicle Communication," in *VANET '05: Proceedings of the 2nd ACM International Workshop on Vehicular Ad Hoc Networks*, Cologne, Germany, 2005, pp. 87–88.

[13] PTV AG, "Vissim," http://www.ptv.de/cgi-bin/traffic/traf_vissim.pl.

[14] "The Network Simulator ns-2," http://www.isi.edu/nsnam/ns/.



(a) $\rho = 0.25\,\frac{\text{vehicles}}{\text{r}}$, no SSUs.

(b) $\rho = 0.25\,\frac{\text{vehicles}}{\text{r}}$, stand-alone SSUs at market places.

(c) $\rho = 0.25\,\frac{\text{vehicles}}{\text{r}}$, networked SSUs at market places.

(d) $\rho = 0.25\,\frac{\text{vehicles}}{\text{r}}$, stand-alone SSUs at high traffic density areas.

(e) $\rho = 0.25\,\frac{\text{vehicles}}{\text{r}}$, networked SSUs at high traffic density areas.

(f) $\rho = 0.75\,\frac{\text{vehicles}}{\text{r}}$, no SSUs.

(g) $\rho = 0.75\,\frac{\text{vehicles}}{\text{r}}$, stand-alone SSUs at market places.

(h) $\rho = 0.75\,\frac{\text{vehicles}}{\text{r}}$, networked SSUs at market places.

(i) $\rho = 0.75\,\frac{\text{vehicles}}{\text{r}}$, stand-alone SSUs at high traffic density areas.

(j) $\rho = 0.75\,\frac{\text{vehicles}}{\text{r}}$, networked SSUs at high traffic density areas.

Fig. 9. Geographical information dissemination after 500 seconds.