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# Information-Centric Opportunistic Data Dissemination in Vehicular Ad Hoc Networks

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***Abstract*— This paper addresses the problem of efficient data dissemination in Vehicular Ad Hoc Networks (VANETs), which particularly suffer from changing densities in the network topology due to congested and sparse traffic on the roads. We present a new network layer protocol in the family of geographic network protocols, which makes use of distance and time information following a dissemination strategy to efficiently distribute messages adapting to the varying densities in VANETs. We have evaluated the protocol in different road density scenarios and its performance has been proved in comparison to two other recent protocols of the art.**

***Keywords*— GeoNet Routing, Opportunistic Data Dissemination, VANET, DENM, CAM, Car-2-Car**

## I. Introduction

In the last years, an important research effort on Intelligent Transportation Systems (ITS) has been done in order to improve road safety and enhance traffic efficiency. Car-2-Car (C2C) communications is the technology which aims to interconnect road vehicles by means of wireless communications. Vehicles and road-side units will be able to exchange information about the position and other aspects of the vehicle's state, as well as the general traffic situation, enabling cooperative situation awareness and a set of fundamentally new applications.

An example of such a Car-2-Car application is *Vehicle to Vehicle (V2V) Decentralized Notification* [1] which provides information about special events and road conditions to drivers, like roadwork construction or an accident. A vehicle detecting a hazardous situation creates an event message which needs to be disseminated to all vehicles in the vicinity of the event.

The relevance of these notifications has time and spatial constraints. Network protocols should use these parameters to disseminate the information only 'when' and 'where' it is relevant. Consequently, an optimized while still not overly complex data dissemination strategy should be information-centric as it depends on the event's temporal and spatial information.

The highly dynamic topology and the non-uniform distribution of the nodes in VANETs raise a great challenge for networking strategies. In high density situations, for example during a traffic jam, a large number of vehicles may detect the situation and send notifications about it. In addition, in multi-hop enabled VANETs these notifications may even be rebroadcasted which leads to a lot of redundant information in the network and cause congestion problems. A good dissemination strategy should try to keep a trade-off between healthy redundancy to overcome unpredicted changes in the network and an economic resource usage.

Similarly challenging is the fact that message propagation in VANETs has to deal with frequent network partitioning. Depending on the type of road, location and time, the node density on the roads can be low, like in the case of rural areas or at night time. The initially low market penetration of vehicles equipped with Car-2-Car technology also leads to sparse networks in particular in the first years after market introduction. This results in situations where the node density is too low to allow for an end-to-end path between two vehicles at a given time, even in multi-hop mode.

Thus, VANETs need scalable data dissemination strategies which can adapt to frequent topology changes and deal with the variable vehicle density. As *V2V Decentralized Notifications* can report dangerous situations for the drivers, the data dissemination should be as fast as possible and high delivery ratios need to be maintained. However, when there is a partition in the network the protocol has to be delay tolerant, storing the message and forwarding it as soon as a new opportunity is found.

It is important that the protocol works in a fully decentralized way, with no need of additional ITS infrastructures along the road or centralized controllers. By using vehicle movements the protocol should be able to keep the message alive in a certain area for some time even on sparse roads. Furthermore, the protocol shall avoid single points of failures and provide a certain degree of redundancy in order to be robust against spontaneous failures. To further increase robustness, the protocol shall avoid dependencies to external data sources and behave failure-tolerant.

The remaining of this paper is organized as follows: In the next section, the data dissemination problem is described formally. In the subsequent section, the state of the art in VANETs networking is summarized. Afterwards, our Information-centric Opportunistic data dissemination algorithm is described in section IV. Section V shows the simulation setup and the results. Finally, section VI presents conclusions and future work.

## II. PROBLEM DEFINITION

The objective of a data dissemination algorithm in VANETs is to disseminate information over a network of (mobile) nodes to those nodes that obtain a utility from it, e.g.:

- avoid an accident with a broken-down vehicle
- find a better route which bypasses the traffic jam

Information is more or less relevant for a node depending on the:

- event location on the node's future driving route
- time period since the event occurred
- criticality (type of event)

In this sense, a warning message of a traffic jam which is located on a road which a node will approach in 1000m is of high utility to this node. On the other hand, a broken-down vehicle warning dated yesterday on a road which the node will not enter is of very low utility for this node.

Thus, the reception probability R has to be in accordance with this utility function:

$$U(x) \sim R \sim P \quad (1)$$

where x represents a vector of relevant inputs to the utility function (e.g. the location of the event, the delay, the criticality, etc). The more utility a node obtains from the message the higher shall be the reception probability and vice versa. With this approach we try to maximize the utility of the communication system.

Besides others (e.g. transmit power adjustment), the rebroadcast of a message is a means to control the reception probability over larger areas. This rebroadcast factor P has to be in accordance with the reception probability R which is aimed for. Finally, to achieve a high utility the rebroadcast probability has to be proportional to the utility function which is obviously the case under the assumption of a uniform node distribution and a deterministic channel model.

## III. RELATED WORK

A simple approach for data dissemination is flooding. In flooding every receiver of a message rebroadcasts the message exactly once. In large networks flooding often is terminated by a maximum time-to-live which limits the number of hops. The simple flooding mechanism is easy to implement and due to the high data replication, message dissemination to all possible receiving nodes is highly reliable. Of course, in this approach the wireless network suffers from exponentially increasing packets which leads to several problems like high contention and a large number of packet collisions.

The larger the number of vehicles rebroadcasting the packet, the higher is the probability of several vehicles trying to access the medium in a certain area at the same time. The situation aggravates if the vehicle density increases, becoming unlikely to have contention-free medium access, in other words, nodes that are able to access the medium directly. In addition, this high contention and the lack of collision detection and RTS/CTS mechanism in broadcast communication make collisions a serious problem.

To reduce or even avoid the negative effects of flooding, an optimized protocol should reduce the number of retransmissions but maintain the delivery ratios obtained by flooding. In our approach the number of retransmissions is reduced by inhibiting certain nodes from rebroadcasting. It is known that flooding results in several problems when the node density is high. This situation is referred to as the *Broadcast Storm Problem* and is for instance analyzed in [2] in the context of MANETs.

In [3] Haas et al. proposed a means to reduce the Broadcast Storm Problem called Gossiping. In Gossiping, if a node receives a message it rebroadcasts it with a probability $P$, so with probability $1\text{-}P$ the packet will be discarded. If $P=1$ Gossiping is equal to flooding. Otherwise, this approach shows an exponential decrease of the reception probability based on the hop number. For instance, a node which is located 5 hops away from the source has a reception probability of $0.8^5=0.33$ if Gossiping is applied with a fixed rebroadcast probability of 0.8.

Since Car-2-Car communications is subject to extremely varying signal propagation characteristics (high signal disturbances in urban areas vs. free-space in rural areas), the communication range varies significantly. Thus, hop based approaches are disadvantageous since they do not reflect the utility function of the event appropriately. A solution to this problem is to use the geographic distance between the event and the forwarder instead of the hop number. This requires a positioning system on each vehicle which can be assumed in vehicles deployed with a Car-2-Car communication device.

State of the art geographic data dissemination algorithms [4] use area-bounded flooding. With this approach one achieves a high reception ratio for all nodes inside this area and a zero reception ratio for all other nodes. The dissemination area is defined by the source node which detected the event and all forwarders use this area definition to decide whether to rebroadcast the message. These kinds of protocols approximate the utility of event information by a fixed area definition with hard boundaries. This binary approach shows a very high redundancy within the area with an immediate drop-out at the borders.

Ni et al. proposed in [2] a distance-based and a location-based scheme (see also [5]) in order to reduce the broadcast storm problem. In both schemes the additional coverage which can be achieved by rebroadcasting the message is calculated by every receiver according its distance and location respectively. Both algorithms have the problem that they rely on a sound calculation of the communication range which is not given due to the aforementioned reasons.

As mentioned previously, in VANETs we encounter the problem of a fragmented network. In order to deal with these partitions, the vehicles need to have the capacity of store and carry the messages for some time, thus the latency requirements for data delivery must be relaxed to some degree. This is the reason that they are considered 'delay tolerant' networks.

Several lines of research consider this delay tolerant approach. The GeOpps protocol [6] exploits the availability of information from the navigation system in order to opportunistically route a message to a certain geographical location. The protocol takes advantage of the navigation system's suggested routes to select the carrier vehicles that are likely to take the information closer to the final destination of the message, each time.

GeoDTN+Nav [7] is a hybrid protocol that includes the greedy mode, the perimeter mode, and the Delay Tolerant Networks (DTN) mode. Switching from one mode to another is made by estimating the connectivity of the network based on the number of hops a packet has traveled, neighbor's delivery quality, and neighbor's direction with respect to the destination.

The drawback of these protocols is that they require that every vehicle is equipped with a navigation system and also the privacy problem raised by the fact that the navigation information of the driver is exposed in the network.

Our work does not have such comprehensive requirements and is more similar to the ones presented in Epidemic Routing [8], where the packet is forwarded whenever another vehicle is in vicinity or in MoVe [9] where the packet is forwarded only to vehicles that drive towards the destination. As in MoVe, we also make the trajectory prediction only based on the knowledge of the neighbor's velocities and headings thus no navigation system is needed.

## IV. INFORMATION-CENTRIC OPPORTUNISTIC DATA DISSEMINATION

### A. *Message types*

There are two types of messages currently under specification in ETSI TC ITS [10], which are routed on the network layer in VANETs:

**-Cooperative Awareness Messages (CAM)** serve as beacons that are sent periodically by all vehicles. They contain basic status information like the current position, speed, acceleration, or heading, as well as the vehicle identifier. As this information is very relevant for safety applications, CAMs are transmitted on the control channel (CCH) using single-hop broadcast. There is an ongoing discussion whether and under which conditions receiving nodes should forward CAMs on one of the service channels (SCH), however, for the time being as CAMs are most relevant in the source vehicle's vicinity, the primary communication method is single-hop broadcast.

**-Decentralized Environmental Notification Messages (DENM)** report the information related with certain events, so they are sent only on event detection. The information contained in DENM is the event type, event location, event timestamp, expected event lifetime and relevant area of the event. These fields are highly important for the data dissemination of DENM messages. They need to be disseminated in a distribution area that is usually larger than the single-hop communication range; hence the network layer will use multi-hop mechanisms to efficiently deliver these safety relevant messages in the control channel. Our protocol is particularly designed for this kind of pattern.

### B. *Geographic Gossiping*

Haas et al. proposed in [3] a hop-based exponential decreasing rebroadcast. In [4] Festag et al. proposed a geographical rebroadcasting with hard boundaries. In the following we propose a data dissemination algorithm which provides the advantages of both kinds of algorithms and at the same time eliminates the disadvantages. In our *Geographic Gossiping* the rebroadcast probability decreases with the geographical distance. Thus, the rebroadcast probability near the event location is high and converges to zero the more far away a forwarder is located from the event location. With a uniform node distribution and a deterministic channel model the requirements of proportion (1) are fulfilled. An exemplary rebroadcast probability is given by the function:

$$P(d) = e^{-\frac{d^2}{2\sigma^2}} \tag{2}$$

with $\sigma$=500m and *d* as the distance between the forwarder and the event location. Thus, the rebroadcast probability distribution looks like the one depicted in figure 1a). The actual reception rate obtained from an exhaustive set of simulations is shown in figure 1b). Within a distance of 350m around the event location the reception probability is 100% because every node which is in the communication range of the source node received the message during the first hop. In the simulations we applied an ideal channel model and, thus, every node in communication range receives the message.

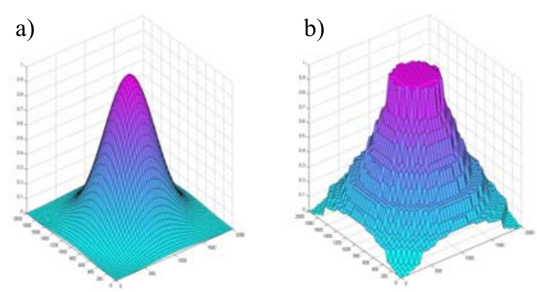


Fig. 1: a) Rebroadcast probability b) Reception probability obtained from simulations

This approach also allows comparing and prioritizing the relevance of different events. If a vehicle receives notifications of different events, like for example the situation shown in the figure 2, it will have to choose which one will be retransmitted in first place. In these cases, event 1 should be given a higher priority because the vehicle is nearer to event 1 than to event 2. In this example we can also see that events can have different utility functions, i.e. event 2 has a denser function than event 1 because it may be less relevant in larger distances. A prioritized handling of events can be achieved, for instance, by a priority queue as it has been applied in [11].

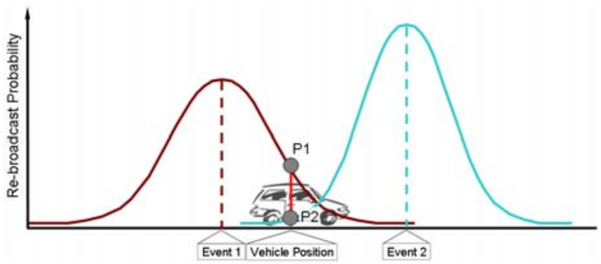


Fig.2: The vehicle receives two event notifications. The utility of event 1 is higher so the probability of rebroadcasting this event is higher

### C. Density-based Gossiping

The above described *Geographic Gossiping* fails, if nodes are not uniformly distributed as it is usually in reality. In this case the reception probability R is not proportional to the geographical re-broadcast probability P(d) with the definition of equation (2). If the node has relatively few neighbors, there is a chance that none of them rebroadcasts the message, thus the message propagation will die. The rebroadcast probability should be set high for vehicles located in sparser areas, as they have less shared coverage. On the other hand, in dense areas the connectivity of the network increases, thus a small rebroadcast probability *P* is sufficient to achieve a high percentage of receptions.

This is the main reason to use a *Density-based Gossiping* similar to the one described by Haas in [3]. The idea is set the probability *P* according to the node density in the area around the rebroadcasting node. The local number of neighbors of a vehicle is a parameter that gives an estimate of network density and can be used to choose the rebroadcast probability.

This technique works under the assumption that every vehicle is aware of the number of its one-hop neighbors. This assumption is justified because all vehicles are beaconing CAM messages every 0.5-2 seconds; thus vehicles have information about the number (as well as geographic position, speed and movement direction) of their current neighbors.

We use different discrete probability values for a discrete set of number range of one-hop neighbors, determined empirically. The best probabilities and ranges values have been extracted through simulations.

Finally, this *probability of rebroadcast based on the network density* and the *probability of rebroadcast based on the distance to the event location* are combined. The final rebroadcast probability is defined as the product of both probabilities. The scheme of the rebroadcast decision is shown in figure 3.

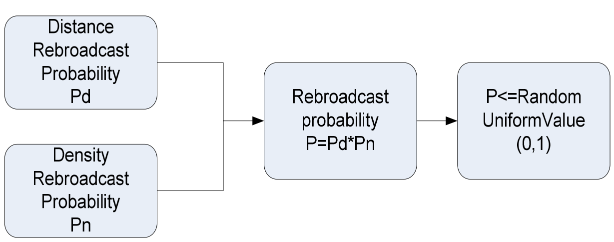


Fig. 3: Implementation of the vehicle rebroadcast decision using distance and density information.

### D. Opportunistic broadcast

So far, scalable message dissemination for high density scenarios has been addressed in the protocol proposed, but the existence of partitions in the network has not been considered yet. The dissemination algorithm described so far dies as soon as a partition is encountered, so in sparse networks the percentage of receptions would be low and some vehicle in or close to the distance of interest will not receive the messages.

In addition, this technique only considers the instant propagation of the messages, whereas environmental notifications usually have a lifetime value which can vary from seconds to days; in other words, the message has to remain alive in the dissemination area as long as it is still relevant for new vehicles that are arriving to the zone. Therefore, the dissemination protocol has to include a functionality which extends the duration of the message propagation.

We have identified different solutions to this problem. The first one consists of periodic rebroadcasts of the message through vehicles or even road-side units, if available. As the vehicle arrival rate (the rate with which new vehicles arrive to the area of interest on average) can be variable, this approach entails the difficulty of how to set the correct rebroadcast period and duration trying not to miss new arriving vehicles and not doing too many unnecessary retransmissions when there are no new vehicles approaching.

The other solution is that vehicles store the packet when a partition is encountered and they wait for a suitable forwarder to transmit the packet to it. The drawback is that this strategy leads to an increasing number of retransmissions if the vehicle arrival rate increases.

Our opportunistic dissemination protocol is a combination of both ideas, where each vehicles will switch between two modes, *periodical mode* and *store and forward mode*, depending on their current number of neighbors, see figure 3 for an illustration.

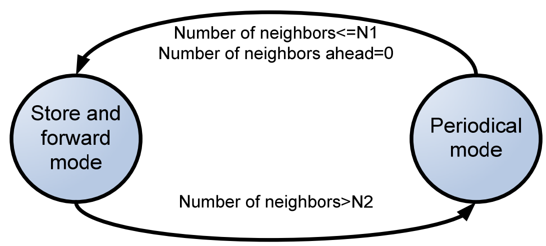


Fig. 4: Two mode model and switching mode conditions

Vehicles are by default in periodical mode, from which they switch into the store and forward mode once the number of neighbors decreases passing a lower threshold *N1* and no other vehicle is known to support increasing density in the dissemination area anytime soon.

Once the vehicle is in store and forward mode and the number of neighbors increases passing *N2*, it switches to periodical mode. *N2* is higher than *N1* in order to establish a hysteresis in the mode transition.

Either of the two modes particularly support the strengths of the respective performance of the algorithm given the current situation as we will describe in the following.

**1) The periodical mode**

In periodical mode vehicles repeat the rebroadcast of messages every certain period of time until the lifetime of the messages is expired. If every vehicle restarts the flooding burst at nearly the same time and the density is high, the protocol will lead to broadcast storms paired with a high packet collision probability. In order to avoid this situation, in our protocol the vehicle will activate a contention procedure, similar to the contention mechanism of CSMA for MAC layer, in which every receiver chooses a random waiting time before attempting to rebroadcast the packet. The first vehicle finishing the waiting time will win the contention and rebroadcast the message. The rest of vehicles that heard this transmission cancel their current waiting times and restart the waiting time value.

In case of a decreasing density of vehicles in the distance of interest, the probability of retransmission will be likely too low and the message will not be retransmitted anymore. That means that the message is lost before its lifetime expires, and therefore, the protocol fails. Hence, this situation is tried to avoid by switching to the store and forward mode.

**2) The store and forward mode**

Store and forward is the strategy that aims to solve the partitions problem storing the packet and carry it over space and/or time between one disconnected part of the network to another. If a vehicle in store and forward mode receives a packet with its lifetime not expired, it will store it, rebroadcasting it at a later point in time when suitable candidates arrive. Suitable candidates are vehicles within the distance of interest or vehicles farther than the distance of interest that are moving towards the event location. By using the neighbor position knowledge and the event location, a vehicle is able to estimate if the forwarder candidate is driving towards the event location or not. Of course, a vehicle can suddenly change its direction but this approach is particularly valid in highway scenarios where vehicles maintain the same direction for long periods of time.

One approach for selecting a good candidate vehicle to store and forward a message builds on the observation that vehicles tend to move in clusters. That means that they drive in groups with similar directions and speed. For the purpose of carrying the message to another partition, it is in principle enough if one vehicle in the cluster carries the message.

Based on this observation the dissemination strategy can be further optimized by applying this as a selection criterion to our protocol. Consequently, the condition for a vehicle to enter in store and forward mode is that there are no more vehicles in front of it, driving in the same direction, so it is the head of its cluster and it will carry the information until another cluster is found. A CAM message from a new vehicle triggers the packet rebroadcast decision. The vehicle decides to rebroadcast if this new vehicle is a good forwarder for the packet.

## V. EVALUATION

This section evaluates the previously described protocol based on comprehensive simulations. For that purpose, the network simulator ns-3 has been chosen. The evaluation is divided in two parts:

In the first part a comparison of density-based flooding with other techniques in a congested scenario is performed. In these tests, vehicles formed a connected network and the message propagation is evaluated.

The second part comprises the evaluation of our opportunistic dissemination protocol in non-connected, i.e. partitioned VANETs.

The two modes described have been evaluated separately and in combination of both.

### A. Scenario description

Our evaluation is based on a freeway scenario [12]. With the purpose of achieving high node density situations, we have modeled a section of a freeway with 8 lanes in each direction. The length of the section is 2000 meters and the width of every lane is 4 meters which makes a scenario with dimensions 2000x64 m. In the case of the opportunistic dissemination protocol evaluation, the tests have been done in a two lanes freeway and a road length of 15 km.

On the freeway, vehicles are modeled to come into the road section and go out of it in random time intervals which are assumed to follow a Poisson process in the simulation. Hence, we have modeled the vehicle arrival times with an Erlang distribution of parameter $k=1$ and the rate parameter $\lambda$ will be a variable of each simulation. The vehicles are equipped with virtual 802.11p wireless radios. All messages are sent using the same (CCH) channel of 10 MHz.

Other simulation parameters are summarized in table 1.

| Parameter | Value |
|---|---|
| Transmission power | 27dBm |
| Average packet size | 400 bytes |
| Data rate | 6 Mbps |
| Vehicles speed | 30 m/s |

Table 1: Parameters used in the simulation experiments.

### B. Measurements

In the congested scenario, the metrics that have been used to evaluate the performance of the protocol are:

**- Probability of reception:** The probability of reception is defined as the number of packet receivers divided by the total number of vehicles in the network. All vehicles are included in the total number as in this case we have a connected network.

**- Maximum delay:** The maximum delay is the time elapsed since the message generation until the last node has received the message.

**- Saved broadcasts:** This metric represents the number of retransmissions that are saved with the protocol. If $r$ is the number of vehicles that receive the packet and $t$ the number of vehicles retransmitting the packet, then the saved broadcasts parameter is calculated as follows:

$$SB = \frac{r-t}{r} \tag{3}$$

In the second part, the opportunistic dissemination evaluation, the comparison has been done in terms of:

**- Percentage of receptions:** Percentage of the vehicles that come into the area of interest that receive the notification message.

**- Mean uncertainty duration:** Average time that vehicles spend in the area of interest not being aware of the notification.

**- Number of retransmission:** Total number of retransmission per minute in the simulation.

### C. *Evaluation results*

#### 1) *Density-based evaluation*

In order to have some background traffic in the network, several notifications are injected into our simulation in addition to CAM messages which are sent by every vehicle with a periodicity of one.

Figure 5 depicts the maximum delay over the total number of vehicles at the moment of sending the message. This parameter increases with the node density for high values of the rebroadcast probability as the contention is higher. In case of *P=1* (flooding), it decreases because the number of receivers is smaller due to the large number of collisions.

Density-based delay remains almost constant with number of vehicles. In this protocol, the reduction of the rebroadcast probability values in every node implies a lower contention as the number of nodes trying to send at the same time is smaller.

Figure 6 represents the probability of reception over the total number of vehicles at the moment of sending the message. Density-based outperforms flooding and gossiping in this parameter as it ensures a good percentage of reception for all vehicle densities. Gossiping needs a large number of vehicles to ensure a good probability of reception, whereas flooding leads to many packet losses if the vehicle density is high.

Finally, in figure 7 the number of saved broadcasts over the vehicle density is shown. The number of saved broadcasts is higher if the rebroadcast probability is lower due to the fact that there are more vehicles that decide not to retransmit the message. As this probability is variable with the density in the case of density-based, the saved broadcasts parameter also represents different values depending on the number of vehicles in the simulation. Better results are obtained when the vehicle density is high because the rebroadcast probability values chosen by the vehicles are lower.

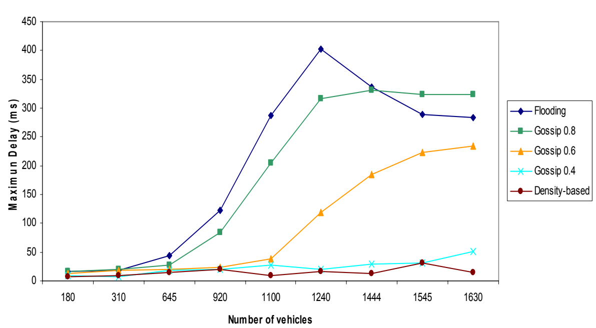


Fig. 5: Maximum Delay

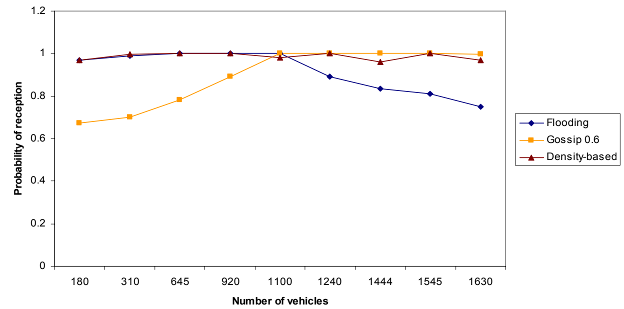


Fig. 6: Probability of reception

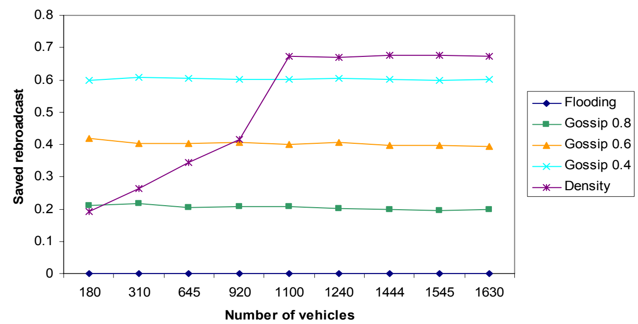


Fig. 7: Saved broadcast

#### 2) *Opportunistic dissemination evaluation*

In this part we will evaluate the message propagation during the whole lifetime of the message, which was chosen to be one day. The aim is to verify how many vehicles received the packet when they are geographically close to the event location, i.e. within the distance of interest, and how long they spend within this distance without receiving the notification. This distance of interest has been chosen to be 800 meters in our simulations. In each simulation, the traffic generation rate is varied in order to have different vehicle densities.

In figure 8, the results for the percentage of receptions are plotted over the traffic generation rate. If only periodical mode is implemented, the protocol fails in sparse situations. The reason is that this mode is restricted to the area near the event and if the network is sparse, vehicles do not encounter any possible forwarder in the area and the packet propagation dies. In store and forward mode this situation does not occur as there are no distance constraints for the packet retransmission. These graphs show the limit in the arrival rate and give an approximated point to switch mode conditions.

In figure 9, we can observe that with only the use of store and forward, most of the vehicles get the message before arriving to the area. By using only periodical flooding in the area the results present the same transition in the values where the protocol starts to fail. The mean uncertainty duration increases when the network is sparse because the message is lost at some point.

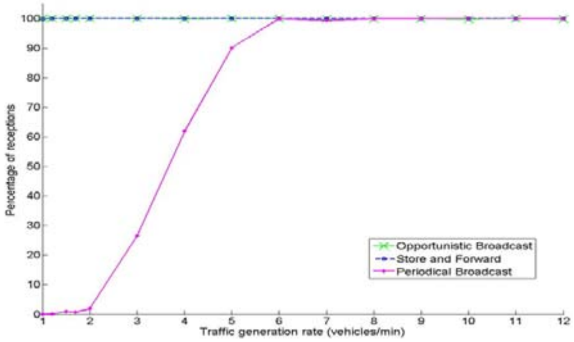


Fig. 8: Percentage of reception

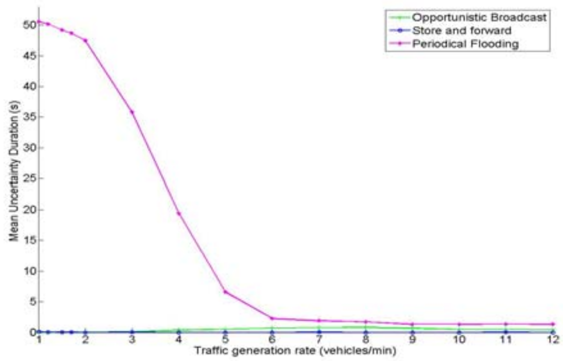


Fig. 9: Mean Uncertainty Duration

So far, store and forward seem to outperform the others. The real benefit of combining both approaches is shown in figure 10. When considering the number of retransmissions per minute, in case of store and forward this number increases with the vehicle density. The opportunistic broadcast is more efficient in the number of retransmissions. Furthermore, if the network is enough populated, it permits to restrict the data dissemination to the area of interest as vehicle change to periodical mode. The overall performance of the combined approach outperforms a small extra delay for some vehicle densities.

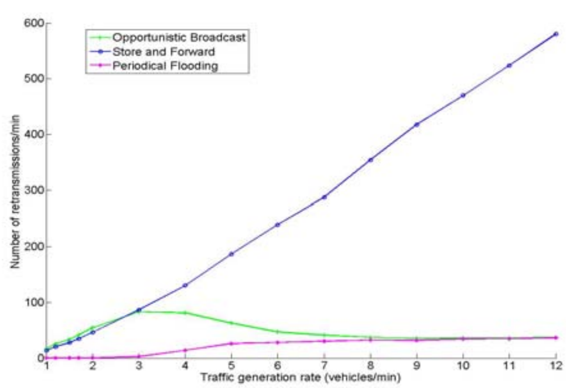


Fig. 10: Number of retransmission per minute

## VI. Conclusions and Future Work

In this paper, we propose an information-centric opportunistic dissemination protocol scalable for different vehicle density situations. In this approach, data dissemination is adaptive to spatial and temporal characteristics of the events.

Density-based approach turns out to be a good solution to minimize the number of rebroadcast packets in high density scenarios while good retransmission latency and number of receptions are maintained.

On the other hands, opportunistic dissemination ensures good performance even in low density situations.

For the future work, an evaluation of the protocol in urban scenarios should be done. Furthermore, if a navigation system is available more information can be considered to select the next packet carrier.

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