A comparison of long-range dissemination techniques for cooperative crash avoidance on highways

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ABSTRACT
In the near future, cars will be equipped with sensors to detect accidents on highways through Intelligent Transport Systems (ITS) using Wireless Sensor Networks (WSN). Information about an accident needs to be transferred to cars near the accident so that chain collisions can be avoided. This information is also relevant for emergency response services to be able to facilitate first aid. Another group interested in this information is infrastructure management, to set up an alternative route, and vehicles approaching the accident location, to be able to take a detour if needed. The dissemination of this information can be done through intelligent sensing and communication systems placed in cars. These systems communicate with each other to relay data sensed on the cars to other road users and possibly infrastructure placed along the road. One of the main problems in disseminating this information is too many messages being sent in high-density traffic, causing packets to collide. This problem is called broadcast storm. This paper compares vehicle to vehicle to vehicle to infrastructure (v2v2i) communication, vehicle to infrastructure to vehicle (v2i2v) communication and vehicle to vehicle to infrastructure to vehicle to infrastructure (v2v2i2v2i) communication. Based on these definitions we can define our problem statement as follows.

2. PROBLEM STATEMENT
To define our problem statement we first need to describe the different techniques for dissemination of cooperative collision avoidance (CCA) information on highways.

2.1 Vehicle to vehicle (v2v)
This technique uses inter-vehicular wireless data transfer to create an ad-hoc network to relay information in a multi-hop network. An overview of communication protocols is given by Hartenstein in [6] and the main challenges by Blum in [2], respectively.

2.2 Vehicle to infrastructure (v2i)
The v2i method relays information gathered by individual vehicles through a road-side infrastructure. Using this technique, the vehicles send CCA information to the infrastructure which broadcasts the relevant information to all vehicles. This technique uses wired communication between infrastructure nodes (infrastructure to infrastructure or i2i) and wireless communication between vehicles (v2v) [1]. Based on these definitions we can define our problem state-
ment. Current research is mostly focused on standardising the way vehicles and infrastructure communicate as well as defining dissemination schemes for v2v and v2i solutions. However, there is a lack of research into selection methods that describe how to choose between the different techniques of data dissemination in CCA on highways.

3. RESEARCH QUESTIONS
The main research question of this paper is the following:

In which situations is vehicle to vehicle communication a superior alternative to vehicle to infrastructure communication, when the goal is cooperative collision avoidance on highways?

To be able to answer this question we must learn more about the relevant properties of existing data disseminating techniques. To do this, we must ask ourselves the following questions:

1. What are the relevant properties of dissemination techniques?
2. To which groups of users does the information need to be relayed?
3. What are the advantages and disadvantages of using vehicle to vehicle communications for cooperative collision avoidance?
4. What are the advantages and disadvantages of using vehicle to infrastructure communications for cooperative collision avoidance?

We will limit our scope in answering all of the above questions to highway situations and evaluate the performance of proposed dissemination protocols by only looking into the following properties:

- **Latency**: required time in the ITS to propagate CCA related information from the place of the accident to a pre defined location or vehicle;
- **Reachability**: which user groups can be reached;
- **Broadcast storm induced**: The number of transmissions generated (within the entire ITS) while disseminating a message from the place of the accident to a pre defined location or vehicle.

These properties will be investigated by means of simulations.

4. STATE OF THE ART

4.1 Definitions
To be able to describe the state of the art in dissemination protocols, we must first define a categorisation based on the goal of dissemination, and determine which groups are interested in the message to be disseminated. For example, an emergency warning should be disseminated to cars in the direct vicinity of the accident but also to road management authorities. In this example, nearby cars and the department of transport are different groups interested in the information which is disseminated. We will make a categorisation based on the destination of the disseminated information and assume the source is a single vehicle which sends out an emergency crash warning. First we will identify different groups of vehicles in different locations. The Accident vehicle represents the source of the message to be sent. In the following definitions, we assume a vehicle is in the direct vicinity of another vehicle if it is reachable within a single hop.

- **Group A**: Vehicles in the direct vicinity of the accident, travelling towards the accident vehicle. This group needs to be able to receive the message as soon as possible. For communication to this group, many protocols using v2v communication have been developed, most of which use broadcasting with a mechanism to minimise congestion of the medium.
- **Group B**: Vehicles not in the direct vicinity of the accident but planning to use the road on which the accident occurred. These vehicles need to be warned to take an alternative route. Time-constraints are less of a priority because lack of an immediate response is not life threatening. The reach of the dissemination protocol on the other hand is important: the further the protocol can reach the more chance there is a highway exit will still available to provide a detour.
- **Group C**: Vehicles in the direct vicinity of the accident, travelling in the opposite direction of the accident vehicle. Ideally, this group is not inconvenienced (in terms of having to stop while this is not necessary or reduction of bandwidth available) by the message the accident vehicle broadcasts. This group can however be used to carry the accident vehicle’s message and communicate it to vehicles in group B.
- **Group D**: Vehicles in the direct vicinity of the accident, going in the same direction as the accident vehicle but in front of the accident. These vehicles could function as a relay to the infrastructure but otherwise should not have any role in dissemination.

4.2 Dissemination protocols
Dissemination protocols can be grouped based on the type of approach they use to try to avoid a broadcast storm. We have conducted literature research on different types of dissemination protocols which together form the state of the art of dissemination protocols in Vehicular Ad-Hoc Networks (VANETs). We will discuss v2v protocols first, afterwards we will describe the role of infrastructure in these protocols.

- **Gossiping (GO)** [3]: The idea behind gossiping is to transmit the message to a limited set of nodes that can be reached in one hop. This is done repeatedly to provide multi-hop functionality. This approach is not suitable for disseminating emergency messages because there is no guarantee that the message is transmitted to every node at the same rate, if at all.
- **Geocast (GE)** [9]: Geocast uses location information to determine which nodes should receive and forward the message and which nodes should drop the message. Within VANETS, GPS-location and direction of travel (gained through GPS) can be used to determine to which group the current vehicle belongs [12]. Another approach is to identify segments of road, for instance with an RFID-chip in every segment[15]. Geocast has the advantage that it makes sure the message is only sent to the nodes that should receive it. However it needs broadcast storm suppression techniques to ensure reliable connectivity within the target group.
• **Probability** (PR) [16]: In probability based approaches, the decision whether or not to retransmit a message is based on a given probability. This approach is not suitable for critical communication because the risk of emergency messages being dropped as a consequence of a probability check are too high.

• **Clustering** (CL): Clustering works based on the creation of (limited sized) clusters of nodes within VANETs. The idea behind this is limiting the amount of retransmissions needed because broadcasting is only needed to provide connectivity between clusters [10]. Within clusters certain nodes are selected to be responsible for communication between clusters [8]. This approach is useful for emergency applications since the emergency message would first be transmitted within a cluster and then transmitted to vehicles in group B using inter cluster communication. The disadvantage is that there is no guarantee that all cars in group A are in the same cluster. One special case of clustering is platooning which not only clusters nodes in the network structure but also based on location. A platoon is usually a group of vehicles configured to travel together as a convoy. Note that platooning is not merely a dissemination protocol but a way to structure vehicles within ITSs.

• **Infrastructure** (IN): If infrastructure is available, it can be used to listen to broadcast messages from vehicles and relay them to vehicles far away using wired communications. The advantage of this technique is that large distances can be covered quickly. The disadvantage is the financial cost of covering road networks with infrastructure nodes.

There is a distinct relationship between the defined groups and which dissemination protocols could be used. We will state which protocols have the largest chance of success for every group. For instance, within group A, geocast can be used to make sure the message to stop quickly is only needed to provide connectivity between the accident vehicle and the vehicles approaching the accident vehicle. Clustering based on location can also be used to make sure the entire cluster approaching the accident vehicle receives the message in a timely fashion. Gossiping and probability are not an option since guarantees the message is received by every member of this group are needed.

In order to get messages to vehicles in group B, clustering based on geocast can also be used. By this we mean creating clusters only in the direction of dissemination. The reach of the dissemination would then be limited by the density of traffic, and the amount of broadcast storm would be influenced by the size of the clusters. An alternative approach would be using infrastructure. In this case the reach is limited by the amount of infrastructure available. Gossiping and probability are also options, however the reach of these protocols is heavily influenced by the random factors specified in the protocols as well as the density of traffic. Therefore, we consider these less favourable options.

Since group C can be reached in a single hop from the accident vehicle, the only requirements for this protocol is detection of location and direction, which is provided by geocast or infrastructure (by checking infrastructure identifiers, for example). Reliability is also very important but outside of the scope of this paper. In general, vehicles in group C store the message for a given period before rebroadcasting it to vehicles in group B, where group B’s dissemination protocol is used to forward the message within group B. Group D only needs to be identified as going in the same direction but being in front of the accident vehicle. This can be done using geocast or infrastructure.

### Table 1. Protocol-group relations

<table>
<thead>
<tr>
<th>Group</th>
<th>Protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>GE, CL</td>
</tr>
<tr>
<td>B</td>
<td>GE, CL, PR, GO, IN</td>
</tr>
<tr>
<td>C</td>
<td>GE, IN</td>
</tr>
<tr>
<td>D</td>
<td>GE, IF</td>
</tr>
</tbody>
</table>

5. **EXPERIMENTS**

We have conducted experiments to test the performance of dissemination protocols in terms of latency and reachability. We will first describe our simulation suite. After that, we will explain which protocols we simulated and why. In section 5.3, we will discuss the properties of the dissemination protocols that have been studied and how these have been assessed. Finally, we will discuss the results of our experiments.

#### 5.1 Simulation suite

To simulate connectivity, we first needed to define a MAC-protocol. The MAC-protocol is responsible for regulating access to the wireless channel and making sure this is not congested. Due to time constraints, we have chosen not to fully implement the IEEE DSRC [17] MAC-protocol but a simplified version which only lets nodes communicate when they are within a predefined range of each other. This simplification has allowed us to develop a simple test suite instead of using complex existing simulation frameworks such as ns-2 [7] or Ptolemy [4].

We have created a simple simulation framework in Java which simulates nodes communicating with each other in the following way: When a node broadcasts a message, the MAC-protocol determines which nodes are in range and sends the message only to these nodes. Note that the range is defined as a fixed distance for every transmission and packet loss is not taken into account. This allows us to focus exclusively on the properties of the dissemination protocols without counting retransmissions caused by the MAC-protocol used. To simulate the latency of dissemination, we have defined v2v hops to have a duration of 5ms and i2i hops to have a duration of 1ms. These times are chosen based on the assumption that fewer retransmissions will be needed over the wired infrastructure connections compared to v2v wireless connections. However, this simplification does mean that the latencies can only be compared with other latencies measured using the same framework. The fixed properties used in our simulation can be found in table 3. Variable parameters and the values that have been used are found in table 2. The valid range for vehicle density is 1 (nearly empty road) to 300 (traffic jam).

On initialisation, for every vehicle a random empty location on the road is found. Every vehicle except for the accident vehicle is moving at a speed between 90 and 120 km/h. When a vehicle reaches the end of the simulated road, it is placed at the beginning of the road to simulate a constant flow of vehicles. Because of this, we have specified a maximum amount of hops a message can disseminate before being dropped, to prevent infinite dissemination. The vehicle furthest away from the accident vehicle on this defined section of road and on the same lane as the accident...
vehicle is determined. This vehicle will now be referred to as the last vehicle. In all simulations, the time between initial broadcasting and reaching the last vehicle is considered to be the latency.

### 5.2 Protocol selection

We have chosen to conduct experiments on group B, because this group has the highest diversity of dissemination protocols possible and because to reach group B, infrastructure and v2v communication can both be used. Comparing these two mechanisms is interesting because it can provide insight on the added value of infrastructure compared to v2v protocols. This information can be used to determine whether the added value of infrastructure in terms of latency reduction and reachability makes up for the added cost of placing infrastructure nodes on highways.

We have chosen to implement the geocast and clustering dissemination protocols with and without infrastructure support. The implementation of these protocols will be further explained in sections 5.4 and 5.5.

### 5.3 Properties examined

Using our simulation suite, we have benchmarked each protocol against the following properties:

- **Latency**: The time it takes for the accident message to be disseminated from the accident vehicle to the last vehicle.
- **Reachability**: The total amount of vehicles that received the accident message as a percentage of the total amount of vehicles going in the same direction. This is measured when the last vehicle receives the message, therefore it is related to the latency.
- **Broadcast storm**: The total number of messages received (by any node) before the last vehicle received the disseminated message.

### 5.4 Clustering geocast

We have implemented a simple version of a clustering protocol. This is based on the black-burst broadcasting technique [8] to determine which node in a cluster is responsible for forwarding the message to the next cluster. The clusters are generated when needed. This means that when a node receives an accident related message and is not already part of a cluster it creates a new one. The creation of the cluster is done by way of a one-hop broadcast to determine which groups are in range followed by the black-burst phase to determine the forwarding node. The initial broadcast also includes the accident related information, so once a node is a member of a cluster and it is not the forwarding node, it can discard all packets. The forwarding node broadcasts the message and the receiving nodes start creating a new cluster. This protocol is tested with and without infrastructure support. With infrastructure enabled, all infrastructure nodes which receive the message send it to the infrastructure nodes further down the direction of dissemination and rebroadcast the message there. The vehicles respond in the same fashion but will ignore the messages which are received at a later time, because they are already in a cluster.

### 5.5 Geocast with infrastructure

Geocast with infrastructure support is a flooding mechanism in which the node only processes a message if it has not received the message yet, if it is approaching the sender and if it is going in the same direction as the sender. Infrastructure supports consists of rebroadcasting the received message through infrastructure nodes further down the road. The infrastructure forwards the message with the same direction information as the original sender to make sure the packet is not erroneously dropped.

### 5.6 Experiment results

The results of our experiments can be found in figure 1 to 6. These results are averaged over five runs each to provide a reasonable spread. This is needed because of the random placing of vehicles, the effect of which is a variable distance between the accident vehicle and the last vehicle. The random placing of vehicles also causes a variable number of vehicles to be between the accident vehicle and the last vehicle. This influences the number of hops, reach and latency greatly.

Reach is measured in terms of percentage of vehicles going in the same direction as the accident vehicle with 1.0 representing 100%. The reach is measured at the time the last vehicle receives the disseminated accident message. Latency is measured in milliseconds. The figures are to be read as follows: figure shows four groups of three bars. Each group of three bars represents an infrastructure density setting. These settings are in number of infrastructure nodes per kilometer. The infrastructure densities displayed are (from left to right): 1, 3, 5 and no infrastructure. Within each group of three bars, each bar represents a vehicle density setting. The vehicle density is given in the number of vehicles per kilometer per lane. The vehicle densities displayed are (from left to right): 10, 30 and 50.

We will discuss the three investigated properties reach, latency and broadcast storm separately. In figure 1 and 2 we see that the use of clustering greatly increases the reach of the protocol. One of the reasons for this is that using clustering geocast, groups are first created before the message is forwarded to the next group. This means that while the group is being made, the many vehicles are reached before the message is disseminated further. This results in more vehicles reached before the accident related message reaches the last vehicle.

A noticeable drop in reach can be seen when the infrastructure density is 3. This can be explained by the placing of the infrastructure nodes at this density: they are placed at coordinates 333 and 666, which enables the last vehicle to receive the accident message quickly through the infrastructure. When it does, the number of vehicles that have been reached is measured. This results in fewer vehicles measured as reached because there was not enough time for the messages to disseminate through the network. This is also seen in the lower number of hops and the lower delay when using an infrastructure density of 3 in-

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### Tables

<table>
<thead>
<tr>
<th>Property</th>
<th>Values</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Veh. density</td>
<td>10, 20, 30</td>
<td>veh./km/dir.</td>
</tr>
<tr>
<td></td>
<td>1, 3, 5</td>
<td>nodes/km/dir.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road length</td>
<td>500</td>
<td>m</td>
</tr>
<tr>
<td>Comm. range</td>
<td>50</td>
<td>m</td>
</tr>
<tr>
<td>Maximum hops</td>
<td>25</td>
<td>-</td>
</tr>
<tr>
<td>Lanes per direction</td>
<td>2</td>
<td>-</td>
</tr>
</tbody>
</table>
In figure 3 and 4 we notice two things: the number of hops when using infrastructure rises very quickly when the vehicle density is increased, especially when clustering geocast is used. When using clustering with infrastructure in dense traffic moving at different speeds, rapid creation of groups occurs which costs a lot of hops. The reason for this is that the infrastructure broadcasts the accident message at every infrastructure node. When the message that has been disseminated without using the infrastructure reaches this group, more hops are needed to inform all groups of this message. This problem could be solved by using message identifiers, which could be part of future improvements.

The reason for this is that the infrastructure broadcasts the accident message at every infrastructure node.

The second fact that stands out is the number of hops needed in high-density traffic by clustering geocast. This is partly explained by the reasons mentioned above, another factor is the number of hops needed to sustain the group within a mobile network. Because vehicles enter and leave the group all the time because of speed differences, groups have to be rebuilt when a new message is received. This is partly due to the use of a very basic clustering algorithm, which could be optimised in future work.

In figure 5 and 6 the latencies of the accident message can be found. Here we find that clustering geocast is much more effective at producing lower latencies for a single message. The reason for this is that in every group the message passes through, a single node is determined to be responsible for forwarding the message. Because this node is chosen based on distance from the other side of the group, the number of hops needed is reduced and therefore the latency of the message. Note that the influence
of infrastructure is limited due to the relatively short road length. As displayed in figure 6, infrastructure can have a negative effect as well. We reckon this effect will not be as strong when using smaller infrastructure densities, due to the fact that wired communication then provides a greater advantage.

6. CONCLUSION
The main research question in this paper was In which situations is vehicle to vehicle communication a superior alternative to vehicle to infrastructure communication, when the goal is cooperative collision avoidance on highways?. We have found that the answer to this question is as follows: Vehicle to vehicle communication is a superior alternative to vehicle to infrastructure communication when using high infrastructure density (3 or more). Infrastructure has theoretical advantages, however they are not visible in our simulation because of the limited road length. We have found answers to our sub-questions as well:

- What are the relevant properties of dissemination techniques? Relevant properties of dissemination techniques are latency, reach and broadcast storm produced.

- To which groups of users does the information need to be relayed? The accident-information needs to be relayed to vehicles in the direct vicinity of the accident as well as to vehicles planning to use the road in the near future. We have focussed on the latter group in this paper.

- What are the advantages and disadvantages of using vehicle to vehicle communications for cooperative collision avoidance? Vehicle to vehicle communication is more direct than vehicle to infrastructure communication, therefore it is useful to broadcast the first accident-related information for one or two hops, when very low latency is crucial for safety reasons. For long-range dissemination vehicle to vehicle communication is also useful, but it cannot be used in simple broadcast form because the amount of messages this generates in high-density traffic is too high. It needs broadcast-suppressing techniques to be useful for this purpose, such as geocast.

- What are the advantages and disadvantages of using vehicle to infrastructure communications for cooperative collision avoidance? Vehicle to infrastructure communication is useful for long-range dissemination of messages. The main goal is to disseminate information on roads being unavailable due to an accident to future users of that road.

6.1 Future work
Future work could include extending the simulation using longer roads and different protocols for groups A, C and D. This could provide a better view of the capabilities of dissemination algorithms and the influence of infrastructure in other dissemination scenarios with other protocols used.

7. REFERENCES