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Design and Evaluation of two Geocast protocols for Vehicular Ad-hoc Networks

Maria Kihl, Mihail L. Sichitiu, and Harshvardhan P. Joshi

***Abstract*— Vehicular ad-hoc networks (VANETs) offer a large number of new potential applications. One of the envisioned applications is of course Internet access, which can be provided with the help of some roadside basestations. Many of the applications benefit from multi-hop relaying of information, thus requiring a routing protocol. Characteristics unique to VANETs (such as high mobility and the need for geographical addressing) make many conventional ad hoc routing protocols unsuitable. In this paper we design and evaluate two different, so called, geocast protocols for VANETs. One protocol is designed for fast communication across a large area. The purpose of the other protocol is to provide a routing service for a future reliable transport protocol (enabling Internet applications). We evaluate the performance of the protocols using realistic network and traffic models.**

***Index Terms*– VANET, routing, reliable geocast, simulation**

I. INTRODUCTION

For many years research projects have been focused on issues regarding inter-vehicle communication (IVC) systems [1]–[3]. The objective of those projects has been to create the fully connected vehicle. By letting vehicles communicate both with each other and with base stations along the road, accidents can be avoided and traffic information can be made available to the driver. Of course, the goal is to have in-vehicle Internet access as well. A couple of years ago the term VANET (Vehicular Ad-hoc Network) was introduced, combining mobile ad-hoc networks (MANETs) and IVC systems.

Vehicular Ad-hoc Networks (VANETs) are envisioned to both decrease the number of deaths in traffic and improve the travel comfort by, for example, increasing inter-vehicle coordination. Understandably, the most commonly considered applications are related to public safety and traffic coordination. Collision warning systems and vehicle platooning are two applications that projects work on. Also, traffic management applications, traveller information support and various comfort applications have the potential to make travel (considerably) more efficient, convenient and pleasant [4].

Most VANET applications require that data is transmitted in a multi-hop fashion, thus prompting the need for a routing protocol. In many aspects, a VANET can be regarded as a MANET. However, the inherent nature of a VANET imposes the following three constraints for a routing protocol: Short-lived links, lack of global network configuration, and lack of knowledge about a node's neighbors.

The first issue is due to the mobility of the vehicles. Studies have shown that the lifetime of a link between two nodes in a VANET is in the range of seconds [5]. Similar to a MANET, no central coordinator can be assumed in a VANET. Finally, although a hello protocol (as in OSPF) can be used to discover the neighbors of a node, this may be an expensive and difficult to tune solution. The routing protocol should discover the neighbors as needed. It is also preferable that the routing protocol works for a wide range of applications and traffic scenarios. Several papers propose solutions for specific VANET applications [6]–[8].

Some VANET applications require unicast routing. For example, some envisioned comfort applications, as on-board games and file transfer, will likely need unicast routing with fixed addresses. Many papers have proposed unicast protocols for VANETs. Some papers suggest that VANETs should use already existing unicast protocols for MANETs, as AODV [9], [10] or cluster-based protocols [11], [12]. Other papers propose new unicast protocols for VANETs [13], [14].

However, many VANET applications require position-based multicasting (e.g., for disseminating traffic information to vehicles approaching the current position of the source). A natural match for this type of routing is the geocasting protocols [7], [15] that forward messages to all nodes within a Zone of Relevance (ZOR). The geocast concept has been studied for VANETs since the beginning of 1990s [17]. Previous research work on geocast schemes for vehicular networks has mostly proposed various flooding schemes.

One problem with a pure flooding-based geocasting protocol is that the flooding can cause network congestion [16]. Therefore, selective flooding may be used in which the forwarding is based on an intelligent decision that should maximize the spreading of the message at the same time as it minimizes the network load caused by the message spreading. In [28] an emergency warning dissemination system was proposed. A congestion control was included in the flooding scheme in order to minimize the risk of packet congestion. In [29]], two broadcast protocols that use flooding with selective re-broadcast were proposed. One re-broadcast scheme assumed that GPS information was exchanged between vehicles. The other re-broadcast scheme used time delays. In [30], a flooding scheme was proposed where vehicles also stored messages for a while, thereby using the mobility of the vehicle as a way to relay messages. [31] proposed a flooding mechanism with data aggregation, thereby avoiding packet congestion in scenarios with many vehicles.

In [18] a geocasting protocol for VANETs was described. In this approach a node forwards a message after a delay that depends on the distance from the last sender. Variants of this protocol have been proposed in [19], [20], [32].

Another problem with flooding-based geocasting protocols is that the flooding mechanism is commonly based on broadcast, and it is, thus, best effort. However, some applications will require multicast transmission with end-to-end QoS. Flooding-based geocast protocols are not intended for these types of applications. Therefore, there is a need to develop multicast protocols for VANETs that can support end-to-end

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QoS mechanisms implemented in a transport layer protocol.

In this paper, we present two different geocast protocols for VANETs, Distributed Robust Geocast (DRG) and RObust VEhicular Routing (ROVER). Both protocols are state-less and they efficiently spread a message across the ZOR. The objective of DRG is to enable a fast and reliable forwarding of messages that minimizes the network load, in a best-effort fashion. The objective of ROVER is to provide a basis for a future reliable transport protocol, enabling Internet based applications in the VANET.

Distributed Robust Geocast (DRG), is a geocast protocol that is completely distributed, without control overhead and state information. Also, it is resilient to frequent topology changes. We use a distance-based backoff similar to [18]–[20] for directed and restricted flooding. However, unlike [18]–[20], our approach is not limited to a one-dimensional road and a one-dimensional target region. The algorithm can overcome temporary network partitioning or temporary lack of relay nodes and it has a mechanism to prevent loops.

The RObust VEhicular Routing (ROVER) protocol offers reliable geographical multicast. The protocol uses a reactive route discovery process within a ZOR, inspired by AODV. ROVER could be used by applications that require end-to-end QoS, by implementing a transport layer protocol that uses the multicast tree set up by ROVER.

Both protocols are evaluated with a realistic simulation setup. We consider a generic data transfer application, in which a vehicle sends a data message to all vehicles within a specified ZOR. The results show that both protocols deliver the data with reasonable delays (with regard to their objectives) to 100% of the intended vehicles for almost all scenarios. Since the protocols have different objectives, no direct comparison of them should be performed.

II. DISTRIBUTED ROBUST GEOCAST (DRG)

In this section we will describe the Distributed Robust Geocast (DRG) protocol.

A. Definition of terms

We first define certain terms used in this and subsequent sections. The *Zone of Relevance (ZOR)* is the set of geographic criteria a node must satisfy in order for the geocast message to be relevant to that node. The *Zone of Forwarding (ZOF)* is the set of geographic criteria a node must satisfy in order to forward a geocast message.

A *coverage disk* is the disk with the transmitting node at the center and the transmission range as the radius. All nodes within the coverage disk receive the transmission with a probability of 1. The *coverage area* or *reception area* is the area around the transmitting node within which all the nodes are supposed to receive a fraction of transmitted packets above a threshold value. The coverage area is not required to be circular, and it is a more realistic model of radio transmission with fading, pathloss and radio obstacles.

We assume a physical model that allows for a symmetrical radio reception, i.e., if node A can receive a transmission from node B with probability x, the reverse is also true. The symmetrical radio model can work even in city environments, where the transmission area is not circular but rather elongated along the streets.

B. Forwarding algorithm

It has been shown that simple flooding causes redundant transmissions resulting in significant contention and collisions [16]. However, the redundancy can be reduced by selecting only those nodes with the most forward progress towards the destination as relays. A completely distributed algorithm to select the relay node using a backoff scheme that favors the nodes at the edge of the transmission range was proposed in [18]. On receiving a message, each node schedules a transmission of the message after a distance-based backoff time. Any node that loses the backoff contention to a node closer to the destination cancels the transmission. If each node waits for a time inversely proportional to its distance from the last sender before retransmitting, the farthest node will be the first to transmit by winning the contention. The distance-based backoff can be calculated using the following formula:

$$BO_d(R_{tx}, d) = MaxBO_d \cdot S_d \left(\frac{R_{tx} - d}{R_{tx}} \right) \tag{1}$$

where BO_d is the backoff time depending on the distance from the previous transmitter, $MaxBO_d$ is the maximum backoff time allowed, S_d is the distance sensitivity factor used to fine tune the backoff time, R_{tx} is the nominal transmission range, and d is the distance of the current node from the last transmitter. A collision avoidance mechanism like random backoff can also be added.

C. Network fragmentation

Since VANETs are prone to frequent, though temporary, fragmentation a mechanism to overcome them can improve the performance. One of the approaches is periodic retransmission of the message until a new relay transmits the message, which is treated as an *implicit acknowledgement* by the previous relay. We propose a burst of retransmissions with short interval to overcome communication losses, and retransmission after a long interval to overcome network fragmentation.

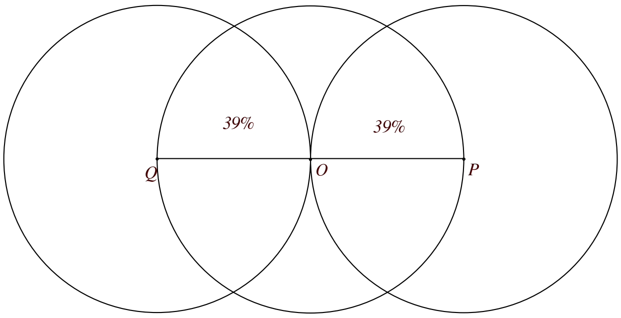
A relay, after its transmission at time t, schedules retransmission of the message at $t + MaxBO_d$, using (1). Thus, the existing relay enters the contention for the next transmission, but with the least preference for winning. The minimum value for $MaxBO_d$ should be at least the round trip time for the packet to the farthest node in the coverage area.

$$MaxBO_d \geq 2 \times \text{(maximum end-to-end delay)} \tag{2}$$

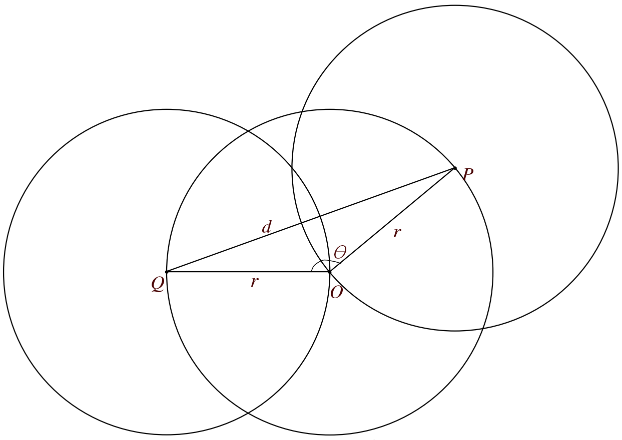
Selecting a value higher than this bound will result in unnecessarily longer delays. Hence, the equality in (2) gives the value for $MaxBO_d$. A *long backoff time* ($LongBO_d$) is used after a certain number of retransmissions, denoted *maximum retransmissions* ($MaxReTx$). A few retransmissions at short duration are needed to make sure that the absence of implicit acknowledgement is not due to the channel losses. However, after a few retransmissions it can be safely assumed that an implicit acknowledgement is not received due to network fragmentation. Hence, the next retransmission can be scheduled after a comparatively longer period $LongBO_d$, which allows time for the network to get repaired. The selection of value for $LongBO_d$ is a trade-off between redundant transmissions and end-to-end delays. The maximum value of long backoff, $MaxLongBO_d$, should be the time it takes a vehicle to reach the relay node after it enters the coverage area. Thus,

$$MaxLongBO_d = \frac{R_{tx}}{V_{max}} \tag{3}$$

where, V_{max} is the maximum velocity of the vehicles.



(a) Two nodes on the edge of center node's transmission range



(b) Two nodes forming an angle θ at the center node

Fig. 1. Two cases of overlap of transmission ranges of two nodes.

D. Two-dimensional scenario

The forwarding algorithm as described above does not have a mechanism to select a proper relay in a two-dimensional network, since all the nodes at equal distance from the sender have equal probability of becoming a relay. The nodes that forward messages with a two-dimensional ZOR also face the decision on which transmissions to accept as implicit acknowledgements.

To spread the message throughout the two-dimensional ZOR, the relay nodes should have a wide angular distance to cover substantially new regions of the ZOR. Similarly, if a node receives the same message from relays that cover a major portion of its own coverage area, there is a high probability that other nodes in its coverage area would also have received the message and transmission by the node would be redundant. The ratio of the area of overlap of two or more nodes with respect to their average coverage area is called *coverage ratio*. Hence, the angular distance and the coverage ratio of the relays should be greater than certain thresholds, *angular threshold* and the *coverage ratio threshold* respectively, to ensure spreading and flooding of the message.

Let us, momentarily, assume a disk model of radio transmission. If two nodes are at a distance d, and have a transmission range R_{tx}, the coverage ratio CR is inversely related to the distance d: it is minimum (zero) for $d \geq 2R_{tx}$, and maximum (one) for $d = 0$. For two nodes within each other's transmission range, CR is minimum when $d = R_{tx}$. As shown in [21], for two nodes within each other's transmission range,

$$CR_{min} = \frac{2}{3} - \frac{\sqrt{3}}{2\pi} \approx 0.391 \tag{4}$$

An ideal scenario for geocast on a straight road is shown in Fig. 1 (a), where nodes O and P relay the message from Q respectively. From (4), we know that the Q and P cover approximately 78% of node O's coverage area. If the coverage ratio threshold is higher than 78%, node O will continue to retransmit the message without any gain in spreading or flooding of the message. Thus, the upper bound on coverage ratio threshold $CR_{threshold}$ is:

$$CR_{threshold} \leq 0.78. \tag{5}$$

The success of the $CR_{threshold}$ criterion depends on a very accurate estimate of the actual transmission range. However, the disk model assumed here is not very realistic: the actual transmission range may change with time, and may not be circular in shape. Not only is the coverage ratio calculation inaccurate, but it also increases in complexity for multiple nodes. We propose to use an angle based criterion instead by mapping a minimum coverage ratio to an angle, e.g., coverage ratio of 78% is mapped to 180^o. A general case is shown in Fig. 1 (b), where nodes P and Q make an angle θ at the center node O. Let our desired $CR_{threshold}$ be x. What should be the minimum value of θ for the minimum coverage ratio to be more than the threshold x? We need to find an angle θ such that the area of intersection of disks P and Q should not be more than $(0.78 - x)$, i.e.,

$$A_{P \cap Q} \leq (0.78 - x) A_{disk}, \tag{6}$$

$$A_{P \cap Q} = 2r^2 \arccos\left(\frac{d}{2r}\right) - \frac{d}{2}\sqrt{4r^2 - d^2}, \tag{7}$$

where d is the distance between nodes P and Q.

Without loss of generality, we can assume the disks to be unit circles, or the transmission range r to be 1. Thus, equation (6) becomes,

$$2 \arccos\left(\frac{d}{2}\right) - \frac{d}{2}\sqrt{4 - d^2} \leq (0.78 - x)\pi, \tag{8}$$

where $0 < d \leq 2$.

From the Fig. 1 (b), the relation between distance d and angle θ is:

$$\theta = 2 \arcsin\left(\frac{d}{2r}\right). \tag{9}$$

Thus, from equations (8) and (9) we can find a value of θ_{min} such that the minimum coverage ratio is above the $CR_{threshold}$. The calculation of θ_{min} is one-time, and significantly reduces the complexity of calculating coverage ratio by each node by replacing it with simple calculation of angle between three nodes. Thus, when a node receives a message from at least two other nodes that make an angle $\theta \geq \theta_{min}$, the message should be considered to be acknowledged and spreading in desired direction and all retransmissions of that message should be canceled since a retransmission will not significantly add to the coverage.

III. ROBUST VEHICULAR ROUTING (ROVER)

In this section we will describe the routing protocol ROVER (RObust VEhicular Routing). In short the main difference between geocasting and ROVER is similar to the difference between flooding and a MANET reactive protocol such as AODV: both in ROVER and in AODV only control packets

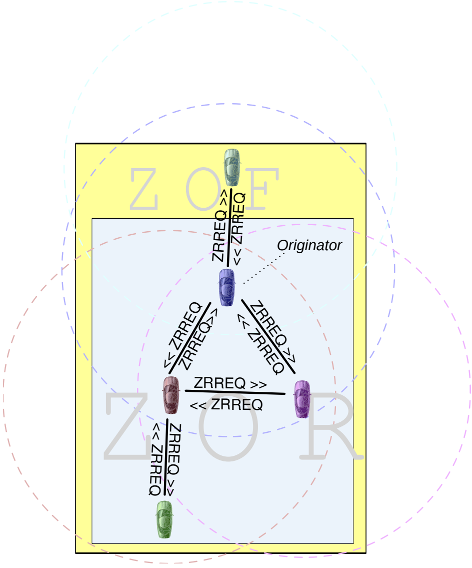


Fig. 2. ZRREQ messages are flooded from the originator (source) vehicle.

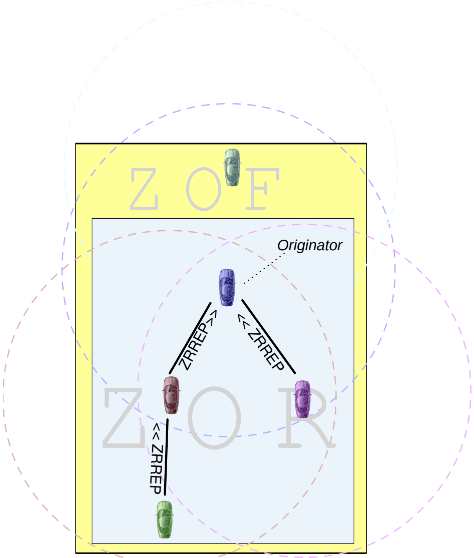


Fig. 3. ZRREP messages are unicasted the one-hop neighbors from where the ZRREQ was first received.

are flooded in the network - the data packets are unicasted, potentially increasing the efficiency and reliability. Each vehicle is assumed to have a unique Vehicle Identification Number (VIN). Also, the vehicles are assumed to have a GPS receiver and access to a digital map.

The objective of the protocol is to transmit a message, M, from an application, A, to all other vehicles within an application-specified ZOR, Z. The ZOR is defined as a rectangle (although other definitions can be easily accommodated) specified by its corner coordinates. Thus, a message is defined by the triplet $[A, M, Z]$. When a vehicle receives a message, it accepts the message if, at the time of the reception, it is within the ZOR. Similar to geocasting protocols we also define a Zone Of Forwarding (ZOF) as a zone including the source and the ZOR. All vehicles in the ZOF are part of the routing process, although only vehicles in the ZOR deliver the message to their corresponding application layer (specified by A).

A. *Route Discovery*

The first time the routing layer receives a packet $[A, M, Z]$ from the application layer, a route discovery process is triggered. The process is also initiated if the previous ZOR is no longer valid. The objective of the route discovery process is to build a multicast tree from the source vehicle to all vehicles within the ZOR Z.

As shown in Figure 2, the route discovery process is initiated when the originator vehicle floods a Zone Route Request (ZRREQ) message containing its VIN, location, the current ZOR, and a route sequence number, SS, throughout the ZOF. The flooding procedure uses the selective forwarding procedure described in the next section.

Any vehicle that receives a ZRREQ for the first time for this session sequence number accepts the message if the vehicle is within the ZOF, and if it is not too far away from the sender. The reason for including the distance to the sender is to build a robust multicast tree. The *Cutoff Distance* is calculated as $\alpha \cdot R$, where R is the (assumed) maximum radio range and $0 < \alpha \leq 1$. In this paper we have used $\alpha = 2/3$.

If a vehicle accepts a ZRREQ, it replies to the one-hop vehicle that forwarded the ZRREQ with a Zone Route Reply (ZRREP) message, containing its VIN. It also stores the information $[SS, Z]$ in a routing table. Finally it re-broadcasts the ZRREQ, including the original VIN, ZOR, and SS. The vehicles in ZOF but not in ZOR do not reply to ZRREQ messages unless they receive a reply themselves. The sequence number SS in conjunction with the VIN of the source vehicle (originator) is used as a unique identifier in the routing tables formed by the route discovery process.

After flooding the ZRREQ throughout the ZOF, unlike for AODV, the ZRREP messages are not sent back to the source. Instead they are only transmitted to the node transmitting the ZRREQ. All recipients of a ZRREP message store the VIN of the vehicle that sent the ZRREP and the corresponding SS and source VIN. Data packets from the same source VIN and SS will be forwarded to the sender of the ZRREP. This way all nodes store the local information needed to build a multicast tree rooted at the source node. Once the tree is formed, i.e., after the ZRREP are sent to parents in the tree, data can be disseminated in the tree (as shown in Figure 3.

B. *Data transfer*

Since each vehicle stores next-hop(s) information about the source VIN and SS, data will be forwarded through the tree as a function of those numbers. The source forwards the data packets immediately after it receives a ZRREP message. The source (and all forwarding nodes in the multicast tree) unicasts the message M to all the vehicles from which it received a ZRREP. The message is also stored in a buffer for a short time in case it receives a ZRREP after it receives the message. Thus, each message is propagated through the multicast tree according to the "route table" stored during the route discovery process. Also, all receivers deliver the packet if they are within the ZOR. Since the data is transferred using unicast, it benefits of the normal MAC-layer acknowledgments.

C. *Route Timeout*

As vehicles move, the ZOR for a certain application will change in time. However, if a vehicle sends several messages to the same ZOR application within a short time, there is no need to perform a route discovery for each message. For example, for vehicles travelling at 90km/h, the ZOR may only change by 25m in one second. If the initial ZOR has a radius of several kilometers, the same ZOR can be used. We considered a ZOR to be invalid when the source vehicle moved for more than 25m from the initial route discovery position.

IV. SIMULATION ENVIRONMENT

We have evaluated ROVER and DRG using the simulation package Jist/SWANS [22], [23] with the STRAW module [24]. Jist/SWANS is a simulator for mobile ad-hoc networks, similar to ns-2, implemented in JAVA. STRAW uses real maps from the Topologically Integrated Geographic Encoding and Referencing (TIGER) system available from the US Census Bureau Geography [25]. We enhanced the simulation setup in several respects and implemented ROVER and DRG as new routing modules. At the time we performed the simulations, the development of Jist/SWANS was an ongoing project, and the STRAW module was developed for city scenarios with low speeds and a road grid. It also had a number of incomplete protocol specifications (e.g., missing sequence number in 802.11). Furthermore, since the original protocol stack used unicast with fixed addresses, we had to make a number of modifications to the original Jist/SWANS/STRAW packages.

A. A Data Transfer Application

To evaluate the performance of the proposed routing protocols, we used a generic data transfer application. In this application a vehicle sends a message to vehicles behind it. The message could represent an emergency warning message when using the DRG protocol, or the beginning of a file transfer when using the ROVER protocol. Note that the two protocols have different objectives, DRG should be used for applications that need a fast and reliable (but best-effort) transmission, whereas ROVER should be used by applications that include a reliable end-to-end transport protocol.

The vehicle that sends out the message will be referred to, in the rest of the paper, as the Source Vehicle (SV). When an SV sends a message, the application determines a suitable ZOR. In this paper, the ZOR will be a rectangle directly behind the SV, with length L meters and width W meters. W is large enough to cover all lanes of the current road that go in the same direction as the SV. The message should then be delivered to all vehicles within the ZOR, as fast and reliable as possible. The Zone of Forwarding (ZOF) region is defined by adding 15 meters to the ZOR boundaries.

B. Road and Traffic Models

STRAW uses real road maps by default. Since the objective of the investigations was to evaluate the proposed routing protocols, we wanted to have a generalized road model to avoid any effects caused by the specific road map used. Therefore, we constructed a straight highway in TIGER format and then used this road in the simulations. The highway was of length 10km and with 3 lanes in each direction. The maximum allowed speed on the highway was 120 kilometers per hour. This road model is well established and used by several papers investigating inter-vehicle communication systems, see, for example [18]–[20], [29].

Vehicles moved according to a well-known car-following model [26]. We implemented lane changing behavior. Originally, STRAW did not implement this feature, and we observed cases where one lane was heavily congested while the other lane was not. In our setup, vehicles may change lane if the vehicle in front of them moves too slow.

C. Communication Model

At the physical layer we used the Rayleigh fading model supplied by SWANS. This model has a gradual transition from 100% to 0% reception rate as the distance between the sender and receiver increases. The physical layer data rate we used was 54Mbps, consistent with the 802.11a data rates (which in turn are similar to the Dedicated Short Range Communications (DSRC) standard [27]).

At the MAC layer we used the CSMA/CA scheme used in IEEE 802.11 (similar to DSRC). At the network and transport layer we used slightly modified versions of IP and UDP. In particular, since we used geographical addressing, instead of the normal IP addresses we used VIN numbers for the vehicles and ZOR and ZOF (specified by the coordinates of the corners) to specify the destinations.

D. Simulation Setup

In the beginning of a simulation, N vehicles were placed on the highway at regular intervals. All vehicles attempt to travel with the maximum posted speed while using the car following model. Three seconds into the simulation a vehicle sends a message to vehicles in a ZOR behind itself. In our implementation the ZOR specifies the following:

- The VIN of the source node.
- The current location of the source node (absolute coordinates).
- The boundaries of the ZOR (relative to the source node).
- The direction of the movement of the source node.
- The maximum deviation of the direction of a vehicle from the direction of the SV such that it can still be considered in the ZOR. Nodes that deviate from more than this specified value are in ZOF but not in ZOR.

In the simulations, we used 180 degrees as the maximum deviation (i.e., all vehicles in the ZOR will deliver their packets to the application layer). The ZOF was specified as the ZOR and an additional buffer zone 15 meters wide.

The default simulation parameters (shown in parenthesis) and the range of values we investigated are shown in Table I. During the simulations we varied one parameter at a time while maintaining the rest fixed at the default value.

TABLE I

SIMULATION PARAMETERS

Parameter	**Value**
Number of vehicles/km	10, 45, (272), 545
Radio transmission range [m]	100, 200, (300), 400
Length of the ZOR [km]	0.5, (1.5) 2.5, 3.5

E. Performance metrics

We used two performance metrics when evaluating the protocols. The first metric was the packet delivery ratio, PDR, i.e. the percentage of vehicles that (1) are within the ZOR when the message is sent and (2) receive the message. To measure the PDR for each message from the SV we counted the number of vehicles in the ZOR at the time the message was generated and compared it with the number of vehicles that received the message. Since more vehicles can enter the

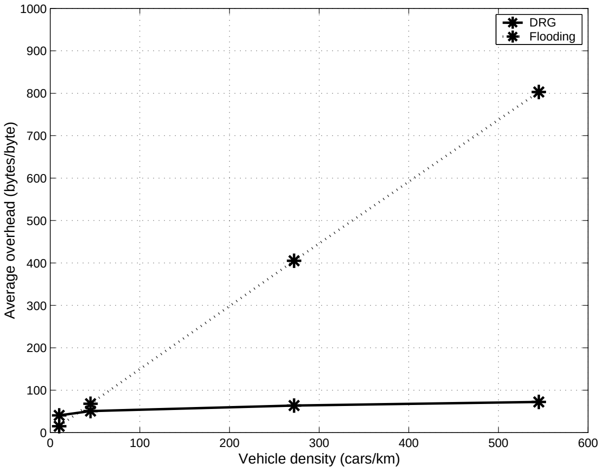


Fig. 4. The overhead for DRG as a function of the vehicle density.

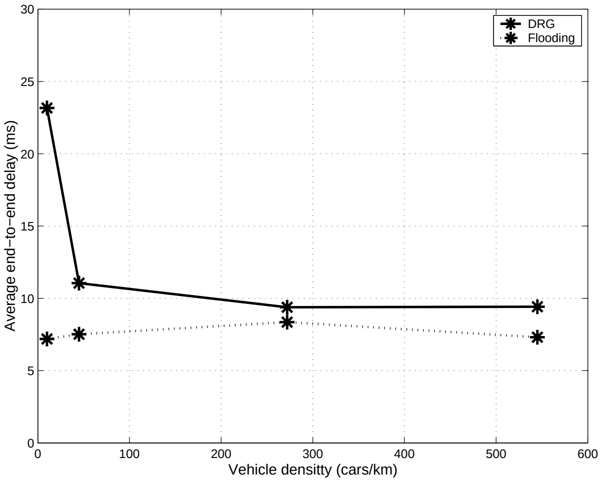


Fig. 5. The average end-to-end delay for DRG as a function of the vehicle density.

ZOR before the message is transmitted throughout the ZOR, PDR can be (slightly) larger than 100%.

The second metric was the average packet delivery time, T_D, i.e., the average delay between the time a message was sent by the SV until the vehicles received the message.

For the DRG protocol, we also evaluated the Overhead, which was defined as the ratio of the number of network layer bytes transmitted to the number of bytes sent by the application layer for a unique message. The overhead is a measure of the effciency of the routing protocol in reducing redundant transmissions for restricted flooding based protocol.

All results shown here are averages from 30 runs (with different seeds), and most confidence intervals are within 10% of the average.

V. RESULTS FOR DRG

In this section we present the performance results for the DRG protocol. The results are compared with equivalent simulations using a modified flooding algorithm (in the following denoted *Flooding*). The simple flooding algorithm is modified to restrict the flooding to the ZOR, and to include a collision avoidance scheme based on random slot backoff. The collision window and slot size are selected to provide optimum performance in a typical scenario.

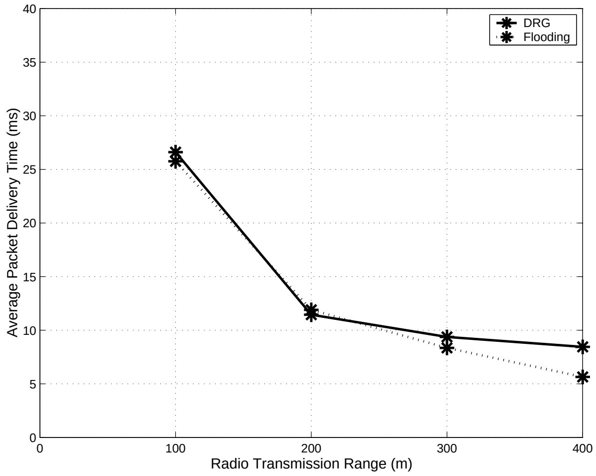


Fig. 6. The average end-to-end delay for DRG as a function of the radio transmission range.

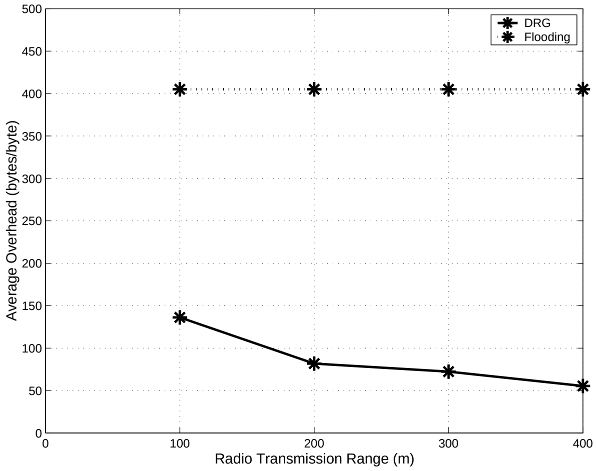


Fig. 7. The overhead for DRG as a function of the radio transmission range.

A. *Vehicle density*

The average packet delivery ratio is 100% for all scenarios in this paper, also for low vehicle densities. However, the number of transmissions for Flooding is of the order of $O(n)$, where n is the number of nodes in the ZOR and ZOF. Hence, the overhead for Flooding increases linearly with the node density. Due to the distance-based backoff mechanism in DRG, the number of transmissions for DRG is of the order of $O(k)$, where k is the number of hops in the ZOR and ZOF. Thus, the number of transmitting nodes are not significantly affected by node density. Hence, DRG scales much better than Flooding in a well connected, dense network as seen in Fig. 4.

The effect of vehicle density on the end-to-end delay is shown in Fig. 5. With a given coverage area, a higher node density causes more contentions or collisions for broadcast based protocols like Flooding, resulting in a higher end-to-end delay. However, the contention avoidance mechanism introduced for Flooding effectively reduces the rate of growth in end-to-end delay. The node density does not significantly affect the end-to-end delay for DRG in a well connected network.

B. *Radio transmission range*

Fig. 6 shows the average end-to-end delay and Fig. 7 the overhead when varying the radio transmission range. Flooding

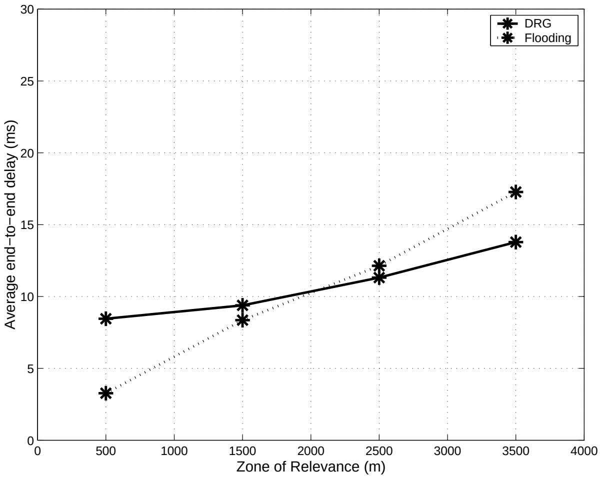


Fig. 8. The average end-to-end delay for DRG as a function of the ZOR.

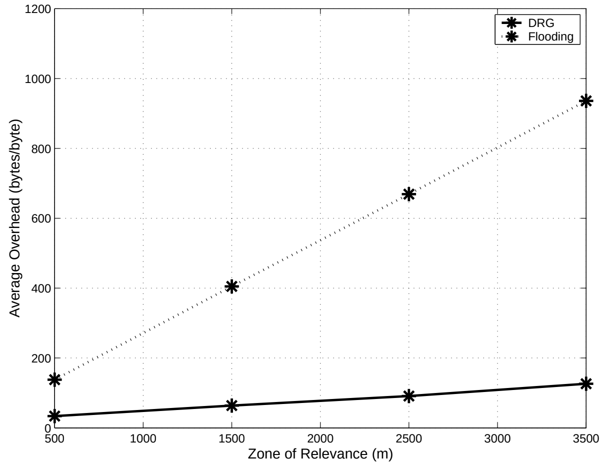


Fig. 9. The overhead for DRG as a function of the ZOR.

and DRG directly transmit the data packets, thus a larger transmission range results in a smaller number of hops and hence, a lower delay. The overhead for Flooding remains constant, irrespective of the transmission range, as long as the number of nodes in the ZOR and ZOF remain the same. However, since the overhead for DRG depends on the number of hops, larger transmission range reduces the overhead.

C. Zone of Relevance (ZOR)

The effects of a larger zone of relevance on the end-to-end delay and overhead are shown in Fig. 8 and Fig. 9. A larger ZOR not only increases the number of nodes in the ZOR, it also increases the number of hops required to propagate a message through the ZOR. Thus, the delay for both protocols increases with the length of the ZOR. However, the increase in delay for DRG is at a slower rate than Flooding.

The overhead for Flooding also increases linearly with the ZOR, since the number of nodes within a ZOR increases linearly with the length of the ZOR. On the other hand, the overhead for DRG increases at a rate equivalent to the ratio of the length of the ZOR and the transmission range. In other words the overhead increases with the number of hops.

D. Comparison with other work

As discussed in the introduction, several other papers have investigated flooding-based routing protocols for vehicular networks. Most of these papers evaluate their proposed protocols with similar metrics as in this paper, that is packet delivery ratio, delay, and overhead.

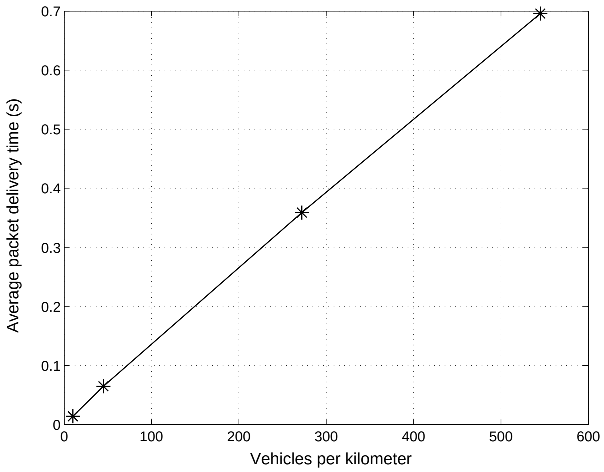


Fig. 10. The average end-to-end delay for ROVER as a function of the vehicle density.

In [18], it was shown that 15-25% of the vehicles should be equipped with radio transmitters in order for the packet delivery ratio to be near 100%. The packet delivery time was about 600 ms for a zone of relevance of 9 hops.

In [19], a simulation model with maximum 40 vehicles was used. The packet delivery ratio was high and the overhead was low. The packet delivery time was about 400 ms for 40 vehicles.

In [20], only the packet delivery ratio was evaluated. The highway was 10 km long and they simulated a maximum of 200 vehicles. The packet delivery ratio was above 95% for this scenario if the radio range was more than 250 meters.

In [29], it was shown that the overhead for pure flooding is much higher than for a protocol with selective forwarding.

VI. RESULTS FOR ROVER

In this section we present the performance results for the ROVER protocol when varying the vehicle density, the transmission range and the size of the zone of relevance. Since no other paper has proposed a similar protocol, we cannot compare the results with other work.

A. Packet Delivery Ratio (PDR)

The results show that ROVER delivers 100% of the messages for almost all scenarios. It is only when the vehicle density is very low (10 vehicles/km) that a message sometimes cannot reach all vehicles within the ZOR. In this case, the average distance between the vehicles is 100 meters, which means that if a ZZREQ or a ZZREP message is lost, a part of the multicast tree may be lost. A solution could be to implement the periodic retransmission scheme used in DRG, thus overcoming network fragmentation. For all other scenarios, the PDR is 100%.

It can be noted that the cutoff mechanism in the route discovery process has a major impact on the performance. It is crucial that the multicast tree is robust and therefore it is important that linked nodes are relatively close to each other due to the fading channel. It is better with several short (reliable) hops than a few long (unreliable) hops.

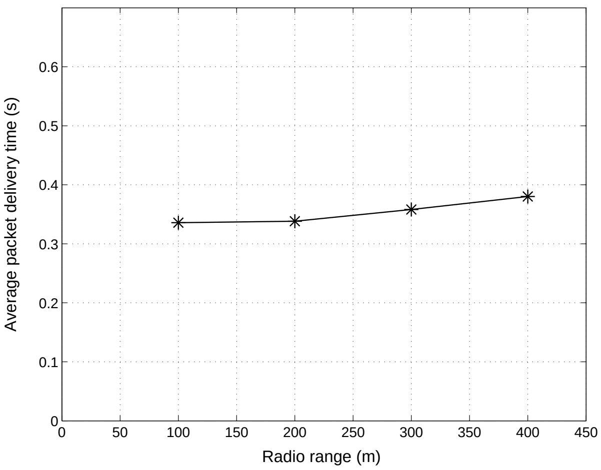


Fig. 11. The average end-to-end delay for ROVER as a function of the radio transmission range.

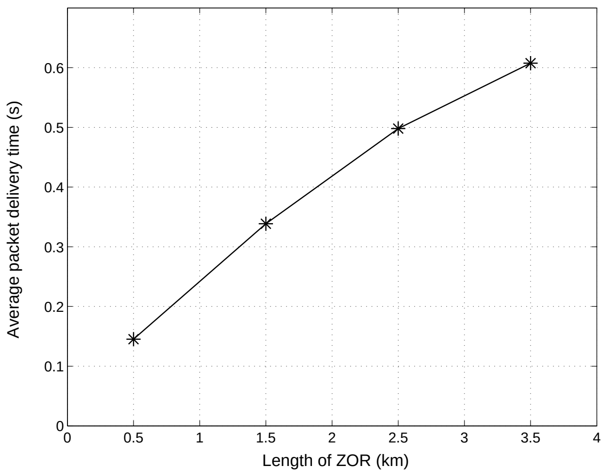


Fig. 12. The average end-to-end delay for ROVER as a function of the ZOR.

B. Vehicle Density

As the number of cars increases, the packet delivery time, T_D, also increases, as shown in Fig. 10. The Route Discovery Process is based on flooding. With more cars, packet collisions and backoff times increase at the MAC layer and the effect is longer delays on the application layer. Several papers (see, for example, [18]) have suggested an improved flooding mechanism in which a node has a waiting time before forwarding a packet. The waiting time depends on the distance to the previous sender and nodes further away from the sender will forward the packet sooner than nodes close to the sender. We implemented this feature in ROVER, but could not see any obvious improvements in the performance.

C. Radio Transmission Range

One could expect that a longer radio range would decrease the packet delivery time, due to fewer hops. However, our results for these scenarios showed that the radio range is not a major factor in the delivery time, see Fig. 11. As the transmission range increases, each transmission will be heard by more nodes. Therefore, the risk of packet collisions and hidden terminals increases. Also, one major part of the packet delivery time is the protocol handling delay in the nodes. This delay will of course not be shorter just because the radio range increases.

D. Zone of Relevance

As expected, the delivery time is proportional to the length of the ZOR, see Fig. 12.More hops are needed to cover the larger area and therefore the delivery time increases. Remarkable is that even for a ZOR as long as 3.5 km, the delivery time is as low as 600 ms and 100% of the vehicles within the ZOR receives the data. Therefore, ROVER is well suited for VANET applications that require multicast with end-to-end QoS.

VII. CONCLUSIONS

Vehicular ad-hoc networks have the potential to both reduce accidents as well as enhance the comfort of the driver and passengers. Different applications will enforce different requirements on the network protocols used. In this paper we have presented two location-based multicast routing protocols aimed at VANET applications.

The Distributed Robust Geocast (DRG) protocol is developed for applications that require a fast and reliable transmission, though without any end-to-end QoS requirements. The DRG protocol works in both one-dimensional and two-dimensional network topologies. The reliability of DRG is comparable or even better than that of the highly redundant Flooding, since the overhead is much smaller. The scalability of DRG is also better as its performance is less sensitive to network size or node density. However, most importantly, DRG adapts itself to fit network topology and ensures a high delivery ratio in a sparse and disconnected network by increasing overhead, while it efficiently delivers the packets in a well connected and dense network.

The RObust VEhicular Routing (ROVER) Protocol is aimed at applications that require end-to-end QoS. For those applications there will be a need for a reliable transport protocol. In order for a reliable transport protocol to work properly, a routing protocol is needed that maintains some information about sender and receivers. ROVER uses geographical addressing to form a multicast tree within a zone of relevance. The tree is formed on-demand and can be used to forward multiple data packets from the same source. Therefore, it can be used by a reliable transport protocol to ensure end-to-end QoS. We have evaluated the performance of the protocol in a realistic environment with detailed models both for the vehicular traffic as well as for the physical environment

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