

# Distributed Robust Geocast

## Multicast Routing for Inter-Vehicle Communication

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**Abstract.** Numerous protocols for geocast have been proposed in literature. It has been shown that explicit route setup approaches perform poorly with VANETs due to limited route lifetime and frequent network fragmentation. The broadcast based approaches have considerable redundancy and add significantly to the overhead of the protocol. A completely distributed and robust geocast approach is presented in this paper, that is resilient to frequent topology changes and network fragmentation. A distance-based backoff algorithm is used to reduce the number of hops and a novel mechanism to reduce redundant broadcasts is introduced. The performance of the proposed protocol is evaluated for various scenarios and compared with simple flooding and a protocol based on explicit route setup.

## 1 Introduction

Considerable research effort is concentrated on inter vehicle communication (IVC), which is expected to make road transport safer and more comfortable, while reducing travel time. The term vehicular ad hoc networks (VANETs) is frequently used for mobile ad hoc networks (MANETs) in the context of IVC, highlighting its distinct characteristics. Differences include, high node velocity, constrained mobility (to roads), anonymity of the users, and availability of position information through global positioning system (GPS). The high node mobility in a VANET causes frequent changes in the network topology and the network is subject to frequent fragmentation. Furthermore, the route lifetime drops to nearly route discovery time for more than a few hops [1]. Given these characteristics, it is generally accepted that VANETs should use some form of geographical routing. Several algorithms that use location information for efficient route discovery have been proposed [2]. For many of the applications of IVC listed above, especially safety and traffic control applications, it is desirable to send a message to a particular geographic region. The multi-cast of a message to nodes satisfying a set of geographical criteria is called *geocast*. Several algorithms for geocasting have been proposed based on location information [3, 4]. These algorithms, though distributed compared to other traditional routing protocols, require at least some state information, like the knowledge of neighbor nodes.

Keeping state information adds overhead and consumes resources like bandwidth and memory.

In this paper we propose Distributed Robust Geocast (DRG), a geocast approach designed for VANETs that is completely distributed, without control overhead and state information and is resilient to frequent topology changes. We use a distance-based backoff similar to [5–8] for directed and restricted flooding. However, unlike [5–8], our approach is not limited to a one-dimensional road and a one-dimensional target region. We use a state-less forwarding algorithm that efficiently spreads the message through the target region and ensures delivery to all relevant nodes. The forwarding algorithm can work for two-dimensional street networks as well as one-dimensional highways and a target region of any shape. Furthermore, the algorithm is resilient to the underlying radio transmission range model and can work with non-circular transmission range models caused by fading and pathloss. The algorithm can overcome temporary network partitioning or temporary lack of relay nodes and has a mechanism to prevent loops. We also show a completely distributed method for keeping a message alive in the target region thereby ensuring that a node entering the region even after the spread of message receives the message.

## 2 Related Work

In a seminal work, [9] outlines two schemes for location-based multicast to a geographical region called multicast region. Both these schemes are based on restricted flooding and does not require topology information. It is shown in [10], that memory-less routing algorithm based on direction of destination, such as scheme 1 in [9] or [11], do not guarantee loop-free paths. However, routing algorithms that forward to nodes closest to the destination or with the most forward progress are inherently loop-free. In [12], use of Voronoi diagram or convex hull for finding a neighbor closest to the destination or having the most forward progress is proposed. These algorithms require at least one-hop neighbor location information, and hence introduce additional overhead of location updates or query.

Due to its simplicity, flooding the network is a tempting solution for IVC message dissemination. A comparison of broadcasting techniques for MANETs is presented in [13]. The broadcasting techniques are classified as probability based methods, with full flooding as a specific case with broadcast probability of 100%; area based methods, discussed below; and neighbor knowledge methods, which require state information on 1-hop or 2-hop neighbors. In [14], it is shown that full flooding has significant redundancy, and can cause considerable contention and collisions. It is proposed that, to alleviate the contention and collision, the redundancy in broadcasts should be reduced. Some area based schemes are proposed, which assume equal transmission range for all nodes, and are founded on the concept that a node should not rebroadcast unless the broadcast can significantly add to the coverage of previous broadcasts. In the distance-based scheme, a node does not rebroadcast unless its distance from the previous sender

is above a certain threshold. For location-based scheme a convex polygon test is proposed to determine if a rebroadcast will add significantly to the coverage. However, this test works only if the node has received the same packet from at least three other nodes, a serious limitation for a highway scenario. We propose a simple angle based test instead of the convex polygon test which works with two nodes.

A completely distributed forwarding algorithm tailored for inter-vehicle communication is presented in [5,6]. In [7,8], geocast approaches based on [5,6] are proposed. These approaches are designed for collision warning application on a one-dimensional highway scenario, and do not adapt well to a two-dimensional city street scenario or other applications.

In [15,16], the problem of radio obstacles in city affecting the performance of routing algorithms is addressed by routing around the obstacles using greedy routing. However, neighbor tables with frequent updates are required and nodes need to detect street junctions.

It may be useful, or even essential, for a message to be available to vehicles that enter the geocast region after the message has spread. In [17], three different approaches to time persistent geocast are proposed. In the server approach, the message is stored on a central server and delivered to new nodes in the geocast region. In the election approach, one or more nodes within the geocast region are elected to store and deliver the message. In neighbor approach, each node store the message and delivers to a new neighbor either by periodic broadcasts or on notification. In [18], a numerical and analytical evaluation of the these approaches for a random waypoint mobility model is presented, and it is shown that approaches with local message storage cause less network load.

### 3 Distributed Robust Geocast

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; while, 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 fraction of transmitted packets above a threshold value. The coverage area need not 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.

### 3.1 Forwarding Algorithm

It has been shown that simple flooding causes redundant transmissions [14] resulting in significant contention and collisions. 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 [6]. 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 winning the contention. The distance-based backoff can be calculated using the following formula:

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

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.

### 3.2 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.

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

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. This limit is necessary in case the relay node is the node that is involved in an accident. Thus,

$$MaxLongBO_d = \frac{R_{tx}}{V_{max}}, \quad (3)$$

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

### 3.3 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 forwarding message with a two-dimensional ZOR also face the decision on which transmissions to accept as implicit acknowledgement.

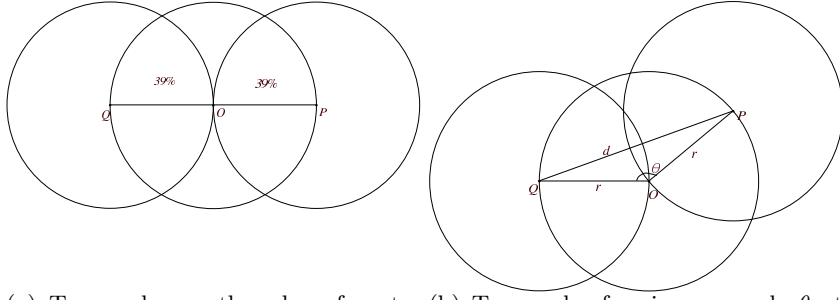
To spread the message throughout the two-dimensional ZOR, the relay nodes should have a wide angular distance to cover substantially new regions of the ZOR. Similarly, if a node receives the same message from relays that cover a major portion of its own coverage area, there is a high probability that 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 coverage area or coverage disk 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  $d = R_{tx}$ . In [19], for two nodes within each other's transmission range,

$$CR_{min} = \frac{2}{3} - \frac{\sqrt{3}}{2\pi} \approx 0.391. \quad (4)$$

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:

$$CR_{threshold} \leq 0.78. \quad (5)$$



(a) Two nodes on the edge of center node's transmission range (b) Two nodes forming an angle  $\theta$  at the center node

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

The success of the  $CR_{threshold}$  criterion depends on a very accurate estimate of 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 angle based criterion instead by mapping a minimum coverage ratio to an angle, e.g., coverage ratio of 78% is mapped to  $180^\circ$ . A general case is shown in Fig. 1 (b), where nodes  $P$  and  $Q$  make an angle  $\theta$  at the center node  $O$ . Let our desired  $CR_{threshold}$  be  $x$ . What should be the minimum value of  $\theta$  for the minimum coverage ratio to be more than the threshold  $x$ . We need to find an angle  $\theta$  such that the area of intersection of disks  $P$  and  $Q$  should not be more than  $(0.78 - x)$ , i.e.,

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

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

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,

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

where  $0 < d \leq 2$ .

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

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

Thus, from equations (8) and (9) we can find a value of  $\theta_{min}$  such that the minimum coverage ratio is above the  $CR_{threshold}$ . The calculation of  $\theta_{min}$  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.

### 3.4 Time Persistence

We propose a simple yet efficient technique for time persistent geocast based on periodic rebroadcast approach of [17]. Each node sets a persistence timer on receiving a new geocast message. Upon expiration of the timer, only those nodes that have not received a transmission of that message recently, i.e., within recent time threshold for persistence  $T_{Rp}$ , broadcast the message. To determine the value of  $T_{Rp}$ , we propose the following formula:

$$T_{Rp} = \epsilon \frac{R_{tx}}{V_{max}} + rand(CW_{min}, CW_{max}), \quad (10)$$

where,  $\epsilon$  is the sensitivity factor,  $R_{tx}$  is the nominal transmission range,  $V_{max}$  is the maximum velocity of the vehicles,  $CW_{min}$  and  $CW_{max}$  are the minimum and maximum collision window respectively, and  $rand(a, b)$  is a function that generates a random number uniformly distributed between  $a$  and  $b$ .

Thus, a new node entering the ZOR can be expected to receive a transmission of the geocast message  $1/\epsilon$  times before it reaches one hop distance into the ZOR.

## 4 Simulation Environment

The network simulator SWANS based on the simulation engine JiST [20], along with the STRAW [21] module is used for evaluating performance. JiST/SWANS is a wireless simulator, similar to ns-2 and GloMoSim, capable of simulating large networks. SWANS has radio propagation models including disk model (i.e. no fading) and Rayleigh fading. STRAW is a mobility model for vehicles on city streets. STRAW uses a car-following model to model mobility of vehicles within a road segment. Certain changes, like implementing lane changing behavior for vehicles in STRAW based on a model proposed by Kesting et al. [22], and modifying SWANS to work with geographical addressing, were made.

The performance of DRG is evaluated and compared with a modified flooding algorithm. 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.

We use a collision warning application as a representative for the safety applications. In this application, if a vehicle is either involved in or detects a collision or breakdown, it sends a warning message to other vehicles. A suitable zone of relevance (ZOR) is determined by the application. In our simulations, the ZOR

is rectangular with a length  $L$  and width  $W$ , and all the vehicles within the rectangle are part of the ZOR, regardless of their direction. The zone of forwarding (ZOF) is defined by adding 15 meters to the bounds of ZOR.

The performance on collision warning application is evaluated on two scenarios: a straight highway and a city street network. The performance is evaluated based on three metrics. *Packet Delivery Ratio (PDR)* is the ratio, as percentage, of the number of nodes receiving the packet and the number of nodes that were supposed to receive the packet. When a source generates a new geocast message for a particular ZOR, a list of nodes belonging to that ZOR is created and this is used to identify the nodes that are supposed to receive the geocast message. *End-to-End Delay* is the time delay between the time a geocast message is sent by an application at the source node to the time the application running on receiver node receives the message. *Overhead* is the ratio of the number of network layer bytes transmitted to the number of bytes sent by the application layer for a unique message, and is a measure of efficiency of the routing protocol in reducing redundant transmissions for restricted flooding based protocol.

## 5 Results and Discussion

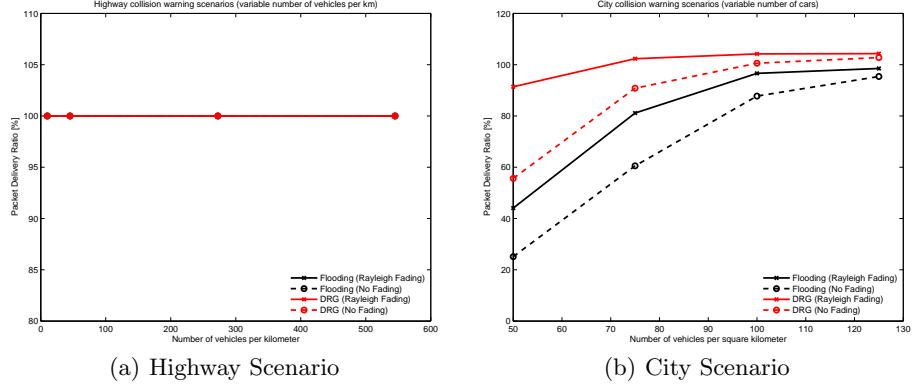
We evaluate the performance of the three approaches by varying the vehicle density on a highway scenario and a city street scenario. We use a straight highway 10km long and with 3 lanes in each direction. The maximum speed allowed on the highway is 120km per hour. The vehicles are placed at a regular distance depending on the density of the vehicles. The lead vehicle "crashes" three seconds into the simulation and generates a single collision warning message. The 300 meters wide ZOR starts at the colliding vehicle and extends to 1.5 km behind it. The nominal transmission range is 300 meters.

We use a city scenario with a relatively sparse network and short transmission ranges to evaluate the performance of the protocols. The city is a grid of 2km x 2km, streets placed 100 meters apart and perpendicular to each other. The vehicles are placed randomly. The vehicle that sends the collision warning message is always placed at the center of the grid. The ZOR is a square of  $1km^2$  with the source node at the center. The default nominal transmission range is 200 meters to account for radio obstacles in a city environment. In order to show the effect of time-persistent geocast, we set the time-to-live (TTL) to 15 seconds for DRG. The default value of TTL for Flooding is 64 hops.

A more detailed discussion of the performance evaluation for transmission range and the size of the ZOR, and for a traffic monitoring application, is presented in [19]

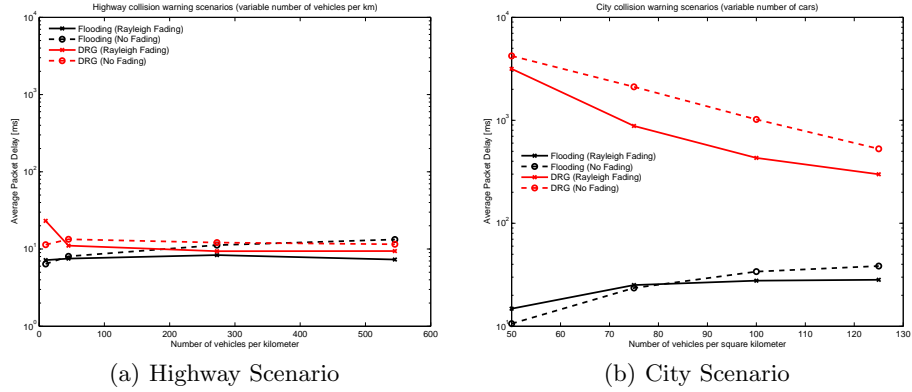
**PDR** The PDR for Flooding and DRG in highway scenario, as shown in Fig. 2(a), is 100% since the network remains connected even for low vehicle density. In a city scenario, Fig. 2(b), the reliability of DRG is much better than Flooding in a scarce network. This is due to the mechanisms used by DRG to overcome temporary network fragmentation. Also note that the PDR is more





**Fig. 2.** The average packet delivery ratio as a function of vehicle density

than 100% for DRG in certain cases, since the geocast message is kept alive for 15 seconds by which time new nodes enter the ZOR and the message is delivered to them.



**Fig. 3.** The average end-to-end delay as a function of vehicle density

**End-to-End Delay** The effect of vehicle density on the end-to-end delay is shown in Fig. 3. 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.

In a sparse network the DRG delivers to vehicles, once temporarily separated by network fragmentation, when they enter the coverage area of a relay. Since, vehicle movements take much longer time than the time taken by a packet to propagate through a well connected network, the average end-to-end delay is dominated by the time taken by vehicles to bridge network fragmentation in a sparse network, as seen in Fig. 3(b). However, as the connectivity improves, the end-to-end delay reduces. The delay still is much larger than that of simple Flooding, mainly because the geocast message is kept alive for a long duration, and the message is delivered to nodes which enter the ZOR even after a long time.

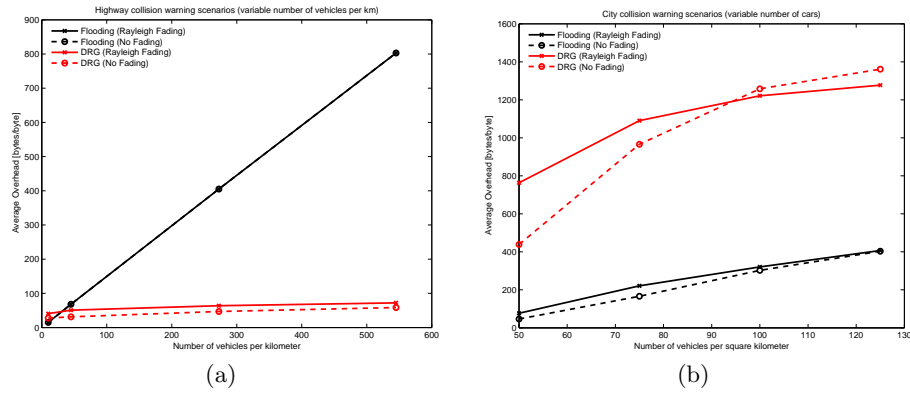


Fig. 4. The average overhead as a function of vehicle density

**Overhead** 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(a).

The higher PDR for DRG in a fragmented network comes at the cost of a higher overhead, as seen in Fig. 4(b). The retransmissions to overcome network fragmentation or to keep the message persist in time add heavily to the overhead. However, the overhead for DRG grows much slower than that of Flooding or ROVER in a connected network. Thus, DRG tends to reduce redundancy, when it is not required to ensure delivery.

## 6 Conclusion

We present algorithms that work in both one-dimensional and two-dimensional network topology. We have shown through simulations on various scenarios that while the reliability of DRG is comparable or even better than that of the highly redundant Flooding, 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.

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