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Optimized Abiding Geocast for Warning Message Dissemination in Vehicular Networks

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Abstract: The most important goal of vehicular networks is to support safety applications, for which multi-hop broadcast represents the key technique to disseminate warning messages. The core problem in multi-hop broadcasting is how to minimize the number of redundantly received messages while maintaining good latency and reachability that are hard to achieve simultaneously due to the vehicles mobility and the lossy wireless channel. Schemes that use periodic rebroadcasts have been proposed. However, they haven't acquired the optimal time period that carefully considers the tradeoff between reception reliability and transmission overhead. In this paper, we propose an Optimized Abiding Geocast protocol (OAG), which efficiently acquires an optimal dynamic periodicity that adapts OAG to sparse and dense networks by exploiting the vehicular networks characteristics. Simulations are conducted and results are presented to show that our proposed scheme has a better performance over existing competing solutions.

Key words: VANETs · Safety applications · Warning message dissemination · Optimized abiding geocast

INTRODUCTION

Vehicular Ad hoc NETworks (VANETs) have gained considerable attention in the past few years due to their promising applications such as safety warning [1, 2], transport efficiency or mobile infotainment [3]. A multi-hop broadcast protocol works as a basis for many vehicular applications including the safety ones which are the most important applications in VANETs. For example, after two vehicles collided with each other on a highway, or traffic congestion happens because of heavy rain or snow, the upcoming vehicles need to be notified immediately. In both cases, the warning messages should be disseminated out with short delay to vehicles that are up to several kilometers away, not only to prevent more possible accidents, but also to enable the vehicles to make a detour as early as possible to avoid congestion. There are three main performance goals in warning messages broadcast (1). High reliability, which is usually measured as the percentage of vehicles that received the warning message (2). Fast dissemination, that is the warning messages should be delivered to the vehicles with short end-to-end delay (3). Low overhead, which means the warning message's propagation should incur low transmission overhead(especially when the network is dense),since unnecessary transmissions waste precious bandwidth resource in VANETs. However, in real VANETs these goals are hard to achieve simultaneously due to the high mobility, frequent partitions and varying traffic density. Protocols developed for Mobile Ad hoc Networks (MANETs) are not suitable for VANETs since the characteristics of vehicles movement and relative speed of mobile nodes are different from those of a MANET. A classical broadcast based on flooding cannot be used since it causes a protocol overhead and high number of message collisions, which is known under the name of Storm Broadcast Problem [4].Various schemes were proposed to mitigate this problem, such as probability based schemes [5] and timer based schemes [6-9]. To enhance the reliability of warning message dissemination in VANETs, schemes that use periodic rebroadcasts have been proposed [10-13]. However, they haven't acquired the optimal time period that carefully considers the tradeoff between reception reliability and transmission overhead. Typically, a timer is used to determine whether retransmit or not. A retransmission is used when a sender node cannot confirm the reception within a given time period. However, the optimal time

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period is difficult to acquire. The larger the time period, the lower the reliability will be. The time period cannot be too small because that will result many unnecessary retransmissions. In a high density networks, the useless retransmissions will increase the collisions and the MAC layer contention time at each node.

In this paper, we introduce an Optimized Abiding Geocast protocol (OAG) for warning message dissemination between vehicles, which aims at simultaneously achieving high reliability and fast propagation while incurring low broadcast overhead. Optimality, in terms of delay and transmission count, is achieved using a broadcast strategy that exploits opposite vehicles. To carry out reliable and efficient broadcast coordination, an optimal dynamic periodicity that effectively adapts OAG to sparse and dense networks is acquired.

The rest of this paper is organized as follows. Section 2 presents the related work and Section 3 describes our protocol OAG. The simulation behavior used and obtained results are discussed in Section 4. Finally, Section 5 concludes the paper.

Related Work: Several strategies have been suggested to improve the simple flooding approach where various heuristics have been proposed to coordinate the rebroadcasting of the message [9, 14-16]. However, they can’t ensure reliability in sparse networks since a relay node rebroadcasts only once. The major challenge comes too from the lossy wireless transmissions [17, 18] and the vehicles mobility, which undermine the reliability of one-hop broadcast. Since it often incurs high complexity to enhance the reliability of broadcast from the link layer, some previous works have focused on broadcast strategies that use periodic network layer retransmissions. However, they can't achieve simultaneously high reliability, fast propagation and low broadcast overhead since the optimal time period that considers the trade off between reception reliability and efficiency is difficult to acquire. In [12], if the sender doesn’t receive an explicit BACK after max-wait-time(the maximum delay of receiving a BACK from a forwarder),it rebroadcasts the warning message periodically according to max-wait-time until receiving a BACK from a next relay or reaching the maximum number of transmissions. This static periodicity generates additional overhead and can't ensure reliability in sparse networks. In [13], the time period value depends of the local traffic density achieved by exchanging beacons among neighbors, which delays the rebroadcast of the warning message and implicates a significant overhead in time and bandwidth especially in dense networks. A path diversity mechanism for sender-oriented broadcast protocols in VANETs has been proposed [19]. It uses two paths to deliver a packet to each relay node in order to provide a high reliability and a low delay for multi-hop broadcast protocols. However, it can’t ensure reliability in sparse networks and a significant broadcast overhead is generated in dense ones. In [10], periodicity that ensures informing relevant vehicles at least with braking distance away from the sender has been proposed. However, this short and static periodicity generates useless overhead specifically by the dissemination initiator in large scale. Furthermore, authors have considered passing information only through vehicles traveling in the same direction, rather than taking advantage of traffic in opposite direction lanes. In [20], a formal model of data dissemination in VANETs is proposed to study how VANET characteristics affect the performance of data dissemination and the results show how opposite vehicles can be exploited as carriers to quickly disseminate information to the vehicles that follow. In [11], a system of abiding geocast that uses opposite vehicles is presented. However, its periodicity takes in consideration only vehicles travelling in the opposite direction, which leads to dangerous situations and specifically in unidirectional roads. Furthermore, this periodicity is changed dynamically only when receiving (directly or indirectly) a message from other vehicles traveling in the same direction, which generates additional overhead in time and bandwidth especially that this system broadcasts the last opposite vehicle information with every message to inform relays indirectly. In sparse networks, this system can’t ensure reliability since its dissemination initiator is a vehicle leaving the event.

In this paper, we present an approach which efficiently exploits the VANET characteristics to acquire the optimal time period that can guarantee high reliability, limited latency and low overhead under different traffic densities. Our time period ensures informing opposite vehicles since they reduce broadcasts and accelerate the message delivery, but also vehicles traveling in the same direction to ensure high reliability. In order to save unnecessary broadcasts while keeping the warning message in the alert zone, we dynamically set the wait time of the relay vehicle(and even of the initiator vehicle) for the next broadcast when it receives the same message from a new relay farther than him to the event whenever its moving direction. Moreover, intermediary vehicles are

Warning information							Sender –information				
Initiator-ID	topic	content	location	safety Distance	time Limit	effect Distance	ID	direction	speed	location	send Time

Fig. 1: The warning message form.

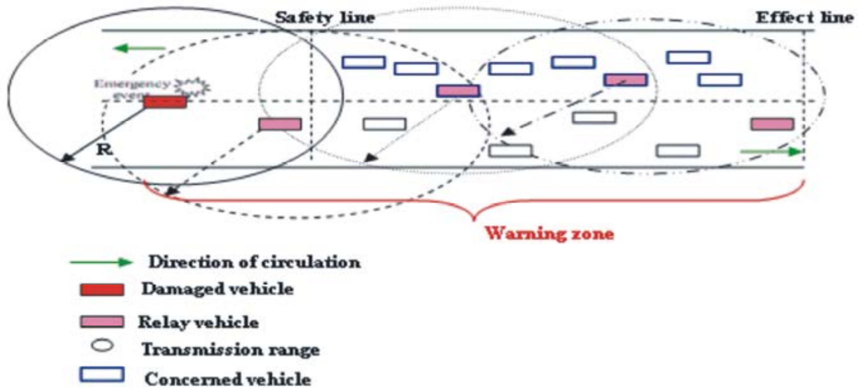

Fig. 2: A warning message dissemination.

used to connect relays indirectly using the last leaving relay information which is broadcasted only when it's necessary and in a reduced message, saving consequently both time and bandwidth.

Proposed Protocol (OAG)

Context: Vehicles performing OAG should be equipped with embedded computers, GPS receivers and unidirectional radio antennas of range R. Communications between vehicles are supposed to be bidirectional and are based on the broadcasting of messages. Each vehicle has a unique identifier nod-id in the network and circulates with a constant speed randomly chosen in the interval $[S_{mean}-\varepsilon, S_{mean+}\varepsilon]$ where S_{mean} is the speed mean and ε represents its variation. Only one initiator of disseminating is assumed, other vehicles act as relays. The warning message has the following form:
where, Safety Distance represents the distance between the event and the safety line (warning line). It means that vehicles moving towards the event should be informed at least distance away from the event and Time limit is the validity of the warning event. Effect line is used to indicate beyond which point vehicles will become inactive and not broadcast any more, whereas effect distance is the distance between the event and the effect line. The area between these two points is called warning zone. Effect distance is set by the beginner of dissemination and then it will be constant and delivered to other vehicles with the message.

Protocol Description: When an accident occurs, the damaged vehicle which is the initiator of disseminating must broadcast a warning message to inform relevant vehicles about the danger. In each accident side, only one vehicle among all vehicles receiving this message must react to ensure its rebroadcast in order to inform others. This relay must be the farthest one from the initiator. It can be a vehicle leaving or approaching the event but it must be the farthest one from the sender comparing to the event in order to quickly cover the greatest geographic zone not yet covered. Once the broadcast done, it is taken by a new relay and so on. In each time, the relay is selected according to this principle (Figure2). We note that only the drivers of vehicles approaching the accident are alerted to avoid unnecessary and hasty reactions.

To favor the farthest vehicle from the sender to the accident to becoming relay, we propose that a vehicle receiving the warning message must first verify its relative position in report with the sender. If it is farther than the sender to the accident, it starts executing the DDT (Distance Defer Transfer) algorithm [14] to see if it is the farthest vehicle from the sender or no. We have adopted the same DDT mechanism principle (wait time inversely proportional to the distance) but modified the formula used to calculate the wait time value (defertime).

The value of defertime(x), computed by a vehicle(x)receiving the warning message from a sender (s)and which is candidate to retransmit it, is given by (1):

$$defertime\ (x) = \max\_defer\_time * \frac{R^{\varepsilon} - D_{xs}^{\varepsilon}}{R^{\varepsilon}} + \alpha \quad (1)$$

$$defertime\ (x) = \max\_defer\_time * \frac{R^{\varepsilon} - D_{sx}^{\varepsilon}}{R^{\varepsilon}} \quad (2)$$

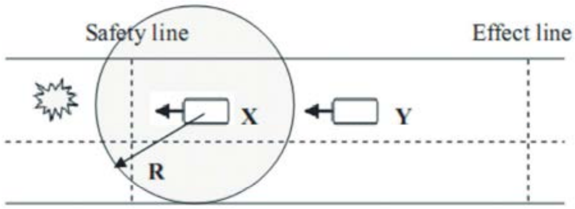

Fig. 3: Approaching relay separated from the safety line with a distance smaller than R.

Equation 2 is the formula used in [10] to calculate the defertime value, which is in turn an improvement of the formula used in the DDT mechanism in order to accelerate the warning message dissemination. Where R is the transmission range, D_{sx} is the distance between (s) and(x) and ε is a positive integer. Assuming a uniform distribution of nodes over the area, the choice of ε=2 will give a uniform distribution of the various value of defertime in [0, max-defer-time].The value of max-defer-time is equal to twice the average of communication delay. This formula allows selecting the farthest vehicle. The receivers calculate the distance to the sender using the position inserted in the message. A waiting time inversely proportional to this distance is then engaged before rebroadcasting. Thus, the first rebroadcasting vehicle will be the most distant node which has the minimal value of defertime and the other vehicles cancel their retransmissions when receiving the broadcasted message.

Our contribution consists in adding a random variable α (that takes values of order ms) when calculating defertime (1) in order to overcome the multiple relays problem, when two (or more) vehicles equidistant to the sender designate them self as relay at the same time. The vehicle getting the smallest value of α will have the shortest waiting time and has to rebroadcast the message. This optimizes in turn our proposed broadcast scheme since it minimizes competitions and collisions by assuming vehicles different α values when they have the same distance to the sender.

The initiator vehicle must broadcast the warning message periodically according to a dynamic period Δθ which depends on the relays availability in the warning zone. Initially it broadcasts according to (3), where S_{max} represents the maximum allowable speed, to ensure informing relevant vehicles at least with braking distance (Dbrake) away from the accident [10], especially in sparse networks where these vehicles cannot be informed before. When it knows that other relays are active, it stops its broadcasts until the disappearance of these relays from the warning zone and restarts after according to (3). That is in order to avoid unnecessary broadcasts while keeping the message in the alert zone.

$$\Delta\theta = \frac{R - Dbrake\ (S_{\max})}{S_{\max}} \tag{3}$$

Note: In our protocol, it's the damaged vehicle which initiates the warning message broadcast but when its embarked system is completely damaged, it's the first vehicle detecting the event which must ensure this task. Several methods can be used for the event detection. For example, when an accident occurs, the airbags activation can initiate the warning message broadcast.

***Ensuring Reliability:** In order to overcome network fragmentation and ensure reliability, in our system, the relay vehicle has to broadcast the warning message periodically according to a period ?θ which ensures informing opposite vehicles since these later are the preferred relays which allow overcoming fragmentation and disseminating the alert quickly and efficiently. This period also takes in consideration vehicles traveling in the same direction especially when the relay is a vehicle approaching the accident and separated from the safety line with a distance smaller than R, in order to ensure informing vehicles approaching the event before they reach the safety line, avoiding consequently dangerous situations (Figure3).

The wait time of a relay vehicle for the next broadcast is set according to transmission range, its speed S_{self}, current location Curr-loc, location of safety line and maximum speed of vehicles with the conservative assumption that the vehicle is moving at the maximum allowable speed S_{max}. The wait time can be set for a relay leaving or approaching the event using (4):

$$\Delta\theta = \min\left[\frac{R + |\ Curr\_loc\ -\ Safetyline\ |}{S\max}, \frac{2*R}{S\max + Sself}\right] \tag{4}$$

For a leaving relay, during this time, opposite vehicles which are vehicles approaching the accident cannot travel from beyond the transmission range, pass then leave its range or cross the safety line. So, this periodicity ensures informing approaching vehicles before they reach the safety line.

For an approaching relay, this periodicity ensures that opposite vehicles are informed to overcome fragmentation and disseminate quickly the alert. During

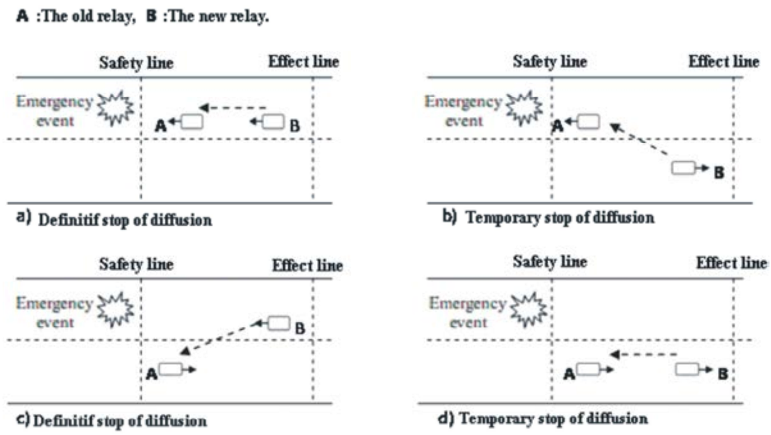

Fig. 4: Direct communication between relays.

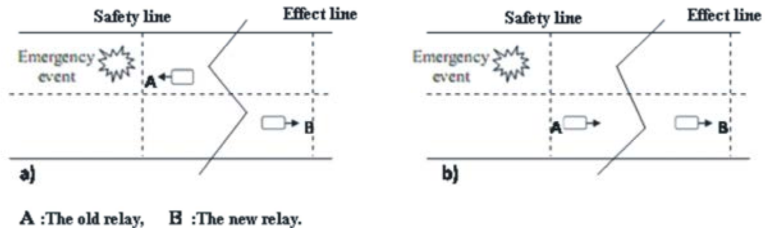

Fig. 5: Cases of fragmentation between relays.

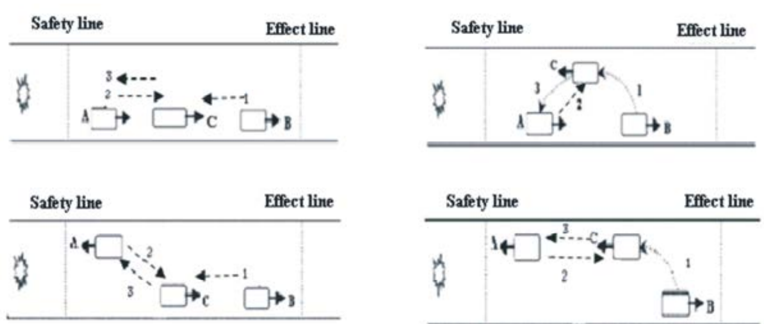

Fig. 6: Indirect communication between relays.

this time too, vehicles traveling in the same direction cannot travel from beyond the transmission range, pass then leave its range or cross the safety line. So, this periodicity ensures informing approaching vehicles before they reach the safety line.

***Updating the Relay Wait Time Dynamically:** In order to save unnecessary broadcasts while keeping the warning message in the alert zone, we dynamically set the wait time of the relay vehicle for the next broadcast when it receives (directly or indirectly) the message from a new relay farther than him to the event.

If this new relay is a vehicle approaching the accident (Figure4.a, Figure4.c), the relay must stop its periodic rebroadcasts definitively because the new relay will ensure this task.

If this new relay is a vehicle leaving the accident (Figure4.b, Figure4.d), the relay must stop its periodic rebroadcasts momentarily until the new relay leaves the warning zone. In this case, the wait time is calculated with location of effect line, actual location and speed of the leaving relay.

The relays can communicate directly (Figure4) when the network is not fragmented; otherwise they can't (Figure5). In this case and in order to avoid unnecessary broadcasts while keeping the warning message in the alert zone, we exploit intermediary vehicles (approaching or leaving) to connect them indirectly (Figure6) using the last leaving relay information as follows:

A vehicle(C)leaving or approaching the event, receiving the warning message from a leaving relay and receiving after the same message from another

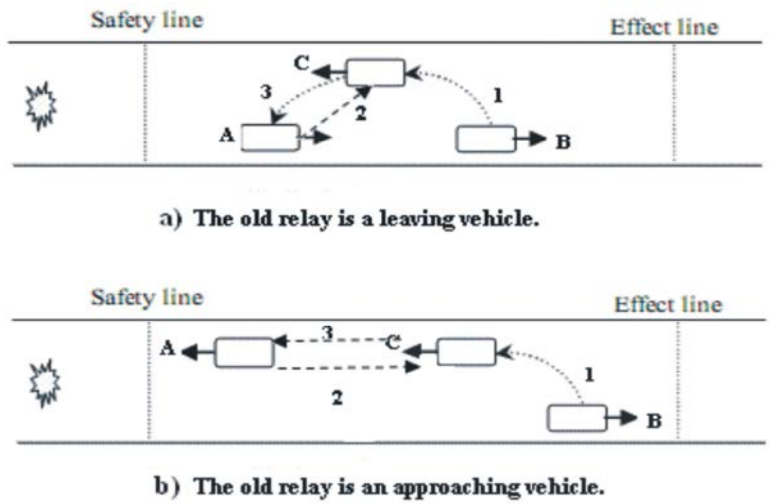

Fig. 7: Example of an indirect communication between relays.

relay(approaching or leaving)nearer than the first relay to the accident before the first relay leaves the warning zone, must inform the second relay about the first by broadcasting a message, named message ’STOP’. This message contains the first relay information<ID, direction, speed, location, Send Time>which vehicle(C) has registered when receiving the message from the first relay. In our protocol, every vehicle must save the last received warning message if its sender is a vehicle leaving the event. When receiving the message ’STOP’, the second relay must stop its rebroadcasts until the first relay leaves the warning zone.

The case of multiple (C)where many vehicles(C)receive the message from the relay(A)and are candidates to inform it about the relay(B) is resolved by selecting the farthest (C) from(A)to the accident in order to reduce competitions, collisions and redundancy.

To clarify more, Figure7 shows an example of an approaching vehicle(C) which serves to connect two relays indirectly.

In Figure7.a and Figure 7. b, the relay (A) is broadcasting periodically then (B) is selected as new relay since it is the farthest from (A) to the accident. Assuming that, when (B) starts its broadcast, the (A) was outside its transmission range and hasn’t received the message of (B). Consequently, (A) will not stop its periodic broadcasts. The (C) has received the message firstly from (B) and during its traveling he will surely receive the message from (A) since it’s its opposite vehicle. When receiving this message, the vehicle(C) must broadcast a message ’STOP’ to inform (A) about (B). Thus, the vehicle (A) will stop its broadcasts until (B) leaves the warning zone.

So, we have succeed in saving unnecessary broadcasts while keeping the warning message in the warning zone using the last leaving relay information which is broadcasted only when it’s necessary(fragmentation)and in a reduced message; saving consequently both time and bandwidth specially in dense networks which adapts our protocol to sparse and dense networks. Our protocol is also efficient in unidirectional roads since the periodicity of relays approaching the event takes in consideration vehicles traveling in the same direction in addition to opposite vehicles and we propose that vehicles leaving the event in these roads will not be used as relays to avoid useless broadcasts.

To take in consideration the situation of overtake, in our protocol, a vehicle which was a relay and which has stopped definitively its periodic broadcasts must resume as relay in the case it receives the same warning message and it’s the farthest vehicle from the sender to the accident. Also, a vehicle which was a relay and which has stopped its periodic broadcasts until the exit of the new relay must resume as relay even before the expiration of its waiting time in the case it receives the same warning message and it’s the farthest vehicle from the sender to the accident.

Performance Evaluation: In order to evaluate the performance of OAG against ODAM (Optimized Dissemination of Alarm Messages) [10] and AG (Abiding Geocast) [11], we created a mobility model to simulate the vehicles behavior on the road. We carried out series of simulations using the network simulator NS2 [21]. In addition to OAG, we have simulated ODAM and AG

Table I: Parameters

Description	Value
Transmission range(R)	200m
Mac layer	IEEE802.11
Data rate	2Mbps
Paquet size	64Bytes
Safety Distance	200m
Effect Distance	6Km
Trafic Density(N)	1, 3, 6, 9, 12,15 vehicles/Km/lane
Speed mean(Smean)	25m/s
Speed variation ε	5m/s

since these two protocols are proportionally more effective than other proposed ones and from them we were inspired. This section presents the simulation parameters, performance metrics and obtained results.

Simulation Parameters: The parameters of our model are listed in Table I. The vehicles are uniformly distributed on a bidirectional road consisting of two lanes at a rate of N vehicles per Kilometer per lane and run at constant speed throughout the lanes. The speed of each vehicle is randomly selected in the interval [S_{mean}-ε, S_{mean}+ε] and it can overtake other vehicles. For all the simulations, we fix the length of the straight road to 15Km. The location of the accident is at 0 meters, the safety distance is 200 meters, the effect distance is 6Km and the lifetime of the event is 500s. For ODAM and OAG, the beginner of dissemination is the damaged vehicle and it is a leaving vehicle located at the safety line when the event occurs for AG. Initially, all vehicles approaching the accident are located before the safety line.

Performance Metrics: We have evaluated our system in comparison to the others by measuring the following performance metrics:

Message Delivery Ratio: Represents the ratio of the approaching vehicles that receive the message to the total number of approaching vehicles.

Ratio of Vehicles Informed Before the Risk Zone: Represents the ratio of the approaching vehicles that receive the warning at least with braking distance away from the accident to the total number of informed approaching vehicles.

Ratio of Vehicles Informed Before the Safety Line: Represents the ratio of the approaching vehicles that receive the warning before reaching the safety line to the total number of informed approaching vehicles.

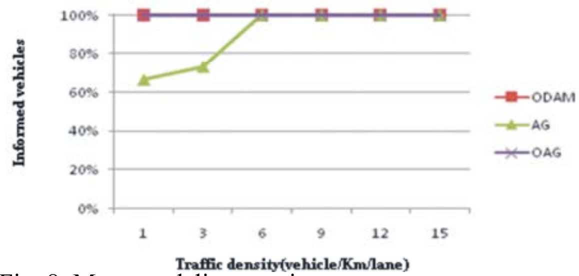

Fig. 8: Message delivery ratio.

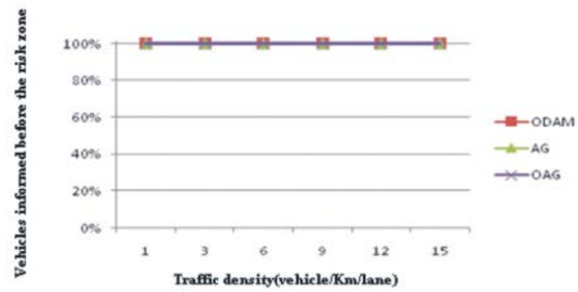

Fig. 9: Ratio of vehicles informed before the risk zone.

Delivery Average Delay: Is determinate through: $(^{A}\Sigma_{i=1}Ti)/A$, where T_i is the time when approaching vehicle i was informed and A is the number of informed approaching vehicles.

Broadcasted Messages Number (Broadcast Overhead): Represents the number of broadcasted messages during the lifetime of the emergency.

Simulation Results: Figure 8 compares the message delivery rate for different vehicles densities. We can remark that OAG and ODAM achieve 100% delivery rate for all densities. This is justified by the relays availability in dense networks and by the initiator periodic broadcasts in sparse networks. AG cannot alert all relevant vehicles in sparse networks (N=1,3vehicles/Km/lane) due to the fact that the initiator vehicle is a vehicle leaving the accident which prevents vehicles entering the alert zone after its exit from receiving the alert. Its delivery ratio increases with the traffic density which allows keeping the warning message in the alert zone and informing new approaching vehicles after the initiator exit.

We can see in Figure 9 that the three protocols ensure informing vehicles before the risk zone in sparse and dense networks. For higher traffic densities, this is justified by the relays availability which allows informing vehicles early. For sparse networks, this is justified by the periodic broadcasts of the initiator vehicle which allows informing approaching vehicles early during its traveling in AG and at least with braking distance away from the

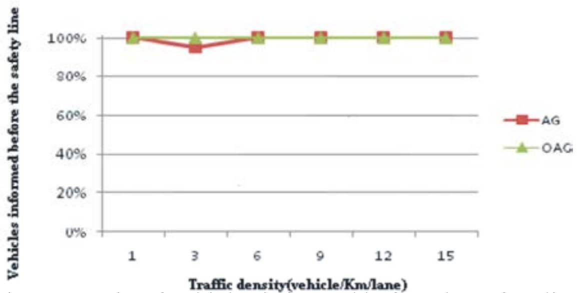

Fig. 10: Ratio of vehicles informed before the safety line.

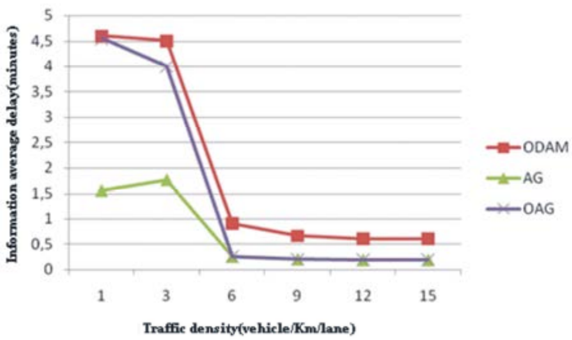

Fig. 11: Delivery average delay.

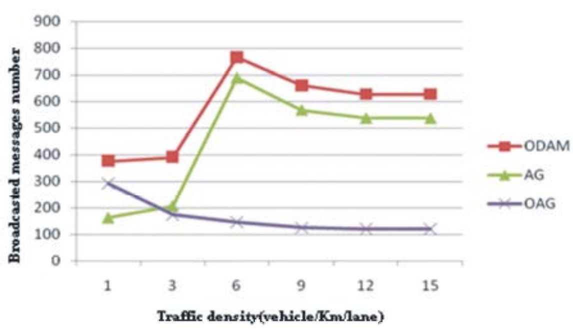

Fig. 12: Broadcast overhead.

accident in OAG and ODAM. Figure 10 shows that informed vehicles with OAG have received the alert before crossing the safety line in sparse or dense networks. For higher densities, this is due to the relays availability specially those far away from the safety line which allow informing early concerned vehicles. For weak densities, the reason is that the initiator vehicle ensures informing vehicles which have not receive the alert due to the lack of relays in the alert zone coupled whit the fact that the periodicity of relays approaching the event ensures informing vehicles traveling in the same direction before crossing the safety line. The lack of these two factors which doesn't allow 5% from vehicles informed with AG to receive the alert before reaching the safety line with the traffic density 3 vehicles/Km/lane. With a traffic density of 1 vehicle/Km/lane, informed vehicles with AG have received the alert before reaching the safety line because they have received the warning from the leaving initiator vehicle. For higher densities, informed vehicles have received the alert before crossing the safety line due to the relays availability too.

Figure11 compares the delivery average delay for different traffic densities. OAG shows better performance than ODAM for all densities. The fact is that OAG doesn't limit rebroadcast to approaching vehicles as ODAM does, but it uses also leaving (opposite) vehicles which allow informing earlier concerned vehicles. For higher densities, we can remark that OAG and AG have the same average delay because they use the same relay selection strategy and have the same relays periodicity when these relays are close to the effect line. For weak densities, AG has the minimal delay compared to OAG due to the fact that most informed vehicles have received the alert earlier from the leaving initiator which doesn't stop its periodic rebroadcasts until its exit. Moreover, this delay is that of informed vehicles which represent 66,66%, 73,33% from the total number of concerned vehicles. The increase of this delay between 1 and 3 vehicle/Km/lane proves this because with a higher density, the number of informed vehicles increases and consequently the delivery average delay increases. The average delay of the tree protocols decreases significantly with the traffic density (6vehicles/Km/lane) and decreases more with the density increase due to the relays availability which allows informing earlier concerned vehicles.

Figure12 compares the number of broadcasted messages (broadcast overhead). OAG shows much better performance than ODAM for all traffic densities. The first reason is the static periodicity of the initiator vehicle which broadcasts the alert periodically according to the period $\Delta\theta$=1,66s during all the lifetime of the accident, contrary to OAG where the initiator set dynamically this periodicity according to the relays availability in the warning zone. Moreover, the relay periodicity in ODAM is shorter than that in OAG and ODAM doesn't use opposite vehicles which allow avoiding certain broadcasts especially in sparse networks. With the traffic density 1vehicle/Km/lane, AG has slightly better performance than OAG because the damaged vehicle doesn't broadcast the message contrary to OAG where this last one broadcasts periodically in order to alert all concerned vehicles replacing the relays lack in sparse networks. However and unfortunately, AG doesn't ensure informing all relevant vehicles which has reduced more the number of broadcasted messages. For all other densities, OAG shows much better performance than AG.

The reason is that AG proposes that the relay sets dynamically its periodicity only when the new relay is traveling in the same direction in order to connect relays indirectly using the last opposite vehicle information, contrary to OAG where the relay sets dynamically its periodicity whenever the direction of the new relay and the efficient use of the reduced message 'STOP' which allows connecting relays indirectly faster and avoiding consequently many periodic broadcasts comparing to AG. The number of broadcasted messages with OAG decreases significantly with the density increase because the initiator dynamic periodicity increases with the relays availability which minimizes the number of broadcasts. Furthermore, the relays periodic broadcasts decrease with the availability of new relays.

CONCLUSION

This paper has presented OAG, an Optimized Abiding Geocast protocol for warning message dissemination between vehicles in VANETs. We have shown through simulation that our OAG protocol, compared to similar solutions, improves the message delivery time and rate and reduces the broadcast overhead in sparse and dense networks by acquiring an optimal dynamic periodicity. As a future work, we will extend OAG to handle intersections, where special mechanisms need to be developed.

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