Safety Message Propagation Using Vehicle-Infrastructure Cooperation in Urban Vehicular Networks

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Abstract. A soaring number of vehicles in modern cities bring in complicated urban transportation and severe safety risks. After a traffic accident occurs, how to quickly disseminate this alert to other vehicles is very important to avoid rear-end collision and traffic jam. Existing studies mainly use the vehicles travelling in the same direction as the collision vehicles to forward safety messages, which strictly limit the performance improvements. In this paper, we propose a safety message propagation scheme using vehicle-infrastructure cooperation in urban vehicular networks, named SMP. On straight roads, the opposite-lane front vehicles help to relay data when no further collision-lane back vehicles exist, while at intersections, the deployed roadside units create new safety messages with updated dissemination parameters and distribute them in the upstream lanes. The collaboration of vehicles in two directions and roadside units enhances the performances of safety-related applications. Besides, three checking policies are designed to avoid transmission failures and hence save network resources. Simulation experiments show that SMP achieves a high reception ratio and a short propagation delay.

Keywords: Urban vehicular networks · Safety message · Vehicle-infrastructure cooperation · Roadside units · Transmission checking

1 Introduction

Nowadays, as the number of vehicles in cities sharply rises, the urban transportation becomes more and more complicated. When there is a collision between two vehicles, if the safety message is not propagated to other vehicles immediately, it is probable to result in a multiple-vehicle collision, and the traffic jam thereafter further aggravates the severe transportation states. One of the main application of urban vehicular networks [16] is to improve the driving safety by utilizing communications between vehicles and roadside infrastructures [17].

An urban vehicular network consists of mobile vehicles carrying sensors to sense the vehicle status and the surrounding environments, and roadside units to connect the vehicles to Internet and provide powerful communication or

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computing capabilities [14,19]. Through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, a safety message can be disseminated to those vehicles which may be affected quickly [1]. Therefore, the drivers could take actions ahead of time, in order to avoid dangers or jammed roads [10].

Current researches on safety message propagation usually focus on the improvement of MAC protocol rather than the data forwarding among the vehicles and roadside units. Besides, alert messages are often relayed by the vehicles driving in the same lane/direction. However, since the multi-lane multi-direction straight roads and the intersections are very common in modern cities, how to use the vehicles travelling in different directions as well as the stable roadside units deployed at intersections to enhance the alert dissemination, becomes a key problem.

In this paper, we propose a safety message propagation scheme using vehicle-infrastructure cooperation in urban vehicular networks, named SMP. On a straight road, the safety messages are mainly distributed to and forwarded by the vehicles in collision lane, while the opposite-lane vehicles relay data when no more collision-lane vehicle exists in the communication range. In addition, around an intersection, the nearby roadside unit conducts message propagation to upstream lanes in light of divide and conquer method. Meanwhile, in order to reduce the probability of transfer failures, we design several transmission checking policies.

The main advantages of our proposal are listed below. (1) Safety message forwarding by the opposite-lane vehicles helps to extend the dissemination area and accelerate the data propagation. (2) Roadside units create a new safety message for each upstream lane, and start its propagation by V2U communications. Hence the severe problem of bandwidth competition at intersections is addressed. (3) The transmission checking policies avoid the waste of communication resources due to interrupted transmissions.

The remainder of this paper is organized as follows. After surveying the related work, we briefly introduce the network scenario and analyze the problem. Then the transmission checking policies and the safety message propagation algorithms for vehicles and roadside units are discussed in detail. After that, we present and analyze the simulation results, and finally conclude this paper.

2 Related Work

Recently the safety message propagation in vehicular networks becomes a hot research domain because of its important use in intelligent transportation systems (ITSs) [2]. Some studies analyze the performance of safety message propagation and explore the elements affecting the safety applications in vehicular networks [22]. Regarding sparse bidirectional highway scenario deployed with RSUs, Pan and Wu analyze the delivery delay of safety messages with general and decelerating "store-carry-forward" mechanisms [13]. Hafeez et al. analyze the reliability of a dedicated short-range communication (DSRC [8]) control channel (CCH) to handle safety applications in vehicular networks, and design an adaptive algorithm to address DSRC's performance degradation in dense and high-mobility conditions [6]. Dinh and Kim develop information centric networking to disseminate safety information efficiently by exploiting V2V and vehicle-to-road communications [3]. Omar et al. compare IEEE 802.11p standard [15] and a time-division multiple access protocol VeMAC via computer simulations in different highway and city scenarios [12].

Besides, some researchers propose efficient safety message dissemination schemes to enhance the quality of services. For vehicle-safety-related communication services, Ucar et al. combine IEEE 802.11p-based multihop clustering and LTE for safety message dissemination, which achieves a high delivery ratio and a short delay with a small use of the cellular architecture [20]. Ghandour et al. present a cognitive network architecture with spectrum sensing and allocation schemes to dynamically extend control channel used by vehicles for safety-related data transmission [4]. Hassanabadi and Valaee design a sublayer in the application layer of the WAVE stack, which rebroadcasts network coded safety messages to increase the overall reliability of safety application [7]. Based on mobility aware clustering, Gupta et al. improve MAC to support dynamic beacon generations and allow for different data transmission rates [5].

Although a majority of the above work focuses on the link layer protocol, there exists some related work on the higher layers than MAC in safety message propagation schemes. To disseminate time-sensitive event-driven safety warning messages through lossy links, Li et al. propose an opportunistic broadcast protocol to increase reception ratio and accelerate dissemination, and utilize acknowledgements to avoid redundant data transmissions [11]. Wang et al. divide the coverage area of a relay node using regular hexagon equilateral triangle, and set vehicle groups accordingly. They guarantee that only one relay node forwards message in each group and each relay node forwards the same message only once [21].

However, to the best of our knowledge, most of the present researches only utilize the vehicles driving in the same direction as the source of the safety message to forward data. Therefore, the alert dissemination is strictly limited, and hence affects the quality of services. In urban vehicular networks, how to fully utilize a large number of vehicles in different directions and the resource-rich roadside units to improve safety message propagation is our basic motivation.

3 Network Scenario and Problem Statement

For a clear discussion about the problem, we focus on the roads with two lanes in different directions. We assume all the vehicular nodes have the same communication radius CV, and the roadside units have the same communication radius CU. Usually $CU > CV$. The vehicular nodes and the roadside units use omnidirectional antenna to propagate signals. In other words, the signals are disseminated in all the directions, and every node in the communication range can receive this signal theoretically. When a node gets this signal, it decides on whether to receive the data or not by checking the destination field in the packet.

When a vehicle in a collision creates a safety message, it is called the source of this message, and the lane having the collision is called the collision lane. Those vehicles travelling in the collision lane are named collision-lane vehicles, denoted by $S = \{s_1, s_2, ..., s_i\}$, while those vehicles in the opposite lane are called opposite-lane vehicles, denoted by $O = \{o_1, o_2, ..., o_j\}$. For two collision-lane vehicles, along its driving direction, the one in front of the other is called collision-lane front vehicle, while the other is collision-lane back vehicle. Similarly, we have opposite-lane front vehicle and opposite-lane back vehicle.

An instance of safety message dissemination is shown in Fig. 1. When vehicles s_2 and s_3 have a collision, a safety message is generated by and disseminated from s_3 (the source of the safety message). Compared with s_3, s_1 is a collision-lane front vehicle, while s_4 is a collision-lane back vehicle. Similarly, comparing o_1 and o_2, o_1 is opposite-lane front vehicle, while o_2 is opposite-lane back vehicle. Since the crash may lead to a rear-end collision of s_4 or at least slow it down, s_4 should receive the safety message as soon as possible for an immediate reaction. Therefore, s_4 is regarded as one of the destination nodes of this safety message. In this scenario, s_4 receives the data from s_3 by one hop V2V communication.

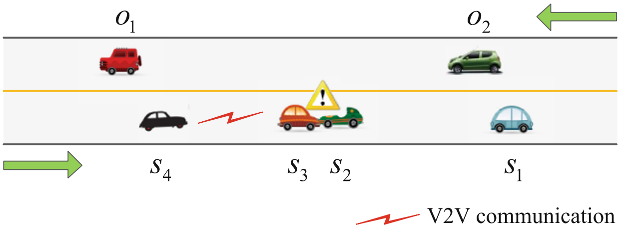


Fig. 1. An instance of safety message dissemination.

From this instance, we get that the safety message dissemination aims to propagate the safety message to those vehicles within a specific distance, whose driving behaviors might be affected by this accident. In specific, in terms of straight roads and intersections in urban road networks, the data dissemination schemes are also different. On straight roads, the safety message propagation aims to deliver the message to the collision-lane back vehicles of the source; in the intersections, the safety message needs to be distributed to those vehicles which might drive into the collision lane. Besides, in order to avoid failed transmissions, we design some policies for transmission validity checking. Next we will introduce these policies first, and then details how to disseminate safety messages on straight roads and in the intersections.

4 Transmission Checking Policies

Since the high velocity results in an unstable inter-vehicle connectivity, it is common that some V2V data transmissions are interrupted when the two communicating vehicles leave each other's communication range. This kind of invalid transmissions occupy the valuable wireless bandwidth, and hence lead to resource wastes. Besides, after transmission failures, vehicles have to reselect some forwarders to continue data relay, which prolongs data dissemination latency. Considering the safety messages require a high quality of service, we design three policies to distinguish the invalid transmissions ahead of time, based on the expected data transmission time, the current distance of the sender and the receiver, and their velocities. Before a vehicular node sends some data, it uses the policies to check this transmission first. If the result is true, it starts to transmit; otherwise, it gives up this transmission.

The transmission checking in safety message dissemination consists of three policies, i.e., the timing checking, the location checking, and the distance checking. If and only if all the three policies return true, the checking result is true; otherwise, it returns false. Next we will give a brief introduction of the time and location checking policies, and then discuss about the distance checking policy in detail.

In the timing checking policy, the vehicle compares the remaining lifetime of the safety message and the expected transmission time. If the safety message has a longer lifetime than the expected transmission time, the checking result is true; otherwise, it is false. In addition, the location checking policy checks the expected location of the receiver when it receives the whole data. If it is within the specific propagation range of this safety message, the policy returns true; otherwise, the result is false. Moreover, the distance checking policy checks whether the two communicating nodes keep in their communication ranges during the expected transmission time. Specifically, it has different rules with respect to the different travelling directions of the sender and the receiver. We will discuss about it in four cases as follows.

(1) Distance checking for transmission between collision-lane vehicles.

From above analysis, we know the collision-lane front vehicles should transmit the safety message to collision-lane back vehicles. On the one hand, for unicast transmission from a vehicle s_i to its back vehicle s_{i+1}. The velocities of s_i and s_{i+1} are v_i^S and v_{i+1}^S respectively, and the current distance between them is $f_{i,i+1}^S$ ($f_{i,i+1}^S \leq CV$). The expected time to transmit the safety message is τ. Based on geometry theory, the distance checking condition is

$$vsgn(v_i^S - v_{i+1}^S) \times [\tau(v_i^S - v_{i+1}^S) + f_{i,i+1}^S] \leq CV, \tag{1}$$

where $vsgn()$ is a variation of sign function, in which $vsgn(x) = 1$ when $x \geq 0$, and $vsgn(x) = 0$ when $x < 0$. On the other hand, for multicast transmission, take a collision-lane front vehicle s_i sending data to all the collision-lane back nodes in its communication range as an instance. If there exists at least one back vehicle which satisfies the condition (1), then s_i sends data out and the receivers determine whether to obtain the data or not according to their own results of the condition (1).

(2) Distance checking for transmission from collision-lane vehicle to opposite-lane vehicle.

From our SMP scheme below, there only exists unicasting from collision-lane vehicle to opposite-lane vehicle, rather than multicasting. In addition, the collision-lane vehicle is nearer to the source than the opposite-lane vehicle. For example, a collision-lane vehicle s_i wants to send data to an opposite-lane vehicle o_j. Their velocities are v_i^S and v_j^O, and their distance is $f_{i,j}^{SO}$ ($f_{i,j}^{SO} \leq CV$). The lane width is D. After computing the distance between vehicles in different directions, we get the checking condition

$$\sqrt{D^2 + [\tau(v_i^S + v_j^O) + \sqrt{f_{i,j}^{SO\ 2} - D^2}]^2} \leq CV. \tag{2}$$

(3) Distance checking for transmission between opposite-lane vehicles.

In SMP, only unicasting from an opposite-lane front vehicle to an opposite-lane back vehicle is supported. Similar with transmission between collision-lane vehicles, the distance checking condition for two opposite-lane vehicles o_j and o_{j+1} with velocities v_j^O and v_{j+1}^O and distance $f_{j,j+1}^O$ is

$$vsgn(v_j^O - v_{j+1}^O) \times [\tau(v_j^O - v_{j+1}^O) + f_{j,j+1}^O] \leq CV. \tag{3}$$

(4) Distance checking for transmission from opposite-lane vehicle to collision-lane vehicle.

In SMP scheme, this kind of transmission is multicasting from an opposite-lane vehicle to those collision-lane vehicles which are further to the source than the sender. For instance, o_j with velocity v_j^O wants to send message to s_i with velocity v_i^S and their distance is $f_{j,i}^{OS}$. The checking condition is

$$\sqrt{D^2 + [\tau(v_i^S + v_j^O) - \sqrt{f_{j,i}^{OS\ 2} - D^2}]^2} \leq CV. \tag{4}$$

When multicasting, if any of the receivers satisfies the above condition, o_j sends this message, and each receiver decides whether to receive it according to its checking result.

5 Safety Message Propagation Scheme

5.1 Safety Message Propagation on Straight Roads

For safety message propagation on straight roads, we propose a propagation scheme using vehicles travelling in two directions. The main idea is to use the collision-lane vehicles to forward the safety message, but when there is a coverage hole (no more collision-lane vehicle can continue data dissemination), the opposite-lane vehicles are utilized to enlarge the coverage area and shorten the propagation delay.

(1) Data propagation algorithm for the collision-lane vehicles.

After the safety message is generated, the source sends this message to all the collision-lane back vehicles in its communication range. In order to propagate the message quickly and efficiently, the farthest collision-lane back vehicle from the source is selected as the next relay. There are two main reasons for this selection. (1) The farthest back vehicle is in the communication range of the current relay node (or the source node), therefore there is no hole (uncovered road segments) in the data propagation. (2) Because of the same communication radius, the communication area of the farthest back vehicle covers that of other back vehicles, which accelerates the dissemination. Other collision-lane vehicles work in the same way as the source.

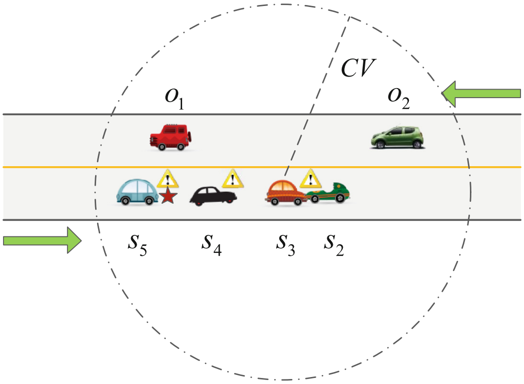
However, sometimes there may be no collision-lane back vehicles, but exist vehicles in the other lane. Compared with the collision-lane nodes, the opposite-lane vehicles usually meet a new collision-lane vehicle earlier. Therefore, SMP attempts to use the opposite-lane vehicles to achieve a quick propagation. In specific, among all the opposite-lane vehicles in the relay's communication range, the front one is selected as the next forwarder. Since the opposite-lane nodes are not the destinations of the safety message, they only take the role of forwarder. Besides, the front vehicle has a high probability to meet a collision-lane vehicle earlier than others.

The data propagation algorithm for a collision-lane vehicle s_i is shown in Algorithm 1. In the algorithm, $BV(i)$ is the set of collision-lane back vehicles of s_i in its communication range; $OV(i)$ is the set of opposite-lane vehicles in s_i's communication range.

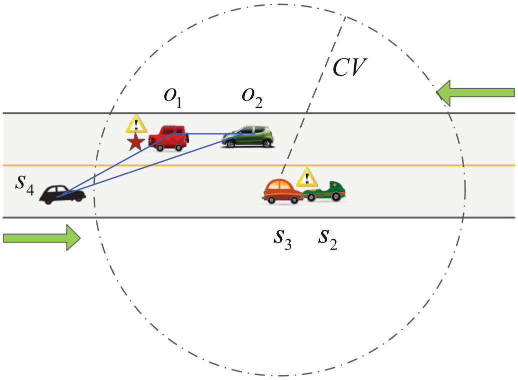
Algorithm 1. Data propagation algorithm for a collision-lane vehicle s_i

```
if $BV(i) \neq \emptyset$ then
    send the safety message to $BV(i)$;
    select $s_x \in BV(i)$ with max $f^S_{i,x}$ to be the next relay;
else
    if $OV(i) \neq \emptyset$ then
        select the front $o_y \in OV(i)$ to be the next relay;
        send the safety message to $o_y$;
    else
        keep going ahead carrying the safety message;
    end
end
```

An instance of data propagation at a collision-lane vehicle s_3 is shown in Fig. 2. In Fig. 2(a), the source of a safety message s_3 sends the message to its collision-lane back vehicles, including s_4 and s_5. Besides, s_5 is selected as the next relay and continues the data propagation to its collision-lane back vehicles. Another case is shown in Fig. 2(b). The source s_3 has no collision-lane back vehicles in its communication range, but it has two opposite-lane vehicles, i.e., o_1 and o_2. In this case, s_3 sends the safety message to o_1, and then o_1 forwards it to another collision-lane vehicle s_4. According to the triangle theory, in Fig. 2(b), $f^{OS}_{1,4} < f^{OS}_{2,4}$. Therefore, o_1 has a larger coverage of new collision-lane vehicles than o_2, and o_1 is a good next relay.



(a) between collision-lane vehicles



(b) from collision-lane vehicle to opposite-lane vehicle

Fig. 2. An instance of safety message propagation at a collision-lane vehicle.

(2) Data propagation algorithm for the opposite-lane vehicles.

After an opposite-lane vehicle receives a safety message, it carries the message until encountering a new collision-lane vehicle. At this time it forwards the data to all the new collision-lane vehicles, and selects the farthest one as the next relay. Besides, before encountering a collision-lane vehicle, if another opposite-lane vehicle passes the carrier, for a quick propagation, the carrier forwards the message to this passing vehicle.

The data propagation algorithm for an opposite-lane vehicle o_j is shown in Algorithm 2, where $SV(j)$ is the set of newly meeting collision-lane vehicles.

Algorithm 2. Data propagation algorithm for an opposite-lane vehicle o_j

```
if $SV(j) \neq \emptyset$ then
    send the safety message to $SV(j)$;
    select $s_x \in SV(j)$ with max $f_{j,x}^{OS}$ to be the next relay;
    remove the safety message from cache;
else
    if $o_y$ passes $o_j$ then
        send the safety message to $o_y$;
        select $o_y$ to be the next relay;
        remove the safety message from cache;
    else
        keep going ahead carrying the safety message;
    end
end
```

Figure 3 illustrates an example of data propagation at an opposite-lane vehicle o_1. In Fig. 3(a), o_1 sends the safety message when encountering new collision-lane vehicles s_4 and s_5. s_4 and s_5 both receive the data, but only s_5 is the next relay. As shown in Fig. 3(b), when o_2 passes o_1, o_1 transmits the safety message to the new next relay o_2. After delivery, the replica in o_1 is removed since o_1 is not a destination of the safety message.

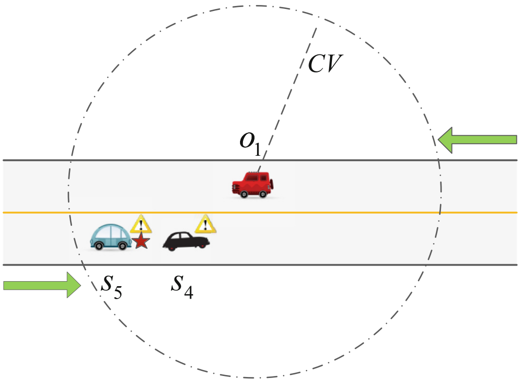
To sum up, SMP disseminates the safety message in the collision-lane back vehicles mainly through collision-lane relays and sometimes through opposite-lane forwarders, which help to increase the coverage and shorten the propagation latency when no further collision-lane relay exists.

5.2 Safety Message Dissemination at Intersections

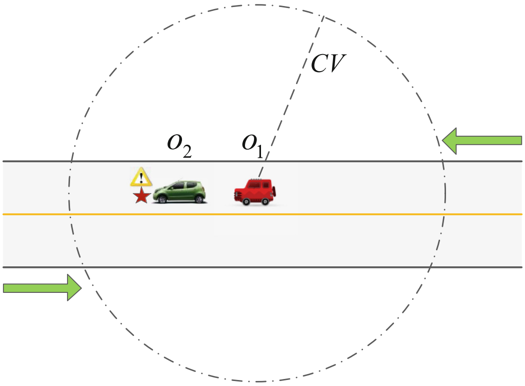
In urban transportation scenarios, a safety message is forwarded along a straight road segment, and then arrives at an intersection deployed with a roadside unit. Regarding the roadside unit has a stronger communication capability than those vehicular nodes, SMP uses the roadside unit to take charge of the safety message disseminate around the intersection.

Specifically, when a roadside unit receives a safety message from some vehicle, firstly it gets the collision lane, where the safety message is from, by analyzing the collision location in the alert message. Since the safety message only needs to be disseminated in those lanes where the vehicles may drive into the collision lane (called the upstream lanes), the roadside unit finds these lanes according to the geographical information of the intersection.

Then the roadside unit calculates the remaining propagation distance in each upstream lane according to the source location and the overall propagation distance. If the remaining propagation distance is positive, then the roadside unit creates a new safety message for further dissemination in this lane, which takes the roadside unit as its source and the remaining propagation distance as the



(a) from opposite-lane vehicle to collision-lane vehicles



(b) between opposite-lane vehicles

Fig. 3. An instance of safety message propagation at an opposite-lane vehicle.

propagation distance, and has the same warning information as the original safety message. After that, this new safety message is distributed to the vehicles in this lane and in the roadside unit's communication range, among which the farthest one from the roadside unit is selected as the next forwarder. Similar with above analysis, the relay selection helps to accelerate the safety message propagation.

The safety message dissemination algorithm for roadside units is presented in Algorithm 3. LF is upstream lanes; $RD(l)$ is the remaining propagation distance in the lane l; $LV(l)$ is the vehicles in the lane l and in the communication range of the roadside unit; $f^{UL}_{k,z,l}$ is the distance between the roadside unit u_k and the vehicle v^l_z in the lane l.

For a clear presentation, we give an example in Fig. 4. Vehicles can turn left or right at an intersection deployed with a roadside unit u_1. When u_1 gets a

Algorithm 3. Data dissemination algorithm for a roadside unit u_k

```
find the upstream lanes $LF$;
for $\forall l \in LF$ do
    if $RD(l) > 0$ then
        generate a new safety message for lane $l$;
        if $LV(l) \neq \emptyset$ then
            send the new safety message to $LV(l)$;
            select $v_z^l \in LV(l)$ with max $f_{k,z,l}^{UL}$ to be the next relay in lane $l$;
        else
            carry the new safety message;
            try to send it to vehicles in lane $l$ later;
        end
    end
end
```

safety message from s_5, it finds three upstream lanes, which are marked with red arrows in the figure. Assume that the remaining propagation distances for all the three lanes are positive, and u_1 creates three new safety messages. Since there are some vehicles in these lanes, u_1 sends the new messages to them. Hence the vehicles d_1^U, d_1^L, d_1^D and d_2^D all receive their messages respectively. Moreover, d_1^U, d_1^L and d_2^D are the next relays in their lanes.

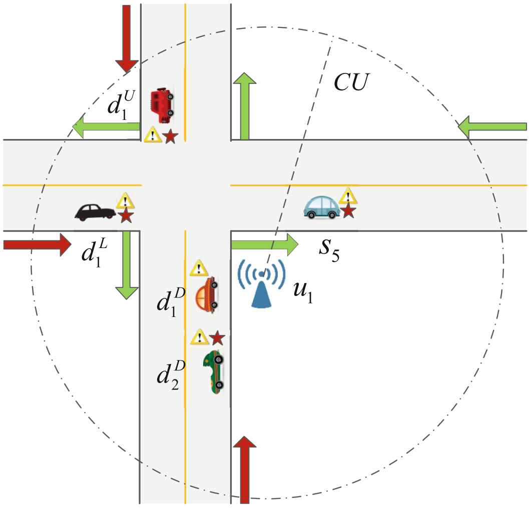


Fig. 4. An instance of safety message dissemination at an intersection.

Overall, in an intersection, SMP utilizes the idea of divide and conquer to replace the original safety message with several new safety messages for different lanes. In each lane, SMP attempts to cover as many vehicles as possible and accelerate data dissemination by multicasting and relay selection.

6 Performance Evaluation

6.1 Network Configurations

To evaluate the performance of our proposal, we take simulation experiments on the opportunistic network environment simulator (ONE) [9,18]. More experiments based on real world data are left to our future work. The network configurations are listed in Table 1 with some discussions below.

Table 1. Simulation environment configuration

Parameter	Value
Roads	5000 m with 2 lanes
Intersection locations	An intersection every 1000 s
Road width	10 m
Vehicle departure interval	4–18 s
Number of roadside units	5
Communication radius of vehicular nodes	300 m
Communication radius of roadside units	500 m
Velocity on straight roads	Random in [60, 110] km/h
Velocity at intersections	Random in [45, 65] km/h
Safety message transmission time	2 s
Lifetime of safety message	120 s
Safety message propagation distance	5000 m
Scenario preparation time	240 s

Since the vehicle density greatly affects the performance of safety message propagation, we conduct experiments in scenarios with different vehicle densities. In order to provide different densities as well as the mobility randomness, we let the vehicle departure interval range from 4 s to 18 s, and select random velocities in a specific range for all the vehicles. Besides, at the beginning of the experiments, we take 240 s to prepare well the scenario with vehicles on the roads. Then simulate a collision at the end of one road, and start safety message propagation.

Considering that our safety message propagation scheme focuses on the higher layers than MAC layer in IEEE 802.11p, SMP can be integrated with those MAC-enhanced protocols. To the best of our knowledge, our proposal is an innovative attempt to fully utilize the vehicles and infrastructures to improve the alert dissemination. Therefore, in the experiments, we select the propagation scheme using only collision-lane vehicles (PCL), the propagation scheme using collision-lane vehicles and opposite-lane vehicles but without roadside units (PBV) as our compared schemes. Comparing the results of PBV and PCL, we can see the advantages of opposite-lane vehicles, while comparing PBV and SMP, we get the performance of roadside units.

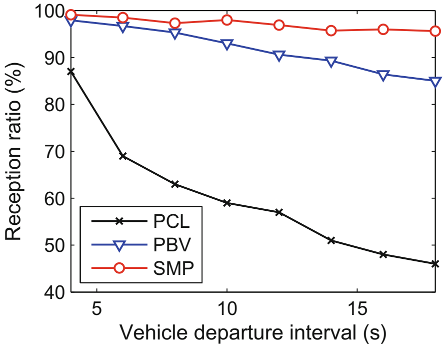
We use four criteria, i.e., the reception ratio, the propagation delay, the transmission overhead, and the number of detected failed transmissions. The reception ratio is the ratio of the number of destinations which receive the safety message to the number of all the destinations. A higher reception ratio indicates a better data dissemination. Besides, the propagation delay is the duration from the time when the safety message is generated by its source to the time when it reaches the boundary of the propagation area. A short propagation delay implies a quick response to the accident, and hence works well for urgent events. Moveover, the transmission overhead is the number of safety message transmissions, which shows the communication consumption of the data dissemination. Note that for a multicast transmission with one sender and multiple receivers, we take it as one transmission. Last but not the least, the number of detected failed transmissions directly presents the benefits from the transmission checking policies.

6.2 Simulation Results

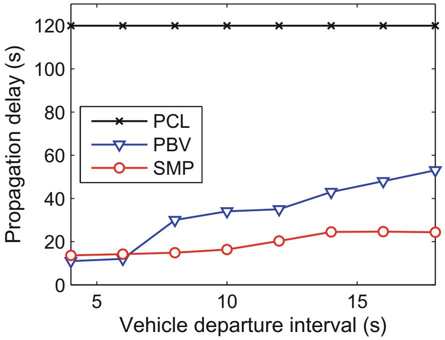
The simulation results of the three compared schemes, i.e., PCL, PBV and SMP, are illustrated in Fig. 5.

From Fig. 5(a), we see that when the vehicle density increases (in other words, the vehicle departure interval decreases), SMP keeps a relatively stable reception ratio above 95%, while the reception ratios of PBV and PCL grow from 85% to 98% and from 46% to 87% respectively. The main reasons are as follows. More vehicles bring in more opportunities of V2V communications. Since PCL and PBV only use vehicles to forward data, the advantages of a high density are obvious. By contrast, SMP also utilizes the roadside units with powerful communication abilities to relay data, therefore its reception ratio growth is relatively small. However, compared with PCL and PBV, SMP always has a higher reception ratio in the scenarios with different numbers of vehicles.

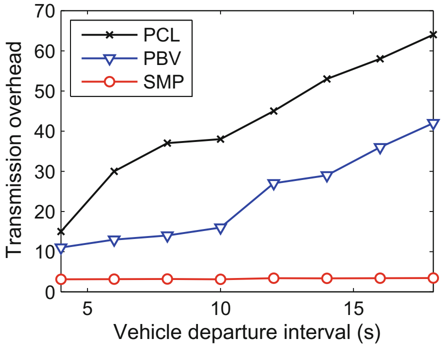
As shown in Fig. 5(b), PCL keeps the longest propagation delay 120 s, while PBV shortens its delays from 53 s to 10 s as the vehicle density rises. Actually, in PCL, the safety message does not reach the boundary of the propagation area because of the limited transmissions between collision-lane vehicles. In other words, the warning information is not fully disseminated. After the lifetime 120 s finishes, the messages are out of date and removed from their carriers. Besides, PBV uses the opposite-lane vehicles to disseminate the alerts within the propagation range, and a high vehicle density produces new communication opportunities and hence results in a short delivery latency. It is noteworthy that SMP keeps a stable and short propagation latency at round 20 s, because the roadside units accelerate the data dissemination at intersections.



(a) receptionratio



(b) propagationdelay



(c) transmissionoverhead

Fig. 5. Simulation results.

In Fig. 5(c), as the vehicle density decreases, the transmission overheads of PCL and PBV have rapid growths, because the safety message has to be transmitted several times due to the severe inter-vehicle transmission conditions. In comparison, because of the advantages of stable roadside units, SMP has the smallest transmission overhead.

Since the safety message transmission time is short (2 s) in the above experiments, there are few transmission failures. In order to clearly present the performance of our transmission checking policies, we range the safety message transmission time from 2 s to 10 s, and keep the vehicle departure interval to be 8 s. The numbers of detected invalid transmissions in the three schemes are shown in Fig. 6.

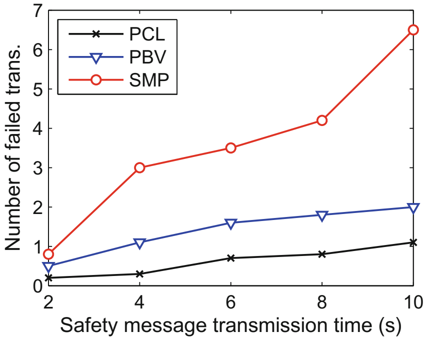


Fig. 6. Results of the number of detected failed transmissions.

We see, in Fig. 6, the numbers of detected failed transmissions in SMP, PBV and PCL rise from less than 1 to 6.5, 2 and 1 individually, when the safety message transmission time ranges from 2 s to 10 s. When transmitting a safety message takes a longer time, it is more probable that the two communicating vehicles travel out of each other's communication range during the data transfer. In particular, SMP with the most communication chances has the most failed transmissions. In one word, the transmission checking policies improve the communication efficiency to some extent, especially when the data transmission takes a long time.

In conclusion, compared with PCL and PVB, our scheme SMP keeps a high reception ratio, a short propagation delay, and a small transmission overhead, in the scenarios with different vehicle densities. Besides, the transmission checking policies have an obvious advantage to avoid invalid transmissions in SMP.

7 Conclusion

For safety applications in urban vehicular networks, we put forward an efficient safety message propagation scheme combining the advantages of vehicles and infrastructures, named SMP. Specifically, on straight roads with two directions, the collision-lane back vehicles are the destinations of the alerts, and the farthest among them is selected as the next relay. If no more collision-lane vehicles can obtain data, the opposite-lane font vehicle is taken as the next forwarder, which helps to shorten the dissemination latency. Besides, at intersections, the roadside units deliver new safety messages with updated information to the upstream lanes. The strong communication capacity of roadside units also improves the warning dissemination. In addition, the transmission checking policies avoid the potential failed transmissions, and thus save resources. Finally the simulation results show that compared with those schemes using only collision-lane vehicles and only vehicles in two directions, SMP has a high reception ratio and a short propagation delay at a small transmission cost.

Although we design several transmission checking policies, there still exist some complex factors affecting the data delivery, such as the bandwidth competition, the packet scheduling, etc. Analyzing these elements may enhance the performance of safety-related services. Besides, the construction and evaluation of an architecture integrating our propagation scheme and new MAC-enhanced protocol also require further study.

References

1. Ali, G.G.M.N., Noor-A-Rahim, M., Chong, P.H.J., Guan, Y.L.: Analysis and improvement of reliability through coding for safety message broadcasting in urban vehicular networks. IEEE Trans. Veh. Technol. **67**(8), 6774–6787 (2018)
2. Bi, Y., Zhou, H., Zhuang, W., Zhao, H.: Safety Message Broadcast in Vehicular Networks. Springer, Heidelberg (2017). https://doi.org/10.1007/978-3-319-47352-9
3. Dinh, N., Kim, Y.: Information-centric dissemination protocol for safety information in vehicular ad-hoc networks. Wirel. Netw. **23**(5), 1359–1371 (2017)
4. Ghandour, A.J., Fawaz, K., Artail, H., Felice, M.D., Bononi, L.: Improving vehicular safety message delivery through the implementation of a cognitive vehicular network. Ad Hoc Netw. **11**(8), 2408–2422 (2013)
5. Gupta, N., Prakash, A., Tripathi, R.: Adaptive beaconing in mobility aware clustering based MAC protocol for safety message dissemination in VANET. Wirel. Commun. Mob. Comput. **2017**(1246172), 1–15 (2017)
6. Hafeez, K.A., Zhao, L., Ma, B., Mark, J.W.: Performance analysis and enhancement of the DSRC for VANET's safety applications. IEEE Trans. veh. Technol. **62**(7), 3069–3083 (2013)
7. Hassanabadi, B., Valaee, S.: Reliable periodic safety message broadcasting in vanets using network coding. IEEE Trans. Wirel. Commun. **13**(3), 1284–1297 (2014)
8. Kenney, J.B.: Dedicated short-range communications (DSRC) standards in the United States. Proc. IEEE **99**(7), 1162–1182 (2011)
9. Keranen, A., Ott, J., Karkkainen, T.: The ONE simulator for DTN protocol evaluation. In: Proceedings of International Conference on Simulation Tools and Techniques (SIMUTools). ACM, Rome, 2–6 March 2009
10. Khan, F.A.: Safety-message routing in vehicular ad hoc networks. Technical report, Georgia Institute of Technology, Atlanta, USA (2013)
11. Li, M., Zeng, K., Lou, W.: Opportunistic broadcast of event-driven warning messages in vehicular ad hoc networks with lossy links. Comput. Netw. **55**(10), 2443–2464 (2011)
12. Omar, H.A., Lu, N., Zhuang, W.: Wireless access technologies for vehicular network safety applications. IEEE Netw. **30**(4), 22–26 (2016)

13. Pan, B., Wu, H.: Analysis of safety messages delivery in vehicular networks with interconnected roadside units. IEEE Access **1**, 1–10 (2017). https://doi.org/10.1109/ACCESS.2017.2769344
14. Piao, J., McDonald, M., Hounsell, N.: Cooperative vehicle-infrastructure systems for improving driver information services: an analysis of COOPERS test results. IET Intell. Transp. Syst. **6**(1), 9–17 (2012)
15. Rezgui, J., Cherkaoui, S.: About deterministic and non-deterministic vehicular communications over DSRC/802.11p. Wirel. Commun. Mob. Comput. **14**(15), 1435–1449 (2014)
16. Sun, G., Zhang, Y., Liao, D., Yu, H., Du, X., Guizani, M.: Bus trajectory-based street-centric routing for message delivery in urban vehicular ad hoc networks. IEEE Trans. Veh. Technol. **67**(8), 7550–7563 (2018)
17. Tang, X., Hong, D., Chen, W.: Data acquisition based on stable matching of bipartite graph in cooperative vehicle-infrastructure systems. Sensors **17**(6), 1–22 (2017)
18. Tang, X., Pu, J., Cao, K., Zhang, Y., Xiong, Z.: Integrated extensible simulation platform for vehicular sensor networks in smart cities. Int. J. Distrib. Sens. Netw. **2012**(4), 22–26 (2012)
19. Tang, X., Pu, J., Gao, Y., Xie, Y., Xiong, Z.: GPS-based replica deletion scheme with anti-packet distribution for vehicular networks. Comput. J. **58**(6), 1399–1415 (2015)
20. Ucar, S., Ergen, S.C., Ozkasap, O.: Multihop-cluster-based IEEE 802.11p and LTE hybrid architecture for VANET safety message dissemination. IEEE Trans. Veh. Technol. **65**(4), 2621–2636 (2016)
21. Wang, X., et al.: Regular-hexagon-equilateral-triangle area grouping-based broadcast protocol for safety message in urban vehicular ad hoc networks. Int. J. Distrib. Sens. Netw. **13**(1), 1550147716683829 (2017)
22. Yin, X., Ma, X., Trivedi, K.S.: An interacting stochastic models approach for the performance evaluation of DSRC vehicular safety communication. IEEE Trans. Comput. **62**(5), 873–885 (2013)