

An Emergency Event Driven Routing Algorithm for Bi-directional Highway in Vehicular Ad Hoc Networks

Yajie Yang^{1,2}, Demin Li^{1,2}, Guanglin Zhang^{1,2}(✉), Chang Guo^{1,2},
and Saifei Jin^{1,2}

¹ College of Information Science and Technology, Donghua University,
Shanghai 201620, People's Republic of China

{yangyajie, guochang}@mail.dhu.edu.cn, {deminli, glzhang}@dhu.edu.cn

² Engineering Research Center of Digitized Textile and Apparel Technology,
Ministry of Education, Donghua University, Shanghai 201620,
People's Republic of China

Abstract. Vehicular Ad Hoc Networks (VANETs) play a significant role in preventing traffic accidents on the highway. But it is a challenge to reduce the messages transmission delay under emergency condition. In this paper, an emergency event driven routing algorithm for bi-directional highway is proposed. Each vehicle maintains a real-time special neighbor nodes set which includes the next-hop vehicle and vehicle ID in three different directions. In particular, when there is no vehicle ahead or behind the accident vehicles we use the vehicles from reverse direction to reduce the intermittent link. And the emergency events of vehicles are divided into two types, according to the different influence of events on vehicles ahead and behind. And different emergency events launch different transmission algorithms. This ensures that the emergency messages (EMs) can transmit to the vehicles affected much more by the emergency events. Furthermore, we derive the transmission delay formula based on the proposed algorithm. Finally, the algorithm is verified by the simulation of the transmission delay formula. The results show that the proposed emergency event driven routing algorithm can reduce the transmission delay effectively.

Keywords: Vehicle Ad Hoc Networks · Emergency messages · Event-driven · Routing algorithm

1 Introduction

In recent years, with more vehicles on the road, traffic accidents are increasing. However, if the vehicles which are surrounding the accident vehicle can receive the emergency messages (EMs) in time and take corresponding measures, more serious accidents can be reduced and even be avoided. Vehicular Ad Hoc Networks (VANETs) [1] show great potential in reducing traffic accidents. VANETs

is an important part of Intelligent Transportation System (ITS) [2] and the Internet of things (IoT) [3]. The applications of VANETs mainly include two aspects, security applications [4,5] and user applications [6]. Security applications cover accident pre-warning, intersection-driving and route planning. Internet communication, resources sharing and commercial advertising belong to user applications. There are three kinds of information transmission modes in the VANETs. Respectively, they are Vehicle-to-Vehicle (V2V) [7], Vehicle-to-RSU (V2R) [8,9], and hybrid communication [10].

This paper mainly discusses how to reduce the EMs transmission delay on the highway. In [11], the authors achieve broadcast redundancy, transmission latency by choosing the furthest broadcast vehicle in a queue on the basis of directive broadcast. Minimizing duplicate retransmissions by combining location-based method and time reservation-based method with the aid of Global Positioning System (GPS) of neighboring nodes is proposed in [12]. [13] designs an event-driven Inter-Vehicle Communication protocol that learns about traffic conditions ahead and recommends optimal velocities in order to prevent the formation of vehicular shock waves. And this approach of reacting in case of traffic fluctuations leads to significant improvements in overall traffic flow. Protocol in [14] sends the periodic safety message and event driven safety message by using priority in the messages and context-based communication. Through these papers, we think that making the algorithm adapt to the changeful road scene is a way to reduce the transmission delay and intermittent link.

In this paper, we propose an emergency event driven EMs transmission algorithm for bi-direction highway. The routing algorithm not only reduce the transmission delay but also reduce the intermittent link. The contributions of this paper are as follows.

- (1) Each vehicle needs to maintain a real-time special neighbor nodes set. These sets can help to adapt to the diversity of the highway scene and find the next-hop node quickly to reduce the transmission delay.
- (2) When there is no next-hop vehicle in the same direction, we use the vehicles from reverse direction to transmit EMs. Because vehicles from reverse direction will meet the accident vehicle at a time. In this way, the intermittent link can be reduced.
- (3) The emergency events of vehicles are divided into two types. This ensures that the EMs can be transmitted to the greater affected vehicles firstly.

The rest of context is organized as follows. In Sect. 2, the system model is introduced. The Sect. 3 is the specific design of routing scheme and the estimation of EMs transmission delay. The analysis of the scheme through the simulation results is introduced in Sect. 4. Finally, We conclude this paper in Sect. 5.

2 System Model

The high speed of vehicles on the highway leads to the frequent change of the vehicle density. This phenomenon leads to that the EMs can't transmit timely

and effectively. So finding the next-hop vehicle quickly is an important factor to achieve uninterrupted communication. In this paper, we propose a real-time special neighbor nodes set for each vehicle. These sets are mainly used to help each vehicle to judge whether there exist vehicles that can communicate with in three different directions: ahead, behind and reverse line.

In general, the highway is a bi-directional road. If the vehicles from reverse direction can be reasonably utilized, the intermittent link can be reduced effectively. For example, in low traffic density, there may not exist a vehicle in the communication radius of the accident vehicle for a long time. This would cause the EMs can not transmit, which means that the communication link is interrupted. But the accident vehicle will meet the vehicles from reverse direction at a time, the EMs can transmit to the vehicles from reverse direction. Then the vehicles from reverse direction transmit EMs to the target vehicles. As shown in Fig. 1, the circle represents the vehicle transmission range, and road width is negligible compared to the vehicle transmission radius. That is to say, the adjacent vehicles in two lanes can communicate with each other. The intersecting circle represent the vehicle can communication with each other. When the accident vehicle needs to transmit EMs to vehicles ahead, the EMs will transmit as yellow arrow. Although there is no vehicles ahead the accident vehicle with in the transmission radius, the vehicles beside the accident vehicle can help transmit the EMs. Doing so ensures that the transmission link would not be broken.

The accidents are divided into two categories according to different accidents having different influence on the surrounding vehicles. For instance, traffic jam, sudden deceleration and braking. When these accidents occur, the influence on the behind vehicles are much more serious than on the ahead vehicles. So the EMs should transmit to the behind vehicles firstly. When other accidents such as brake failure, overtaking and accelerating occur, the influence on the ahead vehicles are much more serious than on the behind vehicles. So the EMs should transmit to the ahead vehicles firstly. Therefore, the type of events determines the EMs transmission direction. In this paper, we design different transmission algorithm for the two categories events, so the transmission delay can be reduced effectively.

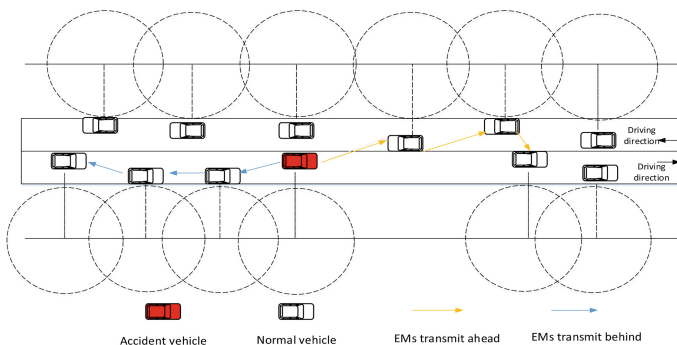


Fig. 1. EMs transmit model on bidirectional highway. (Color figure online)

Meanwhile, we assume that each vehicle has a unique ID. So ID is the unique identifier to distinguish the vehicles. The vehicle transmission radius is the same. The location of vehicles can be known by GPS measurement instrument. This paper uses a two-dimensional highway model. And we stipulate one of the direction for the positive direction, the other direction is the negative direction. Positive direction and negative direction are used to judge whether the vehicles are in the same direction.

3 Proposed Scheme

In this section, the proposed routing scheme is described. First, we describe the problem formulation. Then, the EMs transmission algorithm is proposed. Finally, the transmission delay formula is derived.

3.1 Problem Formulation

Each vehicle has a vehicle packet, the packet data will be updated and saved in real time. But when a vehicle occurs some accident, this vehicle packet will become an EMs. EMs transmit among vehicles to remind the surrounding vehicles. The packet contains five items:

- (1) Attribute value. When this value is 0, this indicates that the vehicle is in normal condition. And the packet is vehicle packet. When it is 1, this indicates that the vehicle is under emergency condition. And the packet become EMs.
- (2) Parameter 1. Vehicle's ID, which is the only item to identify the vehicle. We use the vehicle's license plate as vehicle's ID.
- (3) Parameter 2. Vehicle's driving direction, its main role is to distinguish the vehicles in the same direction or reverse direction.
- (4) Parameter 3. Vehicle's location, which can be obtained from GPS data. The distance between vehicles can be roughly calculated by using GPS data.
- (5) Parameter 4. EMs Transmission direction, Transmission direction is the direction that the EMs need to transmit to. This item depends on the type of the emergency events. Under normal condition, it is null.

The format of vehicle packet and EMs show in Table 1. The second line is the format of vehicle packet, and the third line is the format of EMs:

Table 1. The format of vehicle packet and EMs.

Attribute value	Parameter 1	Parameter 2	Parameter 3	Parameter 4
0	Vehicle ID	Driving direction	Location	Null
1	Vehicle ID	Driving direction	Location	EMs transmission direction

In addition, each vehicle needs to maintain a real-time special neighbor nodes set. The special neighbor nodes set contains three items. The first item is (ρ_f, ID_f) . ρ_f stands whether there exist vehicles ahead itself, if there exist, the item is 1, otherwise, is 0. And ID_f is the next-hop vehicle ID. If there are more than one vehicle ahead of the vehicle, the vehicle select the furthest vehicle within the communication radius as the next-hop vehicle. The second item is (ρ_b, ID_b) . ρ_b stands whether there exist vehicles behind itself, if there exist, the item is 1, otherwise, is 0. And ID_b is the next-hop vehicle ID. If there are more than one vehicle behind the vehicle, the vehicle select the furthest vehicle within the communication radius as the next-hop vehicle. The third item is (ρ_s, ID_s) . ρ_s stands whether there exist vehicles beside itself, if there exist, the item is 1, otherwise, is 0. And ID_s is the next-hop vehicle ID. If there are more than one vehicle beside the vehicle, the vehicle will select the furthest vehicle within the communication radius as the next-hop. The format of special neighbor nodes set, namely, $\{(\rho_f, ID_f), (\rho_b, ID_b), (\rho_s, ID_s)\}$.

In this paper, we adopts dynamic programming to select the next-hop vehicle in three directions for each vehicle. r is the transmission radius of vehicles. $d(ID_x, ID_i)$ is the distance between ID_x and ID_i , $i = 0, 1, 2, \dots, N$. $D(ID_x)$ is the distance between ID_x and the furthest vehicle ID_i in ID_x communication radius. $M(ID_x, ID_x)$ is the derivative of $D(ID_x)$.

Objective function:

$$D(ID_x) = \max\{d(ID_x, ID_0), d(ID_x, ID_1), d(ID_x, ID_2), \dots, d(ID_x, ID_i)\} \quad (1)$$

Constraint Conditions:

$$0 < D(ID_x) < 2r \quad (2)$$

Decision Variable:

$$M(ID_x, ID_i) = \lim_{\Delta d \rightarrow 0} \frac{\Delta d(ID_x, ID_i)}{\Delta d} \quad (3)$$

If there exist $D(ID_x)$ and $M(ID_x, ID_i) < 0$, this means vehicle ID_x and ID_i are in the different direction and ρ_s is 1. If there exist $D(ID_x)$ and $M(ID_x, ID_i) > 0$, this means vehicle ID_x and ID_i are in the same direction and ρ_f or ρ_b is 1.

3.2 EMs Transmission Algorithm

When a vehicle occur a certain accident, it will produce an EMs. And the transmission of EMs should reference the special neighbor nodes set. According to the EMs package the EMs transmission direction can be known. If the EMs should transmit to the vehicles ahead, the ρ_f will be viewed first. If $\rho_f = 1$, the EMs will transmit to the accident vehicle's next-hop vehicle. Otherwise, the ρ_s will be viewed. If $\rho_s = 1$, the EMs will transmit to the vehicles on the reverse lane. If $\rho_s = 0$, EMs should wait for a while. If the EMs should transmit to the behind vehicles, the ρ_b will be viewed first. If $\rho_b = 1$, the EMs will transmit to the accident vehicle's next-hop vehicle. Otherwise, the ρ_s will be viewed. The specific algorithm is shown in Algorithm 1:

Algorithm 1. Event-driven transmission algorithm

```

if {Attribute value=1} then
  if {EMs' driving direction = vehicle's driving direction} then
    if { EMs needs to transmit ahead } then
      if {  $\rho_f = 0$  } then
        if {  $\rho_s = 1$  } then
          { transmit EMs to the vehicles from reverse direction }
        else
          { wait for a time interval t }
        end if
      else
        { transmit the EMs to the vehicle' next-hop vehicle directly }
      end if
    else
      { EMs need to transmit behind }
      if {  $\rho_b = 0$  } then
        { whatever  $\rho_s$  is, transmit the EMs to vehicles from reverse direction }
      else
        { transmit the EMs to the vehicle's next-hop vehicle directly }
      end if
    end if
  else
    if { $\rho_s = 1$ } then
      { transmit the EMs to vehicles from reverse direction }
    else
      { wait for a time interval t }
    end if
  end if
else
  { Vehicle is in a normal condition }
end if

```

3.3 The Estimation of EMs Transmission Delay

The time of EMs transmission includes two parts: carry time and forwarding time. Calculation formula is as follows:

$$T = t_1 + t_2, \quad (4)$$

T denotes the total transmission delay, t_1 is the carry time, t_2 is the forwarding time. According to the algorithm, we know there are five kinds of transmission delay.

Case 1: EMs need to transmit ahead. $\rho_f = 0$, $\rho_s = 1$.

Accident vehicle transmit the EMs to the vehicle from the reverse direction. So there only exists forwarding time. t_{hop} denotes an interaction time.

$$T_1 = t_2 = 2t_{hop}, \quad (5)$$

Case 2: EMs need to transmit ahead. $\rho_f = 1$.

Accident vehicle can transmit the EMs to its next-hop vehicle directly. The next-hop vehicle ID can be find in the accident vehicle's special neighbor nodes set. So there only exists forwarding time (Fig. 2).

$$T_2 = t_2 = t_{hop}, \quad (6)$$

Case 3: EMs need to transmit behind. $\rho_b = 0, \rho_s = 0$.

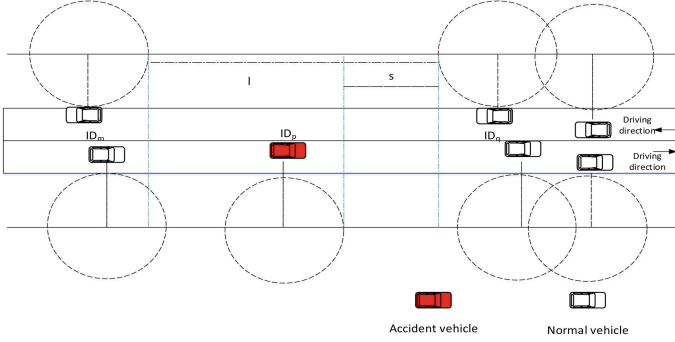


Fig. 2. EMs transmit model when $\rho_b = 0, \rho_s = 0$.

If the EMs need to transmit ahead it is a pursuit problem but if EMs need to transmit behind it is a meeting problem. It is assumed that vehicle ID_p need to transmit EMs, vehicle's transmission radius is r . v_{ID_x} is the vehicle ID_x 's speed. Vehicle ID_p need drive s to get into the communication range of vehicle ID_q which is on the reverse lane. The distance between two vehicles ID_p and ID_m in the same direction is l ; According to algorithm the total time is as following:

$$T_3 = t_1 + t_2 = \frac{s}{v_{ID_p} + v_{ID_q}} + \frac{2r + l}{v_{ID_q} + v_{ID_m}} + 2t_{hop}, \quad (7)$$

Case 4: EMs need to transmit behind. $\rho_b = 0, \rho_s = 1$.

This case is the same as case 2. Accident vehicle transmits the EMs to the vehicle on the reverse lane. So there only exists forwarding time.

$$T_4 = t_2 = 2t_{hop}, \quad (8)$$

Case 5: EMs need to transmit behind. $\rho_b = 1$.

This case is the same as case 3. Accident vehicle will transmit the EMs to the next-hop vehicle directly. And the vehicle ID can be find in the accident vehicle's special neighbor nodes set. So there only exists forwarding time.

$$T_5 = t_2 = t_{hop}, \quad (9)$$

Assuming the probability of occurrence of case i is P_i , then the total time is as follows:

$$T = \sum_{i=0}^4 P_i T_i. \quad (10)$$

4 Performance Evaluation

In this paper, we use MATLAB to carry on the comparative test and confirmatory test for the model and formulas given above. We assume that s is 150, l is 60 and the EMs should transmit to the n hop vehicles in ahead or behind the accident vehicle.

Assuming the five cases obey uniform distribution, so $P_i = \frac{1}{5}$. The transmission delay of event driven routing scheme is shown in Fig. 3. With the increase of n , T increased too. But when n is constant, as the increase of r , T changed little.

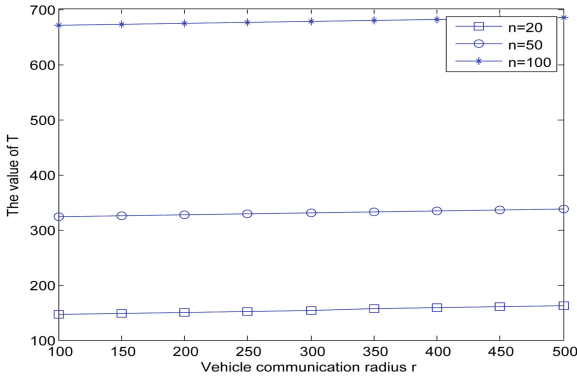


Fig. 3. The time T of event-driven algorithm.

In this paper, we use directive broadcast model to be compared. And assume $n = 50$, the T of directive broadcast model and event driven model are shown in Fig. 4.

Both the directive broadcast model and event driven model transmission delay will increase with the increase of vehicle transmission radius r . The time delay of event-driven model is lower than directive broadcast models. And with the increase of r event-driven's advantage is increasing too. So the proposed event driven routing algorithm have an advantage in reducing transmission delay and intermittent link.

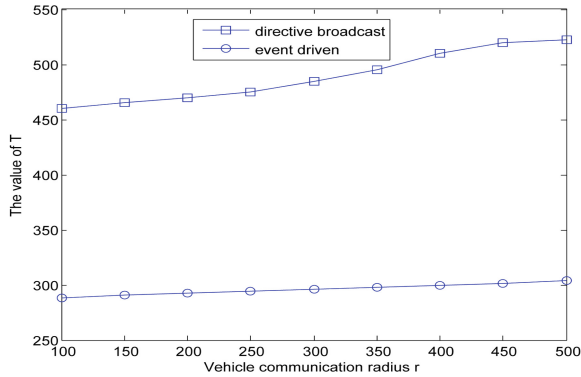


Fig. 4. The contrasting result of time T.

5 Conclusion

In this paper, we put forward an emergency event driven routing algorithm for bi-directional highway. The real-time special neighbor nodes set makes the algorithm more adaptable to the changeful highway. Through using the vehicles from reverse direction the intermittent link reduce effectively. Event classification makes the EMs transmit quickly to the greater affected vehicles. Besides, we derive transmission delay formula. Through the simulation results, we verify our proposed algorithm, which achieves better performance on reducing transmission delay. In terms of future work, we will devote to reduce transmission delay on the network layer and analyse capacity on the basis of the proposed algorithm.

Acknowledgement. This work is supported by the NSF of China under grant 71171045, 61301118; the Innovation Program of Shanghai Municipal Education Commission under Grant No. 14YZ130; the Fundamental Research Funds for the Central Universities and a DHU Distinguished Young Professor Program.

References

1. Li, Y., Wang, W.: Horizon on the move: geocast in intermittently connected vehicular ad hoc networks. In: Proceedings of the IEEE INFOCOM, pp. 2553–2561 (2013)
2. Blum, J., Eskandarian, A., Hoffman, L.: Challenges of inter-vehicle ad hoc networks. *IEEE Trans. Intell. Transp. Syst.* **5**(4), 347–351 (2004)
3. Sotiriadis, S., Bessis, N., Asimakopoulou, E., Mustafee, N.: Towards simulating the internet of things. In: Workshop Paper for the 28th IEEE International Conference on Advanced Information Networking and Applications, 13–16 May, Victoria, Canada, pp. 444–448 (2014)
4. Abboud, K., Zhuang, W.: Modeling and analysis for emergency messaging delay in vehicular ad hoc networks. In: Proceedings of IEEE GLOBECOM, pp. 1–6 (2009)

5. Almulla, M., Wang, Y., Boukerche, A., Zhang, Z.: A fast location-based hand-off scheme for vehicular networks. In: IEEE ICC Ad-Hoc and Sensor Networking Symposium, pp. 1464–1468 (2013)
6. Lee, K., Lee, S.-H., Cheung, R., Lee, U., Gerla, M.: First experience with cartorrent in a real vehicular ad hoc network testbed. In: 2007 Mobile Networking for Vehicular Environments, pp. 109–114 (2007)
7. Bazzi, A., Masini, B., Pasolini, G.: V2V and V2R for cellular resources saving in vehicular applications. In: Wireless Communications and Networking Conference (WCNC), pp. 3199–3203. IEEE (2012)
8. Paier, A., Faetani, D., Mecklenbrucker, C.: Performance evaluation of IEEE 802.11p physical layer infrastructure-to-vehicle real-world measurements. In: 2010 3rd International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL), pp. 1–5 (2010)
9. Villas, L., Leandro, A.: Network partition-aware geographical data dissemination. In: 2013 IEEE International Conference on Communications (ICC), pp. 1439–1443 (2013)
10. Jer, M., Marlier, P., Senouci, S.M.: Experimental assessment of V2V and I2V communications. In: IEEE International Conference on Mobile Ad Hoc and Sensor Systems (MASS) (2007)
11. XU, S., Zhou, H., Li, C., Zhao, Y.: A multi-hop V2V broadcast protocol for chain collision avoidance on highways. In: IEEE Proceedings of ICCTA, pp. 110–114 (2009)
12. Nuri, D.M., Nuri, H.H.: Strategy for efficient routing in VANET. In: IEEE, pp. 903–908 (2010)
13. Forster, M., Frank, R., Engel, T.: An event-driven inter-vehicle communication protocol to attenuate vehicular shock waves. In: International Conference on Connected Vehicles and Expo (ICCVE), pp. 540–545 (2014)
14. Kumar, A., Nayak, R.P.: An efficient group-based safety message transmission protocol for VANET. In: International conference on Communication and Signal Processing, pp. 270–274 (2013)