Design and Implementation of Distributed Broadcast Algorithm Based on Vehicle Density for VANET Safety-Related Messages

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Abstract. Vehicle ad hoc network (VANET) is a research hotspot in industrial and academic fields now and after. Dedicated short-range communication(DSRC) is a key technology of vehicular safety services and most research adhere to IEEE 802.11p standard. The safety-related services face channel congestion,message collision, and hidden terminal problem in different traffic conditions. This paper focuses on the broadcast of safety-related message under different vehicle densities. In this paper, we firstly divide the safety-related messages into three categories and assign them different broadcast priorities. Secondly,we design different distributed broadcast algorithms for the three type messages. Then, we propose a method used to evaluate the vehicle density and present the relationship between the vehicle density and the transmit power. Then the safety module selects proper transmit power according to the relationship before the message is sent. Finally, we conduct the simulation experiment using NS3 software in the Linux environment. Simulation results show that the broadcast scheme can effectively ensure that the emergency message is correctly received in the 200 meters range for high vehicle density. Compared with the algorithm without considering the vehicle density, the performance has been greatly improved.

Keywords: distributed broadcast; vehicle density; transmit power; transmission distance

1 Introduction

There are more traffic accidents and fatalities on the road every day. Once the vehicle ad hoc network technology is mature and put into use, not only can make the traffic more convenient, but also greatly reduce the harm to people's lives and property. As we all know,vehicles usually have a higher speed, their speed is at least 30km/h on the urban traffic roads, even up to 120km/h on highways. Then traffic accidents take place in a few seconds or even in a second. If drivers can predict the danger ahead of time, many lives and property will be protected from danger. Vehicle ad-hoc networks(VANETs) are mobile ad hoc networks that communicate with each other between vehicles in a traffic environment. We call the communication method as vehicle-to-vehicle(V2V) communication. The goal is to build a self-organizing, low cost, easy to build and access wireless communication network in a variety of traffic environments. Therefore, the vehicle ad hoc network can provide drivers safety-related services, for example, traffic accident warning, assist driving, traffic information query function, vehicular communication and so on, which is realized by broadcasting safety-related message to the surrounding vehicles.

Dedicated short-range communication(DSRC) radio technology with a 75-MHz bandwidth at the 5.9-GHz band [1] is projected to support low-latency wireless data communications among vehicles and from vehicles to roadside units. IEEE802.11p standard defines specifications of the physical layer and the medium access control(MAC) layer of the vehicular wireless communication networks based on DSRC, has been created and distributed for discussions. V2V communications form a basis for decentralized active safety-related applications,which is expected to reduce accidents and their severity [2].

In general, when a vehicle equipped with a DSRC device and a GPS positioning system travels on a road, traffic information and beacon information are often exchanged with other vehicle nodes. The transmit power of message determines its transmit distance. In contrast to the general message, the safety-related messages have higher delay requirements. Rebroadcasting message by the source node is the common method that can resolve broadcast failure in some situation but can bring broadcast storm if there exists traffic jam. We consider another situation. If the vehicle on the road travels slowly, the probability of terminal package collision is higher if the communication distance of message is long. And if the running vehicles on the road are very few, wasting energy is not advocated. Therefore, the paper adopts the distributed broadcast algorithm and designs different distributed broadcast algorithm based on vehicle density for safety-related messages.

The remainder of this paper is organized as follows: Section 2 briefly reviews the work related to the design and modeling of safety-related message broadcast in VANETs.Section 3 firstly divides the safety-related message into three types, and introduces the distributed broadcast algorithm of safety-related message. Section 4 presents the vehicle density assessment scheme and analyses the relationship between the transmission power and the vehicle density and applies to the algorithms. In section 5, the proposed algorithm is validated by extensive software simulations. This paper is concluded in Section 6.

2 Related Work

The safety-related services face channel congestion,message collision, and hidden terminal problem in different traffic conditions. And there have been lots of active researches on the analysis of broadcast strategy for safety services in VANETs. In summary, we divide these broadcast schemes into the following four categories according to the different influence factors.

(1) Control Transmit Power

The transmit power is higher, the impact range of the message is larger, and the message can achieve more farer. But in the case of high vehicle density, the more serious the information loss if the transmit power keep the same because of channel congestion problem. The scheme on controlling the transmission power of message has been studied.

Torrent-Moreno et al. [3], [4] proposed a distributed vehicle transmission power adaptive algorithm which calculated the minimum transmit power to meet the communication within the perceptual range.

All vehicles in the perceived range would use the same transmit power. However, the coordinated transmit power doesn't necessarily meet all vehicle requirements. And the method also requires infrastructure support, poor feasibility. Gozalvez et al. [5] proposed an opportunity-driven adaptive radio resource management scheme (OPRAM) that increases transmission power at a crossroads to avoid vehicle collisions. But when the crossroads congestion is more serious, the package collision rate is relatively high, even the special signal of the channel is cleared, collision will happen.Hafeez et al. [6] analyzed the influence range of single-hop broadcasts and established a mathematical model that can assess the interference range of the transmission distance. The mathematical model can be used to calculate the maximum communication distance available for single-hop broadcast.

(2) Control Information Sending Frequency

The channel load of VANETs is larger if the vehicle density is higher. Fixed message transmission frequency is easy to cause broadcast storm, which leads to channel congestion and information loss. In this case, the probability is very small that the information can be received correctly by the surrounding node. By controlling the transmission frequency of the information, especially the transmission frequency of the general message, it is possible to reduce the collision event of the packet.

In [7], [8], Christoph et al. proposed a new urban vehicle ad hoc network communication protocol, which is prone to broadcast storms due to the fixed periodic transmission of beacon message in the vehicle information system. Congestion and loss of message, the system uses a dynamic cycle to send beacons.

In [9], Tielert et al. proposed a design principle for designing collision control in an on-board ad hoc network, including distributed principles, participatory principles,and fairness principles, and based on this design principle, a method called PULSAR rate control protocol. In [10], [11], He Jianhua et al. designed an adaptive rate control vehicle network security application for DSRC. The application can control the message transmission rate so that the emergency information can quickly access the channel so that the emergency message can be sent as soon as possible.

(3) Control the Carrier Listening Threshold

It is difficult for the sending node to judge the status of the current receiving node, and it is difficult for the transmitting node to control the hardware of the receiving node to change the communication parameter by using the forwarding policy which center is transmitting node. Therefore, some scholars have proposed a forwarding strategy based on the receiving node as the central control carrier sense threshold, and the strategy can be realized by the network simulator. In [12], Robert et al. proposed a method for controlling the transmission of information by controlling the perceived threshold to ensure that the security information can be received normally for the loss of information caused by high load on the vehicle network.

(4) Combine the Above Several Factors

The transmission power, the transmission frequency and the carrier sense threshold have an impact on the network congestion. Some scholars have proposed a new congestion control forwarding strategy. In [13, 14], the control of the channel congestion was realized by controlling the transmission power, the transmission frequency, the carrier sense threshold, and the competitive back-off window. But these methods are still not very good to adapt to urban traffic and highway traffic environment under different vehicle density.

In summary, a series of studies have been carried out on broadcast of the safety-related message in VANETs, and vehicle density is an important factor. But vehicle density doesn't be considered to broadcast of safety-related message in VANETs now.

3 Distributed Broadcast Algorithm of Three Type Safety-related Messages

As mentioned above, there are safety-related services and non-safety-related services in VANETs, So each vehicle node here is equipped two modules: the non-safety-related application module and the safety-related application module. In this paper, we only discuss the processing of the safety-related module. Different type safety-related application requires different response time. Once an emergency situation occurs, it is critical to inform surrounding vehicles as soon as possible. Because the driver reaction time to traffic warning signals can be on the order of 700ms or longer, the update interval of safety messages should be less than 500ms(we refer to it as the lifetime of safety messages) [15], and according to the requirements in [15], the probability of message delivery failure in a vehicular network should be less than 0.01. Firstly we classify the safety-related messages in a VANET into three categories.

- The Class-one messages are emergency warning messages, mainly includes: the front vehicle braking message, the front vehicle collision message and other hazardous road conditions, such message has the highest priority. For example, when the front vehicle emergency brakes, emergency braking message will be send to the surrounding vehicles, the surrounding vehicles can make the right judgment and avoid traffic accidents.
- The Class-two messages are lower in priority than Class-one messages. This type of messages is a long-distance notification, mainly on environmental warning and traffic warning, help drivers know the road conditions ahead

and select the appropriate traffic routes. Although this type of messages is sent at a lower frequency, it must be sent prior to the general message.

- The Class-three messages stand for periodic beacon messages which inform the location of the vehicle, the movement direction of the vehicle, the speed of the vehicle and so on. The running vehicle periodically broadcasts its own beacon message and receives beacon message from other nodes around it, and updates its own adjacent node table (ANT).

3.1 Priority Mechanism of Three Type Safety-related Messages

According to the definition of safety-related messages, their priority is descending from class-one to class-three. The traditional IEEE802.11 adpots distinct ranges of backoff window sizes and AIFS duration to distinguish different services. Now we design preemptive priority scheme as Fig.1.we set the backoff window of emergency message as zero, and the backoff window of beacon message as nonzero. And we divide a DIFS interval into a number of minislots. The length of minislot l_m and the number of minislots n_m can be calculated as Eq.(1) and Eq.(2). The adopt of minislot [16] ensures the emergency message broadcast prior to beacon message broadcast when their backoff window are zero.

$$l_m = 2\sigma + SIFS \tag{1}$$

$$n_m = \lfloor DIFS/L \rfloor \tag{2}$$

where σ is the maximum propagation delay at the farthest communication distance,*SIFS* is the switching time between the receiving mode and the sending mode.In this paper, we set wait1,and wait2 respectively for class-one messages and class-two messages and $L \leq Wait1 \leq Wait2 \leq DIFS$. Figure 1 shows the broadcast priority for different type safety-related messages.

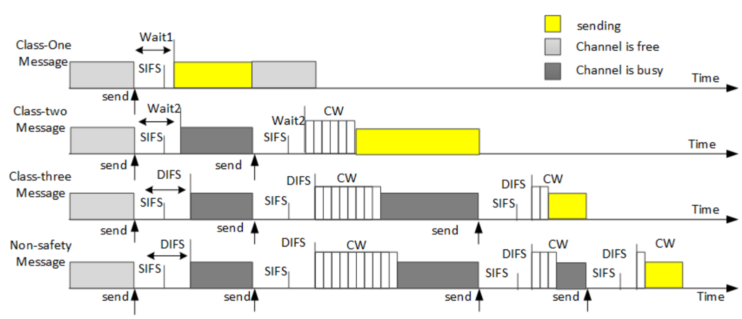

Fig. 1: The Broadcast Priority for Different Type Messages

3.2 The Distributed Broadcast Algorithm of Class-one Safety-related Message

One or more vehicle node will receive the message after the source vehicle node transmits the emergency message. Then some of these vehicles who receive message successfully in first cycle will be selected as the relay node to rebroadcast the message. And the selected node activates a delay Timer (AD timer). The value of the Timer derived from the following expression.

$$t_{AD} = T_{Max}\left(1 - \frac{d}{R}\right) \tag{3}$$

Where t_{AD} is the value of a timer, d is the distance between the vehicle node and the sending node, R is the maximum communication distance of the vehicle node,T_{Max} is the maximum delay time and is usually less than the life cycle of the message. According to the above formula, we can find that the value of timer is smaller if the distance between the receiving vehicle node and the sending node is larger, so that the remote nodes can quickly repeat the emergency message broadcasting.

Please remember that the vehicle node who receive message successfully can calculate the distance from the sending node according to the adjacent node table (ANT). Otherwise, each receiving node can distinguish a copy of broadcast packets and new generation according to 12 serial number in the MAC header by IEEE802.11 [17] design. All selected nodes will rebroadcast in the manner described above until the number of copies of the emergency message reaches a certain number N_c.

The sending node will monitor the forward situation of other nodes after broadcasting the message. If the number of copies of the emergency message doesn't reach the expected number when T_{max} finishes, then the source node will rebroadcast the emergency message. Note that the receiver will inform the sender about the error if an error occurs in the forward processing. Each sender assigns an identification serial number and the sender identification serial number for the message or the copy of the message.Even if there are some errors caused by message-self or broadcast collision, the source node can record the number of copies of the emergency message. The following Alg. 1 is the process of broadcast of class-one safety-related messages.

3.3 The Distributed Broadcast Algorithm of Class-two Safety-related Messages

The class-two messages broadcast selects the farthest distance receiving node in the direction of the source node in the maximum communication range as the relay node. The distance between the node and the sending node is defined as the projection of the Euclidean distance between nodes, and the node moves along the direction of movement of the source node. The distance between the relay node and the source node is shown in Fig.2.

Algorithm 1 Broadcast Algorithm of Class-one Safety-related Messages

```
if messageCountOfNode ≤ N_c then
    if lifeOfMessage ≠ 0 then
        if nodeID == messageNodeID then
            if messageCountOfNode ≠ 1 then
                messageCountOfNode ← messageCountOfNode+1
                return
            else
                Send tone
                info
                Start monitor module
            end if
        else
            Start t_AD timer
            Send tone
            messageCountOfNode ← messageCountOfNode+1
        end if
    else
        return
    end if
    return
end if
```

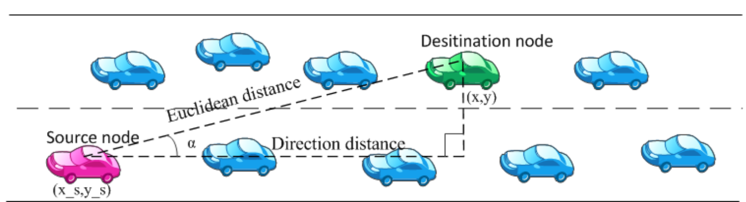

Fig. 2: The direction distance between the forwarding node and the source node

Assuming the position of the relay node is $(x,\, y)$, the position of the source sending node is $(x\_s,\, y\_s)$. And we assume that the direction distance is d_d and the Euclidean distance is d_e, the following relationship can be obtained:

$$d_d = d_e cos\alpha \tag{4}$$

Among them, the European distance can be obtained by the following formula:

$$d_e = \sqrt{(x - x\_s)^2 + (y - y\_s)^2}$$

$$\alpha = arctan(\frac{y - y\_s}{x - x\_s})$$

So the timer t_{AD} and the direction distance have the following relationship:

$$t_{AD} = T_{Max}(1 - \frac{d_d}{R}) \tag{5}$$

Where $= T_{Max}$ is the maximum delay time and R is the communication distance of the sending node. When the vehicle receives the class-two messages, the value of the timer will be set as shown in Eq.(5). Equation (5) shows that nodes far from the source node can send message faster and the sending frequency may be higher.

Note that when the timer of the vehicle node is running, the success of correctly received emergency message from other nodes, then the node will stop the timer, and cancel the rebroadcast action. Because of radio interference caused by collision or noise information broadcast failure, leading to other nodes have received an error message, there may even be the farthest node or partial node does not receive emergency message. This kind of situation is likely to exist, so when this happens, other candidate nodes will continue to maintain the timer count, until a certain candidate node as relay node of the new rebroadcast of the emergency message. The process will continue until the emergency message is relayed by the relay node at least once in the maximum communication range. Algorithm 2 describes the process in detail.

Algorithm 2 Broadcast of class-two safety-related messages

```
if message in messageListOfNode then
    if lifeOfMessage = 0 then
        return
    else
        if NodeID ≠ nodeIDOfMessage then
            Start t_AD timer
        end if
        Send tone
        Send message
        Start monitor module
    end if
else
    Stop t_AD timer
    return
end if
```

3.4 The Distributed Algorithm of Class-three Safety-related Message

According to the above definition, the class-three safety-related message about the position, direction and speed of the broadcast vehicle are periodically given to the surrounding vehicle nodes. If the beacon message comes from other vehicle node, the program will update its adjacent node table and send the message, if the beacon message derives from its own, then directly send it.

3.5 Monitor Module

The sending node monitors the status of the class-one and class-two safety-related messages. For the class-one safety-related messages, the source node will record the broadcast times of the message after the message is be broadcasted, if the sending delay time of the message finishes but the life of the message is not over, and the number of copies of the message doesn't reach N_c, then the monitor module will rebroadcast the message. For the class-two safety-related messages, the sending node listens to the channel after the message is sent. If the sending delay time of the message finishes but the life of the message is not over, and the message is not be rebroadcasted with the presence of other nodes around, then the sending node will rebroadcast the message. Finally, the sender will rebroadcast the message if the sender has been told that there are some errors in the message. The callback function of the monitor module is described in Algorithm 3.

Algorithm 3 The callback function of the listener module

if message.T_{Max}==0 **and** lifeOfMessge $\neq$ 0 **then**
if ANT.IsEmpty() **then**
return
else
if (typeOfMessage =1 **and** countOfMessage $\leq N_c$) **or** (typeOfMessage =2 **and** message in messageListOfNode=0) **then**
if nodeIDOfMessage $\neq$ NodeID **then**
Start T_{AD}
end if
Send tone
Send message
end if
end if
else
return
end if

There is no manager in the distributed broadcast algorithm of safety-related message in VANETs, so the entire protocol does not add additional hardware overhead to the vehicle node except that each vehicle node need install a hardware device for sending safety-related message hints. The hardware device that sends the safety-related message hints sends an unmodulated low frequency signal, so the bandwidth is very small.

4 Distributed Broadcast Algorithm Based on Vehicle Density for Safety-related Messages

4.1 Vehicle Density Assessment

The traffic condition varies over time, we defined the number of vehicles within the unit distance as the vehicle density. When the vehicle density is high, if the maximum communication distance is large, it will affect the communication of other nodes around the node, and even cause broadcast collision. When the vehicle density is low, if the maximum communication distance is short, emergency message may not be received by other nodes. Therefore, under different traffic conditions, the vehicle nodes should use different transmission power according to the different vehicle density. Assuming that the maximum communication distance of the vehicle node is R, the sensing range of the vehicle node is $2R$. Setting the perceived distance of the vehicle to twice the communication distance can suppress the broadcast collision caused by the hidden terminal and improve the reliability of the emergency message broadcast. Then the node density in the area around the vehicle node is:

$$\rho = \frac{N}{2R} \tag{6}$$

Where N is the number of nodes in the currently adjacent node table and R is the communication distance. Assuming the distance between the two junctions is 1000 meters, each car is 5 meters length, then a lane will have up to 200 cars. If there are four lanes on the road, then 1000 meters on the road there will be up to 800 cars. Assuming that the communication distance is 500 meters, then the sensing distance is 1000 meters, so the maximum vehicle density is 0.8 in the sense range of the vehicle node, and the minimum vehicle density is 0.

4.2 The Transmission Power based on the Vehicle Density

Assuming that the maximum communication distance is 500 meters and the sensing distance is 1000 meters. Taking into account the impact of vehicle density on vehicle communications, the message transmission power based on vehicle density is as follows:

$$P_{tx} = P_{min} + (P_{max} - P_{min})(0.2C - \rho) \tag{7}$$

Where P_{tx} is the transmission power of the vehicle node, P_{min} is the minimum transmission power (this paper refers to the transmission power of 100 meters), P_{max} is the maximum transmission power (this paper refers to the transmission power of 500 meters), C is the number of lane (C is at least 1).

4.3 Distributed Broadcast Algorithm Based on Vehicle Density

Now we know how to judge the vehicle density, and the relationship between signal transmission power and signal transmission distance. Section 3 has given the whole process of the distributed broadcast algorithm without vehicle density. Now, we call a function CalTranPower() before send message and get the current best transmit power. Firstly, the vehicle calculates the vehicle density within the minimum communication distance range based on the ANT. As the assumption, minimum communication distance is 100 meters, and the vehicle is 5 meters length, then the single lane up to 40 vehicles on the sense range of the vehicle, therefore, four lanes will have 160 vehicle nodes, It can be concluded that the vehicle density is at most 0.8. If the vehicle density is above 0.4(include 0.4), the vehicle will use the minimum transmission power. When the vehicle density is less than 0.4, the transmission power will be calculated using Equation (7) (see Algorithm 4)

Algorithm 4 CalTranPower()

```
if n/(2*dmin) ≥ 0.4 then
    return pmin
else
    return pmin+(pmax-pmin)*(0.2C-n/(2*dmin))
end if
```

5 Experimental Setup and Simulation Results

In this paper, two reliability indexes are used to evaluate the performance of the safety-related message broadcast strategy, which are the packet delivery ratio (PDR) and the packet reception ratio (PRR).

- PDR refers to the possibility that the packet send by source node is received successfully by all the receiving nodes at the maximum communication distance range [18, 19].
- PRR refers to the ratio of nodes that successfully receive packets to all receivers within the maximum communication distance after the source sends the packet [20, 21].

The definition showed that PDR is the sender-centric evaluation criteria, and PRR is the receiver-centric evaluation criteria. In comparison, PDR is more stringent and more sensitive to a variety of factors. For example, channel attenuation, channel noise and other factors will have some impact on the message broadcast, PDR fluctuations can reflect the impact of these factors.

5.1 Simulation Settings

The cost of actual experiment about VANETs is very expensive, especially when the vehicle density is high, thousands of vehicles and vehicle drivers are needed, so most scholars tend to use the simulation software to validate theory. At

Table 1: Experimental Parameters for Simulation

Parameter name	Parameter value	Parameter value	Parameter value
Communication distance	500m	CWMin	$15 \sim 1024$
Slot	$20\mu s$	Channel bandwidth	10MHZ
DIFS	$50\mu s$	Modulation	BPSK\QPSK\ 16-QAM\64-QAM
SIFS	$10\mu s$	delay	$1\mu s$

present, the more commonly used simulation software includes NS2, NS3, OPNET, OMNET++ and so on. This paper is executed under NS3 experimental simulation. Table 1 is the parameters of the simulation experiment in this paper.

In the simulation experiment, the channel decay model uses Nakagami attenuation model, the packet transmission frequency is $0.1 \sim 0.2$, the path loss intensity is $3 \sim 5$, the scene area is set to a 5000-m-long freeway and the positions of vehicles spatially form a Poisson process. Assuming all vehicle nodes perceive the default range of 1000m, is twice the max communication distance, used to suppress hidden terminal problems.

5.2 Performance Analysis

In this paper, we carried out three group simulation experiments. First is the broadcast of non-safety messages with IEEE802.11p under different vehicle density. Second is the distributed broadcasting strategy of class-one safety-related messages without considering the vehicle density. The last is the distributed broadcasting strategy based on the vehicle density for the class-one safety-related messages. R represents transmit distance, and λ represents the vehicle density in all figures.

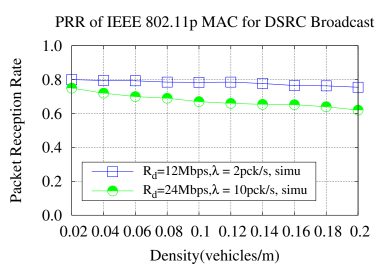

Fig. 3: PRR of non-safety services($R = 500m$)

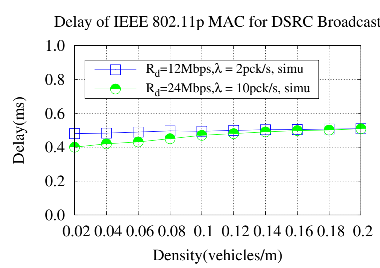

Fig. 4: Delay of non-safety services($R = 500m$)

Figures 3 and 4 show that the PRR and delay of non-safety messages under common 802.11p. The PRR is usually under 0.8 which doesn't meet the safety-related messages' requirments. And the fast data rate leads the PRR to drop. Fig. 4 shows that the delay is under 0.6ms.

Figures 5 and 6 show that the PRR and delay of safety messages under distributed broadcast algorithm with different vehicle density. We find that the

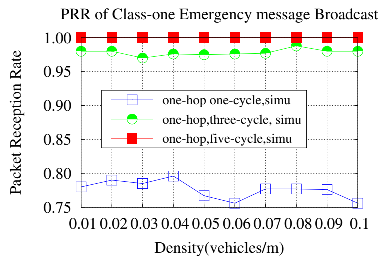

Fig. 5: PRR of safety services($R = 500m$)

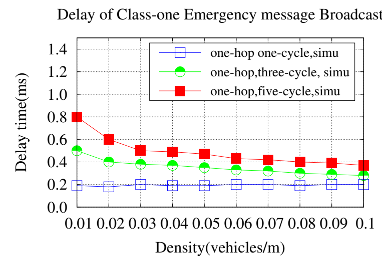

Fig. 6: Delay of safety services($R = 500m$)

PRR of one-hop safety services can reach up to 0.9 when the number of rebroadcast is five, and the delay time can meet the requirments of the emergency message.

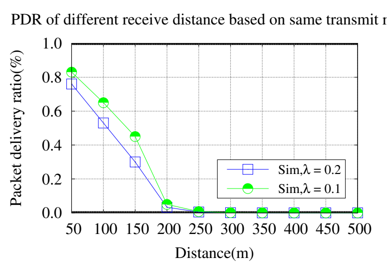

Fig. 7: PDR of different receive distance with $R = 500m$

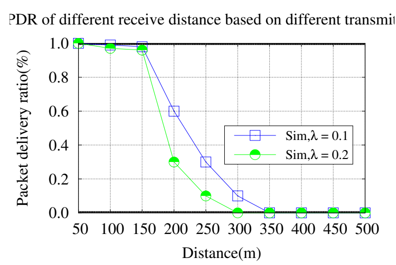

Fig. 8: PDR of different vehicle density with varying R

As shown in Fig.7, if we adopt the fixed transmit power, the algorithm can ensure that emergency message can be received successfully within 100 meters in the case of high vehicle density. The PDR of the safety-related message is higher in the case of low vehicle density, but the PDR of the safety-related message is lower in the case of high vehicle density.

As contrast, from Fig.8, we can see that the PDR in the range of 200 meters is better, but the PDR descends more severe out of 200 meters. This mainly due to the transmit power will be reduced when the vehicle density is high resulting in the nodes away from the sending node can't receive the message. And the PDR of the safety-related message is higher in the case of low vehicle density, the PDR of the safety-related message is lower in the case of high vehicle density.

6 Conclusion

In this paper, we design the distributed broadcast algorithm based on vehicle density of safety-related messages in VANETs. Generally speaking, the algorithm includes three kinds of distributed broadcast algorithm of different safety-related messages, a monitor module and a transmission power adjustment scheme based on the vehicle density. Then, we evaluate our scheme using NS3 simulation software in Linux environment. Simulation results show that the scheme can meet the requirements of the safety-related messages, and the optimization algorithm can effectively ensure that the emergency message in the 200 meters range is correctly received in the case of high vehicle density. Compared with the algorithm without considering the vehicle density, the performance has been greatly improved. Our algorithm is a feasible scheme for the urban traffic environment which always changes with time, and it provides a new idea and method for the emergency message transmission mechanism in VANETs.

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