An IEEE 802.11p based Distributed Channel Assignment Scheme Considering Emergency Message Dissemination

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Abstract—**Vehicular Ad-hoc Networks (VANETs) has been regarded as an emerging and promising network for transportation because it can provide safety and useful traffic information for passengers. VANET employs IEEE 802.11p standard as transmission protocol that defines media access control (MAC) and physical layers, where provide one control channel and six service channels. IEEE 802.11p MAC protocol is a contention-based protocol that has low channel utilization under heavy traffic load. In this paper, we propose a Distributed Channel Assignment Scheme (DCAS) to increase the successful rate of channel reservation and avoid hidden terminal problem to increase the channel utilization. Besides, we also propose an emergency state transition mechanism when VANETs need to transmit emergency messages. Through state transition, vehicles in normal state using non-safety applications will enter emergency state to rapidly forward emergency message to reduce transmission delay. Simulation results show that the proposed scheme can improve 27% channel utilization in average comparing with random channel selection scheme.**

Keywords: channel assignment, emergency message, IEEE 802.11p, multichannel, VANET.

I. Introduction

Vehicular ad-hoc network has been emerging to enable new vehicular services and applications, including safety and non-safety applications. Safety applications require quick and reliable transmission. Non-safety applications need high throughput. It is important to efficiently utilize channels for both safety and non-safety applications.

IEEE 802.11p [1] provides a control channel (CCH) and six service channels (SCHs). Vehicles transmit control and safety messages through CCH. SCHs are used to transmit non-safety messages. However, only one control channel for transmitting emergency messages is not fast and reliable while many vehicles do the same actions. It will delay the dissemination of emergency messages that is one of the major concerns in VANET to warn the drivers after emergency events occur.

So many works propose methods to use SCHs as CCH to transmit messages. Thus several channel selection methods [2]–[4], have been proposed to improve SCHs utilization. These methods separate vehicles into groups and select a vehicle as a coordinator to coordinate a group and assign SCHs to its group members. Since the topology of VANET changes rapidly, these methods need extra control messages to maintain and update information of groups. Coordinators have heavy traffic load because they are gateways between different groups and have to maintain its group. Thus, how to devise a scheme to reduce control messages and assign service channels efficiently has become an important issue in VANETs.

In this paper, we propose a Distributed Channel Assignment Scheme (DCAS) and an emergency state transition mechanism to reduce control messages and assign service channels in distributed way. DCAS is based on position information of receivers to select service channels to reduce messages, where the position information can be known by GPS or updated by regular information exchange. By using DCAS, each vehicle can select service channels by itself. In order to shorten the transmission time of emergency messages. We also propose an emergency state transition mechanism which defines three states for vehicles to change states according to coming events. By transiting among these states, the VANET is able to respond to the emergency events in a short time and keep latest emergency information.

The organization of this paper is as follows. In Section II, we introduce IEEE 802.11p and review related works. The proposed DCAS and emergency state transition mechanism are described in Section III. Section IV shows simulation results. Finally, Section V concludes this work.

II. Related Works

IEEE 802.11p is an amendment that adds Wireless Access in Vehicular Environment (WAVE) to support Intelligent Transportation System (ITS). United States Federal Communications Commission (FCC) approved 75 MHz band in 5.9GHz for ITS wireless environment. The 75 MHz bandwidth is divided into seven channels. Channel 178 is assigned as the CCH which is only used for transmitting safety or system control messages, as shown in Fig. 1. The other six channels are SCHs supporting non-safety applications. The protocol stack of WAVE presents the cooperations of two MAC protocols

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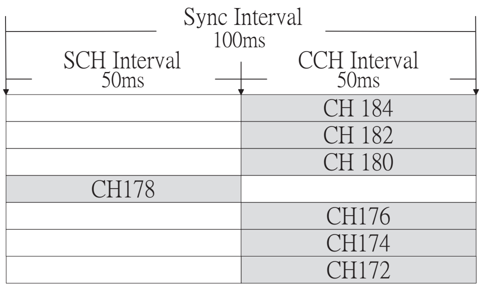

Fig. 1: Multichannel structure of WAVE system.

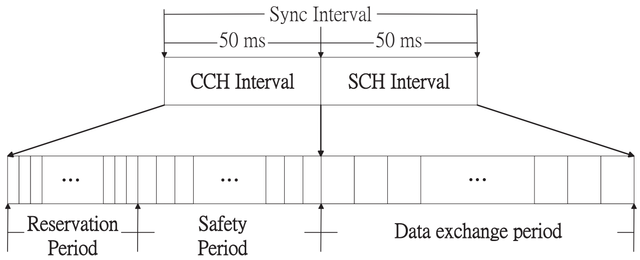

Fig. 2: Time structure of DCAS.

that IEEE 1609.4 [5] defines multichannel operation and IEEE 802.11p is in charge of resource management.

IEEE 1609.4 provides a Coordinated Universal Time (UTC) scheme to give an efficient coordinating channel access on CCH and multiple SCHs. Through the UTC, IEEE 1609.4 defines a 100 ms sync interval consists of a CCH interval and a SCH interval, each of 50 ms, as shown in Fig. 1. IEEE 802.11 employs distributed coordinated function (DCF), a contention-based MAC, as fundamental MAC protocol [6]. When the traffic load is heavy, more recourses will be wasted on channel contentions and packet collisions which cause low channel utilization. In this situation, vehicles may not be able to reserve SCHs for data transmission, which will decrease the system performance.

So vehicles rely on the multichannel coordination strategy to switch between CCH and SCHs to improve the system performance. Several multichannel coordination schemes were proposed for VANET. These schemes use a time division multiple access (TDMA) based method to share channel resources. They follow the fixed channel assignment proposed by FCC and assign time slots for vehicles. All of these schemes can be classified into two categories, distributed coordination scheme and centralized coordination scheme.

Channel selection has been studied earlier in ad-hoc networks [7], [8]. The channel assignment is a NP-complete problem that is proofed by work [9]. Three criteria are commonly used in channel selection for ad-hoc networks, namely, idle state, traffic load, and random assignment schemes [10]. Reference [2] proposed the Vehicular Mesh Network (VMESH) protocol which has the drawback that vehicles rely on coordinators to maintain mesh groups to coordinate SCHs utilization. In [4], a distributed token ring protocol has been proposed to provide QoS in inter-vehicle communication. It assumes that each vehicle is equipped with two radios, one operating over CCH and the other operating over one of the six service channels. However, this protocol spends much effort on group maintenance and costs extra radios to listen to the control channel and service channel simultaneously.

Reference [3] proposed a centralized scheme, RSU-Assisted MAC (RAMC) protocol, that uses roadside units (RSU) as the coordinator. However, this scheme needs RSUs to gather safety messages and coordinate vehicles so RSUs need to be deployed everywhere. Vehicles cannot use SCHs without RSUs and they have to register to RSUs again when they move from a RSU radio range to another one. Besides, RSUs also require extra radios to monitor each channels.

III. The Proposed Scheme

In this paper, we assume a scenario on highway having multiple lanes. The proposed scheme can also be used in the urban area. Every vehicle in the system is equipped with a GPS receiver and a single antenna WAVE transceiver. Communication range of the transceiver is about 300 to 400 meters.

A. Distributed Channel Assignment Scheme (DCAS)

The proposed scheme is a TDMA-based scheme. Fig. 2 shows the time structure of DCAS that sync interval has two intervals: CCH interval and SCH interval. The CCH interval is divided into two periods, reservation period and safety period. Vehicles reserve one or more service channels in reservation period and the safety period is used to transmit control messages and safety messages, including acknowledgment of reservation and one-hop neighbors information. Both periods are further partitioned into the same number of slots. But slots in different period have different sizes because reservation messages are smaller than control messages and safety messages. The SCH interval is also divided into several slots for data transmission. Every vehicle maintains two tables. One is neighbor table which records vehicles within two-hops in reservation period and safety period. The other is reservation table that records occupied slots of every SCH in data exchange period.

The number of slots in CCH interval is the key factor to design DCAS. In order to avoid interference with other vehicles, vehicles use different slots within two-hop neighbors. Assume that the distance a head between two vehicles is 12.5 meters. The maximum travel speed of vehicles will be under 15 kilometers per hour, as traffic jam conditions. So the safety distance can be transformed into time domain, two seconds [11]. The maximum capacity of a highway with one lane is 80 vehicles per kilometer. Therefore the proposed scheme needs at most 240 slots to make sure every vehicle can get the resource. The size of reservation message, safety message and the piggybacked control message is a total of 500 bytes and the transmission rate is 20 Mbps. We can derive about 260 slots in a CCH interval. That is enough for the use of DCAS. The number of slots in SCH interval should consider over all applications in VANET to get the average packet size to decide slots size. It is not the major concern of our system.

Algorithm 1 shows the psdudocode for slot selection and works as follows. When a vehicle newly joins a network, its neighbor table is empty. The vehicle listens to CCH for a whole sync interval to collect information of its two-hop neighbors. Since every vehicle adds its one-hop neighbors' map into safety messages, vehicles can collect the information of two-hop neighbors. After collecting information, the vehicle knows the users in every slot in both periods. Therefore, the vehicle randomly chooses idle slots in reservation period and safety period. Because of the same number of slots in both periods, each vehicle will select the same slot number for the reservation period and safety period. Our scheme also employs cooperative collision detection [12] to help vehicles detect collisions.

Algorithm 1 A Slot Selection Pseudocode for DCAS

```
procedure
for every newly joined vehicle v do
    listen to CCH for a whole sync interval to update neighbors table
end for
v selects available slots in reservation period and safety period randomly
repeat
    repeat
        v sends reservation in reservation period
        v sends safety messages in safety period
    until collisions notified by other vehicles
    v clears neighbors table
    v listens to CCH for a whole sync interval to update neighbors table
    v reselects an available slot randomly
until v is turned off by driver
end procedure
```

As shown in Fig. 3, the transmission area of a vehicle is a circle and is divided into six sectors equally and every sector represents one of the six service channels. The circle defined by channel assignment scheme is rotatable and the minimal rotating angle is 60 degrees, also called a phase. When no available slot of the service channel in data exchange period or reservation failed in last sync interval, vehicles rotate their circles to find available slots. By rotating the circle, vehicles can avoid selecting the same service channels with other vehicles. Equation (1) is the definition of the different sectors that each channel is assigned:

$$60 \times n < a \leq 60 \times (n+1), \qquad 0 \leq n \leq 5 \tag{1}$$

where a is the angle that is calculated from the relative position between receiver and sender, and n is one of the six sectors. Since the circle in this scheme can be rotated, the channels that is designated to certain sectors may be different among vehicles. Algorithm 2 shows the channel assignment and reservation scheme.

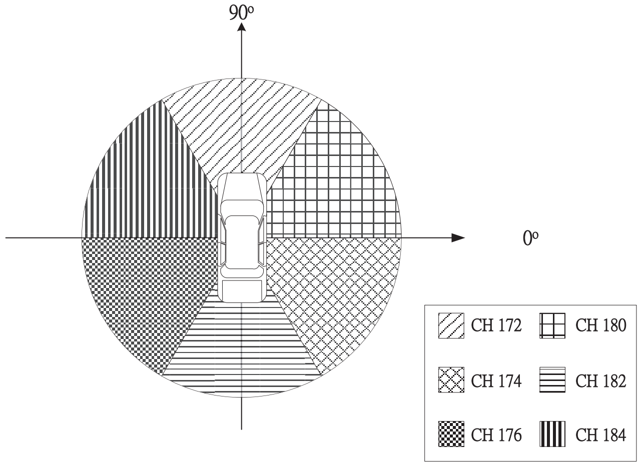

Fig. 3: Channel assignment scheme of a vehicle.

Algorithm 2 Service Channel Reservation for DCAS

```
procedure
for every vehicle v reserves slots of SCHs in a sync interval do
    while v cannot select slot of SCHs in data exchange period do
        channel = selected by channel assignment scheme
        v looks up reservation table to find channel has available slots
        if channel has available slots then
            slot = a randomly chosen slot of selected service channel in data exchange period
        else
            v rotates its circle a phase and set channel to unselected
        end if
    end while
end for
v broadcasts channel and slot in reservation period
if ACK is received in safety period then
    v can use channel and slot
else
    v rotates circle a phase
    v tries to reserve SCHs again in next reservation period
end if
end procedure
```

1) Vehicle v selects a service channel based on the relative position of the receiver. The selection result of each vehicle may be different because the circle is rotatable.
2) Vehicle v looks up its neighbor table to find whether the selected SCH has available slots. Vehicle v then randomly chooses an available slot from the SCH and reserves it in reservation period. If there is no available slot, v will rotate its circle a phase and backs to step 1.

3) After sending reservation message, vehicle v waits for control message, i.e. acknowledge (ACK), from receiver during safety period. It can use the reserved channel if an ACK is received. Otherwise, it rotates again its circle a phase for next sync interval.
4) Listening to CCH in reservation period is not only to receive reservation messages but also to update the reservation table to avoid reserving the same slot within the same SCH conflicting other vehicles. Vehicles replies an ACK that piggybacks on the safety message in a safety period slot if the designated SCH and slot is available.

Since safety messages have to be periodically transmitted, vehicles can know which slot in safety period is occupied by receiving safety message in consecutive sync intervals. If vehicles do not receive safety messages in a specific slot in safety period for consecutive three sync intervals, vehicles will mark the slot as available in its neighbors table because the slot is not used anymore.

B. Emergency State Transition Mechanism

In order to reduce the number of vehicles involved in chain collisions, the transmission delay should be less than 0.1 second [13], [14]. The emergency state transition mechanism is proposed for emergency message dissemination to reduce the transmission delay and increase efficiency. Emergency state transition mechanism has three states which are normal state, emergency sender state, and emergency receiver state. **Normal state** is the initial state of a vehicle. In this state, vehicles operate the proposed DCAS scheme described in Section III-A. When a vehicle detects emergency events or run into an accident, it will enters the **Emergency sender state**. It will send safety messages in the reserved slot in safety period to alert other drivers. When a vehicle receives a emergency or safety messages, it will enters the **Emergency receiver state**. And then it broadcasts emergency messages in reservation period and broadcast safety messages in safety period. Vehicles in both emergency sender/receiver states will send safety messages with a flag to indicate that they are in emergency states, where the flag is used to record vehicles' identifies.

Those two emergency states take transmission of emergency messages and safety messages as the highest priority. The SCH interval would be used as CCH interval for the purpose of updating messages faster and more efficiently so that reservation periods lost functionality. Therefore, the emergency messages are sent in reservation periods. To distinguish between normal state and emergency states, vehicles in emergency states send out safety messages with a flag which indicates the senders enter emergency states.

Vehicle could be in either CCH interval or SCH interval when it detects emergency event and enters emergency sender state. There are different schemes for each interval to send emergency messages and inform other vehicles to change to emergency receiver state.

In CCH interval, as mentioned in Section III-A, we reserve the last slot in safety period for vehicle that changes to emergency sender state to transmit emergency message if it had passed its slot.

In SCH interval, vehicle cannot communicate with all the other vehicles because they use different service channels. For the reason, vehicle waits for the next sync interval to transmit the emergency message in its own slot in reservation period and safety message in safety period.

The slot reserved for emergency event will be used once for warning other vehicles in shorter time. Then the vehicle in emergency sender state uses its own slot to transmit emergency and safety messages. So that the emergency message can be transmitted to vehicles less in than one sync interval, in other words, less than 0.1 second.

IV. SIMULATION RESULTS

We use network simulator 3 (ns-3) [15] to simulate the proposed method. The scenario is on a three-lane highway without any RSU. Every vehicle is equipped with IEEE 802.11p transceiver and GPS receiver so that vehicle knows its position and can communicate with other vehicles. The transmission range of each vehicle is 250 to 300 meters and the transmission rate is 27 Mbps. The quantities of slots in reservation period and safety period are set to 100. The amounts of slots of each SCHs is set to 10. Each vehicle has a safety message to send in every safety period and tries to reserve a slot of a service channel to send data to a randomly selected receiver in every sync interval. Vehicles travel on the highway at a maximum speed of 25 m/s but every vehicle may travel at different speed and change among lanes. The highway is empty at the beginning and vehicles enter the highway from the head of highway.

Fig. 4 shows the relation between successfully reservation ratio and the number of vehicle in a sync interval. The rapidly changed curve is caused by the random select scheme when the number of vehicles is small. The random select scheme selects receiver randomly. While the quantity of vehicles grows, the ratio gets stable and the gap between DCAS and random select is bigger. Under the same circumstance, DCAS is more stable comparing to random select. The ratio of random select changes more frequently as figure showed. The curve of random select drops more comparing to DCAS as the number of vehicles increased. The average enhancement of successful reserved ratio is about 10 percents by DCAS. The maximum difference between DCAS and random select is more than 20 percents under the same number of vehicles in a sync interval.

Since vehicles have the chance not to make reservations in a reservation interval, we are interest in the relation between services channels' utilization and numbers of vehicles. A vehicle can transmit about 17.2 Kbytes in a service channel slot because the number of slots of SCHs is set to 10. We assume that a vehicle transmits 15 Kbytes when it gets a SCH slot. Fig. 5 shows average data size of total transmission in a SCH interval. Vehicles reserve only one SCH slot in a sync interval so the data size grows as the number of vehicles

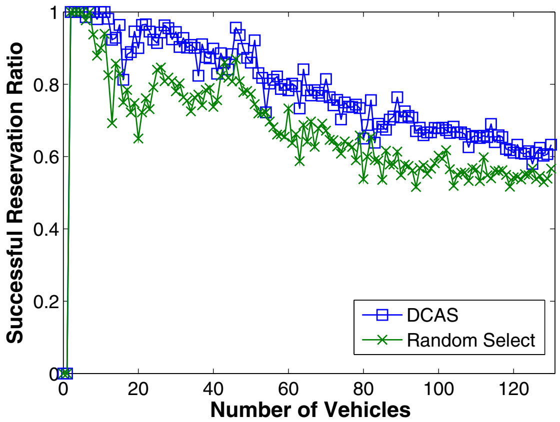

Fig. 4: Channel assignment scheme of a vehicle.

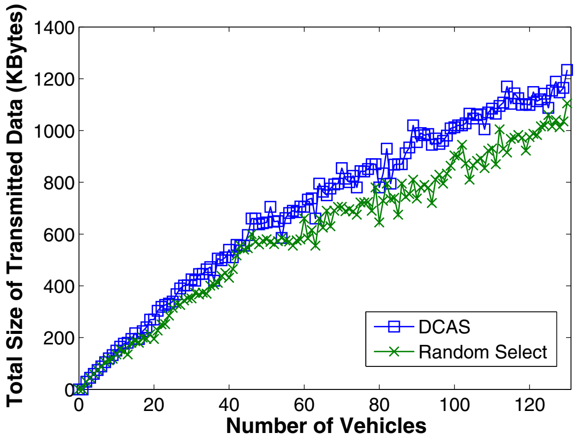

Fig. 5: Channel assignment scheme of a vehicle.

increase. Two approaches have similar performance under small number of vehicles but the advantage of DCAS shows when vehicles are more than 30 and increases as more vehicles entered highway. The curve of random select changes more rapidly and is below the curve of DCAS. So that the DCAS has more steady performance than random select and transmits 27% more data comparing to random select. From Fig. 4 and Fig. 5, we can see that although the successful reservation ratio decreases as the number of vehicles increased, the transmission data increases. Since the successful reservation ratio of DCAS is better than random select, it is obvious that DCAS can transmit more data than random select in a SCH interval.

V. Conclusion

In this paper, we propose a Distributed Channel Assignment Scheme (DCAS) and an emergency state transition mechanism based on IEEE 802.11p. When vehicles travel on highway or under some situations, the fixed channel assignment may not employ service channels and therefore causes unused channels. DCAS employs the six service channels in a distributed manner without interfering the users that are designated to use the specific channels. Emergency state transition mechanism increase the efficiency of control channel for transmitting emergency message and reduces the transmission latency. In the simulation results, DCAS improves 27% channel utilization in average comparing with random channel selection scheme. Our approach improves the channel utilization and considers the transmission of emergency message dissemination.

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