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A Fast Safety Message Transmission Mechanism for Heterogeneous Vehicular Networks

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Abstract: Safety messages initiated by accident vehicle in a vehicular network may be for accident rescue, accident notification, and diversion notification. Traditional vehicular networks adopt a vehicle-to-vehicle (V2V) method to transmit safety messages. Under this mechanism, safety messages may be impeded when there are too many vehicles near the accident vehicle or there is no vehicle close enough at the rear of the accident vehicle to detect a safety message, preventing the accident and diversion notifications from being effectively transmitted. In addition, existing mechanisms cannot effectively convey accident rescue messages. This study combines vehicle-to-vehicle and vehicle-to-infrastructure (V2I) network transmission methods, and proposes a fast safety message transmission (FSMT) mechanism. In addition to making use of wider transmission range characteristics of V2I networks to achieve accident rescue, this mechanism reduces safety message transmission time through the help of V2I when it determined that the situation is not conducive to V2V transmission. Simulation results reveal that vehicles within and outside V2V signal range can on average receive safety messages 0.86 second and 0.85 minute earlier respectively by adopting this method. It also reduces redundant messages and accomplishes accident rescue notification.

Keywords: safety message, vehicle-to-vehicle, vehicle-to-infrastructure

1 Introduction

Vehicle accidents and their subsequent impacts can be reduced by the effective transmission of safety messages between vehicles and the accident handling unit. A safety message transmission performs one of three functions: accident notification, diversion notification, or accident rescue. In a traditional vehicular network, a safety message is passed via a V2V (vehicle-to-vehicle) network. When vehicle density is higher, as illustrated by the topology shown in Fig. 1, many vehicles will simultaneously use the same media to help forward this safety message. These signals will interfere with each other, that is, their message packets will collide, impeding transmission. Many papers [1,2,3,4] have proposed ways to reduce signal interference and lower the probability of packet collision so as to successfully transmit accident notifications. Although these methods can reduce the probability of packet collisions and increase the success rate of accident notifications, the limited range of V2V network transmission means that if there is no receiver near the accident vehicle, as shown in Fig. 2, the message cannot be propagated. This would confine the safety message to within the vicinity of the accident and result in the distant drivers advice for diverting their routes can not be transmitted. For the accident rescue function, a V2V network lacks the necessary infrastructure, for each of its communication points is peer-to-peer and there is no central control unit to compile and process messages and to schedule and dispatch accident rescue units.

In this paper, we propose a fast safety message transmission mechanismFSMT. With this mechanism, safety messages are transmitted by combining V2V networks (IEEE802.11p [7]) with V2I (vehicle-to-infrastructure) networks (IEEE802.16e [8]). When the vehicular network topology may prevent a V2V network from transmitting accident notifications or diversion notifications, a V2I network will be used to support message transmission. For accident rescue messages, which cannot be transmitted by a V2V

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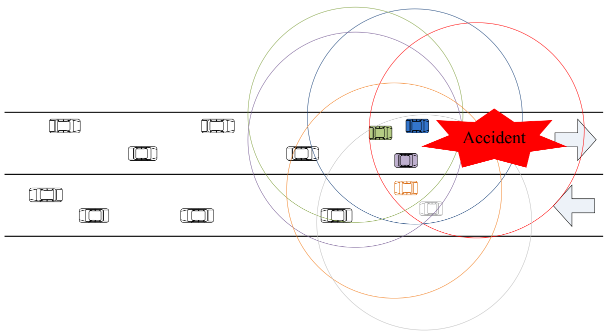


Fig. 1: High vehicle density

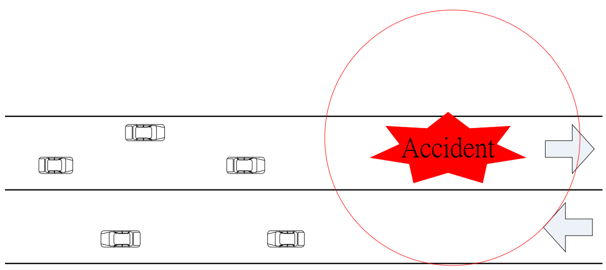


Fig. 2: No following vehicle within transmission range

network, this study adopts a V2I network and develops a dedicated safety message transmission procedure. An accident rescue system for the V2I network is developed to allow accident vehicles to directly contact related accident handling units.

2 Related work

This section introduces the vehicle-related wireless technologies, operating mechanisms of V2V and V2I networks, and heterogeneous vehicular networks.

2.1 V2V network transmission

Vehicle-to-vehicle (V2V) communication allows vehicles to directly communicate with each other on a peer-to-peer basis without passing through base stations (BS) (infrastructure), as shown in Fig. 3. Since vehicles may move, their transmission is similar to MANET (mobile ad-hoc network) and has been called VANET (vehicle ad-hoc network). To avoid additional vehicles crashing into an accident scene, it is desirable to transmit a safety message to all vehicles that are following within a certain distance of the accident scene. To meet this demand, a directional broadcast method has been proposed: Nave Broadcast (NB) [1,9]. The vehicle will help to rebroadcast the safety message only when this safety

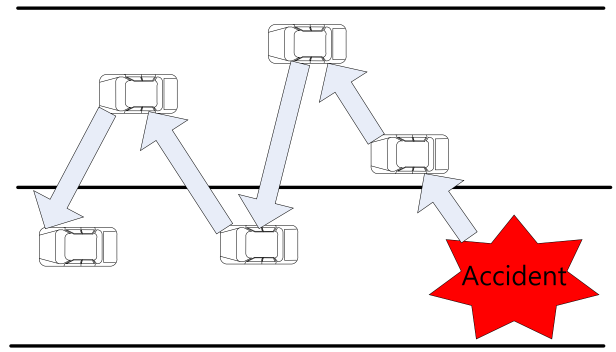


Fig. 3: Data transmission conceptual diagrams of V2V networks

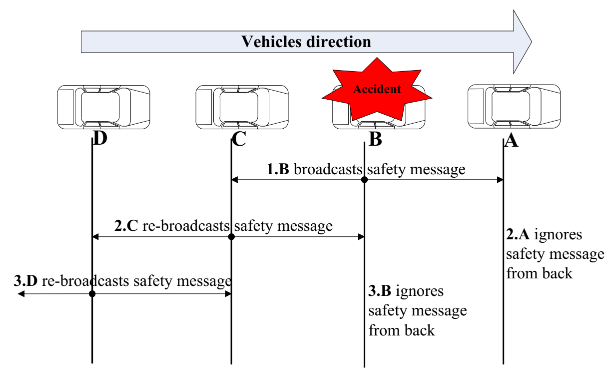


Fig. 4: Conceptual diagram of Nave Broadcast

message comes from the forward direction of travel of the vehicle. The detailed operation of this process is shown in Fig. 4. When vehicle B had an accident, this would trigger the vehicle B to broadcast a safety message through V2V mode. When vehicle A received this safety message, it would ignore this message because vehicle A is traveling away from vehicle B. In contrast, when vehicle C received this message, due to its position behind the accident vehicle B, vehicle C would broadcast this safety message. Although the traditional Nave Broadcast method can support directional broadcasting by sending safety messages only to vehicles behind the accident vehicle, this would result in delayed transmission packets and reduced network performance due to the media competition characteristics of 802.11, under which the broadcast storm caused by continuous broadcasting will increase the chance of message collisions at the media access control layer.

To address this, many improved V2V network transmission methods have been proposed. Biswas et al. [1] proposed Intelligent Broadcast with Implicit Acknowledgment, in which a vehicle receiving a safety message will wait a random period of time before forwarding this message. If during that interval, the vehicle received the same safety message from behind, it

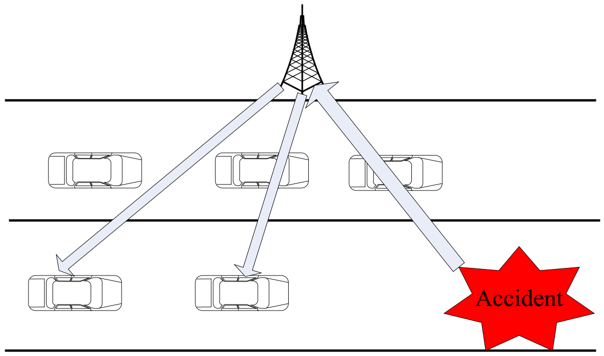


Fig. 5: Data transmission conceptual diagrams of V2V networks

would refrain from forwarding the message, thus reducing the probability of packet collision. Blum et al. [2] proposed an approach for lowering packet collisions at the link layer and network layer. At the link layer, a modified distributed coordination function would add a random amount of time before sending the packet, so as to stagger the original simultaneously transmitted packets. At the network layer, a routing protocol would require all vehicles receiving the safety message to wait for a period of time inversely proportional to their distance from the accident. Marc et al. [3] proposed two methods: the first being to minimize signal interference between vehicles by means of power control, the second being a routing protocol modified from Blum et al.'s method that first pre-selects a farthest node as a pre-forwarding node to reduce time for selecting a forwarding node. The method of Wang et al. [4] is to reduce collision probability by adjusting backoff window sizes according to the number of vehicles on the road. Although these methods can effectively reduce the probability of packet collisions and increase the success rate of accident notification, they fail to convey the safety message if no receiver is near the accident vehicle.

2.2 V2I network transmission

Vehicle-to-infrastructure (V2I) communication involves the normal wireless network communication, in which the vehicles directly communicate with base stations, as shown in Fig. 5. WiFi was the most common wireless technology. If WiFi were used under a V2I framework, vehicles on the move would have to perform several handoffs with BS because of WiFis limited transmission range, causing increased communication interruptions and decreased performance. Therefore, most of the previous papers adopted the V2V framework, even though the instability of its network topology often caused interruption of message transmission. With the advancement of wireless network technology, numerous papers have been adopting WiMAX as a vehicle message transmission mechanism. The wide transmission range of WiMAX prompted researchers to assume that it would be deployed primarily in vehicle-to-infrastructure architectures.

Chou et al. [10] directly measured performance for WiFi and WiMAX, showing that solely within the WiFi transmission range (around 200m), WiFis throughput and delay are better than those of WiMAX. Andr et al. [11] conducted an overall assessment for WiMAX when used in a vehicular network; the paper cited the requirements of vehicle communications: mobility, timeliness, coverage area, and bandwidth, and it proposed suitable parts for WiMAX. Aguado et al. [12] used Opnet network simulation software to simulate a WiMAX network, finding longer delays while crossing Access Service Networks. Ikbal et al. [13] used QualNet network simulation software to compare advantages and disadvantages of 802.11p and WiMAX in a V2I network, showing that WiMAX has a greater transmission range and transfer rate, quite suitable for the vehicular network environment.

These papers mainly focused on comparing simulation and actual measurement. They did not propose a mechanism for safety message transmission and accident rescue messages based on the characteristics of WiMAX. Since the transmission range of a V2V network is smaller than that of a V2I network, propagating messages in a V2V network requires their being forwarded many times. Moreover, a V2V network cannot convey a safety message to accident rescue-related units (such as a disaster management center). In contrast, transmitting safety messages through a V2I network would exploit V2Is wide transmission range, support the three types of safety message, and help minimize the impact of an accident.

2.3 Heterogeneous vehicular networks

The heterogeneous vehicular network refers to the integration of these two network technologies. Hossain et al. [14] stated that heterogeneous vehicular networks were needed because even after 10-20 years, none of the network technologies can fully meet the needs of vehicular networks. The authors also conducted a comprehensive survey of heterogeneous vehicular networks and described many network technologies suitable for the vehicle environment and their applications under vehicular network.

The advantage of a V2V network lies in the rapid and timely data receipt of the safety message by a vehicle not involved in the road incident. However, due to vehicles' mobility, the network topology will change dramatically, which will inevitably cause network connection breakage and packet transmission failure. In contrast, a V2I networks delay in having to transmit the safety message through infrastructure will be outweighed by its larger transmission range. Therefore, V2I can serve as a secondary transmission mode whenever the V2V network topology becomes unstable.

The feasibility of a heterogeneous vehicular network was examined in CVIS (Cooperative Vehicle Infrastructure Systems), which equipped each vehicle with a device similar to an aircraft black box. Brickley et al. [15] proposed a strategy using a CVIS framework for data transmission that considered the throughput and network load between two co-existing networks, WLAN and UMTS (both of which are V2I networks), and then selected the more suitable network to transmit information.

In order to address frequent network disconnects and message transmission failures caused by dramatic changes in VANET network topology while transmitting a non-safety message, Hung et al. [16] proposed a heterogeneous vehicular network architecture in which a WiMAX network would allow all vehicles to regularly transmit their own information to a BS, the sender would be required to contact the BS before transmitting information, and BS would determine the transmission path along its 802.11p network based on the relative speed, direction, and position information on all vehicles. If the BS determined that an 802.11p network connection was about to be interrupted, then it would ask the sender to switch to a WiMAX network. Since this method requires the sender to first ask the BS to decide which network the sender should use, this method is not suitable for highly delay-sensitive safety messages.

3 Fast safety message transmission mechanism

To achieve the three functions of safety message, this paper combines V2V and V2I network transmission, and proposes a fast safety message transmission (FSMT) mechanism. FSMT mechanism uses V2I networks to compensate for the inadequacies of V2V networks. The details of heterogeneous vehicle network architecture as well as the operation of FSMT mechanism are described in the following.

3.1 Heterogeneous vehicular networks architecture

The architecture of the heterogeneous vehicular networks proposed in this paper is shown in Fig. 6. This architecture assumes that in addition to having a GPS for obtaining geographic information, each vehicle is equipped with an IEEE 802.11p antenna for communicating through a V2V network and an IEEE 802.16e antenna for transmitting safety messages through a V2I network to the centrally controlled server, which would then forward the safety message on the vehicles behalf.

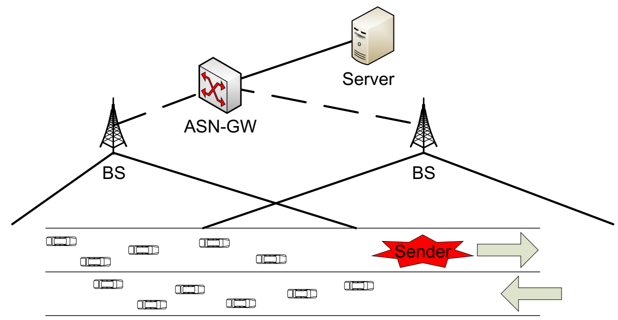


Fig. 6: Heterogeneous vehicle networks architecture

WiMAX base stations (BSs) installed along the roadside would be responsible for receiving information, such as position, direction, speed, density, etc., on all vehicles within the BS signal coverage. The BS would deliver these messages to a back-end traffic management center (Server, responsible for analysis and decisions) through the links with an ASN-GW (access service network-gateway). The Server would house the Traffic Control Center, whose main task is to analyze and handle the messages. When the Server received a safety message, it would transmit the message if the Server determined that the V2V network was impeded from doing so. To reduce the safety message transmission delay time and directly control local traffic flow, a traffic management center would be deployed about every 40 to 50 km.

3.2 Operations of FSMT mechanism

FSMT mechanism consists of three procedures: SendSafetyMessage(), ReceiveSafetyMessage(), and ServerReceiveMessage(). Whenever an accident occurs, an involved vehicle would use procedure SendSafetyMessage() to transmit the safety message. When the safety message reached a vehicle not involved in the accident, the latter vehicle would execute the procedure ReceiveSafetyMessage(), which selects an appropriate network and forwards the safety message accordingly. The procedure ServerReceiveMessage(), which would be activated at the Traffic Control Center after it received the safety message, would transmit the safety message over the V2I network to an accident rescue unit.

The entire transmission process is shown in Fig. 7. Whenever an accident occurs, the accident vehicle (Sender) will trigger SendSafetyMessage() to simultaneously transmit safety messages to all vehicles within the coverage area via the 802.11p network, and to the Traffic Control Center (Server) via the 802.16e network and the BS. When Receiver1 receives the message sent over the 802.11p network, it will activate ReceiveSafetyMessage() to determine whether the current network topology is suitable for V2V network

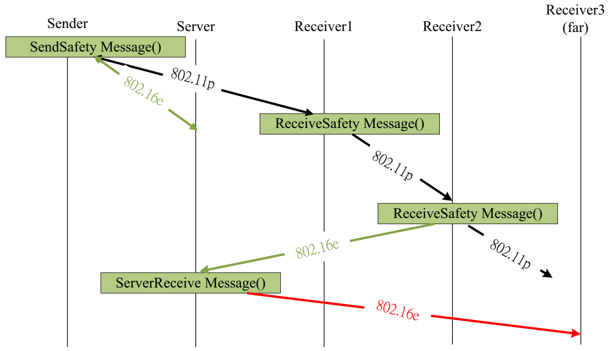


Fig. 7: Transmission process flowchart

transmission or not. If suitable, Receiver1 will transmit over the 802.11p network (which in Fig. 7 is received by Receiver2); but if no receiver is within signal coverage (as is the case in Fig. 7 because Receiver3 is too distant from Receiver2) or if there seem to be too many vehicles in the vicinity, the vehicle will transmit over both 802.11p and 802.16e networks.

When the Server receives the safety message, it will invoke ServerReceiveMessage(), which based on the messages content will determine whether the message is for accident rescue or the message is for notification but the V2V network is unable to transmit it. If either case is true, the Server will transmit the safety message over the 802.16e network (as shown by the red line in Fig. 7). If a vehicle should receive a given safety message over the V2V network and then over the V2I network, it would discard the latter and cease forwarding the safety message.

3.3 Procedure ReceiveSafetyMessage( )

The function of procedure ReceiveSafetyMeaage() is to select an appropriate network and forwards the safety message accordingly. When a vehicle receives a safety message from V2V network, the procedure forwards the message to other vehicles by V2V network if the safety message comes from the front vehicle. Furthermore, when there are too many vehicles near the accident vehicle (too many close vehicles) or there is no vehicle close enough at the rear of the accident vehicle to detect a safety message (no rear reachable vehicle), this message will be forwarded to Traffic Control Center by V2I network. Here, rear reachable vehicles refer to those vehicles located at the rear of the accident vehicle and separated by more than 20 meters and within the signal coverage of 802.11p protocol. Vehicles at this distance can forward safety messages via a V2V network and not cause packet collisions. Conversely, close vehicles refer to those vehicles located less than 20 meters from the accident vehicle. At this distance, when the vehicle density reaches the critical value, too many vehicles help in forwarding the message, may cause packet collision and safety message transmission failure.

On the other side, if a vehicle receives a safety message from V2I network, it means that the safety message has been transmitted by V2I network and does not need to be transmitted by V2V network. The transmission of this message will be stopped. Such mechanism can overcome the disadvantage of Nave Broadcast routing protocol.

To obtain the numbers of rear reachable and close vehicles, we modified the hello (beacon) message to collect information such as the positions of vehicles in the same direction as and upstream of the accident vehicle in order to gauge whether the vehicle density near the accident vehicle is too high or not. The hello message is a packet with no data. When no vehicles use the V2V network forwarding message, each vehicle will broadcast the hello message periodically for maintaining the network topology. By calculating the number of received hello message, the vehicle could realize how many vehicles exist within its transmission range.

We use a reserved field (9 bits) in the hello message to determine the before and after relationship between two vehicles. We read out the location of the vehicles, take the vehicle with higher rate of change in GPS coordinates, take its hundreds digit and tens digit, store them into the reserved field, and finally broadcast the hello message. When another vehicle receives the hello message, procedure ReceiveHelloMessage() will be executed to compare the data in the reserved field with the current location, calculate the numbers of rear reachable and close vehicles, and then use them to determine whether to request support from V2I or not.

3.4 Procedure ServerReceiveMessage( )

To make the contents of safety message realized by Traffic Control Center, a V2I network packet is developed and used for exchanging information between Control Center and vehicle. The format of V2I network packet is shown in Fig. 8.

In addition, two tables maintained in the Traffic Control Center, periodic message and safety message tables, are used to store the information derived from packets. Periodic message table stores periodically received beacon packet information to facilitate traffic control for traffic flows. It contains the fields of time, nodeID, position, direction, and speed. Safety message table stores received safety messages and it contains the fields of time, nodeID, position, direction, accident nodeID, accident position, and accident direction. These data will be used by Traffic Control Center as raw data for vehicle accident statistics. Traffic Control Center also analyzes the accident vehicles information for conducting accident rescue. The pseudo code of ServerReceiveMessage() is shown in Fig. 9.

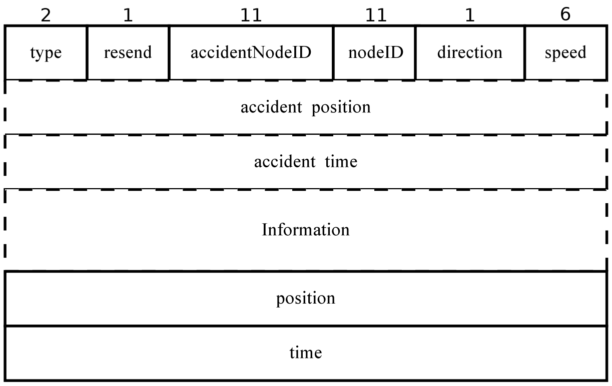
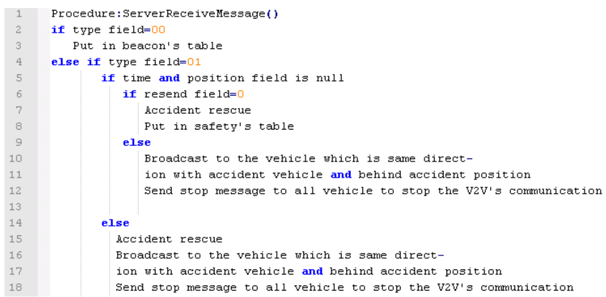


Fig. 8: V2I network packet format



```
Procedure:ServerReceiveMessage()
if type field=00
   Put in beacon's table
else if type field=01
       if time and position field is null
          if resend field=0
             Accident rescue
             Put in safety's table
          else
             Broadcast to the vehicle which is same direct-
             ion with accident vehicle and behind accident position
             Send stop message to all vehicle to stop the V2V's communication

       else
          Accident rescue
          Broadcast to the vehicle which is same direct-
          ion with accident vehicle and behind accident position
          Send stop message to all vehicle to stop the V2V's communication
```

Fig. 9: The pseudo code of ServerReceiveMessage()

Table 1: PHY layer simulation parameters of 802.11p and 802.16e

Paremeter	802.11p	802.16e
Frequency	5.87 GHz	3.5 GHz
Channel bandwidth	10 MHz	10 MHz
BS Tx power	Null	33 dBm
BS antenna height	Null	32 m
BS antenna gain	Null	15 dBi
MS Tx power	23 dBm	23 dBm
MS antenna height	1.5 m	1.5 m
MS antenna gain	0 dBi	-1 dBi
Type of antenna	Omnidirectional	
Pathloss	Two-ray	

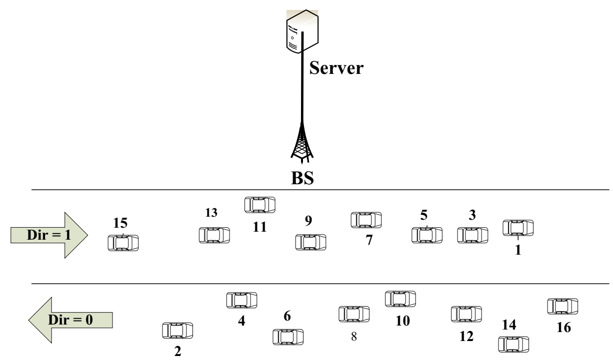


Fig. 10: Normal density simulation topology

4 System simulation and performance evaluation

To verify the applicability of FSTM mechanism, a simulation is conducted using Qualnet network simulator [5] and MOVE (MObility model generator for Vehicular networks) software [6] to evaluate the performance of FSTM from the aspects of the time first received safety message and the number of safety message tranmitted. In this paper, safety message is transmitted by Nave Broadcast routing protocol in V2V network. The simulation performs three different scenarios to simulate the normal density, high density, and low density traffic topologies, respectively. All three scenarios have the same PHY layers simulation parameters [13] listed in Table 1. The details of scenarios and simulation results are described in the following.

4.1 Normal density topology

This scenario simulates the topology of normal density, shown in Fig. 10. The size of topology was set to 4000m by 25m, and 16 vehicles, numbered from 1 to 16, were moving in the topology. Odd-numbered vehicles moved from left to right (denoted by Dir 1), while even-numbered vehicles moved from right to left (denoted by Dir 0). The maximum speed of a vehicle was 144 km/hr, and the simulation time was 129s. The transmission ranges of 802.11p and 802.16e are 460m and 4.5 km, respectively. Every vehicle, except for vehicles 15 and 16, has a reachable neighbor vehicle and no close neighbor vehicle. We assumed that after 120 seconds from the beginning of simulation, vehicle 1 had an accident at the location with coordinates (3884.67, 0). After that, a 64-byte safety message was sent out by vehicle every 0.1 s [4].

The time of the first received safety message by each vehicle is shown in Fig. 11, where the number at the top of bar denotes the source vehicle number of first received safety message. The result reveals that all vehicles receive the first safety message within 0.5 ms after the accident. It means that the topology is ideal for using the V2V network to transmit a safety message and that the V2I network will not be activated by FMST to perform accident-and-diversion notifications when vehicle 1 had a vehicle accident. Thus, the Traffic Control Center will receive only the safety message sent by the accident vehicle through the V2I network and send only an accident rescue message.

With regard to accident rescue, the simulation showed that after an accident occurs, the rescue-requesting

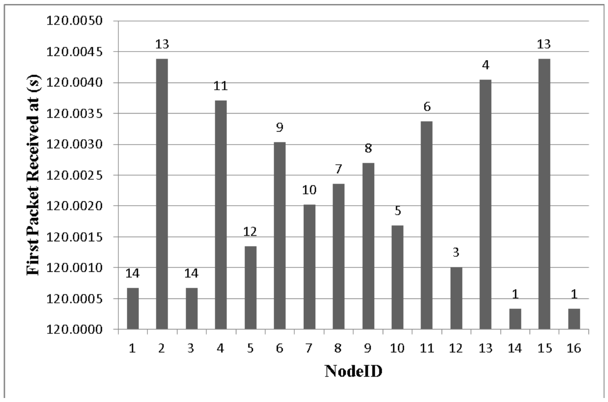


Fig. 11: The time first received safety message of each node - normal density

```
1  CBR Client: node 1 sending data packet at time 120.000000000S to CBR server 190.0.1.2
2      size of payload is 64
3  PayLoad:01 0 1 N 1 0.000000 (3884.670000,0) 120.000000000 Three injured!
4
5  CBR Server 18: packet transmitted at 120.000000000S
6      received at 120.180799418S
7      client is 190.0.3.1
8      connection Id is 1001
9      seqNo is 1200
10 01 0 1 N 1 0.000000 (3884.670000,0) 120.000000000 Three injured!
11 Get !!msg,Ambulances and police cars are coming
```

Fig. 12: Accident rescue under normal-density topology - notification message for successful transmission

message can be transmitted to the Traffic Control Center within 18 ms. Fig. 12 indicates that after a vehicle accident occurred (at 120s), the accident vehicle (node 1, IP address of 190.0.3.1) immediately sent out a 64-byte safety message through the V2I network to the Traffic Control Center (node 18, IP address of 190.0.1.2) to request accident rescue (lines 1-2). Line 3 shows the content of the safety message: type 01 indicates it is a safety message, resend 0 represents no V2I network forwarding required, the node ID of the accident vehicle is 1, direction is 1, speed is 0, the GPS coordinates of the accident vehicle are (3884.67, 0), time of accident is 120s, and the related information reveals that there are three injured persons (Three injured!). When the Traffic Control Center received this safety message at 120.180799418s (lines 5 to 10), it also immediately contacted an ambulance and police to complete the accident rescue function (line 11).

4.2 High density topology

This scenario simulates the topology of high density. The simulation topology is shown in Fig. 13. The size of topology sets to be 27003m*25m and 43 vehicles, numbered from 1 to 43, were moving in the topology. Vehicles move from left to right denoted by Dir 1, while vehicles move from right to left denoted by Dir 0. The maximum speed of vehicle is 36km/hr and the experiment

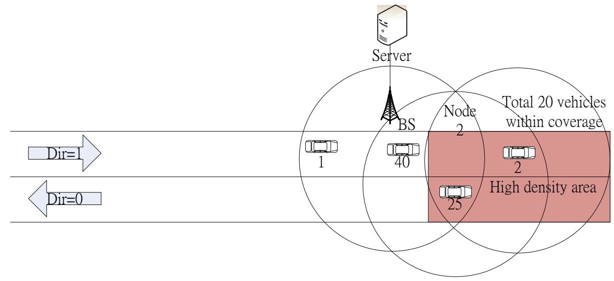


Fig. 13: High density simulation topology

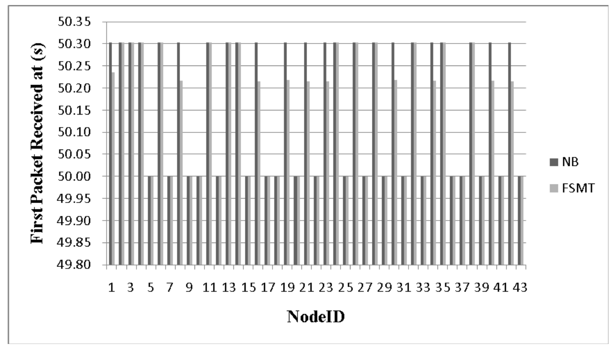


Fig. 14: The time first received safety message of each node - high density

time is 60s. Both transmission ranges of 802.11p and 802.16e are 460m and 4.5km, respectively. We assumed that after 50 seconds from the beginning of simulation, vehicle 2 had an accident at the location with coordinates (27000.62, 0). After that, a 64-byte safety message is sent out by vehicle every 0.1s [4].

Under the high density environment, we compare FSMT mechanism and Nave Broadcast (NB) routing protocol, as shown in Fig. 14. In the case of NB routing protocol, due to packet collisions, the time of some vehicles first received a safety message delayed to 50.3s; on the contrary, in the case of FSMT mechanism (through the help of V2I network), we can find that the time of all vehicles first received a safety message are less than or equal to those of NB, it reveals that V2I network's help indeed accelerates the transmission of safety message.

The comparison of the number of safety messages transmitted is shown in Fig. 15. With FSMT, after the Server received a safety message and helped to forward it, the Server simultaneously transmit a message for accident help and diversion notifications to all vehicles through the V2I network to inform them to stop forwarding on the V2V network In contrast, in the NB routing protocol, since there is no mechanism to stop safety message forwarding, all vehicles will keep forwarding the safety message.

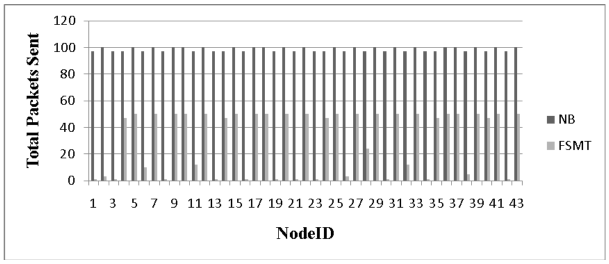


Fig. 15: Comparison of the number of safety messages transmitted - high density

```
1  CBR Client: node 2 sending data packet at time 50.000000000S to CBR server 190.0.1.1
2      size of payload is 64
3  PayLoad:01 1 2 1 0.000000 (27000.620000,0) 50.000000000 Three injured!
4
5  CBR Client: node 25 sending data packet at time 50.100000000S to CBR server 190.0.1.1
6      size of payload is 64
7  PayLoad:01 1 2 25 0 3.390000 (27000.620000,0) 50.000000000 Three injured!
8          [27000.000000,0] 50.100000000
9
10 CBR Server 44: packet transmitted at 50.100000000S
11     received at 50.146069310S
12     client is 190.0.4.25
13     connection Id is 1025
14     seqNo is 501
15 01 1 2 4 0 3.390000 (27000.620000,0) 50.000000000 Three injured!
16 [27000.000000,0] 50.100000000
17
18 Get !!msg,Ambulances and police cars are coming
19
20 CBR Server 44: packet transmitted at 50.000000000S
21     received at 50.626323550S
22     client is 190.0.4.2
23     connection Id is 1002
24     seqNo is 500
25 01 2 1 (27000.620000,0) 50.000000000 Three injured!
```

Fig. 16: Accident rescue under high-density topology - notification message for successful transmission

With regard to accident rescue, the simulation showed that after an accident, the rescue-requesting message can be transmitted to the Traffic Control Center within 40 ms. As shown in Fig. 16, after a vehicle accident occurred (at 50s), the accident vehicle immediately sent out a 64-byte safety message through the V2I network to the Traffic Control Center to request accident rescue. Line 3 shows the content of the safety message: type 01 indicates it is a safety message, resend of 1 requests V2I network forwarding, the node ID of accident vehicle is 2, direction is 1, speed is 0, the GPS coordinates of the accident vehicle are (27000.62, 0), time of accident is 120s, and the related information reveals that there are three injured persons (Three injured!). The Traffic Control Center did not receive this safety message until 50.626323550s because of the high traffic density (lines 20-25). On the other hand, when vehicle 25 received the safety message at 50.000336002s through the V2V network, vehicle 25 sent the safety message through the V2V network and requested the support of accident rescue and diversion notification through the V2I network (lines 5-6). Traffic Control Center receives this safety message at 50.146069310s (lines 10-14).

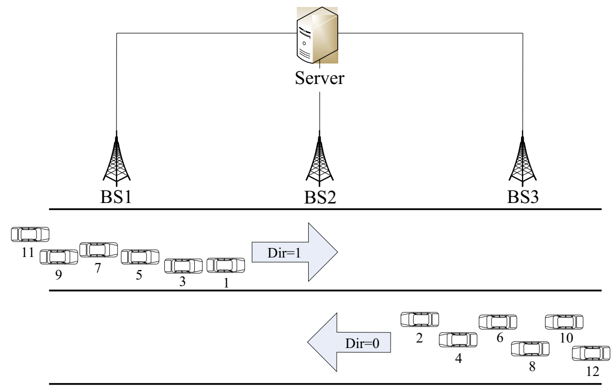


Fig. 17: Low density simulation topology

4.3 Low density topology

This scenario simulates the topology of low density. The topology of simulation is shown in Fig. 17. The size of topology sets to be 27000m*250m and 12 vehicles, numbered from 1 to 12, were moving in the topology. Vehicles move from left to right denoted by Dir 1, while vehicles move from right to left denoted by Dir 0. The maximum speed of vehicle is 144km/hr and the experiment time is 992s. The transmission ranges of 802.11p and 802.16e are 460m and 4.5km, respectively. We assumed that after 352 seconds from the beginning of simulation, vehicle 1 had an accident at the location with coordinates (13514.36, 0). After that, a 64-byte safety message is sent out by vehicle every 0.1s [4].

In low density topology, when using V2V network to transmit safety message, the safety message will be confined and unable to be transmitted. Conversely, with FSMT mechanism, when V2V network operating in poor performance, a V2I network will be used to support the accident and diversion notifications. The time first received safety message of each vehicle in low density topology is shown in Fig. 18.

The comparison of the number of safety messages transmitted in a low density topology between NB and FSMT mechanisms is shown in Fig. 19. With FSMT, when the Traffic Control Center received the safety message, a message for accident help and diversion notifications was sent to all nodes through the V2I network to inform them to stop forwarding on the V2V network. Hence, when the safety message has been passed to all vehicles (at 352.2s), unnecessary forwarding operations will be no longer performed on the V2V network. Thus, the V2V network medium busy time can be reduced. Therefore, except vehicle 1 and vehicle 2 sent 2, 1 safety messages, the vehicles 3 to 12 received safety message coming from V2I network before they had received the safety message coming from V2V network, so vehicles 3 to 12 will not send any safety message through the V2V network. In contrast, in the NB routing

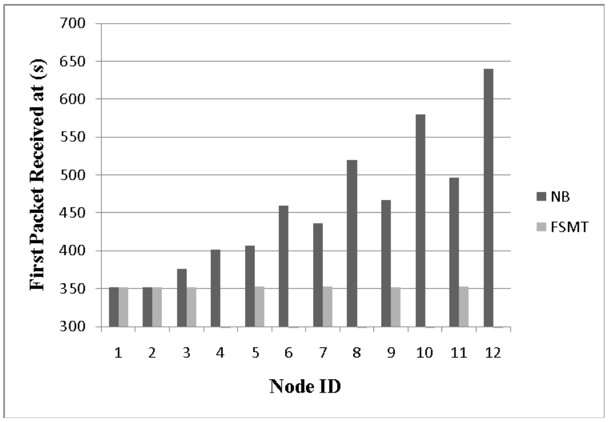


Fig. 18: The time first received safety message of each node - low density

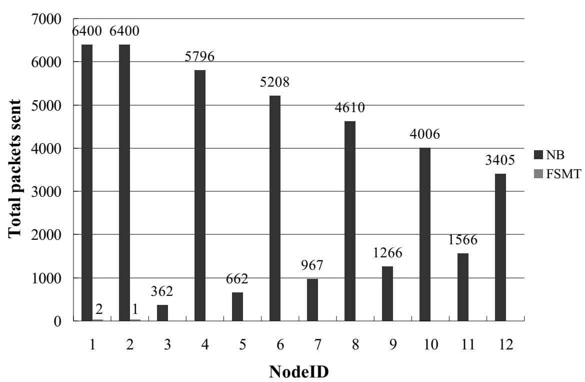


Fig. 19: Comparison of the number of safety messages transmitted - low density

protocol, since there is no mechanism to stop safety message forwarding, all vehicles will keep forwarding the safety message during the time remaining in the simulation.

With regard to accident rescue, the simulation showed that after an accident occurred, the rescue-requesting message can be transmitted to the Traffic Control Center within 20ms in low-density environments.

5 Conclusions

Under heterogeneous vehicular network, a FSMT mechanism has been proposed to transmit safety messages. When the V2V network is inappropriate for safety message transmission, the V2I network will be enabled to help in transmitting safety message and completing accident and diversion notifications. Simulation results revealed that, in the high density environment, when V2V network failed to pass safety message out due to media congestion, safety message can be received ahead of time to 0.86 second through V2I networks help. On the other hand, in low density environment, safety message can be received significantly ahead of time to 0.85 minute by leveraging V2I networks wide transmission range to allow the rear vehicles well prepared in advance, and thus minimize accident damage.

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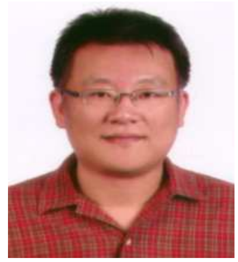

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