EMERGENCY MESSAGE BROADCASTING SCHEME BASED ON V2V AND V2I

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Abstract *–As an important part of the advanced Intelligent Traffic System (ITS) in the Internet of Vehicles (IoV), Vehicle to everything (V2X) communication technology provides reliable end-to-end connection and efficient packet transmission. Currently, the main challenge is design and implementation of the multi-hop broadcast protocol. In particular, the network topology is constantly changing because of the high-speed vehicle and diversified road structure, which troubles the selection of forward nodes. Therefore, we propose an Emergency Message Broadcast Protocol (EMBP). In this method, we select the optimal relay node according to the directionality and mobility, channel fading, and link connectivity and apply a suboptimal relay node selection mechanism to guarantee the reliability of broadcast. Simulation results show that EMBP is more efficient and stable than part classical protocols. Due to the complex communication environment of urban roads, to better improve the reliability of emergency message transmission, a broadcasting scheme Roadside Unit (RSU) Emergency Message Broadcast Protocol (REMBP), based on Vehicle to Vehicle (V2V) and Vehicle to Road (V2R) hybrid transmission of emergency messages is proposed on the basis of EMBP. Compared with EMBP, REMBP has better performance in terms of delivery rate, number of forwarding hops, end-to-end delay, average number of collisions, number of packet redundancy, and number of retransmissions.*

Keywords – Emergency message, Internet of Vehicles, multi-hop broadcast, protocol, relay node

NOTE: Part of this research has been accepted for the conference THE 2022 IEEE International Conference on Metaverse, but this paper improves and expands on it.

1. INTRODUCTION

Metaverse and the Intelligent Transportation System (ITS) are disruptive technologies that have the potential to transform the current transportation system by decreasing traffic accidents and improving driving safety [1]. The Internet of Vehicles (IoV) is an important field of wireless communication technology in ITS [2], to improve the safety and efficiency of road traffic [3]-[4]. Highly reliable transmission of emergency messages is essential to ensure the safety of urban roads and improve the efficiency of vehicle traffic. On urban roads, when a traffic accident occurs, emergency messages need to be quickly delivered to all affected vehicles in the vicinity, and the affected vehicles need to take corresponding measures to avoid secondary accidents after receiving the messages. Owing to limited transmission, one-hop transmission cannot transmit messages to the predetermined area. Therefore, multi-hop transmission is usually used through the relay node [5]. Because the vehicle and network topology are rapidly changing, the transmission of emergency messages is affected by fading, link quality, and channel competition, which complicates the design of the multi-hop broadcast. When designing a multi-hop broadcast solution, the issue of real-time emergency messages must be considered. Emergency messages must be broadcast quickly to vehicles within the affected area. A broadcast storm is another problem [6] that wastes channel resources and generates message conflicts.

Currently, there are many classic multi-hop broadcast protocols, such as flooding, where all vehicles are involved in transmission. When a message is received, the vehicle will broadcast to the vehicles in one hop. If it is dense, this broadcast will bring a great overhead and channel competition to the network. DV-CAST [7], a distributed multi-hop broadcast protocol, solves this problem, which uses a local one-hop topology and calculates the connectivity with periodic beacon messages. In dense areas, it uses a probability-based suppression method, and in sparse areas, it uses storage forwarding technology. However, this protocol also has a high overhead and end-to-end delay in the process of data transmission, so it is difficult to ensure an efficient broadcast. BP-EMD [8] adopted a weighted probability broadcast with a few nodes, reducing the overhead and message conflict.

However, when selecting nodes, the distance weight is the highest, and then the farthest vehicle is selected to broadcast emergency messages, which will reduce the stability of the link.

Based on the above problems, this paper proposes an Emergency Message Broadcast Protocol (EMBP) for urban vehicular networks. For the problem of a high BP-EMD distance weight, the scheme in this study selects the optimal relay node based on the directionality of the vehicle and the weighted probability, which improves the link stability to a certain extent. In addition, a suboptimal relay node selection mechanism is defined to ensure the link stability of emergency messages. The main contributions of this study are as follows: (1) We proposed EMBP, an emergency message broadcast protocol based on urban vehicle networking, which considers vehicle directionality, channel fading, and link stability. (2) Set the optimal relay node and suboptimal relay node to forward messages. When the optimal relay node fails to forward, the suboptimal relay node is forwarded. (3) Set Region of Interest (ROI), the region affected by the incident, to prevent unlimited message proliferation.

In urban roads, a single Vehicle to Vehicle (V2V) communication can no longer meet the communication needs and reliable message transmission at intersections due to complex traffic and high traffic flow, especially at intersections and road traffic congestion. The efficiency and reliability of emergency message transmission can be improved by placing a Roadside Unit (RSU) at urban intersections. Therefore, based on EMBP, the Roadside Unit (RSU) Emergency Message Broadcast Protocol (REMBP) is proposed to better adapt to the transmission of emergency messages on urban roads. The features of the above protocol are shown in Table 1.

Table 1 – Protocol features

Protocol	Features
Flooding	All vehicles participate in the transmission of messages, high overhead and channel competition
DV-CAST	Local one-hop topology for routing decisions, high overhead and end-to-end latency
BP-EMD	Broadcast emergency messages to as few nodes as possible, poor link stability
EMBP	Optimal relay nodes and suboptimal relay nodes improve link stability
REMBP	Add RSU at the intersection to participate in emergency message broadcast, reducing network overhead

Section 2 introduces related work. Section 3 introduces the method and the model proposed in detail. Section 4 introduces REMBP. In Section 5, we evaluate the proposed method and other protocols through simulation analyses. Section 6 summarizes this article and discusses potential future work.

2. RELATED WORK

Efficient IoV and information dissemination are critical to providing security-related services, and research workers have proposed a number of solutions to address information dissemination to reduce packet loss and to minimize network overhead and latency. Currently, there are two main categories: (1) Vehicle-to-Vehicle (V2V) communication, which is mainly the communication between vehicles. (2) Vehicle-to-Infrastructure (V2I) communication, which is mainly the communication between the vehicle and the Roadside Unit (RSU) devices.

2.1 V2V-based emergency message broadcasting method

[9] proposed a traffic-aware location routing protocol suitable for urban vehicle networking. Based on the Geographic Source Routing (GSR) protocol, an ant colony algorithm is used to find the best path. The best path is found by calculating the weight of each road segment and dropping ant information packets at the intersection. In [10], an invisible Markov model (PRHMM)-based vehicle prediction routing is proposed for fast vehicle speeds, long vehicle distances, and density variations. The future location of a vehicle is predicted based on past vehicle motion traces, which allows the prediction of the short-term path of a vehicle and its group transmission probability to a specific mobile destination. [11] proposed a new clustering technology for two-way roads, namely Probabilistic Direction-Aware Cooperative Collision Avoidance (PDACCA). However, PDACCA cannot satisfy bidirectional road traffic in urban VANET consisting of intersections and roundabouts, allowing nodes to move in different directions. [12] proposed an effective EMS propagation protocol using cluster-based propagation methods in emergencies, which selects nodes farther from the source node to broadcast. Delay-based emergency message broadcasting distinguishes the waiting time of candidate nodes. In the DTBB protocol proposed in [13], the vehicle source node calculates the waiting transmission delay based on the distance and the number of neighbor nodes, where

the neighbor nodes must be valid. This reduced the problem of the broadcast storm. [14] proposed a new definition of the counter protocol and waiting for time based on probability protocol. The waiting time from a random value to a value that can be obtained is based on the speed of the node in each region. It solves the problem of waiting time in sparse and dense areas. [15] proposed a Weighted P-Persistence (WPP) broadcast scheme, Slotted 1-Persistence broadcast scheme, and Slotted P-Persistence broadcast scheme. These schemes calculate the forwarding probability through the node location, transmission range, and vehicle density. These schemes can improve broadcast efficiency and reduce end-to-end delay. However, when vehicle density is high, a large number of packets are generated, resulting in a lot of redundancy and broadcast storms. The Adaptive Weighted Probabilistic Persistence (AWPP) scheme [16] solves the shortcomings of the existing traditional WPP schemes. The scheme divides the road into dense and sparse parts by the number of neighbor nodes. Each vehicle at each location has a different probability value p. But the impact of other factors on emergency message broadcasting was not considered. In [17] proposed a broadcast protocol based on the probability of relative position number and the probability of link quality, through the calculation method of cluster and link utility value. The protocol improves the reliability and efficiency of network transmission.

2.2 V2I-based emergency message broadcasting method

Various important applications in telematics that support intelligent transportation systems include vehicle and RSU, V2V and V2I-based communications. In [18] a multi-hop clustering method based on V2I communication is proposed to improve the performance of vehicle-to-network. Each vehicle can obtain and transmit the state information of its multi-hop neighbors for forwarding node selection. [19] designed a Message Coverage Maximization Algorithm (MCMA), which uses vehicles and carefully deployed RSUs for emergency message dissemination in an urban environment. The message coverage problem of vehicle-vehicle communication is also studied by deriving information about different vehicle densities. Then an algorithm is proposed for the selection of emergency message broadcasters based on RSUs for urban vehicular networks. In [20], an adaptive broadcast interval transmission scheme for emergency messages in the Vehicle to Road (V2R) environment is proposed, where the RSU sends messages to the vehicle after an optimal broadcast interval. The service rate of the network is greatly improved and the overhead of duplicate messages is reduced. In [21], an effective relay vehicle selection mechanism is proposed for the effects of broadcast storms. Two multi-criteria decision tools, fuzzy hierarchical analysis (FAHP) and evaluation based on distance averaged solution (EADS) are used to rank the vehicles in the main areas of relay vehicle selection. The method performs well in terms of performance in terms of redundancy rate and delay.

From the above discussion, it can be seen that many researchers are attempting to design an efficient multi-hop forwarding algorithm, where the key lies in how to select the optimal relay node for more efficient transmission of emergency messages to the affected vehicles. Compared with the above-mentioned types of broadcast methods, in V2V-based communication, EMBP integrates the direction of vehicles, channel fading, and link stability to select the optimal relay node, and adds a suboptimal relay node selection mechanism to improve the efficiency of emergency message transmission. Thus, emergency message dissemination becomes more efficient, and the link is more stable. Based on the EMBP, the V2R communication method is added, and the REMBP combines the urban road environment to select the optimal relay node for V2V communication on the road and forward emergency messages through V2R communication at the RSU at the intersection to improve all aspects of performance.

3. EMBP PROTOCOL DESIGN

3.1 Scene design

Based on an urban scene, Fig. 1 shows an urban road V2V accident scenario showing the multi-hop broadcast process in case of a vehicle accident. Where ROI indicates the range of influence is defined as follows:

$$ROI = L \cup I \tag{1}$$

L represent the area from the accident point to the intersection, and I represent the intersection area. By setting ROI, the wireless diffusion of messages can be prevented and the network overhead can be saved.

In Fig. 1, the accident vehicle W generates an emergency message, which is forwarded through relay node A such as relay nodes until it is transmitted to the affected vehicle in the rear. The distance between the receiving node and the accident vehicle is d_w when the following conditions are met:

$$d_w > (d_{ROI} - d_{ahead}) \tag{2}$$

Then the emergency message is considered invalid, and the other continues to broadcast, in which d_{ROI} represents the length of the ROI and d_{ahead} represents the distance from the accident vehicle to the right boundary of the ROI. When the affected vehicle receives an emergency message, it will take measures such as braking and changing lanes to avoid road congestion.

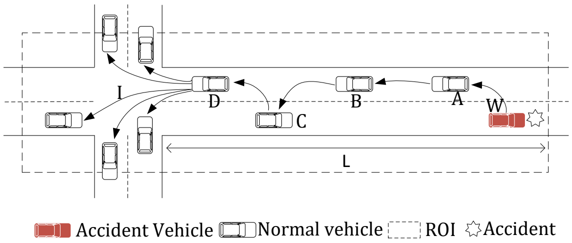

Fig. 1 – V2V accident scenarios on urban roads

In order to analyze this, the following assumptions are made for the vehicle node: (1) All vehicles can obtain positions through the positioning system and are equipped with wireless communication devices, and vehicles can communicate with each other. (2) Two kinds of messages are sent between vehicles: Hello message and emergency message. (3) All vehicles can get information about neighboring vehicles, such as speed, position, and heading, through hello messages. (4) All vehicles use the Dedicated Short-Range Communication (DSRC) standard and the transmission of emergency messages uses a control channel.

For the assumptions, the hello packet is designed as Fig. 2.

Node Id	Message Type	Position	Speed	Direction
2 byte	BSM	8 byte	4 byte	8 byte

Fig. 2 – Hello message packet format

The emergency message packet is designed as Fig. 3.

The ROI field stores four coordinates that are used to determine if the forwarding vehicle is within the affected range.

Node Id	Message Type	Optimal Relay Node	Suboptimal Relay Node	ROI
2 byte	WSM	2 byte	2 byte	32byte

Fig. 3 – Emergency message packet format

3.2 Protocol broadcasting scheme

The algorithm is shown in Algorithm 1.

Algorithm 1:EMBP protocol

N_i is the set of neighbors in the broadcast direction of the accident vehicle node
T_w waiting time for SRN vehicles

```
Broadcast Hello message to update routing table
for vehicle j and direction Ni
   calculation Pij
end
Select the maximum Pij as OPN, the second largest Pij as SRN
Broadcast emergency messages and update relay nodes id
if j == OPN
   OPN forward emergency message
else
   wait Tw
end
if wait time > Tw
   SRN forward emergency message
else
   OPN continues broadcast
end
```

When a traffic accident occurs in a vehicle, the Optimal Relay Node (OPN) and the Suboptimal Relay Node (SRN) are selected to forward the emergency messages through the information exchanged periodically by hello messages. There is a special scenario where two vehicles are each other's optimal relay nodes and continuously exchange emergency messages, resulting in a dead loop. This situation is solved by judging the direction, speed and position of the vehicle. The selected OPN is mainly to reduce the problem of network performance degradation caused by multiple nodes involved in broadcasting in the network, and the SRN is mainly to solve the problem of resending packets when OPN packets are lost, and to improve the stability of the link and the reliability of emergency messages. The specific process is as follows: When a certain vehicle i encounters an accident or congestion, it broadcast "Emergency" messages to all neighboring nodes. After receiving an "Emergency" message, the receiver j checks the optimal relay node field in it. If j is the optimal relay node, the node j continues to broadcast the "Emergency" message to its neighboring nodes. If j is not the optimal relay node but the suboptimal relay node, the waiting time is T_w. If the same "Emergency" message is not received again during the waiting period, node j performs the broadcast operation. Otherwise, node j does not perform the broadcast operation. If j is neither the optimal relay nor the suboptimal relay node, node j does not perform the broadcast operation in any event.

3.3 Routing table creation and maintenance

The information on each vehicle routing table is shown in Fig. 4.

OPN vehicle Id	OPN weighted probability value	SRN vehicle Id	SRN weighted probability value	Deposit Time

Fig. 4 – Routing table

In the network environment, each vehicle periodically broadcasts a hello message, and when the message of the broadcasted vehicle is accepted by the neighboring nodes in the communication range, all the current neighboring nodes establish the initial routing table and deposit the broadcasted vehicle Id and the calculated weighted probability value into the OPN vehicle Id and OPN weighted probability value as the initial values, respectively. After that, the weighted probability value is calculated based on the received hello message, and the weighted probability value is compared with the first accepted weighted probability value, and if it is larger, the first deposited information is deleted and the second deposited into the OPN vehicle Id and OPN weighted probability value, and the first value is deposited into the SRN vehicle Id and SRN weighted probability value. After that, the information in the routing table is updated according to the periodic hello maintenance. To ensure the validity of the information in the routing table, the update time is set to 5s.

3.4 OPN and SRN selection algorithm

When an urgent message is transmitted during the transmission, its neighboring nodes receive the message. To avoid the broadcast storm problem, only one node is selected as the OPN, and the OPN is selected by the sender and receiver travel direction, channel transmission success probability, and link connectivity probability. When the vehicle periodically broadcasts hello messages, it sends its own speed, driving direction, and coordinate information to all neighboring vehicles within the communication range. When the surrounding neighboring vehicles receive the hello message, they will judge whether the vehicle is in the affected area, as shown in Fig. 5. Similarly, when the hello message broadcast by vehicle G is received by vehicle Y, Y can determine whether vehicle G is not in the affected area.

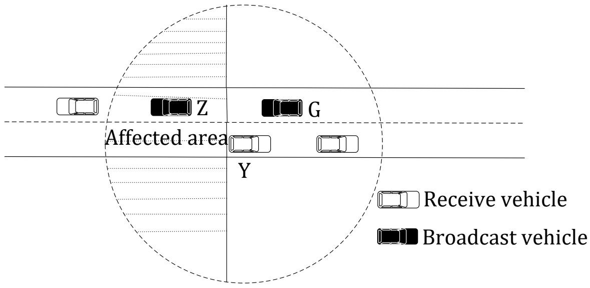

Fig. 5 – Affected area

The success probability of channel transmission and the link connectivity probability can be expressed as:

$$P_{ij} = pr_{ij}(d_{ij}) \times p_l \tag{3}$$

where P_{ij} is weighted probability. $pr_{ij}(d_{ij})$ is successful transmission probability. p_l is link connectivity probability.

The specific relay node selection process is shown in Fig. 6.

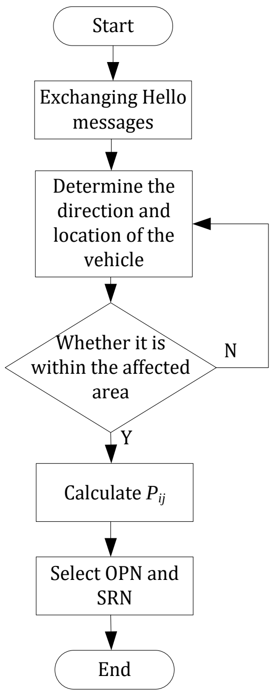

Fig. 6 – OPN and SRN selection process

3.5 Direction calculation

Directionality is an important factor in vehicular networks. The heading of the vehicle is obtained by a hello message, which can be converted into an angle by (4):

$$\theta = \frac{180}{\pi} * rad \tag{4}$$

where rad represents radian, θ represents the angle. The direction is determined as shown in Fig. 7, with 0° as the east direction, the angle offset of ± 45° indicates that the vehicle is traveling east, and the other angle corresponding directions are shown in Table 2.

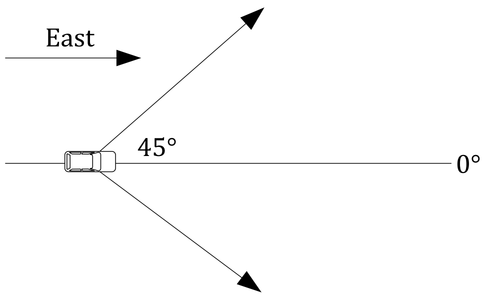

Fig. 7 – Vehicle direction

Table 2 – Directional parameters

Direction	Angle
East	[0,45), [315,360)
South	[225,270), [270,315)
West	[135,180), [180,225)
North	[45,90), [90,135)

3.6 Channel model

At present, many radio channel propagation models have been proposed to simulate the characteristics of radio signals. Some researchers have proposed that the Nakgami-m distribution is the most suitable model for radio propagation fading [22]. Using this model, the probability of successful transmission of data packets from the sending vehicle *i* and the receiving vehicle *j* can be obtained [8]:

$$pr_{ij}(d_{ij}) = 1 - F_d(r_t, m, \Omega) = e^{-\frac{mr_T}{\Omega}} \sum_{i=1}^{m} \frac{(\frac{m}{\Omega} r_T)^{i-1}}{(i-1)!} \tag{5}$$

where $F_d(r_t,m,\Omega)$ is the cumulative distribution function of the received signal intensity, parameter r_T is threshold of received signal, and m is the fading parameter. Ω is the average strength of the received signal.

The value of m determines the received power after fading. Fig. 8 shows the acceptance probability of the TwoRayGround model and the Nakagami model in the communication range [23]. It can be seen that the value of m in the Nakagami model is different, and the acceptance probability is also different. The larger the value of m, the greater the probability of message acceptance. When m is smaller, the channel fades faster. In urban areas with numerous buildings and complex environments, a value of m equal to 1 is more consistent in an urban road channel environment.

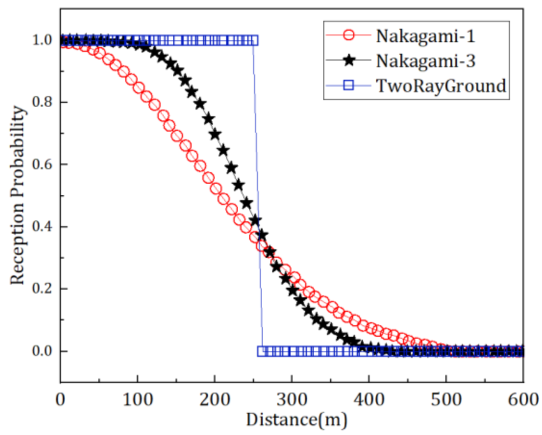

Fig. 8 – Reception probability of TwoRayGround and Nakagami

3.7 Link connectivity probability

In the urban environment, when the packet is transmitted, neither node is in the communication range of the other, and the receiving node cannot receive the messages sent by the sending node. Therefore, link connectivity is also very important [24].

Owing to the mobility of the vehicle, the successful transmission of an emergency message depends on the relative speed of the sender and receiver, the time required to forward the message, and the range of communication. The sender selects the next hop based on the hello message, but if the vehicle is moving at a high speed, the message may be out of date. Then, a new calculation method is proposed to calculate the probability that the link between the sender and receiver maintains communication within a specified time. Given a prediction interval T_d for the continuous availability of a specific link l between two vehicles at t.

The link connectivity probability is defined as follows [25]:

$$pl = \{t \ until \ t + T_d\} \quad (6)$$

In order to calculate the reliability of the link, we use vehicle speed parameters. Suppose the speed of the vehicle follows a Gaussian distribution:

$$v \sim N(\mu, \sigma^2) \quad (7)$$

where μ represents the average speed of the vehicle, and σ represents the standard deviation of the speed. Based on this assumption, $g(v)$ is the probability density function of velocity V and $G(v)$ is the corresponding probability distribution function:

$$g(v) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(v-\mu)^2}{2\sigma^2}} \quad (8)$$

$$G(v < V_0) = \frac{1}{\sigma\sqrt{2\pi}} \int_0^{V_0} e^{-\frac{(v-\mu)^2}{2\sigma^2}} dv \quad (9)$$

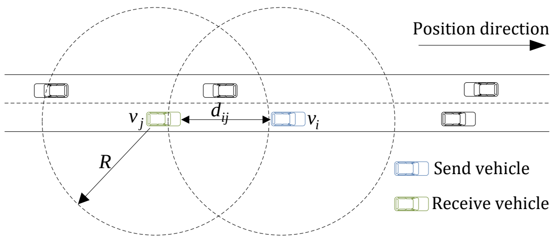

Fig. 9 – Send and receive vehicles

The direction of the arrow in Fig. 9 is positive. Since the speed of the vehicle obeys the Gaussian distribution, the relative speed between the sender and the receiver also obeys the Gaussian distribution:

$$\Delta v_{ij} : \begin{cases} N(\mu^i - \mu^j, \sigma_i^2 + \sigma_j^2), & same\ direction \\ N(\mu^i + \mu^j, \sigma_i^2 + \sigma_j^2), & opposite\ direction \end{cases} \quad (10)$$

The distance d between any two vehicles can be calculated using the relative velocity Δv and the duration T.

$$T = \frac{d}{\Delta v} \quad (11)$$

R represents the wireless communication range of each vehicle, and the maximum distance between any two vehicles that can maintain communication can be determined to be $2R$. When the relative distance between the two vehicles changes from $-R$ to R, $f(T)$ represents the probability density function of the communication duration T. $f(T)$ is calculated as follows [24]:

$$f(T) = \frac{1}{T^2} \frac{4R}{\sigma\Delta v\sqrt{2\pi}} e^{-\frac{(\frac{2R}{T} - \mu\Delta v)^2}{2\sigma^2\Delta v}}, T \geq 0 \quad (12)$$

where $\mu\Delta v$ and $\sigma^2\Delta v$ denote the mean and variance of relative velocity Δv, respectively. T_d is defined as the continuous availability of a particular link l between two vehicles i and j. It can be determined as:

$$T_d = \frac{R - d_{ij}}{\Delta v} = \frac{R - \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{|v_i - v_j|} \quad (13)$$

where d_{ij} is the Euclidean distance between vehicles i and j, and v_{ij} is the relative speed between vehicles i and j. Therefore, the link connectivity probability p_l at time t can be calculated by (14):

$$p_l = \begin{cases} \int_t^{t+T_d} f(T)dT, & T_d > 0 \\ 0, & otherwise \end{cases} \quad (14)$$

4. REMBP BROADCAST PROGRAM

Vehicle-to-Vehicle communication or Vehicle-to-RSU communication is possible in the telematics environment, resulting in V2I communication. V2V communication enables vehicles to transmit emergency messages over single or multiple hops. However, due to the dynamic nature of telematics, communication may be frequently interrupted [26]. To improve the reliability of emergency messaging in the event of an incident, RSUs play a critical role in intermittent network connectivity [27]. However, large-scale deployment is not feasible due to the expensive RSU equipment. Due to the limitations of V2I and V2V, relying on V2I or V2V communication alone is not sufficient to meet various variable communication environments. Therefore, both V2V and V2R hybrid communication methods need to be used. On urban roads, traffic and environmental factors are complex. Especially at intersections, where the number of vehicles is higher, a greater overhead is incurred by V2V communication. If emergency messages are forwarded by placing an RSU at the intersection, the network overhead can be reduced and the reliability of emergency message transmission can be improved. As shown in Fig. 10, when an accident occurs in the front vehicle, the accident vehicle W sends an emergency message hop by hop, and when C is in the communication range of the RSU, D is not in the communication range of C. The relay vehicle C transmits the emergency message to the RSU. When the RSU receives the emergency message, the RSU broadcasts the emergency message to all vehicles in the communication range, such as D. If there is no RSU at the intersection, at this time D does not receive the emergency message transmitted by C, it will cause a break in the link and affect the reliability of the emergency message transmission.

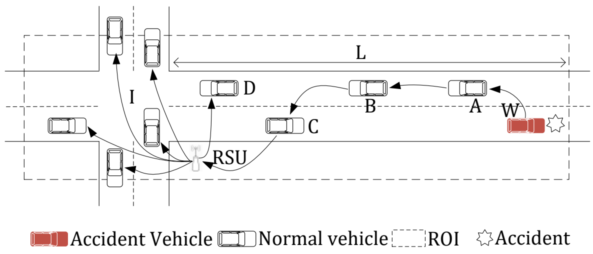

Fig. 10 – V2I accident scenarios on urban roads

The reliability of emergency message transmission in sparse scenarios can also be improved to some extent by mixed V2R and V2V communication. In the proposed scheme, the incident vehicle transmits the emergency message using V2V communication until the emergency message is transmitted to the RSU. Depending on the distance between the source and destination vehicles, if V2V connection is not possible at the intersection, the emergency message is broadcast through the RSU.

5. SIMULATION AND RESULTS

In this section, we first give the simulation environment and main parameters, then conduct some comparison experiments, and to avoid experimental change, a total of 10 experiments are repeated to take the average value. The validity of the proposed EMBP and REMBP is verified.

5.1 Simulation environment and parameters

Using OMNeT++ 5.5.1 and SUMO 1.1.0, the urban traffic scene based on veins 5.0 is established. In the EMBP broadcast scheme, a car is fixed near the intersection as the destination node in order to facilitate the statistics of the experimental data. When an accident occurs in the vehicle ahead, the emergency message is broadcast to the destination node hop by hop, and the source node broadcasts the emergency message every 1 second. In the REMBP broadcast scheme, the RSU is added to participate in an emergency message broadcast. The simulation parameters are shown in Table 3.

Table 3 – Simulation parameters

Simulation parameters	Parameter value
Physical protocols	802.11p
PHY model	Nakagami-m
Number of lanes	6
Transmission range	250m
Vehicle velocity	8-16m/s
BSM period	10Hz
Beacon length	256Byte
WSM period	1Hz
Data length	512Byte
T_w	1ms
Transmission power	23mW
RSU position	(490,470)
Bit rate	6Mbps
Arrival rate	0.1,0.15,0.2,0.3,0.4
ROI length	2km
Simulation time	500s

To verify the EMBP and REMBP performance, the following protocols are compared: (1) Nearest Distance Broadcast Protocol (NDBP); this protocol is that each node selects the nearest node for relay broadcast. (2) BP-EMD protocol; this protocol is a comprehensive probability to select the optimal relay node with the highest weighting of the distance factor.

The following metrics were evaluated for comparative analysis. (1) Packet Delivery Rate (PDR): PDR is the ratio of the number of packets received by the destination node to the number of packets sent by the source node and is used to indicate the reliability of the route. (2) Forwarding Hops (FHs): FH is the number of times a message is forwarded from the source node to the destination node. (3) End-to-End Delay (EED): EED is the duration experienced by a packet from the source node to the destination node and it represents the timeliness of the route. (4) Average collisions: The number of collisions that occur between packets during the broadcast of an emergency message. (5) Packet redundant: The average number of emergency packets received by each vehicle during the transmission of emergency messages. (6) Retransmission: The average number of times an emergency message is retransmitted per vehicle during emergency message transmission.

5.2 Packet delivery rate at different arrival rates

Fig. 11 shows the packet delivery rates for four different protocols with different vehicle arrival rates. As the vehicle arrival rate increases, the packet delivery rates increase for all protocols, mainly due to the shorter distance between vehicles, better communication links, and higher probability of successful forwarding. The NDBP performs the worst, mainly because each time the nearest distance node is selected to broadcast an emergency message this leads to an increase in message redundancy and collision, and thus a higher probability of packet loss, so the PDR is less than the other protocols. BP-EMD selects the node as far as possible from the sender to broadcast the message each time, and the message cannot be received due to fading and the instability of the link. The protocol proposed in this paper considers link quality when selecting OPN and adds an SRN selection mechanism, so PDR is better than the other two protocols. Among them, REMBP adds the V2R communication method on top of EMBP, which reduces the packet loss caused by too many vehicles when vehicles transmit emergency messages at intersections. Therefore, REMBP is optimal.

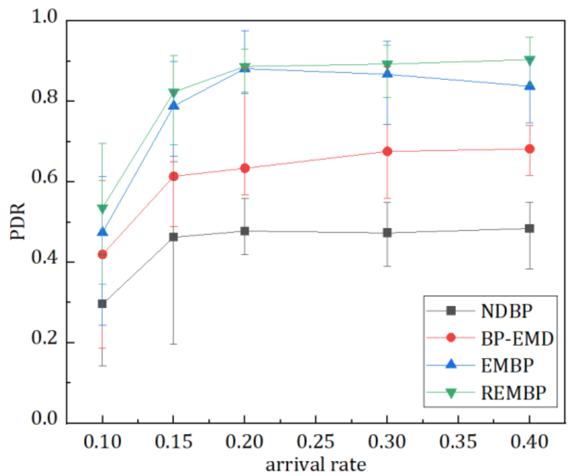

Fig. 11 – Packet delivery rate at different arrival rates

5.3 Forward hops at different arrival rates

In Fig. 12, the number of forward hops varies with the vehicle arrival rate. As the vehicle arrival rate increases, the NDBP has the highest number of forward hops, mainly because the NDBP selects the closest vehicle as a relay node each time, so more nodes join the forwarding process, resulting in more forward hops. The next one is the BP-EMD, because the BP-EMD selects the vehicle as far away as possible as the relay node when selecting the relay node, so the forward hops are the least. The proposed scheme in this paper has more forward hops than the BP-EMD and fewer forward hops than the NDBP in terms of the number of forward hops. Because this paper ensures link stability and communication quality when selecting relay nodes, the forwarding hop count will be higher than that of the BP-EMD protocol. However, REMBP has fewer forwarding hops than EMBP.

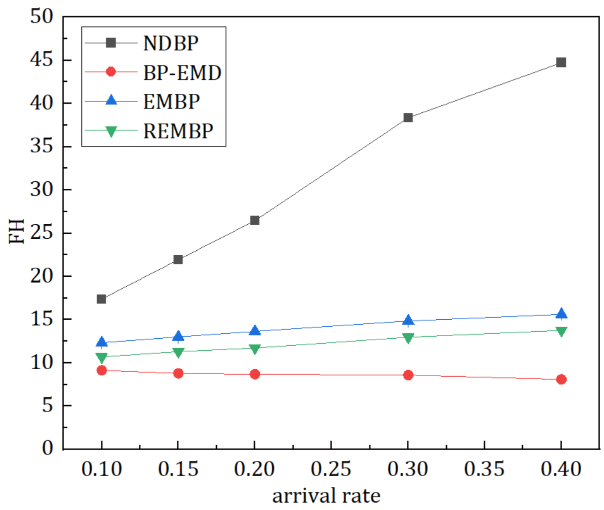

Fig. 12 – Forward hops at different arrival rates

5.4 End-to-end delay at different arrival rates

Fig. 13 shows the end-to-end delay for different vehicle arrival rates. The figure shows that as the vehicle arrival rate increases, the nearest distance broadcast protocol latency increases substantially and performs the worst. This is because the nearest neighbor node is selected as the forwarding node by the nearest distance broadcast protocol, which makes more nodes join the forwarding process, thus increasing the end-to-end delay. And BP-EMD is to select the vehicle as far away as possible to forward emergency messages, which increases the EED owing to unstable link quality and when packets are lost, reselecting nodes to forward messages by competition adds extra waiting time. EMBP takes into account factors such as signal fading, broadcast interference, channel competition, and SRN mechanisms, and has lower delay than NDBP and BP-EMD. REMBP adds an RSU to participate in message forwarding, so the delay is better.

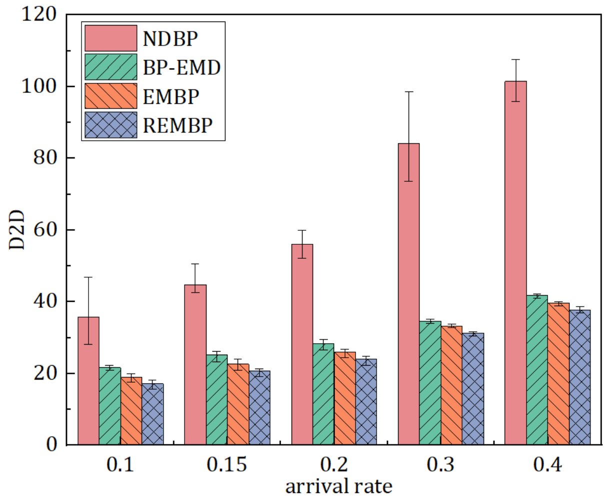

Fig. 13 – End-to-end delay at different arrival rates

5.5 Average number of collisions at different arrival rates

Fig. 14 shows the average number of collisions for the four protocols at different arrival rates. Among them, the NDBP performs the worst because the NDBP forwards emergency messages by more vehicles during emergency message transmission, which leads to a high network overhead and causes huge collision. The next one is BP-EMD. EMBP is compared with REMBP, which not only transmits emergency messages between vehicles but also transmits emergency messages through the RSU. The transmission of emergency messages through the RSU covers a wider area and is more efficient than the transmission of emergency messages between vehicles, which can reduce the conflict of messages during the transmission of emergency messages.

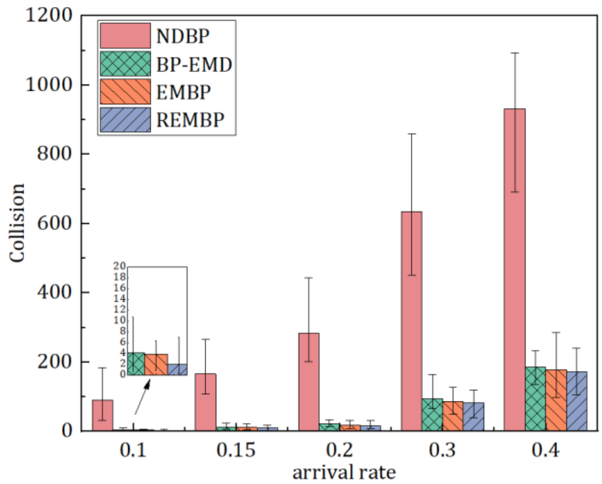

Fig. 14 – Average number of collisions at different arrival rates

5.6 Packet redundant at different arrival rates

It can be seen from Fig. 15 that the NDBP has the highest number of packet redundancy. Because there are more vehicles involved in the transmission of emergency messages, which will cause the vehicles to receive more emergency messages, resulting in packet redundancy. BP-EMD has less packet redundancy than the NDBP because BP-EMD selects better nodes to transmit packets, but due to the selected nodes and because of the instability of the link and the fact that the best node as far as possible may be out of the range of vehicle traffic causing packet transmission EMBP and REMBP perform better, and the reason why REMBP is better than EMBP is because the placement of the RSU at the intersection reduces the overhead of the network.

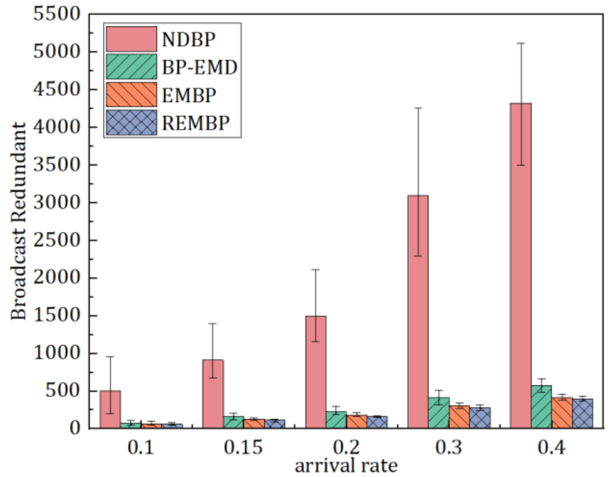

Fig. 15 – Packet redundant at different arrival rates

5.7 Number of retransmissions at different arrival rates

As can be seen in Fig. 16, the number of retransmissions for the four protocols increases with the vehicle arrival rate. The NDBP performs the worst, with a particularly high number of retransmissions at either arrival rate. The number of retransmissions is higher because more vehicle nodes are involved in the transmission of emergency messages and also generate a higher number of channel conflicts and packet loss. Next is BP-EMD. The number of retransmissions is less in REMBP than in NDBP and BP-EMD because various factors are taken into account when selecting the forwarding vehicle so that the number of packet collisions and packet losses are less. The REMBP is optimal. Because REMBP not only selects the optimal node to forward emergency messages, but also combines the RSU to forward emergency messages, which greatly reduces the network overhead and the number of packet collisions.

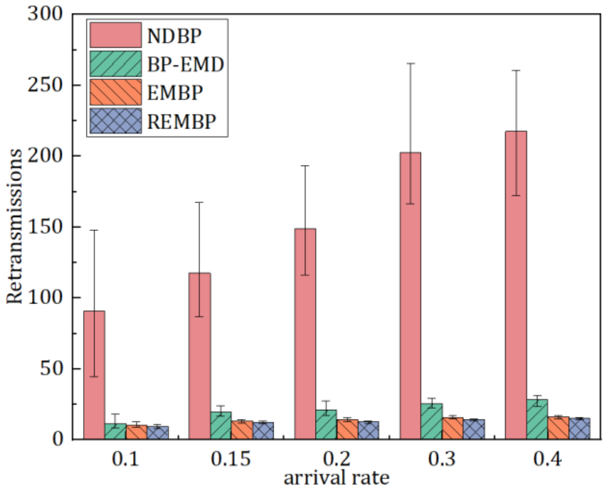

Fig. 16 – Number of retransmissions at different arrival rates

5.8 Impact of attacks on delivery rates at different arrival rates

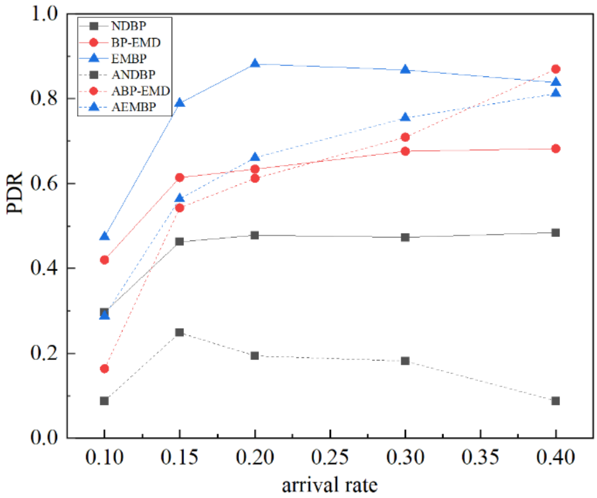

Fig. 17 – Impact of attacks on delivery rates at different arrival rates

Since there are potential security issues during the propagation of emergency messages, the delivery rates of the proposed scheme EMBP and the comparison protocols of NDBP and BP-EMD under gray hole attacks [28] were analyzed. During the experiment, it was set that 10% of the vehicles would be attacked by gray holes during driving, and vehicles attacked by gray holes would drop data packets with a probability of 50%. Fig. 17 shows the delivery rates, represented by ANDBP, ABP-EMD, and AEMBP, at different arrival rates after being subjected to gray hole attacks. It can be seen that gray hole attacks have an impact on the packet arrival rate of all protocols. However, as the arrival rate increases, the impact on AEMBP becomes smaller. This is because when the OPN is attacked by gray holes and data packets are lost, the SRN broadcasts emergency messages, thereby increasing link stability and improving emergency message transmission efficiency.

6. CONCLUSION

In this study, an emergency message broadcast scheme, EMBP, is proposed by combining the characteristics of urban roads. An OPN is selected by considering channel fading, link stability, and directionality. To ensure the stability of the link, an SRN selection mechanism was added. Simulation results prove that the scheme proposed in this paper outperforms the nearest distance broadcasting protocol and the BP-EMD protocol in terms of PDR, end-to-end delay, and conflict count. Owing to the drawback of certain high overheads of the EMBP scheme and to improve the reliability and efficiency of emergency message transmission at urban intersections, the REMBP broadcast scheme is proposed on the basis of EMBP, which makes emergency message transmission more reliable, saves overhead and lower delay, forward hop, higher delivery rate, lower packet redundancy, conflict count, and retransmission count. Based on the current deployment of C-V2X, if the base station utilizes a PC5 interface, REMBP can be replaced, thus saving deployment costs. In future work, we will consider better broadcast solutions to adapt to more complex connected car scenarios.

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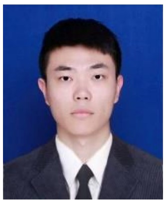

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