Received June 29, 2021, accepted August 2, 2021, date of publication August 9, 2021, date of current version August 19, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3103843

A Probabilistic Broadcasting Scheme for Emergent Message Dissemination in Urban Internet of Vehicles

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This work was supported in part by the National Key Research and Development Program of China under Grant 2019YFE0196600; in part by the National Natural Science Foundation of China under Grant 62072360, Grant 61902292, Grant 62001357, Grant 62072359, and Grant 62072355; in part by the Key Research and Development Plan of Shaanxi Province under Grant 2021ZDLGY02-09, Grant 2019ZDLGY13-07, Grant 2019ZDL-GY13-04, and Grant 2020JQ-844; in part by the Key Laboratory of Embedded System and Service Computing, Ministry of Education, Tongji University, under Grant ESSCKF2019-05; in part by Xi'an Science and Technology Plan under Grant 20RGZN0005; and in part by Xi'an Key Laboratory of Mobile Edge Computing and Security under Grant 201805052-ZD3CG36.

ABSTRACT The Internet of Vehicles (IoV) has attracted increasing attentions for its potential of enhancing driving safety and traffic efficiency. The Multi-hop broadcast is one of the important techniques for time-sensitive data dissemination especially in emergent cases. As a result, how to wisely select the next-hop during Multi-hop routing plays an important role for performance improvement in IoV as well as dependent applications. Nevertheless, in view of the high mobility, frequent changing topology and complicated channel environment, a hazardous and thoughtless selection of the next-hop is easy to make, thus leading undesirable results. To deal with this issue, in this paper, a probabilistic broadcasting protocol for emergent message dissemination (BP-EMD) in Urban IoV is proposed. As the selection guidance for relaying node, the weighted probability is envisioned for each potential relay candidate, which is the combination of distance, link availability and packet reception ratio. After that, the node with the greatest weighted probability has been given the highest priority to relay the packet. In case that the selected relay node fails the forwarding, the other nodes available for relay will assist to disseminate the packet. In this way, the transmission reliability of the emergent messages is significantly guaranteed. Numerical results indicate that our BP-EMD can achieve higher broadcasting efficiency and less redundancy with less delivery latency, average transmission numbers and average End-to-End delay, as well as high packets delivery ratio and dissemination efficiency, compared with some classical multi-hop broadcasting protocols.

INDEX TERMS Internet of Vehicles (IoV), data dissemination, probabilistic broadcasting protocol, multi-hop routing.

I. INTRODUCTION

The Internet of Vehicles (IoV) is a specific research area of wireless communication technology in the Intelligent Transportation System(ITS) [1] to enhance the safety and improve the efficiency of road traffics. In urban IoV, safety related applications usually operate based on wireless broadcast since warning messages (e.g., accident, blocked street, traffic congestion, etc.) need to be delivered to all nearby related vehicles [2]–[6]. For example, in case of traffic accidents or jams, a remote driver expects to get knowledge of such events as early as possible, and then take countermeasures (such as braking, lane changing) to avoid secondary collisions or chooses an alternate driving route to avoid traffic jams in the urban environment [7]–[12]. As shown in Fig.1, the vehicle in front suddenly brakes or finds a traffic accident, it should disseminate immediately emergency messages to the rear vehicles, which need to take countermeasures to avoid

The associate editor coordinating the review of this manuscript and approving it for publication was Kashif Saleem.

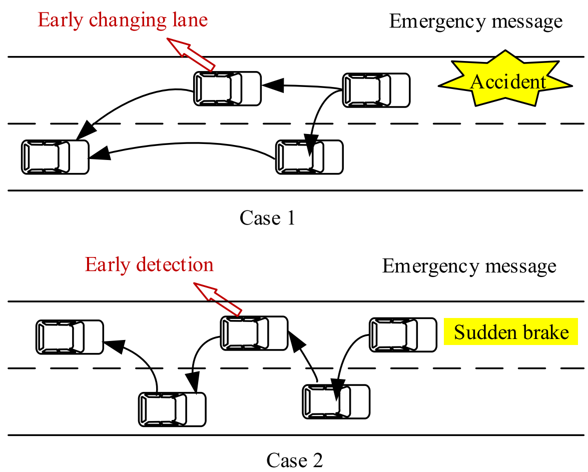

FIGURE 1. Emergency message broadcast.

secondary collisions. In addition, due to the one-hop transmission range of vehicle from 200m to 300m often does not reach the intended distance of emergency message, multi-hop transmission of emergency messages is usually adopted [13]–[16]. The emergency messages have to be diffused hop by hop to all vehicles in the affected area. However, the dynamic changing of network topological structure due to the high mobility of nodes, and poor link owing to fading or obstruction as well as the channel contention poses a great challenge for designing the robust multi-hop broadcast scheme.

To efficiently achieve the above issue, the following aspects must be considered:

- real-time requirement: a delayed emergency message may cause a terrible traffic accident, thus, the emergency messages should be fast and efficiently disseminated to vehicles which are up to several kilometers away. However, in urban IoV, multi-hop transmissions are essential because of the limited wireless communication range. And how to select suitable relay node to forward the emergency messages exerts one important impact on the network performance [17]. A thoughtless selection of relay node can penalize the total routing process by increasing extra retransmission delay caused by packet loss or reception failures. However, the optimal choice of relay node enables the robust and efficiency of packet transmission.
- the broadcast-storm issue [18]: causes severe message redundancy, medium contention, packet collisions, etc., and obviously wastes the limited channel resource in IoV.
- message reliability: the loss of an emergency message may lead to terrible casualties [19]. Consequently, the loss of an emergency message caused by weak links or frequent collisions in IoV cannot be neglected.

In summary, considering the characteristics of IoV and the application requirement of disseminating the emergency messages, on the one hand, the design of multi-hop broadcasting protocol needs to adapt to the dynamic changing of topology and reduce the message redundancy; on the other hand, it should ensure the fast dissemination of warning messages, with a high reliability and scalability [20]–[24].

There were already many valuable protocols, e.g., flooding-based and area-based [25] etc., but it is still difficult to directly apply them into urban IoV due to the strict QoS requirements of emergency message. In fact, to disseminate emergency messages, many schemes have been proposed [26]–[30]. Their common ideas generally select the farthest node to rebroadcast the emergency messages. However, due to the high speed of vehicles and limited radio range, the farthest node may move out of the communication range of the sender with a high probability. Therefore, the broadcasted message cannot be received, causing the multi-hop broadcasting process to be interrupted. In [31], an adaptive broadcast scheme is proposed. Neighbor nodes are assigned different priorities by sender based on the information extracted from the beacons. According to the priority queue, receivers rebroadcast packet in sequence. Although considering the link quality, this protocol cannot characterize the changes of the network topology when transmitting. In addition, these protocols do not take information validity into account. For example, with the increase of time or the extension of space, some emergency messages may have expired, which is to say their information validity turns to be zero. A message with zero information validity is useless for any vehicle. The spread of the invalid message not only waste the network resources, but also prevent the diffuse of new messages.

In order to efficiently address the aforementioned challenges in urban IoV, a probabilistic broadcasting for emergent message dissemination (BP-EMD) in urban IoV is proposed in this paper. Firstly, to address the broadcast-storm problem, we select the optimal one with the greatest weighted probability which is a combination of per-hop progress, link availability and packet reception probability. The optimal one with the greatest weighted probability has the highest priority to relay the packet and other nodes will assist in disseminating the packet once the optimal node rebroadcast unsuccessfully. Next, we define the TTL(Time To Live) of the emergency message to prevent infinite diffusion of messages and save network overhead.

In summary, the main contributions of this paper are listed as follows:

- Based on the accident represented by the emergency message, only the subsequent vehicles will be affected. Similar to "hot spot area [32]", we define the concept of RoS(Region of Sensitivity), which indicates the area affected by the accident. So we just need to ensure that vehicles within the ROS range receive emergency messages, which prevent infinite diffusion of messages and save network overhead.
- As the selection guidance of Expected Relay Node (ERN), we propose the weighted probability metric which takes into account three key impact factors,

i.e., distance, link availability and packet reception probability, to assign a weight for each relay candidate.
- Based on the weighted probability, the sender selects the node with the highest weighted probability as the ERN. When the ERN cannot successfully receive the packet, other nodes will assist to disseminate the packet. Through our proposed scheme, the reliability and efficiency for emergency messages dissemination can be enhanced to a great extent.

The rest of our paper is organized as follows. Section II briefly review some related works. The protocol design is introduced in section III. Section IV evaluates the performance of proposed protocol. Our paper is concluded in Section V.

II. RELATED WORK

Indeed, there have been a number of broadcast schemes proposed before to support safety-related applications in IoV. These protocols can be classified into probability-based [26], [27], waiting-based [28], Cluster-based, MAC(Medium Access Control) layer-based [33], etc. The Mflood [31] is one of the most common broadcast protocols. Although it provides fast and reliable spread, the problem of broadcast-storm [33] in dense network would seriously reduce its performance. To mitigate broadcast-storm, previous works have made a lot of achievements. This section reviews a number of the prominent existing broadcast protocol and discusses their pros and cons especially for their applicability in IoV.

A. PROBABILITY-BASED BROADCAST PROTOCOLS

Probability-based schemes allow receivers with a certain probability to forward packets to reduce redundancy. Wisitpongphan *et al.* [26] and Tonguz *et al.* [27] proposed two probability-based multi-hop broadcast protocols, including Weighted-p and Slotted-p. In the Weighted-p protocol and Slotted-p protocols, vehicles which are farther away from the previous forwarder have the higher probabilities to rebroadcast packets. By the schemes, the hop progress can be maximized and the end-to-end delay can also be reduced. However, when the vehicle density is higher, the protocols will lead to the repeated rebroadcast of message, resulting in a large number of redundant and the broadcast-storm. The Adaptive Weighted Probabilistic Persistence Scheme (AWPP) [34] addresses of shortcomings of the existing traditional WPP scheme. The scheme logically partition the road into two parts, i.e., dense and sparse location using the number of neighbors. Each vehicle at each location has a specific different value of probability p.

B. WAITING-BASED BROADCAST PROTOCOLS

The basic idea of waiting-based protocols is to distinguish the waiting time of candidate nodes, which is inversely proportional to the distance between the receiver and the sender. The Binary-Partition-Assisted Broadcast (BPAB) program [28] is proposed to improve the latency performance with a binary-partition scheme. Based on the positions of the sender, BPAB uses the different broadcast scheme to disseminate the emergency messages. However, the Request to Broadcast (RTB)/Clear to Broadcast (CTB) handshake may be interrupted. In addition, the directional broadcast is sequentially adopted in different road directions, which incurs the emergency message transmission delay. In [35], a RObust and Fast Forwarding (ROFF) broadcast protocol is proposed. It solves the unnecessary delay in the contention process by allowing a candidate node to use the waiting time which is inversely proportional to its forwarding priority. In addition, ROFF was able to avoid collision by considering the short difference in waiting time. But the overhead of ROFF is large in high-density network because extra information is piggybacked on the broadcast data. Naja *et al.* [36] proposed a new definition of the waiting time for both counter and probability based protocols. The waiting time from a random value to a value that can be obtained according to the node's speed in each area. It solved the problem of the generation of the waiting time in sparse and dense areas. The simulation show that the proposed method helps to improve the performances in terms of saved rebroadcasts.

C. CLUSTER-BASED BROADCAST PROTOCOLS

The clustering algorithm is based on the graph model. In the Fig.2, a cluster consists of one cluster head node, several gateway nodes, and a series of member nodes. The head node is responsible for sending packets to all nodes in the cluster. The gateway node is responsible for packet broadcasting between clusters (The cluster head node can also act as a gateway Node). The member node only receives the packet. The algorithm suppresses the forwarding of some nodes in the formed cluster, which reduces the number of forwarding nodes of the whole network and solves the broadcast-storm problem to a certain extent. In [37], a cluster based emergency message broadcasting algorithm is proposed for collision avoidance. The authors [38] developed a new data dissemination scheme based on directional clustering and probabilistic broadcasting, which allows us to solve the critical issues such as long latency, high collision probability and worse information coverage. But during clustering initialization and maintain, the price of extra overheads cannot be avoided, likely to affect network performance.

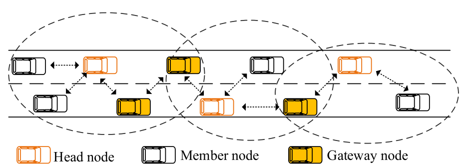

FIGURE 2. Cluster-based emergency message broadcast.

D. MAC-BASED BROADCAST PROTOCOLS

To deal with the problem that the MAC cannot support reliable broadcast, a variety of MAC layer-based broadcast protocols have been proposed to improve the network performance by modifying handshake mechanism. Urban Multi-hop Broadcast (UMB) [29] is presented to cope with the broadcast-storm and reliability issues. They use the directional broadcast to make the selection of remote forwarding nodes via RTB/CTB handshake on straight roads. At intersections, UMB uses repeater to broadcast emergency messages. Meanwhile, the protocol increases the Acknowledge Character (ACK) mechanism to ensure the reliability of broadcast. In [29], an urban multi-hop broadcast protocol (UMBP) is proposed to disseminate emergency messages. UMBP utilizes iterative partition, mini-slot and black-burst to quickly select remote neighboring nodes. To reduce message redundancy and guarantee message, the protocol selects forwarding node by the eRTS/eCTS handshake in each hop. But the handshake and ACK mechanisms will result in significant latency and large network overhead.

E. CONTENTION-BASED BROADCAST PROTOCOLS

Contention-based broadcast protocols adjust the size of Contention Window (CW) according to the packets' priorities. In [39], an emergency-degree-based broadcast protocol (EDCast) is proposed in a typical highway scenario. It presents the concept of emergency-degree(ED) to assess packet's information quantity. The packets with higher ED values are distributed high priorities and a smaller size of CW. The main different between our protocol and EDCast is that we distribute the size of CW according to three key factors: distance, link availability, packet reception probability in the urban environment.

III. THE BP-EMD PROTOCOL DESIGN

As we stated before, the multi-hop broadcasting is the most suitable and effective method for emergent information dissemination in IoV. The key problem is how to select the relay node to rebroadcast or forward the messages for the purpose of guaranteeing the robust and efficient transmission of data packets. The BP-EMD is discussed in the following subsections. In subsection III.A, we put forward the assumption of this paper. In subsection III.B, we define the concept of information utility and establish a link model to estimate the link availability between a sender and a receiver in urban IoV, and the proposed model considers the signal fading, channel contention and movement characteristics. In subsection III.C, we introduce the metric of the relay node. In subsection III.D, combined with the selection of relay nodes, we carry out the overall design of the protocol. In subsection III.E, a toy example is given to illustrate our scheme.

Fig.3 shows the flow diagram of our broadcast scheme. When an accident occurs on a road segment, the source node sends the emergency message to all nearby related vehicles. The emergency message adopts the multi-hop broadcast mode. The source node first selects an optimal relay node and broadcasts the packet, the metric of the optimal relay node is introduced in subsection III.C. We set up an RSU(Roadside Unit) at the intersection to store the emergency message. When the intersection of the RSU received the emergency message, the RSU will broadcast messages at a certain frequency to vehicles at the crossroads. The broadcast process will not end until the packet's TTL expires.

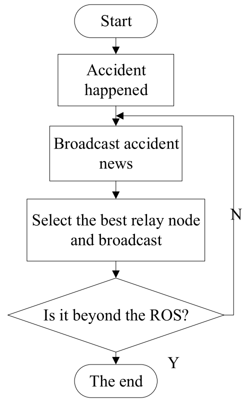

FIGURE 3. The flow diagram of our broadcast scheme.

A. ASSUMPTIONS

- The scenario under consideration consists of road segments with intersections. Each road segment has multi-lanes where vehicles drive in different directions.
- Each vehicle can get its position and speed by the Global Position System. The location of the destination can also be known via the location management system.
- All vehicles can be aware of the information of their neighbors through periodical Hello messages.
- We set up an RSU at the intersection to store and rebroadcast the emergency message.

B. SYSTEM MODEL

1) REGION OF SENSITIVITY

In the actual vehicular networks, the emergency messages are disseminated through multi-hop to warn the vehicles driving towards the place where the emergency happened. Taking a typical urban scenario as an example, as shown in Fig.4, we can notice that an emergency packet is forwarded hop by hop until it covers the whole RoS. Here, we give the definition of RoS as follows:

Definition 1: We can abstract the city map as one directed graph $G(V, E)$ which is composed of road segments and intersections(intersections include crossroads, T-junction and roundabouts). Suppose one accident occurs in position $a(a \in L)$ of road segment L with two intersections M and N. Then the RoS is defined as the zone $S = L \cup M$. RoS indicates that vehicles in this area need to take countermeasures (such as braking, lane changing) to avoid secondary collisions in the event of a traffic accident or blockage and the driver will chooses an alternate driving route to avoid traffic jams in the intersection M.

In the actual scene, when the accident occurs, the emergency messages have a high probability of being broadcast multiple times. Before the accident is handled properly,

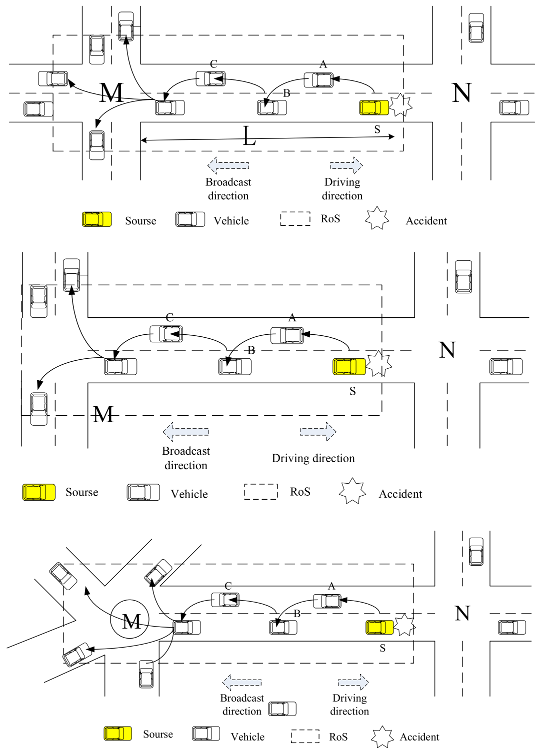

FIGURE 4. Example of RoS.

the emergency message needs to repeat the broadcast in the sensitive area. The vehicles that repeatedly receive the same messages within the road will result in message redundancy. So we set up an RSU at the intersection, the RSU will store the received emergency message, and broadcasts messages at a certain frequency to vehicles at the crossroads. And then these vehicles can change the route to improve travel efficiency. In addition, we give each emergency message packet to set an TTL, when the packet expires, it means the accident has been resolved, the road resumed. Given an emergency packet p, it is generated by vehicle S with the location (x_0, y_0), After broadcasting by vehicle S, packet p is received by vehicle A with current location (x_c, y_c). So as long as the vehicle A is not out of RoS, it should be broadcast continuously. Each packet can be defined by an 4-tuple $\{x_0, y_0, x_c, y_c\}$. For example, once a vehicle receives a packet p, we can say that, during the time, the packet covers a distance by

$$d_c = \sqrt{(x_c - x_0)^2 + (y_c - y_0)^2} \tag{1}$$

when $d_c > d_{RoS}$, we think that the emergency message has been invalid, the road resumed; otherwise continue to broadcast.

2) CHANNEL MODEL

In urban environments, nodes often experience packets loss due to obstruction or signal fading caused by multi-path, reflection or distortion. Many radio channel propagation models have been proposed to model the characteristics of wireless channel. It is demonstrated that the Nakagami-m distribution with parameter m is the most suitable model to describe the fading of radio wave propagation for IoV [40]. Using this model, we can get the successful transmission probability of a packet between the sender v_i and the receiver v_j as follows:

$$\begin{aligned} p_{ij}^f &= 1 - F_d(r_T; m; \Omega) \\ &= e^{-\frac{mr_T}{\Omega}} \sum_{i=1}^{m} \frac{(\frac{m}{\Omega} r_T)^{i-1}}{(i-1)!}, \end{aligned} \tag{2}$$

where $F_d(r_T; m; \Omega)$ represents the Cumulative Distribution Function (CDF) of received signal power. And r_T indicates the reception threshold of a signal, Ω is the average received signal strength at distance d_{ij}. They can be given by:

$$r_T = \frac{p_t}{R^2} G, \quad \Omega = \frac{p_t}{d_{ij}} G, \tag{3}$$

where p_t represent the transmission power, G is a constant value which is equal to $\frac{G_t G_r \lambda^2}{4\pi^2 L}$, G_t and G_r are the antenna gains of the sender and receiver, respectively, λ is the wave-length, L is the pass loss with a value of 1, R is wireless communication range. Note that the fading parameter m [40] is related to d_{ij}:

$$m = \begin{cases} 3, & d_{ij} < 50m \\ 1.5, & 50m \le d_{ij} \le 150m \\ 1, & d_{ij} \ge 150m \end{cases} \tag{4}$$

3) LINK CONNECTIVITY PROBABLITY

In the urban environment, the transmitting node sends the packets with a certain power (which ensures that the receiving node can receive the packet in the case of channel fading). But during the packet transmission the two nodes are not within the communication range of each other, even if the power requirements are met, the receiving node still cannot receive the data packet. So we also need to consider the requirements of connectivity [41]. In this section, we will calculate the probability of connectivity of two nodes during packet transmission [42].

Two nodes can communicate with each other, when the inter-vehicle distance between them is less than the transmission range. Considering the transmission range is much larger than the width of road segments, for simplicity, we can abstract each road as one-dimension. Because the mobility of nodes, the successful transmission of one packet depend on the relative velocity between the sender and its receiver, the transmission time needed for forwarding a packet and the transmission range. A sender select one neighbor as the next hop based on the information extracted from the beacons. However, because of the mobility of the nodes, the information may be outdated. In order to deal with the issue, we propose a new concept named as link availability which is defined as the probability that the link between the sender and the receiver can keep communicating with each other during one specified interval.

Suppose the velocity vector of a node follows the Gaussian distribution [43]:

$$\bar{v_i} \sim N(\mu^i, \sigma^i), \tag{5}$$

where μ^i represents the average velocity, σ^i is the standard deviation of velocity.

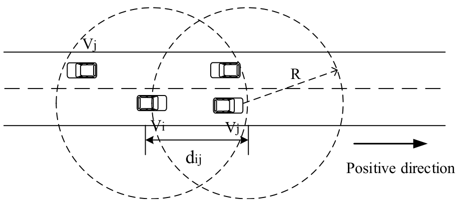

FIGURE 5. Link availability.

In order to estimate link availability, we set the direction of the arrow as a positive direction, as shown in Fig.5. Then, their relative velocity Δv_{ij} between the sender v_i and its receiver v_j also follows the Gaussian distribution:

$$\Delta v_{ij} \sim \begin{cases} N(\mu^i - \mu^j, \sigma^i + \sigma^j), & samedirection \\ N(\mu^i + \mu^j, \sigma^i + \sigma^j), & oppositedirection \end{cases} \tag{6}$$

Denote the time T_e needed for forwarding one packet successfully. The link availability between them can be expressed as follows:

$$\begin{aligned} p_l &= P(0 \leq d_{ij} \pm \Delta v_{ij} \times T_e \leq R) \\ &= \int_{-\frac{d_{ij}}{T_e}}^{\frac{R-d_{ij}}{T_e}} f(\Delta v_{ij}) dv, \end{aligned} \tag{7}$$

where $T_e = \frac{l}{r_d}$, l is the length of the packet, r_d indicates the data transmission rate, and d_{ij} is the initial inter-vehicle distance. Function $f(\Delta v_{ij})$ is the corresponding accumulative distribution function.

4) CHANNEL CONTENTION

The transmitting node satisfies a certain transmission power and the receiving node is within its communication range, the receiving node may not receive the packet. This is because more than one vehicle transmits at the same time slot, resulting in the packet collision, when the transmitting node sends the data packet. So the channel competition should also be considered.

The vehicular networks utilize the contention-based MAC to address the channel contentions. The DCF (Distributed Coordination Function) is applied for the MAC scheduling.

If a vehicle initially has a packet and senses one free channel for its $AIFSN(Arbitration\ Inter\ Frame\ Spacing\ Number) \times t_s$, it will broadcast the packet, otherwise it will select a contention window from $(0 - CW_{min})$, where CW_{min} is the minimum contention window specified in Table 1 for the specified class $AC3$. The process will decrement the back-off counter with probability $(1-p)$, if it senses an idle channel in any time slot; otherwise it will halt the counter for the whole period of the ongoing transmission $T_t = \frac{l}{R_d} + T_{DIFS} + \delta$, where δ is the channel propagation delay, R_d is the data rate and T_{DIFS} is the Distributed Coordination Function Inter Frame Space time. When the back-off timer reaches zero state, the vehicle will broadcast the packet. Fig.6 shows the Markov chain for emergency processes. We assume that the back-off counter will stay at the same state b_i with probability p if it senses a busy channel. The p is displayed by data packets to be transmitted, and independent from other vehicles on the road.

TABLE 1. Simulation parameters.

AC	Access Class	CWmin	CWmax	AIFSN
0	Background Traffic	15	1023	9
1	Best Effort	7	15	6
2	Voice	3	7	3
3	Video	3	7	2

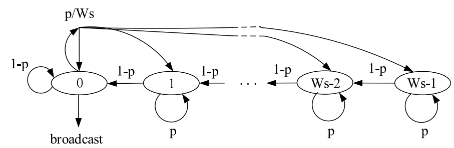

FIGURE 6. Emergency and status packets Markov chain.

From the stationary distribution of the Markov chain in Fig.6, we derive the following relationships: Let b_K denotes the probability that the process is in state (k), then we can solve the discrete Markov chain as follows:

$$b_k = \frac{W_e - k}{W_e} \frac{p}{1-p}, \quad 1 \leq k \leq (W_e - 1), \tag{8}$$

where W_e represents the minimum contention window.

By using equation.8 and the normalized condition $1 = \sum_{k=0}^{W_e-1} b_k$, we can solve b_0 as follows:

$$b_0 = \frac{2(1-p)}{2 - 3p + pW_e} \tag{9}$$

To derive the probability τ_e that a vehicle transmits an emergency packet in a randomly selected slot: First the vehicle has to have an emergency packet ready for transmission. Second, it will transmit this packet only when the back-off counter is in or reaches zero state b_0 with probability of $(1-p)$. Each vehicle generates its messages at a rate denoted by λ_e. The result in [40] shows the probability τ_e that a vehicle transmits a packet in a randomly selected slot is:

$$\tau_e = \frac{2(1-p)^2}{2 + pW_e - 3p} (T_e \lambda_e), \tag{10}$$

where T_e is the length of the time slot.

Then, we calculate channel performance from the tagged transmitting node point of view. Assuming that nodes placed on the path follows a Poisson distribution with network density β. Define p_b as the probability that the tagged node senses channel sensed is busy. When the channel is determined as busy if there is at least one node transmitting in the carrier-sensing range of the tagged node, we can draw the following conclusions:

$$p_b = 1 - \sum_{i=0}^{\infty} (1-\tau_e)^i \frac{(2\beta L_{cs})^i}{i!} e^{-2\beta L_{cs}}, \quad (11)$$

where L_{cs} is the carrier-sensing range. With the number of nodes increases, the probability of collision of packets increases, probability of a packet to access channel successfully will decrease.

Finally, the successful transmission probability ($p_{r_{ij}}$) of a packet between the sender v_i and the receiver v_j under fading model is show as:

$$p_{r_{ij}} = p^f_{r_{ij}} \times p_l \times p_b. \quad (12)$$

In a real scenario, each vehicle maintains the successful transmission probability which is calculated and updated upon receiving a beacon packet from its neighbor.

C. RELAY SELECTION

When one sender broadcasts a warding message, its neighbors will receive the message. In order to avoid the issue of broadcast-storm, only one optimal node is selected as ERN [17]. As the selection guidance of ERN, we propose one novel weighted probability model to assign each neighbor of the sender with one different weight. For dealing with the mobility of nodes, guaranteeing the fast transmission of data packets, the model takes the signal fading, per-hop progress, and link availability into account, which can be expressed as:

$$p_{wp} = \frac{d_{ij}}{R} \times p_{r_{ij}} \quad (13)$$

where p_{wp} represents the weighted probability.

When receiving the emergency message, each receiver judges whether it is ERN by checking ID. If yes, it rebroadcasts the message immediately; otherwise, the receiver is not the ERN, it will set one waiting time to contend for forwarding the warning message. The waiting time can be calculated by:

$$T_w = [NW_{min} + (NW_{max} - NW_{min})(1 - p_{fp})]t_{slot}, \quad (14)$$

where N represents the number of their neighbors, t_{slot} is the number of time slots, CW_{max} and CW_{min} are respectively maximum and minimum sizes of contention window, p_{fp} is its forwarding probability which is given by:

$$p_{fp} = (\frac{\sum_{k=0}^{N} p_{r_{jk}}}{N}) \times \frac{d_{ik}}{R}, \quad (15)$$

where the node k is the neighbor node of j except the ERN.

However, if the receivers receive the message for the second time during the period of waiting, which indicates that relay node has been selected, the node will stop the waiting process.

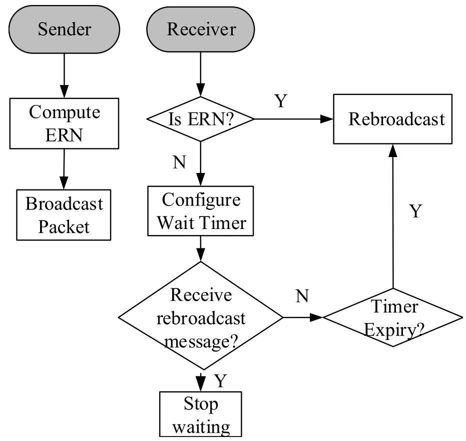

FIGURE 7. **The flow diagram of our proposed broadcast scheme.**

D. PROTOCOL DESIGN

As shown in Fig.7, the details of the protocol are as follows:

step1. The sender calculates the weighted probability p_{wp} of each neighbor node by Equation13 based on the state messages extracted from beacons before broadcasting. Next, the sender selects the node with the maximum value as the ERN and marks its ID at the head of the packet. When receiving the emergency message, each receiver judges whether it is ERN by checking ID. If yes, it rebroadcasts immediately; otherwise, go to Step2.

step2. If the receiver is not the ERN, it estimates the relay forwarding probability p_{fp} by Equation12. The node starts the distributed cooperative forwarding process by configuring different waiting time based on the p_{fp}.

step3. If the receiver receives the message for the second time during the period of waiting, which indicates that the relay node has been selected, the node will stop the waiting process; if the node does not receive the broadcast message again at the end of the waiting time, the node starts forwarding the broadcast message; otherwise, go to Step4.

step4. If there is no vehicle to forward the packet after one specified time, the sender retransmits.

step5. Repeat steps 1-4 until the packet is transferred to the RSU at the intersection, which periodically broadcasts the emergency message to the vehicle around the intersection. Until the packet transmission range exceeds the RoS area or the lifetime expires, the broadcast is stopped. **Algorithm 1** shows the pseudocode of our BP-EMD in Urban IoV.

E. A CASE STUDY

This protocol is further described below in connection with the Fig.8.

In an urban scenario, an accident occurred on a road section, as shown in the Fig.8. When vehicle A finds an accident or congestion in front, it immediately notifies the vehicle behind it of the emergency message. Vehicle A first calculates the weight probability of each neighbor node according to Equation13, and selects the neighbor node with the highest probability as the forwarding node. Here we assume that in

Algorithm 1 A Probabilistic Broadcasting for Emergent Message Dissemination (BP-EMD) in Urban IoV

Notations:

N_i is the neighbor set of the vehicle node v_i in the broadcast direction;

Timer is distributed waiting timer for vehicle;

T_w is the distributed waiting time for vehicle.

```
SENDER v_i:
for each vehicle j in N_i do
    Compute p_wp,
end for
Select the neighbor node corresponding to the maximum
    p_wp as ERN
Broadcast the packet with ID of ERN
RECEIVER v_j in N_i:
if J == ERN then
    Broadcast the packet
else
    Set Timer according to Equation14
end if
if v_j receives a duplicate broadcast packet before Timer
    expires then
    Discard(Timer)
else
    v_j as ERN
end if
```

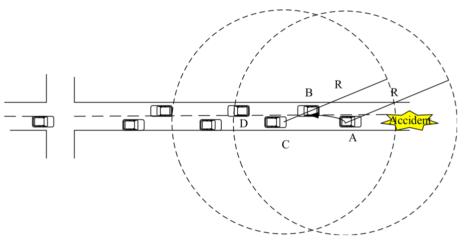

FIGURE 8. A case study of emergency message broadcast.

the neighbor nodes of A, node C has the highest probability of weight, then node C will be the relay node. Vehicle A adds the ID of node C to the header of the packet and forwards the packet. If node C receives the packet, it will immediately repeat above process to select the next expected relay node and then broadcast the emergency message. The other neighbor nodes (assuming B and D are their neighbors) start to calculate the forwarding probability according to Equation15 after receiving the data packet and calculate their own waiting time by the forwarding probability according to Equation14. If the packet is received again before the end of the waiting time, it means that the expected relay node has successfully received and forwarded the packet, and the other nodes will stop the waiting process. If the node B and D do not receive the data packet again, it indicates that the node B did not receive the data packet successfully. Then the nodes B and D continue to wait for the process. The vehicle with the shortest waiting time becomes relay nodes and forward packets. It is

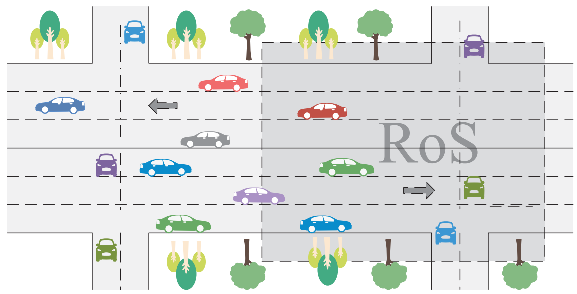

FIGURE 9. The simulation scenario.

assumed that the waiting time of node D is smaller than that of node B. After the waiting time of node D ends, the expected relay node starts to forward the packet. Node B stops the waiting process after receiving the broadcast message again. Repeat the process until the broadcast message reaches the intersection to end the broadcast process.

IV. SIMULATION AND PERFORMANCE ANALYSIS

A. SIMULATION ENVIRONMENT

The MATLAB is used to evaluate the performance of BP-EMD. The simulation scenario is a multi-hop broadcast in the city streets. The topology consists of a bidirectional road and 40m wide with 6 lanes. First, the length of the fixed RoS is set to be 2000 m and contains a crossroads. Multi-hop broadcast is necessary for emergency messages to cover the whole RoS. The initial position of the vehicles is randomly generated in the RoS. The size of the velocity is randomly selected between 8m/s and 16m/s. The multi-hop broadcast starts at the vehicle at one end of the RoS and ends at the other end of the RoS. The communication range of each vehicle is set to be 250m, and carries the omnidirectional antenna with channel bandwidth, the size of the broadcast message is 256kb. The value of simulation parameters are listed in Table 2.

TABLE 2. Simulation parameters.

parameter	parameter value
PHY model	Nakagami-m
MAC model	802.11DCF
Lanes, bidirectional	6
Communication range	250m
RoS length	1.2km 1.4km1.6km 1.8km 2km
Vehicle number	20,40,60,80,100 vehicles/2km
Vehicle velocity	8-16m/s
Status packets rate	5 packets per second
Packet size	256kb
Status packets rate	5packet/s
Status Min. Content window	15
Emergency Max. Content window	7
Emergency Min. Content window	3
The Max. waiting latency	1ms

To evaluate the performance of BP-EMD, We will comparatively study the following protocols under the same configurations as:

- **Optimized by the furthest:** The vehicles that are farther to sender are assigned higher priority to access the channel in terms of less waiting time. In this way, during the procedure of multi-hop broadcast, one-hop forwarding can achieve higher geographical progress and less latency.

- **Optimized by the nearest:** The vehicles that are nearer to sender are assigned higher priority to access the channel. In this way, during the procedure of multi-hop broadcast, one-hop forwarding can achieve higher reliability.

The following metrics are evaluated for comprehensively understanding the benefit of BP-EMD:

- **Packet delivery ratio(PDR):** It is the percentage of the received packet number to the total packets number in the whole RoS, which indicates the reliability of broadcast.
- **Average transmission numbers (ATN):** It is the number of broadcast transmissions in the entire RoS area, including the number of retransmissions.
- **End-to-end average delay(EED):** It is the duration the emergency message experiences from the broadcast source node to the last node at the end of the RoS received, which includes the delay of relaying the broadcast packets on the link and the waiting delay in the distributed decision.
- **Dissemination Efficiency (DE):** It is the average covering speed of one-hop forwarding in multi-hop broadcast.

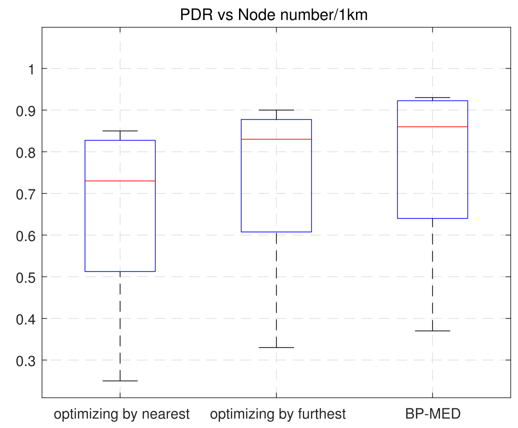

FIGURE 10. **PDR vs. vehicle density.**

B. SIMULATION RESULTS

From Fig.10, when the PDR changes with the vehicle density, the BP-EMD protocol proposed in this paper shows its superiority at the maximum value, minimum value or average value. In the two protocols used for comparison, when setting the priority, the distance between each neighbor node and sender is considered alone. In Optimizing by furthest, the bigger the distance, the higher the priority. The other is that the closer the distance, the higher the priority. This design priority mechanism is too simple. Especially in the second scheme, selecting the nearest neighbor node as the next hop is more likely to cause the network storm and then cause the broadcast process to fail. The BP-EMD protocpl proposed in this paper, because of comprehensive consideration of the communication link and the quality of the transmission node, it always chooses a relatively reliable neighbor node to broadcast emergency messages, to reduce the possibility of unsuccessful transmission. This makes the PDR of the BP-EMD is superior to other two schemes.

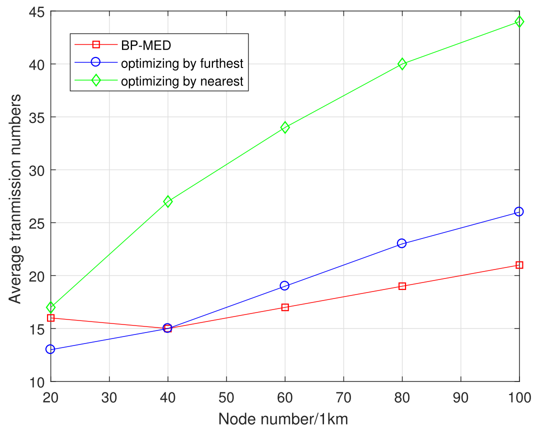

FIGURE 11. **ATN vs. vehicle density.**

Fig.11 shows that the average number of transmissions varies with vehicle density. As the number of vehicles increases, Optimizing by nearest always selects the nearest neighbor node as relay, increasing the number of transmission. Optimizing by furthest always chooses the furthest neighbor node every hop, so its performance is better than Optimizing by nearest. But as the number of neighbor nodes increases the probability of successful reception of farthest neighbor node is reduced due to the influence of channel fading and channel competition, resulting in an increase in the number of retransmissions. The BP-EMD proposed in this paper is the balance of the propagation distance and the reception rate, so the performance is superior to other strategies. When the density of the vehicle is relatively low on the road, the number of retransmissions is higher because it's difficult to find the next hop node during the transmission process; as the vehicle density increases, the average number of transmission will be slightly increased because the channel competition occupies the dominant factor; when the vehicle density is $40veh/1km$, the number of transmissions obtains the minimum value.

Fig.12 shows the number of broadcast transmissions with the length of RoS. As the length of the RoS increases, more broadcast relays are needed to cover broadcasts in the streets, so the number of broadcast transmissions for all three broadcast strategies increases. Optimizing by furthest sacrifices latency to wait for the furthest node to relay broadcast, it has the lowest number of broadcasts. Optimizing by nearest always selects the nearest neighbor node as relay, increasing the number of transmission. BP-EMD is the balance of the

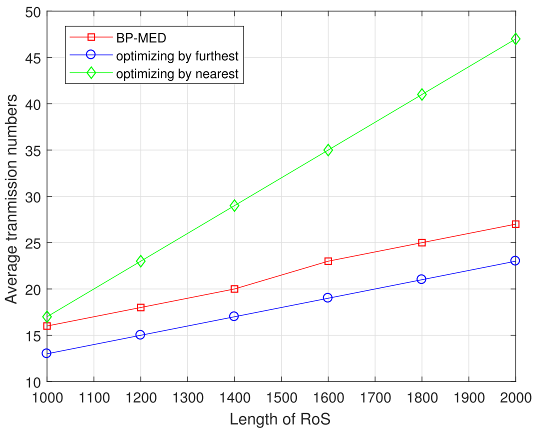

FIGURE 12. ATN vs. the length of RoS.

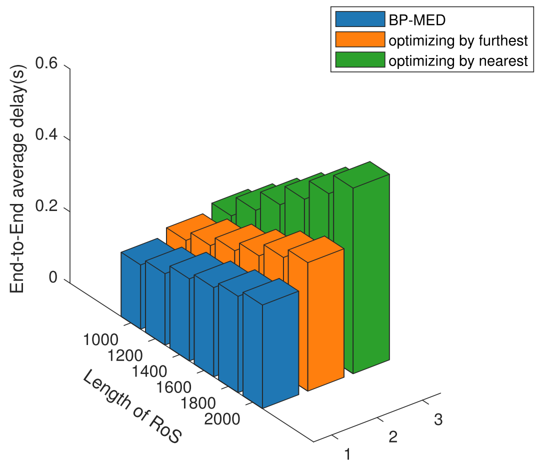

FIGURE 14. EED vs. the length of RoS.

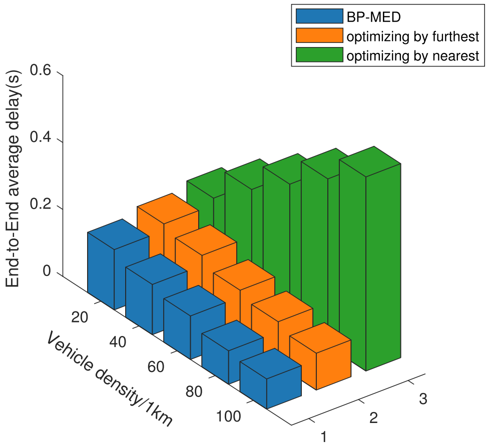

FIGURE 13. EED vs. vehicle density.

one-hop transmission distance and number of transmissions, so performance is better than optimizing by nearest.

In order to illustrate the influence of the size of RoS on the performance of multi-hop broadcast, we will observe the change of the average End-to-End delay by fixing the vehicle density to $20veh/km$ and changing the length of the RoS from $1200m$ to $2000m$. Fig.13 shows that the average End-to-End delay varies with vehicle density. As the number of vehicles increases, the Optimizing by nearest always selects the nearest neighbor node as relay, making much more nodes join the forwarding process, thus increasing the average End-to-End delay. The Optimizing by furthest always chooses the furthest neighbor node every hop, so its performance is better than Optimizing by nearest. BP-EMD proposed in this paper select the best node, which is the balance of the propagation distance and the reception rate, so the performance is superior to other strategies.

Fig.14 shows the multi-hop broadcast delay with different length of the RoS. As the length of the RoS increases, the average End-to-End delays of all protocols are going up. Since the Optimizing by nearest always chooses the nearest neighbor node every hop, with the increase of the vehicles which joining in the forwarding process, the delay get higher. Although Optimizing by furthest always chooses the furthest neighbor node as relay, the furthest node will not receive the broadcast message because of the poor link quality. This will make the active selection of the relay node meaningless, so its delay is higher than the BP-EMD. The delay performance of BP-EMD is better than the other strategies because the balanced propagation coverage and packet reception rate are considered in each broadcast transmission process.

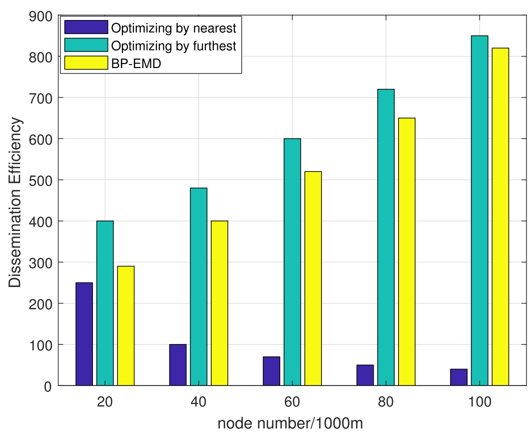

FIGURE 15. Dissemination efficiency vs. vehicle density.

Fig.15 shows the multi-hop broadcast dissemination efficiency with vehicle density. With the increase of vehicle nodes, the broadcasting dissemination efficiency of Optimizing by furthest and BP-EMD is on the rise. Due to Optimizing by nearest always selects the nearest neighbors with low diffusion efficiency, the efficiency of broadcast diffusion declines gradually. Optimizing by furthest tends to choose the furthest neighbor to relay message, it has a higher dissemination efficiency. Due to the delay, BP-EMD sometimes choose the more reliable neighbors as expect rebroadcast nodes, sacrificing part of the transmission times to increase the

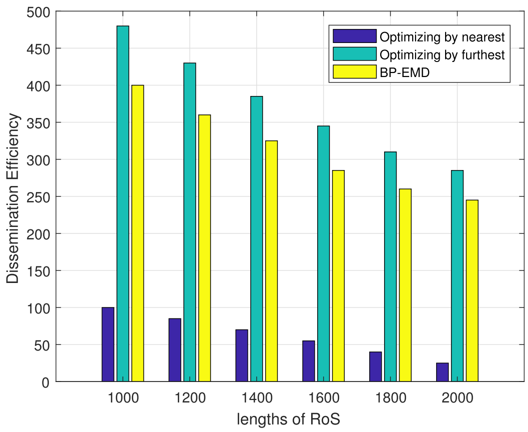

FIGURE 16. **Dissemination efficiency vs. lengths of RoS.**

delay, and its broadcast dissemination efficiency approaches Optimizing by furthest.

Fig.16 shows the multi-hop broadcast dissemination efficiency with lengths of RoS. As the length of the RoS increases, the broadcasting dissemination efficiency of the three strategies shows a downward trend. Optimizing by furthest has higher diffusion efficiency because of fewer transmission times. The BP-EMD proposed in this paper is the balance of the propagation distance and the reception rate, it will increase additional transmission times, so its dissemination efficiency worse than the Optimizing by furthest almost.

V. CONCLUSION

In this paper, we propose a probabilistic broadcasting for emergent message dissemination (BP-EMD) in Urban IoV. First, we define a RoS to prevent infinite diffusion of messages. This is to save network overhead. As the selection guidance of ERN, the node with the greatest weighted probability has the highest priority to relay the packet and other nodes will assist in disseminating the packet if specified relay node rebroadcast unsuccessfully. By this way, the reliability and efficiency of emergency messages transmission can be guaranteed. Simulation results indicate that BP-EMD obtains a substantial improvement on latency and emergency packet delivery ratio. In the future, we will achieve better broadcast performance in the case of low node density.

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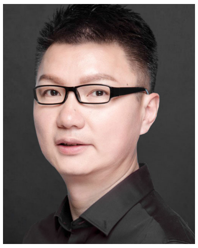

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