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A V2V Emergent Message Dissemination Scheme for 6G-Oriented Vehicular Networks

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Abstract — To ensure traffic safety and improve traffic efficiency, vehicular networks come up with multiple types of messages for safety and efficiency applications. In sixth-generation (6G) systems, these messages should be timely and error-free disseminated through vehicle-to-vehicle (V2V) communication to ensure traffic safety and efficiency. V2V supports direct communication between two vehicle user equipments, regardless of whether a base station is involved. We propose a packet delivery ratio (PDR)-based message dissemination scheme (PDR-MD) between V2V in 6G-oriented vehicular networks to select relay vehicles when broadcasting emergent messages. This scheme grasps the balance between vehicle distance and PDR so as to reduce transmission delay while ensuring reliable PDR. We compared the PDR-MD scheme with other probabilistic broadcasting schemes. The experimental results show that the PDR-MD protocol can maintain close to 95% and above PDR in transmitting emergent messages, and the transfer rate stays below 40%.

Key words — Internet of vehicles, 6G, Vehicle-to-vehicle (V2V) communication, Data dissemination.

I. Introduction

Intelligent transportation systems (ITS) [1] combine vehicles and various traffic participants to address the traffic safety and efficiency problems in traditional transportation. Especially in urban road traffic, after an emergent accident, the current vehicle must ensure rapid and accurate dissemination of emergent messages to vehicles in the region of sensitivity, in order to avoid secondary accidents and traffic congestion, and provide emergent assistance. Therefore, using the characteristics of cellular vehicle to everything (V2X), it is also a hot topic to design a low latency and high reliability based emergent message dissemination method considering the channel and vehicle movement characteristics.

Vehicle-to-vehicle (V2V) [2]–[4] communication is the core technology for the emergent messaging dissemination method. There are two main wireless communication methods for V2X; one is cellular V2X (C-V2X) proposed by 3rd Generation Partnership Project (3GPP) and the other is 802.11p proposed by the Institute of Electrical and Electronics Engineers (IEEE). Under the active promotion of 3GPP, C-V2X has become the current mainstream technology. Especially in release 14, it is proposed that vehicles can directly use Long-Term Evolution V2X (LTE-V2X) sidelink (SL) for data transmission without passing through a base station (BS), which further robust the development of C-V2X. With the rapid development of 5th generation mobile communication technology (5G) [5]–[8], release 16 also enhances new radio (NR) to support ultra-reliable low latency communication (URLLC) for C-V2X. NR-V2X supports not only broadcast technology but also multicast technology. Flexible numerology, modulation and coding scheme (MCS) , and hybrid automatic repeat request (HARQ) is also a feature of NR-V2X.

With the development of ITS, more and more autonomous vehicles are replacing today's manually

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driven vehicles. The access of a large number of vehicles, roadside units (RSU), and cloud central with network connection capability brings a significant challenge to the communication capability of the network [9]. Although 5G NR-V2X has largely met the need for low latency and high reliability for emergent messaging dissemination, it cannot meet the massive wireless access. In 6G [10], [11] architecture, the ground network is combined with air network to build a more reliable, safer and smarter ubiquitous network. In the 6G-V2X environment, V2V can be used for the ground-based network in the space-air-ground integrated network (SAGIN) [12] in the mmWave/THz frequency band. With the capability of 6G, super reliable communication of emergent messages can be guaranteed with ultra-low power consumption, extremely small latency and full sensor connectivity. In order to realize effective communication and ensure traffic safety, the vehicular network uses two types of security-related message formats: cooperative awareness message (CAM) [13] and distributed environment notification message (DENM) [14]. The periodically sent CAM contains information related to cooperation perception, such as vehicle location, attributes, and speed. On the other hand, DENM is an event-trigger message, which carries all event information and is mainly used to inform related stations of safety-related events detected, such as sudden braking, wrong driving, road work, etc.

In designing the packet dissemination scheme oriented 6G, transmission efficiency and quality should be considered. In terms of transmission efficiency, some studies select the farthest node to relay the message when transmitting emergent information [15], leading to a multi-hop broadcast interruption in the sparse scenario. There are also some studies that select relay nodes with a certain probability [16], which will also bring broadcast storms and cause transmission collisions in the environment with dense vehicles. In terms of transmission quality, the transmission protocol proposed by [17] analyzing the influence of co-channel and adjacent channels. Few transmission protocols have considered the packet delivery ratio (PDR) influenced by electromagnetic wave propagation conditions and interference on packet transmission, including the influence of path loss on signal transmission power, multipath fading on packet acceptance rate, packet conflict during transmission, and the transmission of hidden nodes.

To solve the above-mentioned problem, this paper proposed a packet deliver ratio-based message dissemination scheme (PDR-MD) oriented 6G in the urban area. In the scheme, when selecting the relay node, the vehicle obtains the information of the current vehicle and surrounding vehicles through CAM message and then selects the vehicle with advantages PDR as the next hop through calculation. To avoid the unrestricted geographical spread of messages, the maximum number of forwarding messages and regions of sensitivity is set. The algorithm flow chart is shown in Fig.1.

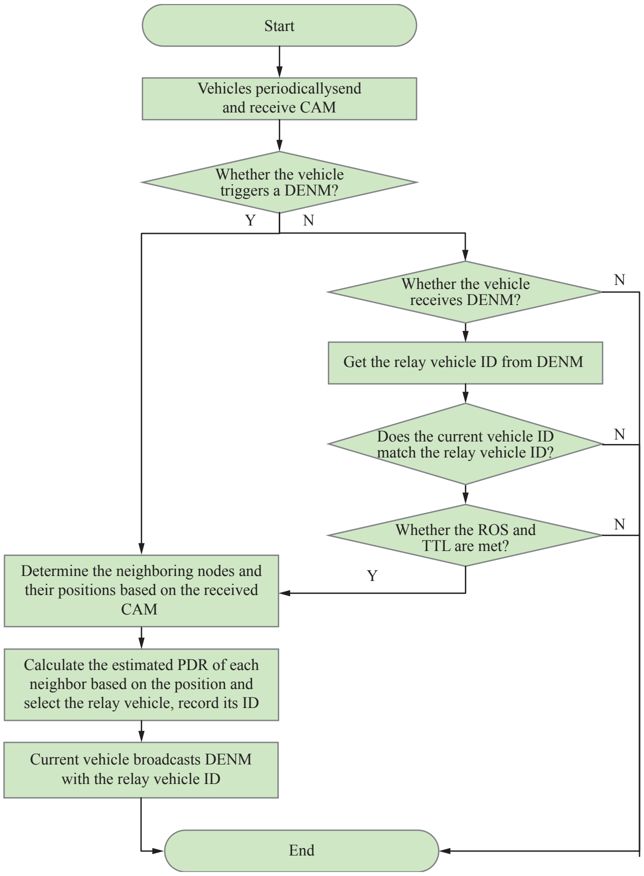

Fig. 1. Proposed Algorithm flowchart.

According to the above analysis, the main contributions of our paper focus on:

1) Taking the channel model in mmWave/subThz (90–450 GHz) [18] into consideration, we proposed a PDR-based message dissemination algorithm oriented 6G to select the relay node. Considering the distance between vehicle nodes and vehicle density, the calculated PDR and the distance between Tx-Rx are balanced to select a relay node within the current vehicle's transmission range. By simulation, it is clear our algorithm has advantages in PDR and transmits ratio;

2) In order to simulate the process of driving a real Internet-connected vehicles, instead of using the global vehicles position information, we obtain the latest CAM message from the local dynamic map (LDM) [19], and use the vehicle's position decoded from CAM to calculate the distance between vehicle nodes;

3) Set the time to live (TTL) and range of sensitivity (ROS) to ensure the packet only transmitted to related vehicles and reduced unnecessary resource waste.

The remainder of the paper is organized as follows.

Section II introduces the related work, and Section III summarizes the protocol design process. Section IV evaluates the performance of the proposed scheme. Section V gives the summary.

II. Related Works

In this section, we will present the existing research on 6G V2X and some V2V broadcast mechanisms in NR V2X, LTE V2X and 802.11p.

Research on 6G V2X is still in its infancy, few studies have proposed V2X communication schemes, and most still focus on channel modeling, interference analysis, and beam formation. Tultul *et al.* [18] developed a theoretical channel model of device-to-device (D2D) communication at terahertz, which mathematically models data rate, outage probability and energy efficiency, experimentally confirming that end-to-end data rate and energy efficiency are greatly improved and termination probability is reduced at terahertz. Morandi *et al.* [20] propose a 6G-based beam selection scheme against 5G V2V communication, derive a vehicle mobility model by analyzing the road topology, and finally construct a probabilistic codebook (PCB) with a preferred beam based. The experimental results show that the model overcomes the environment dependence of the conventional method and reduces the beam selection time by 67% on average. Petrov *et al.* [21] analyzed interference from side lanes in a combination of measurement, simulation, and analysis methods for highway and urban road scenarios in order to explore the communication performance of mmWave and subterahertz. The focus is on the consideration of multipath interference and interference from vehicles traveling in neighboring lanes to the current vehicle. Experimental results show that interference from the side lane can be fitted to a two-bit random model and the interference significantly impacts the performance of V2V communication systems. Based on the 6G V2V channel, Huang *et al.* [22] propose a massive multiple-input multiple-output (MIMO) millimeter wave (mmWave) geometry-based stochastic model (GBSM). Based on the vehicle density and mobility characteristics, static vehicle clusters and dynamic vehicle clusters are proposed, and the spatio-temporal-frequency non-smoothness of V2V channels are simulated successively. Finally, the effects of vehicle density and trajectory on the statistical properties of the channel are jointly modeled.

Currently, there are few V2V message dissemination methods for 6G communications. However, V2V message dissemination for 5G, 4G and 802.11p has been extensively studied. Some researches in packet transmission based on 5G-NR are in [23]–[27], which all use the side-link of the new 5G NR interface for emergent message broadcasting, further compensating for the safety limitations of in-vehicle sensors. In [28]–[32], many data dissemination schemes in LTE are proposed. Among them, hidden terminals, path loss, and other factors are also taken into account and used to ensure fast and stable dissemination of emergent messages. In [33]–[35], based on 802.11p, researchers used dedicated short-range communications (DSRC) for secure messaging. Unlike 5G and LIE, DSRC uses a WIFI architecture rather than a cellular network architecture for communication.

The main purpose of routing protocols is to minimize communication time and network resources in message transmission. Mohammed *et al.* [36] proposed a data dissemination algorithm based on clustering and avoids a broadcast storm. The algorithm relies on the V2V connection in multi-hop broadcast and achieves a reliable signal-to-noise ratio (SNR). Ullah *et al.* [37] avoided the data dissemination overhead by estimating the link stability and proposed a reduced broadcast overhead scheme for emergency message dissemination (RBO-EM). In RBO-EM, the message reliability can maintain an ideal value in high mobility scenes. Laha *et al.* [38] proposed a local centrality-based dissemination scheme to select the super-spreader nodes in V2V communication. Vehicles obtain the neighbor vehicles' information within the tow-hop and choose the better one to relay messages. Liu *et al.* [39] proposed a novel temporary warning network (TWN) to solve the problem of transmitting an emergent message in an urban environment. In TWN, the vehicle trajectory in spatiotemporal is obtained to choose the relay node. In [40], a new method based on counting and probability (CAPP) is proposed for different network densities.

Based on the 6G channel model and interference analysis, we combine the cellular V2X resource sensing and selection process to estimate the PDR of each neighboring node. Using the estimated PDR of the neighboring nodes, we proposed a 6G-oriented emergency message dissemination scheme to select the appropriate node for message relaying, thus reducing resource waste and improving transmission ratio.

III. Routing Design

1. Resource allocation in C-V2X

C-V2X generally adopts the sensed semi-persistent scheduling (S-SPS) mechanism for resource allocation. In V2V communication, this process is usually performed autonomously by the vehicles without the involvement of the BS [41].

As shown in Fig.2, before transmitting data, vehicles will sense the transmission channel to avoid using busy resources. The one-stage channel state information (CSI) [42] is used to indicate the channel status, which is transmitted on the physical sidelink control channel (PSCCH). The CSI records which resources have been reserved and cannot be used for data transmission. The sensing window is generally 1000 ms, within the sensing window, the UE will continuously measure the reference signal receiving power (RSRP) of the channel. If the RSRP is higher than the threshold, it means that if transmitting data in this channel encounters strong interference, these resources will not be used as candidate resources. RSRP can also set different values according to the priority of the transmission service, further indicating that the high-priority service can use the channel first. Since the vehicle specifies which resources can be used for the next data transmission during the resource-sensing process. In the next resource selection window, the vehicle selects the appropriate resource to transmit data. If the ratio of resources in the selection window relative to the total resources is below a certain value, the reference signal receiving power can be readjusted.

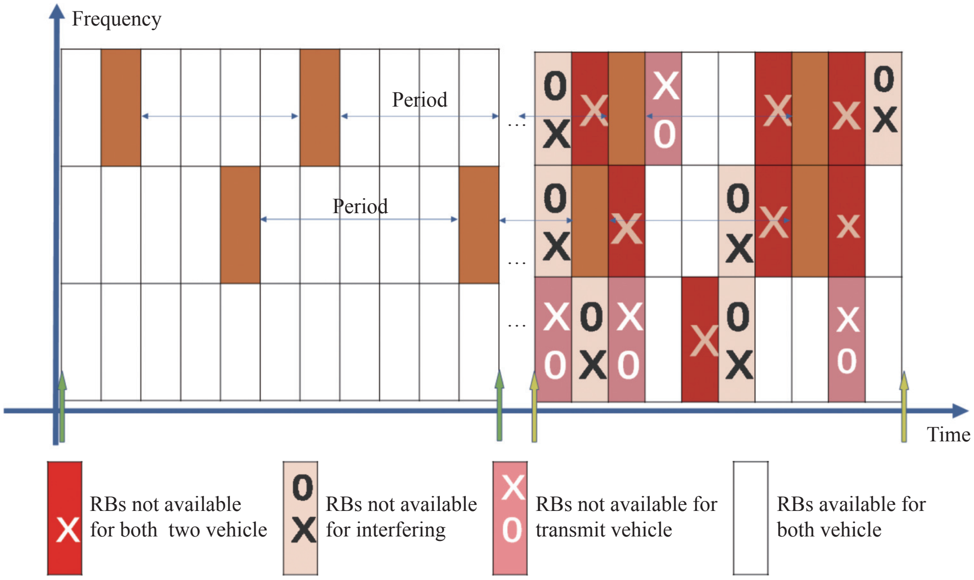

Fig. 2. C-V2X resource allocation (RBs: resource blocks)

2. Analytical models

In studying the packet transmission problem, we abstract the vehicles in the scenario as an undirected graph in two dimensions, donated by $G=(V,A)$, where V denotes the set of vehicles, $V=\{v_1,v_2,\dots,v_n\}$, n is the number of vehicle nodes. A presents the linkage between vehicle nodes, and $A=\{a_{i,j}|i=1,2,\dots,n, j=1,2,\dots,n\}$, among $a_{i,j}=0$ or 1, $a_{i,j}=1$ means vehicles can precept each other and can communicate with each other, $a_{i,j}=0$ means vehicle nodes are hidden node to each other. Among V, we use v_t to represent transmission vehicles, v_r as receivers, v_s as the other vehicles, v_i as the hidden nodes, and v_j as the interference.

To model the probability that v_r does not correctly receive an emergent message from v_t, we consider four perspectives. 1) The probability of the packet can not be correctly decoded because the received signal power is below a threshold. 2) The probability that the packet can not be correctly adjudicated because the received signal-to-noise ratio is too low. 3) The probability of packet collision because the same channel resource is selected by v_t for transmission with the interferences. 4) The probability of half-duplex transmission, which causes the receiver to be unable to receive data. In order to describe the modeling process more clearly, Table 1 lists the meaning of each symbol appearing in the text, and Fig.3 shows the process of computing the estimated PDR. The probability of receiving node successfully getting the emergent information from the packet is expressed as follows [43]:

$$\begin{aligned}\mathrm{PDR}\left(d_{t,r}\right)=&\left(1-p_p\left(d_{t,r}\right)\right)\cdot\left(1-p_s\left(d_{t,r}\right)\right)\\&\cdot\left(1-p_c\left(d_{t,r}\right)\right)\cdot\left(1-p_h\left(d_{t,r}\right)\right)\end{aligned}\tag{1}$$

where

$$0\le p_p,p_s,p_c,p_h\le 1\tag{2}$$

and

$$0\le \mathrm{PDR}\le 1\tag{3}$$

Formulas (2) and (3) indicate that the probability of the above four transmission types and successful reception and decoding packets is between 0 and 1. $d_{t,r}$ is

Table 1. Summary of notations

Notation	Definition
p_p	The probability of packet error due to the receiving power lower than power threshold
p_s	The probability of packet error due to a low SNR
p_c	The probability of packet error due to packet collision
p_h	The probability of packet error due to a half-duplex
v_t	Transmission vehicles
v_r	Receiving vehicles
v_s	Others vehicles
v_j	Interference vehicles
v_i	Hidden vehicle
P_T	Power threshold
P_r	Receiving signal power
PL	Passloss
$d_{t,r}$	The distance between v_t to v_r
P_t	Transmission signal power
m	The number of RBs
PSR	Packet sensing ratio
$p^i_{c,ht}$	p_c of hidden vehicles
$p^j_{c,ct}$	p_c of interference vehicles
p_{int}	The probability of v_s' SINR is too high to prevent v_r correctly receiving the packet from v_t
$p_{ht,sim}$	The probability of v_i using the same resources with v_t to transmit packets
$p_{ct,sim}$	The probability of v_j using the same resources with v_t to transmit packets
I_s	Interference from v_s
RB_o	RBs available for both v_s and v_t
RB_a	RBs available for v_t
T_w	Resource select window
N_{sb}	Number of subchannels
R	Communication range
p_{det}	The probability of v_j can correct detect the reservation resources
p_{st}	The probability of v_s and v_t choose the same resource for transmission
p_{osr}	Resources overlap sensing ratio
$N_{\max}$	The max number of resources for one transmission
τ	Packet freequency

the distance between the transmission node v_t and the receiving node v_r.

1) In equation (1), if the transmission power P_t from v_t is too low or the channel condition is terribly worse, the packet receiving power may be too low to be decoded by the receiver. We define p_p as the probability of packets transmission errors and decoding errors caused by the receiving power being lower than the power threshold, it can be expressed as

$$p_p\left(d_{t,r}\right) = \int_{-\infty}^{P_T} f_{P_r,d_{t,r}}(p)\mathrm{d}p = \frac{1}{2}\left(1 - \operatorname{erf}\left(\frac{P_t - PL\left(d_{t,r}\right) - P_T}{\sigma\sqrt{2}}\right)\right) \quad (4)$$

where $f_{P_r,d_{t,r}}(p)$ is the probability density function (PDF) of P_r, considering the urban environment and antenna height under subTHz, the $PL\left(d_{t,r}\right) = 40\log_{10}(d[\mathrm{km}]) + 30\log_{10}(f_c[\mathrm{MHz}]) + 49$ [10] is the D2D non-line-of-sight (NLOS) path loss from v_t to v_r under f_c channel frequency, σ is the variance of the shadow, which follows a lognormal random distribution with a mean of 0, erf is the error function, P_t is the power threshold. We define $PSR = 1 - p_p\left(d_{t,r}\right)$ as packet sensing ratio.

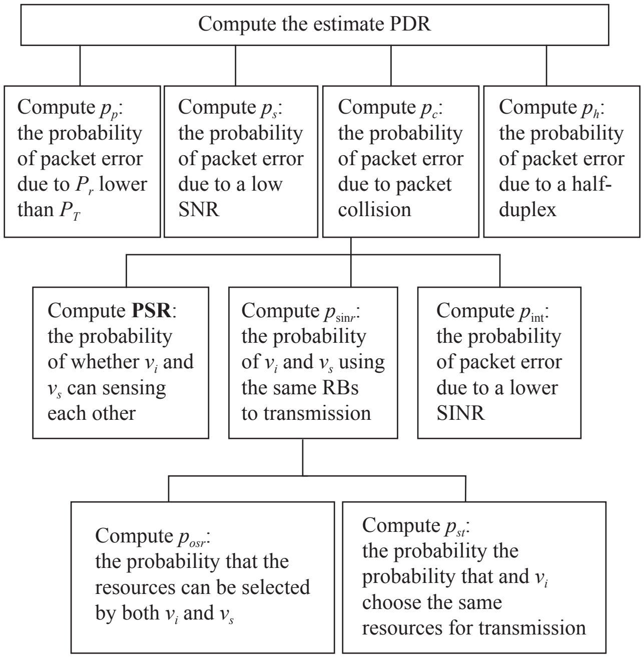

Fig. 3. Process of computing estimate PDR.

2) If the packet with sufficient receiving signal power, the packet may still not be correctly received due to the propagation effect. Especially a flexible MCS will bring out more influencing factors even though 6G advocates an ultra-low block error rate (BLER). The probability of decoding errors due to the low SNR of data packets is p_s in equation (5). The main reason for this is the attenuation in the physical layer, which leads to a high BLER.

$$p_s\left(d_{t,r}\right) = \sum_{s=-\infty}^{+\infty} BLER(s) \cdot f_{\mathrm{SNR}|P_r>P_T,d_{t,r}}(s) = \begin{cases} \displaystyle\sum_{s=-\infty}^{+\infty} BLER(s)\frac{f_{\mathrm{SNR},d_{t,r}}(s)}{1-p_p}, & \text{if } P_r>P_T \\ 0, & \text{if } P_r\le P_T \end{cases} \quad (5)$$

where

$$\mathrm{SNR}(d_{t,r}) = \frac{P_r}{m \cdot PL(d_{t,r}) \cdot N} \quad (6)$$

In (5), $BLER(s)$ is the BLER under SNR$=s$, $f_{\mathrm{SNR}|P_r>P_T,d_{t,r}}(s)$ is the PDF of SNR where $P_r > P_T$. Since both p_s and p_p are generated by channel interference in the physical layer, we ignore the influence of equation (4) in the above probability. We only consider the p_s when $p_r > p_T$, and it is normalized by $1-p_p$. Also, we compute the SNR under subThz. In considering the factors affecting SNR, we take into account the effect of additive Gaussian white noise N and pass loss $PL(d_{t,r})$ from v_t to v_r on m resources block.

3) After sensing the channel resource, the vehicle will exclude the reserved resources and choose the RBs in the remaining resources to transmit the emergent messages. In this way, v_t and interference v_s may use the same RBs to transmit packets at the same time. The resulting interface may lead to an error decoding in v_t because the receiving SNIR is below the sensing threshold. The probability of this situation is p_c:

$$p_c\left(d_{t,r}\right) = 1 - \prod_s \left(1 - p_c^s\left(d_{t,r}, d_{t,s}, d_{s,r}\right)\right) \tag{7}$$

where

$$\begin{aligned} p_c^s\left(d_{t,r}, d_{t,s}, d_{s,r}\right) = {} & p_{c,ht}^i\left(d_{t,r}, d_{t,i}, d_{i,r}\right) \\ & + p_{c,ct}^j\left(d_{t,r}, d_{t,j}, d_{j,r}\right) \end{aligned} \tag{8}$$

Packet collision may be due to interference nodes or hidden nodes choosing the same RBs as v_t for transmitting, so we take the interference in Fig.4 and hidden nodes in Fig.5 into consideration in this case.

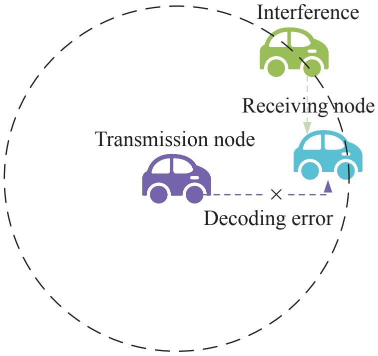

Fig. 4. Transmission node and interference node transmit message in the same RBs.

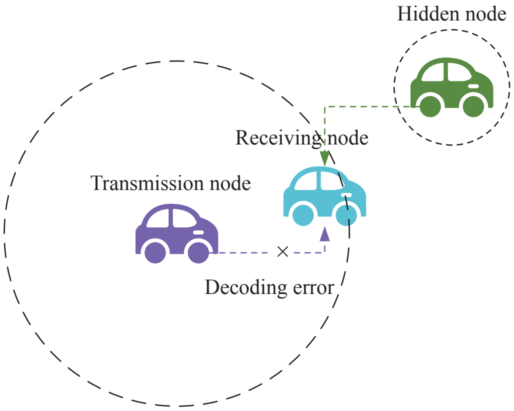

Fig. 5. Transmission node and hidden node transmit message in the same RBs.

In (8), $p_{c,ht}^i$ is the probability of packet loss due to collisions by hidden nodes, $p_{c,ct}^j$ is the probability that due to v_t and v_j sending packet at the same RBs, i.e.,

$$\begin{aligned} p_{c,ht}^i\left(d_{t,r}, d_{t,i}, d_{i,r}\right) = {} & \left(1 - PSR(d_{i,t})\right) \\ & \cdot p_{int}(d_{t,r}, d_{i,r}) \cdot p_{ht,sim}(d_{t,i}) \end{aligned} \tag{9}$$

$$\begin{aligned} p_{c,ct}^j\left(d_{t,r}, d_{t,j}, d_{j,r}\right) = {} & PSR(d_{j,t}) \\ & \cdot p_{int}(d_{t,r}, d_{j,r}) \cdot p_{ct,sim}(d_{t,j}) \end{aligned} \tag{10}$$

As mentioned above, PSR indicates whether v_i, v_j, and v_t can sense each other, that is, to determine whether each is a hidden node. In addition, $p_{c,ht}$ and $p_{c,ct}$ are also related to whether the same RBs are used to transmit the emergent messages by interference vehicle and transport vehicle. p_{int} is the probability of whether the signal-to-interference and noise ratio (SINR) of packets sent by the interference vehicle is large enough at the receiving vehicle to prevent packets from the transport vehicle from being successfully received.

i) The probability of the SINR below the SINR threshed:

In order to calculate p_{int}, we first calculate the *SINR* at the receiver based on subThz. The SINR is influenced by the interference $I_s = p_s/PL(d_s, r)$ of v_s, the Gaussian white noise N and the pass loss $PL(d_{t,r})$ from v_t to v_r and the signal power p_t in m resource blocks:

$$SINR(d_{t,r}, d_{s,t}) = \frac{p_t/PL(t,r)}{m \cdot (I_s + N)} \tag{11}$$

It can be seen that SINR is related to the interference signal power and transmission signal power, we can calculate the probability of not receiving the packet correctly at the receiving vehicle due to the low SINR brought by interference as

$$\begin{aligned} p_{int}\left(d_{t,r}, d_{s,r}\right) = {} & \frac{\sum\limits_{s=-\infty}^{+\infty} BLER(s) \cdot f_{SINR|P_r > P_T}}{1 - p_s(d_{t,r})} \\ & - \frac{p_s(d_{t,r})}{1 - p_s(d_{t,r})} \end{aligned} \tag{12}$$

In (12), $BLER(s)$ is the $BLER$ under $SINR = s$. $f_{SINR|P_r > P_T}$ is the PDF of $SINR$ where $P_r > P_T$. There is no doubt that p_{int} is also related to $d_{s,r}$ and $d_{t,r}$. Considering that the low $SINR$ is not only brought about by interference vehicles, a situation already calculated in (5), we also eliminate this probability.

ii) The probability of v_s and v_t transmit the data in the same RBs:

Because C-V2X uses distributed resource allocation scheme, the channel is sensed before resource selection, and the appropriate sensed-free resources are selected for data transmission. Therefore, we analyzed the similarity between the interference vehicles and the transmitting vehicles in two processes, resource sensing and resource selection, respectively.

iii) After resource sensing, v_s and v_t obtained the select-able resources from SCI passing through PSCCH, we define the probability that the resources can be selected by both v_t and v_i as overlap sensing ratio p_{osr}:

$$p_{osr}(d_{t,s}) = \frac{RB_o}{RB_a} = 1-\left(1-\frac{RB_a}{(T_w)\cdot N_{sb}}\right)\cdot \min(1, \frac{d_{t,s}}{2R}) \tag{13}$$

where p_{osr} represents the percentage of the same resources available to v_s ans v_t in the total resources available to v_t. RB_o is the resources can be selected by both v_s and v_t, RB_a is the resources can be selected by v_t. p_{osr} is closely related to the distance between two vehicles, the closer the vehicles are to each other, the higher the probability of sensing the same resource. When the distance between two vehicles is far enough, it can be assumed that the perceptions of the two vehicles do not interfere with each other, which is also related to the transmission range R. N_{sb} donates the subchannel number for SL. T_w represents the resource select window for transmission.

iv) The probability of packet collision due to v_t and v_i select the same resource to transmit data:

When studying resource allocation and collision, we also discuss the effects brought by interference and hidden vehicles separately. Hidden vehicles refer to those who cannot perceive each other's presence with v_t, so v_t cannot obtain the resource occupation of hidden nodes. When hidden nodes and v_t send messages to v_r at the same time, packet collision can easily occur. For interference nodes, it can generally perceive the resource occupation with v_t. However, since there is an empty window between the end of resource sensing and the start of data transmission, the resource occupancy in this window cannot be accurately evaluated, resulting in a possible packet collision.

For interference, the probability of packet collision depends on the probability that v_i can correctly detect the reservation resource p_{det} [43], the resource sensing similarity p_{osr}, and the probability that v_t and v_i choose the same resource for transmission P_{st}:

$$p_{ct,sim}(d_{t,j}) = (1-p_{det})\cdot p_{osr}(d_{t,j})\cdot P_{st} \tag{14}$$

For the hidden nodes, since they cannot sense each other's presence with v_t, we assume that they cannot correctly sense v_t's resource occupation at all. Therefore, the packet collision probability of the hidden node is $p_{ht,sim}$:

$$p_{ht,sim}(d_{t,i}) = p_{osr}(d_{t,i})\cdot P_{st} \tag{15}$$

The probability that a vehicle selects the same resource for transmission is p_{st}, where $N_{\max}$ is the maximum transmission resource RBs used for one transmission and $N_{\max}-1$ is the maximum resource available for re-transmission.

$$P_{st} = 1-\frac{\binom{RB_a-1}{N_{\max}}}{\binom{RB_a}{N_{\max}}} \tag{16}$$

4) V2V devices generally use half-duplex (HD) mode when transmitting data, and vehicles can only receive or transmit data at the same moment, but not transmit and receive data at the same time. Therefore, when the v_t transmits an emergent message while v_r is also sending packets in the same subframe, v_r will not receive the emergent message. The probability of this situation is p_h:

$$p_h = \tau\cdot\frac{1}{T_{subfram}} = \frac{\tau}{1000} \tag{17}$$

where τ is the packet frequency, $T_{subfram}$ means the subframe time equals to 1 ms, 1000 means a second can be divided into 1000 subframes.

3. Protocol design

In the PDR-MD algorithm, we need to obtain the position of neighbor vehicles from the received CAM message, select the relay vehicle according to equation (1) and record the vehicleID first. Second, vehicles check the vehicleID on receiving the DENM, if the vehicleID matches, broadcast the packet. Third, if all nodes within the message transmission range have already relayed DENM, it will check if the receiver's neighbors' acceptance rate is below 3%. If so, the data packets will be broadcast by the receiver as is shown in Figs.6 and 7. The detailed algorithm is shown in Algorithm 1.

Algorithm 1 PDR-Based DENM dissemination (PDR-DenD) scheme

```
Data: transmitter vehicle $v_t$
neighbors of $v_t$:$V_i$
neighbors of $v_t$ who received but not delayed DENM: $V_{id}$
neighbors of $v_t$ who received DENM: $V_{ir}$
neighbors of $v_t$ who not received DENM: $V_{in}$
distance threshold $D_{THR}$
Result: $v_n$ as relay node or $V_B$
1: transmitter vehicles $v_t$
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```
while $TTL > 0$ and $v_t$ in $ROS$ do
    if $V_{id}$ != NULL then
        for $v_r$ in $V_{id}$ do
            compute $d_{tr}$
        end
        if $d_{tr} <= D_{THR}$ then
            $v_n = v_r|\mathrm{MAX}(d_{tr})$;
        end
        else
            $v_n = v_r|\mathrm{MAX}(d_{tr})$ and $d_{tr} <= D_T HR$
        end
        Broadcast the packet with ID of $v_n$
    end
    else
        if $len(V_{in}) / len(V_{ir}) > 0.06$ then
            for $v_r$ in $V_{ir}$ do
                $V_B.add(v_r)$
            end
        end
    end
end
```

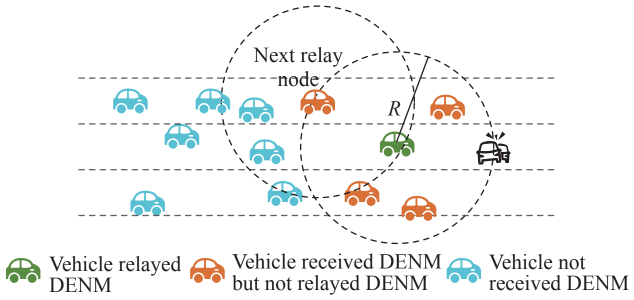

Fig. 6. Select the relay node has the competitive PDR.

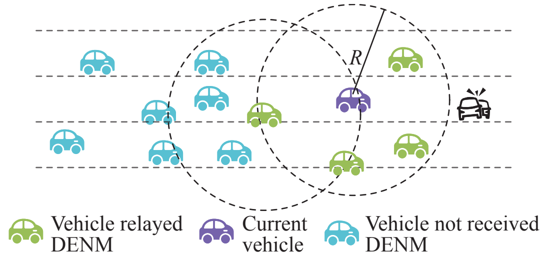

Fig. 7. Select the relay node whose neighbor with less reception.

IV. Experiment and Performance Analysis

We used Matlab and Python co-simulation to calculate the PDR and select the relay node and used traffic datasets collected from Luxembourg [44] and Colonel [45] as the test data set. Wherein, vehicle density in Luxembourg is about 0.12 vel/m, while vehicle density in Cologne is 0.05 vel/m. The DENM frequency in the dense area and the sparse area is 10 Hz. The size of a DENM packet is 450 bytes.

Using the above parameters in Table 2, we calculated the relationship between the different distances and the estimated PDR in 6G through Section III.2, as shown in Fig.8. Due to path loss and signal fading, the estimated PDR remains a constant value first and then reduce sharply with the distance between vehicles increasing. We select the vehicle in the critical distance before PDR sharply drops as the relay vehicle.

Table 2. Parameter table

Label	Notation
MAC model	6 G
ROS length	1500 m
Vehicle density	0.12 vel/m, 0.05 vel/m
Packet size	450 bytes
Packet rate	6 Mbps
Transmission power	23 dB
Packet frequency	10 Hz
Max waiting latency	1 ms
Transmission range	280–400 m

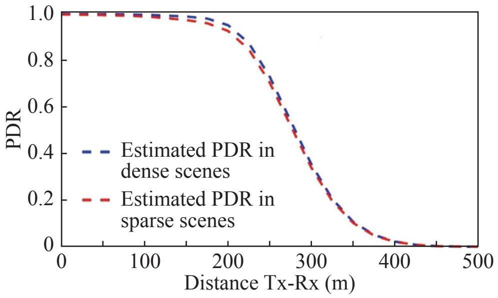

Fig. 8. Relationship between estimated PDR and the distance between v_t and v_r.

To evaluate the advantages of PDR-MD, we compare protocols in the same configuration:

- Positions probabilistic-based protocols: If the vehicle node receives DENM, it forwards the packet with probability p in equation (18).

$$p = dist\left(lv_p, v_p\right)/2R \tag{18}$$

where $dist\left(lv_p, v_p\right)$ is the distance between the last sending node and the current vehicle. R is the transmission range.

- Epidemic-based dissemination algorithm (Epic) [46]: Referring to the epidemic model, once receiving the DENM, the vehicle decides the forwarding probability based on the acceptance rate of neighboring nodes.

To demonstrate the effectiveness of the PDR-MD in terms of transmission time, Fig.9 shows the dissipation time of PDR-MD and Epic in two scenarios. As can be seen from the figure, using PDR-MD in the dense scenario, DENM messages can be transmitted to more than 97% of vehicles in ROS in about 120 ms. Us-

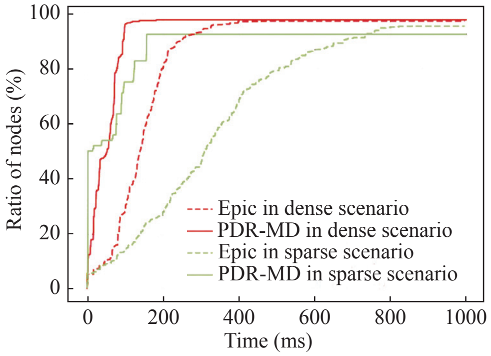

Fig. 9. Dissipation time of DENM within different scenarios.

ing PDR-MD in the sparse scenario, the DENM messages can be transmitted to about 94% of vehicles in ROS in about 200 ms. However, using Epic in the dense scenario, DENM takes about 300 ms to reach the same ratio as PDR-MD within the ROS. In the sparse scenario, using the Epic algorithm, it takes longer for the DENM message to be received by vehicles within ROS. It can be clearly seen that the PDR-MD can transmit DENM messages within ROS in a very short time in both sparse and dense scenarios, ensuring the timeliness of emergent message propagation. In addition, the different performance of PDR-MD in sparse and dense scenarios is due to the fact that PDR-MD always selects the vehicles that are farther away within the critical distance for transmission in dense scenarios, which will reduce the dissemination time. In the sparse scenario, in order to guarantee the PDR, the transmit vehicles will choose the nodes that are closer and have a higher estimated PDR and drop those relay nodes that are farther away, which will result in a larger multi-hops and dissemination time. Even so, DENMs can reach the vehicle within ROS in a short time. In the case of changing communication range, we compared the PDR and the transmission ratio in two scenarios respectively. The transmission ratio indicates the proportion of relay vehicles to the total vehicles. Fig.10 shows

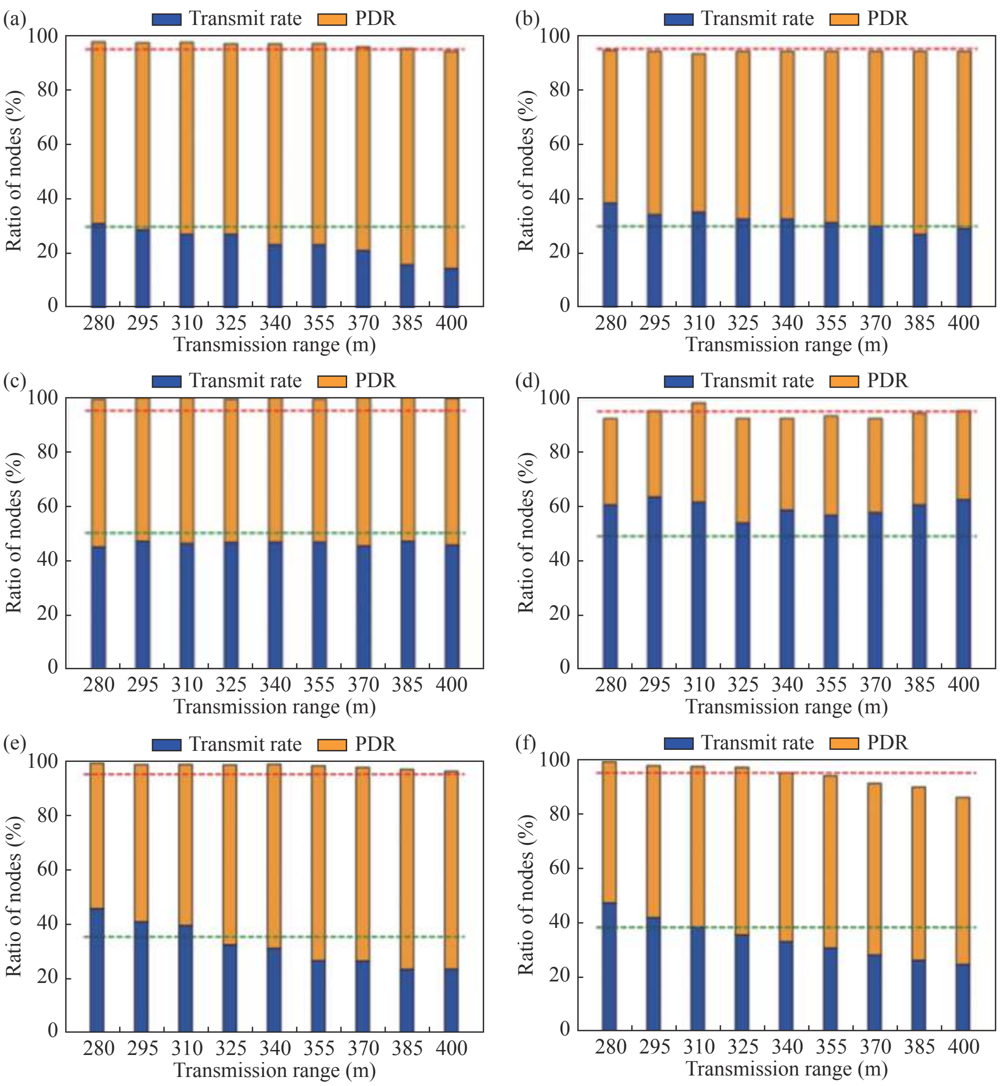

Fig. 10. PDR and transmit ratio vs. communication range.

the experimental results under different scenarios when ROS distance is 1500 m. The blue bar indicates the influence of communication range on transmit rate, and the yellow bar indicates the influence of communication range on PDR. We select 9 points in the range of 280 to 400 m. Fig.10(a) shows the PDR varies slightly with the transmission range in the dense scenario; transmit rate and the transmission range have opposite trends. But the overall PDR maintained around 0.95 and the transmit rate below 0.4. The reason for this phenomenon is that with the transmission range increased, more vehicles will receive the DENM in one broadcast. Fig.10(b) shows the PDR and transmit rate in the sparse scenario, the PDR is lower and the transmit rate is higher. Compared to the dense scenario, sparse has a lower PDR and a higher transmit ratio. The reason is in the sparse scenario, the following scenario may exist: vehicle node is not within the transmission range of any vehicle that has received the packet, which results in a lower PDR. Due to the low density of vehicles in the sparse scenario, more vehicles will be used to relay packets, which brings a higher transmission rate. As is shown in Figs.10(c) and (d), no matter whether in dense or sparse scenarios, the position probabilistic algorithm can maintain a high PDR and a high transmit rate. In Figs.10(e) and (f), the Epic shows a higher transmit rate and PDR in the dense scenario, a lower PDR and a higher transmit rate in the sparse scenario. This further demonstrates that PDR-MD can maintain good performance in both PDR and transmit ratio in different communication ranges.

Fig.11 shows the experimental results under different scenarios and ROS when the transmission range is 340 m. The blue bar in the figure shows the impact of ROS on the transmission rate, and the yellow bar shows the impact of ROS on PDR. As we know, in order to reduce the impact of DENM on unrelated vehicles, we limit the dissemination of DENM only within the ROS.

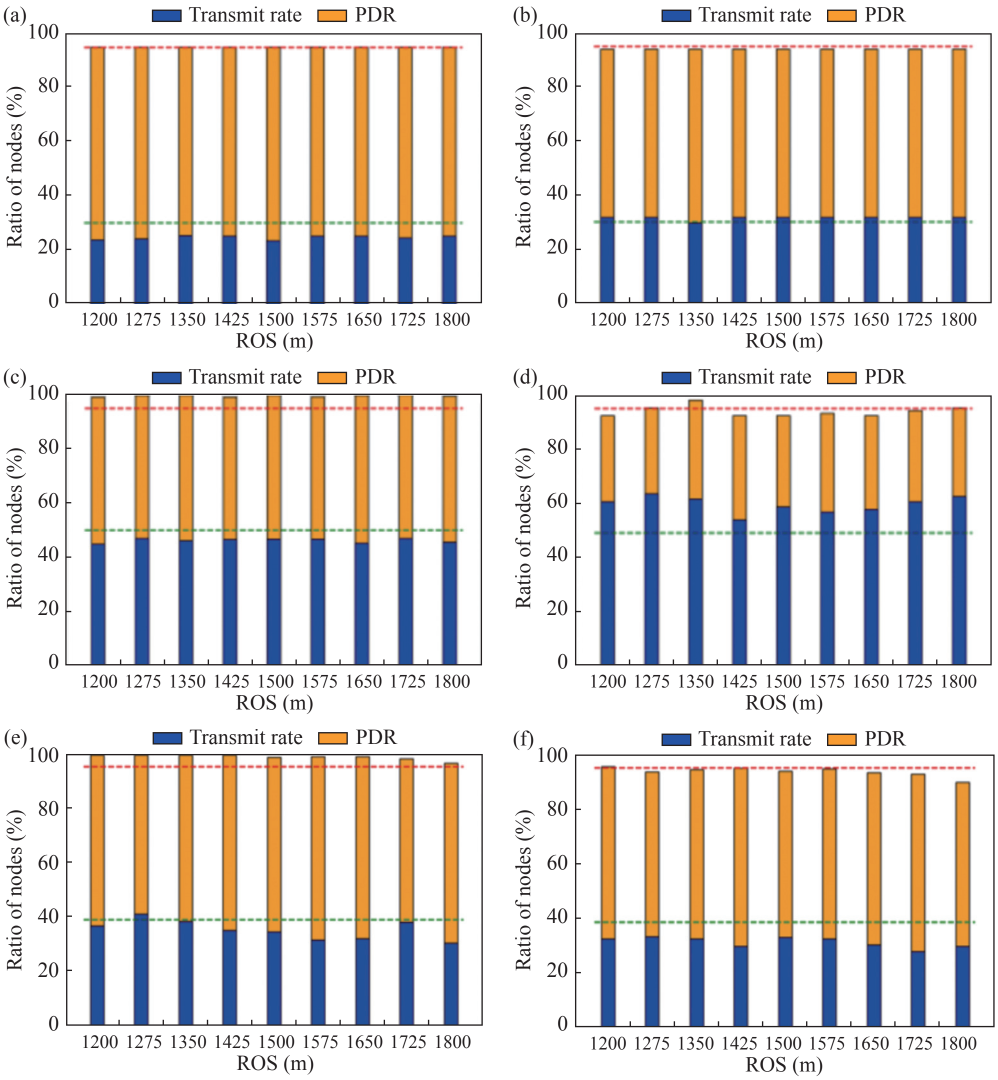

Fig. 11. PDR and transmit ratio vs. ROS.

If the vehicles depart from ROS, it will no longer forward DENM messages. In order to find out the impression of ROS on the experiment, we chose ROS within 1200 to 1800 m to evenly select 9 different ROS lengths. As shown in Fig.11(a), in the dense environment, PDR remains approximately equal to 95% under different ROS, and transmit rate can remain below 0.3, indicating that ROS has little influence on PDR and Transmit rate. That is to say, if the number of vehicles in ROS increases, relay nodes will increase. However, its proportion to the total number of vehicles within the ROS range remains unchanged. The superiority brought by this algorithm reduces the influence of broadcast storms. As can be seen from Fig.11(b), in the sparse scenario, the PDR was reduced by just under 0.5%. As a price, the transmit ratio is relatively high due to the distance between vehicle nodes being large, but it is still effectively controlled at about 30%. As shown in Figs.11 (c) and (d), no matter whether in dense or sparse scenarios, the PDR of the position-based probabilistic algorithm is almost always high. However, there is still a big difference in transmit rate between our PDR-DMD algorithm. In the dense scenario, the transmit rate is slightly lower. the probabilistic algorithm does not perform well due to packet loss and other reasons, which are related to the topology results of vehicles and roads and propagation loss. As can be seen in Figs.11(e) and (f), no matter the dense or sparse scenario, the PDR and transmit ratio of the Epic is higher in the dense scenario.

V. Conclusions

This paper proposes a PDR-based message dissemination algorithm suitable for the urban environment in a 6G-oriented environment. In order to reduce resource waste and packet collision, PDR-MD selects a specific vehicle to relay DENM instead of flooding. In addition, to enhance the reliability of 6G V2V in the absence of suitable relay nodes, vehicles will broadcast DENM if the acceptance rate of neighbors is below the desired point. We also introduce ROS and TTL to prevent infinite diffusion. The experiments show that PDR-MD has great advantages in both PDR and transmit rates.

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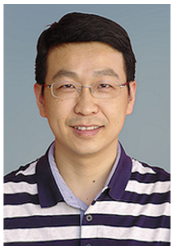

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