Vehicular Communications 33 (2022) 100418

Contents lists available at ScienceDirect

Vehicular Communications

www.elsevier.com/locate/vehcom

V2V-CoVAD: A vehicle-to-vehicle cooperative video alert dissemination mechanism for Internet of Vehicles in a highway environment

Shujuan Wang [a,*], Qian Zhang [b], Guangchao Chen [a]

[a] *School of Information Engineering and Automation, Kunming University of Science and Technology, Yunnan, 650500, China*
[b] *Chongqing Branch of China Mobile Communications Group Design Institute Co., Ltd., China*

ARTICLE INFO

Article history:
Received 5 June 2021
Received in revised form 20 August 2021
Accepted 13 September 2021
Available online 16 September 2021

Keywords:
Internet of Vehicles
Video alert dissemination
V2V cooperative transmission
Relay selection
Clustering

ABSTRACT

Nowadays, traffics on the roads are getting more and more congested due to the fast-rising number of vehicles and the increasing need of citizens for mobility. Accidents happen frequently and result great loss of lives and properties. Internet of Vehicles (IoVs), as an important part of Internet of Things (IoTs), is placed high hope for enhancing traffic safety and controlling the damage caused by traffic accidents. According to statistics, most accidents can be avoided if drivers can be notified of a danger timely, so the key to minimize the damage introduced by road traffic accidents is the realization of fast and efficient data dissemination. However, great challenges exist due to the transmission characteristics of IoVs, such as high-speed movement of vehicles and dynamic changing network topologies. In this paper, we propose a vehicle-to-vehicle cooperative video alert dissemination mechanism for transmitting accident video in the highway scenario of IoVs. A two-way cooperative transmission strategy is designed. Vehicles in the same direction of accident vehicle are formed into clusters and communicate within clusters, while vehicles in the opposite direction select relay vehicles to help spreading video fast and reliably. The difficulties brought in by the characteristics of IoVs are solved through careful considerations of multiple factors such as vehicles' speeds, locations, distances, channel conditions and data receiving statuses in the design of the mechanism. Moreover, Scalable Video Coding (SVC) technology is used for encoding the original accident video, to take care of the performance degradation caused by the heterogeneity of vehicles in different locations. Instantly Decodable Network Coding (IDNC) technology is adopted during the cooperative transmission to further improve the transmission efficiency and reliability. Simulation results justify the proposed mechanism that it effectively shortens the accident video transmission delay, increases the success warning ratio, enhances the reconstructed video quality and improves the user satisfaction.

1. Introduction

Internet of Vehicles (IoVs), as a product of the combination of Internet of Things (IoTs) and Intelligence Transportation System (ITS), can realize communications between vehicles and other things such as vehicles, pedestrians, roadside infrastructure, etc., which is referred to as Vehicle-to-X (V2X). V2X communications empower IoVs to support safety applications such as accident warning, road condition information and non-safety applications such as infotainment, which has great potential in improving traffic safety, traffic efficiency and user comfort [1–3].

In IoVs, great efforts have been put on the design of data dissemination mechanisms which focus on the reliable and efficient data transmission to support many emerging ITSs such as collision avoidance [4,5], accurate positioning [6,7], content centric networks [8,9], etc. Many researches have investigated the data dissemination among vehicles where vehicles are equipped with On-Board Units (OBUs) and exchange information via the Dedicated Short-Range Communication (DSRC) protocol between each other, which is referred to as Vehicle-to-Vehicle (V2V) communications [10–12]. Meanwhile, a number of works have been done towards exploring the data dissemination between vehicles and roadside infrastructures, as known as Vehicle-to-Infrastructure (V2I) communications. With V2I communications, vehicles that are driving through the RoadSide Unit (RSU)'s communication range can request and retrieve information from the RSUs through cellular networks such as Long Term Evolution (LTE) [13–15] or DSRC [16–18].

---

[*] Corresponding author.
E-mail address: shujuanwang0703@126.com (S. Wang).

https://doi.org/10.1016/j.vehcom.2021.100418
2214-2096/

In this work, we consider a typical highway accident video alert dissemination scenario where bidirectional vehicles cooperatively spread the accident video alert via V2V communications. It is reasonable to rely solely on vehicles themselves to transmit the video alert since the high cost of RSUs' deployment restrains the installation of RSUs along the highway and there is a good chance that the area affected by the accident is out of any RSU's coverage. However, it is challenging to design a good strategy for video alert dissemination in such a scenario due to the following characteristics. First, the accident spot usually occupies several lanes and vehicles run behind are affected greatly. Vehicles on these lanes have to slow down immediately and drive carefully pass the area, otherwise serial accidents and congestion could happen and result more damage. It is critical to notify these vehicles the accident video alert timely for damage control. While the high-speed moving of vehicles and quickly changing topologies in IoVs usually lead to unstable channels and very short time window for two vehicles to communicate, making it difficult to achieve reliable data transmission with short delay. In addition, severe interference of V2V communication could happen if multiple vehicles in close area were multicasting data items simultaneously. Therefore, how to coordinate the vehicles for better exploiting the V2V communication is a non-trivial issue. Second, vehicles on different locations are affected by the accident differently, so their requirements for recovered accident video quality are also varied. For example, in Fig. 1, vehicle vh_i is close to the accident spot, while it cannot see the accident directly due to the occlusion of vehicles in front. When vh_i finally approach close enough to find out the accident, it may be too late to take measures to avoid the occurrence of secondary accidents such as rear-end collision. Besides, vh_i is able to deliver assistance to the accident vehicle(s) provided that it can receive high quality accident video timely to grasp the specific conditions of the accident vehicle(s). Contrarily, vehicle vh_j is far away from the spot and it only needs to receive a basic quality accident video to understand the accident profile to adjust the driving strategy. The personalized video recovery quality requirements of vehicles should be respected to provide more satisfying accident warning and rescue service. Third, owing to the individualized video recovery quality requirements of vehicles and the unreliable channel conditions among vehicles, vehicles may cache and request different video packets and it is important to schedule the most suitable data as well as the vehicles for multicasting to maximize the wireless channel efficiency.

To address the above problems, this paper is dedicated to investigating the typical highway video alert dissemination scenario in IoVs and exploring the potentiality of data dissemination among vehicles driving in opposite directions. A novel mechanism as well as corresponding algorithms is proposed to effectively improve the video transmission performance and increase the success ratio of accident warning. The main contribution of this work can be summarized as follows:

(i) We give an insight into the existing challenges of transmitting accident video alert in the highway scenario of IoVs. An efficient and reliable accident video alert dissemination mechanism is proposed on the basis of thorough research and joint consideration of multiple factors that have strong effect on the realization of accident warning, such as the specific performance requirements of accident alerting in highways, personalized video recovering requirements of vehicle users and the transmission characteristics of IoVs. Moreover, it promotes the coordination among vehicles driving on bidirectional lanes to share their cached data items efficiently.

(ii) To tackle the problems introduced by the high speed moving of vehicles, we analyze the highway accident video alert dissemination scenario deeply and put forward two distinct algorithms for vehicles run on the same/opposite direction based on their features. On one hand, vehicles run on the same direction of accident vehicle will be forced to slow down and get together, creating good opportunities for information exchange among vehicles nearby. Thus, we design a clustering algorithm to organize the cooperative transmissions of equidirectional vehicles. On the other hand, vehicles on the opposite lanes will not be affected by the accident and they can receive the accident video from the accident vehicle when driving through the spot, making them perfect potential helpers for relaying necessary video items. Therefore, we design a dynamic relay selection algorithm to locate the most suitable opposite vehicles to complement the video packets cached by equidirectional vehicles and to expedite the spread of video alert. With efficient cooperation of the two algorithms, vehicles can receive required video items from multiple sources quickly and recover the accident video in short delay.

(iii) In view of the personalized video recovering requirements of vehicles, we propose to utilize Scalable Video Coding (SVC) [19] technology to encode the accident video for dissemination, to overcome the difficulties and performance degradation caused by vehicles' heterogeneity and mismatching between the limited resources of IoVs and the big volume of videos. The decreasing importance of encoded video layers and the decoding dependency exists in sequential video layers, as significant properties of SVC, are highly valued and artfully handled to smoothly integrate the SVC technology into the overall mechanism.

(iv) To realize optimal data scheduling and maximum bandwidth utilization, we employ Instantly Decodable Network Coding (IDNC) technology to find the most profitable data combination in both clustering and relay selection algorithms for transmission. Moreover, the specific decoding properties of SVC data are recognized by assigning proper weights to corresponding vertices in the IDNC graph, and the optimal data scheduling problem is transformed to a maximum weighted clique problem over the graph.

(v) We evaluate the performance of the proposed V2V cooperative video dissemination mechanism through a large number of simulation experiments. Simulation results show that the mechanism has good performance in terms of transmission delay, success ratio of accident warning, recovered video qualities and user satisfaction, which proves the effectiveness of the proposed mechanism.

The rest of this paper is organized as follows: Section 2 outlines the related works of emergency information and video dissemination in IoVs. Section 3 describes the system model. Section 4 introduces the proposed V2V cooperative video alert dissemination mechanism in detail. Section 5 provides a large number of simulation experiment results and evaluates the performance. Finally, Section 6 concludes this paper.

2. Related works

2.1. Emergency data dissemination in IoVs

In existing works, researchers have proposed different data dissemination algorithms from numerous perspectives for transmitting data in IoVs. The classical dissemination method is flooding, by which the vehicle transmits all received data to all vehicles within its coverage. This method causes serious broadcast storms, channel contention, and a large amount of information redundancy, thus introducing a great waste of network resources [20]. In view of this, the authors proposed a data dissemination scheme based on probability broadcasting in [21]. Firstly, the vehicles are formed into clusters according to their positions and driving directions. The cluster members then calculate the forwarding probability in the light of many parameters, such as channel conditions, to broadcast the received data. Clusters can increase the connection time between vehicles and reduce the cost of deploying RSUs. An emergency message dissemination scheme based on clustering was proposed in [22]. Vehicles with similar destinations and interested message contents are formed into clusters, and emergency messages are transmitted between clusters. This scheme uses clustering to effectively solve the broadcast storm problem. However, it doesn't consider the mobility of vehicles and the update of formed clusters, which affect the transmission performance negatively. Broadcasting emergency messages to the surrounding vehicles in advance will reduce the occurrence of serial accidents. Reference [23] proposed an accident warning message dissemination protocol that allowed vehicles to detect the location of the scene of a traffic accident and to send accident alerting messages to neighboring vehicles, so as to avoid serial accidents and to prevent traffic congestion. Whereas, this protocol only considers the location of the accident vehicle as the main parameter that affects the transmission performance, while multiple factors can have nonnegligible influence on the performance in fact. Tian et al. [24] proposed an emergency message broadcast protocol. In this protocol, a vehicle determines what message it receives based on the identifier of the emergency message, and it judges whether to broadcast the information by only considering the content itself. The lack of consideration for practical factors such as the locations of neighboring vehicles and data receiving requirements may lead to errors in the broadcast decision making process and thus degrade the efficiency.

2.2. Video streaming in IoVs

When transmitting application data such as accident alert and road traffic information, video communication in IoVs is more attractive than pure text [25]. In [26], a multi-hop broadcast protocol was proposed for emergency multimedia messages transmission. The scheme divides the multimedia message into multiple segments, and allocates multi-hop transmission time slots for each segment according to the size of multimedia messages, the distances between vehicles and the end of the transmission area. A vehicle can not obtain the emergency multimedia message until it receives all the segments. In [27], a relay selection method for video dissemination in vehicular networks was proposed. With this method, a vehicle determines whether it can become a relay node to forward the video stream by jointly considering the maximum repeated packets that can be received and the waiting time, but it does not consider the mobility of the vehicles and the characteristics of the video itself, and the node may be affected when it forwards the video. In [28], authors proposed an emergency video transmission scheme to enhance throughput. The scheme selects the vehicle with the best throughput based on the location of vehicles, as the relay node to transmit the emergency video. While considering only the throughput might not be enough for optimizing the transmission delay. In [29], authors used RSUs to help vehicles transmit multimedia messages. The multimedia messages are generated by RSUs and are forwarded to the destination by passing vehicles. RSUs help vehicles that carrying multimedia messages to find the best forwarding node. If there is no suitable forwarding node, RSUs store the data. This solution uses RSUs to select the next hop forwarding node during V2V communication, which is not suitable for multimedia messages transmission on highways with open environments and few RSU deployments. In the Cellular-based Vehicular Ad hoc NETworks (C-VANETs), due to the limited bandwidth of cellular networks, it is difficult for vehicles to receive multimedia messages with desired Quality of Service (QoS). By considering the distances between a vehicle and its neighbor nodes, the relative speeds, and the available cellular bandwidths, [30] proposed a cooperative video downloading scheme. The scheme enables vehicles and their neighbor nodes to download video data from the Internet to improve the recovering video quality. [31] proposed a low delay and multi-description video streaming transmission method based on a cross-layer architecture, which mainly focused on improving the received video qualities. However, emergency video dissemination for accident warning is time-sensitive, and reducing the overall transmission delay is the major objective. Therefore, more efforts should be made to reduce the transmission delay while enhancing the recovering video qualities at the same time.

2.3. Video dissemination using SVC in IoVs

In view of the fact that the transmission performance of video messages in IoVs is affected greatly by channel fading and dynamic topology changes, An et al. [32] proposed an optimal scheduling algorithm for video stream with the assistance of SVC. The basic idea is to seek the most efficient way for SVC layer scheduling in the location varying and data rate limited network. Based on this work, authors in [33] studied the questions of how to select the relay vehicular users and how many video layers should be transmitted for each user. The research focuses on the SVC layer scheduling problem to optimize the resource utilization in IoVs. However, these methods are not suitable for accident video dissemination in IoVs where the accident video need to be transmitted to vehicles before they arrive the accident spot and each vehicle has unique video recovery quality requirement. [34] proposed a video stream multi-segment cooperative transmission strategy, combining SVC with video cooperative transmission to solve the problems of video quality degradation caused by limited bandwidth and frequent topology changes in IoVs. The proposed strategy divides the road into sections, and selects appropriate video forwarding nodes in consideration of the position, speed, and driving direction of vehicles. Whereas, this work mainly considers the video streaming for entertainment. The vehicles are assumed to be equipped with both 3G and DSRC communication interfaces and these two kinds of communications are advocated. Meanwhile, multiple video servers are deployed in the system to reduce the transmission delay. These features are highly different from the highway accident video transmission environment and thus preventing its application in accident video dissemination. In [35], a clustering-based video streaming transmission method was proposed. Moving vehicles are grouped into cooperative clusters to enhance the video distribution. The Cluster Head (CH) receives SVC messages from nearby base stations and transmits them to its Cluster Members (CMs). [36] extended the above work to the case of V2I communications. The proposed methods only consider the channel conditions when selecting CHs for multicasting SVC data items. However, the lack of consideration of data characteristics and transmission requirements makes it unsuitable for accident warning applications in IoVs.

This paper proposes a cooperative video alert dissemination mechanism, which relies on communications between vehicles in the open highway scenario to transmit emergency accident video messages to vehicles in the affected area in the shortest possible time. The unique transmission requirements of this particular application scenario have been analyzed thoroughly and given full consideration. Firstly, this work proposes V2V communication for accident video dissemination since V2I communication is hard to realize due to the limited RSUs deployment along the road. Secondly, to achieve better damage control and fast rescue, vehicles are allowed to specify video qualities according to their locations, computing and processing capabilities and other

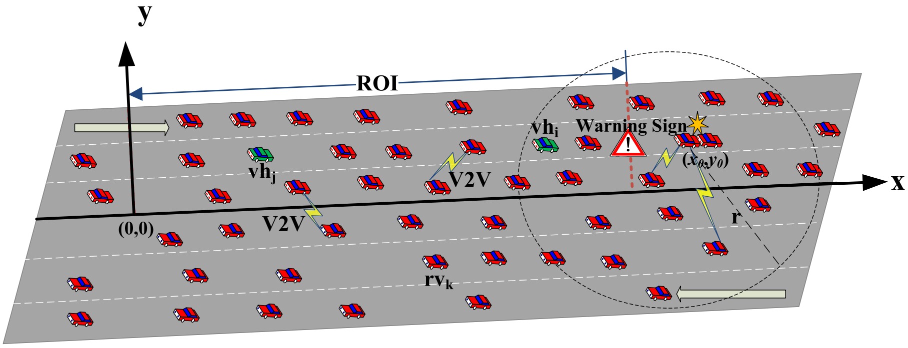

Fig. 1. System Model.

properties. SVC technology is employed for encoding the accident video before transmission, so as to fulfill the demand of each vehicle's video recovery quality efficiently. Thirdly, to fully explore and utilize the data sharing opportunities in the concerned scenario, two distinct algorithms are proposed for V2V cooperative communication among vehicles on the same/opposite directional lanes, respectively. Clustering-based communication is proposed for equidirectional vehicles and reverse relay vehicles are selected to help providing video packets more quickly. Lastly, IDNC technology is employed to further improve the bandwidth utilization and to mitigate the packet loss resulted by the high-speed moving of vehicles.

3. System model

In this paper, we consider the accident video alert dissemination in the highway scenario, the system model is shown in Fig. 1. The considered scenario is a two-way multi-lanes highway where vehicles are distributed randomly. The effective communication radius of each vehicle is set as r. Assuming that each vehicle is equipped with a wireless On-Board Unit (OBU) that can communicate with vehicles within its communication range. Vehicles exchange information such as their locations, speeds and driving directions periodically using OBUs. In addition, each vehicle is equipped with Global Positioning System (GPS) and sensors to obtain real time positions, speed information of neighboring vehicles and surrounding roadway information. Each vehicle works in the half-duplex mode that it cannot send and receive data at the same time.

When an accident occurs, a warning sign is placed 150 meters behind the accident vehicle. Vehicles moving in the same direction with the accident vehicle(s) will be affected by the accident particularly, refer these vehicles as the equidirectional vehicles. Vehicles on the opposite lanes are called as reverse vehicles and the accident has little impact on them. The area affected by the accident can be delimited as the rectangle area between the warning sign to a certain distance. This area is called as the Region Of Interest (ROI). In practical environment, vehicles at different locations in the ROI want to learn the accident detail to different degrees, due to their varied computing and processing capabilities, and specific usage of the information (accident warning/avoidance/rescue, route replanning, etc.). To respect the personalized video quality receiving requirements of different vehicles, SVC technology is applied to encode the accident video before transmission. Using SVC, a video can be encoded into a base layer that contains basic video information and a number of enhancement layers which consist of plentiful data that can be used for improving video quality. The encoded video is divided into M layers, including a base layer and $(M-1)$ enhancement layers, which are represented as $l_0, l_1, l_2, \ldots, l_{(M-1)}$. The requirement for recovering accident video of vehicle vh_i is determined by its initial location (the location of vh_i when the accident occurs) and its video receiving and processing capability. Denote E_i as the video quality requirement of vh_i, $E_i = j$ means that vh_i needs to receive and decode all the video data of $(l_0, l_1, \ldots, l_j)$ layers. Record the N vehicles in the ROI as $VH = \{vh_1, vh_2, \ldots, vh_N\}$. The location and speed of vehicle vh_i are respectively marked as (x_i, y_i), v_i, and the position of the accident vehicle is (x_0, y_0). Record the cache of equidirectional vehicle vh_i as H_i, and the cache of reverse vehicle rv_k as H_k^r. Assuming there are Z vehicles on the reverse lanes that have received the multicast SVC packets partly (or completely in the best situation), these vehicles are marked as relay candidates and are put into the relay candidate set $RC = \{rv_1, rv_2, \ldots, rv_Z\}$. The k-th reverse relay candidate vehicle is recorded as rv_k. rv_k's location and velocity are denoted as (rx_k, ry_k) and v_k, respectively.

The video dissemination consists of two stages. First, when the accident happens, the on-board device on the accident vehicle encodes the captured accident video using SVC and the accident vehicle multicasts the SVC packets sequentially from the base layer to the highest enhancement layer. The initial SVC multicast stage completes when the accident vehicle has multicasted all the SVC packets. After that, the accident vehicle stops multicasting and the second stage begins. From the first stage multicast, vehicles on both directional lanes can receive some SVC packets and store them into their caches. In the second stage, vehicles on the equidirectional lanes perform a clustering-based data scheduling algorithm to carry out the cooperative data sharing, and vehicles on the opposite lanes execute a relay selection method for choosing suitable vehicles to transmit missing packets for equidirectional vehicles and to complement the overall mechanism. All relay nodes (including CHs and reverse relay vehicles) adopt IDNC technology to select the most profitable SVC packet combinations for encoding and multicasting, so as to ensure that vehicles can receive and decode the required video qualities in the shortest possible time. The cooperative transmission stage completes when vehicles in the ROI at the beginning of the video dissemination have either successfully decoded the accident video to the required qualities before leaving the ROI (successful warning), or left the ROI without recovering the video correctly (unsuccessful warning).

4. V2V-cooperative video alert dissemination

This section introduces the proposed cooperative video alert dissemination mechanism in detail. To realize efficient accident warning and provide accident video with satisfying qualities for vehicles in the ROI as soon as possible, vehicles on lanes of both directions are proposed to participate in the cooperative transmission. Different schemes are designed for vehicles in the same (opposite) directions of the accident vehicle under comprehensive considerations. A V2V-Cooperative Video Alert Dissemination (V2V-CoVAD) mechanism is proposed and it can be divided into four parts: (1) SVC video multicast; (2) Relay transmission of re-

Table 1
List of symbols.

Symbol	Description
r	Communication radius of a vehicle
N	Number of vehicles in the ROI
VH	Vehicle set in the ROI
vh_i	The i-th vehicle in the ROI
(x_i, y_i)	Position of vehicle vh_i
v_i	Speed of vehicle vh_i
(x_0, y_0)	Position of accident vehicle
M	Number of SVC video layers
l_0	The base layer
l_j	The j-th enhancement layer, $1 \le j \le M-1$
L	All SVC video layers, $L = \{l_0, l_1, ..., l_{(M-1)}\}$
E_i	Video quality requirement of vh_i
H_i	Cache of vehicle vh_i
RC	Reverse relay candidate set
rv_k	The k-th reverse vehicle in RC
(rx_k, ry_k)	Position of reverse vehicle rv_k
H_k^r	Cache of reverse vehicle rv_k
$VH_{success}$	Set of vehicles that are successfully warned
VH_{fail}	Set of vehicles that are failed to be warned
$Need_i$	The data set that vh_i needs to receive to meet its video quality requirement
NB_i	Neighbor nodes set of vh_i
a_{mn}	The n-th data of the m-th video layer
I_m	Importance of the m-th SVC layer
v_{ki}	Relative velocity between reverse vehicle rv_k and vehicle vh_i in the ROI
av_k	Average relative speed of rv_k and all vehicles in the ROI
s_k	Distance from rv_k to geometric center of vehicles in the ROI
avn_i	Average relative speed of vh_i and its neighbor vehicles
sd_i	Distance difference of vehicle vh_i
d_{ij}	Distance between vh_i and its neighbor vh_j
λ_i	Average distance between vh_i and its neighbor vehicles
UN_i	The data set that all neighbor nodes of vh_i need to receive
JD_i	Jaccard distance of vh_i
K_{ij}	The Rician factor of the channel between vehicles vh_i and vh_j
ω_i	Utility value of vehicle vh_i

verse vehicles; (3) Clustering-based transmission of equidirectional vehicles; (4) IDNC-assisted multicast. The symbols used in this paper are listed in Table 1.

4.1. SVC video multicast

When a traffic accident occurs on the highway, the accident vehicle uses its own video capture equipment to record the accident, and a video encoding equipment (which can be integrated on the OBU) to encode the accident video into SVC streams. Starting from the base layer, the accident vehicle sequentially multicasts SVC streams to all vehicles locate within its communication coverage (both equidirectional and reverse vehicles can receive the multicasted packets). Upon receiving, vehicles store packets into their caches and update their positions and speeds. Reverse vehicles that receive the packets become relay candidates automatically and form the relay candidate set RC. Equidirectional vehicles in the ROI check their caches after each multicast to see whether the video decoding requirements are met. If vehicle vh_i receives enough SVC packets to decode the accident video to the personalized quality requirement E_i before it leaves the ROI, vh_i is successfully warned that it can make the most favorable driving strategy in time according to the information provided by the accident video. Thus, vh_i is put into the set $VH_{success}$. Otherwise, if vh_i does not receive necessary packets to reconstruct the accident video before it leaves the ROI, it is failed to be notified of the accident and thus is put into the set VH_{fail}.

4.2. Relay transmission of reverse vehicles

When the accident happens, reverse lanes are hardly affected and reverse vehicles can establish multiple communication links between them and equidirectional vehicles. Therefore, it is natural and beneficial to use reverse vehicles as relays to cooperatively transmit the accident video. The speed of a reverse vehicle rv_k determines its driving time on the road. The slower the speed is, the longer the staying time of rv_k on the road and the longer service time for vehicles in the ROI. Due to the high-speed movement of vehicles, the communication links between vehicles are unstable. The relative speed between two vehicles can be used as an indicator to reflect the channel stability between them. A low relative speed means a stable channel and a high relative speed matches an unstable channel. Denote the relative speed between reverse vehicle rv_k that is in the relay candidate set RC and equidirectional vehicle vh_i that is in the ROI as v_{ki}, v_{ki} can be calculated as follows[1]:

$$v_{ki} = v_i - v_k \tag{1}$$

the average relative speed of rv_k and all vehicles in the ROI is:

$$av_k = \frac{\sum_{i=1}^{N} v_{ki}}{N} \tag{2}$$

The distance between vehicles is another factor that affects the channel stability. The distance s_k between the reverse relay candidate vehicle rv_k and the geometric center of vehicles in the ROI is used to evaluate the channel stability. The calculation of s_k is as follows:

$$s_k = \sqrt{(rx_k - \frac{\sum_{i=1}^{N} x_i}{N})^2 + (ry_k - \frac{\sum_{i=1}^{N} y_i}{N})^2} \tag{3}$$

---

[1] Define the driving direction of the accident vehicle as the positive direction of speed, and the driving direction of reverse vehicles as the negative direction of speed. For convenience, the direction of speed is not notated in this paper, similarly hereinafter.

Moreover, the number of SVC packets received by rv_k describes its capability to serve other vehicles, and a large amount of cached SVC packets is desired since more vehicles can be satisfied by rv_k.

All factors considered, we design μ_k as the utility value of rv_k to characterize the performance enhancement brought on by choosing rv_k as a reverse relay to multicast SVC packets for equidirectional vehicles in the ROI. μ_k is calculated as follows:

$$\mu_k = \frac{\left|H_k^r\right|}{(av_k + v_k) * s_k} \tag{4}$$

where H_k^r is the set of SVC packets that are cached by rv_k, and $|H_k^r|$ is the size of H_k^r.

The vehicle in the reverse relay candidate set RC which has the maximum utility is selected as a reverse relay. A dynamic reverse relay selection method is designed carefully to find out the most suitable vehicle as the reverse relay in each time slot. The pseudocode of the method is shown in Algorithm 1.

Algorithm 1 Reverse relay selection.

```
input: $RC = \{rv_1, rv_2, ..., rv_Z\}$.
output: Reverse relay set $C$
Initialize Reverse relay set $C = \varnothing$; waiting relay set $C_0 = \varnothing$; $H_0 = \varnothing$ ($H_0$ is the union of cache sets of vehicles in $C_0$)
//Calculate the utility value of vehicles in $RC$
for $rv_k \in RC$ do
    calculate the utility value of $rv_k$ according to formula (4).
end for
//Sort reverse vehicles in $RC$ according to their utilities in descending order
$RC' = sort(\mu) = \{rv'_1, rv'_2, ..., rv'_Z\}$;
// Select the reverse relay(s) from set $RC'$
while $C == \varnothing$ do
    $k = 1$;
    if $H_{rv'_k} == L$ then
        Reverse vehicle $rv'_k$ is chosen as the reverse relay, $C \leftarrow C \cup \{rv'_k\}$;
    else
        $C_0 \leftarrow C_0 \cup \{rv'_k\}$;
        $H_0 \leftarrow H_0 \cup H_{rv'_k}$;
        $k = k + 1$;
        function SELECT($rv'_k$)
            if $H_{rv'_k} \setminus (H_{rv'_k} \cap H_0) \neq \varnothing$ then
                $C_0 \leftarrow C_0 \cup \{rv'_k\}$;
                $H_0 \leftarrow H_0 \cup H_{rv'_k}$;
            end if
            if $H_0 == L$ then
                $C == C_0$;
            else
                $k = k + 1$;
                function SELECT($rv'_k$);
            end if
        end function
    end if
end while
```

Using the reverse relay selection method, the utility value of each vehicle in RC is calculated and vehicles are sorted according to their utility values in descending order. After that, the algorithm searches the relay set by recursively check the cache status of each candidate vehicle sequentially. The search continues until the union set of the cached packets of all vehicles in C_0 equals to the SVC packets set L, and the vehicles in C_0 are marked as the selected reverse relays.

Once the reverse relay vehicles are selected, they can initiate communications with vehicles in the ROI that are within their coverage. If vehicles in the ROI receive the invitation and their channels are idle, they shall accept the invitation and establish communication links between themselves and the reverse relay vehicles. When the communication links are established, the selected relay vehicles multicast IDNC encoded SVC packets to help vehicles in the ROI to quickly decode the accident video to their quality requirements.

4.3. Clustering-based transmission of equidirectional vehicles

Equidirectional vehicles that behind the accident vehicles and within the ROI are formed into clusters to propagate the accident video in a reliable and efficient way. Vehicles are categorized into three classes, namely Cluster Head (CH), Cluster Member (CM) and Ordinary Vehicle (OV). A vehicle vh_i periodically exchanges information with its neighbor vehicles and stores the received information into its neighbor list. The exchanging information includes vehicle's ID, location, speed, cache set, data set that is wanted for decoding the required video and the video decoding quality requirement.

It is noticed that when two vehicles run at similar speeds in the same direction, the channel between them is more stable than that between two vehicles run at distinct velocities. Moreover, vehicles have longer time to communicate with each other when their relative speed is small. Thus, we propose to use the average relative speed of vehicle vh_i and its neighbor vehicles, to describe the stability of the channels between vehicle vh_i and its neighbor vehicles. The average relative speed of vh_i is defined as follows:

$$avn_i = \frac{\sum_{vh_j \in NB_i} \left(|v_i - v_j|\right)}{|NB_i|} \tag{5}$$

where NB_i is the neighbor vehicles set of vehicle vh_i, v_i and v_j are speeds of vehicle vh_i and vh_j, respectively.

The distance between two vehicles is another factor that affects the transmission reliability and efficiency. If the distances between vh_i and its neighbor vehicles are similar, there is a great chance that the neighbor vehicles can receive the data packets multicasted by vh_i at the same time. Therefore, a metric of distance difference sd is designed to measure the service capability of each vehicle. The distance difference of vh_i can be calculated as follows:

$$sd_i = \sum_{vh_j \in NB_i} \left|d_{ij} - \lambda_i\right| \tag{6}$$

where d_{ij} is the distance between vh_i and its neighbor vh_j, which is calculated as:

$$d_{ij} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} \tag{7}$$

and λ_i is the average distance between vh_i and its neighbor nodes, which can be calculated as:

$$\lambda_i = \frac{\sum_{vh_j \in NB_i} \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}}{|NB_i|} \tag{8}$$

A small value of sd means that the corresponding vehicle is able to provide data packets for more neighbor vehicles at the same time.

Denote the packets set that vh_i's neighbor vehicles need to decode the accident video at their desired qualities as UN_i, $UN_i = \bigcup_{vh_j \in NB_i} Need_j$, and $Need_j$ is the packets set that vehicle vh_j wants to receive. Obviously, if vh_i cached all packets in UN_i, vh_i can meet the data needs of all its neighbor vehicles. In this paper, we use Jaccard distance JD to measure the contribution that vehicle vh_i can make for its neighbor vehicles to decode the accident video and to reduce the transmission delay. JD_i refers to the difference between the cached data of vehicle vh_i and the data required by its neighbor nodes. The smaller the JD_i is, the smaller the difference between the cache set of vh_i and the data set required by its neighbor nodes, and the greater contribution of vh_i can make for providing its neighbor vehicles their wanted packets. JD_i can be calculated as:

$$JD_i = 1 - \frac{|UN_i \cap (UN_i \cap H_i)|}{|UN_i \cup (UN_i \cap H_i)|} \tag{9}$$

Considering the frequent changes of network topologies in IoVs, rician fading channel is used to describe the wireless channel in highway scenario. Rician K factor directly reflects the channel quality. Reference [37] indicates that the Rician factor is related to the distance between the transmitting node and the receiving node. To better describe the channel between vh_i and its neighbor vehicles, we use the Rician K factor model in [38] which is calculated as:

$$K_{ij} = 39.832 - 0.288 d_{ij} \tag{10}$$

The value of the Rician factor K_{ij} decreases with the increment of the distance between the transmitting node vh_i and the receiving node vh_j. A large K_{ij} means weak channel fading and better channel quality, thus more reliable transmission.

To realize efficient and reliable data transmission between a cluster head and its members, it is preferred to choose vehicle that travels at similar speed with other vehicles and locates in the middle of other vehicles to perform the transmission. In addition, a vehicle that cached more packets than others has better opportunities to satisfy its neighbor vehicles in a short time. Taking all the factors into consideration, the utility of choosing vehicle vh_i as CH is calculated as follows:

$$\omega_i = \frac{|NB_i| * \sum_{vh_j \in NB_i} K_{ij}}{avn_i \ * sd_i * JD_i} \tag{11}$$

For vehicle vh_i that runs towards the scene of accident, it is elected as a cluster head if it does not receive the Cluster Head Announcement (CHA) sent by other vehicles and its utility value is the largest among its neighbor nodes. Otherwise, if vh_i receives a CHA sent by a neighbor vehicle whose cached packets can satisfy vh_i's packets requirement, vh_i becomes a cluster member of this neighbor vehicle. Moreover, the state of a vehicle changes dynamically due to the high speed moving of vehicles, the formed clusters update periodically to reduce the overhead and to guarantee the transmission performance. The pseudocode of proposed clustering algorithm and cluster update algorithm are shown in Algorithm 2 and Algorithm 3, respectively.

Algorithm 2 Clustering algorithm.

```
input:  $VH$
output: $Clusters$
$i = 1$;
while ($i <= N$) do
    for $vh_i \in VH$ do
        Calculate $JD_i$ and $\omega_i$ of $vh_i$ according to formulas (9) and (11) respectively;
        $vh_i$ multicasts $JD_i$ and $\omega_i$ to its' neighbor vehicles;
    end for
    if $vh_i$ does not receive CHA sent by a CH then
        if $JD_i \neq 1$ and $\omega_i$ is greater than the utility value of any other neighbor node of $vh_i$ whose state is OV then
            $State(vh_i)$ =CH, $vh_i$ is appointed as Cluster Head;
            $vh_i$ broadcasts CHA to its neighbor nodes;
        end if
    end if
    if $vh_i$ receives $CHA_j$ sent by CH vehicle $vh_j$ && $Need_i \neq \varnothing$ then
        $vh_i$ sends a request $CM_i$ to $vh_j$, asking permission to become $vh_j$'s cluster member;
        if $vh_j$ receives $CM_i$ then
            if $H_j \cap Need_i \neq \varnothing$ then
                $vh_j$ sends an acknowledgment message $ACK$ to $vh_i$, accepting $vh_i$ as its CM;
                if $vh_i$ receives the $ACK$ message then
                    $State(vh_i)$ =CM, $vh_i$ becomes $vh_j$'s Cluster Member;
                end if
            end if
        end if
    end if
end while
```

Algorithm 3 Cluster update algorithm.

```
input:  $VH$; $State(vh_i)$, $vh_i \in VH$
output: Updated vehicles' states
for $vh_i \in VH$ do
    if $State(vh_i)$ ==CH then
        Compare the utility value of $vh_i$ and its neighbor vehicles;
        if the utility value of $vh_i$ is the largest then
            If $JD_i == 1$, the cluster of $vh_i$ is dismissed and all vehicles in this cluster become ordinary vehicles;
            If $JD_i \neq 1$, $vh_i$ is still CH;
        else if
            $vh_i$'s neighbor node $vh_j$ has the largest utility value;
            if $State(vh_j)$ ==CH and $JD_j \neq 1$ then
                Merge the two clusters into one and assign $vh_j$ as the head of the new cluster, $vh_i$ becomes its member;
            end if
            if $State(vh_j)$ ≠CH and $JD_j \neq 1$ then
                $vh_j$ becomes the new CH; $vh_i$ becomes a member of $vh_j$;
            end if
        end if
    end if
    if $State(vh_i)$ ==CM then
        if The distance between $vh_i$ and its original CH is greater than $r$ then
            $vh_i$ leaves the original cluster and becomes an ordinary vehicle, $State(vh_i)$ =OV;
        end if
        If $vh_i$ has multiple neighbor nodes that are CHs, $vh_i$ selects the cluster head which has the largest utility value to become its member.
    end if
end for
```

4.4. IDNC-assisted multicast

In order to make full use of the limited bandwidth in IoVs and to improve transmission efficiency, the instantly decodable network coding technology is used for data scheduling and distribution in the cooperative transmissions of vehicles. For the relay transmission of reverse vehicles, data sender refers to the selected relay vehicle and data receiver refers to the equidirectional vehicles that have established communication links to the relay vehicle. Similarly, for the clustering-based transmission of equidirectional vehicles, data sender is the head of a cluster and data receiver is the member of the cluster. In the following, we use data sender\data receiver to describe the IDNC assisted multicast detailedly.

At the beginning of multicast, the data sender firstly constructs an IDNC graph $G(V, E)$ based on the packets receiving status of each data receiver. Each vertex in the vertex set V is determined by the SVC packet that the receiver wants to have at present. Let a_{mn} represent the n-th packet of the m-th video layer, $0 \leq m \leq (M-1)$, if the data sender has a_{mn} in its cache and the i-th data receiver needs a_{mn} to decode the video, a vertex $a_{i,mn} \in V$ is generated. If any of the following conditions is satisfied, there is an edge connection between vertices $a_{i,mn}$ and $a_{j,lk}$:

1) $mn = lk$, that is, data receivers i and j need the same video packet;
2) $a_{mn} \in H_j$ && $a_{lk} \in H_i$, that is, packet a_{mn} required by receiver i has been cached by receiver j, and packet a_{lk} required by receiver j has been cached by receiver i.

We give an example to explain the construction of IDNC graph G. After the initial SVC multicast stage, vehicles in the ROI have cached some SVC packets. Assume vehicles v_0, v_1, v_2 and v_3 have grouped into a cluster according to Algorithm 2. v_0 is appointed as the cluster head and the rest vehicles are cluster members. For simplicity, assume the SVC video is encoded into a base layer and an enhancement layer, each layer has three SVC packets, namely $\{a_{01}, a_{02}, a_{03}\}$ for the base layer and $\{a_{11}, a_{12}, a_{13}\}$ for the first enhancement layer. The packets receiving statuses of the three cluster members after the initial SVC multicast are shown in Table 2,

Table 2
The packets reception status of the three cluster members after the initial SVC multicast.

Cluster members	a_{01}	a_{02}	a_{03}	a_{11}	a_{12}	a_{13}
$v_1(E_1=1)$	0	1	1	0	1	0
$v_2(E_2=0)$	0	0	0	1	0	0
$v_3(E_3=1)$	0	1	0	0	1	1

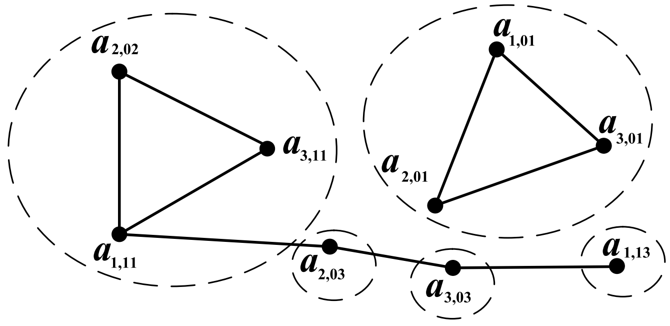

Fig. 2. The IDNC Graph G Constructed on the Given Example.

where "1" indicates the corresponding packet has been cached by the vehicle and "0" denotes that the corresponding packet hasn't been received. $E_i=0$ means vehicle i wants to recover the accident video to the base layer and $E_j=1$ means vehicle j needs to recover the video to the first enhancement layer. Applying the vertex generating and edge drawing rules of the IDNC graph construction, we have the IDNC graph of the given example as shown in Fig. 2. In this graph, the black dot represents the wanted packets of vehicles. For instance, vertex $a_{1,01}$ is generated according to the observation that vehicle v_1 needs packet a_{01} for recovering the base layer and it hasn't receive a_{01} from previous transmissions. The rest vertices in G are produced similarly. Two vertices are connected with an edge according to the above-mentioned conditions. It is easily observed that there are five cliques in graph G, namely $Q_1=\{a_{1,01},a_{2,01},a_{3,01}\}$, $Q_2=\{a_{1,11},a_{2,02},a_{3,11}\}$, $Q_3=\{a_{2,03}\}$, $Q_4=\{a_{3,03}\}$ and $Q_5=\{a_{1,13}\}$, circled in dotted lines. Particularly, clique $Q_1=\{a_{1,01},a_{2,01},a_{3,01}\}$ is induced by the same wanted packet a_{01} at vehicles v_1, v_2 and v_3, and the transmission of a_{01} is instantly decodable by the three vehicles. Clique $Q_2=\{a_{1,11},a_{2,02},a_{3,11}\}$ is induced by two wanted packets a_{11} at vehicles v_1 and v_3, and a_{02} at vehicle v_2. The transmission of combining the two packets identified by the vertices in Q_2, namely, $a_{11}\oplus a_{02}$ is instantly decodable at all three cluster members. When the vehicles receive the XORed packet, v_1 and v_3 can decode out packet a_{11} using the cached a_{02}, and v_2 can decode out packet a_{02} with the help of received a_{11}. In fact, each packets combination generated according to the vertices in the cliques of graph G is instantly decodable on vehicle users. In addition, weights are assigned to the vertices in G. According to the characteristics of SVC encoding, the importance of the m-th layer data is recorded as I_m and $I_m>I_{m+1}$, that is, the importance of the SVC layer decreases as the number of layers increases, and I_m is taken as the weight of each packet belongs to the m-th layer. The weights of base layer and the first enhancement layer in the example are assumed as $I_0=2$ and $I_1=1$, respectively.

Once the IDNC graph is constructed, the optimal scheduling problem for SVC packets is transformed to a Maximum Weighted Clique (MWC) problem over the IDNC graph. The maximum weighted clique over G can be searched by calculating the weighted sum of each clique. The weighted sum of clique Q_1 is $\sum_{i=1}^{3} weight(a_{i,01})$ = 2+2+2 = 6, and the weighted sum of Q_2 can be calculated as $weight(a_{1,11})$ + $weight(a_{2,02})$ + $weight(a_{3,11})$ = 1+2+1 = 4. Similarly, we can have the weighted sums of the rest cliques as WeightedSum(Q_3) = 2, WeightedSum(Q_4) = 2 and WeightedSum(Q_5) = 1. Thus, the maximum weighted clique over G is clique Q_1. The IDNC packet a_{01} generated on Q_1 not only achieves the maximal transmission rate, but also serves vehicle users with the achievable most profitable SVC packets for recovering the accident video satisfyingly. Therefore, the selected IDNC packet is the optimal packets combination for multicast.

In each multicast, the data sender searches the MWC in graph G, and XORs the SVC packets that are corresponding to the vertices in the returned MWC. The IDNC packet encoded on the founded MWC is multicasted to all data receivers and they can decode out their desired packets from the received IDNC packet immediately by using their cached packets.

The overall process of the proposed V2V-cooperative accident alert dissemination mechanism is shown in Fig. 3. After the first stage SVC multicast, vehicles in lanes of both directions have received some SVC packets. Relays are selected using Algorithm 1 and clusters are formed based on Algorithm 2. To start the cooperative transmission, the reverse relay firstly sends a connection request SYN to vehicles in the ROI that are within its communication coverage. When a vehicle vh_i in the ROI receives the SYN, it checks its video decoding status. If vh_i has successfully decoded its required video quality, it sends a feedback $REFUSE$ to the reverse relay node to reject the communication. Otherwise vh_i further checks its channel state. If vh_i currently involves in the communication within cluster, a $BUSY$ signal is sent to the reverse relay. If the channel is free, vh_i feedbacks an $IDLE$ signal to the reverse relay and a communication link between them is established. After then, the cluster head/reverse relay performs IDNC-assisted multicast on the cluster members/neighbor nodes. Upon receiving an IDNC packet, vehicles decode the packet using their cached SVC packets to reconstruct the accident video to their required qualities.

The cache, speed and location of each vehicle will be updated after each multicast. If a vehicle in the ROI receives enough SVC packets to reconstruct the accident video to its desired quality, it is successfully warned and is classified into the set $VH_{success}$. Contrarily, if a vehicle fails to receive enough packets to decode out the accident video to the required quality before it leaves the ROI, it is considered as unsuccessfully warned and is put into set VH_{fail}. The cooperative multicast completes when all vehicles in the ROI are successfully warned or have left the ROI.

4.5. Complexity analysis

We analyze the computational complexity of the proposed algorithms in this section. In Algorithm 1, Z reverse vehicles in the relay candidate set are sorted in descending order according to their utilities. The complexity of sorting is of the order $\mathcal{O}(Z^2)$. After sorting, the algorithm sequentially checks each sorted vehicle's cached data set to determine the final reverse relay set. The checking has to be executed Z times in the worst case, and the complexity is of the order $\mathcal{O}(Z)$. Therefore, the complexity of Algorithm 1 is of the order $\mathcal{O}(Z^2)$. For Algorithm 2, the calculations of JD_i and ω_i of any vehicle vh_i have a complexity of the order $\mathcal{O}(N)$, and N is the number of vehicles in the ROI. Once the values of JD_i and ω_i are determined, the algorithm appoints vh_i the head or a member of the cluster on the consideration of comparisons of multiple conditions in constant time. Thus, the complexity of Algorithm 2 is of the order $\mathcal{O}(N)$. When the cluster updation starts, the old cluster heads' utility values are compared with their neighbor vehicles to help decide their updated statuses, so are the previous cluster members. The execution has to perform $\mathcal{O}(N^2)$ times in the worst case, so the complexity of Algorithm 3 is of the order $\mathcal{O}(N^2)$.

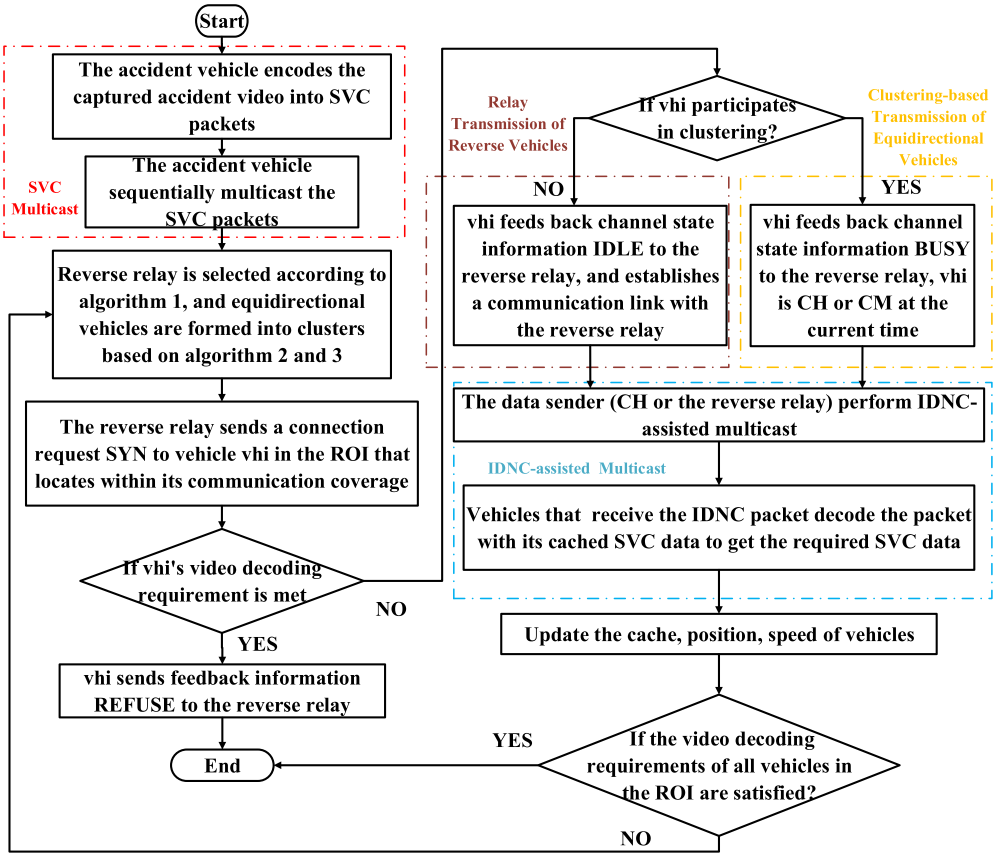

Fig. 3. V2V-Cooperative Video Alert Dissemination.

5. Performance evaluation

5.1. Simulation setup

In this section, we evaluate the performance of the proposed V2V-CoVAD mechanism, the comparison algorithms are as follows: (1) The furthest distance relay transmission (FurthestDistance, FD): This algorithm uses the furthest distance relay selection algorithm in reference [39] to select reverse relay; (2) BDSC(LQ×D): This algorithm uses the Bi-Directional Stable Communication scheme based on link quality and distance proposed in [39] to select reverse relay; (3) BDSC(Th=1.0): This algorithm uses the Bi-Directional Stable Communication scheme based on link quality proposed in [39] to select reverse relay. (4) C-V2V: This algorithm groups vehicles into collaborative clusters, and varies the cluster head dynamically as the wireless channel conditions change, to distribute real-time SVC video in IoVs [35,36]. For comparison algorithms (1)-(3), the clustering cooperative transmission algorithm proposed in this paper is adopted for V2V cooperative transmissions of vehicles on the equidirectional lanes, for the sake of fairness, and all the comparison algorithms use IDNC for data scheduling and multicasting during data transmission.

The simulation scenario is a two-way six-lanes highway. The accident vehicle uses SVC encoder JSVM 9.19.15 to encode the first 50 frames of the video sequence “coastguard.yuv” with resolution 176x144 at a rate of 30 fps into one base layer and three enhancement layers. The GOP size is eight, and the bit rates of each layer are 112.60 kbps, 141.1 kbps, 160.7 kpbs and 176.2 kbps respectively. The size of each SVC data packet is 1000 bytes, and the base layer has 26 data packets, the number of data packets from the first enhancement layer to the third enhancement layer are 4, 3, and 3 respectively. The video decoding requirement E_i of vehicle vh_i generates randomly from the Normal distribution $N(1.5, 1.29)$. The Full Velocity Difference (FVD) car following model [40] is adopted as the vehicle mobility model. The N vehicles in the ROI are randomly distributed on the lanes. The experimental results are obtained on the average of 100 simulation runs. The specific parameter settings are shown in Table 3.

Table 3
Simulation parameter settings.

Parameter	Value
Width of single lane	3.75 m
Number of bidirectional lanes	6
r	250 m
N	10-250
Speed	60 km/h ∼ 120 km/h
ROI range	1000 m
x_0	1150 m
y_0	$[0, 11.25]$ m
Vehicle density in the reverse lane	0.05 vehicles/m

The performance metrics are as follows:

1) Average Transmission Delay: the average value of the time taken by the vehicles in the ROI from the moment that the accident vehicle starts to multicast the video data until the vehicles receive the required video data.
2) Success Warning Ratio: the proportion of the number of vehicles that successfully decode the video before leaving the ROI to the number of vehicles in the ROI at the initial moment, that is, the accident success warning rate = $\frac{|VH_{success}|}{N}$.
3) Average Peak Signal to Noise Ratio (PSNR): PSNR is generally used to measure quality of service in video transmission, and it is calculated from the mean-squared error distortion. The PSNR received by a vehicle is calculated between the original

video sequence and the recovered sequence, obtained by the vehicle after the cooperative transmission. The average PSNR of videos recovered by all vehicles in the ROI at the end of transmission is used to evaluate the video quality received by the vehicles.

4) Base Layer Decodable Ratio: For any vehicle vh_i, the successful reception of all packets in the base layer guarantees that it can decode out the base layer of the accident video and thus grasps the outline of the accident. This metric depicts the capabilities of algorithms for helping vehicle users figure out the basic situation on the road effectively. Denote the number of vehicles that can decode out the base layer successfully as N_{BL}, the calculation of base layer decodable ratio is as follows: Base Layer Decodable Ratio = $\frac{N_{BL}}{N}$.
5) Average User Satisfaction: For vehicle user vh_i whose required video recovery quality is $E_i = j$, if vh_i finally decodes the accident video to the l_{j-x} layer, $0 \leq x \leq j$, before it leaves the ROI, in other words, vh_i is not completely satisfied and it's satisfaction can be calculated as $S_i = \frac{(j-x+1)}{j+1}$. The average user satisfaction can be calculated as $Sa = \frac{\sum_{i=1}^{N} S_i}{N}$. This metric portrays the capabilities of algorithms to serve vehicle users as efficient as possible in a progressive way. In case a vehicle cannot recover its required SVC layers, the gradually cached packets can still provide improving video quality which is meaningful in the accident warning scenario.

5.2. Simulation results

5.2.1. Average transmission delay

The results of average transmission delay are shown in Fig. 4. It can be seen from the figure: (1) The proposed mechanism achieves the shortest transmission delay among all comparison algorithms, indicating that it can alarm vehicles in the fastest way and thus creates enough time windows for vehicles taking the most favorable actions to handle the situation. The reason for this performance advantage is that the proposed mechanism considers not only the characteristics of V2V data communication, but also the SVC video characteristics and the user's personalized decoding requirements, in both directional vehicles' multicast. (2) The average transmission delay increases with the number of vehicles in the ROI. When the number of vehicles in the ROI increases, more vehicles will be affected by the accident and more vehicles need to be warned timely. Thus, the network load increases and the transmission time for each vehicle increases, resulting the increasing average transmission delay. However, it can be seen that the increment of average transmission delay of the proposed mechanism is slower than that of other comparison algorithms, and the curve is more flat. In other words, the video alert dissemination speed of the proposed mechanism is hardly affected by the vehicle density. This is because the proposed mechanism uses distributed and dynamic algorithms for the clustering-based and relay multicasts, which adapt to varying number of vehicles and adjust timely. This characteristic enables the proposed mechanism to work well in highway environment, especially for jammed ones.

5.2.2. Success warning ratio

Fig. 5 shows the experimental results of the success warning ratio. It can be seen that as the number of vehicles in the ROI increases, the success warning ratio increases. That is, the number of vehicles successfully decoding the accident video to their required qualities in the ROI continues to increase. This is because with the increment of vehicles, the cooperative transmission opportunities between vehicles increase, and vehicles have a greater probability of obtaining required video data before leaving the ROI. In addition, the success warning ratio of the proposed algorithm is higher than that of the comparison algorithms under different number of vehicles, which indicates that the proposed algorithm can better adapt to the transmission of accident video messages under different vehicle densities, and provides timely and effective warning to vehicles in the affected area.

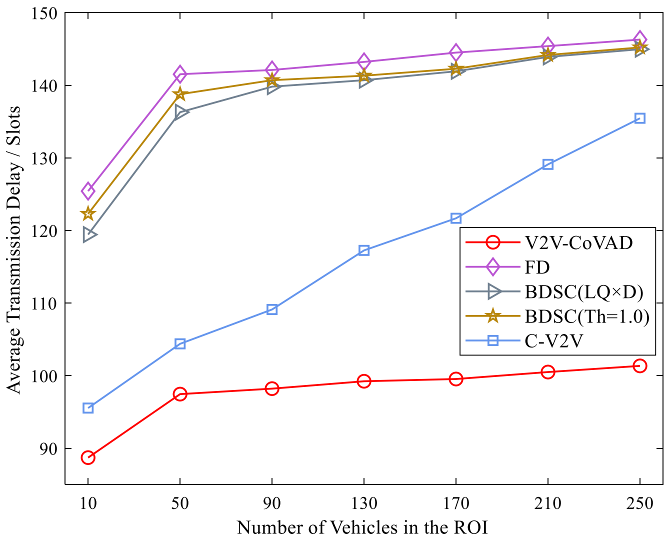

Fig. 4. Average Transmission Delay vs Number of Vehicles in the ROI.

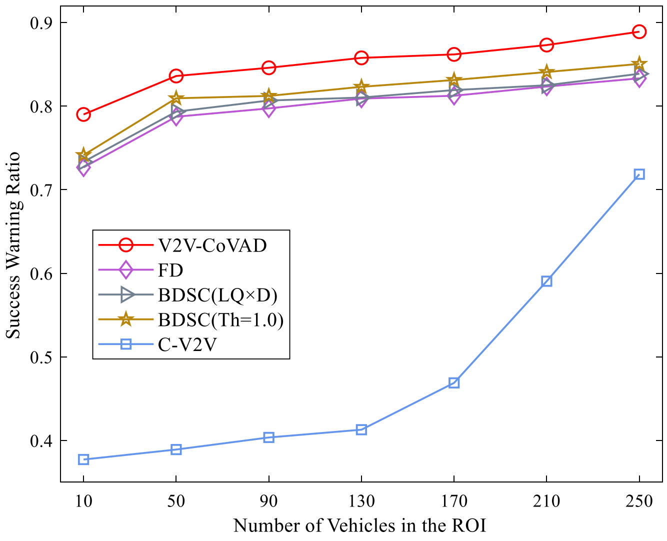

Fig. 5. Success Warning Ratio vs Number of Vehicles in the ROI.

5.2.3. Average PSNR

The results of average PSNR are shown in Fig. 6. It can be seen from the figure: (1) The average PSNR increases with the increment of vehicles in the ROI. This is because with dense vehicles in the ROI, more cooperative opportunities are explored and more reliable transmission can be accomplished. Moreover, the driving speed of a vehicle is sensitive to the vehicle density on the road. The more vehicles, the slower their speeds, and the longer time they stay in the ROI. Therefore, vehicle users can receive more SVC packets before they leave the ROI, and thus recover more SVC layers to obtain higher PSNR. (2) The proposed V2V-CoVAD algorithm achieves the highest average PSNR under different number of vehicles in the ROI. In other words, V2V-CoVAD serves affected vehicle users the accident video with the best qualities averagely, so that drivers can make judgments wisely on the basis of high quality video alert.

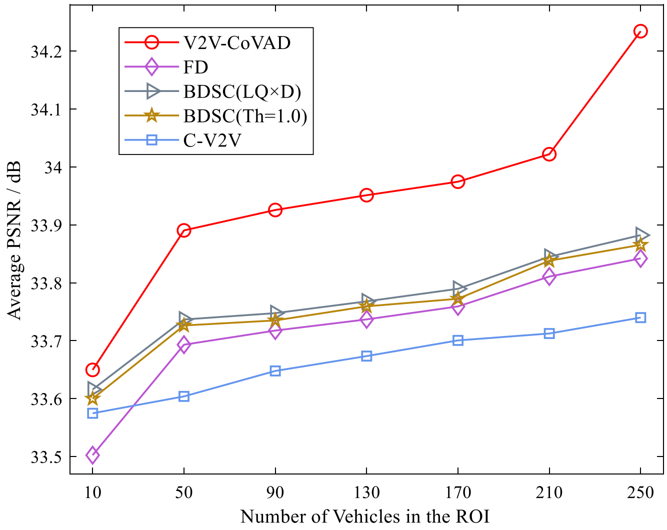

Fig. 6. Average PSNR vs Number of Vehicles in the ROI.

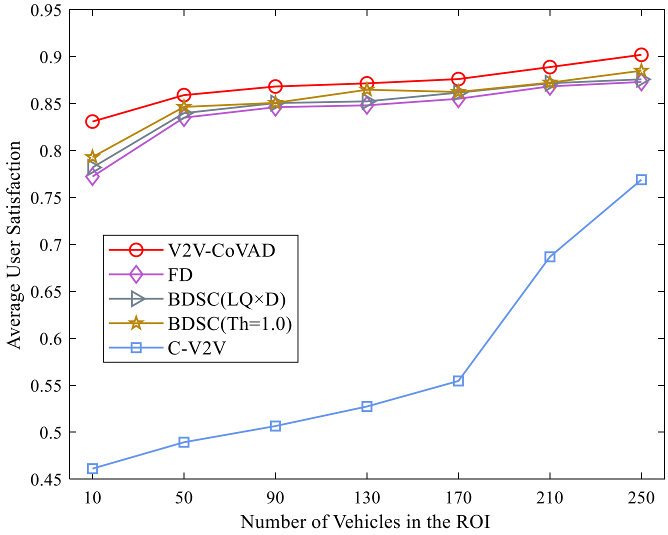

Fig. 8. Average User Satisfaction vs Number of Vehicles in the ROI.

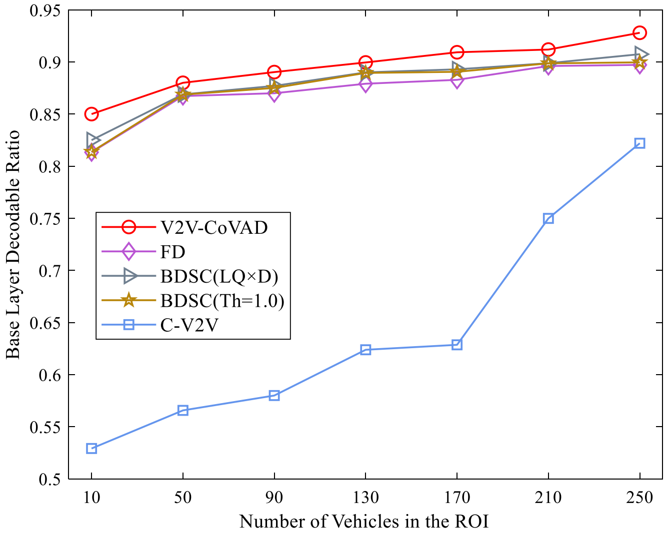

Fig. 7. Base Layer Decodable Ratio vs Number of Vehicles in the ROI.

5.2.4. Base layer decodable ratio

The simulation results of base layer decodable ratio are shown in Fig. 7. It is seen that the proposed mechanism can help the most vehicle users decode out the base layer successfully. With the proposed V2V-CoVAD, vehicle users are encouraged to receive a basic quality accident video with higher probabilities, comparing to other algorithms. The successful decoding of base layer is very important since vehicle users cannot take any action until they can decode out the base layer, and it is also the fundation for further decoding and quality improvement. Thus, the highest base layer decodable ratio of V2V-CoVAD justifies its effectiveness in disseminating SVC video for accident alerting in IoVs. Meanwhile, it is also seen that the base layer decodable ratios of all algorithms increase with the number of vehicles in the ROI. The reason is similar with that in Fig. 5 and Fig. 6.

5.2.5. Average user satisfaction

Fig. 8 presents the simulation results of average user satisfaction under varied number of vehicles. It is noticed that the proposed V2V-CoVAD achieves the highest average user satisfaction with different vehicle densities in the ROI, indicating that V2V-CoVAD serves the most vehicle users with their required video qualities among all algorithms. Meanwhile, V2V-CoVAD manages to maximize the cooperative opportunities among bidirectional vehicles, as well as the utilization of channel resources, thus provides SVC packets for vehicle users as many as possible. With V2V-CoVAD, even if a vehicle fails to receive enough packets for decoding its requested video quality, it can still receive more packets and recover a better video than that with other comparison algorithms. This appealing property of V2V-CoVAD enables vehicle users to make the most suitable driving decisions for themselves, which in turn realizes the most effective accident warning and damage control.

6. Conclusion

Due to the high speed movement of vehicles on the highway, accidents happen from time to time and serious casualties and economic losses are introduced. IoVs has great potential in improving traffic efficiency and safety. Through rapid and accurate data dissemination between vehicles, timely accident warning can be realized and the expansion of the impact of accident, as well as the occurrence of secondary accidents, can be avoided. This paper considers not only the data communication particularities in IoVs such as vehicle speed, position, driving direction, and channel conditions, but also SVC data characteristics such as the sequentially decreased importance of video layers and the decoding dependency exists between different video layers. The difficulties and performance degradation introduced by the vehicle heterogeneity are thoroughly studied and a V2V-Cooperative Video Alert Dissemination mechanism is designed. Vehicles run to the scene of accident are formed into clusters and cooperative transmission within clusters are proposed, while reverse relays are selected from vehicles on the opposite lanes and cooperative transmission between relay vehicles and equidirectional vehicles are performed as a complement. Simulation results show that the proposed mechanism can effectively increase the accident warning ratio, improve the quality of accident video received by vehicles, and reduce the video transmission delay.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This study was supported by the National Natural Science Foundation of China (Grant No. 61962032, 61561029), Yunnan Ten Thousand Talents Plan Young & Elite Talents Project (Grant No. YNWR-QNBJ-2018-224), and Yunnan Province Fund for Excellent Young Scholars (Grant No. 202001AW070003).

References

[1] J. Wang, C. Jiang, Z. Kai, T. Quek, L. Hanzo, Vehicular sensing networks in a smart city: principles, technologies and applications, IEEE Wirel. Commun. 25 (1) (2018) 122–132.

[2] C.R. Storck, F. Duarte-Figueiredo, A survey of 5G technology evolution, standards, and infrastructure associated with vehicle-to-everything communications by Internet of vehicles, IEEE Access 8 (2020) 117593–117614.

[3] J. Wang, C. Jiang, H. Zhu, R. Yong, L. Hanzo, Internet of vehicles: sensing-aided transportation information collection and diffusion, IEEE Trans. Veh. Technol. 67 (5) (2018) 3813–3825.

[4] L. Tao, Y. Watanabe, Y. Li, S. Yamada, H. Takada, Collision risk assessment service for connected vehicles: leveraging vehicular state and motion uncertainties, IEEE Int. Things J. 8 (14) (2021) 11548–11560.

[5] S. Heo, W. Yoo, H. Jang, J.M. Chung, H-V2X mode 4 adaptive semipersistent scheduling control for cooperative Internet of vehicles, IEEE Int. Things J. 8 (13) (2021) 10678–10692.

[6] B. Yang, R. Chen, B. Li, C. Li, Multi-vehicle cooperative positioning based on edge-computed multidimensional scaling, China Commun. 18 (6) (2021) 53–63.

[7] L.-W. Chen, Y.-F. Ho, Centimeter-grade metropolitan positioning for lane-level intelligent transportation systems based on the Internet of vehicles, IEEE Trans. Ind. Inform. 15 (3) (2019) 1474–1485.

[8] Y. Zhang, C. Li, T.H. Luan, C. Yuen, Y. Fu, H. Wang, W. Wu, Towards hit-interruption tradeoff in vehicular edge caching: algorithm and analysis, IEEE Trans. Intell. Transp. Syst. (2021) 1–13.

[9] Y. Zhang, C. Li, T.H. Luan, Y. Fu, W. Shi, L. Zhu, A mobility-aware vehicular caching scheme in content centric networks: model and optimization, IEEE Trans. Veh. Technol. 68 (4) (2019) 3100–3112.

[10] X. Fan, D. Liu, B. Fu, S. Wen, Optimal relay selection for UAV-assisted V2V communications, Wirel. Netw. 27 (5) (2021) 3233–3249.

[11] N. Azzaoui, A. Korichi, B. Brik, M. Fekair, Towards optimal dissemination of emergency messages in Internet of vehicles: a dynamic clustering-based approach, Electronics 10 (8) (2021).

[12] J. Wang, L. Kai, X. Ke, C. Chao, H.S. Sang, Dynamic clustering and cooperative scheduling for vehicle-to-vehicle communication in bidirectional road scenarios, IEEE Trans. Intell. Transp. Syst. 19 (6) (2018) 1913–1924.

[13] C.X. Wang, B. Ji, S. Jian, W. Zhang, M. Zhang, A survey of 5G channel measurements and models, IEEE Commun. Surv. Tutor. 20 (4) (2018) 3142–3168.

[14] H. Jiang, M. Mukherjee, J. Zhou, J. Lloret, Channel modeling and characteristics for 6G wireless communications, IEEE Netw. 35 (1) (2021) 296–303.

[15] H. Jiang, Z. Zhang, L. Wu, J. Dang, G. Gui, A 3-D non-stationary wideband geometry-based channel model for MIMO vehicle-to-vehicle communications in tunnel environments, IEEE Trans. Veh. Technol. 68 (7) (2019) 6257–6271.

[16] S. Wang, Q. Zhang, S. Lu, NCaAC: network coding-aware admission control for prioritized data dissemination in vehicular ad hoc networks, Wirel. Commun. Mob. Comput. 2020 (1) (2020) 1–14.

[17] S. Wang, S. Lu, Q. Zhang, Instantly decodable network coding–assisted data dissemination for prioritized services in vehicular ad hoc networks, Int. J. Distrib. Sens. Netw. 15 (4) (2019).

[18] C. Xu, W. Quan, H. Zhang, L.A. Grieco, GrIMS: green information-centric multimedia streaming framework in vehicular ad hoc networks, IEEE Trans. Circuits Syst. Video Technol. 28 (2) (2018) 483–498.

[19] H.264: Advanced Video Coding for Generic Audiovisual Services, International Telecommunication Union, ITU, https://www.itu.int/rec/T-REC-H.264-201906-I/en, 2019.

[20] S. Boumerdassi, E. Renault, A flooding-based solution to improve location services in VANETs, in: IEEE International Conference on Communications (ICC), 2016, pp. 1–6.

[21] L. Liu, C. Chen, T. Qiu, M. Zhang, S. Li, B. Zhou, A data dissemination scheme based on clustering and probabilistic broadcasting in VANETs, Veh. Commun. 13 (2018) 78–88.

[22] M. Ali, A.W. Malik, A.U. Rahman, S. Iqbal, M.M. Hamayun, Position-based emergency message dissemination for Internet of vehicles, Int. J. Distrib. Sens. Netw. 15 (7) (2019).

[23] H. Barkouk, E.M. En-Naimi, Development of an alert message dissemination protocol based on LEACH protocol to improve VANET road safety, in: 2016 4TH IEEE International Colloquium on Information Science and Technology (CIST), 2016, pp. 923–928.

[24] D. Tian, C. Liu, X. Duan, Z. Sheng, Q. Ni, M. Chen, V.C.M. Leung, A distributed position-based protocol for emergency messages broadcasting in vehicular ad hoc networks, IEEE Int. Things J. 5 (2) (2018) 1218–1227.

[25] E.B. Smida, S.G. Fantar, H. Youssef, Video streaming forwarding in a smart city's VANET, in: 2018 IEEE 11th Conference on Service-Oriented Computing and Applications (SOCA), 2018.

[26] M.A. Javed, J.Y. Khan, D.T. Ngo, Multimedia transmission for emergency services in VANETs, in: 2014 IEEE 80th Vehicular Technology Conference (VTC Fall), 2014.

[27] C. Rezende, A. Mammeri, A. Boukerche, A.A.F. Loureiro, A receiver-based video dissemination solution for vehicular networks with content transmissions decoupled from relay node selection, Ad Hoc Netw. 17 (2014) 1–17.

[28] S. Duan, B. Alkandari, Z. Wang, K. Pahlavan, Enhanced throughput capacity scheme for broadcasting emergency video in vehicle swarm, in: Vehicular Technology Conference, 2016.

[29] M. Xing, J. He, L. Cai, Utility maximization for multimedia data dissemination in large-scale VANETs, IEEE Trans. Mob. Comput. 16 (4) (2017) 1188–1198.

[30] M.A. Yaqub, S.H. Ahmed, D. Kim, Asking neighbors a favor: cooperative video retrieval using cellular networks in VANETs, Veh. Commun. 12 (2018) 39–49.

[31] M.A. Labiod, M. Gharbi, F.-X. Coudoux, P. Corlay, N. Doghmane, Cross-layer scheme for low latency multiple description video streaming over vehicular ad-hoc NETworks (VANETs), AEÜ, Int. J. Electron. Commun. 104 (2019) 23–34.

[32] R. An, Z. Liu, Y. Ji, Video streaming for highway VANET using scalable video coding, in: Vehicular Technology Conference, 2014.

[33] R. An, Z. Liu, Y. Ji, SVC-based cooperative video streaming in highway vehicular networks, in: International Conference on Advanced Information Networking and Applications Workshops, 2017.

[34] O.B. Rhaiem, L.C. Fourati, W. Ajib, Multi-segment cooperative transmission of scalable video streaming over vehicular networks, in: 2019 IEEE Wireless Communications and Networking Conference (WCNC), 2019.

[35] E. Yaacoub, F. Filali, Cluster based V2V communications for enhanced QoS of SVC video streaming over vehicular networks, in: 2014 International Wireless Communications and Mobile Computing Conference (IWCMC), 2014.

[36] E. Yaacoub, F. Filali, A. Abu-Dayya, QoE enhancement of SVC video streaming over vehicular networks using cooperative LTE/802.11p communications, IEEE J. Sel. Top. Signal Process. 9 (1) (2015) 37–49.

[37] J. Meinil, P. Kysti, T. Jms, L. Hentil, WINNER II Channel Models, John Wiley and Sons, Ltd, 2009.

[38] T. Fan, W. Chen, C. Li, X. Shu, F. Chang, Small scale characteristics analysis on highway V2V channel for intelligent transportation systems, in: 2019 5th International Conference on Transportation Information and Safety (ICTIS), 2019.

[39] Osama Rehman, Mohamed Ould-Khaoua, A hybrid relay node selection scheme for message dissemination in VANETs, Future Gener. Comput. Syst. 93 (2019) 1–17.

[40] R. Jiang, Q. Wu, Z. Zhu, Full velocity difference model for a car-following theory, Phys. Rev. E 64 (1) (2001).