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A Mobicast Routing Protocol in Vehicular Ad-Hoc Networks

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Abstract In this paper, we present a "spatiotemporal multicast", called a "mobicast", protocol for supporting applications which require spatiotemporal coordination in vehicular ad hoc networks (VANETs). The spatiotemporal character of a mobicast is to forward a mobicast message to vehicles located in some geographic zone at time *t*, where the geographic zone is denoted as zone of relevance (ZOR). Vehicles located in ZOR at the time *t* must keep the connectivity to maintain the real-time data communication between all vehicles in ZOR. The connectivity is kept of all vehicles in ZOR through the vehicular ad hoc networks (VANETs). The connectivity of ZOR is lost if any vehicle in ZOR suddenly accelerates or decelerates its velocity. The temporal network fragmentation problem is occurred such that vehicle in ZOR cannot successfully receive the mobicast messages. To solve the problem, a new mobicast protocol is presented in this work to successfully disseminate mobicast messages to all vehicles in ZOR via a special geographic zone, called as zone of forwarding (ZOF). The main contribution of this work is to develop a new mobicast routing protocol to dynamically estimate the accurate ZOF to successfully disseminate mobicast messages to all vehicles in ZOR. To illustrate the performance achievement, simulation results are examined in terms of dissemination successful rate, packet overhead multiplication, packet delivery delay, and throughput.

Keywords vehicular ad hoc network · spatiotemporal multicast · mobicast · routing

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1 Introduction

The vehicular ad hoc network (VANET) is the promising and important networking techniques for building the Intelligent Transportation System (ITS) [1]. A VANET is composed of vehicles, while each one has wireless communication device to transmit and receive emergency messages for collision warning and avoidance or broadcast advertisement messages for infotainment service. To provide the short range inter-vehicle wireless communication, Dedicated Short Range Communication (DSRC) standard is developed by ASTM [1]. The VANET is a special case of mobile ad hoc networks (MANETs) [1]. It is known that MANETs is an infrastructureless communication model without any assistance of roadside units. The VANET fundamentally has quite different properties than MANET, such that the fast changeable network topology, high mobility model, and frequent temporary network fragmentation. These new properties of VANETs increases the difficulties of designing protocols in VANETs.

A new multicast communication paradigm called a "spatiotemporal multicast" or "mobicast" was recently investigated in [2–6] which support spatiotemporal coordination in applications over wireless sensor networks (WSNs) [7–9]. The distinctive feature of mobicast is the delivery of information to all nodes that happen to be in a prescribed region of space at a particular point in time, which is necessary for VANETs to provide safety applications for drivers. However, VANETs are fundamentally different to WSNs, such as the property of mobility and rapid changed topology. It is known that VANET is composed of a set of mobile vehicles and WSN is composed of a set of static sensor nodes [10]. The topology of WSNs is stable, but the topology of VANET is rapidly changed. This key difference leads to existing mobicast protocols on WSNs can not be directly applied to VANET. Consequently, we propose a new mobicast protocol to consider the interest property of VANETs. This prescribed region is a geographic zone and is denoted *zone of relevance* (ZOR). The set of multicast message recipients is specified by a *zone of forwarding* (ZOF). This is observed that ZOR and ZOF continuously moves and evolves over time. With keeping the suitable ZOR and ZOF for a moving vehicle, the shape and size of ZOF at different time intervals greatly differs. This provides a mechanism for application developers to express their needs for spatial and temporal information dissemination through the VANETs. In this paper, the spatiotemporal character of a mobicast is to disseminate a mobicast message to all mobile vehicles that will be present at time t in the ZOR, where both the location and shape of the ZOR are a function of time over some interval $(t_{\text{start}}, t_{\text{end}})$. The mobicast is constructed of a series of ZORs over different intervals $(t_{\text{start}}, t_{\text{end}})$, and only mobile vehicles located in the ZOR in the time interval $(t_{\text{start}}, t_{\text{end}})$ must keep the connectivity in order to maintain the real-time data communication between all mobile vehicles in ZOR. The connectivity is kept of all mobile vehicles in ZOR through the vehicular ad hoc networks. That is, all vehicles in ZOR must receive the mobicast messages sent from a source vehicle in ZOR.

One of the challenges posed by this problem is how to develop an efficient mobicast protocol under highly changeable topology and temporal network fragmentation to guarantee that vehicles in the ZOR can successfully receive the mobicast messages in VANETs. The design difficulties is stated as follows. Most of the traffic cases, vehicle must moves at a different velocity, $\overrightarrow{v}$, in the time interval $(t_{\text{start}}, t_{\text{end}})$ in the road. If one vehicle of ZOR accelerates or decelerates its velocity, from $\overrightarrow{v}$ to $\overrightarrow{v'}$, in the time interval $(t_{\text{start}}, t_{\text{end}})$, the connectivity of this vehicle is different. Some vehicles in ZOR may unsuccessfully receive the mobicast messages due to loss the connectivity. This condition also called as temporal network fragmentation problem. To overcome the problem, a mobicast protocol in VANETs is presented to successfully disseminate mobicast messages to all vehicles in ZOR via the vehicles of ZOF. The main contribution of this work is to develop a new mobicast protocol to accurately estimate the ZOF to achieve the high dissemination successful rate.

The rest of this paper is organized as follows. Section 2 reviews related works. Section 3 defines the system model, motivation, and describes the basic idea of our scheme. Section 4 presents the new mobicast routing protocol. Performance analysis is discussed in Section 5. Finally, Section 6 concludes this paper.

2 Related works

Protocol for supporting *mobicast* is not yet investigated in VANETs, but similar problems [2–6] had been investigated in wireless sensor networks (WSNs). A spatiotemporal multicast protocol, namely a mobicast, was presented in WSNs [2–6]. The spatiotemporal characteristic of a mobicast is to forward a message to all nodes that will be present at time t in the forwarding zone. Huang et al. [6] developed a mobicast routing protocol, called face-aware routing (FAR). The FAR protocol is a geometric routing protocol which provides reliable routing results. Chen et al. [2, 3] proposed a variant-egg (VE)-based mobicast routing protocol in sensornets. This VE-mobicast protocol can adaptively and efficiently determine the location and shape of the message forwarding zone.

However, all existing mobicast routing strategies are only applied to WSNs. It is observed that VANET is natively different from WSN. A VANET consists of mobile vehicles, while WSN is composed of static sensor nodes [10]. The topology of WSNs is always stable, but topology of VANETs is rapidly changed. This causes the *link connectivity* problem or *frequent temporary network fragmentation* problem in VANETs. With *frequent temporal network fragmentation* problem, mobicast messages may not be successfully received. VANETs incurred the *frequent temporal network fragmentation* problem, but this problem has never occurred in WSNs. Mobicast protocols must be carefully designed to overcome the *frequent temporal network fragmentation* problem in VANETs [11]. Efforts will be made in this work to develop a new mobicast protocol in VANETs.

Some geographic routing results in VANETs are present to improve the efficiency for transmitting messages to a geographic region [12–15]. To send messages to a specific location in VANETs, Briesemeister and

Hommel [14] proposed a messages disseminating mechanism, by utilizing a distance-based backoff scheme, among highly mobile vehicles. To send messages to vehicles in a geocast region, Bachir et al. [12] proposed a *geocast* for inter-vehicle communication based on routing schemes in [14]. This approach uses periodic broadcasts to overcome temporary network fragmentation. The re-broadcast period is calculated based on the maximum vehicle speed. Maihofer et al. [15] proposed geocast approach by keeping the message for a certain period of time when the message enters into the geocast region. Joshi et al. [13] also proposed a distributed robust geocast protocol for inter-vehicle communication to consider the problem of frequent topology changes and network fragmentation. The zone of relevance (ZOR) is first defined in [13] as a geographic region which vehicles in this region should receive the geocast messages. To enhance the reliability of receiving geocast messages under frequent changeable topology, the zone of forwarding (ZOF) is defined in [13] as the geographic region which vehicles in this region should forward the geocast messages to other vehicles in the ZOR. Note that, ZOF usually surrounds ZOR to ensure the geocast messages can be delivered to vehicles inside ZOR. A periodic retransmission mechanism is proposed in [13] to overcome the network fragmentation.

The geocast routing protocols [12–15] successfully transmit messages to a geocast region in VANETs. However, these protocols can not apply to transmit real-time messages to a dynamically prescribed region which is surrounded by a moving vehicle at time t. That is difficult to handle emergency traffic situation, such as warning notifications initiated from a suddenly braking vehicle. Considered such a vehicle, called as an *event vehicle* [16], we assumed that the brake system of the event vehicle is suddenly and partially failed at time t. All vehicles after the event vehicle, formed a *dangerous* region, encounter a dangerous condition at time t. Observe that, the event vehicle keeps on moving. At time $t+1$, the location of dangerous region is different. It is observed that the dangerous region is simultaneously moving with the event vehicle. The event vehicle must continuously send warning notification to vehicles in the dangerous region to avoid the accident. Existing geocast routing protocols in VANETs can not fully support above requirements. In fact, vehicles inside the dangerous region are difficult to receive warning notifications at time t. This paper proposes a distributed mobicast routing protocol to disseminate mobicast messages to all vehicles in the prescribed dangerous region at time t. This prescribed dangerous region is a geographic zone and is denoted as ZOR_t in this work. To our knowledge, this work is the first study to develop the mobicast routing protocol in VANETs.

3 Preliminaries

This section presents the system model. The contribution and the application examples are also introduced.

3.1 System model

When a vehicle moves at a high speed, the velocity variation between each pair of vehicles is large. The distance between each pair of vehicles quickly changes from time t to time $t+1$. This offers the temporal network fragmentation problem. A vehicle easily moves out of the communication range of the event vehicle and fail to receive mobicast messages. This observations shows that the stable routing is not suitable for mobicasting. Our mobicast routing protocol adopts dynamic forwarding zone to disseminate mobicast messages.

A special case of a “spatiotemporal multicast” protocol is introduced for supporting applications which require spatiotemporal coordination in VANET. This spatiotemporal multicast protocol provides applications that need to disseminate the multicast message to the “right” place (or prescribed region) at the “right” time. In a VANET, a vehicle is said as an *event vehicle* [16] or V_e if an abnormal condition or faulty event is detected and triggered from sensor devices and onboard unit (OBU) of the vehicle. Mobicast messages are initiated from V_e to notify nearby vehicles to avoid the accident. A prescribed region is determined by the event condition if the event is triggered. This prescribed region indicates a coverage area centered on V_e. All vehicles in this region possibly be involved the accident with V_e. To avoid the accident with V_e, these vehicles must receive the mobicast messages from V_e before the accident is occurred. For this purpose, the center of the prescribed region should be the same with location of V_e at any time; therefore, the prescribed region is moving at the same speed as V_e, and toward the same direction with V_e. Furthermore, the large or small size of the prescribed region is depended on the speed of V_e.

In the following, we define ZOR_t (zone of relevance), ZOF_t (zone of forwarding), and $\text{ZOA}_t^{V_i}$ (zone of approaching). Let V_i denote as the vehicle ID and v_{i_t} denote as the velocity of V_i at time t, where $i = \{e, 1, 2, ..., i, i+1, ..., n\}$ throughout this paper. Event vehicle V_e is the mobicast-initiated vehicle which initiates a mobicast routing protocol to disseminate the

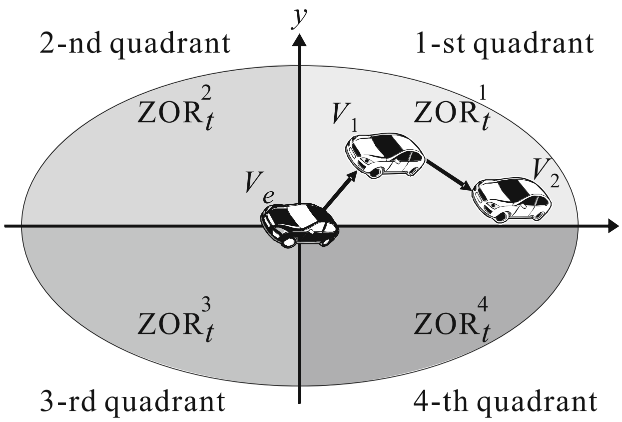


Fig. 1 ZOR_t is the union set of $ZOR_t^1 \cup ZOR_t^2 \cup ZOR_t^3 \cup ZOR_t^4$

mobicast messages to other vehicles in the ZOR_t. For instance as shown in Fig. 1, V_e is an event vehicle and v_{e_t} is the velocity of V_e at time t.

ZOR_t is the prescribed region to indicate which vehicle is relevant to the event occurred on V_e and V_e should announce the condition of event to those vehicles for accident avoidance by disseminating the mobicast message.

Definition ZOR_t(zone of relevance) Given an event vehicle V_e, ZOR_t is an elliptic region determined by V_e at time t, such that vehicle V_i must be successfully received the mobicast message from V_e at time t, where each V_i is located in the ZOR_t. In this work, ZOR_t is split into four quarters, each one is a sub-zone of relevance; they are ZOR_t^1, ZOR_t^2, ZOR_t^3, and ZOR_t^4, respectively. Let ZOR_t^q, $q = \{1, 2, 3, 4\}$, denote a sub-zone of relevance in the q-th quadrant, where V_e is the circle center. Let ZOR_t be constructed by a union of four sub-zones of relevance, where $ZOR_t = \bigcup_{q \in \{1,2,3,4\}} ZOR_t^q$. The center location of ZOR_t is the same with the location of V_e, moving at the same speed as V_e, and toward the same direction with V_e.

Figure 1 shows an example of $ZOR_t = ZOR_t^1 \cup ZOR_t^2 \cup ZOR_t^3 \cup ZOR_t^4$, V_e should send the mobicast message to V_1 and V_2 in ZOR_t^1. Figure 2 gives a continuous-time example of ZOR_i, where $i = t...t+2$, with the temporal network fragmentation problem. The transmission range of each vehicle is assumed to r. Initially, V_e detects an emergency event at time t to form a ZOR_t. V_1 and V_3 are involved by this event and indicated to receive the mobicast message by ZOR_t. V_1 and V_3 are located within the transmission range of V_e; thus V_e directly disseminates the mobicast message to V_1 and V_3. At time $t+1$, V_2 and V_4 approach V_e and they are indicated to receive the mobicast message by ZOR_{t+1}. Observed that although V_4 is out of transmission range of V_e, V_4 can receive the mobicast message by relaying from V_1. At time $t+2$, V_1 moves away from V_4 and V_2 moves out of transmission range of V_e; thus V_2 and V_4 can not receive the mobicast message. The temporal network fragmentation problem occurred on V_2 and V_4. ZOF_t is introduced later to solve this problem.

To overcome the temporal network fragmentation problem, ZOF_t is used to disseminate the mobicast message to all vehicles located in the ZOR_t. The formal definition of ZOF_t is given.

Definition ZOF_t(zone of forwarding) Given a V_e, ZOF_t is a geographic region determined by V_e at time t, such that each vehicle V_j has the responsibility of forwarding the mobicast message sent from vehicle V_e, where V_j is located in the ZOF_t . In this work, ZOF_t is split into four quadrants, each one is a forwarding sub-zones; they are ZOF_t^1, ZOF_t^2, ZOF_t^3, and ZOF_t^4, respectively. Let ZOF_t^q, $q = \{1, 2, 3, 4\}$, denote a forwarding sub-zone in the q-th quadrant, where V_e is the circle center. Let ZOF_t be constructed by a union of four forwarding sub-zones, where $ZOF_t = \bigcup_{q \in \{1,2,3,4\}} ZOF_t^q$.

Observe that, ZOF_t is the union of $ZOF_t^1 \cup ZOF_t^2 \cup ZOF_t^3 \cup ZOF_t^4$, where ZOF_t indicates which vehicle

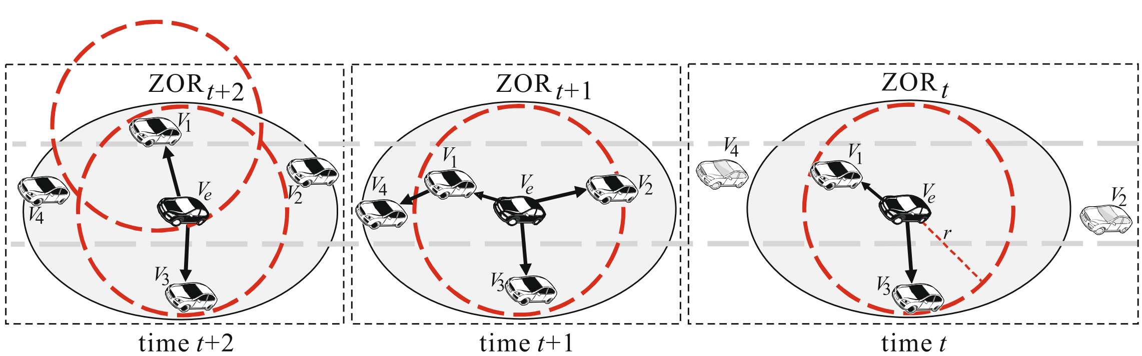


Fig. 2 Operation of mobicasting

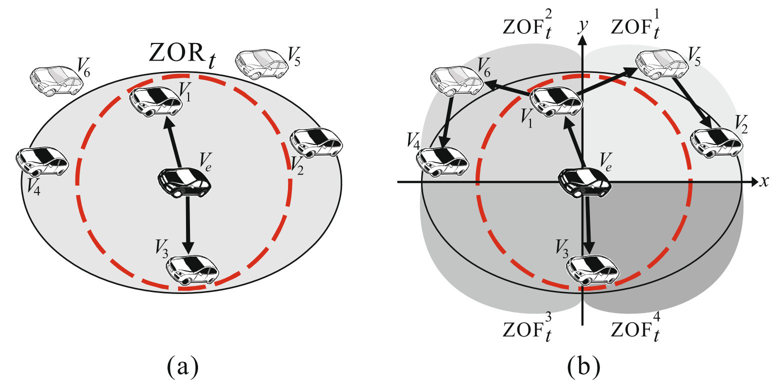


Fig. 3 **a** Temporal network fragmentation problem and **b** example of ZOF$_t$

should forward the mobicast message to other vehicles located in the ZOR$_t$. Figure 3a shows V_2 and V_4 can not receive the mobicast message due to the temporal network fragmentation problem. All vehicles in ZOF$_t$ must forward received mobicast messages, even those vehicles are not located in ZOR$_t$. Example of ZOF$_t$ is illustrated in Fig. 3b, V_5 and V_6 are located in ZOF$_t$ and have the responsibility of forwarding the mobicast message to V_2 and V_4, respectively. Normally, the size of ZOF$_t$ may be larger or smaller than the optimal size of ZOF$_t$. If the size of ZOF$_t$ is larger than the optimal size of ZOF$_t$, some irrelevant vehicles are asked to uselessly forward the mobicast message. If the size of ZOF$_t$ is smaller than the optimal size of ZOF$_t$, the temporal network fragmentation problem is incompletely overcame. Observe that, the size of ZOF $_t$ is difficult to predict and determined under the high speed environment, such that it easily wastes the network resources. Efforts will be made in this work to propose an efficient scheme to estimate the size of ZOF$_t$ is near to the optimal size of ZOF$_t$. Therefore, zone of approaching (ZOA$_t^{V_i}$ or Z$_t^{V_i}$) is proposed herein to accurately predict the ZOF$_t$.

Zone of approaching (ZOA$_t^{V_i}$ or Z$_t^{V_i}$) is the zone of approaching as defined below, ZOF$_t$ is constituted by some different ZOA$_t^{V_i}$ at time t, such that the size of the ZOF$_t$ is near to optimal size of ZOF$_t$. Observe that ZOA$_t^{V_i}$ is proposed herein to overcome the the temporal network fragmentation problem with the high dissemination successful rate and the lower network overhead.

Definition ZOA$_t^{V_i}$ or Z$_t^{V_i}$(zone of approaching) Let ZOA$_t^{V_i}$ or Z$_t^{V_i}$ denote as an elliptic zone of approaching to forward the mobicast message more closed to a destined vehicle and Z$_t^{V_i}$ is initiated by vehicle V_i at time t. Any vehicle in the Z$_t^{V_i}$ has the responsibility of forwarding the mobicast message sent from vehicle V_e. Z$_t^{V_i}$ bounds the mobicast message propagation, vehicles in the Z$_t^{V_i}$ can only forward the mobicast message to other vehicles located in the Z$_t^{V_i}$. If a vehicle cannot successfully forward the mobicast message to any neighbor vehicle in the Z$_t^{V_i}$ which is more closed to the destined vehicle, a new approaching zone is initiated.

We explain how to grow a new zone of approaching Z$_t^{V_{i+1}}$ from an existing zone of approaching Z$_t^{V_i}$ as follows. Given two connected approaching zones Z$_t^{V_i}$ and Z$_t^{V_{i+1}}$, if V_{i+1} in Z$_t^{V_i}$ cannot successfully forward the mobicast message to any neighbor vehicle closed to the destined vehicle, then V_{i+1} initiates a new zone of approaching Z$_t^{V_{i+1}}$, where V_{i+1} is located in Z$_t^{V_i}$. Therefore, multiple zones of approaching are initiated to forward the mobicast message in the q-th quadrant, such that ZOF$_t^q$ is finally formed by all initiated zones of approaching in the q-th quadrant. Therefore, we have ZOF$_t^q$ = ZOR$_t^q$ ∪ Z$_t^{V_1}$ ∪ ... ∪ Z$_t^{V_i}$ ∪ Z$_t^{V_{i+1}}$ ∪ ... ∪ Z$_t^{V_n}$, where $q = \{1, 2, 3, 4\}$. Observe that, ZOR$_t$ is the partial ZOF$_t$ since the mobicast message should be transmitted to all vehicles located in ZOR$_t$. Figure 4 gives an example of the detailed construction of ZOF$_t^1$. Both V_2 and V_4 cannot find out neighbors in ZOR$_t^1$, then Z$_t^{V_2}$ and Z$_t^{V_4}$ are initiated. Continually, V_8 cannot find out neighbors in Z$_t^{V_4}$ closed to V_5, V_8 then initiates Z$_t^{V_8}$. In addition, V_6 has similar condition as V_8, V_6 stops the forwarding since V_6 has no any neighbor vehicle. Finally, ZOF$_t^1$ = ZOR$_t^1$ ∪ Z$_t^{V_2}$ ∪ Z$_t^{V_4}$ ∪ Z$_t^{V_8}$.

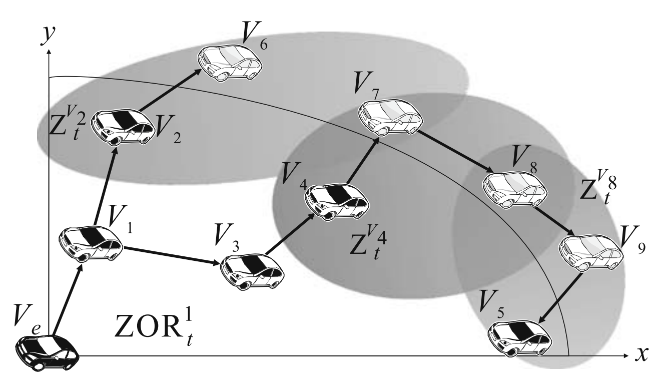


Fig. 4 Example of multiple ZOA$_t^{V_i}$

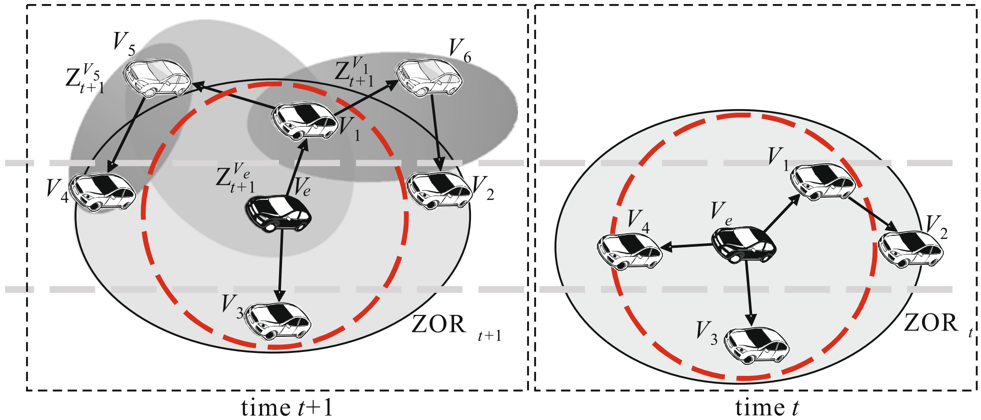


Fig. 5 Link disconnection due to the velocity variation

3.2 Contribution

In this paper, zone of approaching is proposed to dynamically form the forwarding zone to overcome temporal network fragmentation problem in order to forward the mobicast message to all vehicles located in ZOR_t. In existing investigations, a fixed size of ZOF_t is adopted to solve temporal network fragmentation problem. A fixed size of ZOF_t is difficult to handle the rapid changed topology and easily wastes the unnecessary network resource. Therefore, our mobicast routing protocol uses adaptable $ZOA_t^{V_i}$ to dynamically form flexible size ZOF_t to fit current topology at each time t. The contributions are summarized as follows: (1) our mobicast protocol builds a new adaptive and dynamic shape $ZOA_t^{V_i}$ to form the ZOF_t to adaptively determine the size, shape, and location of the forwarding zone to disseminate the mobicast messages to vehicles located in the ZOR_t under highly changeable topology; (2) our mobicast protocol is a fully distributed algorithm which effectively reduces the communication overhead of constructing the ZOF_t and the mobicast message forwarding overhead; (3) our mobicast routing protocol offers high dissemination successful rate using $ZOA_t^{V_i}$. Figure 5 illustrates at time t, V_1, V_2, V_3, and V_4 are located in ZOR_t and receive the mobicast message from vehicle V_e. At time $t+1$, V_2 and V_4 can not directly receive the mobicast messages due to temporal network fragmentation problem. Figure 5 demonstrates a mobicast example in four quarters. At time $t+1$, V_e, V_5, and V_1 initiate $Z_{t+1}^{V_e}$, $Z_{t+1}^{V_5}$, and $Z_{t+1}^{V_1}$ to forward the mobicast messages to vehicles V_4 and V_2. In this case, $ZOF_{t+1}^1 = ZOR_{t+1}^1 \cup Z_{t+1}^{V_1}$, $ZOF_{t+1}^2 = ZOR_{t+1}^2 \cup Z_{t+1}^{V_e} \cup Z_{t+1}^{V_5}$, $ZOF_{t+1}^3 = ZOR_{t+1}^3$, $ZOF_{t+1}^4 = ZOR_{t+1}^4$.

3.3 Application examples

Many interesting and useful applications on VANETs can be supported by our mobicast routing protocol, such as emergency event [17], online game [18], and video advertisement [19]. Our mobicast routing protocol can be effectively used for those VANETs applications for emergency warning, online game invitation, and video advertisement, as illustrated in Fig. 6. Figure 6a shows vehicle V_e has the control failure problem for a short period of time, and warning messages are sent to all nearby vehicles to avoid accident. By our mobicast routing protocol, warning messages can be sent to vehicles in the warning area to avoid accident. Figure 6b shows an online game application, vehicle

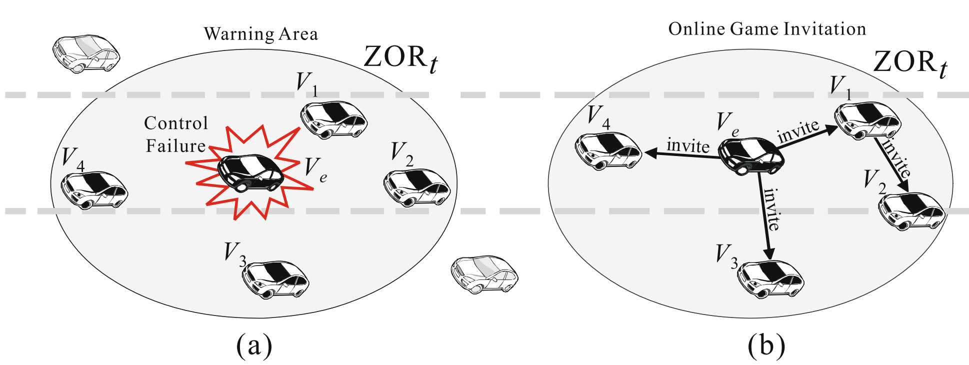


Fig. 6 Two mobicast application examples (**a**, **b**)

V_e can invite those nearby vehicles to be game-playing members for a longer period of time. Our mobicast routing protocol can make sure that the game information can disseminate to all members in the ZOR_t.

4 Mobicast routing protocol

This section presents the mobicast routing protocol. The mobicast routing protocol is split into three phases; (1) ZOR_t creation phase, (2) message dissemination phase, and (3) $\text{ZOA}_t^{V_i}$ growing phase. In the ZOR_t creation phase, ZOR_t is initiated by a V_e if an event is detected and triggered by the OBU of V_e. The region of ZOR_t is determined according to the condition of event. Then, V_e performs the messages dissemination phase. In the message dissemination phase, mobicast messages are disseminated to other vehicle V_i located in the ZOR_t. If the mobicast message can not be disseminated caused by the temporal network fragmentation problem, then $\text{ZOA}_t^{V_i}$ growing phase is executed. In the $\text{ZOA}_t^{V_i}$ growing phase, many $\text{ZOA}_t^{V_i}$ are initiated to dynamically cover ZOF_t in order to ensure all vehicles in the ZOR_t can successfully received the mobicast message. The detailed operation is developed as follows.

4.1 ZOR_t creation phase

The main task of this phase is to identify an elliptic region, ZOR_t, by V_e. In this work, the shape of ZOR_t assumes to be the elliptic due to the nature of vehicle driving. The result is quit different from similar results in WSNs [4–6] by adopting the circular shape. When V_e suddenly occurs an event, the coverage region is determined by the velocity and direction of V_e. Observe that, the coverage region of ZOR_t, in this investigation, is an ellipse as explained.

Theorem 1 *The shape of ZOR_t for an event vehicle V_e is an ellipse.*

Proof Let D_{V_i,V_j} denote the distance from V_i to V_j. Consider an example in Fig. 7a, vehicle V_e, V_{B^1}, V_{B^2}, ..., V_{B^x}, ..., V_{B^n} are moving with the same direction and velocity, then event vehicle V_e suddenly accelerates its velocity and moves forward to a new location V'_e, the distance between V_{B^1} and V_e is shifted from D_{V_e,V_B1} to $D_{V_{e'},V_B1}$, and the distance between V_{B^2} and V_e is shifted from D_{V_e,V_B2} to $D_{V_{e'},V_B2}$. Let D_{V_B1,V_B2} be Δ, D_{V_e,V_B1} be $\overrightarrow{u}$, and $D_{V_e,V_{e'}}$ be $\overrightarrow{v}$. Observe that, Δ is a very tiny distance. The increased distance for V_{B^1} is $D_{V_{e'},V_B1} - D_{V_e,V_B1} = |(\overrightarrow{v} + \overrightarrow{u})| - |\overrightarrow{u}| = |\overrightarrow{v}|$. The increased distance for V_{B^2} is $D_{V_{e'},V_B2} - D_{V_e,V_B2}$, where $D_{V_e,V_B2} = D_{V_e,V_B1} \times \sec\delta_1$ and $D_{V_{e'},V_B2} = D_{V_{e'},V_B1} \times \sec\theta_1$, then $D_{V_{e'},V_B2} - D_{V_e,V_B2} = (|\overrightarrow{v} + \overrightarrow{u}|) \times \sec\theta_1 - |\overrightarrow{u}| \times \sec\delta_1$, and $\theta_1 = \tan^{-1}\frac{\Delta}{|\overrightarrow{v}+\overrightarrow{u}|}$ and $\delta_1 = \tan^{-1}\frac{\Delta}{|\overrightarrow{u}|}$. Therefore, $D_{V_{e'},V_B2} - D_{V_e,V_B2} = (|\overrightarrow{v} + \overrightarrow{u}|) \times \sec(\tan^{-1}\frac{\Delta}{|\overrightarrow{v}+\overrightarrow{u}|}) - |\overrightarrow{u}| \times \sec(\tan^{-1}\frac{\Delta}{|\overrightarrow{u}|})$. Observe that, $|\overrightarrow{v}| > (|\overrightarrow{v} + \overrightarrow{u}|) \times \sec(\tan^{-1}\frac{\Delta}{|\overrightarrow{v}+\overrightarrow{u}|}) - u \times \sec(\tan^{-1}\frac{\Delta}{|\overrightarrow{u}|})$, it means that the increased distance for V_{B^1} is greater than V_{B^2}, while vehicle V_e moves to location V'_e. Then, we can deduce that the increased distance of V_{B^x} is $D_{V_{e'},V_Bx} - D_{V_e,V_Bx} = (|\overrightarrow{v} + \overrightarrow{u}|) \times \sec\theta_2 - |\overrightarrow{u}| \times \sec\delta_2$, and $\theta_2 = \tan^{-1}$

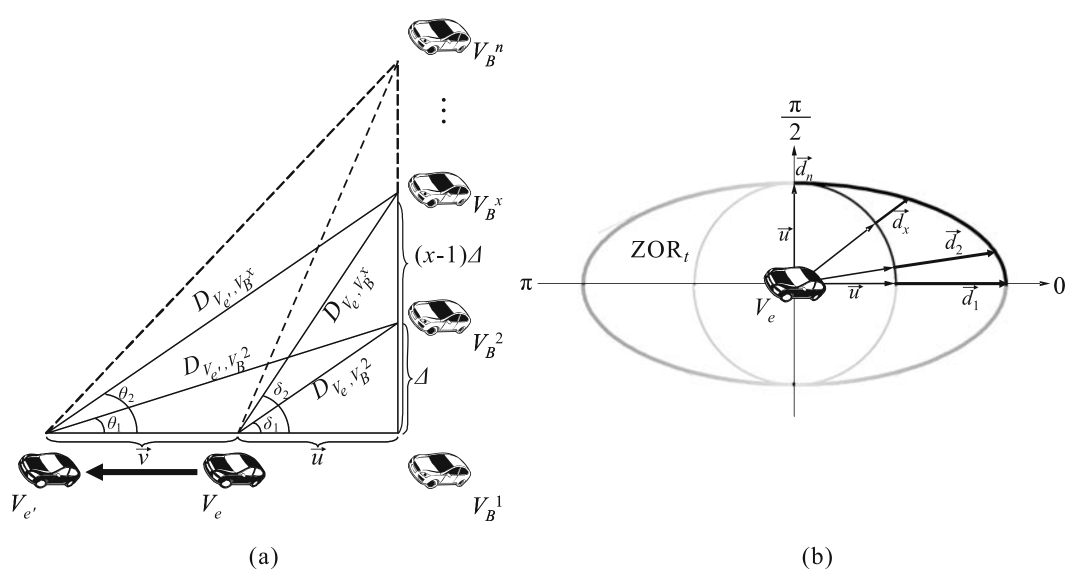


Fig. 7 The shape of ZOR_t for an event vehicle is an approximate ellipse (**a**, **b**)

$\frac{(x-1)\Delta}{|\vec{v}+\vec{u}|}$ and $\delta_2 = \tan^{-1}\frac{(x-1)\Delta}{|\vec{u}|}$. Therefore, $D_{V_{e'},V_{Bx}} - D_{V_e,V_{Bx}} = (|\vec{v}+\vec{u}|) \times \sec(\tan^{-1}\frac{(x-1)\Delta}{|\vec{v}+\vec{u}|}) - |\vec{u}| \times \sec(\tan^{-1}\frac{(x-1)\Delta}{|\vec{u}|})$. Let $|\vec{d_x}|$ denote as the increased distance for V_{B^x}, then $|\vec{d_x}| = D_{V_{e'},V_{Bi}} - D_{V_e,V_{Bi}}$. Observe that, we accumulate the increased distance $\vec{u}+\vec{d_x}$ around vehicle V_e, where $\vec{u}$ is the projection of $D_{V_e,V_{Bx}}$ onto $D_{V_e,V_{B1}}$, the equation is,

$$\int_{\theta=0,x=1}^{\theta=\frac{\pi}{2},x=n} |\vec{u}| + ((|\vec{v}+\vec{u}|) \times \sec\left(\tan^{-1}\frac{(x-1)\Delta}{|\vec{v}+\vec{u}|}\right) - |\vec{u}| \times \sec(\tan^{-1}\frac{(x-1)\Delta}{|\vec{u}|})dxd\theta). \quad (1)$$

The result of this integration in polar coordinates is given in Fig. 7b. From $\vec{d_1}$ to $\vec{d_n}$, the result shows a quarter of shape because we only accumulate from 0 to $\frac{\pi}{2}$. If we accumulate the increased distance $\vec{d_i}$ from 0 to 2π, we can have an approximate ellipse. Therefore, our mobicast routing protocol adopts the ellipse as the size of ZOR_t. □

Example is given in Fig. 8. The size of ZOR_t is determined according to the velocity of V_e. In this paper, each vehicle can acquire location information via location information provider, such as the GPS [20]. Let $(x_t^{V_i}, y_t^{V_i})$ denote as the location of V_i at time t. Each vehicle V_i sends its location $(x_t^{V_i}, y_t^{V_i})$ and velocity information v_{i_t} to its neighbors through the hello message $(V_i, (x_t^{V_i}, y_t^{V_i}), v_{i_t})$. Let $N(V_i)$ denote the set of neighboring vehicles of V_i, where $N(V_i)$ does not include V_i. Let P_L and P_R denote as the left apex P_L and the right apex P_R of the elliptic region (ZOR_t). Example is given in Fig. 8. We always assume a vehicle is located at P_x, where $x = L$ or R. Our mobicast protocol tries to disseminate the mobicast message to a *virtual* vehicle located at P_x, even no real vehicle exists at P_x. This way makes sure that the mobicast message can be disseminated to all vehicle located in ZOR_t. The procedure of the ZOR_t creation phase is given herein.

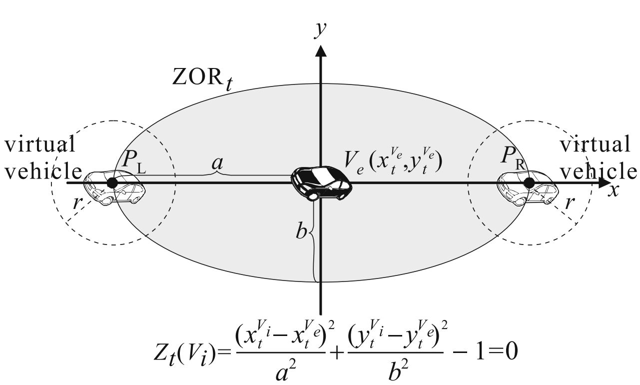


Fig. 8 Creation of ZOR_t

- S1 Event vehicle V_e acquires the location $(x_t^{V_e}, y_t^{V_e})$ and velocity v_{e_t} from its OBU.
- S2 The ellipse region of ZOR_t is determined by $Z_t(V_i) = \frac{(x_t^{Vi}-x_t^{Ve})^2}{a^2} + \frac{(y_t^{Vi}-y_t^{Ve})^2}{b^2} - 1 = 0$, where a is the major axis of the ellipse, $a = v_{e_t} \times \frac{1}{10} \times l_m$, l_m is the average length of vehicle, and b is the minor axis of the ellipse, which is determined by the width of lane.
- S3 The V_e broadcasts the mobicast control packet $P_m(V_e, Z_t(V_e), m)$, where P_m is the control packet to control the dissemination of mobicast message, V_e is the ID of current vehicle, $Z_t(V_e)$ describes the region of ZOR_t, and m is the content of mobicast message. After V_e broadcasting the P_m, message dissemination phase is executed.

In the Step 2, we assume the event is occurred from the brake system. Therefore, the major axis a is set as $v_{e_t} \times \frac{1}{10} \times l_m$ to provide driver to have the enough reaction time. Actually, the value of the major axis a is depended on different kind of the events. For instance, if the event is the game invitation, the major axis a is related to the relative distance to game invited members. As shown in Fig. 8, the ZOR_t is determined by $Z_t(V_i) = \frac{(x_t^{Vi}-x_t^{Ve})^2}{a^2} + \frac{(y_t^{Vi}-y_t^{Ve})^2}{b^2} - 1 = 0$. Vehicles located in the ZOR_t should receive the mobicast messages from V_e.

4.2 Message dissemination phase

In the message dissemination phase, vehicle V_j receives the mobicast control packet P_m from V_i and then forwards packet P_m if V_j is in the ZOR_t. Otherwise, V_j drops P_m. The mobicast control packet P_m is continuously disseminated until P_m approaches to the apex P_x, where $x = L$ or R. The procedure of the message dissemination phase is described below.

- S1 If V_j directly receives P_m from V_i and the location of V_j is $(x_t^{V_j}, y_t^{V_j})$, then packet P_m is forwarded from V_j if $Z_t(V_j) = \frac{(x_t^{V_j}-x_t^{V_e})^2}{a^2} + \frac{(y_t^{V_j}-y_t^{V_e})^2}{b^2} - 1 \leq 0$. Otherwise, V_j drops P_m and terminates the mobicast message dissemination.
- S2 Vehicle V_j decides the packet forwarding depended on the distance between V_i and apex P_x, $x = L$ or R. Let d_{V_i,P_x} denote the distance from vehicle V_i to apex P_x, $x = L$ or R. If $d_{V_i,P_x} > r$, V_j disseminates the mobicast message toward apex P_x, where r is the transmission range. Each

vehicle $V_i|Z_t(V_i) \leq 0$ must forward the mobicast message toward P_x until $d_{V_i,P_x} < r$, where $x = L$ or R. Observe that, the greater part of vehicles in ZOR_t received the mobicast message implies that the dissemination of mobicast messages is successfully done. The apex P_x is P_R or P_L depended on the current location in ZOR_t^q. Let $P_x = P_R$ if V_j is in ZOR_t^1 or ZOR_t^4. Let $P_x = P_L$ if V_j is in ZOR_t^2 or ZOR_t^3.

S3 Vehicle V_j dynamically verified the efficacy of dissemination before V_j broadcasts P_m if $d_{V_i,P_x} > r$. An effective dissemination is to disseminate the mobicast message closed to apex P_x, where $x = L$ or R. A dissemination is called as an effective dissemination if the following two conditions are satisfied; (C1) there at least exists one neighbor $V_k \in N(V_j)$ for V_j, where $Z_t(V_k) \leq 0$ and (C2) $d_{V_k,P_x} - d_{V_j,P_x} < 0$. The condition $Z_t(V_k) \leq 0|V_k \in N(V_j)$ means that the neighbor V_k is in ZOR_t and the condition $d_{V_k,P_x} - d_{V_j,P_x} < 0$ means that the location of V_k is closed to P_x than that of V_j . If the above two conditions are satisfied, then go to Step 4. Otherwise the ZOF_t expansion phase is executed.

S4 If $Z_t(V_k) \leq 0|V_k \in N(V_j)$ and $d_{V_k,P_x} - d_{V_j,P_x} < 0$, V_j broadcasts packet $P_m(V_j, Z_t(V_j), m)$. Before V_j broadcasts P_m, V_j waited for a random backoff time R_{time}, such that

$$R_{\mathrm{time}} = \frac{d_{V_j,P_x}}{d_{V_i,P_x}} \times r_{\mathrm{time}},$$

where r_{time} is a random time. If V_j receive the same P_m from $N(V_i)$ during R_{time} time period, then V_j does not broadcast, otherwise V_j broadcasts P_m if R_{time} of V_j is timeout. The use of random backoff time R_{time} is to prevent the broadcast storm problem [21]. A vehicle V_i closed to P_x has the high priority to forward. The *reachability* of P_m in $Z_t(V_i)$ can be improved, since if some neighbors of V_i are failed to receive the mobicast message from V_i, the other neighbors of V_i may re-broadcast P_m.

Figure 9 gives an example of the message dissemination phase in ZOR_t^2. Vehicle V_1 broadcasts $P_m(V_1, Z_t(V_1), m)$ to V_2 and V_3. The random backoff time R_{time} of V_2 and V_3 is $\frac{d_{V_2,P_L}}{d_{V_1,P_L}} \times r_{\mathrm{time}}$ and $\frac{d_{V_3,P_L}}{d_{V_1,P_L}} \times r_{\mathrm{time}}$, respectively. If R_{time} of V_3 < that of V_2, V_3 broadcasts $P_m(V_3, Z_t(V_3), m)$. Thus, V_2 receives $P_m(V_3, Z_t(V_3), m)$ from V_3, then stop the broadcasting. Similarly, V_4 receives the mobicast control message and try to broadcast; however, V_4 can not find any neighbor closed to P_L in ZOR_t. The mobicast message can not be forwarded to V_5 to produce the temporal network fragmentation problem, V_4 must perform $\mathrm{ZOA}_t^{V_i}$ growing phase.

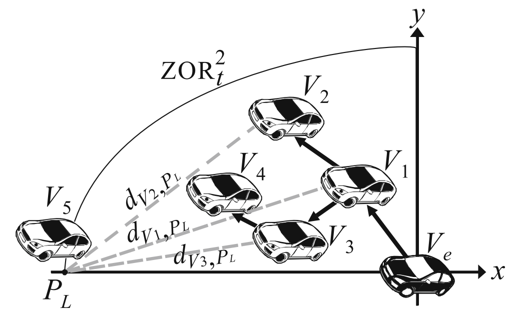


Fig. 9 Random backoff time is depended on distance to P_L

4.3 $\mathrm{ZOA}_t^{V_i}$ growing phase

To solve the temporal network fragmentation problem, $\mathrm{ZOA}_t^{V_i}$ growing phase is needed. The goal of $\mathrm{ZOA}_t^{V_i}$ growing phase is to raise the possibility of sending the mobicast message toward P_x, where $x = L$ or R. The $\mathrm{ZOA}_t^{V_i}$ is initiated to create ZOF_t from vehicle V_i at time t to expand the dissemination area. When the temporal network fragmentation problem is occurred, $\mathrm{ZOA}_t^{V_i}$ growing phase is executed to ensure vehicles in the ZOR_t can successfully receive the mobicast message, a series of new created elliptic shape $\mathrm{ZOA}_t^{V_i}$ are produced if V_i cannot send out the mobicast message. The procedure of the $\mathrm{ZOA}_t^{V_i}$ growing phase is developed.

S1 To raise the possibility of sending the mobicast message from V_i toward P_x, a *reference* vehicle $V_j \in N(V_i)$ is necessary to ensure the mobicast message can be forwarded. To reduce the hop number from V_i to P_x, the reference vehicle V_j is chose as the next node of V_i, where V_j has the minimal distance to P_x than all other vehicles in $N(V_i)$; that is, $d_{V_j,P_x} < d_{V_{k\in N(V_i)},P_x}$.

S2 Vehicle V_i initiates a new elliptic $\mathrm{ZOA}_t^{V_i}$ to include the *reference* vehicle V_j, where V_i is located at one of focuses of $\mathrm{ZOA}_t^{V_i}$ and the coordinate of the center of $\mathrm{ZOA}_t^{V_i}$ is (h, k). Observe that, *reference* vehicle V_j is a possible alternative path to forward the mobicast message closed to P_x. The *reference* vehicle V_j should be included in $\mathrm{ZOA}_t^{V_i}$. The $\mathrm{ZOA}_t^{V_i}$ is created by the function $A_t(V_i) = \frac{(x_t^{Vi}-h)^2}{a'^2} + \frac{(y_t^{Vi}-k)^2}{b'^2} - 1 = 0$, where major axis a' is determined by $\frac{d_{Vi,P_x}}{\alpha \times v_i}$, and minor axis b' is determined by $\frac{\alpha \times v_i}{d_{V_i,P_x}}$, where α is a constant which is used to adjust v_i. Major axis a' and minor axis b' control the shape of $\mathrm{ZOA}_t^{V_i}$. Different shape of $\mathrm{ZOA}_t^{V_i}$

can raise different possibility to find successful route to P_x or reduce the number of growing new $\mathrm{ZOA}_t^{V_i}$. This discussion will be explained later. After a' and b' are determining, (h, k) can be deduced by the locations of V_i and V_j as follows,

$$\begin{cases} \dfrac{(x_t^{V_j}-h)^2}{a'^2}+\dfrac{(y_t^{V_j}-k)^2}{b'^2}\le 1, \\ \sqrt{(x_t^{V_i}-h)^2+(y_t^{V_i}-k)^2}=\sqrt{a'^2-b'^2}. \end{cases}$$

For instance of $\mathrm{ZOA}_t^{V_i}$ as illustrated in Fig. 10a, let c denote as the distance between V_i and $O(h,k)$, and the distance between V_j and two focuses represent as r_1 and r_2, respectively. According to the ellipse nature, $r_1+r_2=2a'$ is known, then $c=\sqrt{a'^2-b'^2}$. The length of c is $\sqrt{(x_t^{V_i}-h)^2+(y_t^{V_i}-k)^2}$, so we have $\sqrt{(x_t^{V_i}-h)^2+(y_t^{V_i}-k)^2}=c=\sqrt{a'^2-b'^2}$.

S3 The V_i broadcasts the $\mathrm{ZOA}_t^{V_i}$ growing packet $E_m(V_i, A_t(V_i), P_m)$ after waiting for the random backoff time R_{time} of V_i. Packet $E_m(V_i, A_t(V_i), P_m)$ is a control packet to control the growing of $\mathrm{ZOA}_t^{V_i}$, where V_i is the ID of current vehicle, $A_t(V_i)$ is the region of $\mathrm{ZOA}_t^{V_i}$, and P_m is the mobicast control packet. The mobicast message is disseminated through $\mathrm{ZOA}_t^{V_i}$ to P_x. It is possible to forward the mobicast message to a *dead-end* vehicle. A vehicle is said as a *dead-end* vehicle if the vehicle does not have any other neighbors except for V_i. Therefore, the *dead-end* vehicle cannot re-forward the mobicast message to any neighboring vehicles. If the mobicast message reaches to a dead-end vehicle, the dead-end vehicle cannot re-forward the mobicast message, then V_i should know that the mobicast message reaches to a dead-end vehicle. If V_i does not receive E_m from any neighbor but $N(V_i)\neq\{\varnothing\}$ for the period of maximum R_{time} after V_i sending out E_m message, it implies that all neighbors of V_i are dead-end vehicles, where $N(N(V_i))=\{V_i\}$. If all neighbors of V_i cannot send out the mobicast message, then V_i replies $d_{V_i,P_x}=\infty$ to previous vehicle to notify that a dead-end situation is occurred. The path passed V_i surely cannot be chose due to $d_{V_i,P_x}=\infty$. Then, go to Step 1 to find another path closed to P_x. Example is given in Fig. 10b, V_k is a dead-end vehicle and V_i tries to find another path toward P_x.

S4 If V_k directly receives E_m from V_i and the location of V_k is $(x_t^{V_k}, y_t^{V_k})$, then packet E_m is forwarded from V_k if $A_t(V_k)=\frac{(x_t^{V_k}-h)^2}{a'^2}+\frac{(y_t^{V_k}-k)^2}{b'^2}-1\le 0$. Otherwise, V_k drops E_m.

S5 If V_k has only one neighbor V_i, $N(V_k)=\{V_i\}$, that means V_k can not send out the mobicast message, then V_k sets $d_{V_k,P_x}=\infty$ at time t, V_k does not broadcast at time t.

S6 Vehicle V_k broadcasts E_m after waiting for time period of R_{time} of V_k, if at least one neighbor $V_l\in N(V_k)$ for V_k exists, where $A_t(V_l)\le 0$ and $d_{V_l,P_x}-d_{V_k,P_x}<0$, then go to Step 3 until the mobicast messages can be transmitted toward P_x. Otherwise go to Step 1.

Let's discuss with the shape of $\mathrm{ZOA}_t^{V_i}$ mentioned in Step 2. The shape of $\mathrm{ZOA}_t^{V_i}$ is depended on value of d_{V_i,P_x}. Figure 11a shows that the shape of $\mathrm{ZOA}_t^{V_1}$ is narrow if $a'>b'$. The shape of $\mathrm{ZOA}_t^{V_3}$ is wide if $a'<b'$ as shown in Fig. 11b. Different shape of $\mathrm{ZOA}_t^{V_i}$ has the different impact of the mobicast message

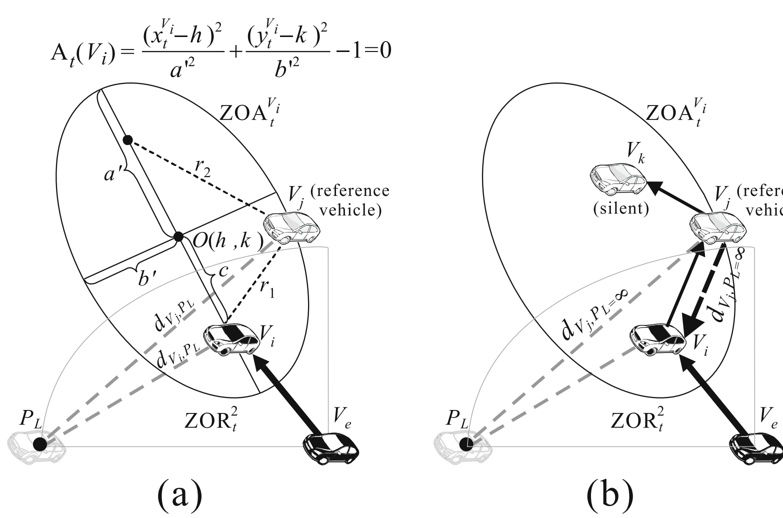


Fig. 10 **a** Growing of $\mathrm{ZOA}_t^{V_i}$ and **b** a dead-end example

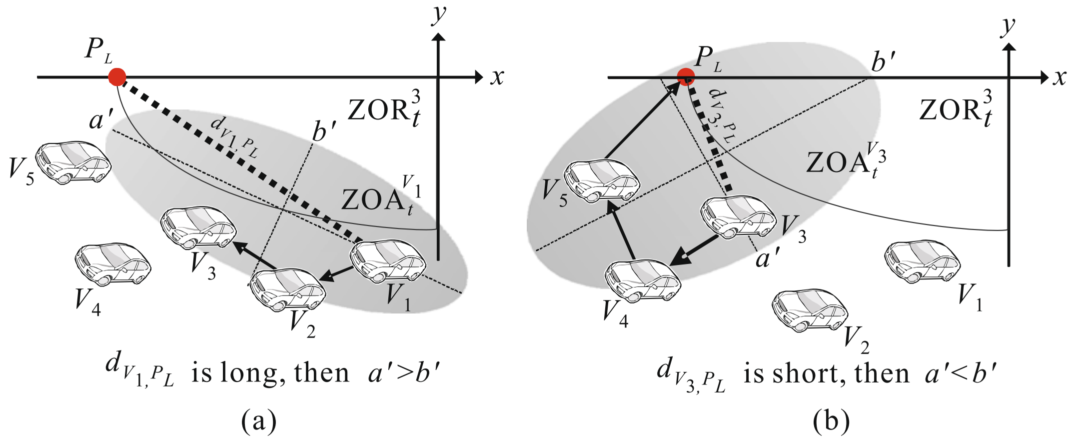


Fig. 11 The shape of $ZOA_t^{V_i}$ is different depended on different distance to P_x (**a**, **b**)

dissemination. If the shape of $ZOA_t^{V_i}$ is narrow, the mobicast message dissemination has the minimal number of hops to P_x and the reduced number of $ZOA_t^{V_i}$ growing. If the shape of $ZOA_t^{V_i}$ is wide, more possible paths to P_x can be discovered.

Figure 12 gives an example to illustrate event vehicle V_e disseminates the mobicast messages to all vehicles in ZOR_t. Event vehicle V_e broadcasts $P_m(V_e, Z_t(V_e), m)$ to V_1, V_2, and V_3. Vehicle V_3 broadcasts $P_m(V_3, Z_t(V_3)\ , m)$ to V_4, then V_4 finally broadcasts $P_m(V_4, Z_t(V_4), m)$, since $d_{V_4,P_R} < r$. Vehicle V_2 cannot forward P_m closer to P_L, then V_2 chooses a reference vehicle V_7 to initiate $ZOA_t^{V_2}$ by V_7. Then, V_2 broadcasts packet $E_m(V_2, A_t(V_2), P_m)$, and V_7 receives E_m from V_2 and re-broadcasts $E_m(V_7, A_t(V_7), P_m)$ to V_8 since $d_{V_8,P_L} < d_{V_7,P_L}$. Then, V_8 re-broadcasts $E_m(V_8, A_t(V_8), P_m)$ and V_8 has a neighboring V_5 in ZOR_t. Observe that, V_5 has the minimum R_{time} in $N(V_8)$ because V_5 is located in the ZOR_t. However, V_5 still cannot forward P_m closer to P_L, then V_5 initiates $ZOA_t^{V_5}$ by V_9 and broadcasts $E_m(V_5, A_t(V_5), P_m)$. Then, V_9 re-broadcasts $E_m(V_9, A_t(V_9), P_m)$ to V_6. Finally, V_6 receives E_m from V_9. Furthermore, the mobicast message can be disseminated through different quadrants. Figure 13 shows the mobicast message is disseminated to ZOR_t^3 from 1-st quadrant because no any neighboring vehicle of V_e exists in 3-rd quadrant.

5 Simulation results

Our paper presents a mobicast protocol. To evaluate our mobicast protocol, our mobicast routing protocol is simulated compared to a forwarding without $ZOA_t^{V_i}$ scheme. This is because that our mobicast protocol is the first mobicast result in VANETs. In our simulation, the forwarding without $ZOA_t^{V_i}$ scheme means that the mobicast message is broadcasting in ZOR_t without the assistance of $ZOA_t^{V_i}$ during the mobicasting. All these protocols are mainly implemented using the NCTUns 4.0 simulator and emulator [22]. The physical and MAC layer in this simulation is adopted the 802.11b protocol.

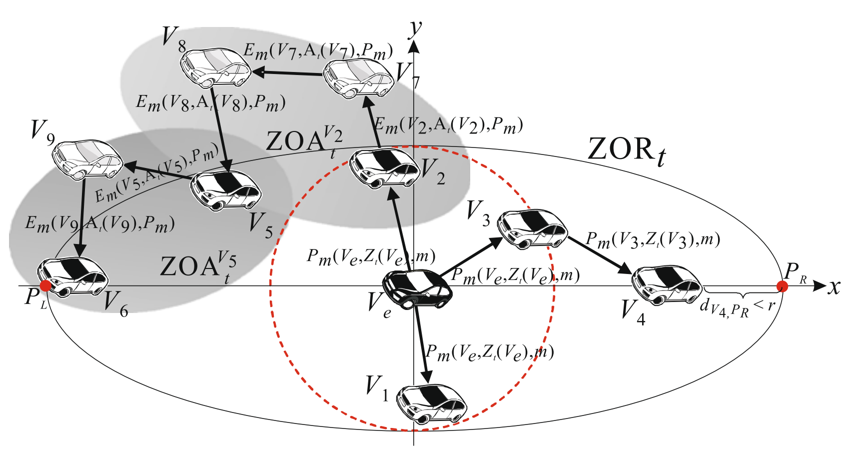
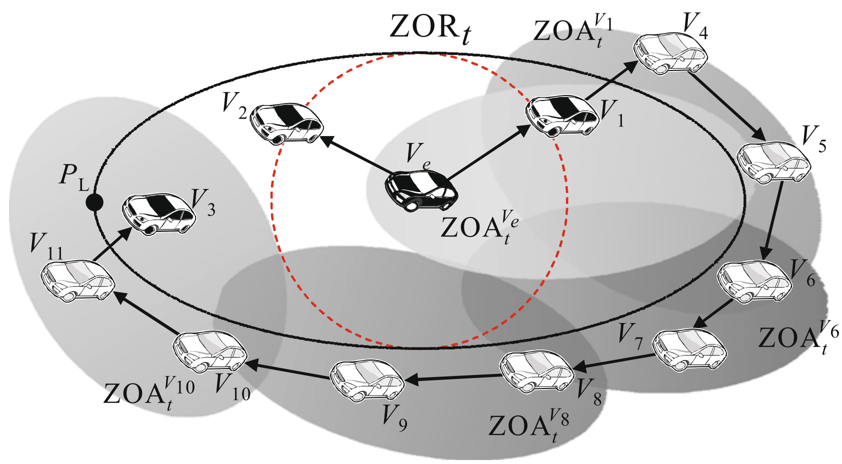


Fig. 12 An example of mobicast operation

Fig. 13 The mobicast message is disseminated to ZOR_t^3



The system parameters are given below. To discuss the effect of the *network density* (ND) of a VANET, our simulator considers a 2000×20 m^2 highway scenario with various numbers of vehicles, ranging from 40 to 400. With the same road area, the ND is changed due to the different number of vehicles. The communication radius of each vehicle is 100 m. Each vehicle knows its location information from the location provider (GPS). The velocity, v, of each vehicle is assumed from 10 to 100 km/h. The simulation time of each round is 300 seconds. Each simulated result is obtained from 100 rounds. The performance metrics to be observed are:

- The *dissemination successful rate* (DSR) is the number of vehicles located in ZOR$_t$ which can successfully receive the mobicast messages from event vehicle V_e, divided by the total number of vehicles in ZOR$_t$.
- The *packet overhead multiplication* (POM) is the total number of packets that all vehicles transmit transmitted used in our mobicast protocol (with the assistance of ZOA$_t^{V_i}$), divided by the total number of packets that all vehicles transmit not used in our mobicast protocol (without the assistance of ZOA$_t^{V_i}$).
- The *packet delivery delay* (PDD) is the average time that a mobicast message is sent from event vehicle V_e to vehicle V_i in ZOR $_t$.
- The *throughput* (TP) is the total number of data packets the vehicle V_i receives from event vehicle V_e in ZOR$_t$ per second.

It is worth mentioning that an efficient mobicast routing protocol in a VANET is achieved with a high DSR, low POM, low PDD, and high TP. In the following, we illustrate our simulation results for *dissemination successful rate* (DSR), *packet overhead multiplication* (POM), *packet delivery delay* (PDD), and *throughput* (TP) from several aspects.

5.1 Dissemination successful rate (DSR)

The simulation results of the DSR under various NDs and velocities are shown in Fig. 14. Figure 14a shows the observed DSR under various NDs, where the maximum velocity, v, is 50, 80, and 100 km/h, respectively. A mobicast routing protocol with the high dissemination successful rate implies that the value of its DSR was high. The DSR was low if v was high for various NDs. It was observed that DSR was very low under $v =$ 100 km/h since it is easily moved out the transmission range of IEEE 802.11b. In addition, the higher the ND is, the higher the DSR will be. For each case, the curve of the DSR of $v = 100$ km/h was lower than that of $v =$ 80 km/h, and the curve of the DSR of $v = 80$ km/h was lower than that of $v = 50$ km/h. Considered a pair of two high speed moving vehicles (even if $v = 100$ km/h) and its velocity variation is small, then it can successfully work for mobicasting. On the contrary, given a pair of two low speed moving vehicles and its velocity variation is large, then it cannot obtain the better of DSR. In average, the velocity variation becomes large if the maximum velocity is large. When the velocity is larger than 90 km/h, DSR drops if its velocity variation is large. Figure 14a shows that the ND is larger than 0.9, DSR does not grow up. This is because that the network contention and collision are occurred in the high density network. Compared to forwarding without ZOA$_t^{V_i}$ scheme, our mobicast routing protocol can improve the DSR as illustrated in Fig. 14a.

Figure 14b shows the observed DSR under various velocity v, with the ND fixed at 0.3, 0.5, and 0.8. In general, the DSR drops as the v increases because the rapid changed topology and frequent happened

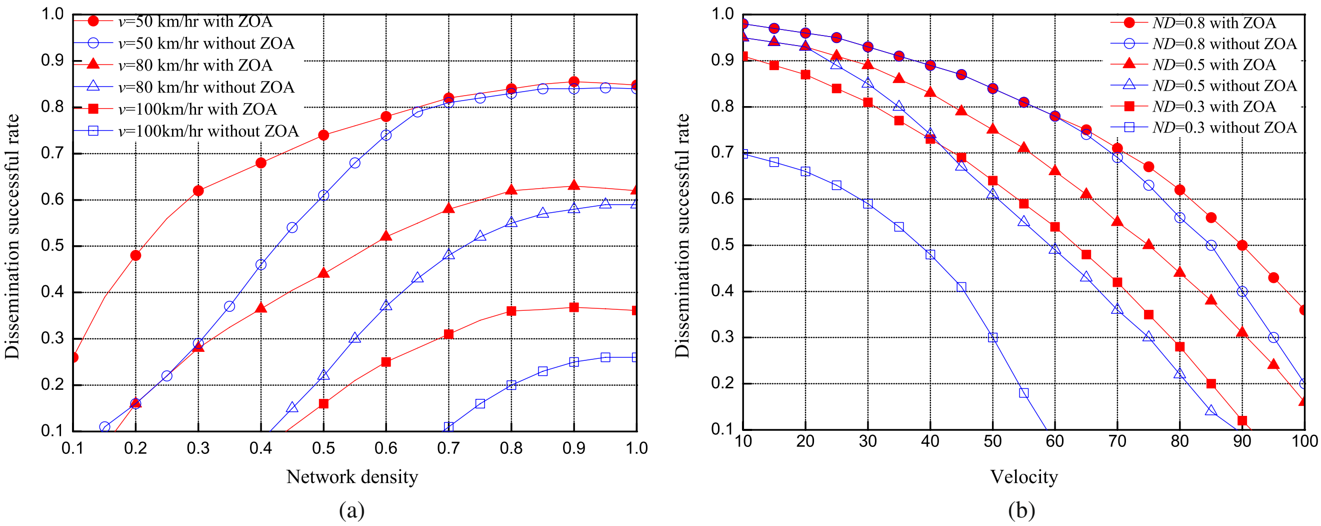


Fig. 14 Performance of dissemination successful rate vs. **a** network density and **b** velocity

temporal network fragmentation problem. The temporal network fragmentation problem is frequently occurred when the ND is low. Therefore, DSR was low when ND was low. For each case, the curve of the DSR of ND $= 0.3$ was lower than that of ND $= 0.5$, and the curve of the DSR of ND $= 0.5$ was lower than that of ND $= 0.8$. As shown in Fig. 14b, compared to forwarding without $\mathrm{ZOA}_t^{V_i}$ scheme, our mobicast routing protocol significantly improves DSR by using $\mathrm{ZOA}_t^{V_i}$.

5.2 Packet overhead multiplication (POM)

The simulation results of the packet overhead multiplication (POM) is shown in Fig. 15. The higher the value of POM is, the larger the number of packets will be. Figure 15a shows the performance of the average POM vs. various NDs, where the maximum velocity v are 50, 80, and 100 km/h. Forwarding without $\mathrm{ZOA}_t^{V_i}$ scheme cannot offer extra packets to solve the temporal network fragmentation problem, the average POM of forwarding without $\mathrm{ZOA}_t^{V_i}$ scheme is near to 1. The average POM of protocol ranges from 1.5 to 4.5 under various maximum velocities v. In general, POM was low if ND was high. The average POM of $v = 50 <$ that of $v = 80 <$ that of $v = 100$. Observe that when the ND is higher than 0.9, POM not keep to decrease due to network contention and collision problems. Figure 15b shows the observed POM under various velocity v, with the NDs fixed at 0.3, 0.5, and 0.8, respectively. In

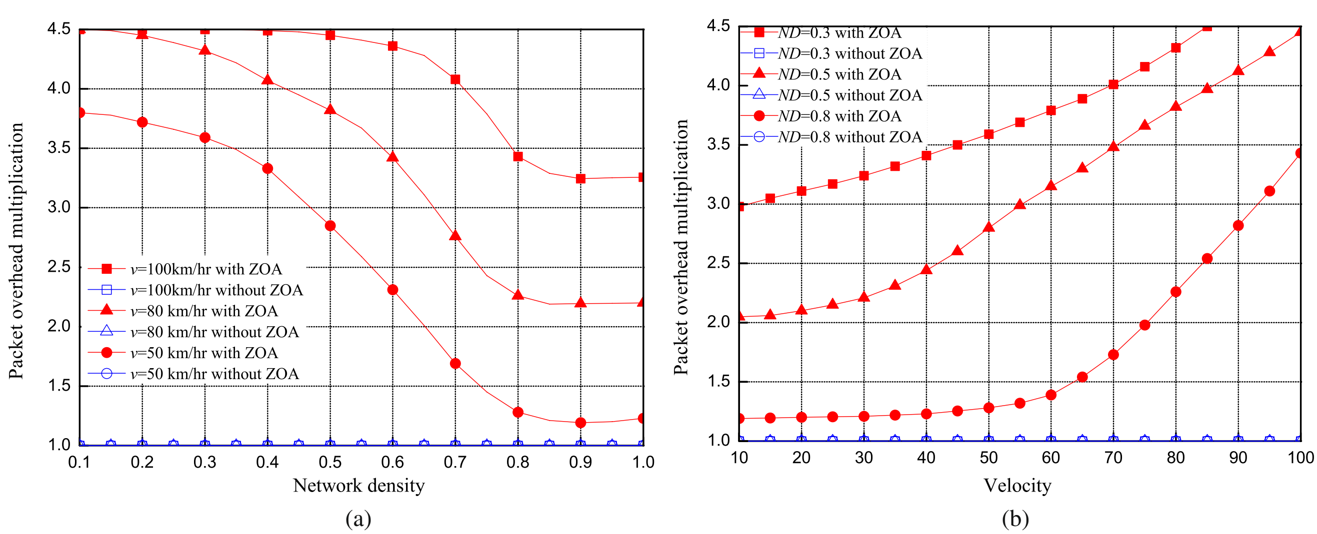


Fig. 15 Performance of packet overhead multiplication vs. **a** network density and **b** velocity

general, the POM grows up as the velocity v increases. The average POM of ND $= 0.8 <$ that of ND $= 0.5 <$ that of ND $= 0.3$. For each case, the higher the ND is, the lower the POM will be.

5.3 Packet delivery delay (PDD)

The simulation results of the PDD under various NDs and v are given in Fig. 16. Figure 16a shows the observed PDD under various NDs, where $v = 50, 80$, and 100 km/h. A mobicast routing protocol with the high dissemination successful rate implies that the value of its PDD was low. The PDD was high if v was high for various NDs. In general, the PDD drops as the ND increases. The average PDD of $v = 50 <$ that of $v = 80 <$ that of $v = 100$. As the ND is lower than 0.3, event vehicle V_e may not find any neighbors to forward the mobicast message. Event vehicle V_e will carry the mobicast message and try to forward the mobicast message to a new incoming vehicle. If ND is low, PDD is greatly growing since the mobicast message can not be sent out by multi-hop transmission. When the ND is higher than 0.9, PDD still not decrease due to network contention and collision problems. Compared to forwarding without $ZOA_t^{V_i}$ scheme, our mobicast routing protocol can improve the PDD.

Figure 16b shows the observed PDD under various velocity v, with the ND fixed at 0.3, 0.5, and 0.8. In general, the PDD grows up as the velocity v increases. The average PDD of ND $= 0.8 <$ that of ND $= 0.5 <$ that of ND $= 0.3$. For each case, the higher the ND is, the lower the PDD will be. Compared to forwarding without $ZOA_t^{V_i}$ scheme, our mobicast routing protocol can provide the better of PDD for various velocities.

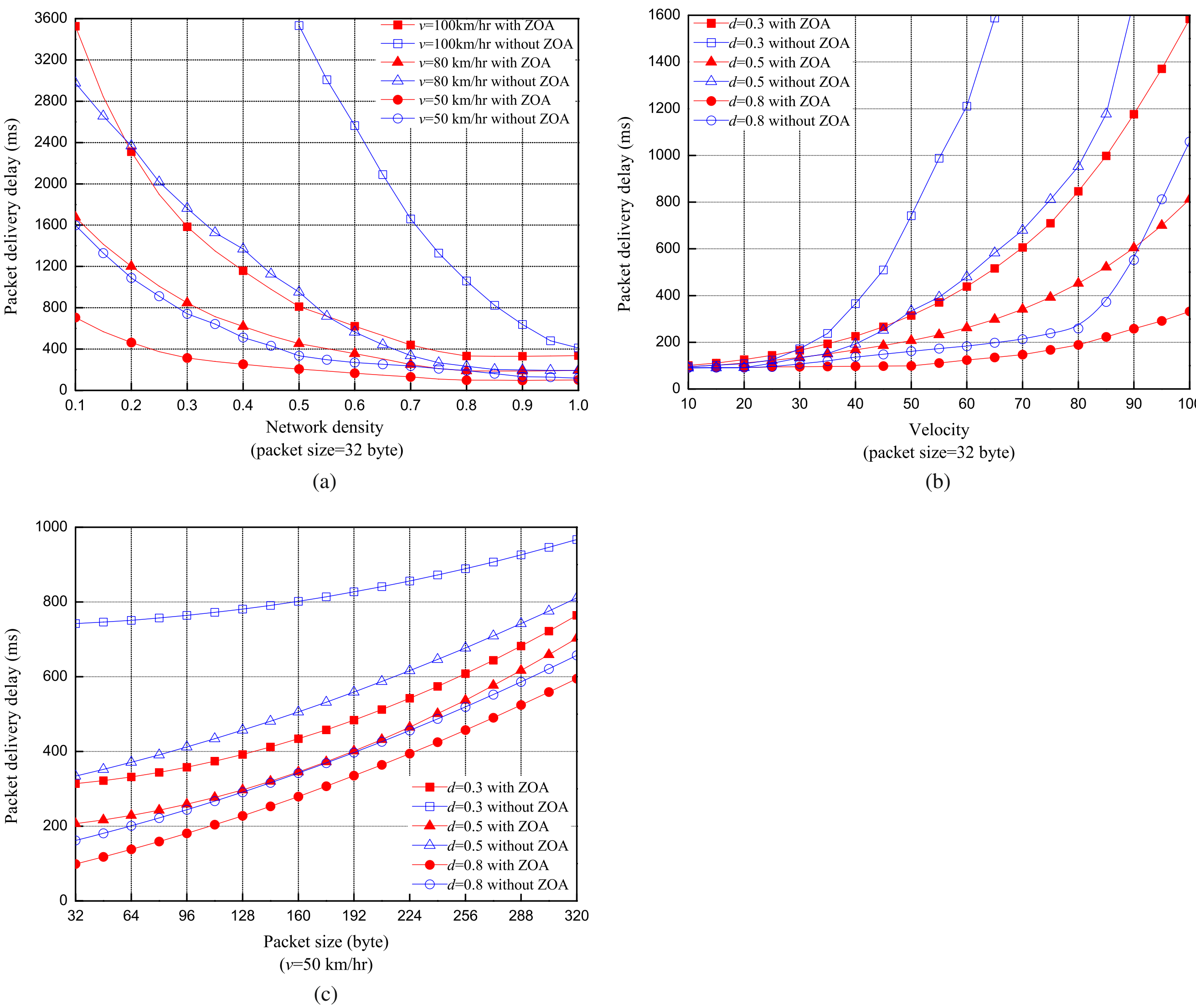


Fig. 16 Performance of packet delivery delay vs. **a** network density, **b** velocity, and **c** packet size

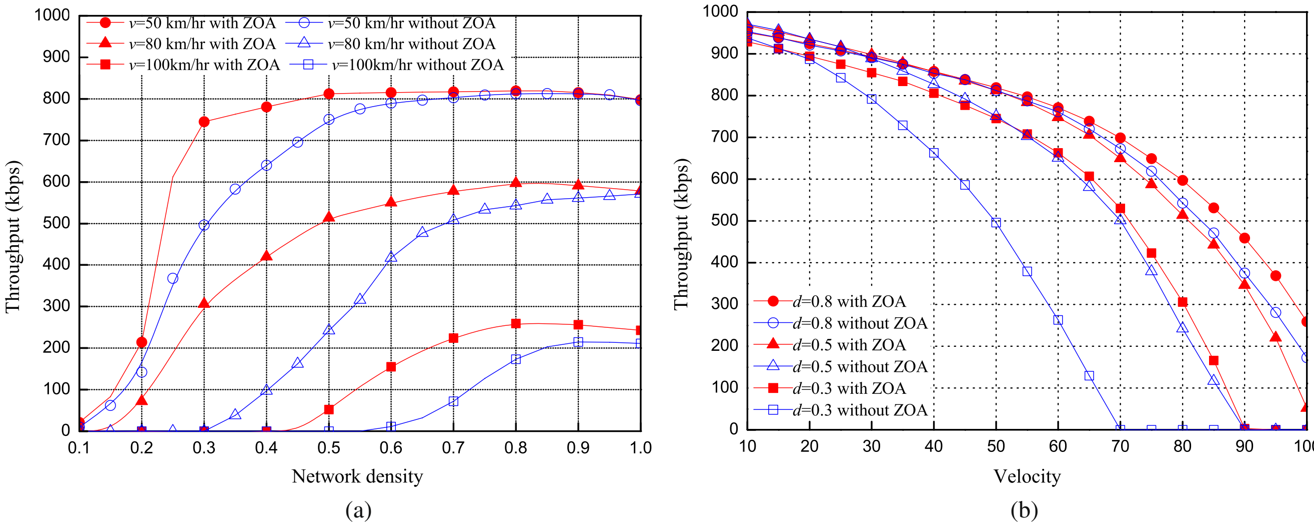


Fig. 17 Performance of throughput vs. **a** network density and **b** velocity

Figure 16c illustrates the observed PDD under various packet sizes ranging from 32 to 320 bytes, with the velocity v fixed at 50 km/h and the NDs are 0.3, 0.5, and 0.8, respectively. The PDD drops as the packet size decreases. The average PDD of ND $= 0.8 <$ that of ND $= 0.5 <$ that of ND $= 0.3$. The higher the ND is, the lower the PDD will be. Compared to forwarding without $ZOA_t^{V_i}$ scheme, our mobicast routing protocol improves PDD under various packet sizes.

5.4 Throughput (TP)

Figure 17 shows the simulation results of the throughput (TP) for our mobicast routing protocol. The result of throughput is obtained by running the video advertisement application. The higher the value of TP is, the higher network utilization will be. Figure 17a shows the performance of the throughput vs. various NDs, where the maximum velocity v are 50, 80, and 100 km/h. The throughput was high where the ND was high under the velocity of 50, 80, and 100 km/h. The average TP of $v = 100 <$ that of $v = 80 <$ that of $v = 50$. Observe that when the ND is higher than 0.9, throughput does not increase since the network contention and collision problem. Compared to forwarding without $ZOA_t^{V_i}$ scheme, our mobicast routing protocol can improve the TP when ND is low.

Figure 17b illustrates the observed TP under various velocity v, with the NDs fixed at 0.3, 0.5, and 0.8. In general, the TP decreases as the velocity v increases. The average PDD of ND $= 0.3 <$ that of ND $= 0.5 <$ that of ND $= 0.8$. For each case, the higher the ND is, the higher the TP will be. Compared to forwarding without $ZOA_t^{V_i}$ scheme, our mobicast routing protocol improves TP for various velocities.

In summary, it was observed that the efficient mobicast routing protocol is achieved by having the results of average DSR < 0.6, average PDD < 500 ms, and average TP < 500 kbps. The dissemination successful rate (DSR) can be improved over 50%, compared to the forwarding without $ZOA_t^{V_i}$ scheme. However, the average POM of our protocol is less than 3.0.

6 Conclusion

In this paper, we present a new "spatiotemporal multicast" protocol for supporting applications which require spatiotemporal coordination in vehicular ad hoc networks (VANETs). The main result of this work is to develop a new mobicast routing protocol to dynamically estimate the accurate ZOF to successfully disseminate mobicast messages to all vehicles in ZOR. To overcome the temporal network fragmentation problem, we have developed a new algorithm by extending some adaptive $ZOA_t^{V_i}$ to significantly improve the dissemination successful rate, even if the connectivity of ZOR is temporally lost due to any vehicle in ZOR suddenly accelerates or decelerates its velocity. Finally, the simulation results illustrated our performance achievements in terms of dissemination successful rate, packet overhead multiplication, packet delivery delay, and throughput. Observe that, the dissemination successful rate can be improved over 50%, compared to a similar data dissemination scheme without using our mobicast protocol. Future work involves developing a multi-mobicast routing protocol which supports applications of multiple event vehicles in VANETs.

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