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 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 temporal network fragmentation problem is occurred if the connectivity of ZOR is lost such that vehicles 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, and packet delivery delay.**

***Index Terms*—vehicular ad hoc network, spatiotemporal multicast, mobicast, routing.**

I. Introduction

The vehicular ad hoc network (VANET) is the promising techniques for building the ITS [1]. Recently, a new multicast communication paradigm called a "spatiotemporal multicast" or "mobicast" was investigated in [2][3] which support spatiotemporal coordination in applications over wireless sensor networks (WSNs). The distinctive feature of mobicast is the delivery of information to all nodes that happen to be in the "right" prescribed region at the "right" 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. This 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 for a moving vehicle. This provides a mechanism for application developers to express their needs for spatial and temporal information dissemination. 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_{start}, t_{end}). That is, all vehicles in ZOR must receive the mobicast messages sent from a source vehicle in ZOR. However, when a vehicle moves at a high speed, the velocity variation between each pair of vehicles is large. A vehicle easily moves out of the communication range of the event vehicle and fail to receive mobicast messages. This condition called as temporal network fragmentation problem. Joshi *et al*. [4] also proposed a distributed robust geocast protocol to consider the temporary network fragmentation problem. ZOR is first defined in [4] as a geographic region which vehicles in this region should receive the geocast messages. To enhance the reliability of receiving geocast messages, ZOF is defined in [4] as the geographic region which vehicles in this region should forward the geocast messages to other vehicles in the ZOR. 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. A fixed size of ZOF_t is difficult to handle the rapid changed topology and easily wastes the unnecessary network resource. That is difficult to handle emergency traffic situation, such as warning notifications initiated from a high speed moving vehicle which has braking problem. 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. To our knowledge, this work is the first study to develop the mobicast routing protocol in VANETs. The rest of this paper is organized as follows. Section II presents the challenges and basic ideas. Section III presents the new mobicast routing protocol. Performance analysis is discussed in Section IV. Finally, Section V concludes this paper.

II. Preliminaries

A. System model

To overcome temporal network fragmentation problem, it observations that the stable routing is not suitable for mobicasting. Our mobicast routing protocol adopts dynamic forwarding zone to disseminate mobicast messages. In a VANET, a vehicle is said as an *event vehicle* or V_e if a faulty event is triggered from on-board unit (OBU) of the vehicle. Mobicast messages are initiated from V_e to notify nearby vehicles to avoid the accident. 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.

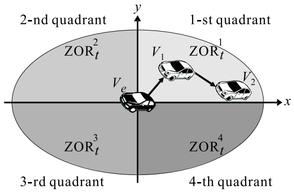


Fig. 1. ZOR_t is the union set of $\text{ZOR}_t^1 \cup \text{ZOR}_t^2 \cup \text{ZOR}_t^3 \cup \text{ZOR}_t^4$.

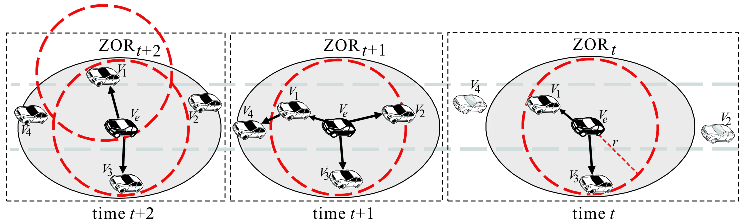


Fig. 2. Operation of mobicasting

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 mobicast messages to other vehicles in the ZOR_t.

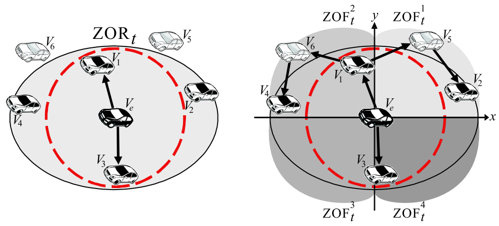
ZOR_t is the prescribed region to indicate which vehicle is relevant to the event occurred on V_e and V_e should announce the condition of event to those vehicles for accident avoidance by disseminating the mobicast message.

Definition 1: **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 $\text{ZOR}_t = \bigcup_{q \in \{1,2,3,4\}} \text{ZOR}_t^q$. 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.

Fig. 1 shows an example of $\text{ZOR}_t = \text{ZOR}_t^1 \cup \text{ZOR}_t^2 \cup \text{ZOR}_t^3 \cup \text{ZOR}_t^4$, V_e should send the mobicast message to V_1 and V_2 in ZOR_t^1. Fig. 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_e directly disseminates the mobicast message to V_1 and V_3. The purpose of mobicast message is to notify nearby vehicles of the real-time information from event vehicle V_e. The mobicast message is different at different time t since the information from V_e is continuously changed. At time $t+1$, 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 2: **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 $\text{ZOF}_t = \bigcup_{q \in \{1,2,3,4\}} \text{ZOF}_t^q$.



(a) (b)

Fig. 3. (a) Temporal network fragmentation problem and (b) example of ZOF_t.

Observe that, ZOF_t is the union of $\text{ZOF}_t^1 \cup \text{ZOF}_t^2 \cup \text{ZOF}_t^3 \cup \text{ZOF}_t^4$, where ZOF_t indicates which vehicle should forward the mobicast message to other vehicles located in the ZOR_t. Fig. 3 (a) 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. 3 (b), 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 ($\text{ZOA}_t^{V_i}$ or $\text{Z}_t^{V_i}$) is proposed herein to accurately predict the ZOF_t.

Zone of approaching, $\text{ZOA}_t^{V_i}$, is proposed herein to overcome the the temporal network fragmentation problem. ZOF_t is constituted by some different $\text{ZOA}_t^{V_i}$ at time t to be near to optimal size of ZOF_t.

Definition 3: **$\text{ZOA}_t^{V_i}$** or **$\text{Z}_t^{V_i}$(zone of approaching):** Let $\text{ZOA}_t^{V_i}$ or $\text{Z}_t^{V_i}$ denote as an elliptic zone of approaching to forward the mobicast message more closed to a destined vehicle and $\text{Z}_t^{V_i}$ is initiated by vehicle V_i at time t. Any vehicle in the $\text{Z}_t^{V_i}$ has the responsibility of forwarding the mobicast

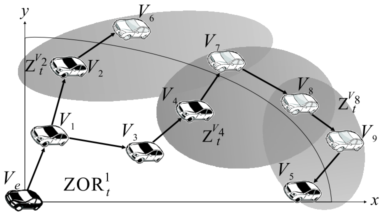


Fig. 4. Example of multiple ZOA$_t^{V_i}$.

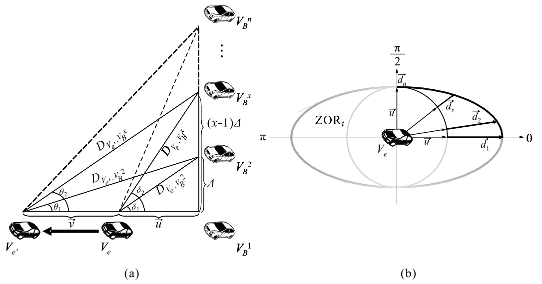


Fig. 5. The shape of ZOR$_t$ for an event vehicle is an approximate ellipse.

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$_t$. Fig. 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$_t^{V_8}$.

III. 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) ZOA$_t^{V_i}$ growing phase. The detailed operation is developed as follows.

A. 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 [3] 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. 5(a), 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 $D_{V_e\prime,V_B1}$, and the distance between V_{B^2} and V_e is shifted from D_{V_e,V_B2} to $D_{V_e\prime,V_B2}$. Let D_{V_B1,V_B2} be Δ, D_{V_e,V_B1} be $\overrightarrow{u}$, and $D_{V_e,V_e\prime}$ be $\overrightarrow{v}$. Observe that, Δ is a very tiny distance. The increased distance for V_{B^1} is $D_{V_e\prime,V_B1} - D_{V_e,V_B1} = |(\overrightarrow{v} + \overrightarrow{u})| - |\overrightarrow{u}| = |\overrightarrow{v}|$. The increased distance for V_{B^2} is $D_{V_e\prime,V_B2} - D_{V_e,V_B2}$, where $D_{V_e,V_B2} = D_{V_e,V_B1} \times \sec\delta_1$ and $D_{V_e\prime,V_B2} = D_{V_e\prime,V_B1} \times \sec\theta_1$, then $D_{V_e\prime,V_B2} - D_{V_e,V_B2}$ = $(|\overrightarrow{v} + \overrightarrow{u}|) \times \sec\theta_1 - |\overrightarrow{u}| \times \sec\delta_1$, and $\theta_1 = \tan^{-1}\frac{\Delta}{|\overrightarrow{v}+\overrightarrow{u}|}$ and $\delta_1 = \tan^{-1}\frac{\Delta}{|\overrightarrow{u}|}$. Therefore, $D_{V_e\prime,V_B2} - D_{V_e,V_B2} = (|\overrightarrow{v} + \overrightarrow{u}|) \times \sec(\tan^{-1}\frac{\Delta}{|\overrightarrow{v}+\overrightarrow{u}|}) - |\overrightarrow{u}| \times \sec(\tan^{-1}\frac{\Delta}{|\overrightarrow{u}|})$. 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 $D_{V_e\prime,V_Bx} - D_{V_e,V_Bx} = (|\overrightarrow{v} + \overrightarrow{u}|) \times \sec\theta_2 - |\overrightarrow{u}| \times \sec\delta_2$, and $\theta_2 = \tan^{-1}\frac{(x-1)\Delta}{|\overrightarrow{v}+\overrightarrow{u}|}$ and $\delta_2 = \tan^{-1}\frac{(x-1)\Delta}{|\overrightarrow{u}|}$. Therefore, $D_{V_e\prime,V_Bx} - D_{V_e,V_Bx} = (|\overrightarrow{v}+\overrightarrow{u}|) \times \sec(\tan^{-1}\frac{(x-1)\Delta}{|\overrightarrow{v}+\overrightarrow{u}|}) - |\overrightarrow{u}| \times \sec(\tan^{-1}\frac{(x-1)\Delta}{|\overrightarrow{u}|})$. Let $|\overrightarrow{d_x}|$ denote as the increased distance for V_{B^x}, then $|\overrightarrow{d_x}| = D_{V_e\prime,V_Bi} - D_{V_e,V_Bi}$. Observe that, we accumulate the increased distance $\overrightarrow{u} + \overrightarrow{d_x}$ around vehicle V_e, where $\overrightarrow{u}$ is the projection of D_{V_e,V_Bx} onto D_{V_e,V_B1}, the equation is,

$$\int_{\theta=0,x=1}^{\theta=\frac{\pi}{2},x=n} |\overrightarrow{u}| + ((|\overrightarrow{v} + \overrightarrow{u}|) \times \sec(\tan^{-1}\frac{(x-1)\Delta}{|\overrightarrow{v} + \overrightarrow{u}|}) - |\overrightarrow{u}| \times \sec(\tan^{-1}\frac{(x-1)\Delta}{|\overrightarrow{u}|}) dx d\theta).$$

The result of this integration in polar coordinates is given in Fig. 5(b). From $\overrightarrow{d_1}$ to $\overrightarrow{d_n}$, the result only shows 1-st quadrant of shape because we only accumulate from 0 to $\frac{\pi}{2}$. If we accumulate the increased distance $\overrightarrow{d_i}$ from 0 to 2π, we can have an approximate ellipse. Therefore, our mobicast routing protocol adopts the ellipse as the size of ZOR$_t$. ■

In this paper, each vehicle can acquire location information via location information provider, such as the Global Positioning System. Let $(x_t^{V_i}, y_t^{V_i})$ denote as the location of V_i at time t. Each vehicle V_i exchanges its location and velocity information to its neighbors by hello message. 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. 6. We always assume a vehicle is located at P_x,

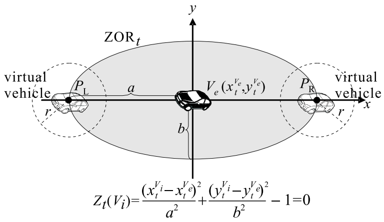
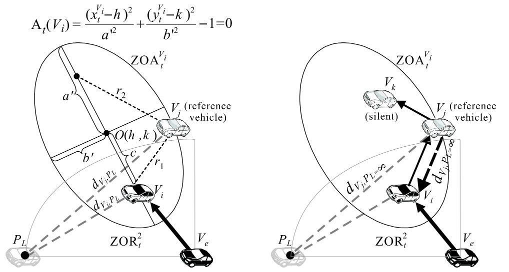


Fig. 6. Creation of ZOR$_t$.



(a) (b)

Fig. 7. (a) Growing of ZOA$_t^{V_i}$ and (b) a dead-end example.

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.

S1. 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, $a = v_{e_t} \times \frac{1}{5} \times l_m$, 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.

S2. 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 broadcasted the P_m, message dissemination phase is executed.

Fig. 6 shows that 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.

B. Message Dissemination Phase

In the message dissemination phase, 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.

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 can disseminate the mobicast more closed to P_x 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) $d_{V_k,P_x} - d_{V_j,P_x} < 0$. 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 $P_m(V_j, Z_t(V_j), m)$ after waiting for a random backoff time R_{time}, such that $R_{time} = \frac{d_{V_j,P_x}}{d_{V_i,P_x}} \times r_{time}$, where r_{time} is a random time. The use of random backoff time R_{time} is to prevent the broadcast storm problem and improve the reliability.

C. ZOA$_t^{V_i}$ Growing Phase

ZOA$_t^{V_i}$ growing phase is to solve the temporal network fragmentation problem by expanding the dissemination area. When the temporal network fragmentation problem is occurred, 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 ZOA$_t^{V_i}$ are produced if V_i cannot send out the mobicast message. The procedure of the 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 ZOA$_t^{V_i}$ to include the *reference* vehicle V_j, where V_i is located at one of focuses of ZOA$_t^{V_i}$ and the coordinate of the center of 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 ZOA$_t^{V_i}$. The 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 ZOA$_t^{V_i}$. Different shape of ZOA$_t^{V_i}$ can raise different possibility to find successful route to P_x or reduce the number of growing new 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,

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

For instance of ZOA$_t^{V_i}$ as illustrated in Fig. 7(a), let c denote as the distance between V_i and $O(h, k)$, and

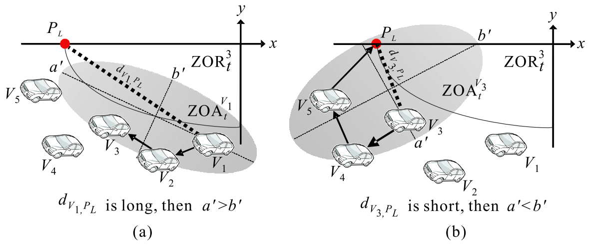


Fig. 8. The shape of $\text{ZOA}_t^{V_i}$ is different depended on different distance to P_x.

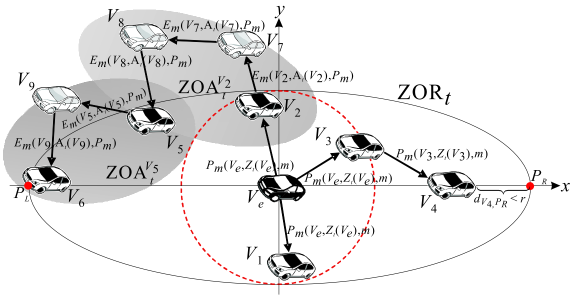


Fig. 9. An example of mobicast operation.

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 $\text{ZOA}_t^{V_i}$ 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 $\text{ZOA}_t^{V_i}$, where V_i is the ID of current vehicle, $A_t(V_i)$ is the region of $\text{ZOA}_t^{V_i}$, and P_m is the mobicast control packet. However, it is possible to forward the mobicast message to a *dead-end* vehicle which has no neighbor except V_i. Therefore, the *dead-end* vehicle cannot re-forward the mobicast message to any neighboring vehicles. 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 $N(N(V_i)) = \{V_i\}$, then V_i replies $d_{V_i,P_x} = \infty$ to previous vehicle to notify that a dead-end situation is occurred. Then, go to Step 1 to find another path closed to P_x. Example is given in Fig. 7(b), 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 $A_t(V_k) = \frac{(x_t^{V_k} - h)^2}{a'^2} + \frac{(y_t^{V_k} - k)^2}{b'^2} - 1 \leq 0$. Otherwise, V_k drops E_m.

S5. 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 $A_t(V_l) \leq 0$ 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 $\text{ZOA}_t^{V_i}$ mentioned in Step 2. The shape of $\text{ZOA}_t^{V_i}$ is depended on value of d_{V_i,P_x}. Fig. 8(a) shows that the shape of $\text{ZOA}_t^{V_1}$ is narrow if $a' > b'$. The shape of $\text{ZOA}_t^{V_3}$ is wide if $a' < b'$ as shown in Fig. 8(b). Different shape of $\text{ZOA}_t^{V_i}$ has the different impact of the mobicast message dissemination. If the shape of $\text{ZOA}_t^{V_i}$ is narrow, the mobicast message dissemination has the minimal number of hops to P_x and the reduced number of $\text{ZOA}_t^{V_i}$ growing. If the shape of $\text{ZOA}_t^{V_i}$ is wide, more possible paths to P_x can be discovered. Fig. 9 gives a complete example to illustrate event vehicle V_e disseminates the mobicast messages to all vehicles in ZOR_t.

IV. Simulation Results

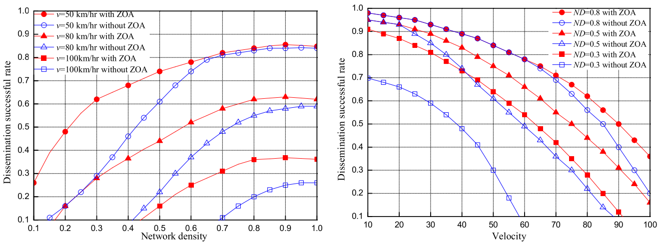
To evaluate the presented mobicast protocol, our mobicast routing protocol is simulated compared to a forwarding without $\text{ZOA}_t^{V_i}$ scheme. This is because that our mobicast protocol is the first mobicast result in VANETs. In our simulation, the forwarding without $\text{ZOA}_t^{V_i}$ scheme means that the mobicast message is broadcasting in ZOR_t without the assistance of $\text{ZOA}_t^{V_i}$ during the mobicasting. All these protocols are mainly implemented using the NCTUns 4.0 simulator and emulator [5]. The physical and MAC layer in this simulation is adopted the 802.11b protocol. The path-loss model and fading model are adopted "Free Space and Shadowing" and "Ricean Fading" respectively. 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. The communication radius of each vehicle is 100 m. The velocity, v, of each vehicle is assumed from 10 to 100 km/hr. 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 $\text{ZOA}_t^{V_i}$), divided by the total number of packets that all vehicles transmit not used in our mobicast protocol (without the assistance of $\text{ZOA}_t^{V_i}$).
- 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.

It is worth mentioning that an efficient mobicast routing protocol in a VANET is achieved with a high DSR, low POM, and low PDD.

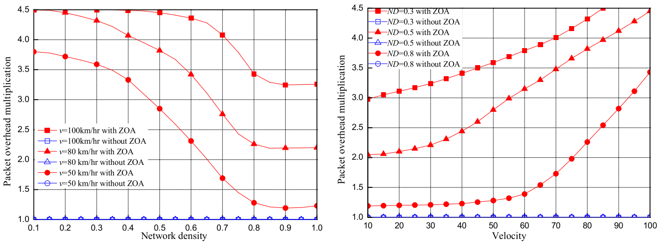
A. Dissemination successful rate (DSR)

Fig. 10(a) shows the observed DSR under various NDs. A mobicast routing protocol with the high dissemination successful rate implies that the value of its DSR was high. It was observed that DSR was very low under v =100 km/hr 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 DSR of v =100 km/hr < that of v =80 km/hr < that of v =50 km/hr. Considered a pair of two high speed moving vehicles (even if v =100 km/hr) and if its velocity variation is small, then it can successfully work for



(a) (b)

Fig. 10. Performance of dissemination successful rate vs. (a) network density and (b) velocity.



(a) (b)

Fig. 11. Performance of packet overhead multiplication vs. (a) network density and (b) velocity.

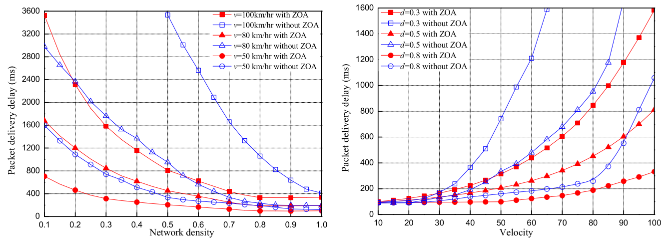
mobicasting. On the contrary, if its velocity variation is large, then it cannot obtain the better of DSR. In average, the velocity variation becomes large if the maximum velocity is large. Fig. 10(a) shows that the ND is larger than 0.9, DSR does not grow up. This is because that the network contention and collision are occurred in the high density network. Compared to forwarding without $\text{ZOA}_t^{V_i}$ scheme, our mobicast routing protocol can improve the DSR. Fig. 10(b) shows the observed DSR under various velocity v. In general, the DSR drops as the v increases because the rapid changed topology and frequent happened 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 DSR of ND=0.3 $<$ that of ND=0.5 $<$ that of ND=0.8. Compared to forwarding without $\text{ZOA}_t^{V_i}$ scheme, our mobicast routing protocol significantly improves DSR.

B. Packet overhead multiplication (POM)

Fig. 11(a) shows the performance of the average POM vs. various NDs. Forwarding without $\text{ZOA}_t^{V_i}$ scheme cannot offer extra packets to solve the temporal network fragmentation problem, the average POM of forwarding without $\text{ZOA}_t^{V_i}$ scheme is near to 1. In general, the average POM of $v = 50$ $<$ that of $v = 80$ $<$ that of $v = 100$. Fig. 11(b) shows the observed POM under various velocity v. In general, 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.

C. Packet delivery delay (PDD)

Fig. 12(a) shows the observed PDD under various NDs. A mobicast routing protocol with the high dissemination successful rate implies that the value of its PDD was low.



(a) (b)

Fig. 12. Performance of packet deliver delay vs. (a) network density and (b) velocity.

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. V_e will carry the mobicast message and try to forward to other vehicles, then PDD is greatly growing since the mobicast message can not be sent out by multi-hop transmission. Compared to forwarding without $\text{ZOA}_t^{V_i}$ scheme, our mobicast routing protocol can improve the PDD. Fig. 12(b) shows the observed PDD under various velocity v. 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 $\text{ZOA}_t^{V_i}$ scheme, our mobicast routing protocol can provide the better of PDD for various velocities.

V. Conclusion

In this paper, we present a mobicast routing protocol to dynamically estimate the accurate ZOF to successfully disseminate mobicast messages to all vehicles in ZOR and overcome the temporal network fragmentation problem by extending the adaptive $\text{ZOA}_t^{V_i}$. Finally, the simulation results illustrated our performance achievements in terms of dissemination successful rate, packet overhead ratio,and packet delivery delay.

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