A Mobicast Routing Protocol with Carry-and-Forward in Vehicular Ad-Hoc Networks

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***Abstract*—In vehicular networks, safety and comfort applications are two quite different kinds of applications to avoid the emergency traffic accident and enjoy the non-emergency entertainment. The comfort application drives the challenges of new non-emergency entertainments for vehicular ad-hoc networks (VANETs). The comfort application usually keeps the delay-tolerant capability; that is, messages initiated from a specific vehicle at time t can be delivered through VANETs to some vehicles within a given constrained delay time λ. In this paper, we investigate a new mobicast protocol to support comfort applications for a highway scenario in vehicular ad-hoc networks (VANETs). All vehicles located in a geographic zone (denoted as zone of relevance, ZOR) at time t, the mobicast routing is to disseminate the data message initiated from a specific vehicle to all vehicles which have ever appeared in ZOR at time t. This data dissemination must be done before time $t + \lambda$ through the carry-and-forward technique. In addition, the temporary network fragmentation problem is considered in our protocol design. In addition, the low degree of channel utilization is kept to reserve the resource for safety applications. To illustrate the performance achievement, simulation results are examined in terms of message overhead, dissemination successful rate, and accumulative packet delivery delay.**

***Index Terms*—vehicular ad hoc network, carry-and-forward, mobicast, routing.**

I. Introduction

The vehicular ad hoc network (VANET) is the promising techniques for building the ITS. Recently, a new multicast communication paradigm called a "spatiotemporal multicast" or "mobicast" was investigated in [1] which support spatiotemporal coordination in safety applications for VANETs. The distinctive feature of mobicast is to deliver a message at time t to all vehicles located in a prescribed region before time $t+1$. The delivery delay of the message should be short because of the safety purpose. On the other hand, the mobicast routing protocol is also able to develop for *region-relevant* comfort applications on VANETs. The purpose of region-relevant comfort applications is to deliver a message or multimedia file initiated from a specific vehicle V to all vehicles which have appeared in a prescribed region at time t, where the prescribed region is near to vehicle V. Comfort applications usually keep the delay-tolerant capability. Messages can deliver to some vehicles within a constrained delay time. Assuming that λ is the constrained delay time. That is, the mobicast routing protocol for region-relevant comfort applications is to deliver a message to vehicles which have ever appeared in a prescribed region at time t before time $t + \lambda$. For example, a driver can send a multimedia file to other vehicles appeared in a prescribed region at time t, and those vehicles should receive the file before time $t + \lambda$. In addition, the message delivery should maintain a low degree of channel utilization to reserve the resource for safety applications.

In this paper, a new mobicast protocol with carry-and-forward is proposed for a highway scenario to support the region-relevant comfort applications. This prescribed region is a geographic zone and is denoted as *zone of relevance* (ZOR) which vehicles in this region should receive the mobicast message. The spatiotemporal characteristic of a mobicast for comfort applications is to disseminate a mobicast message to all mobile vehicles which have ever appeared in the ZOR at time t, and those vehicles must receive the mobicast message before time $t + \lambda$. Observe that, a vehicle easily moves out of the communication range of the other vehicles in a highway scenario and fails to receive mobicast messages. This condition called as *temporary network fragmentation problem*. Joshi *et al*. [2] proposed a distributed robust geocast protocol (DRG) to deliver a message to vehicles located in the ZOR and overcome the temporary network fragmentation problem by using the ZOF which is defined in [2]. ZOF is a geographic region which vehicles in this region should forward the geocast message to other vehicles in the ZOR. However, a fixed size of ZOF is difficult to handle the rapid changed topology and easily wastes the unnecessary channel resource. The main contribution of our work is to achieve high dissemination successful rate and maintain a low degree of channel utilization; meanwhile, the delivery delay should be reduced as much as possible.

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 successfully deliver the mobicast message to vehicles which have ever appeared in the ZOR at time t before time $t + \lambda$, the temporary network fragmentation problem should be considered. In this work, a message is carried by some possible vehicles to forward to overcome the temporary network fragmentation problem and maintain a low degree of channel utilization at the same time. In a VANET, a vehicle is said as an *event vehicle* or V_e if a comfort application is triggered by a user. V_e send the mobicast message to other

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vehicles have appeared in the ZOR at time t. In the following, we define ZOR_t (zone of relevance) to indicate which vehicle should receive the mobicast message and ZOF_{t+i} (zone of forwarding) to indicate which vehicle should carry the mobicast message to forward. Let m_t denote as a mobicast message sent at time t and V_j denote as the vehicle ID, where $j = \{e, 1, ..., j, ..., n\}$ throughout this paper. Event vehicle V_e is the mobicast-initiated vehicle which initiates a mobicast routing protocol to disseminate the mobicast messages m_t to other vehicles which have appeared in the ZOR_t before time $t + \lambda$.

Definition 1: **ZOR_t(zone of relevance):** Given an event vehicle V_e and a constrained delay time λ, ZOR_t is a static elliptic region determined by V_e at time t, such that vehicle V_j must be successfully received the mobicast message m_t from V_e before time $t + \lambda$, where each V_j has ever appeared in the ZOR_t.

Considering the characteristic of VANETs, ZOR_t is an elliptic region, which has been proofed in [1]. Let V_j^t denote as a vehicle which has ever appeared in the ZOR_t and should receive the mobicast message m_t. Fig. 1 (a) shows an example of ZOR_t. V_e initiated a ZOR_t and the transmission range of each vehicle is assumed r. V_1^t, V_2^t, V_3^t, and V_4^t have appeared in the ZOR_t and should receive the mobicast message m_t before time $t + \lambda$. However, V_4^t is out of the communication range of other vehicles and encounters the temporary network fragmentation problem. To overcome the temporary network fragmentation problem, ZOF_{t+i} is used to indicate which vehicle should carry m_t and forward to V_j^t. The formal definition of ZOF_{t+i} is given.

Fig. 2 gives an example of mobicast, which the constrained delay time assumes $\lambda = 2$. Initially, V_e triggers an event at time t to form a ZOR_t. V_1^t, V_2^t, V_3^t, and V_4^t have appeared in the ZOR_t and should receive m_t before time $t + 2$. V_e directly transmits the mobicast message to V_1^t and V_2^t. V_3^t and V_4^t are out of communication range of other vehicles; hence, they cannot receive m_t. V_3^t and V_4^t encounter the temporary network fragmentation problem. At time $t + 1$, V_2^t carries m_t and moves closed to V_3^t, then V_2^t forwards m_t to V_3^t. At time $t+2$, V_1^t carries m_t and moves closed to V_4^t, then V_1^t forwards m_t to V_4^t. Observe that V_5 has not appeared in ZOR_t at time t, therefore V_5 does not receive m_t.

Definition 2: **ZOF_{t+i} (zone of forwarding):** Given a V_e, ZOF_{t+i} is a geographic region determined at each time $t + i$, where i=0, 1, ...,i, such that each vehicle V_j has the responsibility of carrying and forwarding the mobicast message m_t, where V_j is located in the ZOF_{t+i}.

In this works, ZOF_{t+i} is separated by V_e's position into two sub-zones, the rear sub-zone and the front sub-zone. Let ZOF_{t+i}^R denote as the rear sub-zone behind V_e. Let ZOF_{t+i}^F denote as the front sub-zone, which is in front of V_e. This is, $\text{ZOF}_{t+i} = \text{ZOF}_{t+i}^R \cup \text{ZOF}_{t+i}^F$. The center location of ZOF_{t+i} 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 (b) shows V_1^t, V_2^t, V_3^t, and V_4^t located in ZOF_{t+i}; hence V_2^t should directly forward m_t to V_3^t and V_1^t should carry m_t to forward to V_4^t.

B. Basic Idea

The method to deliver m_t can be divided into two techniques, multihop forwarding and carry-and-forward tech-

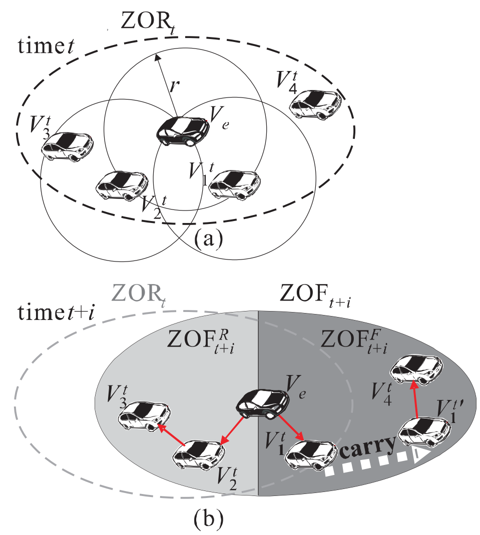


Fig. 1. (a) ZOR_t (zone of relevance) and (b) ZOF_{t+i} (zone of forwarding) is the union set of $\text{ZOR}_t \cup \text{ZOF}_{t+i}^R \cup \text{ZOF}_{t+i}^F$.

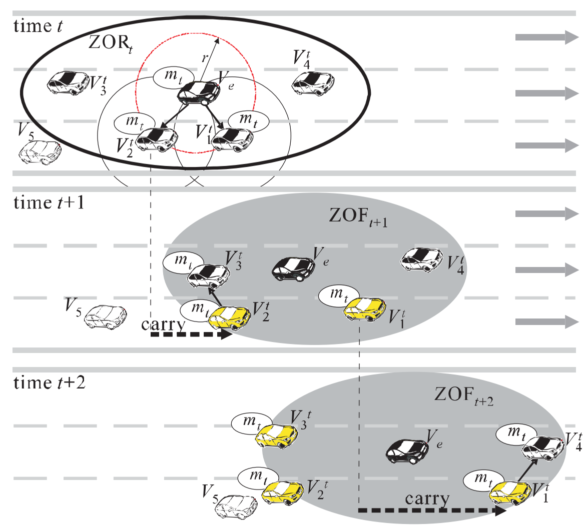


Fig. 2. An example of mobicast routing with carry-and forward.

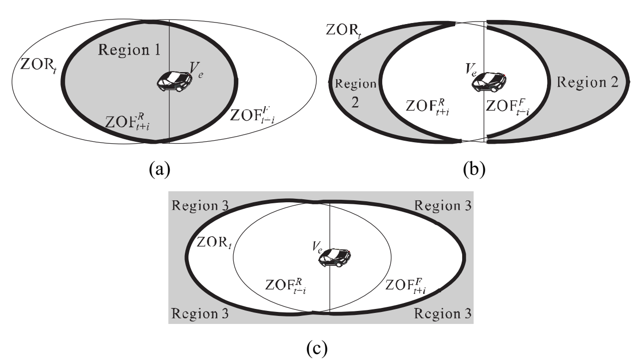


Fig. 3. (a) region 1, (b) region 2, and (c) region 3

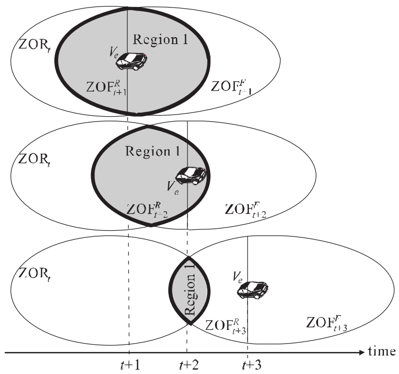


Fig. 4. The area of region 1 is decreasing as the time increasing.

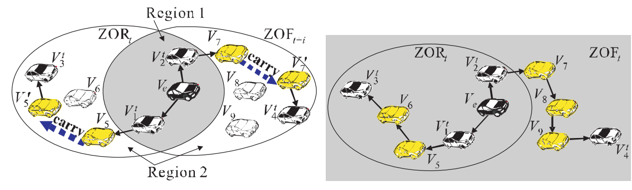


Fig. 5. Protocol comparison: (a) mobicast routing protocol with carry-and-forward and (b) distributed robust geocast protocol.

niques. The multihop forwarding technique delivers m_t to V_j^t by multihop wireless transmission. The channel utilization is high and the delivery delay is short. The carry-and-forward technique delivers m_t to V_j^t by some possible vehicles carrying and forwarding. The channel utilization is low but the delivery delay is long. Comfort applications usually keep the delay-tolerant capability and the channel resource should be reserved for safety application. Hence, the mobicast routing for comfort applications should use the carry-and-forward technique as far as possible. The multihop forwarding technique is only used when it is necessary. The key problem in this work is how to choose the message delivery technique between multihop forwarding and carry-and-forward techniques to achieve high dissemination successful rate and maintain a low degree of channel utilization; meanwhile, the delivery delay should be reduced as much as possible.

In this work, the message delivery techniques are chosen according to the region. Three regions can be identified as shown in Fig 3 because ZOR$_t$ is a static region and ZOF$_{t+i}$ is constantly moving with V_e. Region 1 is ZOR$_t\cap$ (ZOF$^R_{t+i}\cup$ZOF$^F_{t+i}$). Region 2 is (ZOR$_t$ $\cup$ ZOF$^R_{t+i}\cup$ZOF$^F_{t+i}$)$-$ region 1. Region 3 is ˜(ZOR$_t$ $\cup$ ZOF$^R_{t+i}\cup$ZOF$^F_{t+i}$). The key idea of this work is to deliver the mobicast massage by using multihop forwarding technique in region 1, and using carry-and-forward technique in region 2. Considering the trajectory of vehicles, all vehicles are continuously moving ahead. Both region 1 and region 2 can cover V_j^t. However, region 1 can cover V_j^t more easily than region 2. The multihop forwarding technique is used in region 1 because it is necessary to use the wireless transmission to deliver the mobicast message m_t to V_j^t. But compared to region 1, region 2 also covers some other vehicles which do not need to receive the mobicast message. That is the reason why the carry-and-forward technique is used in region 2. For those vehicles which do not need to receive the mobicast message in region 2, there is unnecessary for them to get involved in delivering messages. Therefore, the channel resource can be reserved. There is an exception which the multihop forwarding technique is used in region 2 if the mobicast message can not deliver to destined vehicles before time $t+\lambda$. In addition, the mobicast message m_t is dropped in region 3 because region 3 does not cover V_j^t.

Observe that, the area of region 1 is decreasing as time goes by because ZOF$_{t+i}$ is constantly moving with V_e as shown in Fig 4. Initially, the area of region 1 is large. The multihop forwarding technique is used in region 1 to deliver m_t for most of vehicles V_j^t with short delivery delay. The delivery delay can be reduced as much as possible. As time goes by, vehicles using multihop forwarding technique to deliver the mobicast message are becoming fewer and fewer in region 1. Vehicles use carry-and-forward technique to deliver the mobicast message m_t and overcome the temporary network fragmentation problem in region 2. Hence, more and more channel resource are reserved for safety applications .That is, our mobicast routing protocol reduces the delivery delay time as much as possible, maintains a low degree of channel utilization, and achieves the high dissemination successful rate by overcoming the temporary network fragmentation problem. Fig. 5 (a) shows that our mobicast routing protocol only uses multihop forwarding technique in region 1, and carry-and-forward technique is used to reserve channel resource in region 2. V_6, V_8, and V_9 are not involved to deliver mobicast message in our protocol. Compared to DRG [2] as shown in Fig. 5 (b), our protocol can reserve more channel resource.

III. Mobicast Routing Protocol

The mobicast routing protocol is split into three phases: (1) ZOR$_t$ creation phase, (2) ZOF$_{t+i}$ estimation phase, and (3) message dissemination phase. The detailed operation is developed as follows.

A. ZOR$_t$ Creation Phase

In this paper, we assume that each vehicle can acquire location information via location information providers, such as the Global Positioning System. Let $L_t^{V_j}=(x_t^{V_j},y_t^{V_j})$ denote as the location of V_j at time t. Let v_{j_t} denote as the velocity V_j at time t. Each vehicle V_j exchanges $L_t^{V_j}$ and v_{j_t} to its neighbors by hello message. The procedure of the ZOR$_t$ creation phase is given herein.

S1. V_e announces the ZOR$_t$ which is determined by $Z_t(L_t^{V_j})=\frac{(x_t^{Vj}-x_t^{V_e})^2}{a^2}+\frac{(y_t^{Vj}-y_t^{V_e})^2}{b^2}-1=0$, where a is the major axis of the ZOR$_t$ and b is the minor axis of the ZOR$_t$. Major axis a is determined by the requirement of comfort application and minor axis b is determined by the width of lane.

S2. The usual velocity of V_e is necessary to predict the location of V_e, which is used to describe the border of ZOF$_{t+i}$. Let v_e^h denote as the usual velocity of V_e. Based on the investigation of [3], the velocity is generally assumed as normal distributed in highway scenario. Each driver usually drives a car with a specific velocity pattern; therefore, v_e^h can be used to represent the usual velocity of V_e. Let v_j^{low} and v_j^{upper} denote as the low bound and upper bound velocity of V_j, respectively. The low bound and upper bound velocity of V_e are $v_e^{low} = \overline{v_e} - t_{Gossett} \times \frac{\widehat{S}_{v_e}}{\sqrt{n}}$ and $v_e^{upper} = \overline{v_e} + t_{Gossett} \times \frac{\widehat{S}_{v_e}}{\sqrt{n}}$, where $\overline{v_e}$ is the mean velocity of V_e, n is the number of recorded velocities, $t_{Gossett}$ is a parameter under $CI\%$ in Gosset's t-distribution [4], where $CI\%$ denotes the confidence interval of the estimated velocity, and $\widehat{S}_{v_e}$ is the standard deviation of $S(V_e)$, where $\widehat{S}_{v_e} = \sqrt{\frac{\sum (v_{e_t} - \overline{v_e})^2}{n-1}}$. Then, v_e^h can be acquired form v_e^{low} and v_e^{upper} by harmonic mean computing as $v_e^h = \frac{2}{\frac{1}{v_e^{low}} + \frac{1}{v_e^{upper}}}$.

S3. The V_e broadcasts the mobicast control packet $P_m(V_j, v_e^h, Z_t(L_t^{V_e}), m_t, t_s, a)$, where t_s is sending time when V_e sends P_m. After V_e broadcasted the P_m, ZOF$_{t+i}$ creation phase is executed.

B. ZOF$_{t+i}$ Estimation Phase

ZOF$_{t+i}$ is to indicate which vehicle should deliver the mobicast message m_t for V_j^t at each time $t+i$. ZOF$_{t+i}$ consists of ZOF$^R_{t+i}$ and ZOF$^F_{t+i}$. ZOF$^R_{t+i}$ is used to deliver m_t to V_j^t behind V_e and ZOF$^F_{t+i}$ is used to deliver m_t to V_j^t in front of V_e. The detailed operation is developed as follows.

A1. To know the necessary of receiving m_t, V_j checks whether it has appeared in ZOR$_t$ at time t if V_j receives a P_m. If $Z_t(L_t^{V_j}) \leq 0$, V_j is V_j^t and it is necessary for receiveing m_t, then goto to A2. Otherwise, If $Z_t(L_t^{V_j}) \geq 0$, goto message dissemination phase.

A2. V_j^t compares its location with V_e to know it is located in eithor ZOF$^R_{t+i}$ or ZOF$^F_{t+i}$ because ZOF$_{t+i}$ is split by V_e's location. If $(x_{t+i}^{V_j} - x_{t+i}^{V_e}) < 0$, V_j^t is located in ZOF$^R_{t+i}$, then goto A3, where $x_{t+i}^{V_e} = x_t^{V_e} + v_e^h \times i$. Otherwise, if $(x_{t+i}^{V_j} - x_{t+i}^{V_e}) > 0$, V_j^t is located in ZOF$^F_{t+i}$, then goto A4.

A3. To deliver m_t to all V_j^t behind V_e, ZOF$^R_{t+i}$ is formed to cover all V_j^t behind V_e at each time $t+i$ by estimating the major axis a_R of ZOF$^R_{t+i}$. Let v_R^{mean} denote as the mean velocity of all V_j^t behind V_e. The major axis a_R is computed by $a_R = (v_e^h - v_{mean}^R) \times i + a$, where $v_R^{mean} = \frac{2}{\frac{1}{v_j^{low}} + \frac{1}{\text{previous\_}v_R^{mean}}}$. Observe that, v_R^{mean} is computed by low bound of V_j^t in order to cover all V_j^t behind V_e as could as possible. Then goto A5.

A4. To deliver m_t to all V_j^t in front of V_e, ZOF$^F_{t+i}$ is formed to cover all V_j^t in front of V_e by estimating the major axis a_F of ZOF$^F_{t+i}$. Let v_F^{mean} denote as the mean velocity of all V_j^t in front of V_e. The major axis a_F of ZOF$^F_{t+i}$ is computed by $a_F = (v_{mean}^F - v_e^h) \times (t+i-t_s) + a\ V_j^t$, where $v_F^{mean} = \frac{2}{\frac{1}{v_j^{upper}} + \frac{1}{\text{previous\_}v_F^{mean}}}$. Observe that, v_F^{mean} is computed by upper bound of V_j^t in order to cover all V_j^t in front of V_e as could as possible.

A5. ZOF$^R_{t+i}$ and ZOF$^F_{t+i}$ are formed by $F^R_{t+i}(L_{t+i}^{V_j}) = \frac{(x_{t+i}^{Vj} - x_{t+i}^{V_e})^2}{a_R^2} + \frac{(y_{t+i}^{Vj} - y_t^{V_e})^2}{b^2} - 1 = 0$ and $F^F_{t+i}(L_{t+i}^{V_j}) = \frac{(x_{t+i}^{Vj} - x_{t+i}^{V_e})^2}{a_F^2} + \frac{(y_{t+i}^{Vj} - y_t^{V_e})^2}{b^2} - 1 = 0$, respectively. Then goto message dissemination phase.

Fig. 6 shows examples of ZOF$^R_{t+i}$ and ZOF$^F_{t+i}$. Observe that, a_R and a_F are estimated based on v_j^{low} and v_j^{upper}, respectively. The purpose is to enhance dissemination successful rate by covering all V_j^t as far as possible.

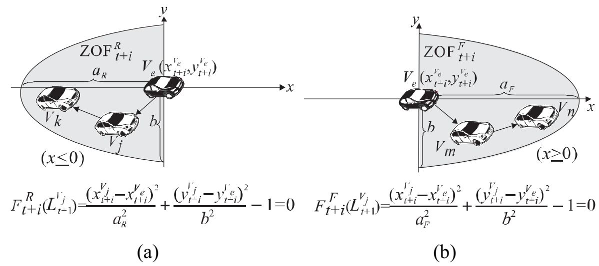


Fig. 6. Creation of (a) ZOF$^R_{t+i}$ and (b) ZOF$^F_{t+i}$.

C. Message Dissemination Phase

In the message dissemination phase, m_t is disseminated to all V_j^t. A node chooses eithor multihop forwarding technique or carry-and-forward technique to deliver m_t according to the region which the node is located. Besides, m_t should be delivered under constrained delay time λ. The procedure of the message dissemination phase is described below.

S1. When V_j receives a P_m at time $t+i$, V_j directly forward P_m to neighboring vehicles using multihop forwarding technique if one of the two conditions is true: (C1) $Z_t(L_{t+i}^{V_j}) \leq 0$ and $F^R_{t+i}(L_t^{V_j}) \leq 0$, or (C2) $Z_t(L_{t+i}^{V_j}) \leq 0$ and $F^F_{t+i}(L_t^{V_j}) \leq 0$. Both the two conditions represent V_j located within region 1. Condition C1 implys V_j located in both ZOR$_t$ and ZOF$^R_{t+i}$. Condition C2 implys V_j located in both ZOR$_t$ and ZOF$^F_{t+i}$. Otherwise goto S2.

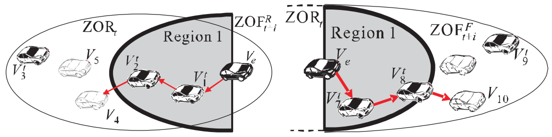
S2. V_j forward P_m to other V_j^t with carry-and-forward technique if one of the two conditions is true: (C3) $Z_t(L_{t+i}^{V_j}) \leq 0$ and $F^R_{t+i}(L_t^{V_j}) > 0$, or (C4) $F^F_{t+i}(L_t^{V_j}) \leq 0$ and $Z_t(L_{t+i}^{V_j}) > 0$. Both the two conditions represent V_j located within region 2. Condition C3 implys V_j located in ZOR$_t$ but outside ZOF$^R_{t+i}$. Condition C4 implys V_j located in ZOF$^F_{t+i}$ but outside ZOR$_t$. In addition, considering the constrained delay time λ, V_j still needs to examine the remaind delivery time. Let R_j and F_j denote as the distance from V_j to left border of ZOR$_t$ and right border of ZOF$^F_{t+i}$, respectively. In condition C3, if $\frac{R_j}{v_j^{upper}} > \lambda - i$, V_j directly forwards P_m to a neighbor vehicle to satisfy the constrained delay time. In condition C4, if $\frac{F_j}{v_j^{low}} > \lambda - i$, V_j directly forwards P_m to a neighbor vehicle to satisfy the constrained delay time.

S3. V_j drops P_m if one condition is true: (C5) $Z_t(L_{t+i}^{V_j}) > 0$ and $F^R_{t+i}(L_t^{V_j}) > 0$ and $F^F_{t+i}(L_t^{V_j}) > 0$. Condition C5 represent V_j located in region 3.

Fig. 7 shows the mobicast message is delivered by multihop forwarding technique in region 1. Fig. 8 shows the mobicast message is delivered by carry-and-forward technique in region 2.

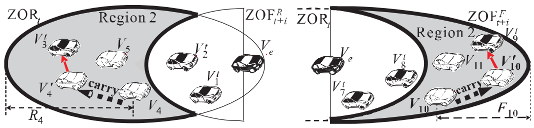
IV. Simulation Results

To evaluate the presented mobicast protocol, our mobicast routing protocol with carry-and-forward (MCF) is simulated and compared to DRG [2]. All these protocols are mainly implemented using the NCTUns 5.0 simulator and emulator



(a) (b)

Fig. 7. The multihop forwarding technique is used in region 1.



(a) (b)

Fig. 8. The carry-and-forward technique is used in region 2.

[5]. 802.11p protocol is used for physical and MAC layer in this simulation. 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 constrained delay time λ assumes 35 seconds. Each time unit i assumes 500ms. V_e broadcasts a new P_m per minute. The performance metrics to be observed are:

- *Message overhead* (MO) is the total number of bytes that all vehicles transmitted to deliver the mobicast message.
- *Dissemination successful rate* (DSR) is the number of vehicles have appeared in ZOR$_t$ which can successfully receive the mobicast messages before time $t + \lambda$ ($\lambda = 35$ seconds), divided by the total number of vehicles have appeared in ZOR$_t$.
- *Accumulative packet delivery delay* (APDD) is the accumulative delay time when a mobicast message is received by a vehicle V_j^t.

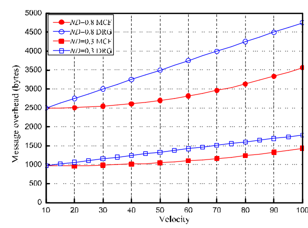
It is worth mentioning that an efficient mobicast routing protocol in a VANET is achieved with a high DSR, low MO, and low APDD.

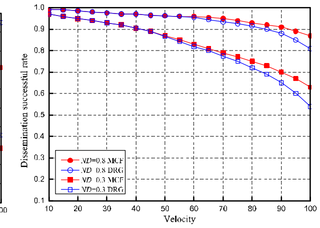
A. Message overhead (MO)

Fig. 9 (a) shows the observed MO under various velocity v. A mobicast routing protocol for comfort applications with the lower message overhead implies the degree of channel utilization was low. The channel resource should be reserved for safety applications. Compared to DRG, our mobicast routing protocol with carry-and-forward significantly improves MO.

B. Dissemination successful rate (DSR)

Fig. 9 (b) shows the observed DSR under various velocity v. A mobicast routing protocol with the high dissemination successful rate implies that the value of its DSR was high. In general, the DSR drops as the v increases because the rapid changed topology and frequent happened temporary network fragmentation problem. The temporary network fragmentation problem is frequently occurred when the ND is low. Therefore, DSR was low when ND was low.





(a) (b)

Fig. 9. Performance of (a) message overhead vs. velocity, (b) dissemination successful rate vs. velocity.

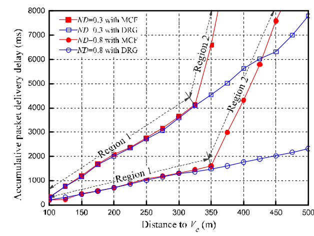


Fig. 10. Performance of accumulative packet delivery delay vs. distance to V_e.

C. Accumulative Packet delivery delay (APDD)

Fig. 10 shows the observed APDD vs. the distance to V_e. APDD accumulates the deliver delay time for each V_j^t. In general, the APDD increases as the distance increases. Observe that, when the distance to $V_e \doteqdot 325$m under ND = 0.3 and the distance to $V_e \doteqdot 350$m under ND = 0.8, the APDD is intense increasing in our mobicast routing protocol. The is because the message is delivered to region 2 and the carry-and-forward technique is tused.

V. Conclusion

In this paper, we present a mobicast routing protocol with carry-and-forward to achieve high dissemination successful rate, maintain a low degree of channel utilization and reduce the delivery delay as much as possible.

VI. Acknowledgements

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