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 $\lambda$. 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 $\lambda$ is the constrained delay time. That is, the mobicast routing protocol for the 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+k} (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 \( j = \{ c, 1, \ldots, j, \ldots, n \} \) throughout this paper. Event vehicle \( V_{c} \) 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 \( V_{c} \) and a constrained delay time \( \lambda \), ZOR_{t} is a static elliptic region determined by \( V_{c} \) at time \( t \), such that vehicle \( V_{j} \) must be successfully received the mobicast message \( m_{t} \) from \( V_{c} \) 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 proved 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}, \( V_{c} \) initiated a ZOR_{t} and the communication range of each vehicle is assumed r. \( V_{1}^{1}, V_{2}^{1}, V_{3}^{1}, \) and \( V_{4}^{1} \) have appeared in the ZOR_{t} and should receive the mobicast message \( m_{t} \) before time \( t + \lambda \). However, \( V_{4}^{1} \) 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+k} is used to indicate which vehicle should carry \( m_{t} \) and forward to \( V_{j}^{t} \). The formal definition of ZOF_{t+k} is given.

Fig. 2 gives an example of mobicast, which the constrained delay time assumes \( \lambda = 2 \). Initially, \( V_{c} \) 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 \( t + 2 \). \( V_{c} \) 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 \( t + 1 \), \( V_{2}^{1} \) carries \( m_{t} \) and moves closed to \( V_{3}^{t} \), then \( V_{3}^{t} \) forwards \( m_{t} \) to \( V_{4}^{t} \). At time \( t + 2 \), \( V_{3}^{t} \) carries \( m_{t} \) and moves closed to \( V_{4}^{t} \), then \( V_{4}^{t} \) forwards \( m_{t} \) to \( V_{4}^{t} \). Observe that \( V_{3}^{t} \) has not appeared in ZOR_{t} at time \( t \), therefore \( V_{3}^{t} \) does not receive \( m_{t} \).

**Definition 2: ZOF_{t+k}(zone of forwarding):** Given a \( V_{c} \), ZOF_{t+k} is a geographic region determined at each time \( t + i \), where \( i = 0, 1, \ldots, i \), 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+k}.

In this work, ZOF_{t+k} is separated by \( V_{c} \)'s position into two sub-zones, the rear sub-zone and the front sub-zone. Let ZOF_{t+k} denote as the rear sub-zone behind \( V_{c} \). Let ZOF_{t+k} denote as the front sub-zone, which is in front of \( V_{c} \). This is, ZOF_{t+k} = ZOF_{t+k} \cup ZOF_{t+k}. The center location of ZOF_{t+k} is the same with the location of \( V_{c} \), moving at the same speed as \( V_{c} \), and toward the same direction with \( V_{c} \). Fig. 1 (b) shows \( V_{1}^{t}, V_{2}^{t}, V_{3}^{t}, \) and \( V_{4}^{t} \) located in ZOF_{t+k}; 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. 4. The area of region 1 is decreasing as the time increasing.

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

 techniques. The multihop forwarding technique delivers $m_t$ to $V_j^f$ by multihop wireless transmission. The channel utilization is high and the delivery delay is short. The carry-and-forward technique delivers $m_t$ to $V_j^f$ 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 multicast 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 $V_c$. Region 1 is $\text{ZOR}_t \cap (\text{ZOR}^{R}_{t+i} \cup \text{ZOF}^{F}_{t+i})$. Region 2 is $(\text{ZOR}_t \cup \text{ZOF}^{R}_{t+i}) - \text{region 1}$. Region 3 is $(\text{ZOR}_t \cup \text{ZOR}^{R}_{t+i} \cup \text{ZOF}^{F}_{t+i})$. The key idea of this work is to deliver the multicast 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 $V_j^f$. However, region 1 can cover $V_j^f$ 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 multicast message $m_t$ to $V_j^f$. But compared to region 1, region 2 also covers some other vehicles which do not need to receive the multicast 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 multicast 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 multicast message can not deliver to destined vehicles before time $t + \lambda$. In addition, the multicast message $m_t$ is dropped in region 3 because region 3 does not cover $V_j^f$.

Observe that, the area of region 1 is decreasing as time goes by because ZOF$_{t+i}$ is constantly moving with $V_c$ 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 $V_j^f$ 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 multicast message are becoming fewer and fewer in region 1. Vehicles use carry-and-forward technique to deliver the multicast 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 multicast 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 multicast routing protocol only uses multihop forwarding technique in region 1, and carry-and-forward technique is used to reserve channel resource in region 2. $V_0$, $V_8$, and $V_0$ are not involved to deliver multicast message in our protocol. Compared to DRG [2] as shown in Fig. 5 (b), our protocol can reserve more channel resource.

### III. MBOICAST ROUTING PROTOCOL

The multicast 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 $L_t^V = (x_t^V, y_t^V)$ denote as the location of $V_j$ at time $t$. Let $v_j$ denote as the velocity $V_j$ at time $t$. Each vehicle $V_j$ exchanges $L_t^V$ and $v_j$ to its neighbors by hello message. The procedure of the ZOR$_t$ creation phase is given herein.

S1. $V_c$ announces the ZOR$_c$, which is determined by $Z_t(L_t^V) = (\frac{y_t^V - y_{c}}{a})^2 + (\frac{x_t^V - x_{c}}{b})^2 = 1 = 0$, where $a$ is the major axis of the ZOR$_c$ and $b$ is the minor axis of the ZOR$_c$. 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 $V_c$ is necessary to predict the location of $V_c$, which is used to describe the border of ZOF$_{t+i}$. Let $v_c^b$ denote as the usual velocity of $V_c$. 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, $v_c^b$ can be used to represent the usual velocity of $V_c$. Let $v_{low}$ and $v_{upper}$ denote as the low bound and upper bound velocity of $V_j$, respectively. The low
bound and upper bound velocity of $V_e$ are $v_{\text{low}} = \overline{v} - t_{\text{Gossett}} \frac{s_{\text{v}}}{\sqrt{n}}$, and $v_{\text{upper}} = \overline{v} + t_{\text{Gossett}} \frac{s_{\text{v}}}{\sqrt{n}}$, where $\overline{v}$ is the mean velocity of $V_e$, $n$ is the number of recorded velocities, $t_{\text{Gossett}}$ is a parameter under the $t$-distribution [4], where $CT\%$ denotes the confidence interval of the estimated velocity, and $s_{\text{v}}$ is the standard deviation of $S(V_e)$, where $S_{\text{v}} = \sum_{i=1}^{n} v_i - \overline{v}$. Then, $v_{\text{h}}$ can be acquired form $v_{\text{low}}$ and $v_{\text{upper}}$ by harmonic mean computing as $v_{\text{h}} = \frac{v_{\text{low}} \cdot v_{\text{upper}}}{v_{\text{low}} + v_{\text{upper}}}$. Then, $S3$. The $V_e$ broadcasts the mocibact control packet $P_m(V_j, v_{\text{h}}, Z_i(L_i), m_t, a)$, where $m_t$ is sending time when $V_e$ sends $P_m$. After $V_e$ broadcasts 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 mocibact message $m_t$ for $V_j'$ at each time $t+i$. ZOF$_{t+i}$ consists of ZOF$_{t+i}^R$ and ZOF$_{t+i}^F$. ZOF$_{t+i}^R$ is used to deliver $m_t$ to $V_j'$ behind $V_e$, and ZOF$_{t+i}^F$ is used to deliver $m_t$ to $V_j'$ in front of $V_e$. The detailed operation is as follows.

A1. To know the necessary of receiving $m_t$, $V_j'$ checks whether it has appeared in ZOR$_r$ at time $t$ if $V_j'$ receives a $P_m$. If $Z_i(L_i) \leq 0$, $V_j'$ is $V_j'$ and it is necessary for receiving $m_t$, then goto A2. Otherwise, If $Z_i(L_i) > 0$, goto message dissemination phase.

A2. $V_j'$ compares its location with $V_e$ to know it is located in either ZOF$_{t+i}^R$ or ZOF$_{t+i}^F$ because ZOF$_{t+i}$ is split by $V_e$’s location. If $(x_j' - x_i') < 0$, $V_j'$ is located in ZOF$_{t+i}^R$, then goto A3, where $x_j' = x_i' + v_{\text{h}} \times i$. Otherwise, if $(x_j' - x_i') > 0$, $V_j'$ is located in ZOF$_{t+i}^F$, then goto A4.

A3. To deliver $m_t$ to all $V_j'$ behind $V_e$, ZOF$_{t+i}^R$ is formed to cover all $V_j'$ behind $V_e$ at each time $t+i$ by estimating the major axis $a_R$ of ZOF$_{t+i}^R$. Let $v_{\text{mean}}$ denote as the mean velocity of all $V_j'$ behind $V_e$. The major axis $a_R$ is computed by $a_R = \frac{(v_e - v_{\text{mean}}) \times (t + i) + v_j'}{2 \frac{v_{\text{mean}}}{a_R}}$. Observe that, $v_{\text{mean}}$ is computed by the low bound of $V_j'$ in order to cover all $V_j'$ behind $V_e$ as could as possible. Then goto A5.

A4. To deliver $m_t$ to all $V_j'$ in front of $V_e$, ZOF$_{t+i}^F$ is formed to cover all $V_j'$ in front of $V_e$ by estimating the major axis $a_F$ of ZOF$_{t+i}^F$. Let $v_{\text{mean}}$ denote as the mean velocity of all $V_j'$ in front of $V_e$. The major axis $a_F$ of ZOF$_{t+i}$ is computed by $a_F = \frac{v_{\text{mean}} - v_j'}{(t + i) - a_F} + a_F$, where $v_{\text{mean}} = \frac{v_{\text{mean}} + v_j'}{a_F}$. Observe that, $v_{\text{mean}}$ is computed by the upper bound of $V_j'$ in order to cover all $V_j'$ in front of $V_e$ as could as possible.

A5. ZOF$_{t+i}^R$ and ZOF$_{t+i}^F$ are formed by $F_{t+i}^R(L_i, V_j') = \frac{(V_j' - a_R)^2}{a_R^2} + \frac{(V_j' - L_i)^2}{L_i^2} - 1 = 0$ and $F_{t+i}^F(L_i, V_j') = \frac{(V_j' - a_F)^2}{a_F^2} + \frac{(V_j' - L_i)^2}{L_i^2} - 1 = 0$, respectively. Then goto message dissemination phase.

S6. shows examples of ZOF$_{t+i}^R$ and ZOF$_{t+i}^F$. Observe that, $a_R$ and $a_F$ are estimated based on $v_{\text{low}}$ and $v_{\text{upper}}$, respectively. The purpose is to enhance dissemination successful rate by covering all $V_j'$ as far as possible.

C. Message Dissemination Phase

In the message dissemination phase, $m_t$ is disseminated to all $V_j'$. A node chooses either 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 $\lambda$. 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) $Z_i(L_j') \leq 0$ and $F_{t+i}^R(L_j') \leq 0$, or (C2) $Z_i(L_j') \leq 0$ and $F_{t+i}^F(L_j') \leq 0$. Both the two conditions represent $V_j'$ located within region 1. Condition C1 implies $V_j'$ located in both ZOR$_r$ and ZOF$_{t+i}^R$. Condition C2 implies $V_j'$ located in both ZOR$_r$ and ZOF$_{t+i}^F$. Otherwise goto S2.

S2. $V_j'$ forwards $P_m$ to other $V_j'$ with carry-and-forward technique if one of the two conditions is true: (C3) $Z_i(L_j') \leq 0$ and $F_{t+i}^R(L_j') \leq 0$, or (C4) $F_{t+i}^F(L_j') \leq 0$ and $Z_i(L_j') \leq 0$. Both the two conditions represent $V_j'$ located within region 2. Condition C3 implies $V_j'$ located in ZOR$_r$ but outside ZOF$_{t+i}^R$. Condition C4 implies $V_j'$ located in ZOF$_{t+i}^F$ but outside ZOR$_r$. In addition, considering the constrained delay time $\lambda$, $V_j'$ still needs to examine the remained delivery time. Let $R_i$ and $F_j$ denote as the distance from $V_j'$ to left border of ZOR$_r$ and right border of ZOF$_{t+i}$, respectively. In condition C3, if $R_i > \lambda - i$, $V_j'$ directly forwards $P_m$ to a neighbor vehicle to satisfy the constrained delay time. In condition C4, if $F_j > \lambda - i$, $V_j'$ directly forwards $P_m$ to a neighbor vehicle to satisfy the constrained delay time. In addition, $V_j'$ drops $P_m$ if one condition is true: (C5) $Z_i(L_j') > 0$ and $F_{t+i}^F(L_j') > 0$ and $F_{t+i}^F(L_j') > 0$. Condition C5 represent $V_j'$ located in region 3.

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

IV. Simulation Results

To evaluate the presented mocibact protocol, our mocibact 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.
[5]. The multihop forwarding technique is used in region 1.

![Fig. 7. The multihop forwarding technique is used in region 1.](image)

![Fig. 8. The carry-and-forward technique is used in region 2.](image)

A. Message overhead (MO)

Fig. 9 (a) shows the observed MO under various velocity $v$. A multihop 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 multihop 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 multihop 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.

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

C. Accumulative Packet delivery delay (APDD)

In general, the APDD increases as the distance increases. Observe that, when the distance to $V_c$ = 325 m under ND = 0.3 and the distance to $V_c$ = 350 m under ND = 0.8, the APDD is intense increasing in our multicast routing protocol. The is because the message is delivered to region 2 and the carry-and-forward technique is used.

![Fig. 10. Performance of accumulative packet delivery delay vs. distance to $V_c$.](image)

VI. CONCLUSION

In this paper, we present a multicast 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.

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