Received June 23, 2019, accepted August 4, 2019, date of publication August 20, 2019, date of current version September 19, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2936456

Data Dissemination of Application Service by Using Member-Centric Routing Protocol in a Platoon of Internet of Vehicle (IoV)

CHUNG-MING HUANG, (Member, IEEE), TZU-HUA LIN, AND KUAN-CHENG TSENG
Department of Computer Science and Information Engineering, National Cheng Kung University, Tainan 70101, Taiwan

Corresponding author: Tzu-Hua Lin (linth@locust.csie.ncku.edu.tw)

This work was supported by the Ministry of Science and Technology of the Republic of China, Taiwan, under Contract MOST 108-2221-E-006-056-MY3.

ABSTRACT In this paper, we proposed routing protocols for transmission over VANET in a platoon of vehicles that are driving together on the highway from the same starting point with the same route, and going to the same destination. The purpose of the routing protocols is to have cooperative video streaming service for a specific platoon member, i.e., it belongs to multiple-source to single-destination transmission. We considered two strategies that route data from multiple-source to single-destination. The first one is the severalty strategy in which each data source forwards packets through a route that contains common nodes of other paths as few as possible. The severalty strategy tries to increase the reliability of the route from source to destination and to achieve load balance by Helper-disjoint algorithm. The another strategy is the merged strategy which merges multiple traffic flows passing some specific nodes together. The main purpose of merged strategy tries to reduce the probability of collision while wireless resource are competing to forward data simultaneously and to increase the utilization of DSRC. In this paper, we proposed On-Demand Member-Centric Routing (OMR) protocol using the severalty strategy and Reactive Member-Centric Routing (RMCM) protocol using the merged strategy. Based on the simulation results, our proposed member-centric routing protocols effectively improve the packet delivery ratio and throughput compared with using others in the aforementioned platoon scenario over VANET.

INDEX TERMS VANET, routing protocol, on-demand, Internet of Vehicle (IoV), data dissemination.

I. INTRODUCTION

In recent years, the vehicular ad hoc network (VANET) has emerged as a popular research topic that receives much attention from these researches [19], [21], [27]–[32]. The Dedicated Short Range Communication (DSRC) is proposed vehicular communication technology with the deployment of WLAN successfully. It also called connected vehicle (CV). Moreover, the 5th and 4th generation mobile telecommunications (5/4G) is another way to provide people to have service applications on mobile devices. Thus, combination between the ubiquitous connectivity of 5/4G network and the high data rate offered by DSRC [27]–[29], [31], [32] makes it attractive.

Due to the application development is rapid in Artificial Intelligence (AI), the data growth rate is increased eventually. However, since the several applications integrate Internet of Vehicle (IoV) technologies and cloud computing system (i.e., traffic flow), the factor of latency cannot be too long. The feasible paradigm is known as ''edge computing''. Edge computing not only reduces the communications bandwidth, but also reduce the latency because of the distance is shorter than cloud server basically. Therefore, there are three challenges should be considered. At first, the amount of data become huge, because the number of devices are too many. That mean is that the 5/4G bandwidth needed is increasing eventually. Secondly, because the amount of data is increasing, the performance between V2V and V2I must be improved. Thirdly, the challenge is that how to maintain or repair the data dissemination because the velocity of vehicle is rapid.

In this paper, we focus on a scenario in which a platoon of vehicles is formed by vehicles that are driving together on the highway from the same starting place with the same path, and going to the same destination. In several researches,

The associate editor coordinating the review of this article and approving it for publication was Ke Guan.

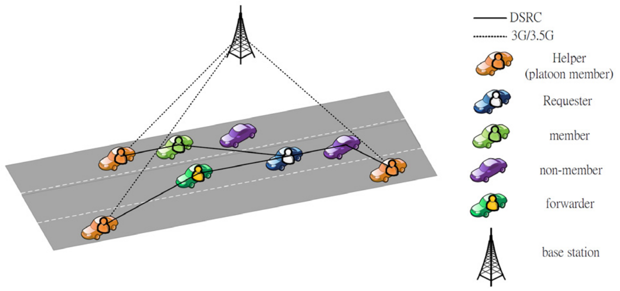


FIGURE 1. An illustrated scenario of the member-centric routing.

there are discussed the same scenario [39]–[41] to import the performance of a platoon over VANET network. An illustrated example of a platoon of vehicles is a group of families/friends who drive their sedans to travel together, which is depicted in Fig. 1. In the platoon mobility scenario, platoon members keep staying as close as possible to communicate with each other using the V2V-based DSRC network. If the platoon is partitioned by some sedans that don't belong to the platoon, the communication of platoon members can be done through those non-members' sedans temporarily. At the same time, platoon members will try to drive to organize a connected topology such that each platoon member can be inside the DSRC communication coverage of one or more platoon members. Therefore, the wireless link connections and changed topology frequently between members are much more stable in a platoon compared with others because the mobile nodes (members) in the platoon tend to keep as close as possible with each member. In addition, we assume that each member is equipped with DSRC interface in the platoon to communicate with each other and also a 5/4G interface to connect to Internet through base stations.

A platoon's member can download multimedia or have the Internet service through its 5/4G equipment. However, since the usable bandwidth of 5/4G becomes low when the vehicle is moving rapidly, it is not possible to satisfy the user need through a single 5/4G connection for some applications between AI and IoV. Therefore, this major work is to design an efficient routing protocol which can aggregate the usable 5/4G bandwidth of members to provide service for a specific member, by means of the help of members in the platoon through DSRC connections. There are five types of mobile node in the platoon-based VANET are Requester, Helper, member, non-member, and forwarder. Requester is a mobile node that needs helps and take advantage of the redundant 5/4G bandwidth of members to achieve the greater service; Helper is a member necessarily in the platoon and it can share its 5/4G bandwidth to download multimedia data and forward these data back to Requester through DSRC; member is a mobile node that is belonging to the platoon; non-member is a mobile node that doesn't belong to the platoon; forwarder is the mobile node that forwards data packets from Helpers to Helpers or Requester. They can be member or non-member in our scenario.

Based on the characteristics of the platoon scenario, some member-centric routing protocols, in which member nodes should be chosen with higher priority for constructing the routing path, can be devised meet the requirement of 5/4G bandwidth aggregation over VANET. Because of the characteristic of the platoon mobility, it is obvious that the links between platoon members should be more stable than the links between members and non-members. Therefore, for member-centric routing protocols, it is reasonable to choose members as forwarders instead of choosing non-members. Since Helpers are k-hop, $k = 1, \ldots, n$, away from Requester, we need to design a suitable routing strategy to route these data from Helpers to Requester efficiently. We introduced two routing strategies: the severalty strategy and the merged strategy. Using the severalty strategy, each Helper forwards packets through a path that contains common forwarders of other paths as few as possible. The goals of using the severalty strategy are to increase the reliability and to achieve load balance. On the contrary, the merged strategy tries to merge multiple traffic flows into some specific nodes together, which is opposite to the severalty strategy. The goals of using the merged strategy are to reduce collision and interference between traffic flows and to increase the DRSC links' utility. In this paper, we proposed two member-centric protocols based on aforementioned two routing strategies. The first one is called On-Demand Member-Centric Routing (OMR) protocol [39], which uses the severalty strategy to establish paths from Helpers to Requester. The second one is called Reactive Member-Centric Routing (RMCM) protocol, which uses the merged strategy to establish paths from Helpers to Requester. Both OMR and RMCM are designed for the platoon-based VANET scenario. OMR and RMCM are belonging to the multiple-source and single-destination transmission because of the platoon scenario that is considered, i.e., several Helpers transmit data cooperatively to a Requester to keep staying the high quality of service.

Our proposed OMR protocol uses an algorithm based on a mechanism of Helper-disjoint to select multiple Helpers which would form maximum node-disjoint paths from themselves to Requester because of the reliability enhancement. Since each path from Helper to Requester is disjoint to others as more as possible, when a link is broken because of vehicle mobility, it would break traffic flow paths as few as possible. OMR organizes Candidate Helpers that have redundant 5/4G bandwidth with reactive approach in the platoon. Each Helper in the platoon would choose a better route that consists of members as more as possible. A cost function is introduced to calculate the cost of path which takes (1) the ratio of the number of non-members to the number of forwarders and (2) stability of non-members into consideration.

In our proposed RMCM protocol, Requester tries to select Helpers that can be merged together to increase DSRC links' utility and reduce link competition. RMCM uses a tree structure to maintain the overlay topology of Candidate Helpers. Generally speaking, since the data rate of DSRC interface is 2-54 *Mbps* and 15-1000 *meter* range in the general condition, it adopts a merged routing strategy that can use DSRC interface bandwidth more efficiently to reduce the number of traffic flows and the probability of collision in the DSRC wireless network environment. The merged strategy reduces the collision caused by two disjoint DSRC links competing to forward data concurrently. Furthermore, our proposed RMCM protocol makes use of the concept called opportunistic forwarding [12], [13] to achieve the merged routing strategy and to select paths which are more stable among member nodes for routing.

The rest of this paper is organized as follows. Section II introduces some related works and VANET routing research. Section III and Section IV introduces our proposed protocol, the On-Demand Member-Centric Routing (OMR) protocol and the Reactive Member-Centric Routing (RMCM) protocol in detail respectively. Section V discuss and analysis the performance evaluation and simulation results. Section VI has the conclusions for our work.

II. RELATED WORKS

In this Section, we introduce some related work, including VANET routing, IEEE 802.11 and IEEE 802.11p, and mobility model.

A. VANET ROUTING

VANET routing can be divided into four categories [14], [17]: ad-hoc routing, broadcast routing [35], cluster routing [33], [34] and geographic routing. Here we focus on ad-hoc routing and introduce some well-known routing protocols [19], [27]–[29], [31], [32]. Ad-hoc routing is originally proposed for the MANET scenario and can be modified accordingly to adapt to the VANET scenario [22]. AODV [1], [36]–[38] and DSR [2], [36]–[38] are two typically well-known routing protocols belonging to ad-hoc routing. The main objective of these two protocols is to maintain a route from source to destination only when data are available to be sent. However, due to the rapid topology changing characteristic of VANET, these two protocols have been proven to suffer from low performance in various traffic conditions [3], [4]. Authors in [3] modified AODV and proposed two new protocols called PRAODV and PRAODVM to reduce the rapid link breakage problem caused by topology changing, in which the authors used the speed and location information of nodes to predict the link lifetime. PRAODV constructs a new alternate route before the end of the estimated lifetime while AODV does it until route failure happens. PRAODV-M selects the maximum predicted life time path among multiple route options instead of selecting the shortest path that is adopted in AODV and PRAODV. The simulation results of both PRAODV and PRAODV-M showed some slight improvements regarding packet delivery ratio. However, these two protocols depend heavily on the accuracy of the prediction method.

NDMR [5], which is extended from AODV, was proposed to increase the reliability of AODV. NDMR selects multiple node-disjoint paths from source to destination and thus the robustness is increased comparing with the single-path approach. NDMR also reduces routing overhead dramatically by recording the shortest loop-free paths which contain the lowest number of hops. Author in [6] proposed DDOR to reduce routing overhead and end to end delay by a destination discovery method. DDOR maintains the position information of data destination by unicasting destination discovery mechanism without using any location service. Furthermore, Author in [20] proposed a routing optimization algorithm to efficiently determine an optimal path from a source to a destination.

Multi-Path disjointness has been studied in [7]–[9]. Nasipuri *et al.* [7] studied the effect of different numbers of multiple paths and different lengths of those paths on routing performance using analytical models. Lee *et al.* [8] proposed the Split Multipath Routing protocol (SMR), which can find an alternate route that is maximally disjoint from the shortest delay route from the source to the destination. Both of the aforementioned protocols are based on source routing. Huang *et al.* [9] studied the influence of mutual interference or path coupling on node-disjoint paths. They concluded that as the distance between the source and destination increases, the effectiveness of node-disjoint paths and the impact of path coupling become more remarkable. Additionally, the performance gap between the minimum-interference node-disjoint paths and the single-path becomes conspicuous only at high packet rates.

In the platoon scenario, member-centric routing has been studied in [39]–[41]. Huang *et al.* [39] and [40] adopt reactive and proactive approach to design the routing protocol. Due to proactive approach, PMCS [40] is suitable in the platoon scenario and the characteristic of platoon. But, it will spend more control message to maintain the changed topology when the form of platoon splits two groups. However, OMR [39] can reduce the control messages efficiently and can dynamically maintain the changed topology. Huang *et al.* [41] adopt geographic routing to aggregate 5/4G bandwidth and pick up the stable links between platoon members to merge multiple flows through the metrics of protocol.

B. IEEE 802.11 & IEEE 802.11P PROTOCOL

Dedicated Short Range Communications (DSRC) is essentially applied in the vehicular communication. DSRC adopts the technique of IEEE 802.11p MAC and 802.11p PHY. Basically, IEEE 802.11p is part of the 802.11-family protocols. The main difference is that the spectrum of IEEE 802.11p is in 5.85-5.925 GHz and the spectrum of IEEE 802.11b, 802.11g, and 802.11n are in 2.412-2.484 GHz. IEEE 802.11p enhances the quality of service based on IEEE 802.11. It is known that the wireless medium is open and those nodes that are within the same frequency and transmission range can communicate with each other. Since there are many nodes in the same transmission range and only one node can access a wireless channel at an instant, some factors such as channel utilization and competition should be resolved necessarily. In [25], Zhefu Shi *et al.* proposed a channel utilization model with a newly derived variable channel access rate which can be applied for all traffic loads. Shi *et al.* [26] proposed an analytical model to understand space, back-off, and flow correlation for the CSMA wireless network. In [26], the authors presented a new continuous-time model for CSMA wireless network in which a node model and a channel model are combined to capture correlation. Using the proposed model, the probabilistic quality of service guarantee can be calculated to optimize the performance by adjusting arrival and back-off rates along various paths.

C. MOBILITY MODEL

Mobility model is used to model nodes' movement in mobile ad-hoc networks' simulation. Different mobility models have different characteristics that can meet different simulation requirements. Random Waypoint Model (RWM) was proposed by Broch *et al.* [16] and is one of the most popular mobility models used in the ad hoc networking research community. The random waypoint mobility model contains pause time between changes in direction and speed. Once a mobile node (MN) begins to move, it stays in one location for a specified pause time. After the specified pause time is timeout, the MN randomly selects the next destination in the simulation area and chooses a speed uniformly distributed between the minimum speed and maximum speed and travels with a speed v whose value is uniformly chosen in the interval $[0, v_{max}]$. There are varieties of the modified random waypoint mobility model such as Random Walk and Random Direction models. Xiaoyan et al. proposed Reference Point Group Model [18] that is used for group mobility. Each node belongs to a group and follows a logical center (group leader) that determines the group's motion behavior. Group member nodes' movements are based on group leader node's movement by adding group leader's moving vector and a small random vector. Thus, the Reference Point Group Model can generate a group of nodes that are moving together. However, the Reference Point Group Model is not suitable for our platoon scenario because the platoon moves in the highway such that the mobility of each platoon member would be limited by the road, the highway's speed limitation, etc. Furthermore, the platoon may be partitioned into several parts by non-member nodes temporarily and then be connected again after a while.

III. THE ON-DEMAND MEMBER-CENTRIC ROUTING (OMR) PROTOCOL

We designed the On-Demand Member-Centric Routing (OMR) [39] protocol using the severalty strategy. In order to increase the reliability and achieve load balance, the main ideas of the OMR protocol are to select multiple Helpers that route through node-disjoint paths from Helpers to Requester and each path consists of members as many as possible.

The OMR protocol consists of four phases: Helper discovery phase, Helper selection phase, data forwarding phase, and route recovery phase. Helper discovery concentrates on the issue of how to find suitable Candidate Helpers, and meanwhile, find a suitable path to send packets from selected Helper to Requester, which can achieve high throughput and high reliability; Helper selection concentrates on the issue of how to select proper Helpers for aggregating 5/4G bandwidth, which can produce high throughput as well. Packets are forwarded hop by hop in the data forwarding phase. Finally, when the link is broken, it will be fixed in the route recovery phase. The position and amount of redundant bandwidth of Helpers are relative to each other so we should take both into account carefully. For example, if we just select a Helper who has the highest 5/4G bandwidth but far from Requester, it may be not suitable because of its large hop count, which results in low throughput even though it can provide the higher 5/4G bandwidth. Fig. 2 shows the operational procedure of message exchanging and different phases of the OMR protocol. The terms and symbols that include several parameters are listed in Table 3.

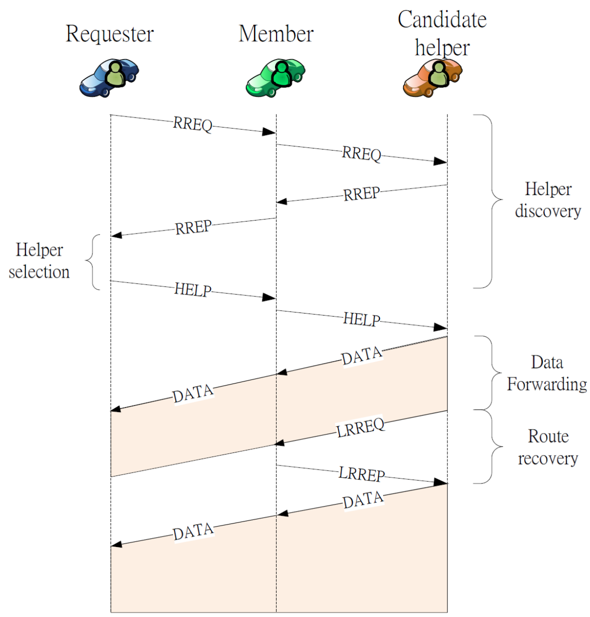


FIGURE 2. The operational procedure of the OMR prorotocol.

A. NON-MEMBER STABILITY FACTOR

Although vehicles in a platoon form a group and travel together to the same destination, it is still possible that some areas do not have members, in which areas OMR should choose some non-members for forwarding data. The Non-member Stability Factor (NSF) is introduced to indicate the cumulatively relative stability among non-members. Non-members tending to drive with the platoon for a while would have higher NSFs; in contrast, non-members that are just passing through the platoon would have lower NSFs. Therefore, choosing non-members with high NSFs for routing purpose is reasonable because members would prefer to choose those non-members that are driving in the platoon neighboring area for a while, which implies that the connections between members and those non-members are more stable than others.

In the OMR protocol, each mobile node broadcasts Hello messages to its neighbor nodes periodically in order to gain routing information from neighbor nodes. After receiving Hello messages, each mobile node stores a neighbor list which not only shows the type of neighbors (member or non-member), but also shows the NSFs of the neighbors and which neighbor nodes are still valid. A neighbor node is considered to be available if it is still within the one-hop range and thus useable for routing; on the contrary, a neighbor node is unavailable if it is out of the one-hop range. It is called the Hello Messaging interval between sending two consecutive Hello message. which represents a trade-off between the maintained loading on the wireless medium and accuracy of the positional information. If a non-member neighbor node is still valid after a Hello messaging, the NSF is increasing for the non-member; if it is no longer valid, the corresponding NSF is decreasing till it drops to 0. Through this method, NSF represents a cumulatively relative stability of a non-member.

B. HELPER DISCOVERY

The Helper discovery procedure of OMR is triggered when Requester would like to have video streaming or services and need other members' help. Requester broadcasts Route Request (RREQ) messages to the whole network with a TTL value set to RREQTTL, which equals the number of vehicles in the platoon subtracts 1. A RREQ message consists of several fields: Requester id, the last Member this RREQ has been forwarded by, path to Requester, and Non-member Stability Factor (NSF) of each Non-member by which the RREQ message has been forwarded.

Intermediate node which receives a RREQ message may cache and rebroadcast it if the RREQ message's TTL isn't zero. Furthermore, each node appends its own identifier and the NSF value of the previous node (if it's a non-member) before forwarding the RREQ message. If one node gets a duplicate RREQ message from Requester, it may check whether it satisfies the following conditions or not: (1) The hop count is smaller than or equal to the first RREQ that has been received in this duplicate RREQ. (2) This duplicate RREQ traversed through a different incoming link from which the first RREQ is received. (3) The retransmission time of RREQ is smaller than a threshold. The duplicate RREQ will be forwarded if it satisfies all of the aforementioned three conditions, rather than just dropping it like AODV acts. The reason is that OMR protocol still forward the duplicate RREQ for providing more different routes. With the constraint of the aforementioned conditions, it make ensure that RREQs provide many different choices for routes to Candidate Helpers and also the control overhead is still limited by a threshold because of these rules.

Once a Candidate Helper receives RREQ, it may set a timer and wait for more RREQs to make a decision for replying back. The metric of selecting a suitable route is based on the cost of the route. The cost is calculated using Equation (1) as follows:

$$\cos t = c_1 \times \frac{number_{non}}{hop_{count}} + c_2 \times \frac{\sigma}{\mu} \tag{1}$$

In Equation (1), $number_{non}$ and hop_{count} are the number of non-members and the number of nodes that this RREQ has traveled respectively; μ represents the average NSF of all NSFs belonging to those non-members in this route. μ is calculated using Equation (2):

$$\mu = \frac{1}{number_{non}} \cdot \sum_{i \in non-member} NSF_i \tag{2}$$

σ is the standard deviation of all NSFs belonging to non-members in this route. σ is calculated using Equation (3):

$$\sigma = \sqrt{\frac{1}{number_{non}} \cdot \sum_{i \in non-member} (NSF_i - \mu)^2} \tag{3}$$

Coefficients c_1 and c_2 weigh the importance of each term respectively. The first term indicates the reliability of this path because it is obvious that the more members are included in the route, which means the better reliability the route has. The second term indicates the reliability of non-members included in the route. With having higher average NSF, it means that the mobile behavior of non-members is similar member in the route tending to be more close to the platoon and thus the link breakage probability between member and non-member is reduced. However, we should also consider the standard deviation of all NSFs in a route because any broken link of a route may break the whole path, which results in the stop of transmission from Helper to Requester.

After the selection of RREQs, a route to Requester is chosen from the smallest cost one. Moreover, a Route Reply (RREP) is sent back to Requester, in which RREP contains the information of the whole route. The purpose of sending RREP is to indicate the route from a specific Candidate Helper to Requester.

C. HELPER SELECTION

A mobile node is selected as Helpers from Candidate Helpers by Requester. Helper selection is quite important procedure because the approaches with different Helper allocation may affect the performance of the whole platoon-based network. Even though there are several low cost routes chosen by Candidate Helpers, if the locations of those Candidate Helpers are quite close with each other, it should not select all of them to be Helpers. It's because that when we consider the routes from Requester to Candidate Helper, these Candidate Helpers may form link-disjoint routes, which results in low reliability [11]. Furthermore, since these Candidate Helpers are quite close in the same hop area, the contention of wireless resources would be serious. It's one of main challenges in resource management, i.e., how to assign resources in our proposed protocol. In our case, we take advantage of helper selection to assign these resource and to reduce the contention.

TABLE 1. Sorted candidate helper table.

ID	Hop count	Route
C	2	R-A-C
E	2	R-A-E
G	3	R-A-D-G
H	3	R-B-E-H
F	3	R-A-C-F

TABLE 2. Jointness of candidate helpers in each iteration.

Iteration	B	C	G	F	I
1	**Helper**	0	0	0	0
2	Helper	**Helper**	1	2	1
3	Helper	Helper	**Helper**	3	4
4	Helper	Helper	Helper	**Helper**	5
5	Helper	Helper	Helper	Helper	**Helper**

In the OMR protocol, we proposed a Helper-disjoint algorithm that can select multiple Helpers forming a maximum node-disjoint path set from Helpers to Requester. Before introducing this algorithm, we introduced a metric for jointness at first. We defined the jointness of a path π using Equation (4):

$$J(\pi) = \sum_{i=1}^{n} (\sum_{j=1}^{m} com_{\pi_i, p_j}), \quad \forall com_{\pi_i, p_j} \in \{0, 1\} \tag{4}$$

In Equation (4), π_i means the i_{th} node of π , and com_{π_i, p_j} means whether route p_j shares the common node π_i with route π or not. If so, com_{π_i, p_j} equals 1; otherwise, com_{π_i, p_j} equals 0. A route with low jointness value represents that either it shares few common nodes with others or its shared nodes are shared only with few different routes.

At first, OMR sorted the Candidate Helpers are sorted based on the ascending order of hop count. Then, in the first iteration, OMR checked the Candidate Helpers in the smallest hop count whether it contains some nodes that also exist in the helperSet or not. Due to Helper isn't existed in the helperSet in the beginning, the Candidate Helper with the smallest hop count will be added in the helperSet and it will be removed from the Candidate Helper table. In the second iteration, the Candidate Helper with the 2nd smallest hop count is checked with the helperSet as well: if there are some mobile nodes are also existed in the helperSet, the Candidate Helper would be chosen as a new Helper from all of Candidate Helpers based on the minimum jointness; otherwise, it would be selected as the 2nd Helper and then be removed from the Candidate Helper table.

The procedure of helper selection is iterative until the needed bandwidth is reached. OMR uses the jointness of the selection metric, it selects the maximum node-disjoint Helpers one-by-one. An example is depicted in Fig. 3 for executing the Helper-disjoint algorithm and the jointness of Candidate Helpers for each iteration is depicted in Table 2. There are five Candidate Helpers in Fig. 3, named C, E, G, H, and F, and the corresponding information is shown in Table 1. Node C would be selected as the first Helper in the iteration because of the smallest hop count. Although node E has the 2nd smallest hop count, it would not be selected as Helper because the common nodes are included in the helperSet (i.e., common node A). Therefore, node H would be selected as the 2nd Helper after it compares the jointness of remaining

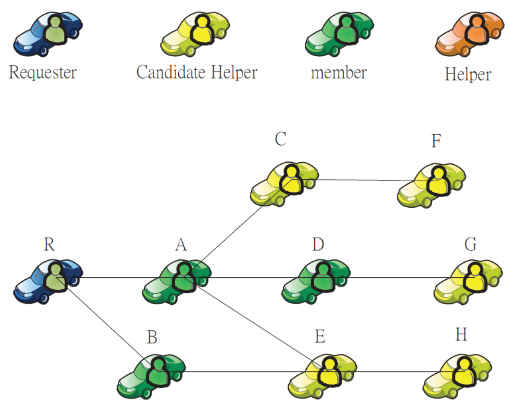


FIGURE 3. An illustrated Helper selection using the Helper-disjoint algorithm.

Candidate Helpers. In the 3rd iteration, G would be selected as the 3rd Helper because it has the smallest jointness calculated in the helperSet. In the 4th iteration, although nodes E and F have the same jointness value, node E would be selected as the 4th Helper because it has the smaller hop count and would be selected prior to node F. In the last iteration, node F would be selected as the 5th Helper. Therefore, for the example depicted in Fig. 3, Helpers are selected in the order of nodes C, H, G, E, and F by using the Helper-disjoint algorithm.

D. ROUTE RECOVERY

In this Section, we introduce how the route recovery work when the changed topology frequently, including local recovery and global recovery.

1) LOCAL RECOVERY

When a mobile node discovers a failure link, it triggers the procedure of local recovery to find an alternative route to its next member. Local Route Request (LRREQ) messages are broadcasted to the whole network. Let the node that needs to find a new route be called repairing node. Each node receiving LRREQs will rebroadcast it if the message's TTL isn't zero. One the repairing node's next-member receives LRREQ, then a Local Route Reply (LRREP) message is sent back to the repairing node and the alternative route is indicated in the LRREP message. After receiving LRREP message from its next member, the repairing node will send data through the alternative route and thus local recovery is done.

After broadcasting LRREQ message, the repairing node will start waiting a LocalRecoveryTimer. If local recovery failed, the repairing node will send a Route Repair (RERR) message to its upstream Helper and try to find an alternative route to Requester using global recovery, i.e., LocalRecoveryTimer was timeout without receiving LRREP message.

2) GLOBAL RECOVERY

The procedure of Global recovery is triggered when a node fails to repair the route to its next-member, which is caused by frequently topology changing. Because of the mobility of vehicles, there is a situation that node X overtakes its forwarding node Y and thus the forwarding node Y becomes farther from Requester than node X; another situation is that the forwarding node Y moves much far from node X. The two aforementioned situations would result in local recovery failure and thus the Helper should re-discovery an alternative route to Requester.

If a node does not receive a LRREP from its next-member after LocalRecoveryTimer is timeout, it would send a Route Error (RERR) message to its upstream Helper. Once a Helper receives a RERR, it would stop sending data and enters into the route recovery phase. Afterward, Global Route Request (GRREQ) messages are broadcasted to the whole network. Each node receiving GRREQs will rebroadcast it if the message's TTL isn't zero. Once Requester receives GRREQ, then a Global Route Reply (GRREP) message is sent back to the Helper and the alternative route to Requester is indicated in the GRREP message; meanwhile, the route to that Helper is updated by Requester. The procedure of global recovery is similar to the procedure of local recovery excluding the senders and receivers of messages.

IV. THE REACTIVE MEMBER-CENTRIC ROUTING (RMCM) PROTOCOL

We designed the Reactive Member-Centric Routing (RMCM) protocol using the merged strategy. Since DSRC links usually have higher bandwidth compared with 5/4G links, the main ideas of the RMCM are to merge Helpers together to increase DSRC links' utility and reduce wireless channel competition.

Four phases of RMCM are Helper discovery phase, Helper selection phase, data dissemination phase, and route recovery phase. When a Requester wants to find extra 5/4G bandwidth to download streaming data, it will start the Helper discovery phase to find available Candidate Helpers and builds up a Candidate Helper Tree. Then, the Requester enters into the Helper selection phase to select suitable Helpers from the Candidate Helper Tree. The selected Helpers download data from their 5/4G interfaces and then transmit the downloaded data back to Requester through members in the data dissemination phase. Meanwhile, the route recovery phase is in charge of link failure while transmitting data back to Requester.

TABLE 3. Terms and symbols for OMR.

Symbol	TERM
NSF	Non-member Stability Factor.
$number_{non}$	The number of non-members
hop_{count}	The number of nodes that this RREQ has traveled.
σ	The standard deviation of all NSFs belonging to non-members in this path.
μ	The average NSF of all NSFs belonging to those non-members in this path.
cost	It takes (1) the ratio of the number of non-members to the number of forwarders and (2) stability of non-members into consideration.
π_i	The i^{th} node of π
com_{π_i, p_j}	It is checked whether path p_j shares the common node π_i with path π or not.
J(π)	Jointness is a value which denotes whether a path has redundant nodes which are shared or not.
TTL	Time to Live.
RREQ	Route Requester
RREQTTL	It is TTL value that the number of RREQ could be rebroadcasted.
RREP	Route Reply
RERR	Route Error
LRREP	Local Route Reply
LocalRecovery Timer	Local Recovery Timer
GRREQ	Global Route Request
GRREP	Global Route Reply

It needs a data structure for Requester to record Candidate Helpers that have replied to Requester during the Helper discovery phase. The structure needs to have overall awareness of these Helpers' connection condition. Since the RMCM protocol tries to choose paths that have as many Helpers as possible to reduce the number of traffic flows, RMCM stores these Helpers in a tree structure to maintain their orders of connection. We call a node's (1) parent Candidate Helper node in the tree as ACH (ancestor Candidate Helper) node and (2) child Candidate Helper node in the tree as DCH (descendant Candidate Helper) node. Note that for every Candidate Helper node, there is only one ACH node, but may connect with several DCH nodes in the Candidate Helper Tree.

A. HELPER DISCOVER

When Requester wants to have 5/4G bandwidth from other members, it will broadcast a RREQ message to its one-hop neighbors. Nodes who receive the RREQ message will rebroadcast it if the message's TTL isn't zero. Similar to the Destination Source Routing (DSR) protocol [2], each node appends its own identifier to the RREQ message's packet when forwarding RREQ. When the RREQ message reaches a Candidate Helper, the node will cache the route stored in RREQ and unicast RREP back to tell Requester its existence and the ACH node it connects to. After this, the Candidate Helper will clear route information stored in RREQ and rebroadcast it if the RREQ's TTL is not zero. The reason of clearing route information in RREQ is that every Candidate Helper needs only to maintain a reverse route to its previous Candidate Helper, i.e., its ACH node. After receiving the 1st RREQ, sometime later, when the Candidate Helper receives other RREQ messages, the Candidate Helper compares the route stored in RREQ and the route cached in its route table, and then (1) discards the RREQ if the cached one is better or (2) sends RREP back if the new one is better.

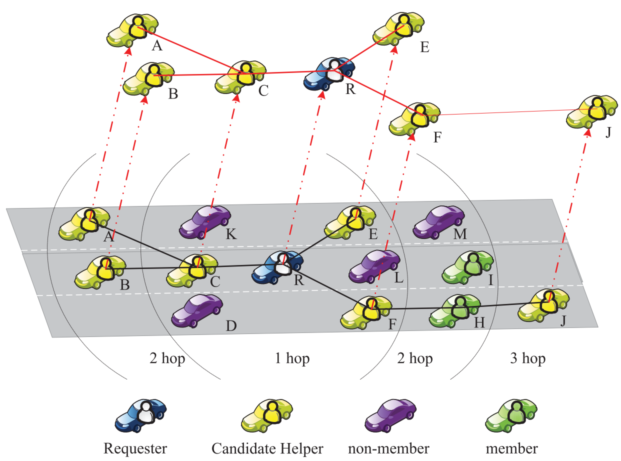


FIGURE 4. The operational procedure of Helper discovery.

While rebroadcasting, nodes will perform the opportunistic forwarding strategy to give different opportunities to different types of nodes to rebroadcast the RREQ message. RMCM assigns different delay time to different types of nodes while rebroadcasting the RREQ message. Non-members have the longest delay time while Candidate Helpers have the shortest one. In Fig. 4, let node C, D and K be in node R's transmission range, in which (1) node C is a member and (2) nodes D and K are non-members. All of them receive the RREQ message broadcasted by node R. Since node C is a member and has shorter delay time than nodes D and K, it will rebroadcast the RREQ message before them. Nodes D and K can overhear the RREQ message broadcasted by node C before its rebroadcasting and thus drop the RREQ message that they are waiting to send. As a result, member node C has more opportunities to append its identifier into the RREQ message and rebroadcast it. The opportunistic forwarding strategy also reduces some redundant flooding messages. Note that a Candidate Helper won't cancel its rebroadcasting because the RMCM protocol tries to maintain the Candidate Helper Tree. An illustrated Candidate Helper Tree that is built after performing the Helper discovery phase is depicted in Fig. 4.

B. HELPER SELECTION

After the Helper discovery phase, a Candidate Helper Tree in which the Requester is the root is built. After sending out the first RREQ message, Requester starts HelperDiscoveryTimer, and starts to select its Helpers from Candidate Helper Tree when the timer is timeout. We can consider the Candidate Helper Tree as the overlay network structure of Candidate Helpers. Since RMCM wants to select Candidate Helpers that are closer to Requester as Helpers, it selects Helpers from the topmost level of the tree to the bottom level of the tree. In the same level, Helpers with higher 5/4G bandwidth are selected first.

After Requester has selected its Helpers, it sends HELP messages to all selected Helpers to let them know that they have been selected as Helper and can start to download and send back the data that Requester needs. To reduce the number of HELP messages, RMCM doesn't send HELP message to each Helper separately. A HELP message, which records all selected Helpers' address, is generated by Requester after it selected its Helpers. Requester and the Candidate Helpers that receive the HELP message sends duplicate HELP messages to each of the DCH nodes that have been selected as Helpers and are recorded in the HELP message.

C. DATA DISSEMINATION

The node which receives the HELP message will change its node type as a Helper and starts to download data for Requester. When a Helper has a data packet to send, the route to the ACH node is included in the packet's header. Intermediate nodes forward the data packet through the route stored in its packet header. Given a Helper node X, when node X receives the data packet, X changes the route and ACH node's address in the packet's header to X's ACH node and forwards the packet. After traveling through several Helpers, the data packet will reach Requester finally. Note that the route to the ACH node has been cached in each Candidate Helper during the Helper discovery phase.

In DSR [2], every packet needs to store the whole path from source node to destination node in its packet header, which may cause a large size of header and consume too much packet payload. RMCM divides the path from a Helper to Requester into several smaller subpaths between Helpers, in which each Helper needs only to cache a subpath to its ACH node. In AODV [1], instead of storing the entire path into the packet header, every node that participates routing needs to cache its next hop to forward packet in the routing table. In the platoon scenario, we don't want non-members cache any route information. Thus RMCM stores all routing information in Helpers and the packet header.

D. ROUTE RECOVERY

When a node discovers some data are going to be forwarded to a failure link, it triggers the local recovery scheme to find another link to forward data. First, the node sends the RERR message to its most recent upstream Helper if the node itself is not a Helper. It is because RMCM tries to find an alternative path starting from a Helper, not from the node with link failure. A more stable path to the ACH node can be found through this way. When a Helper receives the RERR message, it broadcasts the LocalRREQ message. If the LocalRREQ message reaches an ACH node X, node X sends (1) the LocalRREP message to the Helper that sent the LocalRREQ message and (2) the RREP message to tell Requester to update its Candidate Helper Tree. For example, referring to

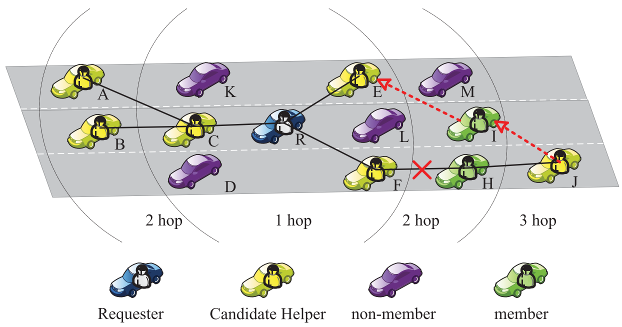


FIGURE 5. The operational procedure of local recovery.

Fig. 5, let link between node F and H is broken while node H wants to forward data towards this link. Node H will send the RERR message to its upstream Helper node J because node H itself isn't a Helper. Node J starts the local recovery scheme and broadcasts the LocalRREQ message to find other links to other downstream Helpers after receiving the RERR message. If Helper node E receives the LocalRREQ message sent by Helper node J, it sends the LocalRREP message to node J to update node J's ACH route and sends the RREP message to Requester node R to update R's Candidate Helper Tree. Data packets of Helper node J will then be forwarded to the new ACH node E through the new path recorded in the LocalRREP message instead of the broken one.

After sending the LocalRREQ message, the node starts a LocalRecoveryTimer. If Local Recovery is failed, i.e., it doesn't receive the LocalRREP message after LocalRecoveryTimer is timeout, the node stops downloading and sends a message to tell all its DCH nodes to stop downloading data.

Requester broadcasts the RREQ message when it wants to have 5/4G bandwidth from other members. If a Candidate Helper receives a RREQ message, it will cache the route, forward the RREQ message and send the RREP message back to Requester. Requester selects Helpers after RequesterSelectHelperTimer timeout and sends the HELP message to inform those selected Helpers to start downloading the data that Requester requested. Helper forwards data packets to their ACH node until the data packet reached Requester. RMCM uses LocalRREQ and LocalRREP messages to perform the route recovery procedure. The terms and symbols that include several parameters are listed in Table 4.

V. PERFORMANCE EVALUATION

Our measurement used NS-2 [15] to simulate our proposed two member-centric protocols (OMR and RMCM) and compare them with AODV. In our simulation, 60 nodes, which consist of 20 platoon member nodes and 40 non-member nodes, are deployed in a rectangular area of 20000 $m \times$ 100 m. Every node uses the IEEE 802.11p protocol in the MAC layer and the transmission range is 300 m. The reason for using 300 m is based on the research result depicted in [23]. The theoretical transmission range of 802.11p is 1 km. But when the transmission range is larger, the signal strength becomes more attenuated, the error rate becomes higher, the collision possibility becomes higher because more nodes can exist in the transmission range, etc. Thus, reference [23] indicates that 300 m is a suitably practical transmission range for 802.11p after experiments. Table 5 depicts the parameter's setting of our simulation.

TABLE 4. Terms and symbols for RMCM.

Symbol	Term
HELP	HELP message
ACH	Ancestor Candidate Helper
DCH	Descendant Candidate Helper
LocalRREQ	Local Route Requester
LocalRREP	Local Route Reply
RequesterSelectHelperTimer	A timer is that Requester selects Helper.
HelperDiscoveryTimer	A timer is that Helper discovery.

TABLE 5. Simulation environment.

Parameters	Value
Simulation area	2000 $m \times$ 100 m
Communication range	300 m
The number of nodes	60
The number of members	20
Transmission type	CBR packet
Simulation time	150 *sec*
Mobility model	Platoon Mobility Model

The reliability and stability of our proposed member-centric routing protocol are concerned with us. But the network situation is more complex, our proposed protocol cannot guarantee that the download task could be finished in reality environment. But, those platoon members intend to keep driving as close as possible with each other in the environment our proposed protocol considered. The cost of spending time could be calculated roughly.

The cost of spending time has two phases, including the transmission time form server to Helper through 5/4G, and transmission time by ad hoc routing. $T_{hostToHelper}$ means that the transmission time form server to Helper through 5/4G. The transmission time by ad hoc routing (T_{adhoc}) is calculated as follows:

$$T_{adhoc} = (T_{av\_one-hop} \times n) + T_{org} + T_{info} + T_{recovery} \quad (5)$$

However, the total time of spending equals as follows:

$$T_{total} = T_{hostToHelper} + (T_{av\_one-hop} \times n) + T_{org} + T_{info} + T_{recovery} \quad (6)$$

$T_{av\_one-hop}$ denotes the average of one-hop transmission time. The n denotes number of hop count. T_{org} denotes that the spending time of organizing the network topology in the member-centric routing protocol, such as NSF calculation, RREP/RREQ message, Helper selection, etc. T_{info} denotes that the spending time of informing those selected Helpers by Requester. $T_{recovery}$ denotes the spending time of local/global recovery when the network partition. Since the situation is very complex, our mechanism gives a threshold to limit a waiting time to avoid that the transmission time is wasted.

Packet delivery ratio, throughput and route recovery successful ratio are compared in the simulation results. Furthermore, two cases have been considered for 5/4G bandwidth distribution in a platoon of vehicles. (1) Case 1: those platoon members are closer to the Requester and they have higher redundant 5/4G bandwidth; (2) Case 2: those platoon members that are in the middle of platoon have higher redundant 5/4G bandwidth. In OMR and RMCM, we used the proposed Helper selection algorithms to select multiple Helpers and provided two strategies (severalty and merged) for aggregating bandwidth, while AODV selects Helpers randomly according to the 5/4G bandwidth.

We take advantage of the simulation results: packet delivery ratio and throughput, to discuss and conclude that our proposed protocol is better than AODV in which scenarios. OMR and RMCM both are member-centric routing protocol and adapt the merged strategy to transmit data packets by aggregating bandwidth. But they used a different kind of merged strategies to aggregate bandwidth in the relationship between OMR and RMCM. Finally, we use two cases to measure the route recovery successful ratios to find the relationship between OMR and RMCM.

A. MOBILITY MODEL

In order to evaluate the performance of our proposed member-centric protocols, we designed a Platoon Mobility Model (PMM) to meet our required scenario instead of using Random Waypoint Model [16] or Reference Point Group Model [18]. PMM is designed for highway scenario in which there are three lanes and vehicles are distributed into two categories: platoon members and non-members. All of the platoon members are toward the same destination with the same direction and move with the same assigned velocity. The velocity of platoon members is assigned by using Normal Distribution and the velocity of non-members is assigned randomly and the velocity is based on a lower bound and an upper bound according to the highway velocity limitation. While the vehicle is moving in the highway scenario, each vehicle will keep a safe range to its previous vehicle or overtake another vehicles if there are no other vehicles in other lanes. Moreover, members keep tracing the member in front of it. When a member y finds that its front member x is going to leave out of its transmission range, the velocity of member y will be changed to the speed limit in order to catch up member x. Once member y reaches the safe range to member x, then the velocity of member y will be the same as member x. By this approach, the characteristics of platoon can be achieved in the simulation.

Obviously, the proposed PMM ensures the mobility behavior of platoon members and non-members in the simulation. Since we believe that these drivers have risks in a practical condition, each node has to keep a safety distance from the car in front, even if each node wants to overtake the other cars. On the other hand, the topology partition of platoon members may happen. Therefore, each platoon member keeps tracking the front platoon members by adjusting its speed and switching to the other lane with a safe distance from the car in front/back. According to the aforementioned description, the mobility pattern of platoon members should be a form of the tree or the line. Therefore, we propose RMCM, which uses the tree-maintained method to compare the performance of feasibility and efficiency in the simulation.

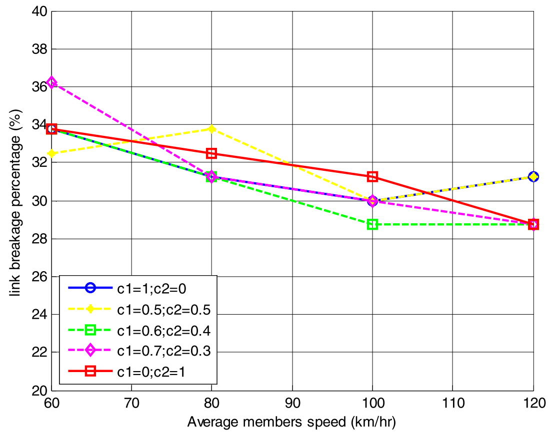


FIGURE 6. Link breakage percentage of different average members' speeds using the cost functions of different parameters' values.

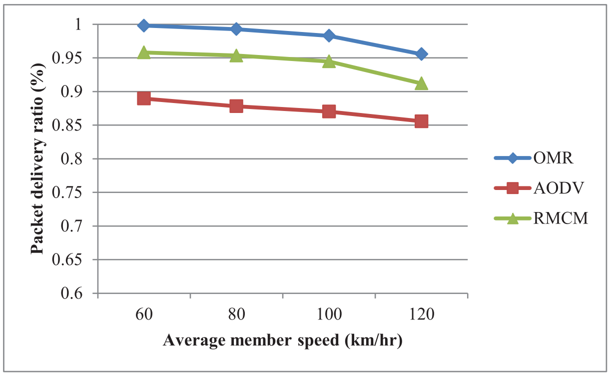
B. THE OPTIMIZATION OF COST FUNCTION

To optimize the cost function depicted in Equation (1) of subsection 3.2, we compare several values' sets of c1 and c2 in the simulation, in which the results are depicted in Fig. 6. The simulation result is in the second case, in which members have high redundant 5/4G bandwidth are in the middle of the platoon. In the second case, those platoon members that are in the middle of platoon have higher redundant 5/4G bandwidth. Since those platoon members that are closer to the Requester have higher redundant 5/4G bandwidth in the first case, we deem that the result of the second case should be much worse than the first case. It is reason that we choose the second case as comparing.

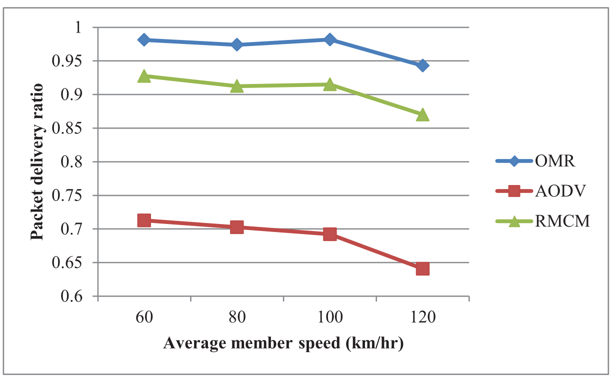
Two parts of the cost function depicted in Equation (1) are path reliability and non-member reliability, both of which are important when a selected path is comprised of some non-members. Thus, our measurements compare the link breakage percentage of cost function with the different constant values. Based on the simulation result, our proposed protocol could find the suitable set that has low link breakage percentage. The link breakage percentage denotes that the broken probability of the selected path. Referring to Fig. 6, our measurement observed that the trend of link breakage percentage in the high speed (100∼120 *km/hr*) is lower than that of the low speed (60∼80 *km/hr*). It is because that the route could be repaired easily when the average members' speed is high. Otherwise, the route has to spend more time to be repaired when the average members' speed is low. According to the result depicted in Fig. 6, our measurement obtained that c_1 and c_2 of the cost function can be suitably set as 0.6 and 0.4 respectively such that the performance of link breakage percentage is lower than others in most places. Please note that the determination of the values of c_1 and c_2 are based on executing the experiments up to 30 times.

C. PACKET DELIVERY RATIO

Packet Delivery Ratio (PDR) is defined as the ratio of totally received packets to totally sent packets. Our measurement studied the effect on the performance of various points of view, i.e., distribution of platoon members which have redundant 5/4G bandwidth, speed of platoon members, etc. It's useful to compare the performance of OMR, RMCM and AODV through the simulation results.



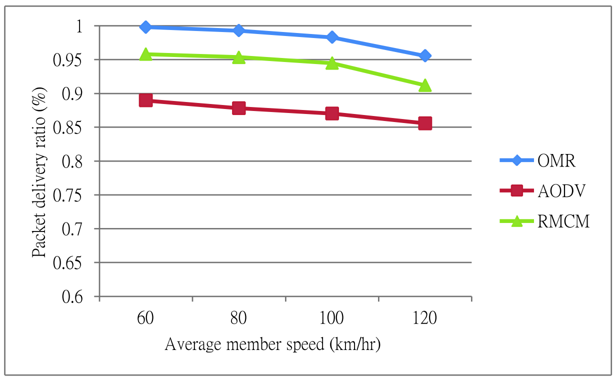
(a) Case 1



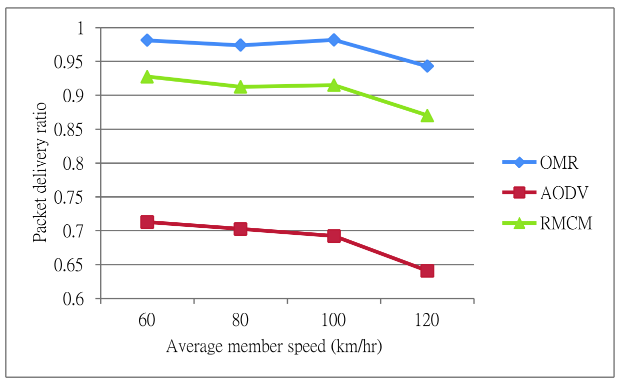
(b) Case 2

FIGURE 7. PDR with different average members' speeds (two Helpers).

Fig. 7-(a) and Fig. 7-(b) compare the results of PDR with the 5/4G distribution of platoon members in Case 1 and Case 2, where those platoon members that have redundant 5/4G bandwidth are closer to Requester and are in the middle of the platoon. Referring to Fig. 7-(a) and Fig. 7-(b), OMR is superior in Case 1 and Case 2. Generally speaking, PDR should be decreased significantly if Helpers are farther away from Requester. Referring to Fig. 7-(a), OMR achieves 98% PDR and RMCM achieves 94% PDR in Case 1 and they outperform AODV, which achieves 87% PDR. Since both OMR and RMCM select platoon members to forward data, the route becomes more stable than that of AODV. Moreover, according to PMM, the platoon members will try to drive within one or more other platoon members' transmission ranges with the assigned speed generally. On the other hand, when the topology partition of platoon members happens, the proposed NSFs of OMR assist platoon members to find suitable non-member nodes as the forwarding nodes. The result shows that the PDR of OMR is better than that of RMCM slightly. In Case 2, we expected that the PDR will be decreased, which is depicted in Fig. 7-(b), because the platoon members that are in the middle of platoon have higher redundant 5/4G bandwidth. Referring to Fig. 7-(b), PDRs of both OMR and RMCM are dropped a little, but the PDR of AODV drops about 18%. In other words, PDR is decreased 18-20% significantly without using the member-centric routing principle and Helper discovery efficiently. It is because that our proposed Helper discovery algorithms efficiently select Helpers that are much closer to Requester. Furthermore, with the member-centric routing principle, members have the higher priority to be selected for data forwarding so that the paths from Helpers to Requester become much more robust.



(a) Case 1



(b) Case 2

FIGURE 8. PDR with different average members' speeds (five Helpers).

Likewise, Fig. 8-(a) and Fig. 8-(b) depict the results of PDR with the distribution of platoon members in Case 1 and Case 2, where those platoon members that have redundant

5/4G bandwidth are closer to Requester and are in the middle of the platoon. Referring to Fig. 7-(a) and Fig. 7-(b), OMR is superior in Case 1 and Case 2. In contrast, the number of selected Helpers is increased to five in Figure 8. Referring to Fig 8-(a), in Case 1, PDR of AODV is about 80% while PDR of OMR is higher than 95% and PDR of RMCM is 87% in average. Comparing OMR with RMCM, we noticed that when the average member moving speed is increased, PDR of OMR drops slightly while PDR of RMCM drops quickly from 94% to 85%. It is because that RMCM tries to maintain a Candidate Helper Tree, however, when the average member moving speed is increased, the ACH nodes may go away and thus cause all of the downstream paths to DCH nodes being broken. Referring to Fig 8-(b), in Case 2, when the hop count of each Helper is increased, PDRs of both OMR and RMCM drop about 3% in average while the PDR of AODV drops about 12%. From the results depicted in Fig. 7 and Fig. 8, both OMR and RMCM are more suitable for multiple-source routing and OMR is more stable and reliable than RMCM in response to the change of network topology.

In Fig. 7-(a), Fig. 7-(b), Fig. 8-(a) and Fig. 8-(b), all results show that PDR is decreased when the average member speed increases from 60 to 120 *km/hr*. Our measurements further take a look at the performance over different average speeds of members. Our measurement found that the variation of PDRs is less than 3% when the average speed is from 60 to 100 *km/hr*, but the PDR is increased for about 5-10% when the average speed is 120 *km/hr*. For either Case 1 or 2, the results show that the variation of PDRs is small when the average member speed is between 60-100 *km/hr*; PDR is decreased significantly if the average member speed exceeds 100 *km/hr*. Referring to Fig. 8-(a) and Fig. 8-(b), it is found that the maintained Candidate Helper Tree is adverse when the average member speed is increased rapidly in the five Helpers' scenario.

D. THROUGHPUT

Throughput is defined as the total data packet size that Requester receives. The theoretical data rate of 802.11p is 54 Mbps in the maximum but the data rate of DSRC is 27 Mbps in the real environment [24]. Our measurement studied the effect on the performance of various points of view. In Fig. 9-(a) and Fig. 9-(b), both OMR and RMCM outperform AODV in terms of throughput because they use the member-centric routing principle to obtain reliable paths, which consist of the platoon members as more as possible. Especially, the throughput of AODV will be decreased significantly in Fig. 9-(b). Fig. 9-(a) indicates that OMR and RMCM achieve the same performance in Case 1. Furthermore, when the number of Helpers and the hop count of each Helper are low, the selected routing paths using the severalty strategy and the merged strategy are not so different. However, Fig. 9-(b) indicates that OMR outperforms RMCM because the severalty strategy increases the reliability of the routing protocol efficiently when the hop count of each Helper is increased.

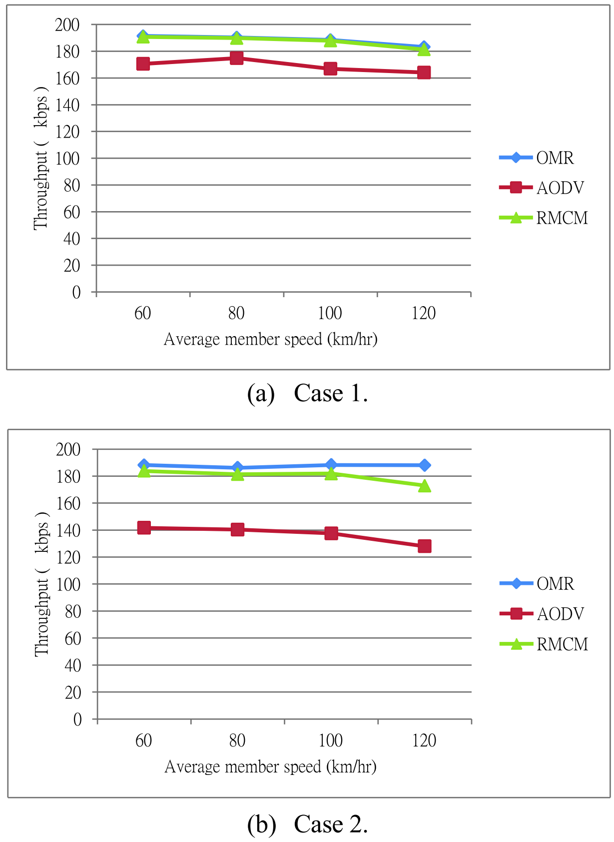
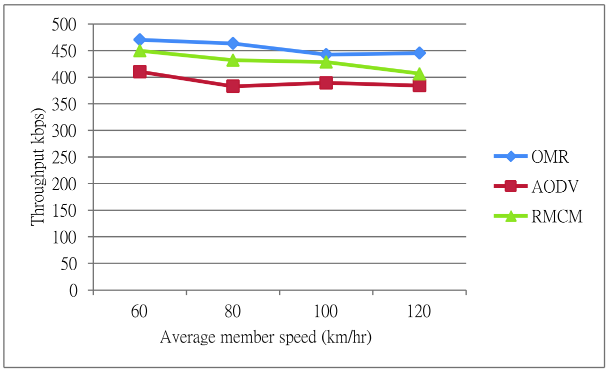


FIGURE 9. Throughput with different average members' speeds (two Helpers).

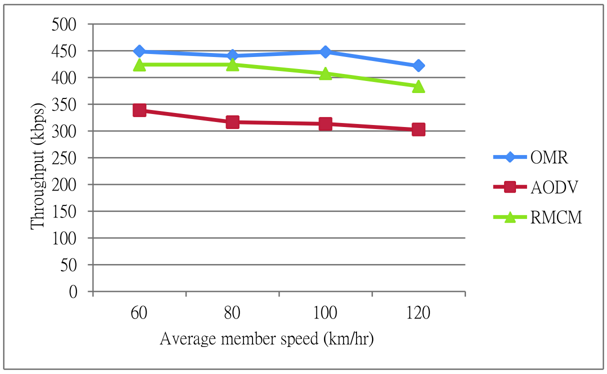
Figure 10-(a) and Figure 10-(b) depicted the results of the number of selected Helpers being increased to five. Referring to Figure 10-(a) and Fig 10-(b), it is obvious that the member-centric routing principle can ensure more stable routes because the throughput of both OMR and RMCM is larger than that of AODV in every case. On the other hand, the Helper discovery of both OMR and RMCM can guarantee that selected Helpers are much closer to Requester. Both OMR and RMCM outperform AODV in every case. Fig. 10-(a) indicates that OMR achieves 18% higher throughput than RMCM and Fig. 10-(b) indicates that OMR achieves 11.25% higher throughput than RMCM. Since RMCM has to maintain the Candidate Helper tree, the success or failure will affect the performance of throughput. OMR selects the maximum node-disjoint paths through Helpers and thus provides high reliability and high throughput. RMCM merges paths of Helpers and thus reduces the contention between multiple Helpers. These two methods efficiently increase the throughput. In summary, OMR and RMCM are more suitable than AODV for bandwidth aggregation because the overall throughput of both OMR and RMCM are much better.

E. ROUTE RECOVERY SUCCESSFUL RATIO

Route recovery successful ratio is defined as the ratio of the number of received LRREPs to the number of sent LRREQs. We try to understand why the throughput and PDR of RMCM

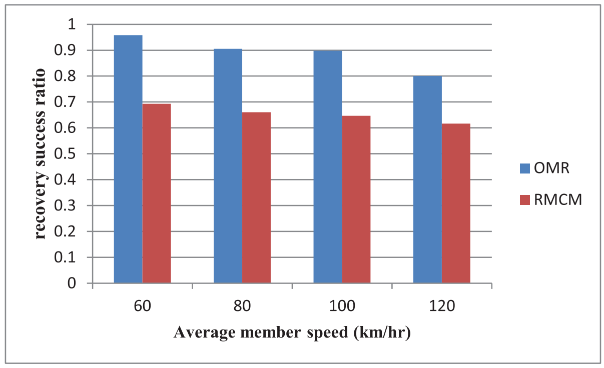


(a) Case 1.

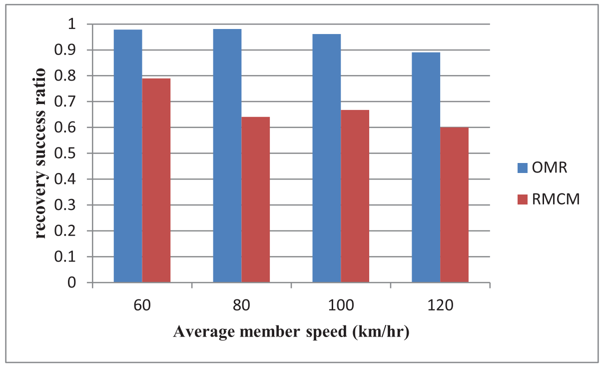


(b) Case 2.

FIGURE 10. Throughput with different average members' speeds (five Helpers).



(a) Case 1.



(b) Case 2.

FIGURE 11. Route recovery successful ratio with different average members' speeds.

is less than that of OMR in Case 1 and Case 2. So we use the successful ratios of route recovery of OMR and RMCM to compare with each other. The successful ratio of route recovery indicates the percentage of the broken routes that can be recovered. Fig. 11-(a) and Fig. 11-(b) show that OMR is better than RMCM. Referring to Fig.11-(a) and Fig.11-(b), OMR achieves higher route recovery successful ratios than RMCM. The reason is that RMCM tries to maintain a Candidate Helper tree structure such that the ACH nodes only can reply the LRREQs sent from Helpers. However, due to the mobility of vehicles, the ACH nodes may either move farther from Requester than DCH nodes or move far away for which LRREQ cannot reach. In these two situations, the route recovery of RMCM should be failed.

Nevertheless, OMR can trigger local recovery to find new next-members when link failure is detected. Once the route that is to its next-member is not found, the node would trigger global recovery to find a new path originating from the upstream Helper to Requester. Referring to Fig. 11-(a) and Fig. 11-(b), the recovery success ratio of RMCM is 20% less than that of OMR. The results disclose that both throughput and PDR of RMCM are less than that of OMR is because the recovery success ratio effects on the performance of throughput and PDR. From the results, OMR selects the non-members that are more stable to the platoon and thus reduces the probability of link failure caused by non-members' leaving with the aid of the cost function. The Helper-disjoint algorithm not only solves the problem brought by topology changing but also ensures the success of route recovery unless there are network partitions between Helps to Requester. Therefore, OMR is better than RMCM in terms of route recovery successful ratio in both cases.

VI. CONCLUSION & FUTURE WORK

In this section, we proposed two on-demand routing protocols called (1) On-Demand Member-Centric Routing (OMR) protocol and (2) Reactive Member-Centric Routing (RMCM) protocol, both of which use the member-centric concept to ensure the reliability of data forwarding for multiple-source to single-destination transmission and aggregate 5/4G bandwidth as well in the platoon scenario. OMR is a member-centric routing protocol that takes the metric of jointness into consideration. The less jointness of routes from Helper to Requester, the more reliability it can improve. The RMCM selects Helpers that can be merged together to increase DSRC links' utility and reduce link competition between multiple flows. Requester in RMCM adopts the opportunistic forwarding strategy to reduce redundant flooding and let members have more opportunity to be selected for data forwarding. The Candidate Helper Tree structure helps Requester to select suitable Helpers and merges paths in the Helper selection phase.

We have improved the route reliability by means of getting stable links between vehicles through members. The simulation results show that both OMR and RMCM protocols outperform other protocol because they take the stability of members and non-members into consideration. The simulation results in terms of packet delivery rate and throughput indicate that OMR and RMCM protocols are both more suitable in the platoon scenario and also can provide routing ways efficiently for members to aggregate their redundant 5/4G bandwidth. Comparing OMR with RMCM, the severalty strategy is more suitable than the merged strategy for the routing in the platoon scenario that consists of member nodes and non-member nodes. It is because that the cost is too high when merged nodes leave; additionally, the maintenance of the tree structure is difficult in the high mobility circumstance.

In summary, our contributions of this work are as follows. (1) Designing two member-centric routing protocols aiming to improve the data dissemination of IoV application, which is problem of platoon mobility in the highway scenario over VANET. (2) Providing two approaches to aggregate the 5/4G bandwidth through DSRC, in which the approaches combine the ubiquitous benefit of 5/4G networks with DSRC. (3) We enhance the stability of connections between vehicles and the reliability of each route from Helpers to Requester through designing an algorithm to find maximum node-disjoint routes using the severalty strategy. (4) Increasing the DSRC links' utility and reducing link competitions between multiple flows using the merged strategy. The possible future work is to have a cross layer method in which the information from the MAC layer is used to assist the member-centric routing protocol for 5/4G bandwidth aggregation over VANET.

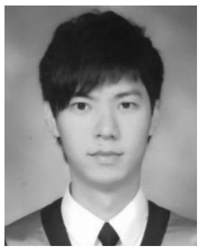
REFERENCES

[1] F. M. Abedi, M. Fathy, and J. Taghiloo, "Enhancing AODV routing protocol using mobility parameters in VANET," in *Proc. IEEE/ACS Int. Conf. Comput. Syst. Appl. (AICCSA)*, Mar. 2008, pp. 229–235.
[2] S. S. Manvi, M. S. Kakkasageri, and C. V. Mahapurush, "Performance analysis of AODV, DSR, and swarm intelligence routing protocols in vehicular ad hoc network environment," in *Proc. Int. Conf. Future Comput. Commun. (ICFCC)*, Apr. 2009, pp. 21–25.
[3] V. Namboodiri, M. Agarwal, and L. Gao, "A study on the feasibility of mobile gateways for vehicular ad-hoc networks," in *Proc. 1st Int. Workshop Veh. Ad Hoc Netw.*, Oct. 2004, pp. 66–75.
[4] G. Liu, B.-S. Lee, B.-C. Seet, C.-H. Foh, K.-J. Wong, and K.-K. Lee, "A routing strategy for metropolis vehicular communications," in *Proc. Int. Conf. Inf. Netw. (ICOIN)*, 2004, pp. 134–143.
[5] X. Li and L. Cuthbert, "A reliable node-disjoint multipath routing with low overhead in wireless ad hoc networks," in *Proc. 7th ACM Int. Symp. Modeling, Anal. Simulation Wireless Mobile Syst.*, Oct. 2004, pp. 230–233.
[6] P. K. Sahu, E. H.-K. Wu, J. Sahoo, and M. Gerla, "DDOR: Destination discovery oriented routing in highway/freeway VANETs," *Telecommun. Syst.*, vol. 50, no. 4, pp. 267–284, Aug. 2012.
[7] A. Nasipuri, R. Castañeda, and S. R. Das, "Performance of multipath routing for on-demand protocols in mobile ad hoc networks," *ACM/Kluwer Mobile Netw. Appl. (MONET)*, vol. 6, no. 4, pp. 339–349, Aug. 2001.
[8] S. J. Lee and M. Gerla, "Split multipath routing with maximally disjoint paths in ad hoc networks," in *Proc. ICC*, vol. 10. Jun. 2001, pp. 3201–3205.
[9] X. Huang and Y. Fang, "Performance study of node-disjoint multipath routing in vehicular ad hoc networks," *IEEE Trans. Veh. Technol.*, vol. 58, no. 4, pp. 1942–1950, May 2009.
[10] F. Li and Y. Wang, "Routing in vehicular ad hoc networks: A survey," *IEEE Veh. Technol. Mag.*, vol. 2, no. 2, pp. 12–22, Jun. 2007.
[11] X. Li and L. Cuthbert, "Stable node-disjoint multipath routing with low overhead in mobile ad hoc networks," in *Proc. IEEE Comput. Soc. 12th Annu. Int. Symp. Modeling, Anal., Simulation Comput. Telecommun. Syst.*, Oct. 2004, pp. 184–191.
[12] S. Biswas and R. Morris, "ExOR: Opportunistic multi-hop routing for wireless networks," in *Proc. ACM SIGCOMM Comput. Commun. Rev. (CCR)*, vol. 35, no. 4, pp. 133–144, Aug. 2005.
[13] H. Dubois-Ferriere, M. Grossglauser, and M. Vetterli, "Least-cost opportunistic routing," in *Proc. Allerton Conf. Commun., Control, Comput.*, 2007, pp. 1–13.
[14] H. Khelifi, S. Luo, B. Nour, H. Moungla, Y. Faheem, R. Hussain, and A. Ksentini, "Named data networking in vehicular ad hoc networks: State-of-the-art and challenges," *IEEE Commun. Surveys Tuts.*, to be published.
[15] *The NS-2*. Accessed: 2019. [Online]. Available: https://www.isi.edu/nsnam/ns/
[16] D. A. Maltz, J. Broch, D. Johnson, Y. C. Hu, and J. Jetcheva, "A performance comparison of multi-hop wireless ad hoc network routing protocol," in *Proc. ACM MobiCom*, vol. 114, Oct. 1998, p. 119.
[17] T. L. Willke, P. Tientrakool, and N. F. Maxemchuk , "A survey of inter-vehicle communication protocols and their applications," *IEEE J. Commun. Surv. Turorials (JCST)*, vol. 11, no. 2, pp. 3–20, 2nd Quart., 2009.
[18] X. Hong, M. Gerla, G. Pei, and C. C. Chiang, "A group mobility model for ad hoc wireless networks," in *Proc. ACM Int. Workshop Modeling, Anal. Simulation Wireless Mobile Syst. (MSWiM)*, vol. 53, Aug. 1999, p. 60.
[19] S. Zeadally, R. Hunt, Y.-S. Chen, A. Irwin, and A. Hassan, "Vehicular ad hoc networks (VANETs): Status, results, and challenges," *Telecommun. Syst.*, vol. 50, no. 4, pp. 217–241, 2012.
[20] K.-W. Jang, "A tabu search algorithm for routing optimization in mobile ad-hoc networks," *Telecommun. Syst.*, vol. 51, nos. 2–3, pp. 177–191, Nov. 2012.
[21] Y.-S. Chen, Y.-W. Lin, and C.-Y. Pan, "DIR: Diagonal-intersection-based routing protocol for vehicular ad hoc networks," *Telecommun. Syst.*, vol. 46, no. 4, pp. 299–316, Apr. 2011.
[22] W.-H. Liao, J.-P. Sheu, and Y.-C. Tseng, "GRID: A fully location-aware routing protocol for mobile ad hoc networks," *Telecommun. Syst.*, vol. 18, nos. 1–3, pp. 37–60, 2001.
[23] C. E. Palazzi, M. Roccetti, and S. Feretti, "An intervehicular communication architecture for safety and entertainment," *IEEE Trans. Intell. Transp. Syst.*, vol. 11, no. 1, pp. 90–99, Mar. 2010.
[24] S. John, "Research challenges in the migration to future mobile systems," in *Proc. IEEE Int. Conf. Workshop Current Trends Inf. Technol. (CTIT)*, Oct. 2011, pp. 92–96.
[25] Z. Shi, C. Beard, and K. Mitchell, "Competition, cooperation, and optimization in Multi-Hop CSMA networks," in *Proc. 8th ACM Symp. Perform. Eval. Wireless Ad Hoc, Sensor, Ubiquitous*, Nov. 2011, pp. 117–120.
[26] Z. Shi, C. Beard, and K. Mitchell, "Analytical models for understanding space, backoff, and flow correlation in CSMA wireless networks," *Wireless Netw.*, vol. 19, no. 3, pp. 393–409, 2013.
[27] S. Al-Sultan, M. M. Al-Doori, A. H. Al-Bayatti, and H. Zedan, "A comprehensive survey on vehicular Ad Hoc network," *J. Netw. Comput. Appl.*, vol. 37, pp. 380–392, Jan. 2014.
[28] B. T. Sharef, R. A. Alsaqour, and M. Ismail, "Vehicular communication ad hoc routing protocols: A survey," *J. Netw. Comput. Appl.*, vol. 40, pp. 363–396, Apr. 2014.
[29] C. Rezende, A. Boukerche, H. S. Ramos, and A. A. F. Loureiro, "A reactive and scalable unicast solution for video streaming over VANETs," *IEEE Trans. Comput.*, vol. 64, no. 3, pp. 614–626, Mar. 2015.
[30] M. Milojevic and V. Rakocevic, "Location aware data aggregation for efficient message dissemination in vehicular ad hoc networks," *IEEE Trans. Veh. Technol.*, vol. 64, no. 12, pp. 5575–5583, Dec. 2015.
[31] A. Dua, N. Kumar, and S. Bawa, "A systematic review on routing protocols for vehicular ad hoc networks," *Veh. Commun.*, vol. 1, no. 1, pp. 33–52, 2014.
[32] A. Moussaoui and A. Boukeream, "A survey of routing protocols based on link-stability in mobile ad hoc networks," *J. Netw. Comput. Appl.*, vol. 47, pp. 1–10, Jan. 2015.
[33] K. Abboud and W. Zhuang, "Impact of microscopic vehicle mobility on cluster-based routing overhead in VANETs," *IEEE Trans. Veh. Technol.*, vol. 64, no. 12, pp. 5493–5502, Dec. 2015.
[34] H. Wang, R. P. Liu, W. Ni, W. Chen, and I. B. Collings, "VANET modeling and clustering design under practical traffic, channel and mobility conditions," *IEEE Trans. Commun.*, vol. 63, no. 3, pp. 870–881, Mar. 2015.

[35] A. T. Akabane, E. R. M. Madeira, and L. A. Villas, "A suitable vehicular broadcast protocol under different traffic patterns for urban scenario," *IEEE Latin America Trans.*, vol. 13, no. 1, pp. 222–227, Jan. 2015.
[36] T. H. F. Khan and D. Sivakumar, "Performance of AODV, DSDV and DSR protocols in mobile wireless mesh networks," in *Proc. 2nd Int. Conf. Current Trends Eng. Technol. (ICCTET)*, Jul. 2014, pp. 397–399.
[37] B. Paul, A. Roy, and S. K. Paul, "Comparison of DSR, AODV, and DSDV routing protocols with varying pause time & Node density over TCP & CBR connections in VANET," in *Proc. Int. Conf. Comput. Intell. Commun. Netw.*, Nov. 2014, pp. 374–379.
[38] K. Sharma, J. Malhotra, and R. Sharma, "Performance evaluation of ADV DSR & GOD in VANET for city & highway scenario," in *Proc. Int. Conf. Futuristic Trends Comput. Anal. Knowl. Manage. (ABLAZE)*, Feb. 2015, pp. 388–393
[39] C.-M. Huang, T.-H. Lin, and K.-C. Tseng, "Bandwidth aggregating over VANET using the on-demand member-centric routing protocol (OMR)," in *Proc. 12th Int. Symp. Pervasive Syst., Algorithms Netw.*, Dec. 2012, pp. 89–95.
[40] C.-M. Huang, T.-H. Lin, and C.-H. Chang, "The proactive member-centric routing protocol using the several strategy (PMCS) for the fleet scenario in the hybrid VANET," in *Proc. IEEE 26th Int. Conf. Adv. Inf. Netw. Appl. (AINA)*, Mar. 2012, pp. 97–104.
[41] C.-M. Huang, T.-H. Lin, and K.-C. Tseng, "Bandwidth aggregation over VANET using the geographic member-centric routing protocol (GMR)," in *Proc. 12th Int. Conf. ITS Telecommun. (ITST)*, Nov. 2012, pp. 89–95.

CHUNG-MING HUANG received the B.S. degree in electrical engineering from National Taiwan University, in June 1984, and the M.S. and Ph.D. degrees in computer and information science from The Ohio State University, in December 1988 and June 1991. He is currently a Distinguished Professor with the Department of Computer Science and Information Engineering, National Cheng Kung University, Taiwan. He has published more than 200 refereed journal and conference papers in wireless and mobile communication protocols, interactive multimedia systems, audio and video streaming, and formal modeling of communication protocols. His research interests include wireless and mobile network protocol design and analysis, media processing and streaming, web technologies, and network applications and services. He also serves as the Director for the Promotion Center for Network Application and Service Platform Technology Consortium (PCNASPT), Ministry of Education (MOE), Taiwan.

TZU-HUA LIN received the B.S. degree from the Department Electrical Engineering, Dayeh University, in 2003, and the M.S. degree from National Dong Hwa University, in 2009. He is currently pursuing the Ph.D. degree with National Cheng Kung University, Tainan, Taiwan. Since 2009, he has been with National Cheng Kung University. His research interests include mobile communication systems, vehicle wireless communication, vehicular ad hoc network (VANET) routing, and cooperative networking.



KUAN-CHENG TSENG received the B.S. degree in computer science from National Tsing Hua University, in 2010, and the M.S. degree from the Department of Computer Science and Information Engineering, National Cheng Kung University, in 2012. His main research interests include vehicle wireless communication and VANET routing protocols.