Performance Evaluation of a Cluster Based Routing Protocol for VANETs

Mazen Alowish, Yasuhiro Takano, Yoshiaki Shiraishi, and Masakatu Morii
Departments of Electrical and Electronic Engineering, Kobe University, Kobe 657-8501, Japan
Email: 160th03t@stu.kobe-u.ac.jp; takano@eedept.kobe-u.ac.jp; zenmei@port.kobe-u.ac.jp; mmorii@kobe-u.ac.jp

Abstract**—**Safety on roadways is expected to be achieved by using vehicular ad-hoc networks (VANETs). A VANET includes dynamically moving vehicles that communicate for a certain purpose. The routing procedure in the VANET protocol is required to deliver requested data packets to the vehicles in a short period of time. Conventionally, routing algorithms like the ad-hoc on-demand vector (AODV) routing, the greedy perimeter stateless routing (GPSR), the direct-sequenced distance-vector (DSDV) routing and the dynamic source routing (DSR) have been utilized in most of ad-hoc networks. However, it is well known that the conventional routing algorithms have problems in utilizing for the VANET. For example, the DSR cannot restore link breakages often experienced in the VANET. The DSDV routing protocol consumes a higher bandwidth for message exchanges and imposes excessive overheads. This paper verifies that the cluster based routing (CBR) protocol proposed by Yuyi et al. can overcome the known problems. According to evaluation results obtained by computer simulations implemented with the OMNeT++, the CBR routing protocol outperforms the AODV, GPSR, and DSR protocols in the sense of the packet delivery ratio and the message overheads.

Index Terms**—**Vehicular ad-hoc network (VANET), cluster based routing (CBR), ad-hoc on-demand vector (AODV) routing, stateless routing (GPSR), dynamic source routing (DSR)

I. Introduction

Ad-hoc networks were developed in the 2000s, they were highly used in dynamic environment, particularly for inter-vehicular communications. Since that time, many researches and development process were dedicated to the Vehicular Ad-Hoc Network (VANET). However, the VANET has a dynamic topology with a large and variable network size, and, of course, it has to support fast mobility of vehicles. These characteristics require a VANET protocol to achieve a high routing efficiency while reducing amount of the needed resource to fit various VANET environments. The major challenges in the VANET are to improve its quality of service (QoS), performance of routing algorithms for cooperative communication and security.

The VANET is a network that was derived from the Mobile Ad-Hoc Network (MANET) [1]. They differ, however, in certain parameters such as cost, reliability, communication range, bandwidth, position estimation, node's lifetime and node's density. Specifically, the topology of a VANET keeps changing dynamically due to fast mobility of vehicles. The VANET is, hence, required to restore frequent disconnections by taking an accurate mobility modeling into account [2]-[4].

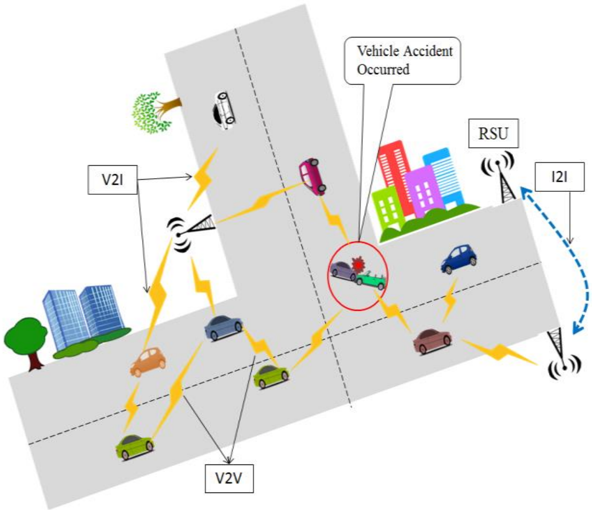

Fig. 1. VANET architecture.

As shown in Fig. 1, the major entities of the VANET are vehicles, road-side units (RSUs) and on-board units (OBUs), where they transmit information by using the vehicle-to-vehicle communication (V2V), infrastructure-to-infrastructure (I2I) and vehicle-to-infrastructure (V2I) communications. These communications are supported by the dedicated short range communication (DSRC) [5]. This vehicular communication system is accessed by the standard IEEE 802.11p which supports the wireless access in vehicular environments (WAVE) [1]. The IEEE 802.11p defines the link layer that supports internet protocol and the WAVE short message protocol (WSMP). The WAVE standard is used for the purpose of minimizing the critical situations such as prevention or identification of occurrence of accidents. The intelligent transport systems (ITS) use the WAVE protocol to broadcast information such as weather conditions, roadways maintenance and road traffic conditions.

The VANET is a network which includes mechanisms for clustering and routing. These mechanisms are needed to improve performance of the VANET over the

Manuscript received December 30, 2016; revised February 27, 2017.
Corresponding author email: 160th03t@stu.kobe-u.ac.jp.
doi:10.12720/jcm.12.2.137-144

conventional MANETs. The routing plays a major role in the VANET for transferring the data between end-users. We note that a routing algorithm has following challenges:

- Dynamic topology changes due to high mobility;
- Frequent link disconnections due to the mobility speed;
- Flexibility to select alternate routes for data transmission;
- Capability to tolerate faults such as link breakages and nodes' positions.

The routing is performed using several routing protocols to improve the Packet Delivery Ratio (PDR) and other network performance metrics. The routing in the VANET is broadly classified into five different protocols, they are the position-based, topology-based, broadcast-based, cluster-based and geo-cast-based routing protocols [6]-[8]. Furthermore, these routing protocols can consist of several routing algorithms. In this way, there are several routing protocols and algorithms for performing effective data transmission from one end-user to another. On other hand, as we summarize in Section III, these algorithms and routing protocols face some problems, therefore, Yuyi et al. proposed the Cluster Based Routing (CBR) protocol [9] in order to solve the problems by

- Performing a position and cluster based routing algorithm to reduce message overheads and to improve the PDR performance; and
- Building a grid based VANET for separating a considered geographical area.

It is theoretically shown in [9] that the CBR protocol outperforms the conventional routing protocol in the VANET. However, as far as we know, the CBR protocol is not well-verified empirically. Therefore, this paper verifies if the CBR protocol overcomes the problems of the low PDR due to high message overheads in a dynamic network topology, by conducting computer simulations in a VANET based on a real-world geography.

This paper is organized as follows. Section II reviews the conventional routing protocols originally proposed for the MANET. Section III describes the problems of the conventional protocols when they are applied in the VANET. Section IV summarizes the cluster based routing protocol to clarify the reason of improvement expected to be achieved in the VANET. Section V presents the experimental results. Section VI concludes this paper.

II. Conventional Routing Algorithms

This section reviews the following conventional routing algorithms: the Ad-hoc On-Demand Vector (AODV) routing [10], the Dynamic Source Routing (DSR) [11] and the Greedy Perimeter Stateless Routing (GPSR) [12] protocols. We note that the AODV and DSR protocols can be categorized into the topology based under reactive routing [3], [13] and the GPSR protocol is the position based routing protocol [13], [14].

A. *The Ad-Hoc On-Demand Vector (AODV) Routing Protocol*

The AODV routing is composed with a route discovery process and a route maintenance process.

The route discovery process is performed only when the end-user has data packets to transmit. Specifically, the source node (one-end user) starts broadcasting a route request (RREQ) packet to its neighbors. The neighboring nodes which received the RREQ check whether they have a route towards the destination node. If one of the neighboring nodes has route to destination, it replies a route reply (RREP) packet to the source node. Otherwise, the RREQ packet is further broadcasted from the neighboring nodes. Finally, the RREQ packet reaches the destination node. When a link break occurs between the nodes, a route error (RERR) packet is generated and sent to the source node.

The route maintenance process is implemented with the sequence number maintained by a receiving end-user. The maintenance of the sequence number is utilized for two purposes: to verify the freshness of the route information and to avoid a loop of a routing path.

B. *The Dynamic Source Routing (DSR) Protocol*

In the DSR routing, similarly, the RREQ packets are flooded from the source node to the neighboring nodes, where each RREQ packet includes a source node's address, a destination node's address and an identity. If the neighboring node has a route to the destination, it replies with the RREP packet to the source node. Otherwise, it re-broadcasts the RREQ packet. As the RREQ reaches the destination node, then it replies with the RREP packet by using the same route as that of the RREQ packet.

The nodes store the copy of the packets in their buffer. The each sent packet is time stamped. The time stamp is included in the RREQ packet so that the packet is discarded after expired. The name source routing is given since the source node initiates the transmission of data packets to the destination node, which includes the entire route's packet header. When any route failure occurs, the nodes generate the REER packets and update their buffer.

C. *The Greedy Perimeter Stateless Routing (GPSR) Protocol*

In the GPSR protocol, a local table identification (ID) maintained by the nodes existing in the network. The table involves with the information about the name (or the ID) and the position of the nodes. This routing is performed with the support of the location information of the nodes. The GPSR protocol follows two modes of working procedure: 1) the greedy forwarding mode and 2) the perimeter mode.

As default, the first greedy forwarding mode is used, in which the data packets are transmitted to the destination nodes that are located nearby in the geographical area. However, the perimeter mode is used for data transmission if the destination nodes are not adjacent to the geographical area.

III. Problem Description

This section describes some problems that exist in three conventional routing protocols: the AODV, DSR and GPSR protocols. These three routing protocols are originally proposed for the MANET but are used in the VANET, too.

It should be emphasized that although many routing protocols have been designed for MANETs, few of which are suitable to be directly implemented to VANETs. This is because factors such as fast moving vehicles, active information transmissions, and the associated high speed of mobile nodes are not assumed originally in MANETs. Table1 summarizes potential disadvantages of the conventional protocols in VANETs.

TABLE I: Demerits of Conventional Routing Protocols (AODV, DSR, GPSR)

Traditional Routing	Demerits
AODV	• Higher processing time • Larger bandwidth consumption • Time taken for the construction of routing table is large • Increases overheads
DSR	• Size of the packet header increases with the length of the route • Collision occurs due to flooding of route requests • Not capable to repair the broken links in the routes • Degradation of performance at higher mobility scenarios • Higher energy consumption
GPSR	• Always requires the global positioning system • Larger energy consumption

A. *Problems of the AODV Protocol*

The AODV routing protocol utilizes to determine the routing path by the sequence number, where the sequence number of the intermediate nodes has to be newer but not newer than that of the destination node. However, if the AODV protocol is implemented into a VANET, it can suffer from a problem that the nodes existing in between the route of the source and destination node may lead to inconsistent route. Since the nodes in the VANET are frequently updated due to their high mobility, the sequence number of the source node can easily become older than that of the nodes in the route. Therefore, the multiple RREQ packets tend to exhaust extra bandwidth because of periodic beaconing. Moreover, heavy overheads occur if a single RREQ packet has multiple RREP packets.

B. *Problems of the DSR Protocol*

Although a link disconnection can happen frequently in a fast mobile environment, the DSR protocol cannot solve the disconnection by its route maintenance process. Therefore, in this DSR routing, flooding of RREQ packets reach all the nodes that are present in the network and they also cause collisions. Consequently, the packet delivery performance using the DSR protocol can be degraded in the VANET. Moreover, in the DSR routing, the size of the packet header keeps on increasing according to the route length.

C. *Problems of the GPSR Protocol*

The GPSR can face a link failure in the VANET due to high mobility of nodes and frequent topology changes. Moreover, a packet loss and a timeout may occur because the number of hops increases in the perimeter mode. The GPSR protocol does not suit in the urban environment because of two reasons. First of all, the greedy forwarding can fail if there are impediments which cause the lack of direct communications between nodes. Then, if a packet is in the greedy mode, the forwarding node tries to find a node that is as close as possible to the location stored in the packet header. It does, however, not check if the destination node is in its neighborhood. Therefore, if the destination node moves away and another node move near the former location of the destination node, the later node is selected as the next hop. Eventually, the packet can be dropped after entering into the perimeter mode, because no other node being closer to the destination location can be found.

Each conventional routing protocols involve with certain demerits which completely fail to support network performance. Hence these problems need to be solved for improving the network performance and also for the data transmission problems even if the number of nodes keeps increasing in the network. All these problems can be improved with the concept of the cluster based routing in the VANET by reducing the message overheads and improving the PDR performance.

IV. The CBR Protocol [9]

A. *Overview*

This section summarizes the CBR protocol proposed in [9], aiming to clarify the reason for the PDR performance gain shown later in Section V. The CBR algorithm performs a cluster head selection and then a data transmission. The CBR protocol geographically divides the coverage area into w^2 grids to efficiently transmit data packets, where the term w represents the side length of the grid. The nodes in a grid are considered as clusters. Further, we select a *cluster head* per each cluster. The data transmission is performed with the support of the cluster heads.

As an example, Fig. 2 shows a VANET using the CBR protocol. The VANET consists of source vehicles, clusters, cluster heads and destination vehicles. The figure illustrates two data transmissions from the source 1 (S1) to the destination 1 (D1) and from the source 2 (S2) to the destination 2 (D2). In the transmission from the S1 to D1 nodes, the vehicle 2 (V2) is selected as the cluster head because it is the closest vehicle to the grid center. The D1 is, however, located in the cluster 3 (C3). Hence, the V2 forwards the data packets to the V3 that is the cluster head of C3. Similarly, in the second transmission from the S2 to D2 nodes, the packets from the S2 is sent to the cluster head vehicle (V8). The V8, then, selects the optimal neighboring cluster head (V3) and forwards the packets to the destination (D2). By this routing protocol, we can reduce the message overheads and can improve the PDR performance in VANETs. Note that since the cluster head keeps on moving, it needs to be re-selected. The next subsection summarizes the cluster head selection procedure.

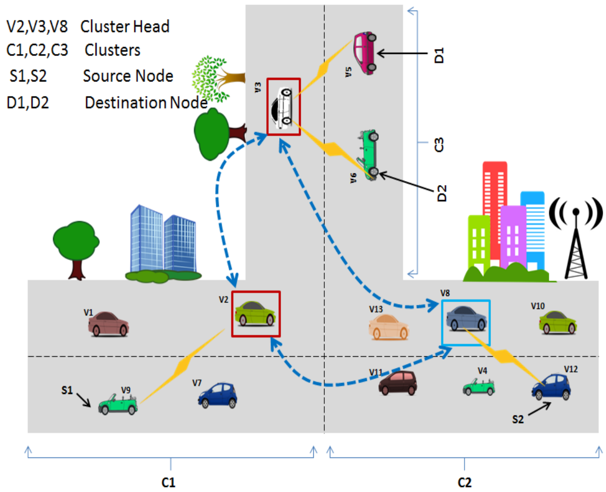

Fig. 2. A VANET using CBR protocol.

B. Cluster Head Selection

Fig. 3 shows pseudo codes for the cluster header selection. In the CBR protocol, the RSU may be utilized as the cluster head. However, this subsection basically assumes absence of the RSU. The cluster head selection procedure proposed in [10] is performed by the following steps:

- The cluster head (CH) 'V_2' initiates to broadcast with the initiate (INI) message to other nodes in the grid. The INI message is comprised of the information about the coordinate of the grid (G) and the location (Loc) of that cluster head. The INI message with (G, Loc) is sent to all the neighboring cluster heads. In case the RSU is available, the INI messages are sent directly from the RSU itself.
- If a node 'V_1' did not receive the INI message within a certain time period of 'T_1', it broadcasts a REQ message along with the (G, Loc) of the node 'V_1'
- If the old cluster head V_2 is present in the grid, it sends the INI message to the corresponding node 'V_1'. But in case the cluster head is changed and the REQ message is received by a normal node, the 'V_1' waits until the time period of 'T_2'. However, if no response is received, further, the 'V_1' intimates itself as the cluster header.
- The cluster head 'V_2' broadcasts a LEAVE message when it moves out from the grid. The LEAVE message includes 'G' (i.e.) coordinate of its grid. The nodes in the grid response with the REQ, on receiving the LEAVE message from the old cluster head. This is followed to select the next new cluster head for that grid.
- According to this procedure the cluster headers are self-selected, and hence, the number of cluster heads may be more than one. Due to this reason when a cluster head receives an INI message from the node in the same cluster, it cancels its function of the cluster head.

Note that each cluster has usually a single cluster head.

In addition, the energy consumption for the formation of cluster could be minimized, since we have considered each gird as a cluster.

Pseudo code for the cluster head selection

1. Begin;
2. CH (V_2) $\rightarrow$ Broadcast INI
3. INI $\rightarrow$ (G, Loc)
4. If (V_1 $\rightarrow$ Did not Receive INI)
   Wait till (T1)
5. Then (Broadcast REQ)
   Wait till (T2)
6. If (No response)
7. Then assign itself as CH

// CH leaving the grid //

8. CH (V2) $\rightarrow$ Broadcast LEAVE
9. LEAVE $\rightarrow$ (G)
10. V_1, V_2, …, V_n $\rightarrow$ REQ;
11. Select New CH;
12. End;

Fig. 3. Pseudo codes for the cluster header selection.

C. Selection of the Optimal Cluster Head and Routing

The CBR protocol selects the optimal series of cluster heads based on the location of the destination node, in order to efficiently forward the packets from the source to the destination cluster. Notice that, according to the CBR protocol, the node having packets to be sent requests the cluster header to forward the packets. Or the header itself has packets for transmission then it starts the transmission by itself.

First of all, the destination node's location is analyzed to select the optimal neighbor cluster head from the source node by measuring the angles enclosed by two rays to the destination and neighboring clusters emanating from the source cluster head. The optimal cluster head to forward the packet is, then, chosen under the minimum angle criterion. The selected optimal cluster head is represented as the next forwarding node.

Fig. 4 illustrates the selection of the optimal cluster head by the minimum angle criterion. In Fig. 4, the cluster header A is assumed as the source cluster header requested to forward packets from the source node S. As abovementioned, the cluster head A searches the cluster header table and finds that the nodes CH1, CH2, CH3, CH4, and CH5 are the neighboring clusters headers. We have angles between the ray A-D and the rays A-CH1, A-CH2, A-CH3, A-CH4, and A-CH5, respectively. Then the cluster head A determines the optimal routing path to the CH2 nodes under the minimum angle criterion.

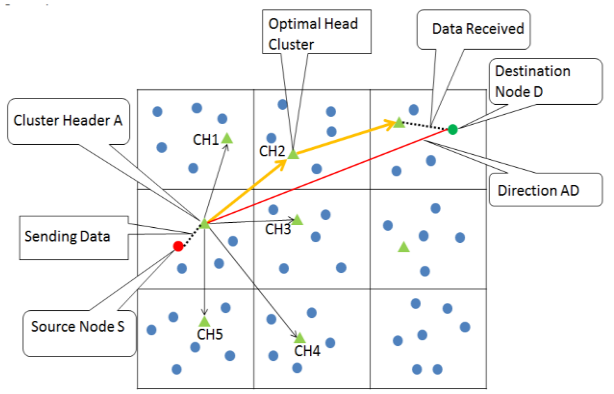

Fig. 4. The optimal cluster head selection.

In case there is no cluster head in the neighboring grid, the node caches the data packets and waits for the selection of new cluster. However, those stored packets are discarded if the caching time exceeds, which requires the source node to transmit the data packets again.

Moving on to the procedure of routing, the source node sends the data packets to the cluster head which is identified from its cluster header table. Then the cluster head applies the above procedure to select the optimal neighboring cluster head. The procedure is repeatedly performed until the forwarded packets reach the destination node's cluster head.

V. Experimental Results

This section verifies the effectiveness of the CBR protocol over the conventional AODV, DSR and GPSR protocols, by showing computer simulation results.

A. Simulation Setups

The simulation is implemented by using the OMNeT++ 4.6 (a network simulator), combining with the SUMO 0.19.0 (a road traffic simulator). As shown in Fig. 5, we use a real-world urban map downloaded from the OpenStreetMap for a part of Kobe city Japan. The routing protocols are implemented as C++ codes and are integrated into the simulators.

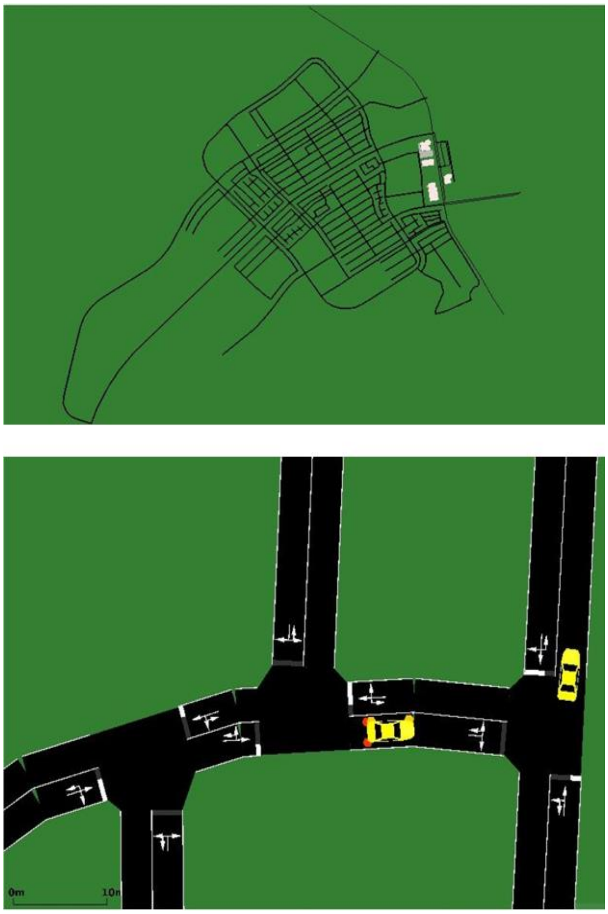

Fig. 5. The generated real-world map with vehicles.

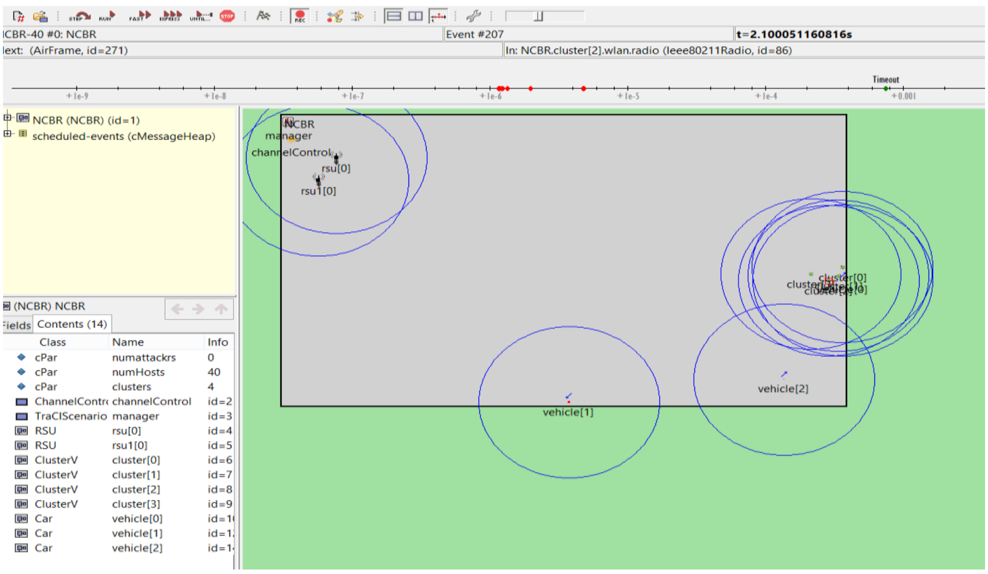

Fig. 6. An example of cluster formation.

Fig. 5 and Fig. 6 illustrate the simulation environment that is designed for this verification, where we assume a real-world map taken from openstreetmap.org for the latitude: 34.7003~34.7235 and the longitude: 134.9864 ~135.0373. The map has been edited with the JOSM (Java Open Street Map) editor and then imported by the SUMO. As per the proposed concept, we have generated 4 clusters with the 40 nodes that are dynamically moving within the real-world map. Table II summarizes the major parameters used to obtain the following simulation results.

TABLE II: SIMULATION PARAMETERS

Specifications	Values
Simulation area	10000 × 10000
Simulation time	60 seconds
Number of vehicles	40
Number of rode side units	2
Number of clusters	4
Routing protocol	Cluster based routing
Average speed of vehicles	22 m/s
Road lane	Two lane
Radio propagation model	Free space model
MAC layer protocol	IEEE 802.11p
Packet size	2024 Bytes
Transmission range	50 m
Transmission power	2mW
Internet protocol	IPv4

A. Packet Delivery Ratio

The PDR is considered as a significant performance metric, which should always be increasing in a network. In a routing protocol, the PDR plays a major role without the network fails to improve its performance. The PDR is defined, as

$$PDR(\%) = \frac{\text{Delivered packets}}{\text{Sent packets}}$$

Fig. 7 shows the PDR curves obtained by using the AODV, DSR, GPSR, and CBR protocols. The number of vehicles increases according to the simulation time, which means that the data transmission among vehicles increases from one cluster to another. As shown in Fig. 8, the PDR of the CBR protocol is superior to the other protocols. It should be noticed that the decay of the PDR curves of the conventional AODV, DSR and GPSR protocols is rapidly decreasing against the simulation time, while that of the CBR is moderate. The next subsection presents the message overheads of the routing protocols to investigate the performance gain with the CBR protocol.

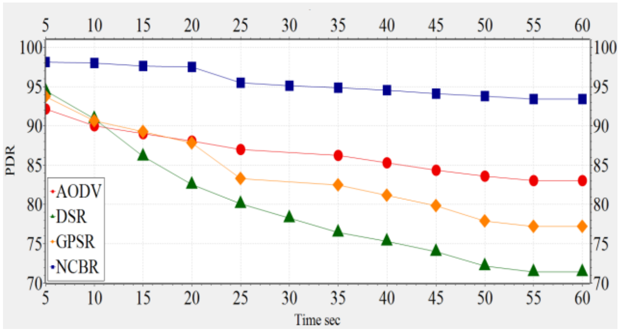

Fig. 7. PDR performance comparison between the AODV, DSR, GPSR and CBR protocols.

B. Message Overheads

The message overheads are caused in a network, in case the data packets are waiting in the buffer for processing. This often occurs due to the increase in the number of users and their data transmission messages. In a routing process, this majorly happens when a node floods the packets.

As observed from Fig. 8, the message overhead curves of the conventional AODV, DSR and GPSR protocols increase as the elapse of time. This is because the conventional protocols suffer from the problems raised in Section III. However, the message overhead curve obtained by using the CBR protocol does not exhibit the problem. This is because, as summarized in Section IV, the CBR protocol does not need to discover the route but can send the data packet to the optimal neighbor cluster header directly.

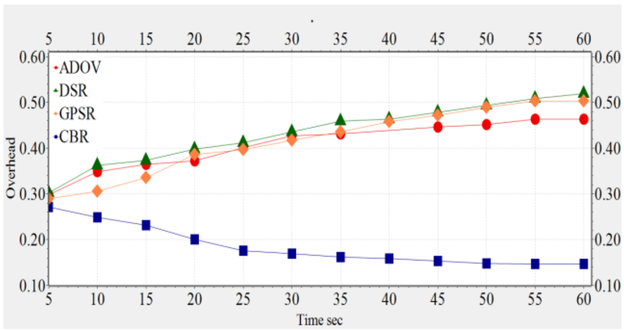

Fig. 8. Comparison of message overheads between the ADOV, DSR, GPSR and CBR protocols.

VI. CONCLUSIONS

This paper has experimentally verified the effectiveness of the CBR protocol over the conventional AODV, DSR and GPSR protocols. The experimental evaluation is conducted via performing computer simulations, where we have implemented a VANET with the network simulator OMNeT++ assuming a real-world urban geography. According to the simulation results shown in this paper, the CBR protocol improves the PDR performance 10% more than that of the conventional routing algorithms. Moreover, this paper has experimentally compared the message overhead size of the CBR protocol to that of the conventional protocols. Future work is to further enhance the PDR performance by improving the cluster head selection algorithm. Moreover, the minimization of deployment cost is needed to be studied by imposing a constraint onto the number of RSUs.

REFERENCES

[1] A. Dua, N. Kumar, and S. Bawa, "A systematic review on routing protocols for vehicular ad hoc networks," *Vehicular Communications*, vol. 1, no. 1, pp. 33-52, 2014.

[2] S. Rehman, M. A. Khan, T. A. Zia, and L. Zheng, "Vehicular Ad-Hoc Networks (VANETs) - An overview and challenges," *Journal of Wireless Networking and Communications*, pp. 29-38, 2013.

[3] S. Benkirane, S. Mostafa, M. L. Hasnaoui, and A. Beni-Hssane, "A New comparative study of ad hoc routing protocol AODV and DSR in VANET environment using simulation tools," in *Proc. 15th IEEE International Conference on Intelligent Systems Design and Applications*, 2015, pp. 458-461.

[4] B. Ayyappan and P. M. kumar, "Vehicular Ad Hoc Networks (VANET): Architectures, methodologies and design issues," in *Proc. Second IEEE International Conference on Science Technology Engineering and Management*, 2016, pp. 177-180.

[5] F. Yu and S. Biswas, "Impacts of radio access protocols on cooperative vehicle collision avoidance in urban traffic intersections," *Journal of Communications*, vol. 3, no. 4, pp. 41-48, September 2008.

[6] S. Zeadally, *et al.*, "Vehicular Ad Hoc Networks (VANETS): Status, results, and challenges," *Telecommunication Systems*, vol. 50, no. 4, pp. 217-241, 2012.

[7] B. T. Sharef, R. A. Alsaqour, and M. Ismail, "Vehicular communication ad hoc routing protocols: A survey," *Journal of Network and Computer Applications*, vol. 40, pp. 363-396, 2014.

[8] M. Benamar, *et al.*, "Recent study of routing protocols in VANET: survey and taxonomy," in *Proc. First International Workshop on Vehicular Networks and Telematics*, 2013.

[9] Y. Luo, W. Zhang, and Y. Hu, "A new cluster based routing protocol for VANET," in *Proc. Second IEEE International Conference on Networks Security Wireless Communications and Trusted Computing*, 2010, vol. 1.

[10] S. Eichler, F. Dotzer, C. Schwingenschlogl, F. J. F. Caro, and J. Eberspaher, "Secure routing in a vehicular ad hoc network," in *Proc. IEEE 60th Vehicular Technology Conference*, September 2004, vol. 5, pp. 3339-3343.

[11] D. B. Johnson and D. A. Maltz,"Dynamic source routing in ad hoc wireless networks," in *Mobile Computing*, Springer US, 1996, pp. 153-181.

[12] B. Karp and H. T. Kung, "GPSR: Greedy perimeter stateless routing for wireless networks," in *Proc. Proc. 6th Annual International Conference on Mobile Computing and Networking*, 2000.

[13] A. Setiabudi, A. A. Pratiwi, Ardiansyah, D. Perdana, and R. F. Sari, "Performance comparison of GPSR and ZRP routing protocols in VANET environment," in *Proc. IEEE Region 10 Symposium*, 2016, pp. 42-47.

[14] R. Bala and C. R. Krishna, "Scenario based performance analysis of AODV and GPSR routing protocols in a VANET," in *Proc. IEEE International Conference on Computational Intelligence & Communication Technology*, 2015, pp. 432-437.

Mazen Alowish received B.E. degree in Computer Systems Engineering from Cordoba University, Aleppo, Syria, in 2009. He obtained Diploma in Web Technology at SV University Syria; in 2012. He is a research student at the Department of Electrical and Electronic Engineering, Kobe University, Japan. His current research interests include information security and computer networks.

Yasuhiro Takano received the Ph.D. (Info. Sc.) and Dr. Sc. (Tech.) degrees, respectively, from Japan Advanced Institute of Science and Technology (JAIST) and the University of Oulu, Finland, in 2016. He is currently with Kobe University. His research interests include signal processing for communications engineering.

Yoshiaki Shiraishi received B.E. and M.E. degrees from Ehime University, Japan, and PhD degree from the University of Tokushima, Japan, in 1995, 1997, and 2000, respectively. From 2002 to 2006 he was a lecturer at the Department of Informatics, Kindai University, Japan. From 2006 to 2013 he was an associate professor at the Department of Computer Science and Engineering, Nagoya Institute of Technology, Japan. Since 2013, he has been an associate professor at the Department of Electrical and Electronic Engineering, Kobe University, Japan. His current research interests include information security, cryptography, computer network, and knowledge sharing and creation support. He received the SCIS 20th Anniversary Award and the SCIS Paper Award from ISEC group of IEICE in 2003 and 2006, respectively. He received the SIG-ITS Excellent Paper Award from SIG-ITS of IPSJ in 2015. He is a member of IEEE, ACM, and a senior member of IPSJ.

Masakatu Morii received the B.E. degree in electrical engineering and the M.E. degree in electronics engineering from Saga University, Saga, Japan, and the D.E. degree in communication engineering from Osaka University, Osaka, Japan, in 1983, 1985, and 1989, respectively. From 1989 to 1990 he was an Instructor in the Department of Electronics and Information Science, Kyoto Institute of Technology, Japan. From 1990 to 1995 he was an Associate

Professor at the Department of Computer Science, Faculty of Engineering, Ehime University, Japan. From 1995 to 2005 he was a Professor at the Department of Intelligent Systems and Information Science, Faculty of Engineering, the University of Tokushima, Japan. Since 2005, he has been a Professor at the Department of Electrical and Electronic Engineering, Faculty of Engineering, Kobe University, Japan. His research interests are in error correcting codes, cryptography, discrete mathematics and computer networks and information security. He is a member of the IEEE.