Experimental Analysis of Cluster-Based Multi-Channel Mechanism for Inter-Vehicle Safety Warning Message Transmission

Lei Ye[1,2], Chong Peng[1], Lingqiu Zeng[3,4], Qingwen Han[1,2], Xiaoying Liu[1], Dongmei Chen[1], and Chen Du[1,2]
[1] College of Communication Engineering, Chongqing University, Chongqing, 400044, China
[2] Chongqing Automotive Collaborative Innovation center, Chongqing, 400044, China
[3] Chongqing Key Laboratory of Software Theory & Technology, Chongqing, China
[4] College of Computer Science, Chongqing University, Chongqing, 400044, China
Email: {Yelei, zenglq, hqw, 20114817}@cqu.edu.cn; chongpeng333@gmail.com; {lxy_cqu, dc45165640}@163.com

Abstract —Early-warning information transmission can provide warning before emergence occur to avoid accident, and the key point is making the right vehicles in need obtain the right information. The stability of network structure and the effectiveness of channel allocation are deemed to be the key factors influencing early-warning information transmission performance. Considering Environmental noise factors, based on vehicular attribute information and early-warning information transmission requirement, a new concept Safety Warning Message (SWM) is defined, and a Cluster-Based Multi-Channel (CBMC) mechanism is proposed in this paper. Moreover, according to the proposed mechanism, the SWM transmission process is designed. A series of experiments on the sensor network testbed are done to evaluate the impact of proposed mechanism on SWM transmission. The experimental results show that proposed mechanism is benefit to improving global dissemination successful rate and shortening packet delivery delay.

Index Terms—VANET, early-warning, SWM, cluster, multi-channel

I. INTRODUCTION

Researches show that about 60% of the vehicle collisions could be avoided if the rear vehicles could be informed 0.5 seconds earlier [1]. As an important information exchange manner in Vehicular Ad-Hoc Networks (VANETs), Vehicle-to-Vehicle (V2V), which exchanges safety relevant information, such as emergency warning and traffic conditions safety warning among neighboring vehicles, is emerging as a critical research area because of increasing passengers' safety need [2].

Emergency Warning Messages (EWM) dissemination is considered as an effective solution to improve road safety condition. As soon as a vehicle falls into an emergency state, it will generate an EWM and broadcast it in Common Control Channel (CCH) as soon as possible to remind surrounding drivers avoiding corresponding accident.

Though high quality EWM dissemination is very helpful in accident avoidance, it could not provide early-warning service. In actual, a large amount of road vehicles act as potentially dangerous sources. For example, some dangerous status, like abnormal wheel, overload, or rugged condition, like dangerous road, flooded street, even bad driving behavior may easily affect some other vehicles and bring them into abnormal state. Therefore, the purpose of early-warning information transmission is warning before emergence occur to avoid accident, and the key point is making the right vehicles in need obtain the right information. In this paper, Safety Warning Message (SWM), which carries safety warning information about any abnormal events, is defined, while the corresponding transmission mechanism is designed.

How to ensure SWM dissemination performance is the key issue for transmission mechanism design. In an Ad-Hoc network, dissemination performance should be influenced in two ways. One is transmission congestion brought by high regional SWM traffic, while the other is contention failure caused by interference, which would prolong delivery-waiting time. Therefore, two problems in SWMs dissemination progress are putting forward.

Firstly, regional SWM traffic should be decreased. Unlike EWM, which is a result of high hazard level event, SWM represents a low hazard level event. The generating probability of SWM should higher than that of EWM. If EWM's broadcasting method were employed in SWM dissemination progress, the instantaneous traffic of a specific region should grow hastily. Therefore, instead of CCH, service channels (SCHs), which are defined to exchange non-safety-related data and provide 5 working frequencies, are used in SWM transmission. To further release regional SWM traffic, a cluster-based algorithm considering the high mobility of vehicles and the influence range of abnormal vehicle, is studied to establish a cluster based demand relationship using as a basis for communication link establishment.

Manuscript received July 11, 2016; revised January 5, 2016.
This work was supported by SRF for ROCS, SEM, open research fund of Chongqing Key Laboratory of Emergency Communications and the 2015 Chongqing University Postgraduates' Innovation Project.
Corresponding author email: zenglq@cqu.edu.cn.
doi:10.12720/jcm.11.1.33-41

Secondly, the interference among SWM transmission should be relieved. As a consequence of multi-channels employing, frequency allocation and reuse problem became another key point for SWM dissemination mechanism design. An effective multi-channel mechanism could provide frequency allocation and reuse solution to relieve co-frequency interference.

Hence, to ensure SWM dissemination performance, a Cluster-Based Multi-Channel (CBMC) mechanism is proposed in this paper, to investigate both SWMs traffic release problem and frequency reuse method. Specifically, the research contributions of this paper are as follows:

- A new concept, SWM, is defined to illustrate potential safety risk of road vehicles. In most of the other studies about the inter-vehicle safety information transmission, emergency message are normally considered. SWM is kind of safety warning messages can inform the around vehicle potential danger vehicles.
- A cluster-based algorithm is proposed to set the transmission area and establish the SWM exchange link.
- A new CBMC mechanism is proposed to allocate the channel resource effectively and improve SWM dissemination performance.
- The performance of proposed method is tested in NetEye, a high fidelity, and indoor sensor network testbed. Experimentation is chosen as opposed to simulation in order to gain higher fidelity and confidence in the observations.

The rest of the paper is organized as follows. Section II presents the related work. The CBMC mechanism is elaborated in Section III. Then the experimental design and results analysis are described in Section IV and Section V respectively, while a conclusion is given in Section VI.

II. Related Work

A. Clustering Algorithms

Clustering-based MAC schemes cluster VANETs into small groups, which have advantages to limit channel contention and effectively control the network topology.

In [3], a hybrid clustering-based MAC scheme for Vehicular Ad-hoc Networks is proposed to overcome the lack of mobility to support channel utilization and network stability. Cluster heads are elected based on their motility factors in order to improve the stability of clusters. Authors in [4] propose a beacon-based clustering algorithm to organize the network into clusters. When two cluster heads encounter each other for a short period of time, this scheme also incorporates a contention method in order to avoid triggering frequent reorganizations. In [5], authors propose a dynamic cluster head (CH) selection algorithm. This proposed scheme is adaptable to drivers' behavior and has a learning mechanism to predict the future speed and position of all cluster members (CMs) based on a fuzzy logic inference system. Reference [6] presents a MAC algorithm for vehicular ad-hoc networks using a new method for TDMA slot reservation based on clustering of vehicles. The algorithm aims to decrease collisions and packet drops in the channel, as well as provide fairness in sharing the wireless medium and minimizing the effect of hidden terminals. In [7], Samo Vodopivec *et al*. propose a new clustering metric for VANET, named vehicle interconnection metric, which is based on sending periodic beacons among vehicles and reflects the communication abilities between them. They also propose a new clustering algorithm whose primary goal is increased connectivity and lower number of disconnects.

Although clustering model has been used in the V2V communications in many works, an algorithm based on the health level of vehicles is proposed in this paper, which haven't been mentioned by all other works. This algorithm helps to maintain the stability of cluster and the transmission efficiency. Both the above methods obtained positive results in improving data delivery reliability, but there is not a study to further develop protocols to address inter-cluster communications.

B. Multi-Channel Protocol

Several MAC protocols have been proposed in VANET to reduce interference and improve the performance of reliability of VANETs. Multi-channel is one of the main topics for network access and attracts researchers' attention.

In [8], authors discuss the multi-hop broadcast problem in multi-channel environment defined by IEEE Wireless Access in the Vehicular Environment (WAVE), and propose a multi-hop broadcast protocol, which conducts efficient channel utilization with single transceiver. They use computer simulations to show the advantage of the proposed protocol over other existing alternatives. Lun Tang in [9], presents an optimization method of the back-off parameters in multi-priority supported multi-channel MAC protocol in VANETs to solve this problem. This method calculates throughput and delay of the network, then determines the optimum transmitting probabilities of the two classes of messages by an optimization model. Duc Ngoc Minh Dang *et al*. propose an Efficient and Reliable MAC protocol for VANETs (VER-MAC) which allows nodes to broadcast safety packets twice during both the control channel interval and service channel interval to increase the safety broadcast reliability [10]. By using the additional data structures, nodes can transmit service packets during the control channel interval to improve the service throughput. Based on the latest standard draft IEEE 802.11p and IEEE 1609.4, reference [11] proposes a variable CCH interval (VCI) multichannel medium access control (MAC) scheme, which can dynamically adjust the length ratio between CCH and SCHs. The scheme also introduces a multichannel coordination mechanism to provide contention-free access of SCHs. Reference [12] presents the design, implementation and simulation results of a multi-channel MAC protocols for dense Vehicular Ad hoc Networks using directional antennas with local beam tables. Numeric results show that our protocol performs better than the existing multichannel protocols in vehicular environment.

Results showed that the proposed protocol is able to provide a shorter delay and a higher reliability, as compared with the traditional approach, but simulation is not convincing to the reader and some assumption is far from the reality.

III. Cluster-Based Multi-Channel Mechanism

A. SWM Message

A sub-healthy vehicle (SHV), which should increase regional road risk level, generates SWMs, to remind surrounding vehicles to avoid potential danger.

A SWM includes various parameters such as the geographical location, source vehicle healthy level, hazard type, velocity, acceleration, and cruising direction. SWM is defined as (1),

$$SWM =< ID, Des, Type, L_{health}, Loc, V, A, D_{cruise} > \quad (1)$$

where *ID* is the unique identification number of the SWM, and indicate the receiver vehicle. *Type* is the hazard type, which implies the possible results of potential danger. L_{health} is the healthy evaluation result of SWM source vehicle. *Loc* is the geographical location, which includes both longitude and latitude information. *V*, *A* denotes the speed, and acceleration of the SWM source vehicle respectively, while D_{cruise} illustrates cruising direction.

Common SWM types are listed in Table I.

TABLE I: SWM TYPE

	Safety Warning Event	Type
Local Event	Abnormal wheel	1
	Brakes failed	2
	Spike stop	3
	No cushion distance	4
External Event	Overtaking	5
	Overload	6
	Dangerous road	7
	Others	8

The real road environment is complex and fast changing such as the various road stretch, drivers' driving habits, pedestrians' behaviors, the vehicle condition, etc. The numerous uncertain factors make the model difficult to construct, thus, the system model in the paper was simplified under the following assumptions:

- Vehicles drive on the road with a nearly common speed, thus, the network topology is assumed to be stationary.
- The model simply focuses on a road segment.

When a SWM generates, it should be sent to the object vehicle in demand in a low interference channel. Therefore, the demand relationship between vehicles is the essential basic for message dissemination. To determine the relationship, a cluster-based method is proposed in this paper.

B. Cluster Structure

A cluster is a circle area whose center is cluster head.

A road region without traffic accident includes two kinds of vehicles, one being a normal vehicle and the other a SHV. Furthermore, the healthy level of a vehicle in the cluster is also considered and shown in Fig. 1. They are characterized by a color code: red, yellow and green. This allows a more introspective study on the region (which is identified by the occurrence of red agents) and ignores other vehicles that do not significant impact on the cluster region.

Hence the cluster head is chosen with regard to the healthy level of the vehicle, the cluster head being a vehicle that performs a bad healthy level and illustrate a high accident probability.

In-car sensors gather vehicle's information, which should illustrate both vehicles' physical performance and real-time driving status. Hence we define L_{health} as follows,

$$L_{health} =< f_{vehicle}, f_{driver} >$$

where $f_{vehicle}$ is obtained according to the fault diagnosis output of ECU. Meanwhile, in [13], we proposed a fuzzy synthesis judgment method to evaluate driver behavior, which is consider as the basis to get f_{driver}. Based on both two factors, we can construct L_{health}. Evaluation model, which is not the focus of this paper and shall be presented in our further work.

Based on the CAN-bus processor, we can get vehicle's healthy level, L_{health}.

Cluster head (CH): The lowest healthy level vehicle in the object region will be chosen as the CH, which is defined as (2),

$$CH = \min\{L_{health}(i) \,|\, i = 1,...,n\} \quad (2)$$

where $L_{health}(i)$ is the healthy level of cluster vehicle V_i, n is the vehicle number of the cluster. A new cluster is generated right after CH has been selected as shown in Fig. 1.

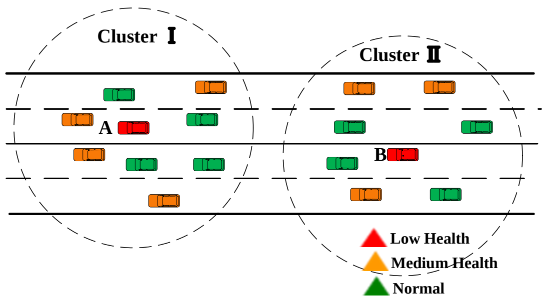


Fig. 1. Result of cluster growing

CH competition: When more than one cluster join to each other and merge to one cluster, CH competition should be considered. Here we select CH according to the number of cluster members. For example, as shown in Fig. 2, cluster I and cluster II get close and merger as one cluster. Vehicle A should be chosen as the unique CH, because there will have more members in the cluster than when vehicle B is selected.

Here we define CH competition as (3),

$$CH = \max\{M_j \mid j = 1,\dots,m\} \tag{3}$$

where M_j is number of possible CM, if V_j is the CH of cluster C_j. m is the number of the competitive clusters head.

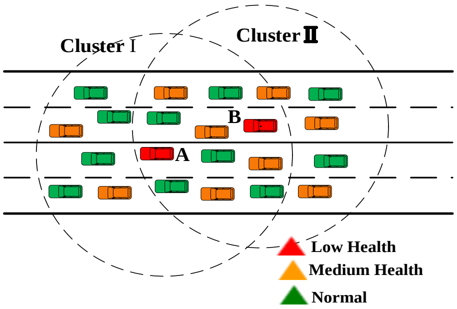


Fig. 2. CH competition

Cluster separation: Cluster members will be prone to fall away from the group, then a new cluster will be separated from the original one with a new CH.

The selection of the gateway: An overlap often exists between two clusters in VANET, and there will be some vehicles belong to more than one clusters. Hence gateway selection problem should be considered. In general, there are two overlapping scenorio.

In first scenorio, the overlapping area does not include CH. In this case, the vehicle that has strongest link with CHs will be chosen as the gateway, as shown in Fig. 3.

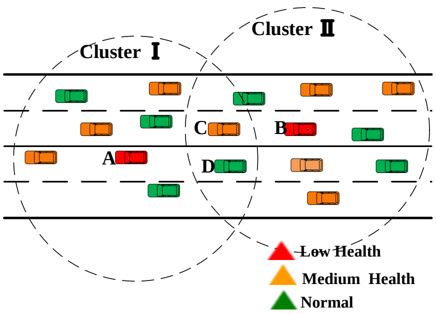


Fig. 3. The selection of the gateway without lapped CH.

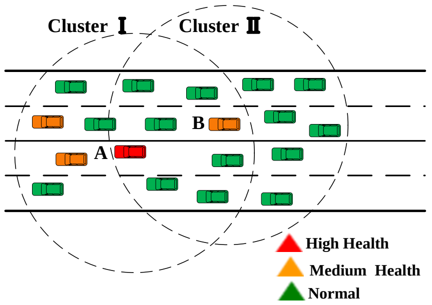


Fig. 4. The selection of the gateway with lapped CH.

In second scenorio, the overlapping area includes a CH. Then the CH should be selected as gateway vehicle. As shown in Fig. 4, vehicle B, which is CH of cluster II, is selected as the gateway to connect Cluster I and Cluster II.

C. Multi-Channel Reuse

As noted, 5 non-overlapping SCHs, are used in SWM transmission. Hence, the frequency allocation and reuse is another key point for SWM dissemination.

When CH receives messages, which are sent to request to join cluster by its members, it also collects whole cluster communication priority level and interference information of every available channel in cluster area. Then CH will take an evaluation *A* for every channel. For channel Ch_i, the available probability, A_{chi} is defined as

$$A_{Ch_i} = \frac{1}{\sum_{j=1}^{n} RSSI_j + mCMSI} \tag{4}$$

where n is the number of interference source whose channel equal to Ch_i in whole cluster, $RSSI_j$ is the received signal strength indication of interference source j, *CMSI* is the multiplex strength indication of one channel, and m is the number of existing multiplexed communications in channel Ch_i. Obviously, the initial value of m is zero and increment 1 for each new adding multiplex transmission need.

After that, according to the healthy level of cluster member, a priority queue, which be used by CH to allocate channels to all cluster nodes, is generated. The CH allocates the channels with maximum A to high priority SHV. Meanwhile, the gateway vehicle should be allocated two channels to build link to two clusters.

D. The System Cycle and Rules of Mechanism

Based on aforementioned cluster structure and multi-channel protocol, a cluster-based multi-channel mechanism, which includes three key stages, is proposed. The system cycle is shown in Fig. 5.

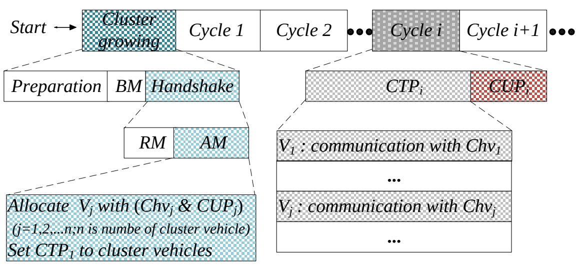


Fig. 5. System cycle

Cluster growing: At the beginning of the system cycle, all vehicles in the VANET switch to default channel and monitor the environmental noise at the same time. Then they broadcast own attribute data message called Beacon Message (BM) to the nearby vehicles. After that, all vehicles in the cluster will get the information about neighboring vehicles' attribute. The CH is selected and every vehicle will take handshake communication with its CH to request and confirm the connection by Request Message (RM) and Acknowledgment Message (AM) respectively. RM, which sent from CM to CH, includes

CM's attribute information and interference information has been monitored. AM which sent from CH to CM, not only includes Cycle Period (CP), Cluster Transmission Period (CTP) and transmission channel of the next system cycle, but also includes Cluster Update Period (CUP) of the CM in the next system cycle, to update cluster. So after all handshake communications have been took, each cluster node will get new time sequence and channel of next system cycle.

SWMs transmission: In CTP, cluster members (including CH) can transmit SWMs to its receiver with specified pre-assigned channel directly, while the receiver is one vehicle of its neighbor list. Otherwise, the member will transmit message to its own CH then the CH will send the message to the receiver. When SWMs are transmitted between two clusters, the gateway may stand a good chance of being the receiver. Then the gateway will judge the message's influencing area and decide to transfer it from one cluster to another with allocation channel.

Cluster update: Due to the mobility of VANET, with the varying of CH or cluster members, cluster structure will also change. Then the CUP is used for updating cluster. During the CUP of one particular system cycle, one by one, each cluster node broadcasts BM in its own time slot, which has been allocated in the previous cycle. After broadcast procedure finishes, each cluster node should retrieve updated neighbor nodes' status, and carry out handshake progress with the lowest healthy level vehicle and consider it as new CH. Meanwhile, a new gateway node should be selected. When all cluster nodes finish the updating progress, the cluster updating finishes and goes into the next system cycle.

The rules of proposed mechanism are summarized and the main steps are explained in Table II.

TABLE II. THE RULES OF CBMC

Preparation:	All vehicles in VANET switch to default channel and monitor the frequency of environmental noise.
Main:	
Step 1: Generate cluster and allocate communication resource (channels & time slots).	
1.1	Every vehicle broadcast BM to its neighbors.
1.2	The lowest healthy vehicle is selected as own CH among neighbors and the others send RM to the CH.
1.3	CH evaluates available probability *A* for every channel, then allot channels and CUP, to every cluster member by sending AM to confirm their request.
Step 2: Transmit SWMs in CTP.	
2.1	According own needs, sender transmits SWMs to its receiver with prescribed channel.
2.2	Gateway receives messages and decides to transfer it to another cluster.
Step 3: Update Cluster & Redistribution in CUP.	
3.1	All vehicles broadcast BM and take handshake communication with their new CH in own CUP.
3.2	CH update cluster information and redistribute the new communication resource (channel & time slot) to the cluster members.

IV. EXPERIMENTAL DESIGN

In order to exam the performance of CBMC Mechanism in SWM dissemination progress, experimentation is chosen instead of simulation to gain higher fidelity and confidence in the observations.

The experiments are done on a wireless sensor network experimental testbed NetEye [14] of Wayne State University. NetEye deploys 130 TelosB motes in a grid with every two closest neighboring motes separated by 2 feet. The grid deployment enables the study of both grid networks and random networks, where random networks can be generated using a subset of the 130 motes in experiments (e.g., using each mote with a certain probability) [15]. Nodes in a 15×7 grid were selected for the experiments as shown in Fig. 6. Each node runs the TinyOS-2.1.0 [16] operating system and are programmed in the C-based programming language NesC. Each node carries a TI MSP430 [17] processor and a Chipcon CC2420 radio [18] operating at 2.4GHz. Zhang *et al*. [19] have shown that, despite its seemingly uniform deployment pattern, NetEye embodies many of the complexities and heterogeneity experienced in outdoor, real-world deployments; for instance, there is a high degree of variability in the background noise power at nodes and in the packet delivery reliabilities for links of equal length, thus reflecting non-uniform network setting as seen in practice.

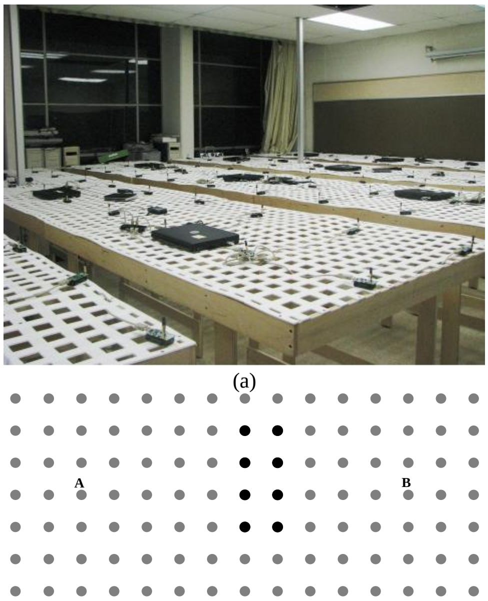


Fig. 6. Sensor network testbed NetEye

For all the experiments in this paper, the default TinyOS MAC protocol B-MAC [20] is used. A broadcast packet is transmitted only once at the MAC layer (without retransmission even if the transmission has failed).

Assume that the relative distance between vehicles has no notable variation within the SWM dissemination procedure and the dissemination model is executed in an instantaneous broadcast manner.

To simulate the vehicles distribution in the stretched road, the gray node A and gray node B in the network are set with high hazard as the SHV, and node A is also the source vehicle. The rest gray nodes are selected as other vehicles on the road, while the black nodes in the middle of network are set as interferers. Node A generates and sends 100 broadcast packets with 19 bytes payload of each packet. Considering the delay of reaching from the node A to the remotest node, the broadcast interval is set to 2 seconds. The jamming node broadcast interference messages with a payload of 18 bytes every 1000ms.

According to DSRC [21] WAVE allows data exchange between vehicular devices in rapidly changing communications environments, where the distances between mobile nodes are between 5 and 500 meters. In our measurement study, we use a radio transmission power of -25dBm (i.e., power level 3 in TinyOS) for simulating V2V communication such that the data transmission reliability is over 95% in the absence of interference for links up to 6 feet long. The transmission power of the adopted interference radio module had 11 levels–the maximum is 0dbm (level 31), the rest levels are 28, 25, 22, 19, 16, 13, 10, 7, 4, 1. The adjustable amount of the jamming node is varies from 0 to 8.

The impact of Cluster-Based Multi-Channel Mechanism should be judged by following two factors.

Dissemination successful rate (DSR): is the number of packets received correctly from source vehicle A, divided by the total number of data packets that should be received. DSR reflects how well the SWM is received by relevant vehicles.

Packet delivery delay (PDD): is the average delay time that a SWM is sent from the source vehicle A to the receiver.

Based on the same experimental hypothesis, another two methods, CSMA based pure flooding protocol and Cluster-Based (CB) mechanism without channel allocation are selected to compare and verify effectiveness of CBMC mechanism.

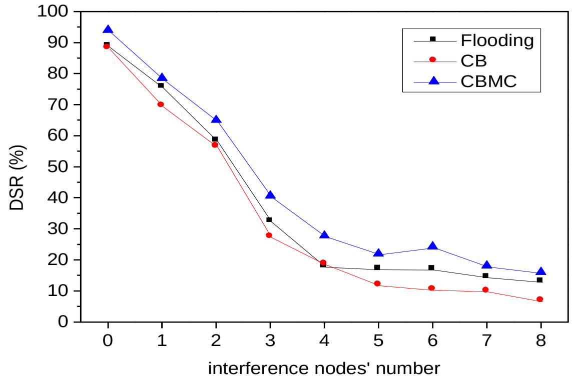
V. Experimental Performance

Wireless sensor networks are inherently dynamic and susceptible to the impact of a variety of uncertainties. One of the uncertainties is the wireless communication itself which assumes complex spatial and temporal dynamics [22]. A broadcast packet would not be retransmitted after a failure transmission in the mote network, where TinyOS B-MAC is used. This link layer non-retransmission affects the number of nodes that can successfully receive the broadcast packet. Based on the non-retransmission mechanism, three experiment scenarios are designed for these three mentioned methods to find out how the CBMC mechanism works in the network.

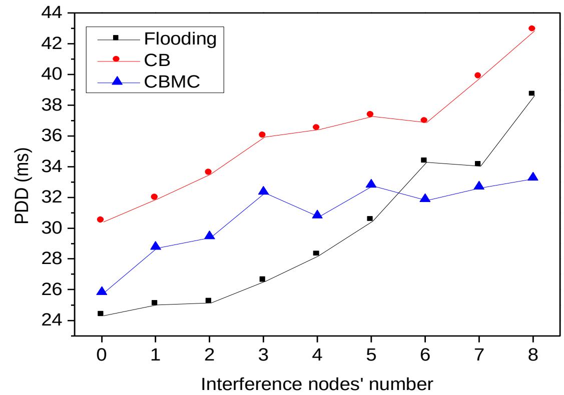
A. Scenario 1

In scenario 1, same amount of gray nodes are selected as vehicles for three methods. Varying number (from 0 to 8) of black nodes are set as interference source, and all set to power level 31. This experiment is aim to study the influence that the number of interference sources would have on three methods' performance. The experiment results are shown in Fig. 7.

As shown in Fig. 7, with the increasing of interference source, CBMC mechanism can provide better DSR performance than flooding and CB mechanism, meanwhile its PDD performance is better than CB and increase slower than Flooding.



(a)



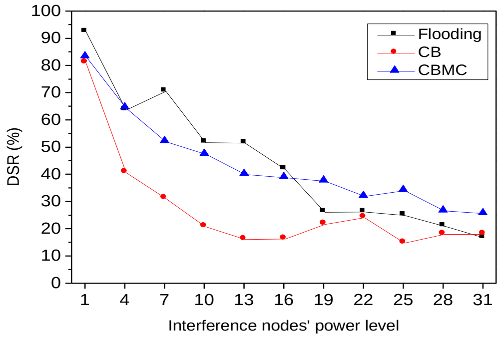
(b)

Fig. 7. DSR and PDD in Scenario 1.

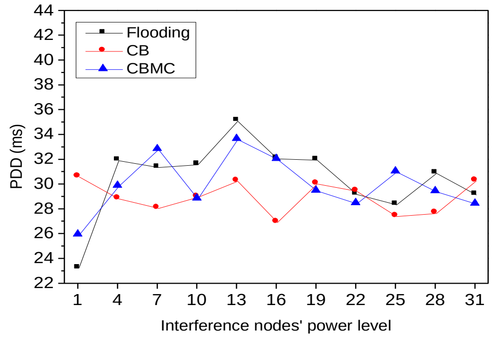
B. Scenario 2

In scenario 2, for all three methods, 4 black nodes are set as interference sources and same amount of gray nodes are selected as vehicles. The power levels of 4 black nodes vary from level 1 to 31. This experiment is aim to study the influence that the power of interference sources would have on three methods' performance.

As shown in Fig. 8, on the one hand, the CBMC mechanism improves DSR performance comparing with CB mechanism. Although DSR of CBMC is slightly worse than flooding when interference power is lower than level 16, it reduces slower and exceeds flooding performance afterwards, which means that CBMC has a better capacity of resisting disturbance than flooding method. On the other hand, although the PDD performance of CBMC is slightly worse than CB and flooding at some points, the PDD value of three methods are very close and floating between 27ms and 33ms.

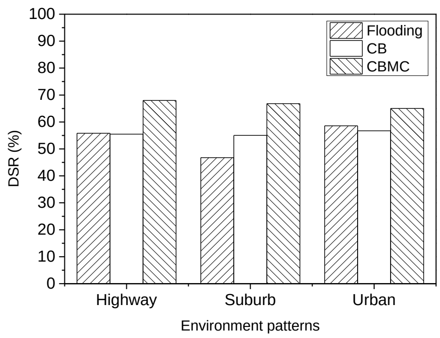


(a)

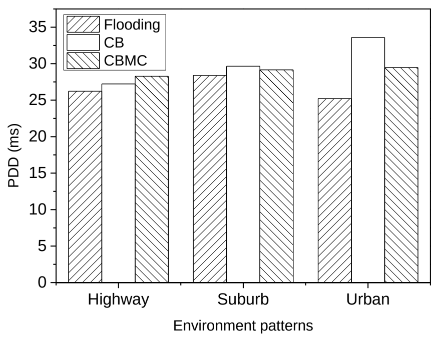


(b)

Fig. 8. DSR and PDD in Scenario 2



(a)



(b)

Fig. 9. DSR and PDD in Scenario 3.

C. Scenario 3

In scenario 3, 4 black nodes are selected as interference sources, and set to power level 31. Then, to simulate three common environments of transportation—highway, suburb and urban, 20, 60, 97 gray nodes are selected as vehicles relatively. This experiment is aim to study the influence that the number of vehicles traveled on the road would have on three methods' performance.

The experiment results of Scenario 3 are shown in Fig. 9. No matter in which transportation environments, CBMC has the best DSR performance among three methods. Meanwhile, although PDD of CBMC is slightly higher than CB in Highway and flooding in all three patterns, CBMC still has a steadier PDD performance than other two methods.

VI. Conclusions

In this paper, A new concept SWM is defined, a stable clustering algorithm and CBMC mechanism is proposed, and results of experiments shows that taking the power level and the density of interference nodes into consideration, comparing with the CBMC mechanism with CB and Flooding, CBMC mechanism have some positive effects on improving global dissemination successful rate and shortening packet delivery delay. These findings provide solid empirical evidence on the conclusion that CBMC can effectively allocate the channel resource and improve SWM dissemination performance.

The experimental analysis of this paper is based on networks of CC2420 radios. Even though we expect the findings of this paper to be valid for networks of IEEE 802.11p or DSRC radios, systematic evaluation of this conjecture and more realistic dynamic experiments are parts of our future work.

Acknowledgment

The authors would like to thank Wayne State University for proving the experimental platform NetEye and thank for the open research fund of Chongqing Key Laboratory of Emergency Communications.

Research is supported by the 2015 Chongqing University Postgraduates' Innovation Project, SRF for ROCS SEM20121707, and SRF for ROCS, SEM.

References

[1] C. D. Wang and J. P. Thompson, "Apparatus and method for motion detection and tracking of objects in a region for collision avoidance utilizing a real-time adaptive probabilistic neural network," U.S. Patent 5 613 039, Mar 18, 1997.

[2] Q. Han, L. Zeng, X. He, *et al.*, "A priority-based CCA threshold adjusting method for EWM dissemination in vehicular ad-hoc networks," *Wireless Networks*, vol. 21, no. 5, pp. 1563–1576, 2015.

[3] N. Gao, L. Tang, S. Li, *et al.*, "A hybrid clustering-based MAC protocol for vehicular ad hoc networks," in *Proc. IEEE International Workshop on High Mobility Wireless Communications*, 2014, pp. 183-187.

[4] E. Souza, I. Nikolaidis, and P. Gburzynski, "A new Aggregate Local Mobility (ALM) clustering algorithm for VANETs," in *Proc. IEEE International Conference on Communications*, 2010, pp. 1-5.

[5] K. A. Hafeez, L. Zhao, Z. Liao, and B. N. W. Ma, "A fuzzy-logic-based cluster head selection algorithm in VANETs," in *Proc. IEEE International Conference on Communications*, 2012, pp. 203-207.

[6] M. S. Almalag, S. Olariu, and M. C. Weigle, "Tdma cluster-based mac for vanets (tc-mac)," in *Proc. IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks*, 2012, pp. 1-6.

[7] S. Vodopivec, M. Hajdinjak, J. Bešter, and A. Kos, "Vehicle interconnection metric and clustering protocol for improved connectivity in vehicular ad hoc networks," *EURASIP Journal on Wireless Communications and Networking*, vol. 1, pp. 1-14, 2014.

[8] C. Wu, S. Ohzahata, Y. Ji, and T. Kato, "Multi-hop broadcasting in WAVE multi-channel vehicular networks: Single transceiver case," in *Proc. IEEE 17th International Conference on Intelligent Transportation Systems*, 2014, pp. 1091-1096.

[9] L. Tang, C. M. Wang, Q. B. Chen, and P. Gong, "An optimal back-off parameters study for multi-channel MAC protocols in VANETs," in *Proc. 22nd Wireless and Optical Communication Conference*, 2013, pp. 1-5.

[10] D. N. M. Dang, C. S. Hong, S. Lee, *et al.*, "An efficient and reliable MAC in VANETs," *IEEE Communications Letters*, vol. 18, no. 4, pp. 616-619, April 2014.

[11] Q. Wang, S. Leng, H. Fu, *et al*. "An IEEE 802.11 p-based multichannel MAC scheme with channel coordination for vehicular ad hoc networks," *IEEE Trans. on Intelligent Transportation Systems*, vol. 13, no. 2, pp. 449-458, 2012.

[12] X. Xie, F. Wang, K. W. Li, P. Zhang, and H. Wang, "Improvement of multi-channel MAC protocol for dense VANET with directional antennas," in *Proc. IEEE Wireless Communications and Networking Conference*, 2009, pp. 1-6.

[13] C. Zhao, "Design and implementation of information collecting and analyzing equipment for driver's behave," M.S. thesis, Dept. College of Communication Eng., Chongqing University., Chongqing, China, 2015.

[14] NetEye. [Online]. Available: http://neteye.cs.wayne.edu/neteye/home.php

[15] H. Zhang, X. Liu, C. Li, *et al.*, "PRK-based scheduling for predictable link reliability in wireless networked sensing and control," in *Proc. ACM/IEEE 4th International Conference on Cyber-Physical Systems*, 2013, pp. 255-255.

[16] Tinyos. [Online]. Available: http://www.tinyos.net/

[17] MSP430. [Online]. Available: http://www.ti.com/lsds/ti/microcontroller/16-bit_msp430/overview.page

[18] CC2420. [Online]. Available: http://www-inst.eecs.berkeley.edu/~cs150/Documents/CC2420.pdf

[19] H. W. Zhang, *et al*., "Adaptive instantiation of the protocol interference model in wireless networked sensing and control," *ACM Transactions on Sensor Networks*, vol. 10, no. 2, Jan. 2014.

[20] J. Polastre, J. Hill, and D. Culler, "Versatile low power media access for wireless sensor networks," in *Proc. 2nd International Conference on Embedded Networked Sensor Systems*, 2004, pp. 95-107.

[21] A. Boukerche, H. A. B. F. Oliveira, E. F. Nakamura, *et al*., "Vehicular ad hoc networks: A new challenge for localization-based systems," *Computer Communications*, vol. 31, no. 12, pp. 2838-2849, July 2008.

[22] H. Zhang "Experimental analysis of link estimation methods in low power wireless networks," *Tsinghua Science & Technology*, vol. 16, no. 5, pp. 539-552, Otc. 2011.

Lei Ye received a B.Sc. degree from Nanjing University of Post and Telecommunications in 2001, and a Ph.D. from the University of York, UK in 2008. Now she is a lecture at the school of Communication Engineering, Chongqing University. Her research is mainly in wireless communications, especially modulation and coding, MIMO and OFDM techniques.

Chong Peng was born in Henan Province, China. He received his B.S. from electronic information engineering institute at Xinyang normal University, China, in 2014, and is currently working toward his M.S. at the College of Communication Engineering at Chongqing University (CQU), China. His research is mainly in Wireless Sensor Network, especially interest in Vehicular Ad-hoc Network and Emergency Warning Message Dissemination.

Lingqiu Zeng was born in Chongqing, 10, 1975, received the B.S. from Chengdu University of Information Technology in 1999, M.S., and Ph.D. degrees from Chongqing University, Chongqing, P.R.C. in 2004, and 2009, respectively. He was a software engineer in Metstar Company from 1999 to 2001. Since July 2004, He became a lecture at the College of Computer Science, Chongqing University. His research interests are in VANET, digital signal processing, and computer graphic and virtual reality.

Qingwen Han was born in Chongqing, 8, 1969, received the B.S., M.S., and Ph.D. degrees from Chongqing University, Chongqing, P.R.C. in 1991, 2003, and 2010, respectively. She was an electric engineer in Chongqing wireless Company from 1991 to 1997. Since July 1997, she became an associate professor at the College of Communication, Chongqing University. She is the author of three books and more than 20 articles. Her research interests are in VANET, multicarrier communication systems, electro-optical signal processing, and time-frequency analysis and wavelets. In past 2 years, she presented 2 inventions in the area of ITS.

Xiaoying Liu was born in Shangdong Province, China, in 1990. She received her B.S. from Communication Engineering at Shandong University in 2014. Now she's pursuing M.S. at the College of Communication Engineering at Chongqing University. Her research is mainly in Wireless Sensor Network, especially interest in Vehicular Ad-hoc Network and Emergency Warning Message Dissemination.

Dongmei Chen was born in Chongqing, China. She received her B.S. from communication engineering institute at Chongqing University, China, in 2011, and now she is pursuing M.S. at the College of Communication Engineering at Chongqing University. Her research is mainly in Wireless Sensor Network, especially interest in Vehicular Ad-hoc Network.

Chen Du was born in Sichuan, China. She is now pursuing her B.S. at the College of Communication Engineering at Chongqing University. Her studying topic is Wireless Sensor Network and Communications Protocol.