Application of the Lowest-ID Algorithm in Cluster-based TDMA System for VANETs

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***Abstract*—To gather data of a larger area and improve the capability in the system, vehicles in Vehicular Ad-hoc NETworks (VANETs) are organized into clusters. Moreover, the effectiveness of application in VANET depends on performance of Medium Access Control (MAC) protocol. In addition, cluster-based MAC protocols can avoid or limit channel contention, provide fairness to channel access, increase radio network capacity management by reusing the spatial network and effectively controlling the topology of the network. This paper proposes a cluster-based TDMA system using the lowest-ID algorithm for Vehicular Ad hoc NETworks (VANETs). Using the lowest-ID algorithm, the analytical and simulated results show that not only the average number of time slots for electing a vehicle head but also total number of time slots before data can be successfully transmitted is less than the existing cluster-based TDMA system and IEEE 802.11p.**

***Index Terms*—VANET, cluster-based TDMA, MAC, the lowest-ID algorithm.**

I. INTRODUCTION

Vehicular Ad-hoc NETwork (VANET) consists of moving vehicles to create dynamical networks. VANET is one of special types of Mobile Ad-hoc NETworks (MANET) but it does not have an existing infrastructure or centralized administration. VANET supports many applications in safe entertainment and vehicle traffic optimization. The VANET classifies of a set of vehicles equipped with communication device and a Global Positioning System (GPS) receiver, called On-Board Unit (OBU) and a set of stationary units along roads, called Road Side Units (RSUs). Based on OBU and RSU, VANET has two essential communications: Vehicle-to-Vehicle (V2V) and Vehicle-to-RSU (V2R). To support V2V and V2R communications, the United States Federal Communication Commission (FCC) dedicated 75MHz radio spectrum in the 5.9GHz band for Dedicated Short Range Communications (DSRC) spectrum [1]. The DSRC spectrum is divided into seven 10MHz channels: six Service CHannels (SCHs) and one Control CHannel (CCH), as shown in Fig. 1. A Sync Interval (SI) comprises of a CCH Interval (CCHI) - 50 milliseconds and SCH Interval (SCHI) - 50 milliseconds. Both CCHI and SCHI have guard interval 4 milliseconds to switch between the CCH and the SCH, as shown in Fig. 1.

One of the important services is high priority safety application proposed for VANETs. Each vehicle broadcasts its information within one-hop neighborhood [2] for the V2V applications such as pre-cash, blind spot warning, emergency electronic brake light and cooperation forward collision avoidance [3]. In V2R application such as the curve speed warning

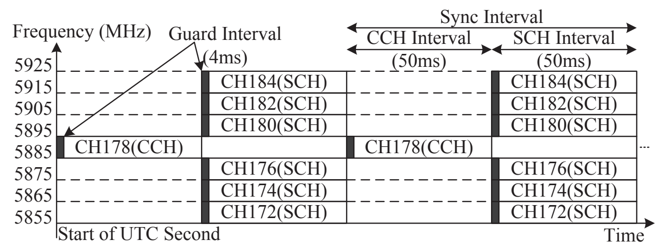

Fig. 1: DSRC spectrum allocation.

and traffic signal violation warning, RSUs broadcast to all vehicles which approach them [4]. To support the high priority safety application in VANET, the Medium Access Control (MAC) protocol is designed to provide efficient broadcast services. For instance, HER-MAC [5] supports more reliable in the safety message broadcast efficient in the service channel utilization. E-VeMAC [6] solves the parallel transmission problem in the VeMAC protocol.

In VANET, vehicle (called node) frequently enters or leaves transmission range of neighbor nodes. Therefore, the connectivity interruption occurs and this creates the high mobility model of VANET. To decrease mobility model in VANET, vehicles are organized into cluster with at least one Cluster-Head (CH) node. CH is responsible for coordination tasks of a cluster. VANET divides the network to smaller and more stable cluster. Thus, vehicles in a cluster seems similar movement patterns is less mobility model compared to the whole network.

VANET is particular case of MANETs. Difference with MANET, properties of VANET are variable network density, large-scale networks, predictable mobility model and rapid topology changes. Since the role of CH is very important in a cluster, many cluster algorithms for MANET and VANET are proposed [7]. VANET clustering techniques focus on mostly only on position and direction of vehicle and are derived from MANET. Therefore, to enhance the stability, clustering algorithms need to refine to take care of the location, direction and speed as well.

Employing clustering technique in IEEE 802.11p is collided when the number of nodes increases in a cluster. To improve the transmission efficiency as the number of nodes is increased, recently cluster-based TDMA is proposed, such as in [8]–[10]. A CH needs to be selected to serve as the network coordinator in cluster-based TDMA. The elected CH is responsible for allocating time slots for data exchange among its Cluster Members (CMs). CMs can avoid collision and achieve fairness due to careful scheduling of time slots. In this paper, we propose a new clustering technique to elect CH faster than existing clustering techniques by using the lowest-ID algorithm.

The rest of paper is organized as follows. Section 2 presents the relation works. Section 3 gives information about cluster-based TDMA system. Section 4 is dedicated to present using the lowest-ID algorithm to elect CH. Section 5 presents application of our proposal in inter-cluster communication. The analytical and simulated results are presented in Section 6 and we conclude this research and suggest some future works in Section 7.

II. RELATED WORK

To support Quality-of-Service (QoS) for timely delivery of real-time data and increase the throughput for non-real time traffics over Vehicle-to-Vehicle (V2V) in VANET, Su *et al.* [11] and Zhang *et al.* [10] develop the cluster-based multi-channel communications scheme based on the infrastructure-free VANET environments. The Cluster Range Control (CRC) (channel 172) use for CMs to broadcast their packets on their predefined slots. The Inter-cluster Control (ICC) (channel 178) is used CSMA/CA technique for CHs to broadcast its cluster information, as shown in Fig. 2. The scheme [11] reduces data congestion and supports QoS for real-time of safety message while efficiently utilizing wireless bandwidth over V2V network. But, this scheme only has 4 channels (channels 176, 180, 182 and 184) for exchange data in intra-vehicle communications.

Ding *et al.* [9] proposed a clustering-based multi-channel V2V communication system to provide traffic accident avoidance mechanism. This system employs a self-organized cluster by assuming two different channels: multiple control channels and a single data channel. The elected CH is a highest candidate probability node. Unfortunately, the author did not address time slots in TDMA.

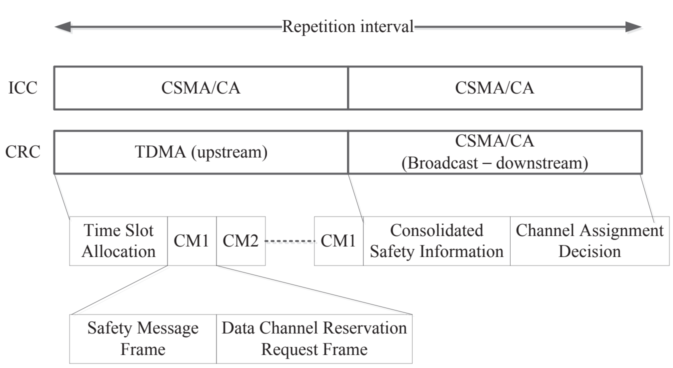

Fig. 2: Time structure in ICC and CRC channels.

Sheu *et al.* [8] proposed a Cluster-Based TDMA (CBT) system for inter-vehicle communications. When the CM increases, the waiting time to elect CH is less than IEEE 802.11p. However, this system applies in the small-sized cluster. A TDMA time slots and MAC-frame format in slot 0 is depicted in Fig. 3.

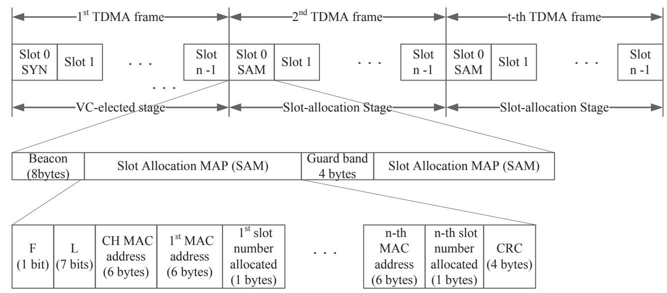

Fig. 3: Time structure in [8].

In this paper, we present a new scheme to elect CH inherited the time division in TDMA frame and MAC-frame format [8]. We use the lowest-ID algorithm to reduce a average number of time slots to electing a CH.

III. CLUSTER-BASED TDMA SYSTEM

A. Cluster Communications

In intra-vehicle communications, cluster-based TDMA system uses simple transmit-and-listen scheme to quickly elect CH and it allows a CM to randomly choose a time slot for Bandwidth Request (BR) without limiting the number of CMs. In a cluster, CH announces its cluster information toward to CMs. Upon CMs receive CH's packet, CMs know about CH' MAC address and the other CMs in a cluster. CMs can transmit data together without collision by announcing a broadcast data packet on their assigned time slots.

A cluster structure has at least one CH. In fig. 4, CH communicates with CMs within its transmission range (*R*). CMs must elect quickly CH with longest time-life and this creates a stable topology.

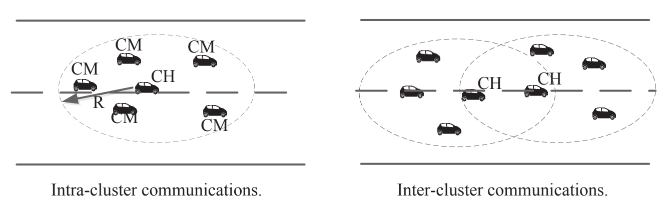

Fig. 4: Intra- and Inter-cluster communications.

B. TDMA Time Slots

For propose cluster-based TDMA system, we design TDMA time slot structure and the associated MAC-layer frame format, as shown in Fig. 5. Slot$\{0, 1\}$ operate with two different purposes. Among 2 time slots on the first frame, nodes broadcast the HELLO packets to set up cluster-based TDMA system. Once a cluster-based TDMA is formed, the elected CH broadcasts slot-allocation map (SAM) via Cluster Head Packet (CHP) to its CMs, and CMs will assign its time slots for transmitting data.

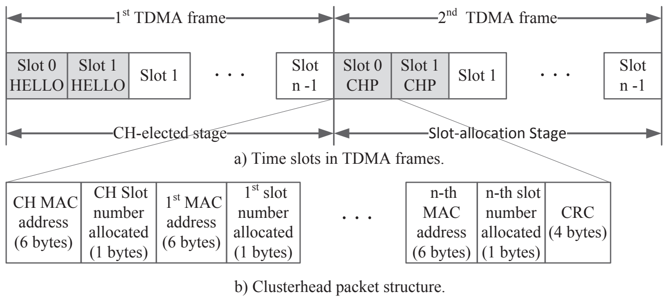

Fig. 5: A new time structure.

In Fig 5, CHP is comprised of following fields:

1) CH MAC Address (6 bytes): The MAC address of a CH.
2) CH Slot Number Allocated (1 byte): The ID of the CH' allocation slot.
3) CM MAC Address (6 bytes): The MAC address of a CM.
4) Slot Numbers Allocated (1 byte): The ID (from 1 to $n-1$) of the allocation slot.
5) CRC (4 bytes): to protect CHPs.

For each CMs, they broadcast the HELLO packets during their assigned time slots to announce its existence, as shown in Fig. 6. If node is an initial node, it only broadcasts Node ID address. Based on this packet, the CH can handle CMs and know about CMs' ID addresses and CMs' slot number allocated. If node hears more one CHP packets from CHs, it becomes a gateway node (GW). Once it detects two CHs, GW will broadcast GW packet, as shown in Fig. 7 to inform its cluster information. GW compares two CH ID addresses, it will decide belong to CH which has lower ID.

Node ID address (6 bytes)	CH MAC address (6 bytes)	CH Slot number allocated (1 bytes)

Fig. 6: Hello packet structure.

Node ID address (6 bytes)	CH MAC address (6 bytes)	CH Slot number allocated (1 bytes)	1st MAC address (6 bytes)	1st slot number allocated (1 bytes)	. . .	n-th MAC address (6 bytes)	n-th slot number allocated (1 bytes)

Fig. 7: Gateway packet structure.

IV. The lowest-ID algorithm to elect CH

Each node is assigned a distinct ID. In initial state, each node chooses the random number before it broadcasts HELLO packet. The value is the backoff counter time. Once one node broadcasts its HELLO packet, the other nodes suspend their packets and compare their ID to sender' ID. We have two ID sets: lower and greater sets. In this paper, since we use the lowest-ID algorithm, the greater set is dismissed. In the lower set, each node based on the back-off value broadcast HELLO packet in the next slot. Lowest-ID node is chosen a CH when after among one slot no node transmits the HELLO packet. After that, the CMs choose time slots for bandwidth request. Hence, a node exists one of four states: initial, quasi-CH, CH and CM, as shown in Fig. 8. The scheme of attempt of a quasi-CH is depicted in Fig. 9.

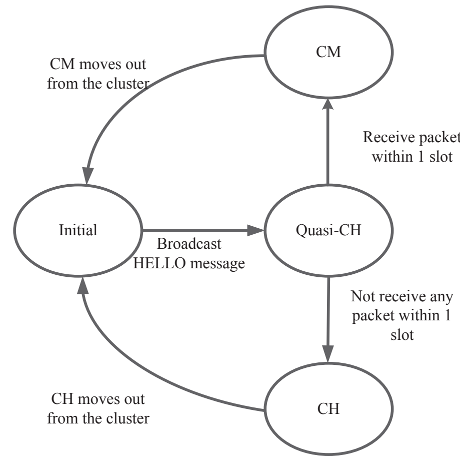

Fig. 8: State transition of intra-cluster communications.

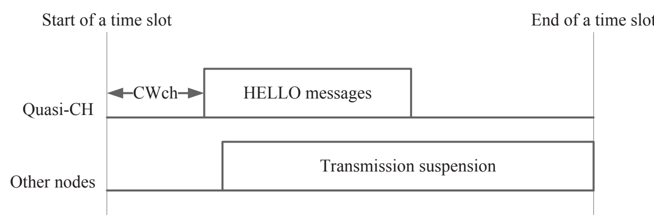

Fig. 9: The scheme of attempt of a quasi-CH.

V. Inter-cluster communications

In highway, nodes move fast and two clusters may share an overlapping area for a certain time. When two clusters overlap together, we assume one node is in between two clusters. This node can hear two CHPs transmitted by CHs. This node is called GateWay node (GW). On the first frame the GW will transmits GW packet to inform its cluster information. We assume node *d* belongs to CH *y* in Fig. 10. Once CH *x* receives GW's packet, it records and compares ID and CHP' CH(*y*). If it knows that the collision will be happened when it move to other CH's transmission range, node CH(*x*) will change to a free time slot of 2 time slots for broadcasting CHP. Simultaneously, node *d* will choose that it belongs to the lower-ID CH, in shown in Figs. 10{a, b}. When node *x* moves to transmission range of CH *y*, it will receive the CH *y*' CHP packet. In next frame, because it knows ID of CH *y* lower or not, it will still keep the role of CH, as shown in Fig. 10a or not, as shown in Fig. 10b. When node *x* is dismissed, based on the CHP packet transmitted by CH *y*, node *x* will choose the free time slot on the frame. Old cluster of node *x* will create a new cluster and elect a new CH.

To prevent collision time slot, before node *x* moves to transmission range of node *y*, we define condition as *the time slot prevent collision (TSPR)* condition. Node *x* receives GW

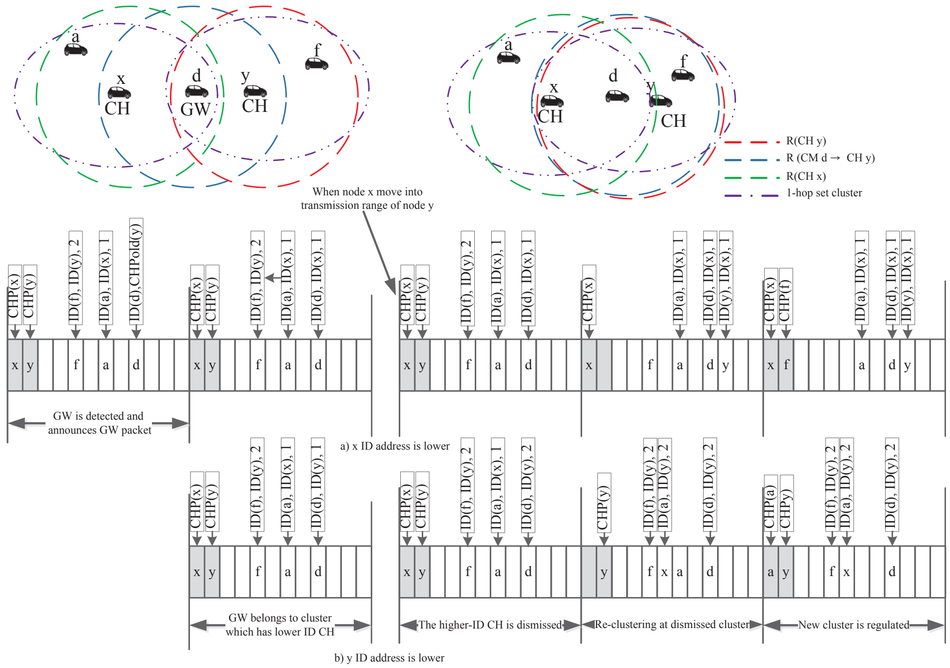

Fig. 10: Operation of inter-cluster communications.

packet transmitted by node *d*, node *x* updates neighbor cluster information. Node *x* compares its CHP to *y*'s CHP. If node *x* uses same time slot with *y*, node *x* switches to a free time on 2 time slots for transmitting CHP. Based on this condition, CH of 3 hop set neighbors can reuse 2 time slots for transmitting CHP, as shown as Fig. 11. If node *x*' CM uses same time slot with node *y*' CM, node *x* will assign a new time slot for this CM and include it into CHP to broadcast. Once CMs receive CHP transmitted by its CH, CMs will update its cluster information and whether or not change its time slot.

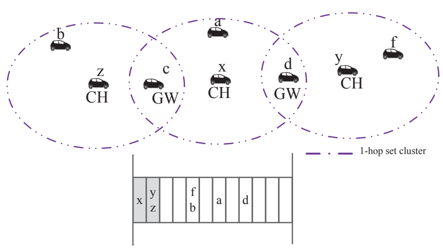

Fig. 11: The reusing time slot in a TDMA frame.

VI. Numerical and Simulation Results

The parameter is listed in Table.I. See [12] for detail and general description of the IEEE 802.11 MAC protocol, each node transmits with probability τ

$$\tau = \frac{2}{CW+1}. \tag{1}$$

Let *Ptr* be the probability that there are at least one transmission in the considered on the considered slot time.

$$Ptr = 1-(1-\tau)^K. \tag{2}$$

TABLE I: Simulation Parameters

$parameter$	$Meaning$
t	Number of TDMA frames
n	Number of slots in a TDMA frame
K	Number of nodes on cluster
$PERM^d{}_c$	the permutation od selecting d from c
L_CHP	CHP size of cluster
R	Transmission bit rate (Mbps)
T_s	Duration of a slot

The probability *Ps* that a transmission occurring on the channel is successful is given by the probability that exactly one node transmits on the channel, condition on the fact that at least one node transmits

$$Ps = \frac{K\tau(1-\tau)^{K-1}}{Ptr} = \frac{K\tau(1-\tau)^{K-1}}{1-(1-\tau)^K}. \tag{3}$$

Let *Pch* be the probability of successful electing a CH,

$$Pch = Ps * \frac{1}{K}. \tag{4}$$

Let *x* be the time slots which CH is successfully elected. The probability density function of *Pch* can be expressed as

$$f(x) = (1-Pch)^{x-1} * Pch \tag{5}$$

The scheme of the lowest-ID algorithm is depicted in Fig. 12. Based on this figure, we can calculate the average time *E[s]* slots required for the electing a CH. Note that a extra slot is added to the average, since our scheme has one slot for guarding time slot.

$$E[x] = \sum_{i=1}^{\infty} xf(x) + 1 = \frac{1}{Pch} + 1 \quad (6)$$
$$= \frac{1-(1-\tau)^K}{K\tau(1-\tau)^{K-1}} + 1 \quad (7)$$

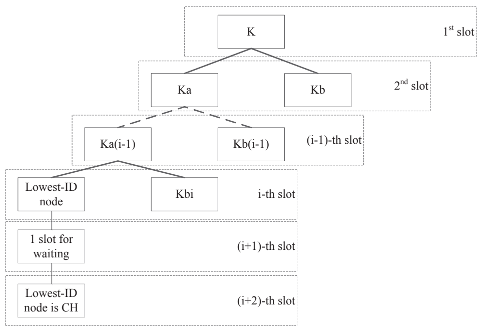

Fig. 12: The schedule of the lowest-ID algorithm.

After CH is elected, CMs will assign their time slots to transmit data. On the first frame, it requires $E[x]$ time slots to elect a CH, it remains $(n - \lceil E[x] \rceil)$ time slots for bandwidth request. For $(K-1)$ CMs, there are a total of $(n - \lceil E[x] \rceil)^{K-1}$ different combination. There are $PERM_{K-1}^{(n-\lceil E[x] \rceil)}$ cases for all the $(K-1)Ns$ to achieve successful bandwidth in the first TDMA frame. Let N_{FBR}^{i} be the average number of failed bandwidth can be expressed as

$$N_{FBR}^{i} = \begin{cases} (K-1) - \sum_{j=1}^{K-1} \frac{PERM_j^{(n-\lceil E[x] \rceil)}}{(n-\lceil E[x] \rceil)^j}; \text{if } n = 2. \\ N_{FBR}^{i-1} - \sum_{j=1}^{N_{FBR}^{i-1}} \frac{PERM_j^n}{n^j}; \text{if } n = 3, 4 ..., t. \end{cases} \quad (8)$$

Thus, we can compute the probability of successful BR issued from $(K-1)$ CMs by using the i^{th} TDMA frame, denoted by P_{BR}^{i}

$$P_{BR}^{i} = \begin{cases} \frac{PERM_{K-1}^{(n-\lceil E[x] \rceil)}}{(n-\lceil E[x] \rceil)^{K-1}} & \text{if } n = 1. \\ \frac{PERM_{N_{FBR}^{i}}^{n}}{n^{N_{FBR}^{i}}} & \text{if } n = 2,3,...,t. \end{cases} \quad (9)$$

Let E[y] be the average number of time slots required the successful BR. Derive Eq. (9), we can compute as

$$E[y] = P_{BR}^{1}(n - \lceil E[x] \rceil) + (\sum_{i=2}^{t}(i * P_{BR}^{i} \prod_{j=1}^{i-1}(1 - P_{BR}^{j}))) * n. \quad (10)$$

After BR request, the CH must broadcast CHP packet to inform toward its CMs. Refer Fig. 5, we can calculate the number of slots to require for CH in a cluster to broadcast CHP packet, denote S_{SAM} as

$$S_{SAM} = \frac{\frac{56*K+32}{R}}{Ts} = \frac{56*K+32}{Ts*R} \quad (11)$$

After CH broadcasts CHP packet, a CM can deliver its data over the designated time slots. It can transmit single-slot or multi-slots. Let $E[z]$ be the average number of time slots required for the waiting before a CM can begin to transmit its data. We can derive it from Eq.(12)

$$E[z] = \begin{cases} \frac{\sum_{t=0}^{K}}{K} = \frac{K-1}{2}; \text{if using single-slot.} \\ \frac{\frac{1+N_{rand}}{2}\sum_{t=0}^{K}}{K} = \frac{(1+N_{rand})(K-1)}{4}; \\ \text{if using multi-slot.} \end{cases} \quad (12)$$

Where N_{rand} is maximum number of requested time slots of a CM. Eventually, we can compute the average number of time slots counting the time electing a CH to the time when a node is ready to transmit its data from Eq.(13)

$$S = E[x] + E[y] + S_{SAM} + E[z] \quad (13)$$

To evaluate our proposal and CBT in [8], we use MATLAB to compute and simulate the average number of time slots for electing a CH, the average number of time slots required for BR and average number of time slots counting the time electing a CH to the time when a node is ready to transmit its data. We ran the simulation 100 times to obtain the mean value of the final performance metric. We choose R = 18 Mbps, which is one of the rates support by the IEEE 802.11p OFDM physical layer for the 5Ghz, Ts = 0.35 ms [13]. We change the number of CMs in a cluster from 2 to 10. When the number of CMs in a cluster equal 2, 4 and 6, the average number of time slots for electing a CH in both 2 system is same. But when the number of CMs increases, our proposal requires time slots less than CBT and IEEE 802.11p. At 10-sized CMs in a cluster, our proposal about 12 time slots and CBT requires 103 time slots, as shown in Fig. 13. We observe that the mathematical results, computed from Eq. (13) are not close to the simulation result, because, simulation results are more realistic and random number is used for CMs to decide whether to transmit or listen. In addition, if lowest-ID node transmits, the processing of electing CH is stopped after one guard time slot.

When the number of CMs in a cluster equals 2, 4 and 6, both our proposal and CBT is the same time slots required to assign BR. But when the number of CMs increases, our proposal requires time slots less than CBT, as shown in Fig. 14. Because the average number of time slots for electing a CH in our proposal is less, the number of free time slots remains more in the first frame and CMs can assign BR in the first frame is more than CBT.

We can compute the average number of time slots counting the time electing a CH to the time when a node is ready to transmit its data. When the CMs in a cluster increases, the total number increases. In our proposal less 2 times compared with CBT at 10 CMs and also less when the number of node is 2, 4, and 6, as shown in Fig. 15. Because using the proposed scheme the elected CH is faster and have more the free time slot remains more in the first frame, the CMs can assign BR is fast to transmit data.

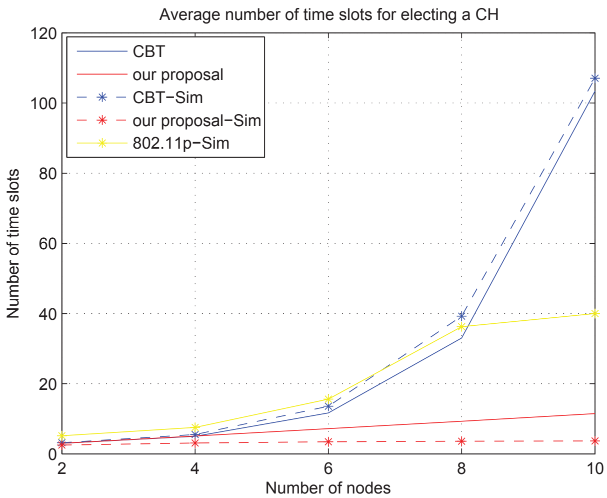

Fig. 13: Average number of time slots for electing a CH.

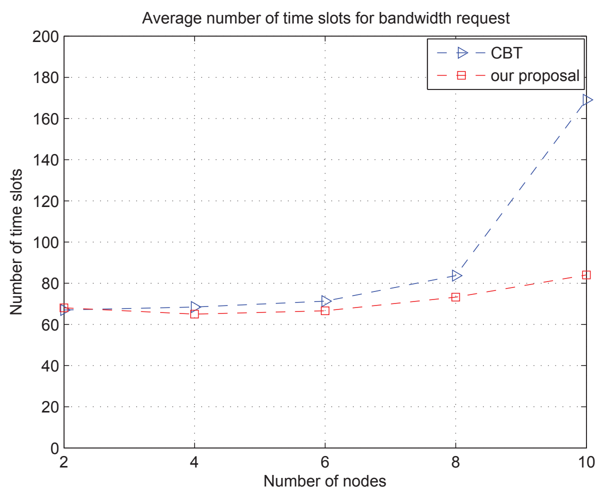

Fig. 14: Average number of time slots for bandwidth request.

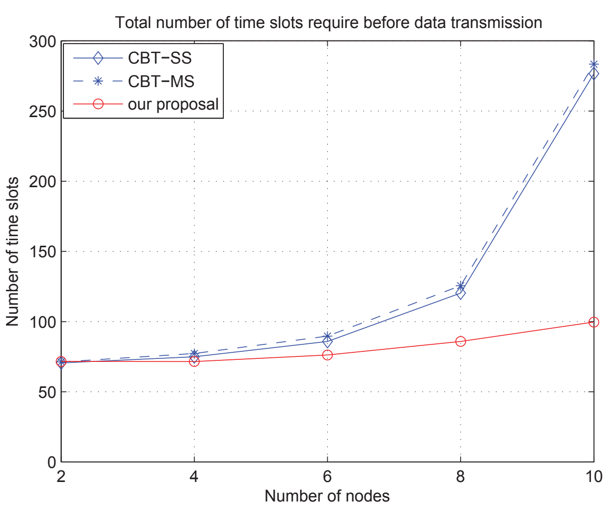

Fig. 15: Total number of time slots required before data transmissions.

VII. Conclusion

In this paper, a novel technique to electing CH for cluster-based TDMA system in VANET is proposed. By using the lowest-ID algorithm, not only the average number of time slots for electing a vehicle head but also total number of time slots before data can be successfully transmitted is less than the existing cluster-based TDMA system and IEEE 802.11p. In the future, our proposal can be extend by considering different traffic types, such as speed, velocity, ...

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