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In vehicle ad hoc network (VANET), the active safety messages, e.g. safety critical application (SCA) information, must be distributed timely by radio channels among vehicles to improve the driver safety. A weight clustering based TDMA-MAC scheme for VANET is presented in this paper. Considering the constrains of radio signal transmitting power in *Green Communication*, the vehicles (nodes) energy consumption in VANET is chosen as one important factor for cluster-head (CH) election, and entropy weight is calculated, which can reflect the subjective intention. For the clustering MAC scheme, each node in a cluster is allowed to communicate by borrowing the scheduling time slots that assigned to other nodes at an access probability. Simulation results reveal the values of access probability for which the network throughput and energy consumption under the weight clustering based MAC scheme yields the better performance compared to the region-based clustering MAC policy. Also, it has the lower average packet contention period, at the expense of a little longer average transmission time of SCA packet.

Key words: VANET, Weighted clustering, TDMA, MAC

TDMA-MAC shema težinskog grupiranja u VANET-u. U ad hoc mreži vozila (VANET), aktivne sigurnosne poruke, npr. informacije za sigurnosno kritične aplikacije, moraju biti distribuirane radijskim kanalom među vozilima na vrijeme, kako bi povećali sigurnost vozača. U ovom radu prikazana je TDMA-MAC shema VANET-a zasnovana na otežanom grupiranju. Razmatrajući ograničenja u snazi pri prijenosu radijskog signala u *Zelenim komunikacijama*, potrošnja energije u vozilima (čvorovi) odabrana je kao važan čimbenik za izbor voditelja grupe (CH), te se računa količina entropije, koja može odraziti subjektivnu namjeru. U svrhu MAC pristupa grupiranju, svakom čvoru grupe dozvoljena je komunikacija posudbom vremenskih intervala u rasporedu koji su pridruženi ostalim čvorovima s pridruženim vjerojatnostima pristupa. Simulacijski rezultati uz MAC shemu zasnovanu na otežanom grupiranju pokazuju bolje vrijednosti mrežne propusnosti i potrošnja energije, u odnosu na MAC sheme grupiranja zasnovane na regijama. Također, ovaj pristup ima niže prosječno vrijeme argumentacije paketa, na uštrb nešto dužeg prosječnog vremena prijenosa SCA paketa.

Ključne riječi: VANET, težinsko grupiranje, TDMA, MAC

1 INTRODUCTION

Vehicle ad hoc network (VANET), an important vehicle communication manner, is becoming the most promising form of mobile ad hoc network. In such a network, the vehicle communication, including vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, is a prospective approach to facilitating road safety, traffic management, and comfortable applications for drivers and passengers.

In VANET, a reliable and efficient medium access control (MAC) protocol is needed, which resolves the contentions among vehicles for radio channel access. The challenges related to MAC issue of VANET include: mobility (i.e., the MAC protocol should support vehicles to leave and join V2V communications at high speed), delay bounded (i.e., the communication must be delay bounded

and real-time), bandwidth efficiency (i.e., the radio resource should be utilized in an efficient and fair manner), scalability (i.e., VANET should scale itself according to the number of vehicles present), cost (i.e., for cost-efficient and reliable communications, VANET should be fully decentralized), fairness (i.e., every vehicle should get a fair chance to get the radio channel) [1].

Several MAC protocols of VANET have been proposed recently. The IEEE 802.11p is a well-known standard [2], which could solve the hidden terminal problem, but it's scalability is poor. Especially, the performance of IEEE 802.11p has a serious decline with the heavy traffic and increasing vehicles, owning to the large amount of broadcasting packets in vehicle network. The ALOHA based MAC protocols adopt distributed slot structure to improve the network performance. However, it brings a new prob-

lem of low bandwidth efficiency [3]. For the special fluid topology environment of VANET, the collision probability among vehicles increases when the number of vehicles is large. To solve the channel collision problem and ensure reliable and timely data delivery for mobile vehicles, clustering MAC protocols for vehicle network are put forward [4,5]. In the protocols, the radio channels of a cluster-member (CM) is assigned by elected cluster-head (CH), which brings the additional overhead, and the energy consumption of vehicles are not taken into consideration.

The information and communication technology (ICT) domain significantly contributes to the global warming. The well-known indicative figure of 3 percent of the worldwide energy consumption is consumed by the ICT infrastructure, which caused about 2 percent of CO_2 emissions [6]. Moreover, it is estimated that ICT is rising at 15-20 percent per year, doubling every five years [7]. With increasing awareness of the potential harmful effects to the environment caused by CO_2 emissions and the depletion of non-renewable energy sources, there is a growing consensus on the need to develop more energy-efficient green communication systems [8].

A weight clustering method for VANET is studied in this paper, in which the clustering indexes and the corresponding entropy weight of different indexes are given by considering the energy savings of nodes. Then, the weight clustering based MAC scheme is presented, in which each CM in a cluster might communicate with CH in slots assigned to other nodes at an access probability, besides the slots assigned to itself, in order to improve the bandwidth efficiency. Finally, the results of our performance study are given, and then we conclude.

2 ENERGY SAVINGS WEIGHT CLUSTERING

In VANET, each vehicle is equipped with an on-board GPS device. The widespread deployment of GPS induces a close attention to the position based clustering algorithms. In geographical adaptive fidelity (GAF) algorithm [9], the thinking of dividing the area with virtual gird for clustering is introduced. The area might be divided into several hexagons (or squares) rather than circularity for the reason that if all the virtual regions are circularity, it cannot cover up the whole area unless they are overlapped [10]. Furthermore, it points out that hexagonal division is superior to foursquare division in the aspects of some metrics like effective coverage. Though GAF has its merits, it cannot reach the optimum energy usage since it elects CHs completely at random, without considering the best position of CH and energy distribution [11].

Therefore, the presented clustering scheme is hexagonal division based, and the CH election includes determining the clustering indexes and calculating the entropy weight of different indexes.

2.1 Clustering Indexes

Four indexes are taken into consideration as clustering indexes for VANET.

1) Difference between the degree of each node and the ideal degree.

The neighbors of node v (i.e., nodes within its transmission range) is defined as the degree of node v, d_v

$$d_v = \left| \bigcup_{v' \in V, v' \neq v} \{v' \,|\, dist(v, v') < TX_{range}\} \right| \cdot \quad (1)$$

where V is the set of nodes, and TX_{range} is the transmission range of node v. The difference between the degree of each node and the ideal degree can be given by

$$D_v = |d_v - \delta| \cdot \quad (2)$$

where δ is the ideal degree, which is a pre-defined threshold to ensure that CHs are not over-loaded and the efficiency of the network is maintained at the expected level.

2) Distance of each node from the ideal CH

In view of energy consumption, if CH is located on the border of a cluster, the energy consumption is 2.4 times as well as that of selecting the nodes in the centre [10]. Accordingly, the ideal CH should be selected near the centre of their cluster for possible for energy saving. In VANET, nodes are distributed randomly, and cannot guarantee that the CH is exactly located the center of a cluster.

In the 2-dimensional Euclidean space, the distance of each node from the ideal CH in a cluster, can be expressed by

$$S_v^* = \sqrt{(v_1 - v_1^*)^2 + (v_2 - v_2^*)^2} \cdot \quad (3)$$

where $v = \{v_1, v_2\}$ and $v^* = \{v_1^*, v_2^*\}$ are 2-dimensional coordinates of node v and the ideal CH v^*.

3) Node mobility

In the 2-dimensional Euclidean space, the node mobility can be computed as

$$\overline{R_v} = \frac{1}{T} \sum_{t=1}^{T} \sqrt{(x_t - x_{t-1})^2 + (y_t - y_{t-1})^2} \cdot \quad (4)$$

where (x_t, y_t) and (x_{t-1}, y_{t-1}) are coordinates of node v at time t and $(t\text{-}1)$ respectively.

4) Node energy consumption

To develop more energy-efficient green communication systems, the energy consumption of each node should be treated as an important index for CH election. It helps in efficient MAC functions and load balancing because it is always desirable to elect a node as CH with more remaining energy (i.e., less energy consumption). The energy consumption of node v can be expressed by

$$E_v = e \cdot M_v \cdot \quad (5)$$

where e is the energy consumption for delivering a packet, and M_v is the number of packets delivered by node v.

2.2 Entropy Weight of the Clustering Indexes

Clustering process (CH election) is multiple attribute decision making problem. Entropy weight method, as one kind of measure tool for an uncertain system mode, takes into account various indexes, and it has obtained a widespread application in the engineering technology [12]. The evaluate model based on entropy weight building step is as follows:

1) Setting up the evaluate matrix D

If there are n evaluated objects, m is the number of evaluate index, then the evaluate matrix D is:

$$D = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & d_{22} & \cdots & d_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ d_{n1} & d_{n2} & \cdots & d_{nm} \end{bmatrix}. \quad (6)$$

The stationary index in the evaluation matrix can be quantified for many kinds of methods, including multistage ratio method, fuzzy method and so on. Here, the set of clustering indexes in VANET, is defined as

$$F = \left\{ D_v, S_v^*, \overline{R_v}, E_v \right\}. \quad (7)$$

2) Determining the normalized matrix R

In multiple attribute decision making, each index in the set of clustering indexes has different dimension, unit, and order of magnitude, therefore normalized process need to be carried on. For a plus index (more bigger more better), it will get

$$r_{ij} = d_{ij} / \max(d_{1j}, d_{2j}, \cdots, d_{nj}). \quad (8)$$

For a moderate index (as closer to given value as possible), it will get

$$r_{ij} = 1/(1 + |a - d_{ij}|). \quad (9)$$

where α is an ideal value. For a negative index (more smaller more better), it will get

$$r_{ij} = \min(d_{1j}, d_{2j}, \cdots, d_{nj}) / d_{ij}. \quad (10)$$

So, the normalized matrix is obtained as

$$R = (r_{ij})_{n \times m}. \quad (11)$$

3) Calculating the entropy value and the relative entropy value for various indexes.

The weight of the jth sample evaluation index characteristic root under the ith evaluation index is

$$p_{ij} = r_{ij} \left/ \sum_{i=1}^{n} r_{ij} \right. \quad (j = 1, 2, \cdots, m). \quad (12)$$

Then, the entropy value for various indexes is given by

$$H_j = -\sum_{i=1}^{n} p_{ij} \ln p_{ij} \quad (j = 1, 2, \cdots, m). \quad (13)$$

Here, when $p_{ij}=0$, $p_{ij} \ln p_{ij}=0$.

It is known from the entropy nature that more closer the index's evaluation value, more bigger its entropy value. When p_{ij} is equal, the entropy value will get maximize value $\ln n$, therefore it's relative entropy value is

$$h_j = H_j / \ln n \quad (j = 1, 2, \cdots, m). \quad (14)$$

4) Calculating the entropy weight of each index.

The entropy weight λ_j of the jth index is defined as

$$\lambda_j = 1 - h_j \left/ m - \sum_{j=1}^{m} h_j \right. \quad (j = 1, 2, \cdots, m) \cdot \quad (15)$$

where λ_j satisfies

$$\sum_{j=1}^{m} \lambda_j = 1 \quad 0 \leqslant \lambda_j \leqslant 1. \quad (16)$$

5) Correcting the entropy weight of each index

Eq. (16) gives the entropy weight of each index objectively. However, in order to reflect the importance of the evaluated index comprehensively, and make the evaluation result be more real and credible, subjectively weight should be taken into consideration. Energy-saving design is important for developing efficient green communication systems. Therefore, we should give priority to node energy consumption in clustering VANET.

The corrected entropy weight of each index is defined by combination the subjective weight λ_j' with the objective weight, as

$$\omega_j = \lambda_j' \lambda_j \left/ \sum_{j=1}^{m} \lambda_j' \lambda_j \right. \quad j = 1, 2, \cdots, m \cdot \quad (17)$$

Then, we can get the set of clustering indexes, $F=f_j$, $j=1, 2, \ldots, m$, and the corresponding weight set, $W=\omega_j$, $j=1, 2, \ldots, m$. The combinatorial weight of clustering indexes for node v is expressed by

$$W_v = \omega_1 D_v + \omega_2 S_v^* + \omega_3 \overline{R_v} + \omega_4 E_v. \quad (18)$$

Subject to:
$$\omega_1 + \omega_2 + \omega_3 + \omega_4 = 1. \quad (19)$$

The node with the smallest W_v would be selected as CH. If more than one node has the smallest W_v, the node with more remaining energy (i.e., less energy consumption) is assigned as CH. All the neighbors of the chosen CH are no longer allowed to participate in the CH election procedure.
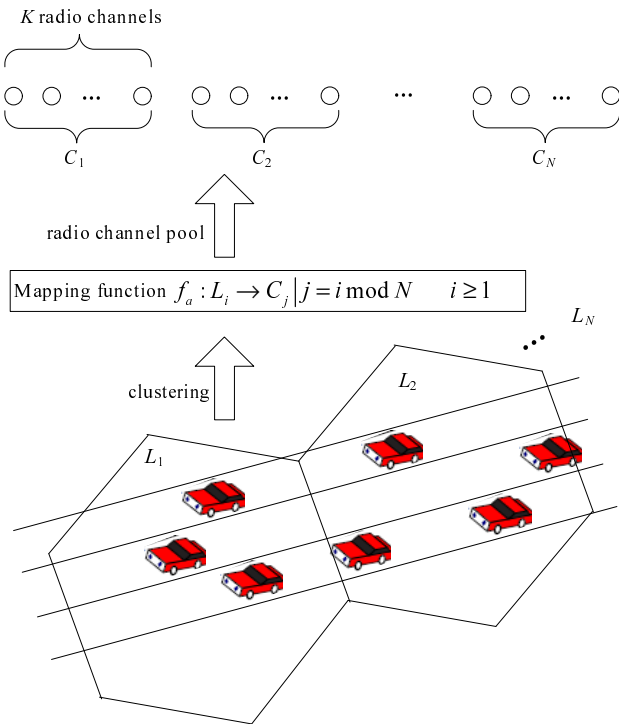
Fig. 1. The model of clustering based MAC Scheme.

3 CLUSTERING BASED MAC SCHEME

3.1 System Model Description

The challenge of successfully deploying VANET services is to ensure timely and reliable data delivery for mobile vehicles. The MAC protocols for VANET are possibly categorized into two different categories: random access based protocols and TDMA based protocols.

The MAC protocols for radio channel access among vehicles are effective under light traffic load. However, when the number of vehicles in the area is large, the protocols may not be able to ensure the desired service due to lack of radio resource (e.g., more contentions among vehicles for random access based protocols like CSMA/CA, [2] and less chance to be allocated a time slot for TDMA based protocols like reliable R-ALOHA [13, 14]), and cause a longer contention period to obtain radio resource.

It has been proven analytically that link utilization that is achievable by any random access schemes is also achievable by time division scheduled access [15]. And, in general, for networks with medium to heavy loads, scheduling transmission has shown to be the preferred access method.

The nodes using TDMA based protocols are often required to be equipped with a GPS or other localization device. In VANET, each vehicle is equipped with an on-board GPS, and the traffic load increases dramatically in urban areas. So, TDMA based MAC protocol is a good choice for VANET.

In this paper, the weight clustering based MAC Scheme is introduced in order to improve the bandwidth and energy efficiency in VANET. As depicted in Fig. 1, the service is divided into a set of hexagonal units (clusters), $L = L_1, L_2, \ldots, L_N$. We limit the number of vehicles in each cluster for the contention of radio channels and each cluster is then associated with a non-overlapping radio channel pool. Since the number of vehicles in each cluster is limited, the contention period is reduced and the energy consumption is decreased.

To simplify our description, we consider one lane only in the geographical area of the network [1]. All vehicles are identical independent distributed (i.i.d.) on one lane, and at most K vehicles could reside in a cluster. Each cluster is associated with a radio channel pool containing K channels so that all the vehicles in a cluster are guaranteed to obtain a radio channel.

In our clustering based MAC Scheme, each timeslot is considered as a radio channel, and several slots are grouped into a cyclic frame structure. Each vehicle (node) can transmit messages in the channel with satisfying either the Cond-1 and Cond-2, or Cond-1 and Cond-3:

Cond-1. The channel must be allocated from the radio channel pool of the cluster.

Cond-2. The channel must be assigned to the node itself.

Cond-3. The channel (at an access probability p) must be assigned to any other node in the cluster, but currently not being used by any other node.

Let the transmission range of the transmitter of a vehicle is r, and the length of a vehicle is at most l. The CM in a cluster must be able to receive the signals sent from CH (vice versa) when it satisfies

$$l \leqslant r \cdot \tag{20}$$

Suppose that there are totally N channel pools, $C_1, C_2, \ldots, C_N$ in VANET, and there are totally $N \times K$ channels required. With the channel reuse technology [16], which can avoid the radio interference, each vehicle executes a mapping function f_a to identify the radio channel pool it can access. The following mapping function f_a is to assign N radio channel pools to all the clusters in the lane:

$$f_a : L_i \to C_j \,|\, j = i \bmod N \qquad i \geqslant 1 \cdot \tag{21}$$

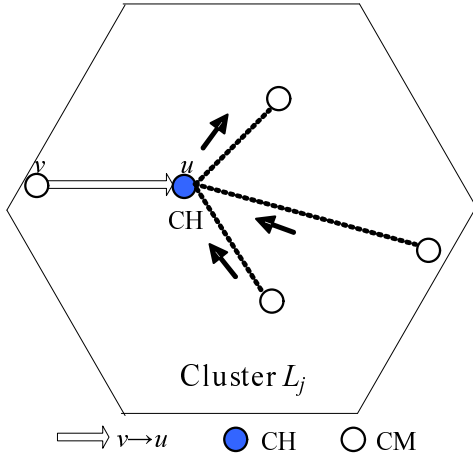This mapping function f_a may not maximize the use of available bandwidth. To make use of the bandwidth more

Fig. 2. An example of transmission $v \to u$.

efficiently, the mapping function can be dynamically set up according to the rate of traffic flow. This issue is not argued in [1]. On the basis of our previous work [17], the value of access probability p which can maximize network throughput is analyzed, and the node energy consumption varying with p is discussed in this paper.

3.2 Clustering Based MAC Scheme

For the clustering based MAC scheme, nodes are allowed to access non-assigned time slots with some nonzero probability. Let k_j denote the number of cluster L_j (j=1, 2, ..., N), where N is the number of clusters in VANET. Let N_v denote the set of neighbors of node v in cluster L_j, and ω_v denote the set of time slots assigned to node v. Each node v always transmits in time slot i if $i \in \omega_v$, and transmits with access probability p in slot i if $i \notin \omega_v$, provided that slot i currently not being used by any other node.

Suppose the CM (CH), node v, wants to transmit to the CH (CM), node u, in a particular time slot i. In order for the transmission $v \to u$, as depicted in Fig. 2, to be successful, two conditions should be satisfied [18]. First, node u should not transmit in the particular time slot i. Second, no neighbor of u, except v, should transmit in time slot i. It is clear that if the nodes that belong in $N_u \cup \{u\} - \{v\}$ transmit, transmission $v \to u$ becomes corrupted.

Let P_i denote the probability that transmission $v \to u$ in time slot i is successful, which is expressed by

$$P_i = \begin{cases} (1-p)^{k_j-1} & i \in \Omega_v \\ p(1-p)^{k_j-1} & i \notin \Omega_v \end{cases}. \qquad (22)$$

Then the average probability of success over a frame for transmission $v \to u$, $\overline{P_i}$ is given by

$$\overline{P_i} = \frac{1}{K}\sum_{i=1}^{K} P_i = \frac{1+(K-1)p}{K}(1-p)^{k_j-1}. \qquad (23)$$

The average throughput for cluster L_j is

$$S_{L_j} = \frac{1}{k_j}\sum_{l=1}^{k_j} \frac{1+(K-1)p}{K}(1-p)^{k_j-1}. \qquad (24)$$

So, the network throughput can be obtained as

$$S = \frac{1}{N}\sum_{\forall L_j \in L} S_{L_j} = \frac{1}{NK}\sum_{j=1}^{k_j}\frac{1+(K-1)p}{k_j}(1-p)^{k_j-1}. \qquad (25)$$

Assume that energy consumption for a node transmitting over a time slot is constant β. The number of time slots occupied by a node transmitting in a frame is given by

$$T = 1 + p(K - 1). \qquad (26)$$

The energy consumption in a frame for transmission is

$$E_F = \beta T = \beta\left(1 + p(K - 1)\right). \qquad (27)$$

Then, the average energy consumption during a frame per successful transmission can be calculated as

$$E = \frac{E_F}{K\overline{P_i}} = \beta\frac{1}{(1-p)^{k_j-1}}. \qquad (28)$$

It can be seen obviously from Eq. (25) and Eq. (28) that the value of access probability p affects the network throughput and energy consumption.

4 NUMERICAL RESULTS

We set up the evaluate matrix D in Eq. (6) as Table 1 in the clustering process for VANET. The entropy weight λ'_j (j=1, 2, 3, 4) for clustering indexes in Eq. (15) can be calculated as {0.23737, 0.25184, 0.24737, 0.26342}. Let the subjective weight (j=1, 2, 3, 4) be {0.3, 0.15, 0.15, 0.4} allowing for the node energy consumption is preferred in clustering VANET. The corrected entropy weight of each index is obtained by Eq. (17) as W={0.28319, 0.15023, 0.14756, 0.41902}.

Table 1. Clustering evaluate matrix.

Node ID	D_v	S_v^*(m)	$\overline{R_v}$(km/h)	E_v(W)
1	2	25	20	0.08
2	4	5	30	0.02
3	1	8	50	0.01
4	5	10	80	0.05
5	3	50	100	0.03

Suppose that the transmission range of the transmitter of a vehicle is 50m, and length of a vehicle is at most 10m [1], the energy consumption for a node transmitting over a time slot is 1mW, the number of nodes is no more than 100 (with 0.5 activated probability of services), the number of
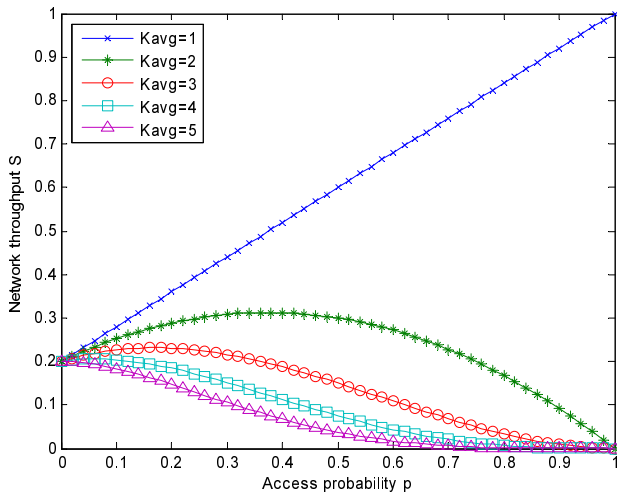
Fig. 3. The effect of the access probability p on the network throughput S
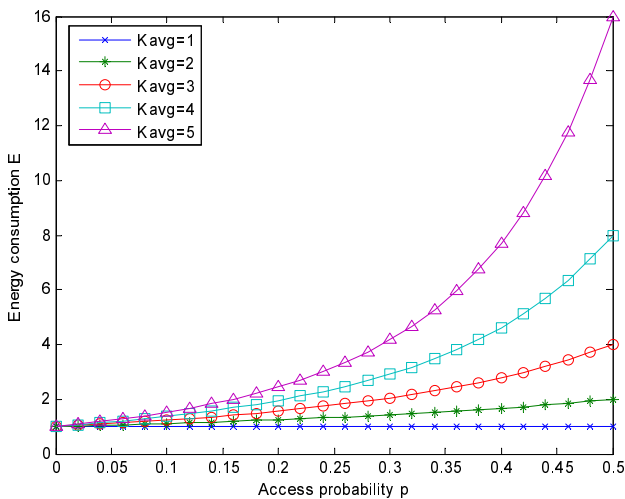

Fig. 4. Energy consumption varying with the access probability p

radio channel pool is 10, and the average number of nodes in a cluster is in the range of 0 and 5.

Fig. 3 shows the effect of the access probability p on the network throughput S. It can be seen that there exists a value for the access probability p_{max} for which the network throughput S might reach its maximum value for given the average number of nodes K_{avg} in a cluster. And, the probability $pmax$ decreases with increasing K_{avg}. This is because that a larger K_{avg} results in more collisions between nodes in a cluster, and the access probability p_{max} becomes smaller to avoid the collision. The value for the access probability p_{max} for which the network throughput S reach the maximum value is 1, 0.38, 0.16, 0.06 and 0, for different value of K_{avg}=1, 2, 3, 4, 5

respectively.

Fig. 4 depicts the energy consumption varying with the access probability p. It is observed that the node energy consumption E increases as the access probability p increases. This is due to the fact that more larger p is, more collisions happen between nodes in a cluster, which results in the much energy consumption. Also, we observe that as K_{avg} increases (i. e., more nodes in a cluster), the probability of collisions between nodes becomes larger, and more energy is consumed for the collisions.

Consequently, in the deployment of VANET, the value of access probability p might be adjusted to satisfy the specified requirements for network throughput and energy consumption.

The comparison of network throughput and energy consumption between the proposed weight clustering based MAC scheme (denoted as WCS-MAC) with the region-based clustering mechanism (denoted as RCM-MAC in [1]) is presented in Fig. 5 and Fig. 6, respectively. From the Fig. 5 and Fig. 6, we can see that the network throughput of WCS-MAC is superior to that of RCM-MAC, and the energy consumption of WCS-MAC is less than that of RCM-MAC. The reason is that the proposed WCS-MAC is a dynamic scheme in which all time slots are potentially utilized by any node with different access probability, results in the less transmission conflict and higher bandwidth efficiency. Consequently, the performance of WCS-MAC is better than the static RCM-MAC. Note that the network throughput S in our scheme is maximized for given the access probability, p_{max}.
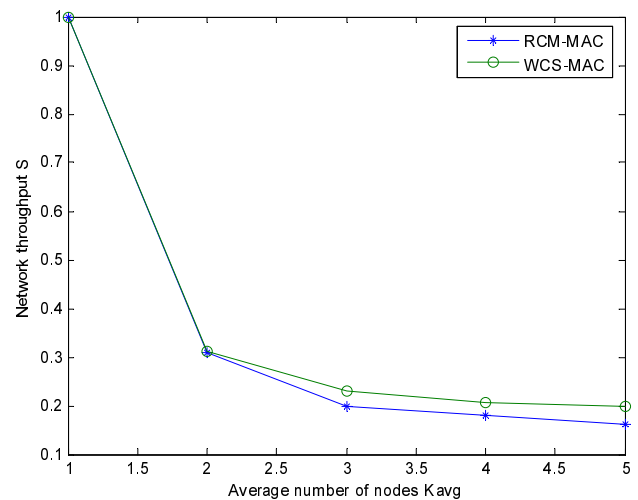

Fig. 5. Network throughput comparison for different values of K_{avg}

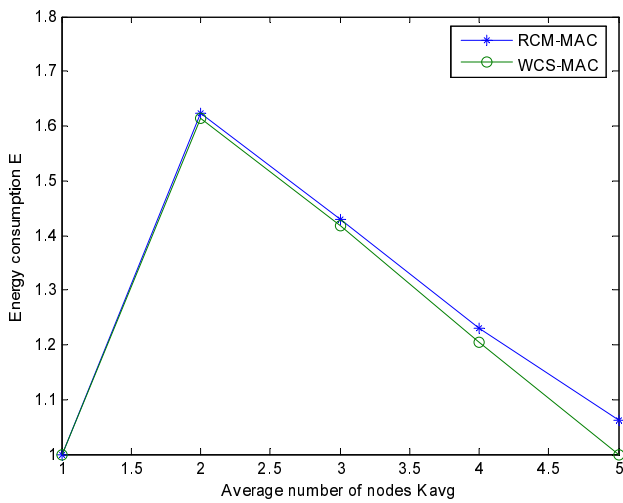Fig. 7 plots the average contention period for the transmission of SCA information in terms of different value of

Fig. 6. Energy consumption comparison for different values of K_{avg}

Fig. 7. Average contention period comparison for different values of K_{avg}

Fig. 8. Average total transmission time comparison for different values of K_{avg}

K_{avg}. In RCM-MAC, the service area is divided into multiple region units, and there is no CH in the region unit. The collision will happen provided there has data to transmit simultaneously for two nodes in a region unit. However, in WCS-MAC, the communication connection is set up only between CH and CM in a cluster, which reduces the chance of collision. Low collision chance is an important factor to guarantee that a node can always occupy the channel in a short contention time. Besides, it is clear that the average contention period increases with larger K_{avg} for both RCM-MAC and WCS-MAC. This is the case that larger K_{avg} setup results in the larger number of nodes in a region unit (cluster), and more nodes contend the radio channels in the same pool.

In Fig. 8, we study the effects of K_{avg} on the average total transmission time of an SCA session for different mobile speed (v_s). It can be seen that the WCS-MAC has the longer average total transmission time of an SCA session by introducing the time delay for CH election. As expected, as the node runs fast (i.e., at higher v_s), the node resides in a region unit (cluster) for a shorter period, handoff is more likely occur in an SCA session, which results in more handoff failures (i.e. longer total handoff latency). Therefore, longer total transmission time for an SCA session is observed. Here, handoff is referred to the operation that the node v may move from a region unit (cluster) to the new region unit (cluster) during the transmission of SCA information. Define the handoff latency as the time period between the time when the node enters the new region unit (cluster) and the time when the node obtains the correct positioning and timing information from GPS.
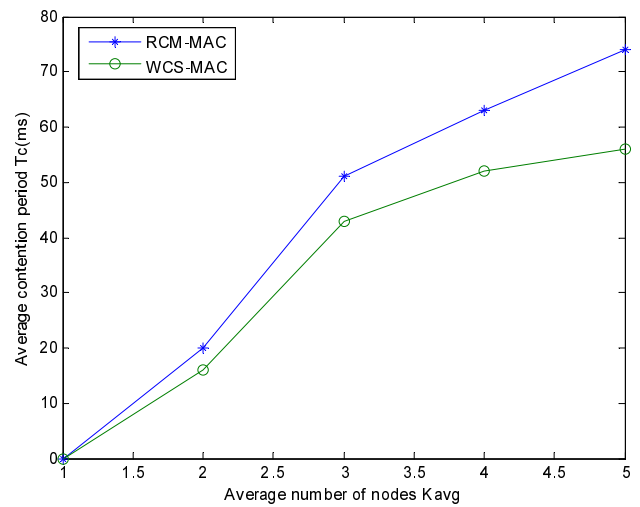
5 CONCLUSION

In this paper, we consider the problem of radio channel access among vehicles to develop more energy-efficient green communication in VANET. In the proposed weight clustering based MAC scheme (WCS-MAC), the clustering indexes and the corresponding entropy weight of different indexes are formulated for the energy savings of nodes. Based on the clustering, a realistic clustering channel access scheme is designed to reduce the collision chance of nodes and guarantee reliable communications in VANET.

Numerical results show that our proposed scheme achieves better throughput and energy consumption performance, relative to the region-based clustering mecha-

nism. At the same time, the scheme decreases the node collision, and results in shorter average contention period. The scheme is clustering based and hence the time delay for CH election results in longer average total transmission time of an SCA session.

For future research, we are currently extending this work to consider larger K_{avg} (i.e., large number of nodes in a cluster) as well as their fairness.

ACKNOWLEDGMENTS

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