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Data Transmission Scheme of VANET Based on CH Selection and Switch between Clusters

Wei Rong[1], Shen Xibing[2] and Yang Yi[3]

[1]*College of humanities, Qinzhou University, Qinzhou, 535000, China*
[2]*College of resources and environment, Qinzhou University, Qinzhou, 535000, China*
[3]*College of software, Guangxi University of Science and Technology, Liuzhou, 545006, China*
E-mail: 404580539@qq.com

Abstract

A data transmission scheme based on cluster is proposed for data transmission of VANETs. Firstly, the selection scheme of cluster head CH is designed. The optimal CH is selected by calculating the utility function of CCHs, which combines node degree (NOD), available resource and mobile information of CHs and CMs, including the characteristic requirements of different user applications. According to the simulation results, the proposed scheme's performance can be improved in terms of throughput, data transmission delay, successful transmission rate and overhead.

***Keywords**: VANET; Cluster; Data transmission; Switch; Resource*

1. Introduction

As a special form of MANET (Mobile ad-hoc network), VANET (Vehicular ad-hoc network) provides a platform for V2VC (Vehicle-to-Vehicle Communication) and V2RC (Vehicle-to-Roadside Unit Communication). Through V2VC, information is shared between vehicles to improve traffic safety. However, due to the high speed movement of the vehicles, dynamic change of the topology structure, characteristics of the channel fading and competition mechanism of the channel in VANET, the data transmission of VANET is challenged. In the ANET, MNs (Mobile nodes) are in free distribution and form swarms, namely clusters, based on their location. Therefore, V2VC of VANET can be realized through the cluster based network structure. According to the literature [1-2], the cluster based scheme can improve the utilization of resources and enhance the network capacity. Although cluster based schemes are widely used in sensor networks [3, 4], the schemes designed based on the sensor network cannot be directly used in VANET due to the different characteristics of the network. To this end, many researchers have conducted theoretical studies on clusters in the VANET. The literature proposes a distributed and dynamic cluster related master CH (Cluster head) selection algorithm, by which the network is divided into several clusters. The algorithm uses the fuzzy logic inference strategy to predict the velocity and location information of CMs (Cluster members). In the literature [6], a novel cluster algorithm based on beacon is adopted, and the new ALM (Aggregate local mobility) scheme is introduced to construct the cluster structure. In the literature [7], the author proposes a simple cluster selection strategy that RSS (Received signal strength) is used as the cluster information index. In addition, for VANET, the literature [8] puts forward LocVSDP (Location-based service discovery protocol). LocVSDP uses cluster based facilities and provides time-sensitive and scalable network architecture with location-based service.

The above research work does not fully consider strategy mechanism of selecting CHs. In addition, the switch between clusters brings dynamic changes of the vehicle

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performance parameters, thus leading to the fact that the selected CH may not be the best, which will reduce the vehicle data transmission performance. For this reason, this paper proposes a novel CH selection algorithm for a given cluster based on three types of information including node degree, available resource of CCHs (Candidate CHs) and velocity difference between CCHs and CMs. In view of the characteristics of the user applications, the UTF (Utility function) related to CM is proposed and the utility variations accessing to different clusters are compared, so that the vehicles can be switched between different clusters.

2. System Model

In this paper, the VANET is considered to be applied based on many vehicles and one AP (Access point). And different clusters are assumed to be constituted by the adjacent vehicles that are close to each other in each region. For each cluster, one CH is selected and other vehicles are considered as CMs. CMs of a cluster have direct communication with other vehicles within the cluster, and CMs must be able to communicate with the CH, through which the data is forwarded to AP or the vehicles in other clusters.

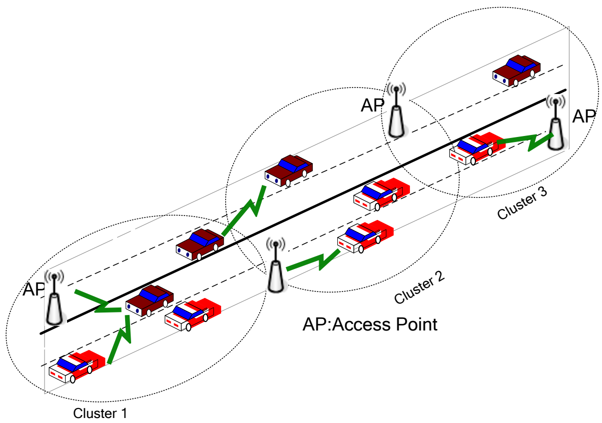

Figure 1. Network Model

As shown in Figure 1, the vehicles constitute three clusters. For the clusters that have been constituted, the optimal CH should be selected. In addition, the vehicles in one cluster can choose to stay within the cluster or request to come into another cluster (request for switch between clusters). And there should be a standard to determine whether to accept the request. In the third section, the selection scheme of CH is analyzed, and the request for switch between clusters is analyzed in the fourth section.

The communication channel model between CH and AP is Nakagamim-m fading channel, with channel gain h_1. Its PDF (Probability distribution function) [6] is as indicated by the formula (1).

$$f\left(h_1\right)=\frac{2m^m}{\Omega\left(d\right)^m\Gamma\left(m\right)}h_1^{2m-1}\exp\left(-\frac{m}{\Omega\left(d\right)}h_1^2\right) \tag{1}$$

Where, m represents the Nakagamim fading parameter $\left(m\geq 1/2\right)$. $\Gamma\left(\cdot\right)$ represents the gamma function [9]. $\Omega\left(d\right)$ represents power loss of the transmission distance d, as indicated by the formula (2).

$$\Omega\left(d\right)=\frac{P_tG_tG_rh_t^2h_r^2}{d^{\theta}L} \tag{2}$$

Where, P_t represents the transmission power, G_t and G_r represent the gains of transmit and receive antennas respectively, h_t and h_r represent the length of transmit and receive antennas respectively. θ represents the path loss index, and L represents the system loss.

The communication channel model between CMs is Cascaded Nakagmai-m fading channel, 2 Cascaded. PDF[10] of channel gain h_2 is as indicated by the formula (3).

$$f\left(h_2\right)=\frac{2}{h_2\Gamma\left(m_1\right)\Gamma\left(m_2\right)}G_{0.2}^{2.0}\left[\frac{m_1m_2h_2^2}{\Omega_1\Omega_2}\Big|_{m_1,m_2}^{-}\right] \tag{3}$$

Where, $G_{0,2}^{2,0}\left(.\middle|:\right)$ is the function of Meijer G- [11]. $\Omega_l=E\left[h_l^2\right]$, $m_1=\Omega_l^2/E\left(h_l-\Omega_l\right)^2\geq 0.5$, and $l=1,2$.

3. Scheme to Select the Optimal CH

In fact, in a cluster, CH plays a role in forwarding nodes for CMs. To this end, the scheme to select the optimal CH should take the transmission performance of CMs into account. The next step is to analyze the scheme for selection of CH.

3.1. Factors Influencing Selection of CH

For a given cluster, to select the optimal CH should consider the following factors:

3.1.1. NOD (Node Degree): The CH in the cluster should have the ability to directly communicate with all the CMs in this cluster. In other words, CH should have the highest NOD in the cluster. The NOD of the vehicle i within the cluster m is marked as N_i^m. Obviously, N_i^m is related to the number of members of the cluster. To this end, the maximum number of the members of each cluster is defined as $N^{\max}$.

3.1.2. NVD (Node velocity difference): Because both CHs and CMs are moving at a high velocity, the vehicle movement information must be considered in order to keep the topological structure of the cluster stable. Obviously, the smaller velocity difference between CHs and CMs makes the cluster structure more stable. Therefore, in selecting CH, there is need to consider its velocity information.

υ_i^m represents the velocity of the vehicle i in the cluster m. The average value $\Delta\upsilon$ of the velocity difference between the vehicle i and CMs in the cluster m is as indicated by the formula (4).

$$\Delta\upsilon=\frac{\sum_{j\in\Omega}m,_{j\neq i}\left|\upsilon_i^m-\upsilon_j^m\right|}{2N^m\upsilon^{\max}} \tag{4}$$

Where, N^m and $\upsilon^{\max}$ represent the number of CMs in the cluster m and the maximum velocity of CMs

3.1.3. AVR (Available Resource)

In order to forward packets to CM, CH needs to consume a certain amount of bandwidth resources. To this end, in selecting CH, the normalized access bandwidth variable is defined, as indicated by the formula (5).

$$B_i^{m,Nor}=\frac{B^{m,av}}{B^{\max}} \tag{5}$$

Where, $B^{m,av}$ and $B^{\max}$ represent the value of the access bandwidth of the vehicle i in the cluster m

3.2. Performance Evaluation of CCHs

In order to comprehensively evaluate the performance of CCHs, the sigmoid function in Machine Learning [11] is applied and the UF (function Utility) is defined.

UF of CCH i in the cluster m is as indicated by the formula (6).

$$U_i^m = \frac{B^{m,Nor}}{1+e^{-s\left(w_n\frac{N_i}{N_{\max}}-\Delta\upsilon+w\right)}} \tag{6}$$

Where, S, w_n and w are parameters of the Sigmoid function. S represents the gradient of the utility curve, w_n and w jointly determine the knee in the curve.

According to the formula (6), the utility value of the cluster m is calculated, and the CCH that has the largest utility is selected as the optimal CH, as indicated by the formula (7).

$$CH_m^* = \arg\max_i U_i^m \tag{7}$$

4. Scheme for Switch between Clusters

For clusters with a selected CH, the data transmission performance of CMs depends on the characteristics of CH and CMs, and the requirements of the user applications.

Let's assume that CM_k belongs to the cluster m. If CM_k goes into the cluster n, CM_k will have the better transmission performance. To this end, CM_k may apply to enter the cluster. In this case, in the decision to accept or reject such request, the cluster n needs to assess the impact of accepting the vehicle CM_k on the performance. In this section, analysis is conducted on this issue. Specifically, the task is to define access to a cluster and accept the UF of a CM.

4.1. UF of CMs

According to the sensitivity of time and throughput, the applications of VANET can be divided into two categories, namely, SA (Safety Application) and UIAA (User Internet Accessing Application).

4.1.1. DSS (Delay-sensitive service)

When the UF is established, the transmission delay should be taken into account. If the link transmission performance is poorer, there is a greater probability that transmission fails and retransmission is needed, finally leading to a longer transmission delay. Therefore, the quality of the link can be used to evaluate the transmission performance of DSS. In addition, in VANET, the communication between CMs and between CM and AP is in accordance with the protocol of IEEE 802.11 based on MAC (Media access). Some collision during the transmission may occur when many nodes transmit messages at the same time, resulting in transmission failure. To avoid such failure, the backoff and retransmission mechanism is introduced. The UF of CM_k in the cluster m is $V_k^{m,de}$, as indicated by the formula (8).

$$V_k^{m,de} = \beta^{de}\frac{P_k^m}{T_k^m} \tag{8}$$

Where, β^{de} represents the transmission efficiency of DSS; P_k^m and T_k^m represent the probability of successful transmission and the transmission time of CM_k in the cluster m respectively. Due to the possibility that CM_k may directly communicate with CH and other CMs, or communicate with AP through CH, the average successful transmission probability is as indicated by the formula (9).

$$P_k^m = p_k^{m,de,dir} P_k^{m,dir} + \left(1 - p_k^{m,de,dir}\right) P_k^{m,AP} \tag{9}$$

Where, $p_k^{m,de,dir}$ represents the probability of direct transmission between CM_k and other vehicles in the same cluster. In general, $p_k^{m,de,dir}$ is far greater than 0.5. $P_k^{m,dir}$ represents the probability of successful direct transmission between CM_k and CMs in the cluster m. $P_k^{m,AP}$ presents the probability of successful transmission between AP and CM_k through CH. According to the channel model defined in the second section, $P_k^{m,dir}$ and $P_k^{m,AP}$ are as indicated, respectively, by formulas (10) and (11).

$$\begin{aligned} P_k^{m,dir} &= \Pr\left(\frac{E_s}{N_0} h_1^2 \geq \psi_{th1}\right) \\ &= 1 - \frac{G_{1,3}^{2,1}\left[\frac{m_1 m_2 N_0 \psi_{th2}}{\Omega_1 \Omega_2 E_s}\middle| \begin{matrix} 1 \\ m_1, m_2, 0 \end{matrix}\right]}{\Gamma(m_1)\Gamma(m_2)} \end{aligned} \tag{10}$$

$$\begin{aligned} P_k^{m,AP} &= \Pr\left(\frac{E_s}{N_0} h_1^2 > \psi_{th1}\right) \times \Pr\left(\frac{E_s}{N_0} h_2^2 > \psi_{th2}\right) \\ &= \left(1 - \frac{\gamma\left(m, \frac{mN_0}{\Omega E_s}\psi_{th1}\right)}{\Gamma(m)}\right) \times \left(1 - \frac{G_{1,3}^{2,1}\left[\frac{m_1 m_2 N_0 \psi_{th2}}{\Omega_1 \Omega_2 E_s}\middle| \begin{matrix} 1 \\ m_1, m_2, 0 \end{matrix}\right]}{\Gamma(m_1)\Gamma(m_2)}\right) \end{aligned} \tag{11}$$

Where, γ represents the incomplete gamma function.

In addition, T_k^m in the formula (8) is as shown in the formula (12).

$$T_k^m = p_k^{m,de,dir} T_k^{m,dir} + (1 - p_k^{m,de,dir}) T_k^{m,AP} \tag{12}$$

Where, $T_k^{m,dir}$ represents the time that CM_k requires to transmit data to other vehicles in the cluster m. The expression of $T_k^{m,dir}$ is as indicated by the formula (13).

$$T_k^{m,dir} = DIFS + T_{RTS} + T_{CTS} + SIFS + T_k^{m,BO} + T_k^{m,Data} \tag{13}$$

Where, DIFS and SIFS represent the distributed inter frame space and the short inter frame space defined in IEEE 802.11 respectively. T_{RTS} and T_{CTS} represent the time to transmit RTS and CTS respectively. $T_k^{m,BO}$ and $T_k^{m,Data}$ represent the backoff time and the time that CM_k in the cluster m requires for data transmission.

$T_k^{m,AP}$ in the formula (12) represents the time that CM_k requires to transmit data to AP through CH, as indicated by the formula (14).

$$\begin{aligned} T_k^{m,AP} &= T_k^{m,dir} + DIFS + T_{RTS} + T_{CTS} + SIFS \\ &\quad + T_H^{m,BO} + T_H^{m,Data} \end{aligned} \tag{14}$$

Let's assume that CM_k uses DSS and switches from the cluster m to the cluster n, the add value of the UF is as indicated by the formula (15).

$$\Delta V_k^{m,n,de} = V_k^{n,de} - V_k^{m,de} - S_k^{m,n,de} \quad (15)$$

Where, $S_k^{m,n,de}$ represents the SC (Signaling cost) of CM_k to switch from the cluster m to the cluster n.

4.1.2. TSS(Throughput-Sensitive Service): In VANET, the user needs to download files, watch video data and other entertainment information. To this end, high quality of the link is needed between CMs to provide a higher throughput of transmission. The access bandwidth resources of CH play an important role in the communication between CMs and AP. Let's assume that the CM_k user in the cluster m uses TSS, the UF of CM_k is as indicated by the formula (16).

$$V_k^{m,th} = \beta^{th} F_{H,k}^m R_k^m \quad (16)$$

Where, β^{th} presents the transmission efficiency of TSS, $F_{H,k}^m$ presents the bandwidth access index of CH, as indicated by the formula (17).

$$F_{H,k}^m = \begin{cases} 1, B_H^{m,av} \geq B_k^{m,req} \\ 0, B_H^{m,av} < B_k^{m,req} \end{cases} \quad (17)$$

Where, $B_H^{m,av}$ presents the access bandwidth of CH in the cluster m, and $B_k^{m,req}$ presents the bandwidth required by CM_k in the cluster m. R_k^m presents the average capacity of CM_k in the cluster m, as indicated by the formula (18).

$$R_k^m = p_k^{m,th,dir} R_k^{m,dir} + \left(1 - p_k^{m,th,dir}\right) R_k^{m,AP} \quad (18)$$

Where, $p_k^{m,th,dir}$ presents the probability that CM_k directly transmits TSS to CMs in the same cluster, usually, $p_k^{m,th,dir}$ is far less than 0.5. $R_k^{m,dir}$ represents the link capacity directly related to CM_k in the cluster m and $R_k^{m,AP}$ represents the capacity of the link from CM_k to AP.

Let's assume C_{kj}^m represents the capacity of the link from CM_k to CM_j in the cluster m, its expression is as indicated by the formula (19) [12].

$$C_{kj}^m = B_{kj}^m \log\left(1 + \gamma_{kj}^m\right) \quad (19)$$

Where, B_{kj}^m and γ_{kj}^m represent the bandwidth from CM_k to CM_j in the same cluster and SNR (Signal Noise Ratio) respectively. Therefore, $R_k^{m,dir}$ is as indicated by the formula (20).

$$R_k^{m,dir} = \sum_{j \in \Omega_m, j \neq k} \frac{c_{kj}^m}{\left(N-1\right)^m} \quad (20)$$

In addition, let's assume C_{kH}^m represents the capacity of the link from CM_k to CH of the cluster m, and $C_H^{m,AP}$ represents the capacity of the link from CH of the cluster m to AP, as indicated by formulas (21) and (22).

$$C_{kH}^m = B_{kH}^m \log\left(1 + \gamma_{kH}^m\right) \quad (21)$$

$$C_H^{m,AP} = B_H^{m,AP} \log\left(1+\gamma_H^{m,AP}\right) \tag{22}$$

Where, B_{kH}^m and γ_{kH}^m represent the bandwidth from CM_k to CH of the cluster m and SNR respectively. $B_H^{m,AP}$ and $\gamma_H^{m,AP}$ represent the bandwidth from CH to AP and SNR respectively. $R_k^{m,AP}$ is as indicated by the formula (23).

$$R_k^{m,AP} = \min\left(C_{kH}^m, C_H^{m,AP}\right) \tag{23}$$

The UF that switches CM_k from the cluster m to the cluster n in the TSS is as indicated by the formula (24).

$$\Delta V_k^{m,n,th} = V_k^{n,th} - V_k^{m,th} - S_k^{m,n,th} \tag{24}$$

Where, $S_k^{m,n,th}$ represents the SC that switches CM_k from the cluster m to the cluster n.

4.1.3. PVS (Probability of Various services): Vehicles in VANET may need to access different services at different times, in a given time zone T, the probabilities that CM_k of the cluster m transmits delay-sensitive data and throughput-sensitive data are as indicated by formulas (25) and (26) respectively.

$$P_k^{m,de} = \frac{T_k^{m,de}}{T} \tag{25}$$

$$P_k^{m,th} = \frac{T_k^{m,th}}{T} \tag{26}$$

4.1.4. Average utility of CMs: The average utility increment $\Delta V_k^{m,n}$ of CM_k in switching from the cluster m to the cluster n is as indicated by the formula (27).

$$\Delta V_k^{m,n} = P_k^{m,de} \Delta_k^{m,n,de} + P_k^{m,th} \Delta_k^{m,n,th} \tag{27}$$

4.2. UF of the Cluster

When CM_k joins the cluster n, the transmission performance of the cluster may change. And the increase of the cluster members will lead to the rise of cluster management and maintenance costs. Due to the movement of the vehicle, the topology of the cluster changes, so the relationship between velocity and location of CM_k should be considered.

Let's assume the velocity of CM_k is υ^k, the normalized velocity difference between CMs and CM_k of the cluster n is as indicated by the formula (28).

$$\Delta\upsilon^{n,k} = \frac{\sum_{j\in\Omega^n} \left|\upsilon^k - \upsilon_j^n\right|}{2\upsilon^{\max}} \tag{28}$$

And the normalized average distance $\Delta d^{n,k}$ between CM_k and CMs of the cluster n is as indicated by the formula (29).

$$\Delta d^{n,k} = \frac{\sum_{j\in\Omega_n} \left(\left|x^k - x_j^n\right|^2 + \left|y^k - y_j^n\right|^2\right)^{1/2}}{2R^{\max}} \tag{29}$$

Where, (x_k, y_k) is the position coordinate of CM_k and (x_j^n, y_j^n) is the position coordinate of CM_j in the cluster n. R^{max} is the maximum transmission distance of the vehicles.

When receiving CM_k, the return $\mathrm{Re}^{n,k}$ that cluster n gains therefrom is as indicated by the formula (30).

$$\mathrm{Re}^{n,k} = \beta_d \frac{1}{\Delta d^{n,k}} + \beta_\upsilon \frac{1}{\Delta \upsilon^{n,k}} \quad (30)$$

Where, β_υ and β_d represents the weights of the velocity difference and the distance difference respectively.

Let's assume the number of CMs in the cluster n is N_n. According to the literature [13], the SC in charge of management and maintenance of the cluster n is αN_n^2, where α is a constant. If the cluster n receives CM_k, the SC is $\alpha(N_n+1)^2$, therefore, the increment $\Delta C^{n,K}$ of SC is as indicated by the formula (31).

$$\Delta C^{n,k} = \alpha\left((N_n+1)^2 - N_n^2\right) = 2\alpha N_n + \alpha \quad (31)$$

In taking in CM_k, it is required to consider the benefits of receiving CM_k and cost increment. The utility of the cluster n is as indicated by the formula (32).

$$\Delta U^{n,k} = \mathrm{Re}^{n,k} - \Delta C^{n,k} \quad (32)$$

4.3. Selection of the Cluster

When the vehicle CM_k is switched from the cluster m to the cluster n, the cluster n uses the formula (32) to evaluate the utility of accepting CM_k. If $\Delta U^{n,k} \geq 0$, the cluster n will accept the request, otherwise, it will not. More specifically, as long as $\Delta U^{n^*,k} \geq 0$ is met, CM_k will be switched from the cluster m to the cluster n^*, where, $n^* = \arg\max \Delta V_k^{m,n}$.

5. Simulation and Numerical Analysis

In this section, the proposed scheme for CH selection and switch between clusters is simulated and compared with the scheme proposed in [5]. The simulation scenario is shown in Figure 2, where the road is 2Km long and there is an AP on the road with a communication radius of 800m, the vehicle's communication radius is 200m. Vehicles are randomly distributed on the road at velocities ranking from 40Km/h to 120Km/h.

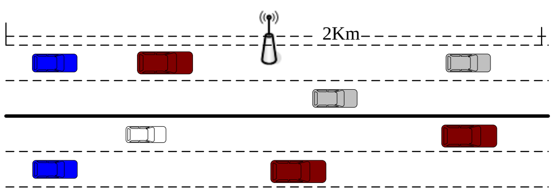

Figure 2. Simulation Scenario

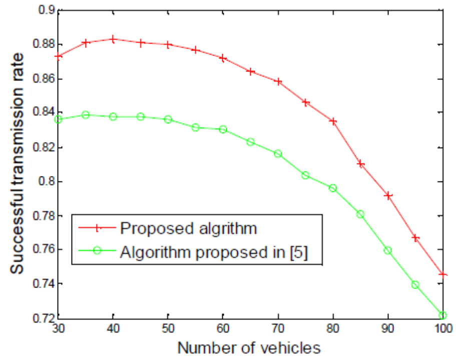

Figure 3. Successful Transmission Rate

Figure 3 shows the impact of the number of vehicles on the successful transmission rate. From the figure we can see that, with the increase of the number of vehicles, the successful transmission rate of the two algorithms drops. This is mainly due to the increase in the number of vehicles, which enhances the probability of data collision and then reduces the successful transmission rate. In addition, from the figure we can also see that, compared with the scheme proposed in [5], the algorithm proposed in this paper improves the successful transmission rate in performance. The reason is that the proposed algorithm combines a variety of factors, including channel characteristics of the physical layer, collision and bandwidth access.

Figure 4 shows the throughput charges of all vehicles along with the change in the number of vehicles. From the figure we can see that the proposed algorithm is better than that proposed by the literature [5] in performance. The reason is that the proposed algorithm considers the bandwidth between CMs and CH as well as the link information between. With the increase of the number of vehicles, the total throughput rises.

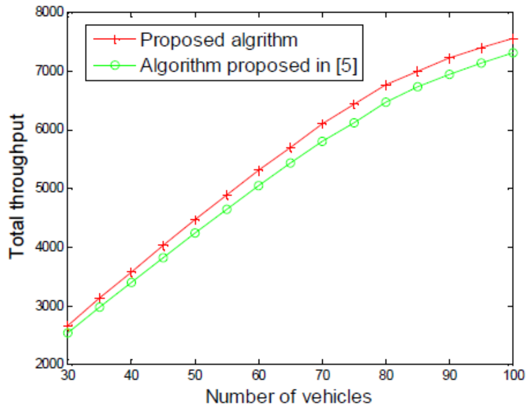

Figure 4. Throughput vs Number of Vehicles

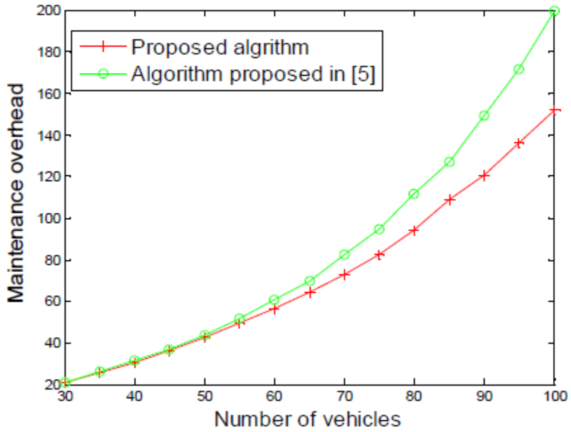

Figure 5. Maintenance Overhead vs Number of Vehicles

Figure 5 shows the variation curves of the two algorithms along with the change in the number of vehicles. From the figure we can see that the overhead of the proposed algorithm is lower than that of the algorithm proposed [5]. It is mainly because the proposed algorithm combines the velocity of vehicles, NOD and bandwidth access information in selecting CH. With this information, the topology of the cluster is more stable, which can reduce the maintenance overhead of the cluster.

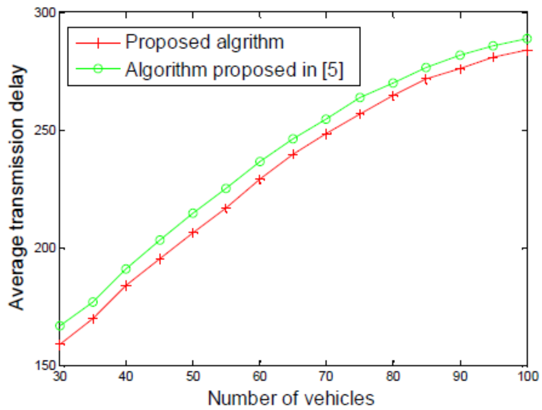

Figure 6. Average Transmission Delay vs Number of Vehicles

The average transmission delay of the two algorithms changes with the change in the number of vehicles, as shown in Figure 6. Compared with the algorithm proposed in [5], the proposed algorithm has a lower transmission delay due to the reason that the proposed algorithm combines the requirements of the applications in switching between clusters as well as the performance between clusters, and CH is selected through the UF to help CM switch between clusters, thus reducing the transmission delay.

6. Conclusion

Due to the characteristics of VANET (Vehicular ad-hoc network), including high speed movement of vehicles, channel fading, competition between channels and QoS (Quality of Service), the data transmission is challenged. To this end, the data transmission strategy VANET based on cluster is adopted with introduction of the selection scheme of CH (Cluster head) and the algorithm of switch between clusters. The selection scheme of CH combines three aspects of information including NOD

(Node degree), access resources of CCHs (Candidate Cluster head) and velocity difference between CCHs and other CMs (Cluster members). In addition, QoS requirements of DSS (delay-sensitive service) and TSS (throughput sensitive service) are taken into account in switching between clusters, and the UF (Utility functions) is established to realize switch between clusters. Finally, the simulation results show that the proposed scheme significantly improves the performance in terms of data transmission delay, overhead, successful transmission rate and throughput.

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Authors

Wei Rong, she graduated from Guangxi University of science and technology, computer science and technology professional. Received master degree in computer applications. Now she is a senior engineer at Qinzhou University in Guangxi, humanities. Her main research direction is computer graphics and computer network security and system analysis. She has published academic papers.