A Cooperative-pricing-based Access Selection Mechanism for Vehicular Heterogeneous Networks

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***Abstract*—Vehicular heterogeneous networks (VHNs) are a special type of wireless vehicular networks. In the VHNs, the nodes choose an access network to download data from the Internet. Most of the existing access network selection mechanisms concentrate on the perspective of individual nodes, only limited work focus on cooperative communications among vehicles. In this paper, a new network selection approach is proposed for vehicles to download data cooperatively in a VHN scenario. The proposed mechanism, namely Cooperative-pricing-based Access Selection Mechanism (CASM), is composed of the cooperative game based pricing strategy and the optimal access node selection algorithm, which are able to minimize access cost and maximize rate-cost ratio. Simulation results demonstrate that our proposed mechanism can ensure the effective data rate while reducing about 40% access costs.**

***Index Terms*—VHN, Access Selection, Pricing Strategy, Cooperative Game Theory.**

I. Introduction

In the recent years, the emergence of vehicular ad-hoc networks (VANETs) makes communications of intra- vehicle, vehicle-to-vehicle and vehicle-to-infrastructure rapidly come true. More applications arise mainly focusing on road safety, entertainment, and driver assistance services, just to mention a few. With the rapid increasing number of vehicles equipped with wireless communication interface and the wide deployment of wireless vehicular networks, more attention have been drawn on data downloading and transmission on road, i.e. the Intelligent Transportation System (ITS), it can support wide range of safety relevant or entertainment relevant applications.

With the popularity of wireless communication technology, vehicles accessing the Internet to get service through several access networks while driving becomes common. During the process of data downloading, due to the characteristics of vehicular networks, e.g., diversity of network topology, high mobility of vehicles, etc., data transmission becomes challenging. While compared with VANET, cellular network is more reliable and can ensure large-scale real-time data transmission. Therefore, cellular network, as a choice of access network, becomes popular in vehicular communication. Moreover, several types of architecture have been proposed to strengthen stability and connectivity of data transmission links, such as communications architecture for land mobile (CALM) [1] and integrated architecture of VANET and universal mobile telecommunications system (UMTS) [2].

In the VANET and UMTS integrated architecture, base stations (BS) or access points (AP) transmit data gathered from vehicles or the core network. Restricted by communication coverage of BS or AP, only a part of vehicles can communicate with BS or AP directly. When a vehicle (or node) enters the coverage of AP or cellular network, this node first detects network and assesses the performance of network, then switches to the target access network for Internet service all by itself. Nowadays, there are few researches on how to choose an access network for vehicular heterogeneous network. If we just follow the methods used in VANET and UMTS integrated architecture for data downloading, nodes out of the communication coverage cannot download data in time. Meanwhile, a vehicle will be more restricted if it is only equipped with one wireless communication interface. Hence, a fair and general mechanism is in need to ensure vehicles on road access the network which satisfies it most.

This paper proposed an access network selection mechanism with a pricing strategy and an access node selection algorithm in HVNs. The communication pattern among vehicles is modeled as a cooperative game which is different from the existing models. Based on the cooperative game theory, a pricing strategy is proposed to stimulate cooperation between vehicles and ensure the payment is reasonable. In this process, source node cuts down access cost and cooperator gains revenue. In addition, in the access node selection algorithm, a new performance evaluation metric, i.e. data rate-cost ratio, is introduced. Considering both access cost and rate-cost ratio guarantees the selected cooperative node with lower payment and higher rate- cost ratio. As a consequence, our proposed CASM can help source node obtain high effective data rate while reducing access costs.

The remainder of this paper is organized as follow. Section II presents the background on related works. Section III introduces the problem, then, proposes the IPASM used for solving the problem. Performance of this access selection mechanism and the relevant discussion are given in Section IV. Finally, Section V concludes this paper.

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II. Related Work

Currently, there are several kinds of wireless communication technology used for vehicular network, including WLAN, cellular technology, dedicated short range communication (DSRC) and WiMAX. These technologies have their own advantages in terms of cost and performance. Suitably combining these technologies to form VHNs can improve performance of network and reduce access cost. In this paper we consider a HVN consisting of a wide-area cellular network interworking with WLAN.

When a vehicle enters a zone covered by cellular network and WLAN, it should select the best one to access for service. The most common technology used is called vertical handoff (VHO). VHO decision is made by the source node itself in terms of user preferences and network preferences [3] [4]. VHO process mainly includes network discovery phase, handoff decision phase and handoff execution phase. In network discovery phase, vehicles discover which access network can be used and what type of service can be provided by each access network. In handoff decision phase, vehicles make a decision on which network to access. And finally in handoff execution phase, vehicles switch to the target access network for Internet service.

Usually in the process of handoff decision phase, metrics taken in the process of network accessing are only the access cost or the lifetime [5] [6]. The authors of [7] developed an optimal, event-activated VHO decision-making algorithm. The proposed algorithm is based on mobility profiles of users including their velocities and preferences in terms of costs or transfer times into consideration. In [8] and [9], authors proposed a VHO method to facilitate the optimization of overall performance of the integrated system of access networks. Source node chose the access network with lowest cost or shortest downloading time to cut down access cost or shorten access time. And in [10] [11], authors proposed non-cooperative game-theoretic algorithms to help select access network. The Nash equilibrium solutions are used to find the optimal prices and maximum profits for service providers.

However, the above mentioned VHO algorithms only focus on the perspective of individual nodes, seldom take the cooperation between vehicles into account. When source node is out of the coverage of WLAN or is only equipped with one wireless communication interface, the access costs cannot be reduced. Furthermore, performance metrics considered are simple and hardly combine the cost with its corresponding QoS. In our study, a cooperative-game-based pricing model is proposed based on the game theory. In addition, a new performance evaluation metric is designed to ensure the selected access node with lower price and high rate-cost ratio.

III. Cooperative-pricing-based Access Selection Mechanism

In the VHNs, when the source node is going to download data, surrounding vehicles may have the same interest or not. Therefore, in this paper, the CASM is proposed for the scenario where surrounding vehicles do not need the same data as the source node.

A. System Model

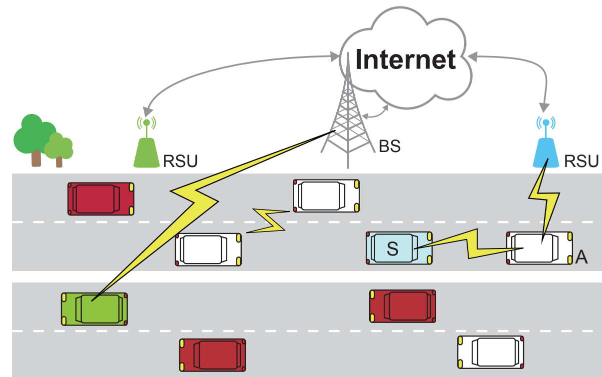

Fig. 1. VHN system scenario

Consider a scenario where cellular network and WLANs interwork to form a VHN. A road is covered by cellular network and along a road, AP is randomly deployed. Vehicles are equipped with 3G/4G cellular network and Wi-Fi interfaces. Cellular system provides a larger coverage area with relatively lower data rate at a higher cost. And different types of unit cost are different according to different service operators. Conversely, WLANs offer a higher data rate at a lower cost in a short coverage. Different types of WLANs charge differently, as they are belonged to different service operators. Communications among vehicles are set free. The whole proposed VHN system model is shown in Fig. 1. Vehicles in different color belonged to different operators. The same as vehicles, unit cost of road side units (RSUs) in different color are different.

Assume there is a set of vehicles on road, the number is n. Among the n nodes, a source node (denoted as S) wants to download application P cooperatively with surrounding vehicles. As Fig. 1 shows, S uses our proposed CASM and chooses node A to help download data. Even S is not in the coverage of RSUs, with the help of node A, it gets the Internet service with lower cost than downloading data itself through cellular network.

When S needs to download application P, firstly, S broadcasts request packet to surrounding vehicles, including the data size of application $P(Bt_P)$ and the payment (C_s) S willing to pay. Secondly, upon receiving request packet, surrounding vehicle i calculates the total cost (C_i) according to Cooperative-game-theory-based Pricing Strategy (CPS) and compares C_i and C_s. If $C_i \geq C_s$, node i ignores the request; while if $C_i < C_s$, node i replies a request confirmation packet which contains the total cost (C_i), the bandwidth (B_i) provided to S for data relaying and hops (H_i) to the source node. Thirdly, among all the received request confirmation packets, node S uses Access Node Selection Algorithm (ANSA) to select the best node A as cooperator and fulfill the downloading task cooperatively. At last, S informs node A as the selected access node with the final payment C_A. Fig. 2 shows the whole process of CASM.

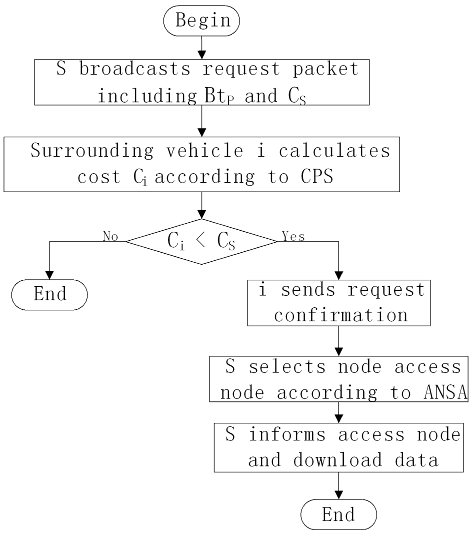

Fig. 2. Process of CASM

As Fig. 2 shows, in CASM, there are two main steps.

1) Surrounding vehicles determine the total cost of this cooperation according to the CPS.
2) Source node determines the cooperative access node using the ANSA.

We will analyze these two steps in detail.

B. Cooperative-game-based Pricing Strategy

The premise of our model is that vehicles are selfish but honest. In other words, when node i receives the request packet from node S, it has no reason to take the initiative to help access the Internet without remuneration. Meanwhile, it should not lowball the price in order to get the chance. Therefore, in this model, to stimulate the cooperation between vehicles, a suitable and fare pricing strategy is in urgent need. This pricing strategy can ensure both sides actively involved and satisfied. Based on this purpose, the cooperative game based Pricing Strategy is proposed. Table I shows the variables used in next analysis.

TABLE I
VARIABLES AND DEFINITIONS

Variable	Definition
P	Application type
Bt_P	Data size of application
C_i	Unit cost
$v(S_i)$	Coalition value
ϕ	Shapley value
B_i	bandwidth
H_i	Hops to source node
$Cost_i$	Payment of node i

As mentioned before, the communication pattern among vehicles is based on the cooperative game. Assume the model is a coalitional game involves a set of vehicular players, denoted by $\mathbb{N} = \{1, 2, ..., N\}$, who seek to form a cooperative group, to strengthen their positions in the game. And this coalition represents an agreement between the players in S to act as a single entity. In addition to the player set $\mathbb{N}$, the second fundamental concept of this coalitional game is the coalition value, denoted by v. In our model, the coalition value is calculated by

$$v(S_i) = -Bt_P \times C_i, \tag{1}$$

where Bt_P denotes the data size of application P, C_i denotes the unit cost of S_i.

After determining the coalition value of pricing model, as a solution concept, we introduce Shapley value [12]. Shapley value ϕ can assign a unique payoff allocation for any game $(\mathbb{N}, v)$. While, the Shapley value was essentially defined for transferable utility (TU) game. Refer to [13], we can demonstrate that our proposed pricing model is a TU case. So for our proposed TU game $(\mathbb{N}, v)$, for every player $n \in \mathbb{N}$, the Shapley value $\phi(v)$ assigns the payoff $\phi_n(v)$ given by

$$\phi_n(v) = \sum_{S \subseteq \mathbb{N} \setminus \{n\}} \frac{|S|!(N - |S| - 1)!}{N!} \left[v(S \cup \{n\}) - v(S) \right], \tag{2}$$

where $v(S \cup \{n\}) - v(S)$ is the marginal contribution of every player n in a coalition S. The weight that is used in front of $v(S \cup \{n\}) - v(S)$ is the probability that player n faces the coalition S when entering in a random order.

Assume in the coalition S there are already n players and n is the last one that enters S. The number of ways that positioning the players of S is $|S|!$. Before n enters S, the number was $(N-|S|-1)!$. Therefore, the probability of such an ordering occurs is $|S|!(N-|S|-1)!/N!$, if the probabilities of all orderings are the same. As a consequence, by solving the Shapley formula, $\phi_n(v)$ is the marginal contribution for forming the grand coalition S.

By using Shapley value, the payment can be calculated as below

$$Cost_i = Bt_P \times C_i + \phi_i(v), \tag{3}$$

where $Cost_i$ is the payment of node i, the payment that source node should pay for one cooperative data downloading.

C. Access Node Selection Algorithm

Upon receiving request packet, surrounding nodes calculate the total cost according to CPS. As mentioned before, only if the calculated cost is less than the payment of S, can they reply a request confirmation packet to S with its payment, provided bandwidth and the number of hops. Then S chooses the most qualified node as the access node. Next, we will analyze in which condition can a node be chosen as the access node.

Assume that source node has received n request confirmation packets from surrounding nodes. These packets all contain three parameters: B_i, H_i and $Cost_i$. When choosing the access node, S will take two aspects into consideration.

1) payment, i.e. $Cost_i$;

2) the data rate-cost ratio. In our research, the ratio can be given by

$$Ratio = \frac{B_i}{\lambda H_i Cost_i}, \quad (4)$$

where $\lambda \geq 1$, $B_i/\lambda H_i$ is the effective bandwidth, $1/\lambda$ is a decay rate.

In the aspect of access cost for S, payment is the lower, the better. In other words, source node hopes to reduce the cost of data downloading as lower as possible. While in the aspect of the rate-cost ratio, it is the higher, the better. That means the source node hopes to get higher data rate with the same price. Based on these two purposes, by solving the optimization problem below, S can finally choose the access node.

$$\begin{aligned} \min \quad & f_i = \alpha C_i + \beta \frac{1}{Ratio} \\ \text{s.t.} \quad & \alpha + \beta = 1 \\ & \lambda \geq 1 \\ & H_i \leq H_{max} \end{aligned} \quad (5)$$

In Eq (5), α and β respectively represent the percentages of evaluation metrics when selecting the access node and the sum of them equals 1. H_{max} is the upper limit of the number of hops between node S and node i.

Using the Access Node Selection Algorithm, source node S can select the most qualified node as the access node. This chosen access node can help S download data with lower payment, meanwhile, ensure data rate.

IV. Performance Evaluation

In this section, we compare the performance of proposed CASM with current VHO algorithm. For this purpose, MATLAB simulation tool is used. The simulation scenario is shown in Fig. 3. Our scenario models an urban road segment with 3500m in length and one lane in each direction. Two types of vehicles (in different color) are concerned, respectively belonged to two operators. So their unit costs of data downloading from cellular network are not the same. Two RSUs are deployed along the road. The unit costs of these two RSUs are also different.

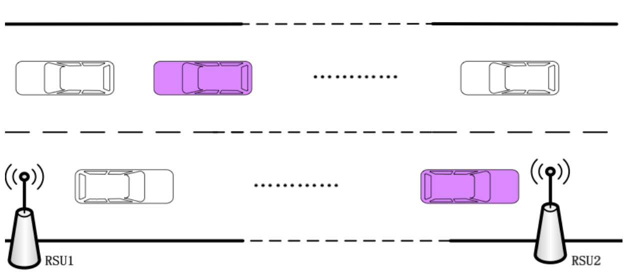

Fig. 3. The simulation scenario

In our simulation, the coverage area of a RSU is set to 500m and communication distance is set 500m. The average data rate of cellular network is 0.6Mbps and for WLAN, it is 6Mbps. A stream of Bt data bits is required to be transmitted. A complete list of the parameters used in our evaluation is given in Table II.

TABLE II
Parameters and Values in Simulation

Variable	Definition
CC1 (Unit cost of operator 1)	1 unit/Mb
CC2 (Unit cost of operator 2)	2 unit/Mb
CW1 (Unit cost of RSU1)	0.1 unit/Mb
CW2 (Unit cost of RSU2)	0.2 unit/Mb
W (coverange of a RSU)	500m
D (distance between two RSUs)	3000 m
R (transmission range of each vehicle)	500 m
ρ (average density of vehicles)	5-15 veh/km
Average speed	60 km/h
Bt (data size)	75 Mb
r_W (average data rate of WLAN)	6 Mbps
r_c (average data rate of cellular network)	0.6 Mbps
x-axis position of RSU1	250 m
x-axis position of RSU2	3250 m
H_{max}	4 hops
t (simulation time)	180 s

In our simulation model, the number of vehicles which belonged to service operator 1 and service operator 2 are equally. The data size that required to be downloaded is 75Mb. The source node broadcasts request packet every 20s. The results are the average value of 30 times simulations with the same parameters settings.

A. Performance of Access Node Selection Algorithm

In the Access Node Selection Algorithm, payment and rate-cost ratio are all taken into consideration. Next, the influence on the final results made by different percentages of cost parameter α and rate-cost ratio parameter β will be discussed.

Consider the source node is belonged to operator 1. Define the payment as the average value of 9 times downloading payments in 180s along the 3500m road.

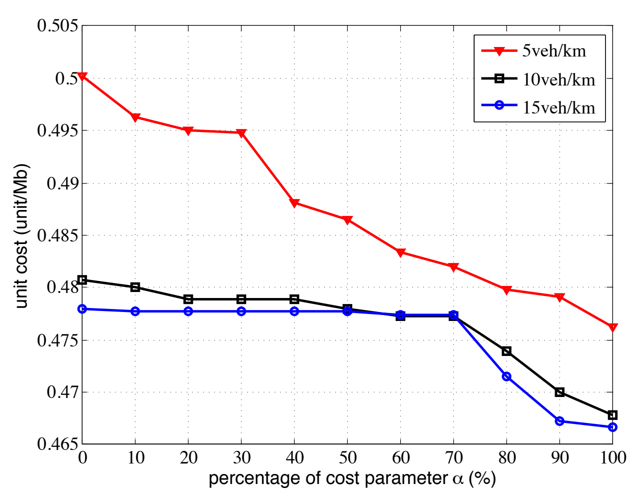

Fig. 4. Payment vs. Percentage of cost parameter α

Fig. 4 shows that the payment changes under different vehicle densities. It is shown that with the increase of percentage of

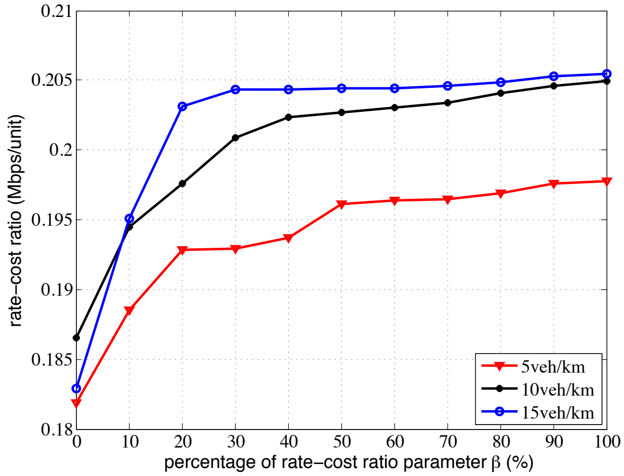

Fig. 5. Rate-cost ratio vs. Percentage of rate-cost ratio parameter β

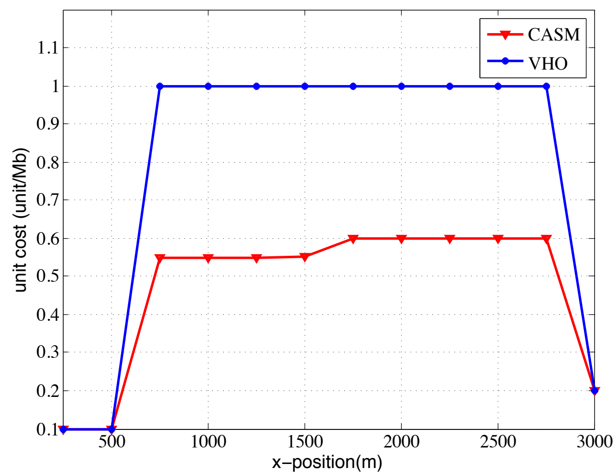

Fig. 6. Payment for CASM and VHO

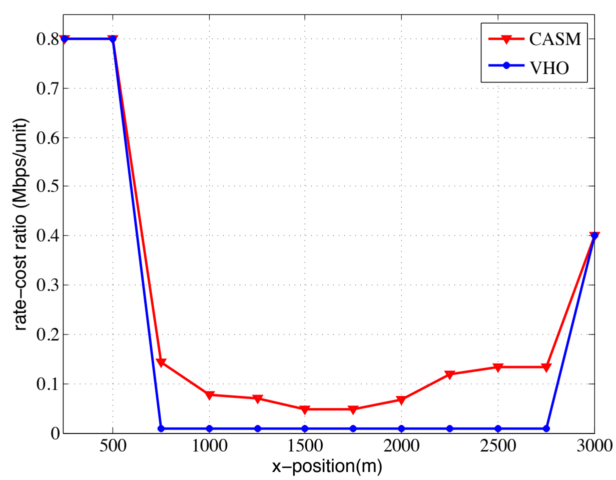

Fig. 7. Rate-cost ratio for CASM and VHO

cost parameter α , the payment decreases. Fig. 4 also indicates that the payments under 10veh/km and 15veh/km are almost the same. However, when the vehicle density is 5veh/km, the payments are higher than that under 10veh/km and 15veh/km.

Fig. 5 shows the average rate-cost ratio under different vehicle densities. As shown in Fig. 5, with the percentage of rate-cost ratio parameter β decreases, the average rate-cost ratio decreases. And when the vehicle density is 15veh/km, source node gains the highest rate-cost ratio. However, source node gains the lowest rate-cost ratio under 5veh/km. As the vehicle density increases, communications between vehicles are carried out more frequently.

Above simulation results prove that different percentages of payment parameter and rate-cost ratio parameter directly affect the selection of access node. When we pay more attention to the cost, the selected access node requires lower payment; conversely, if we concern more about the rate-cost ratio, source node can gain better performance.

B. Performance of CASM

In this section, we will compare the performance of CASM with the current vehicular access selection mechanism VHO. To reduce the impact of vehicle density, our scenario is under the density of 15veh/km with the percentage as $\alpha = \beta = 50\%$.

Fig. 6 shows the payments in the process of data downloading. When the source node is in the coverage of RSU, i.e. x-position is 250m, 500m and 3000m, these two mechanisms come to the same result. While out of the coverage of RSU, the source node pays less by using CASM.

Fig. 7 shows the changes of rate-cost ratio along the 3500m road. When the x-position is 250m,500m and 3000m, the source node is in the communication coverage of RSUs. The rate-cost ratio of these two mechanisms is the same. And at other times, as the source node is only in the coverage of cellular network, using proposed CASM can gain a higher rate-cost ratio.

In the coverage of RSUs, no matter source vehicles use which access mechanism, choosing to access Internet through WLAN can gain higher rate-cost ratio and pay less. However, when source nodes are out of the coverage of RSUs or not equipped with Wi-Fi interface, using CASM can reduce the cost of data downloading and ensure the rate-cost ratio.

Next, payments under different vehicle density of CASM and VHO are compared. As Fig. 8 shows, with the vehicle density increases, payments decrease. When the vehicle density is larger than 10veh/km, payments of CASM gradually become stable and smooth. For nodes using VHO, payments are not affected by vehicle density. Moreover, CASM can reduce about 40% payment than that of VHO.

Fig. 9 indicates that rate-cost ratio increase with vehicle density increase. Especially, when the density is beyond 10veh/km, changes of rate-cost ratio are not obvious. However, for VHO mechanism, vehicle density makes no impacts on

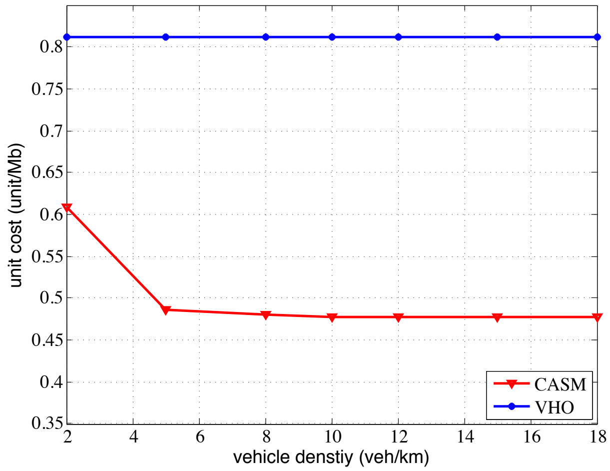

Fig. 8. Payment vs. vehicle density

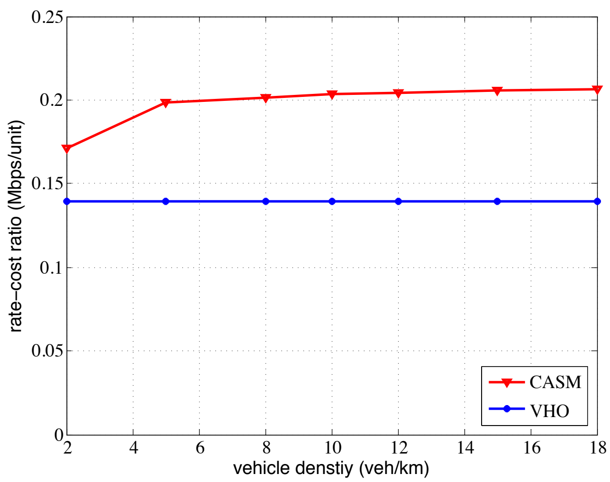

Fig. 9. Rate-cost ratio vs. vehicle density

rate-cost ratio. Furthermore, the rate-cost ratio of CASM is improved by about 48%.

In all, when the vehicle density is larger than 10veh/km, the performance of CASM is better in payment and rate-cost ratio. The reason is that the less the vehicle density is, the larger the spaces between two vehicle are. This limits the communications of vehicles. As the vehicle density increases to a certain extent, the impacts on communications will be reduced.

V. Conclusion

In this paper, we proposed an Cooperative-pricing-based Access Selection Mechanism to efficiently access the Internet in vehicular heterogeneous network. This access selection mechanism stimulates cooperation between vehicles by using Cooperative-game-based Pricing Strategy. Moreover, the source node chooses the optimal access node in terms of the payment with the combination of efficient bandwidth. By using Access Node Selection Algorithm, source nodes choose the access node which performs best in the aspect of payment and data-rate-cost ratio. Simulation results indicate that our proposed CASM reduces about 40% payment than the current VHO mechanism. Moreover, CASM can ensure the quality of service while reducing access costs when the source nodes are out of the coverage of RSUs.

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