

Multi-Object Optimization Based RV Selection Algorithm for VCN

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Abstract—Vehicular communication network (VCN) has recently received considerable attention both from academia and industry. In VCN, vehicles are expected to be capable of communicating with other vehicles as well as stationary infrastructures, i.e., the access points (APs) of wireless access networks. In the case that the direct connection between a source vehicle (SV) and APs is inaccessible, relay vehicles (RVs) can be applied for supporting multi-hop connection between SVs and APs. In this paper, a multi-object based RV selection algorithm for VCN is proposed, which jointly considers the characteristics of physical channel, link status between SVs and RVs, the bandwidth and delay characteristics of RVs and user service requirements. The utility functions of both SVs and RVs are modeled and a multi-object optimization problem is formulated. Applying ideal point method, the problem can be solved and the optimal SV-RV pairs can be obtained. Simulation results demonstrate that compared to previous algorithms, the proposed algorithm offers better performance in terms of user throughput, successful transmission rate and average transmission delay.

Index Terms—Multi-Object; Relay Selection; Utility Function; VCN

I. INTRODUCTION

Vehicular communication network (VCN) has recently received considerable attention both from academia and industry [1-3]. In VCN, three vehicular communication modes are expected to be supported, i.e., vehicle to vehicle (V2V) communication, vehicle to infrastructure (V2I) communication, and hybrid vehicular (HV) communication. Figure 1 shows an example of VCN model.

For both V2I and HV communications, the direct transmission link between a vehicle, referred to as source vehicle (SV) hereafter, and the access points (APs) of wireless access networks might become inaccessible due to the reasons such as the mobility of vehicles, the limited coverage area of APs and the fading characteristics of physical channels, resulting in the unavailability of communication services. To solve this problem, relay vehicles (RVs) which are capable of forwarding data packets between APs and SVs, can be applied. In the case that multiple candidate RVs are available, the problem of optimal RV selection has to be considered.

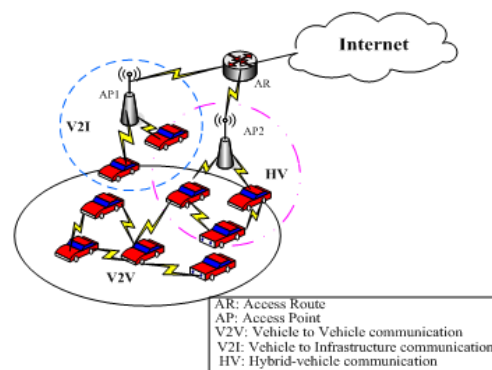


Figure 1. Vehicular communication network mode

In practical VCN scenario, a group of users, for instance, passengers in a bus, may seek to access RVs at almost the same time when the bus moves out of the coverage area of all adjacent APs. In this case, the problem that multiple SVs select RVs arises.

The problem of RV selection for VCN has been studied in previous literatures. While the signal strength of physical channel and the position and velocity information of vehicles are considered in previous works, a number of factors affecting transmission performance of SVs and RVs, such as channel propagation model, channel accessing scheme, available bandwidth of RVs, etc., have failed to be considered extensively. Furthermore, previous works only address the problem of RV selection for one SV, the extension to multiple SVs is still an open issue.

In this paper, we propose a RV selection method for multiple SVs in V2I and HV communication mode, which jointly considers the characteristics of physical link, channel accessing scheme, and the available bandwidth of RVs. The utility functions are modeled for both SVs and RVs and the optimal RV selection scheme which achieves the joint utility optimization of SVs and RVs is presented.

The rest of paper is organized as follows. The related works are discussed in Section II and the system model is described in Section III. The proposed scheme is presented in Section IV. The ideal point method is applied to solve the formulated optimization problem in Section V. Numerical results are given in Section VI. Finally, we conclude the paper in Section VII.

II. RELATED WORKS

In recent years, various relay selection algorithms have been proposed for VCN [4-12]. These algorithms can be classified into three categories, i.e., single attribute based RV selection algorithm, multi-attribute based RV selection algorithm and opportunistic RV selection algorithm.

A. Single Attribute Based RV Selection Algorithms

Single attribute based RV selection algorithms choose one metric as the only selection criterion, and select the candidate relay with the metric being the largest/smallest. For instance, the metric of link quality is chosen as the metric for RV selection in [4] and [5]. More specifically, instantaneous link quality (ILQ) is stressed and a relay selection method which selects the candidate RV with the best ILQ is proposed in [4]. To avoid the drawback of excessive signaling overhead resulted from link quality measurement, [5] proposes an average link quality (ALQ) based relay selection algorithm, which offers the highest throughput at the destination.

B. Multi-Attribute Based RV Selection Algorithm

While the effect of link quality is taken into account in relay selection, many other factors which may also affect the performance of relay selection failed to be considered in [4] and [5]. Multi-attribute based RV selection algorithms jointly consider the factors affecting data forwarding from the relays in designing relay selection criterions.

In [6], the authors propose a cross-layer RV selection algorithm for VCNs. A cost function is defined based on multiple factors, such as the geographic location and velocity of candidate relays, and physical layer channel conditions, the candidate relay with the largest cost is chosen as the target relay. A cross-layer mobile relay selection scheme is proposed in [7] which jointly considers the factors including the status of the links, the bandwidth and delay features of the candidate relays, and the quality of service (QoS) requirements of users. A simple additive weighting (SAW) method is applied to evaluate the performance of the candidate relays and the one with the best weighted value is chosen as the target relay.

To stress the dead spot and out of coverage problem in VCN, a multi-hop relay selection scheme is proposed based on three metrics, i.e., the received signal strength (RSS) from UMTS, route life time (RLT) and available relay capacity to extend the coverage area and decrease the number of handoff in [8]. In [9], physical layer channel condition characterized by signal-to-noise ratio (SNR), geographical locations and velocities of vehicles are jointly taken into account for optimal RV selection.

C. Opportunistic RV Selection Algorithm

Unlike single attribute and multi-attribute based RV selection algorithms, in which a deterministic relay is selected, opportunistic RV selection algorithm assigns various priorities to candidate relays according to certain selection criterion, and the candidate relay with high priority has high probability of being selected as the

target relay. A robust distance-based relay selection scheme for multi-hop broadcast of emergency notification messages is proposed in [10] and the candidate node with longer directional distance to the sender is of higher probability for being selected as the target relay. In [11], the authors propose a novel opportunistic relay protocol for VCN which exploits multiuser diversity and effectively copes with the dynamic fading channel. The relay candidate that has the highest average channel quality is given the highest priority of accessing the channel and becoming the target relay. The authors in [12] propose an ExOR scheme in which the source node sends a possible relay list in the header, and the potential relays having received the message send back an ACK message, based on which the source node can then select the best relay.

While some relay selection algorithms have been proposed for VCN, the factors of affecting the performance of RV selection and data forwarding have not been considered extensively. Furthermore, most research works consider selecting one RV for one SV, however, in some particular application scenarios, multiple RVs may need to be selected for multiple SVs. In this paper, a RV selection method for multiple SVs is proposed for VCN, the utility functions of both SVs and RVs are defined based on the factors including the characteristics of physical link, channel accessing scheme, and available bandwidth of RVs, etc., and the multi-objective optimization problem is solved to obtain the optimal RV selection strategy.

III. SYSTEM MODEL

In this section, the network scenario and channel model considered in this paper are described.

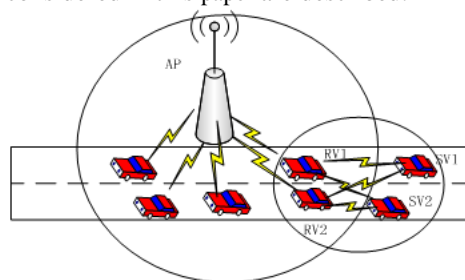


Figure 2. Network model

A. Network Scenario

In this paper, we consider a road segment of which one AP is deployed. Vehicles within the coverage area of the AP are allowed to communicate with the AP directly. Those SVs which are out of the coverage area of the AP have to seek the help from adjacent RVs for data forwarding between the SVs and the AP. In this paper, we focus on the scenario that multiple SVs need to select multiple RVs for data forwarding. Considering the infeasibility and low transmission efficiency that may be resulted from one RV forwarding data for multiple SVs, we assume that each RV can only accept the relay request from one SV and each SV can only choose one RV for data forwarding.

Figure 2 shows an example of network model considered in this paper, which consists of one AP, multiple RVs and multiple SVs. As SV1 and SV2 are out of the coverage area of the AP, they need to choose RV1 or RV2 for accessing the AP.

B. Channel Model

It has been shown that Nakagami fading channel can be applied to model the communication channel between SVs and RVs, and that between RVs and APs [13, 14]. Specifically, the communication channel between a RV and an AP can be modeled as Nakagami fading channel with the channel characteristics h_1 following the probability distribution function (pdf):

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

where m represents the Nakagami fading parameter ($m \geq 1/2$), $\Gamma(\cdot)$ denotes the Gamma function [15], d denotes the transmission distance, $\Omega(d)$ denotes the power loss due to transmission distance d , and can be expressed as:

$$\Omega(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{L} d^{-\theta} \quad (2)$$

where, P_t is the transmission power, G_t and G_r are the antenna gains of the transmitter and receiver, respectively, h_t and h_r are the antenna heights of the transmitter and receiver, respectively, θ is the path loss exponent, and L is the system loss.

The channel between a SV and a RV can be modeled as a cascaded Nakagami fading channel with the number of cascade being 2 and the channel pdf as follows:

$$f(h_2) = \frac{2}{h_2 \Gamma(m_1) \Gamma(m_2)} G_{0,2}^{2,0} \left[\frac{m_1 m_2 h_2^2}{\Omega_1 \Omega_2} \middle|_{m_1, m_2} \right] \quad (3)$$

where $G_{0,2}^{2,0}(\cdot|\cdot)$ denotes Meijer G-function, $\Omega_l = E[h_l^2]$ and $m_l = \Omega_l^2 / E(h_l - \Omega_l)^2 \geq 1/2$, $l=1,2$.

IV. PROPOSED RV SELECTION ALGORITHM

A. Basic Idea

In this paper, we consider the application scenario that multiple SVs of which the direct links to APs are inaccessible need to select optimal RVs. For these SVs, data forwarding through RVs provides an efficient manner for performing communication, thus certain data transmission revenue can be obtained. On the other hand, to receive forwarding services from RVs, SVs need to pay a certain amount of service fees to the corresponding RVs. To choose different RVs for data forwarding, one SV may receive different revenue and undertake different forwarding costs as well. Therefore, each SV tends to choose the optimal RV from which relatively high revenue can be obtained while low cost is required.

The candidate RVs, which are qualified to forward data for SVs, may choose to accept or reject the

forwarding requests from the SVs. On one hand, through offering data forwarding for the SVs, the RVs are capable of receiving a certain amount of data forwarding fees, on the other hand, the RVs have to undertake certain data forwarding costs, for instance, some bandwidth and transmission power have to be consumed. As choosing different SVs for offering data relaying, different revenue and costs might be resulted, the RVs tend to select the optimal SV from which the high forwarding revenue can be obtained while a little cost is required.

As data forwarding revenues and costs are both complicated quantities associated with multiple factors, the exact mathematical modeling is prohibited. In this paper, the concept of utility function [16] is introduced to characterize the revenue and costs of RV selection for both SVs and RVs, and the problem of utility optimization for both SVs and RVs is formulated.

B. Utility Function Modeling of SVs

Assuming the i th SV selects the j th RV for data forwarding, the utility function of the SV can be modeled as follows:

$$U_{ij}^S = W_{ij}^S - C_{ij}^S, 1 \leq i \leq M, 1 \leq j \leq N \quad (4)$$

where W_{ij}^S denotes the revenue the i th SV receives through applying the forwarding scheme from the j th RV. It can be expected that the better data forwarding performance, the higher revenue the SVs can receive. Hence, W_{ij}^S can be formulated as a function of the transmission rate and the availability of the link between the i th SV and the j th RV, the access probability to the j th RV and the available bandwidth of the RV, i.e.,

$$W_{ij}^S = \begin{cases} F_{ij} \alpha_i R_{ij} (1 - P_{ij}^C), & RET_{ij} \geq T_{ij} \\ F_{ij} \alpha_i R_{ij} (1 - P_{ij}^C) \frac{RET_{ij}}{T_{ij}}, & RET_{ij} < T_{ij} \end{cases} \quad (5)$$

where F_{ij} denotes the available bandwidth index of the j th RV, and can be expressed as:

$$F_{ij} = \begin{cases} 1, & B_j^a \geq B_i^r \\ 0, & B_j^a < B_i^r \end{cases} \quad (6)$$

where B_j^a and B_i^r denote the available bandwidth of the j th RV and the required bandwidth of the i th SV, respectively. The available bandwidth of the j th RV can be calculated as [17]:

$$B_j^a = \frac{k \times S_B \times 8}{T} \quad (7)$$

where, k denotes the number of packets sent and received by the vehicle within time period T , S_B denotes the size of packets in byte.

α_i in (5) denotes the unit rate revenue factor of the i th SV, R_{ij} represents the data rate of the link between the i th SV and the j th RV and can be expressed as:

$$R_{ij} = B_j^a \log(1 + \psi_{ij}) \quad (8)$$

where ψ_{ij} denotes the average SNR of the link, which can be expressed as:

$$\psi_{ij} = \frac{E_s}{N_0} E[h_{ij}^2] \quad (9)$$

where h_{ij} denotes the channel gain from the i th SV to the j th RV, E_s denotes the average energy of the transmitted symbol and N_0 is the single-sided power spectral density of additive white Gaussian noise (AWGN).

P_j^C in (5) denotes the probability of collision when multiple SVs/RVs choose to access the j th RV simultaneously, and can be expressed as [18]:

$$P_j^C = \tau[1 - (1 - \tau)^{m_j - 1}] \quad (10)$$

where m_j is the number of adjacent vehicles of the j th RV, τ is the message transmission probability of each vehicle in the considered slot time, and can be calculated by jointly solving the following nonlinear equations:

$$\tau = \frac{2(1 - 2p)}{(1 - 2p)(CW_{\min} + 1) + pCW_{\min}(1 - (2p)^m)} \quad (11)$$

and

$$p = 1 - (1 - \tau)^{m_j - 1} \quad (12)$$

where m is the maximum number of retransmissions and CW_{\min} denotes the minimum contention window.

RET_{ij} in (5) denotes the link duration between the i th SV and the j th RV, and can be calculated as follows. Assuming that the coordinates of the i th SV and the j th RV are (x_i^S, y_i^S, z_i^S) , (x_j^R, y_j^R, z_j^R) , respectively, r_j denotes the maximum transmission range of the j th vehicle, d_{ij} denotes the distance between the i th SV and the j th RV, v_i^S, v_j^R denote the velocity of the i th SV and the j th RV, θ_i^S denotes the angle between the connection line of the i th SV and the j th RV, and the moving direction of the i th SV, θ_j^R denotes the angle between the connection line of the j th RV and the i th SV, and the moving direction of the j th RV. It can be proved that RET_{ij} can be expressed as:

$$RET_{ij} = \frac{-(ab + ce) + \sqrt{(a^2 + c^2)r_j^2 - (ae - bc)^2}}{a^2 + c^2} \quad (13)$$

where $a = v_j^R \cos \theta_j^R - v_i^S \cos \theta_i^S$, $b = y_j^R - y_i^S$, $e = x_j^R - x_i^S$, $c = v_j^R \sin \theta_j^R - v_i^S \sin \theta_i^S$.

T_{ij} in (5) denotes the required transmission time from the i th SV to the AP via the j th RV and can be expressed as:

$$T_{ij} = 2T_{OH} + \frac{S_{PL} + S_{MAC}}{R_{ij}} + \frac{S_{PL} + S_{MAC}}{R_{jA}} + T_{SIFS} + T_{BO} \quad (14)$$

where $T_{OH} = T_{DIFS} + 3T_{SIFS} + T_{RTS} + T_{CTS} + T_{ACK} + 2T_{PLCP}$, T_{DIFS} and T_{SIFS} are respectively, the duration of distributed inter-frame space and short inter-frame space defined in IEEE 802.11 [19], T_{PLCP} denotes the duration of physical layer convergence procedure, T_{RTS} denotes the duration of an RTS frame, T_{CTS} denotes the duration of a

CTS frame, and T_{ACK} denotes the duration of an acknowledgement frame, S_{PL} and S_{MAC} denote the size of an MAC payload and an MAC header, respectively, R_{jA} represent the data transmission rate of the link between the j th RV and the AP, T_{BO} denotes the average backoff time.

In (4), C_{ij}^S denotes the cost the i th SV has to undertake for seeking for data forwarding from the j th RV, and can be modeled as the service fee that the SV has to afford. In this paper, we assume that the service fee of the SV is charged based on the bandwidth resource it spends, and can be calculated as the product of the amount of user bandwidth and unit service fee, i.e.,

$$C_{ij}^S = \beta_j F_{ij} B_i^r \quad (15)$$

where β_j denotes the unit bandwidth price factor for data forwarding of the j th RV.

C. Utility Function Modeling of RVs

Assuming the j th RV offers data forwarding service for the i th SV, the utility function of the j th RV can be expressed as follows:

$$U_{ij}^R = W_{ij}^R - C_{ij}^R, 1 \leq i \leq M, 1 \leq j \leq N \quad (16)$$

where W_{ij}^R represents the revenue received by the j th RV through offering data forwarding service to the i th SV. Assuming that the revenue a RV received is proportional to the bandwidth resource it offers, furthermore, for higher probability of successful transmission, better data forwarding performance can be obtained, thus higher revenue can be received. Hence, W_{ij}^R can be modeled as:

$$W_{R_{i,j}} = F_{ij} P_{ij}^S \beta_j B_i^r \quad (17)$$

In (16), C_{ij}^R denotes the data forwarding cost the j th RV undertakes when forwarding data for the i th SV. In this paper, we apply Sigmoid function which was originally introduced in Machine Learning theory [16] for quantifying the cost the RV undertakes. C_{ij}^R can be modeled as:

$$C_{ij}^R = \frac{c_j F_{ij}}{1 + e^{\theta_j (\varphi_j - P_{jAP}^S P_{ij}^S B_i^r)}} \quad (18)$$

where θ_j , φ_j are both parameters characterizing the steepness and the inflection point of the cost curve of the j th RV, c_j denotes the unit cost factor of the j th RV, P_{ij}^S denotes the successful transmission probability of the link between the i th SV and the j th RV, similarly, P_{jAP}^S denotes the successful transmission probability of the link between the j th RV and the AP. The successful transmission probability can be evaluated as the probability that the SNR at the receiving node is larger than a given threshold. According to the channel model defined in Section III, P_{ij}^S and P_{jAP}^S can be calculated respectively as follows:

$$P_{jAP}^S = \Pr\left(\frac{E_s}{N_0} h_{jAP}^2 > \psi_{th1}\right) = 1 - \frac{\gamma(m, \frac{mN_0}{\Omega E_s} \psi_{th1})}{\Gamma(m)} \quad (19)$$

$$P_{ij}^S = \Pr\left(\frac{E_s}{N_0} h_{ij}^2 > \psi_{th2}\right) = 1 - \frac{G_{1,3}^{2,1}\left[\frac{m_1 m_2 N_0 \psi_{th2}}{\Omega_1 \Omega_2 E_s} \middle|_{m_1, m_2, 0}\right]}{\Gamma(m_1) \Gamma(m_2)} \quad (20)$$

where h_{jAP} denote the channel gain from the j th RV to the AP, ψ_{th1} and ψ_{th2} denote the given SNR thresholds and γ represents incomplete Gamma function.

D. Optimization Problem Modeling

As it is assumed that one SV can only select one RV for forwarding data, the SV evaluates the utility function resulted from choosing various RVs and tends to select the one corresponding to the maximal utility. Similarly, assuming each candidate RV can only forward data for one SV or choose no SV for data forwarding, the RV evaluates the utility function resulted from choosing various SVs for data forwarding and tends to select the SV leading to the maximal utility. Therefore, the optimal RV selection problem can be modeled as a multi-object optimization problem:

$$\begin{aligned} \max \quad & U_i^S = \sum_{j=1}^N x_{i,j} U_{ij}^S, \quad i = 1, 2, \dots, M \\ \max \quad & U_j^R = \sum_{i=1}^M x_{i,j} U_{ij}^R, \quad j = 1, 2, \dots, N \\ \text{s.t.} \quad & x_{i,j} \in \{0, 1\}, \sum_{i=1}^M x_{i,j} \leq 1, \sum_{j=1}^N x_{i,j} \leq 1. \end{aligned} \quad (21)$$

where M and N denote, respectively the number of SVs and RVs.

V. IDEAL POINT METHOD BASED OPTIMIZATION SOLUTION

The problem formulated in (21) is a multi-object optimization problem, the optimal solution of which is in general difficult to obtain. In this section, the ideal point method [20] is applied to solve the optimization problem.

The basic idea of ideal point method is that for each objective function, the optimal solution, referred to as ideal solutions can be obtained independently without considering the joint constraints and the feasibility of the solutions, then the joint solutions subject to given constraints can be calculated by minimizing the distance between the feasible solutions and the ideal solutions.

Collection all the objective functions formulated in (21), we define:

$$f_i(X) = \sum_{j=1}^N x_{i,j} U_{ij}^S, \quad i = 1, 2, \dots, M \quad (22)$$

$$f_{M+j}(X) = \sum_{i=1}^M x_{i,j} U_{ij}^R, \quad j = 1, 2, \dots, N \quad (23)$$

Denoting the optimal solution to each objective problem by x_l^* , $l = 1, 2, \dots, M+N$, and assuming x_l^* exists in the range of D :

$$D = \left\{ x_{i,j} \in \{0, 1\}, \sum_{i=1}^M x_{i,j} \leq 1, \sum_{j=1}^N x_{i,j} \leq 1, 1 \leq i \leq M, 1 \leq j \leq N \right\} \quad (24)$$

The corresponding objective functions can be expressed as:

$$f_l^* = f_l(x_l^*) = \max_{x \in D} f_l(x), l = 1, 2, \dots, M+N \quad (25)$$

Rewriting (22) and (23) in vector form, we obtain:

$$F(x) = (f_1(x), f_2(x), \dots, f_{M+N}(x))^T \quad (26)$$

Define $F^*(x) = (f_1^*(x), f_2^*(x), \dots, f_{M+N}^*(x))^T$ as the ideal point in the space R^{M+N} of the vector objective function $F(x)$, then

(1) If $x_1^* = x_2^* = \dots = x_{M+N}^*$, that is, $f_l(x_l^*) \geq f_l(x)$, for $l = 1, 2, \dots, M+N$, then x_l^* is the optimal solution of the optimization problem.

(2) In the case that $x_1^*, x_2^*, \dots, x_{M+N}^*$ are not equal, namely, the ideal point is infeasible in the set D , the optimal solution can be obtained by evaluating the distance between the ideal solutions and the feasible solutions, and choosing the solution corresponding to the minimal distance. To examine the distance between the solutions, we define the p th order norm in the objective space R^{M+N} as:

$$u(F) = \|F - F^*\|_p = \left[\sum_{l=1}^{M+N} (f_l - f_l^*)^p \right]^{\frac{1}{p}}, 1 \leq p \leq \infty \quad (27)$$

The original multi-objective optimization problem can be converted into a single object optimization problem:

$$\min_{x \in D} u(F) = \min_{x \in D} \left[\sum_{l=1}^{M+N} (f_l(x) - f_l^*)^p \right]^{\frac{1}{p}} \quad (28)$$

which can then be solved to obtain the optimal solution of the original optimization problem.

VI. NUMERICAL RESULTS

In this section, the performance of the proposed RV selection algorithm is examined and compared with previous algorithms, including the algorithms proposed in [8] and [9]. In the simulation, we consider a straight road of 1Km with one AP being deployed in the middle of the road. A number of vehicles are randomly located and move along the road with the velocity randomly chosen from 80Km/h to 120Km/h. The number of total vehicles varies from 20 to 60, with the numbers of SVs and RVs being equal. The detailed parameters used in the simulation are summarized in Table I.

Figure 3 shows the throughput of all the vehicles versus the number of vehicles. It can be seen that for all the three algorithms, the total throughput increases with the increase of the number of vehicles. This is because the connectivity of the network improves accordingly. Comparing the total throughput resulted from three algorithms, it can be seen that the proposed scheme outperforms the algorithms proposed in [8] and [9]. The reason is that the proposed algorithm takes into account

both available bandwidth of RVs and the link quality between SVs and RVs in selecting the optimal RV.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Simulation area	1KM
Number of AP	1
Position of AP	500m
Height of AP	20m
Transmission range of AP	300m
Number of vehicles	20-60
Transmission range of vehicles	200m
Velocities of vehicles	80-120Km/h
Packet length	1000bits
Size of control messages	60 units

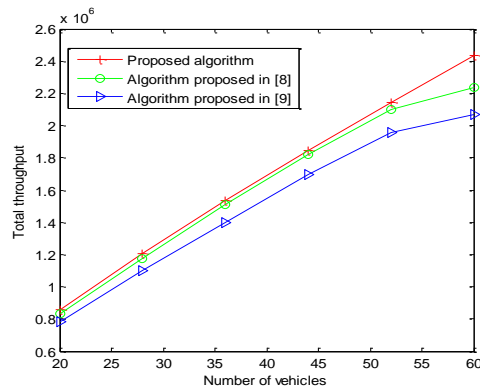


Figure 3. Overall throughput

Figure 4 plots the average transmission delay of various algorithms versus the number of vehicles. It can be seen from the figure that for all the three algorithms, as the number of vehicles increases, the average transmission delay increases, this is mainly because the collision probability increases resulting in large channel accessing time. Comparing the average transmission delay resulted from three algorithms, it can be seen that the proposed algorithm offers much lower transmission delay compared to the other two algorithms. The reason is that the factors affecting transmission delay, i.e., packet collision and data transmission rate are both considered in the proposed algorithm.

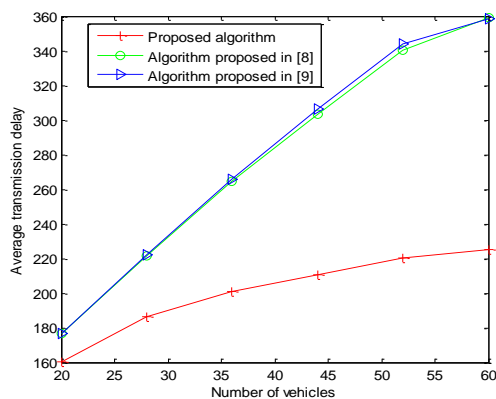


Figure 4. Average transmission delay

Figure 5 shows the successful transmission rate versus the numbers of vehicles obtained from various algorithms.

It can be seen from the figure that the successful transmission probability increases first and then decreases. This is mainly because when the number of vehicles is small, the connectivity of the vehicles may be limited, thus resulting in low probability of successful transmission. When the number of vehicles increases, the connectivity of the vehicles improves, resulting in larger probability of successful transmission. However, on the other hand, the probability of collision increases with the increase of the number of vehicles. As the effects of data collision dominates the performance of data transmission for a large number of vehicles, thus resulting in the decrease of successful transmission probability. It can also be seen from the figure that the proposed algorithm offers higher successful transmission rate compared to two other algorithms. That is because the factors affecting successful transmission including physical channel characteristics, access collision and the bandwidth of candidate RVs are taken into account in the proposed algorithm, whereas two other algorithms fail to consider extensively.

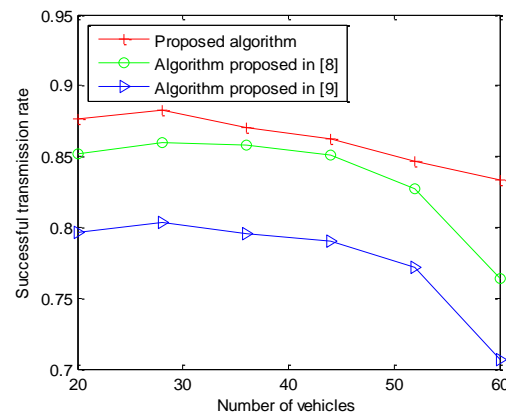


Figure 5. Successful transmission rate

VII. CONCLUSION

In this paper, a multi-object utility optimization based RV selection algorithm is proposed for VCN. The utility functions of both SVs and RVs are modeled respectively by choosing the metrics, i.e., available RV bandwidth, collision probability, packet successfully received probability, link capacity and stability, and different utility functions are designed for SVs and RVs. To maximize the utility of each SVs and RVs, a multi-object optimization problem is formulated and solved based on ideal point method. Numerical results demonstrate that compared to previous algorithms, the proposed algorithm offers better performance in terms of throughput, transmission delay and successful transmission rate.

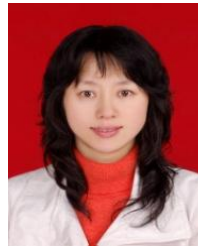
ACKNOWLEDGMENT

This work was supported by National Natural Science Foundation of China (61102063), National Science and Technology Specific Project of China (2011ZX03005-004-02), the special fund of Chongqing key laboratory (CSTC) and the project of Chongqing Municipal Education Commission (Kjzh11206). The authors would

like to thank Dr. Niki Pissinou and the reviewers for their valuable comments.

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