Towards Efficient Data Services in Vehicular Networks via Cooperative Infrastructure-to-Vehicle and Vehicle-to-Vehicle Communications

[*]Byungjin Ko, [†]Kai Liu, and [*]Sang H. Son
[*]Department of Information and Communication Engineering, DGIST, Daegu, Korea
Email: {byungjin.ko, son}@dgist.ac.kr
[†]College of Computer Science, Chongqing University, Chongqing, China
Email: liukai0807@gmail.com

***Abstract*—This paper investigates information services in vehicular networks via cooperative infrastructure-to-vehicle (I2V) and vehicle-to-vehicle (V2V) communications. In particular, we consider the cooperation among multiple roadside units (RSUs) in a bidirectional roadway scenario in providing data services. The primary objective is to best explore the channel efficiency for I2V/V2V communications to maximize the system performance. Specifically, we formulate the problem and propose a Maximum Service (MS) algorithm which combines the following three approaches. First, a hybrid I2V/V2V data dissemination scheduling policy is proposed to enable data services in the RSU's coverage. Second, a cooperative V2V data sharing mechanism out of the RSUs' coverage is proposed by assigning server-vehicles (SVs) to offload RSUs' workload. Third, a data dissemination policy for SVs is proposed to further enhance overall system performance. Finally, we build the simulation model and give a comprehensive performance evaluation to demonstrate the superiority of the proposed solution.**

Keywords—Data dissemination; scheduling algorithm, cooperative communications, vehicular networks

I. INTRODUCTION

Efficient data dissemination is one of the most critical issues in vehicular networks to enable a variety of emerging intelligent transportation systems and enhance system performance on vehicle safety, transportation efficiency, passenger comfortableness, etc. [1]. Dedicated short range communication (DSRC) is one of the most promising wireless communication technologies dedicated to enabling the applications via both infrastructure-to-vehicle (I2V) and vehicle-to-vehicle (V2V) communications. To this end, roadside units (RSUs) need to be installed along the road and on-board units (OBUs) need to be mounted on vehicles.

Data services have been extensively studied in vehicular networks. Diverse medium access control (MAC) protocols for vehicular networks have been proposed to minimize wireless communication interference and reduce the packet loss rate [2, 3]. To provide the delay tolerant services, different routing protocols based on the carry-and-forward method have been studied in [4-6]. The scheduling algorithms at the application layer have been investigated for coordinating I2V and V2V data services [7] and balancing workloads among multiple RSUs [8]. Nevertheless, none of existing work considered the problem of providing efficient data services via the hybrid of I2V and V2V communications and the cooperation of multiple RSUs in a bidirectional road scenario.

In this work, we present an efficient data dissemination system, which provides location based services such as parking, gas station, traffic information services, etc., via the hybrid of I2V and V2V communications. The primary objectives are to improve channel efficiency and enhance overall system performance in terms of both increasing the service ratio and decreasing the service delay. To this end, we propose to designate proper vehicles to assist data services so that they are able to serve the requests with their cached data items via V2V communication within RSU's coverage. Moreover, in order to further alleviate the RSU's workloads and improve the V2V channel efficiency, we also consider the service out of the RSU's coverage via V2V communication. Specifically, the RSU cooperates with its neighboring RSUs by transferring the unserved requests so that other RSUs may designate proper vehicles to broadcast their cached contents to serve vehicles driving in the opposite direction when they are meeting with each other via V2V communication. It not only alleviates the service workload of RSUs, but also enhances the channel efficiency of V2V communication. These vehicles are selected based on vehicles' service status and cached contents, which are called server-vehicles (SVs).

The main contributions of this work are outlined as follows. First, we present a multi-RSU cooperated data service system where the hybrid of I2V and V2V communications is exploited to enhance the data service performance. Second, we propose a solution which combines the following three approaches: a hybrid data dissemination scheduling policy in the RSU's coverage, a SV designation mechanism for data services out of RSUs' coverage, and a mechanism of scheduling data items at the RSU for SVs. Third, we build the simulation model and give a comprehensive performance evaluation to demonstrate the superiority of the proposed solution.

The rest of this paper is organized as follows. Related works are reviewed in Section II. Section III illustrates the system model. The solution is proposed in Section IV. In Section V, we build the simulation model and give the performance evaluation. Finally, we conclude the paper and discuss future work in Section VI.

II. Related works

Diverse medium access control (MAC) protocols for vehicular ad-hoc networks (VANETs) have been proposed in literature [2, 3]. To improve the reliability of transmission and quality of service (QoS) for safety and non-safety applications, F. Yang et al. [2] proposed a multi-channel cooperative clustering-based MAC protocol. F. Peng et al. [3] investigated a time division multiple access (TDMA)-MAC protocol for VANETs to reduce packet latency and packet loss rate. These previous works can decrease the packet loss rate. However, they do not cover the data scheduling issue regarding the location based services in vehicular networks.

Routing protocols using the carry-and-forward method were proposed to provide the delay tolerant services in [4-6]. F. Malandrino et al. [4] proposed to use a time-expanded graph to find the optimal routing of data from internet-based servers to a downloader vehicle. The data item is transmitted from a roadside access point (AP) to the vehicle directly or through the carry-and-forward method. O. Trullo-Cruces et al. [5] investigated the method to complement a roadside AP based data service through V2V communication so as to augment the download process. M. Sardari et al. [6] proposed an efficient way to achieve reliable dissemination to vehicles by using *rateless* coding at RSU and using the vehicles as data carriers. These previous works mainly considered routing problems via V2V communication. Unlike the above studies, this work investigates how to efficiently exploit I2V and V2V communications with the purpose of improving channel efficiency and offloading workloads at RSUs.

The scheduling algorithms at the application layer have been investigated in [7, 8]. K. Liu et al. [7] investigated the data dissemination via the hybrid of I2V and V2V communications to improve the bandwidth efficiency of RSUs. The work considered the scalability, fairness, and robustness of data dissemination in vehicular networks. A scheduling algorithm called SFR is proposed to best exploit the joint effects of I2V and V2V communications by transforming the data scheduling problem to the maximum weighted independent set (MWIS) problem and solving MWIS using a greedy method. In order to balance workloads among multiple RSUs in I2V based service, [8] proposed to transfer the delay tolerant requests to the next RSU where the vehicle is heading. They considered request delay tolerance, current load of the transferee RSU, and the vehicle's driving direction while transferring the requests. Nevertheless, the above works did not consider particular issues of V2V data sharing in bidirectional traffic scenarios.

The data dissemination in bidirectional traffic scenario has been studied in literatures [9-12]. P. Fan et al. [9] analyzed packet reachability in end-to-end (E2E) and store-carry-forward (SCF) connections. In [10], an inter vehicle ad-hoc routing metric, which is called EFD (expected forwarding delay), was proposed based on the traffic densities and velocities. For disconnection between two co-directional clusters, the opposite directional clusters are exploited as a bridge for a message propagation in order to reduce the delay. Y. Liu et al. [11] investigated the insights of message delivery delay towards message delivery distance and density of vehicles based on a bidirectional vehicle traffic model. J. Wang et al. [12] proposed a cluster-based algorithm to implement efficient data sharing. They designed a policy of time slot division to assign the clusters with specific slots. Unlike the above studies, this work proposes the SV designation policy through the cooperation among multiple RSUs to enhance the chance of data services out of RSUs' coverage.

III. Data dissemination system

The data dissemination system in a multiple-RSU environment is shown in Fig. 1. RSUs are interconnected through a wired backbone network so that they can share information and cooperatively provide data services [13]. The OBU is mounted on every vehicle to enable both I2V and V2V communications. The dotted circle indicates RSU's service coverage, namely, vehicles are able to communicate with the RSU via I2V communication. The non-shadowed block represents the requested data item of vehicles. The shadowed block represents the cached data item of vehicles. The dashed bidirectional arrow represents that the two vehicles are within their V2V communication range. The solid arrow with the identifier of data item shows the data dissemination via I2V or V2V communication.

In this system, the data service method is divided into two schemes depending on the vehicle's location. One is cooperative I2V and V2V communications within RSU's coverage. The other is a pure V2V communication out of RSU's coverage. In accordance to DSRC, five channels are involved in the system, including one control channel (CCH) and four service channels (SCHs). The CCH is used to transmit basic safety messages (BSMs), control messages, and auxiliary information for designating proper sender vehicles. Two SCHs are respectively used for I2V and V2V communications in the RSU's coverage, and the other two SCHs are respectively used for SVs driving in opposite directions out of the RSU's coverage. In order to provide data services efficiently through these SCHs, the system follows the following two schemes.

Scheme 1: to serve the requests via the hybrid of I2V and V2V communications in the RSUs' coverage, DSRC devices operate the following four phases periodically.

- In the first phase, vehicles broadcast the BSM messages through CCH, so that each vehicle can identify a list of its neighbors, to which it can transmit-receive data items via V2V communication.
- In the second phase, the vehicles transmit a probe vehicle data (PVD) message [14], including the lists of neighboring vehicles, cached data items, and requested data items to the RSU. The message is transmitted through CCH via V2I communication, and each request corresponds to one data item in the database. The pending requests are pended in the service queue at the RSU.

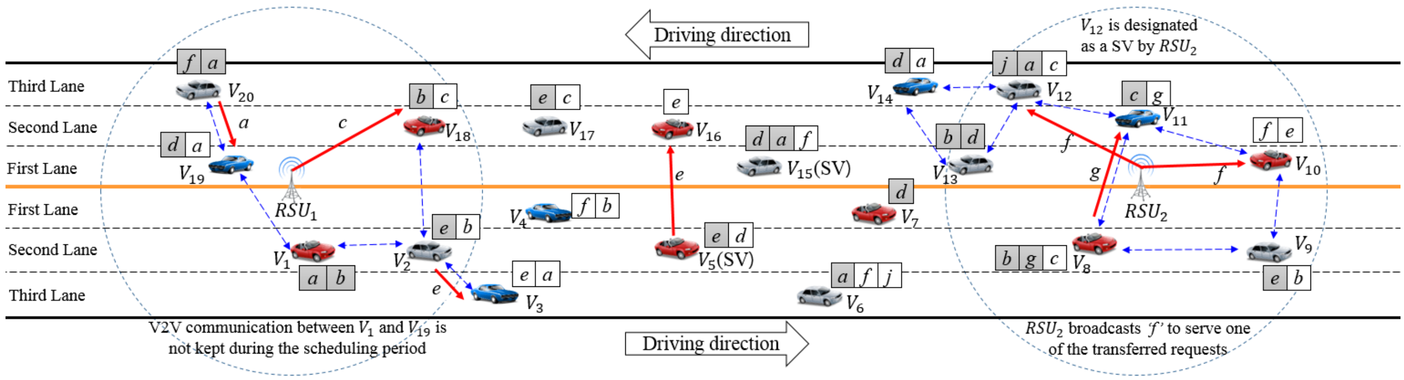


Fig. 1. Data dissemination system via cooperative I2V and V2V communications in a bidirectional road environment

- In the third phase, every RSU schedules data dissemination on the basis of the received messages from the vehicles. Then, it broadcasts the WAVE service advertisement (WSA) message including the scheduling result (e.g., the sender vehicle IDs, the corresponding data IDs to be shared, the receiver vehicle IDs, and the vehicles' transmission mode to be set) to every vehicle in its coverage through CCH.
- In the fourth phase, data items are disseminated via either I2V or V2V communication, according to the scheduling result. Note that multiple instances of data dissemination may take place at the same time and the V2V communication is constrained to one-hop.

Scheme 2: in addition to the scheduling in its own coverage, every RSU monitors unserved requests (i.e., vehicles have left but have not yet retrieved the data items) and informs other RSUs according to vehicles' driving directions. In this way, other RSUs may prepare in advance for serving these outstanding requests (e.g., by designating its SVs and the data items to be broadcast by the SVs). Every vehicle follows three phases to share data items out of RSUs' coverage.

- In the first phase, a SV broadcasts the WSA message including the identifier of SV, the list of cached contents, and the SCH number that the SV exploits for V2V data sharing through CCH.
- In the second phase, the vehicles that require a data service from the SV in the opposite direction transmit the WSA message including the identifier of service requester and an identifier of outstanding request to the SV. After that, the vehicles tune to the SCH in which the SV utilizes for V2V data sharing. Note that a SV can be a requester and it follows the same method in this phase.
- In the third phase, the SV broadcasts the data item, which is corresponding to the first received WSA message, through the SCH. Note that a SV, which has transmitted the WSA message in the second phase to receive data service, goes back to the first phase to provide data services if the SV cannot receive the requested data item.

Note that vehicles out of RSUs' coverage follow the above phases when they do not transmit or receive data items.

Fig. 1 gives a toyed example. In RSU_1's coverage, RSU_1 is not designating a SV. To enhance the channel efficiency and offload workload at the RSU, the vehicles in RSU_1's coverage follow the scheme 1. As a result, RSU_1 sets the vehicles' communication mode (i.e., either I2V or V2V mode), the vehicles' service role (i.e., either a sender or receiver), and the corresponding data IDs to be transmitted by the senders. In addition, V2V data sharing between a vehicle within RSU's coverage and a vehicle out of it can be included in the result when the vehicle in the RSU's coverage is a sender. For instance, data service from V_2 to V_3 can be scheduled although V_3 is out of RSU_1's coverage. That is because RSU_1 knows that V_3 is a V_2's neighboring vehicle and V_3's outstanding requests are listed in the service queue until V_2 leaves RSU_1's coverage. For this service, the vehicle leaving the RSU's coverage (e.g., V_3) tunes to the SCH used for V2V data sharing within RSU's coverage during the SCH interval until moving the distance of V2V range. Based on the result, data items are disseminated via the hybrid of I2V and V2V communications and the data items can be shared through V2V communications with the alleviated signal interference towards efficient data service. However, it is challenging to design the cooperative data service mechanism via I2V and V2V communications. First, adjacent vehicles that can communicate with each other may suffer from interference when they try to exploit the same channel simultaneously to transmit or receive data items. Second, vehicles with single-radio OBUs can only switch to either I2V or V2V mode at a time. Third, DSRC devices are half duplex, which means that they cannot transmit and receive data items simultaneously. Forth, traffic feature is dynamic on each lane.

After the data service, RSU_1 transfers the unserved requests, which are submitted by the vehicles heading to RSU_2, to the RSU_2. They are not deleted from the list of transferred requests at the RSU_2 until the vehicle that generated the requests enters the RSU_2's coverage. (e.g., '*f*' and '*j*' which are V_6's outstanding requests will be deleted from the list when V_6 reaches the RSU_2's coverage.) In RSU_2's coverage, data items are also disseminated via the hybrid of I2V and V2V communications, but I2V communication is mainly used to serve one of the transferred requests through a SV. In the current time slot, RSU_2 designates V_{12} as a SV to further alleviate the RSU's workloads and improve the V2V channel efficiency, expecting that V_{12} best serves the transferred requests from other RSUs with its cached contents (e.g., '*a*' and '*j*') via V2V communication out of RSU's coverage. At the same time, RSU_2 broadcasts data item *f*, which is not cached on the designated SV (i.e., V_{12}), to serve the transferred request. Note that a vehicle can receive the data item from the RSU when designating a SV if the vehicle requires the same data item, which is broadcast by the RSU (e.g., V_{10} receives the data item *f*). It is challenging to maximize the chance of data services out of RSU's coverage. First, the RSU needs to select the proper vehicle to enhance the data service performance by considering the cached contents and the transferred requests. Second, there is the trade-off at the RSU between directly serving vehicles in its own coverage and indirectly serving other vehicles by designating a SV. Namely, the RSU has to allocate certain time slots to transmit the data item to the SV corresponding to the transferred request. Thus, it may sacrifice the performance of serving the vehicle within its own coverage if the schedule is not well designed.

In order to alleviate the interference on SCHs and orchestrate efficient data services, the algorithm to be presented in the next section will address the following issues: (1) How to schedule data dissemination within RSU's coverage? (2) How to designate a SV? (3) What data item does the RSU transmit to a SV?

IV. MS Algorithm

In order to give efficient data services in a bidirectional road scenario with multiple RSUs, we propose an algorithm called *Maximum Service* (*MS*). The proposed algorithm schedules I2V and V2V communications in the RSU's coverage. The algorithm also designates proper SVs and determines the data item to transmit to SVs through the vehicles' cached contents and the transferred requests to enhance V2V data sharing out of RSUs' coverage.

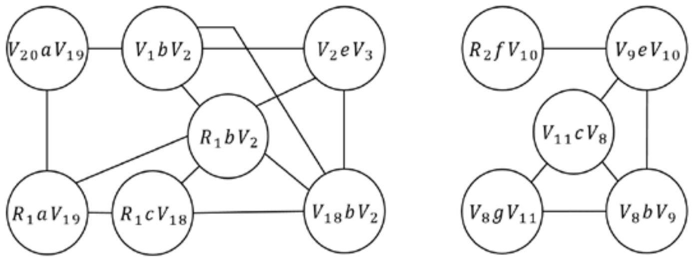
A. Scheduling policies for cooperative I2V/V2V communications

For the efficient data service using the hybrid of I2V and V2V communications, RSUs need to determine the vehicles' communication mode (i.e., I2V or V2V mode), service role (i.e., sender or receiver), and the data item to transmit or receive through the scheduling scheme. To this end, we formulate the scheduling problem and transform it to the maximum independent set (MIS) problem [15] to find approximately solutions. The independent set is the set of vertices that are not connected via edges in an undirected graph *G* as shown in Fig. 2. MIS represents the set with the maximum number of vertices that are not connected through edges. Note that the basic idea of graph construction is referred from [7]. However, this work considers the different issues (i.e., a SV designation and a bidirectional road scenario) when transforming the problem.

The scheduling problem for cooperative I2V/V2V communications within RSU's coverage is formulated as follows. The database is denoted by $D = \{d_1, d_2, \dots, d_{|D|}\}$, where $|D|$ is the total number of data items. The set of vehicles within the RSU's coverage is denoted by $V(t) = \{v_1, v_2, \dots, v_{|V(t)|}\}$, where $|V_{(t)}|$ is the total number of vehicles at time *t*. The vehicle set is divided into two sets depending on the communication mode: $V_I(t)$ and $V_V(t)$. $V_I(t)$ is the set of vehicles in I2V mode and $V_V(t)$ is the set of vehicles in V2V mode. While transmitting or receiving a data item, vehicles can keep only one mode. In other words, $V(t)$, $V_I(t)$, and $V_V(t)$ follow $V_I(t) \cap V_V(t) = \emptyset$ and $V_I(t) \cup V_V(t) = V(t)$. In order to receive data service through each communication mode, vehicles submit the requests to RSUs. The set of requested data items of v_i $(1 \le i \le |V(t)|)$ is denoted by $RD_{v_i}(t) = \{rd_{v_i}^1, rd_{v_i}^2, \dots, rd_{v_i}^{|RD_{v_i}(t)|}\}$, where $|RD_{v_i}(t)|$ is the total number of requested data items. This set is divided into $CD_{v_i}(t) = \{cd_{v_i}^1, cd_{v_i}^2, \dots cd_{v_i}^{|CD_{v_i}(t)|}\}$ and $PD_{v_i}(t) = \{pd_{v_i}^1, pd_{v_i}^2, \dots, pd_{v_i}^{|PD_{v_i}(t)|}\}$ where $CD_{v_i}(t)$ and $|CD_{v_i}(t)|$ represent cached data item set and the number of the cached data items respectively and $PD_{v_i}(t)$ and $|PD_{v_i}(t)|$ represent pending data item set and the number of the pending data items respectively. $RD_{v_i}(t)$, $CD_{v_i}(t)$, and $PD_{v_i}(t)$ follow $CD_{v_i}(t) \cap PD_{v_i}(t) = \emptyset$ and $CD_{v_i}(t) \cup PD_{v_i}(t) = RD_{v_i}(t)$. Given that the RSU caches all data items, data service for $PD_{v_i}(t)$ stands a chance of receiving data service through I2V or V2V communication when a neighboring vehicle in $N_{v_i}(t)$ caches the data item corresponding to the pending request, where $N_{v_i}(t)$ is the set of v_i's neighboring vehicles. For the data service through I2V communication, $pd_{v_i}^j$ needs to follow $\{pd_{v_i}^j | pd_{v_i}^j \in D(t)\}$ $(1 \le j \le |PD_{v_i}(t)|)$. For the data service through V2V communication, $pd_{v_i}^j$ needs to follow $\{pd_{v_i}^j | pd_{v_i}^j \in CD_{N_{v_i}}(t)\}$. The data service which satisfies either of the above two conditions is called the tentative data service via I2V or V2V communication.

With the above problem formulation, we introduce the details of transforming the scheduling problem to MIS problem as follows. First, for each tentative data service, we create a vertex in the graph *G*. Vertices mean the tentative data services via I2V and V2V communication, and they are represented with the identifiers on the vertices as shown in Fig. 2. An identifier of vertex represents a tentative data service via I2V or V2V communication in Fig. 1. For instance, R_1bV_2 means that RSU_1 transmits *b* to V_2, and V_1bV_2 represents that V_1 transmits *b* to V_2. When generating a vertex, the algorithm follows the below instructions.

- Vertex regarding I2V data service: Every tentative I2V data service within RSU's coverage can be included in *G* when the RSU does not designate a SV. For instance, every tentative I2V data service is represented in (a) of Fig 2. When designating a SV, the vertex related to I2V data service is not included in *G* in order to transmit the data item to the SV. However, if a vehicle requires the same data item, which is transmitted from the RSU to the SV, it can be represented as a vertex. For instance, the



(a) (b)

Fig. 2. Examples of problem transformation

vertices related to I2V data service are not shown in (b) of Fig. 2 except R_2fV_{10}.

- Vertex regarding V2V data sharing: It measures the relative velocity between sender and receiver vehicles to verify that they can successfully transmit and receive a data item during the scheduling period. If they can keep the V2V connection during that time, it can be represented as a vertex. In (a) of Fig. 2, only V_1aV_{19} is not included in the *G*, but other tentative V2V services are indicated as the vertices. Note that, in order to guarantee the data transmission from the RSU to a SV, the vertex which represents that a SV is either a receiver or a sender of V2V communication is not included in *G*. For instance, $V_{11}cV_{12}$ is not represented as a vertex in (b) of Fig 2.

After generating the vertices, they are connected through edges. Each edge in our *G* represents a conflicting relationship between the vertices, which means they cannot be operated simultaneously due to the characteristics of wireless communication and the hardware limitations. Detailed constraints and conflicting relationships are defined as follows along with examples shown in Fig. 1.

- Two vertices which represent I2V communications are in conflict with each other because RSU broadcasts only one data item at a time. (e.g., conflict each other: R_1aV_{19} *and* R_1bV_2)
- Two vertices which respectively represent I2V and V2V communications are in conflict with each other if the receiver of I2V is same with the sender or receiver of V2V. This is because OBU can be only in either I2V or V2V mode at a time. (e.g., conflict each other: R_1bV_2 *and* V_2eV_3)
- Two vertices which represent transmitting different data items via V2V communications are in conflict each other if senders of both vertices are the same vehicle. This is because OBUs can transmit only one data item at a time. (e.g., conflict each other: V_8gV_{11} *and* V_8bV_9)
- Two vertices which represent V2V communications are in conflict with each other if a sender of one vertex and a receiver of the other are the same vehicle. This is because OBUs cannot be a sender and a receiver at the same time. (e.g., conflict each other: V_2eV_3 *and* $V_{18}bV_2$)
- Two vertices which represent V2V communications are in conflict with each other if a receiver is a neighboring vehicle of both the senders. This is because data collision occurs at the receiver. (e.g., conflict each other: V_1bV_2 *and* $V_{20}aV_{19}$)

With the above rules, the constructed graphs based on the examples in Fig. 1 are represented in Fig. 2.

According to the constructed *G* based on the mentioned above, independent set, which is the set of vertices not connected via any edge, represents the viable data services without any conflict. Namely, the data services can be provided simultaneously. In order to enhance the data service performance, the independent set is required to contain the maximum number of vertices. To this end, we transform the scheduling problem to MIS problem.

Due to the NP-hardness of the MIS problem [16], we adopt a greedy method proposed in [15] to approximately solve it. The greedy method is applied to *G*. Its basic concept is outlined as follows. First, it computes the value of $1/(d(v)+1)$ for each vertex, where *v* is an abbreviation of vertex and $d(v)$ represents the degree of the vertex. Second, it selects the vertex with the maximum value of $1/(d(v)+1)$. In case of a tie, it selects one according to the search order. Third, it removes the selected vertex and its neighboring vertices. Forth, it repeats the above steps until no vertex remains in *G*.

After the greedy method, the scheduling result is determined through the selected vertices (i.e., independent set), and the vehicles participate in the data dissemination based on the result. Note that the data transmission from the RSU to the SV needs to be included in the result to serve the transferred requests although we do not represent it as a vertex.

B. SV designation policy

The RSU transfers the unserved request within its coverage to the neighboring RSU where the vehicle is heading, and the neighboring RSU can estimate the outstanding requests out of the RSUs' coverage. In order to further alleviate the workloads among RSUs and improve V2V channel efficiency, the RSUs designate proper vehicles as SVs, which provide V2V data sharing out of RSUs' coverage, through the cooperation among them. To designate a SV, RSU determines a set of candidate SVs which are about to leave the RSU's coverage and assigns the weights to them to select the best SV in terms of the channel efficiency and the alleviation of RSUs' workloads. The candidate SV with the maximum weight is designated as a SV, and the RSU includes the SV in the set of server-vehicles (SVS) that are designated by the same RSU and do not reach the next RSU's coverage yet. In order to assign a weight, which is denoted by w_i where *i* is the vehicle ID, to each candidate SV, we consider two factors.

The first factor is the number of cached data items of the vehicle *i*. It is denoted by $|CD_i(t)|$, where $CD_i(t) = \{cd_1, cd_2,\ldots,cd_{|CD_i(t)|}\}$ means the set of cached data items of the vehicle *i* at time *t*. This factor means the extent of increasing service capacity out of RSUs' coverage, and more cached data items may give a higher service probability of the vehicle. The second factor is the number of transferred requests which ask for the data items cached in $CD_i(t)$. It is denoted by $|TRS_i(t)|$, where $TRS_i(t)$ is a set of the transferred requests asking for the data items cached by vehicle i. Namely, $TRS_i(t)$ is represented by

$$TRS_i(t) = PR(t) \cap CD_i(t) \quad , \qquad (1)$$

where $PR(t)$ is the set of pending requests (i.e., required data items) out of the RSUs' coverage, which are estimated from the transferred requests from the neighboring RSU. The higher value of $|TRS_i(t)|$ indicates that vehicle i may serve more requests when driving out of the RSU's coverage. With the above analysis, the weight of each candidate SV is computed as follow

$$w_i = \alpha|CD_i(t)| + \beta|TRS_i(t)| \quad , \qquad (2)$$

where α and β are tuning parameters to weight the service diversity and the service potentiality for transferred requests.

To alleviate the signal interference at the vehicle requesting a service out of RSUs' coverage, RSUs designate SVs by considering at the specific moment when the distance between the previous SV and the new SV is expected to be more than V2V range. The distance is predicted based on the average speed of vehicles within the RSU's coverage.

C. Data transmission policy for SV

After designating a SV, the RSU decides a data item to transmit to the SV. In order to serve the transferred requests as many as possible, the RSU follows three conditions in selecting the data item. First, the data item is not duplicated with other SVs' data items because it stands a chance for the transferred requests to be served via other SV. Second, the data item is not duplicated with the SV's cached items. The above two conditions are represented by

$$d_k \notin \cup_{sv\_id \in SVS} CD_{sv\_id(t)} \quad , \qquad (3)$$

where sv_id is the SV's ID and d_k is an element of data set which satisfies the equation (3) and is denoted by $DS(t)$. Third, the item needs to satisfy the maximum number of transferred requests which are not corresponding to the SVs' cached data. It is denoted by

$$d_{SV} = max\{d_k \in PR(t) \cap DS(t) \mid |d_k|\} \quad , \qquad (4)$$

where d_{SV} is the selected data item to transmit to the SV and $|d_k|$ means the number of transferred requests corresponding to the data item d_k.

V. PERFORMANCE EVALUATION

The simulation model is built based on the system architecture presented in Section III, and it is implemented by CSIM 19 [17]. The arrival pattern of vehicles in each lane follows the Poisson process. The traffic flow is simulated based on the Greenshield's model, which is commonly adopted in simulating macroscopic traffic scenarios. Specifically, it assumes a linear relationship between the vehicle speed and the traffic density [18]. The vehicle speed (v) is represented by $v = V^f - \frac{V^f}{K^j} \cdot k$, where V^f is the free flow speed (i.e., the maximum speed limit) and K^j is the jam density (i.e., the density leading to zero velocity of vehicles). k is the current density of vehicles on each lane. The default parameters are set as follows. For each driving direction, the free flow speeds of Lane 1, Lane 2 and Lane 3 are set to v_1^f=120 km/h, v_2^f=110 km/h, and v_3^f=100 km/h, respectively. K_j is set to 100 vehicles/km. The tuning parameters α and β for SV designation are both set to 1. We simulate the system with the diverse traffic volume levels in order to comprehensively evaluate algorithm performance in different traffic environments (e.g., highway and urban environments). A higher value of ID corresponds to a heavier workload (i.e. a higher vehicle arrival rate). The detailed statistics are summarized in TABLE 1.

The distance between two RSUs is set to 3km. The communication radius of RSU is set to 300m and the communication range between OBUs is set to 150m. The scheduling period is 1sec. It is reasonable because DSRC supports 6~27 Mbps data transmission rate [19] and the size of data items is typically a few Mbytes in common applications. Therefore, 1 sec is enough for both computation and transmission time. The database consists of a hundred data items. Vehicles generate 1 to 7 requests with the Uniform distribution within every RSU's coverage, and the data access pattern follows the Zipf distribution [20] with the parameter θ=0.6. Specifically, for d_i, its access probability is computed by $\frac{(1/i)}{\sum_{j=1}^{|D|}(1/j)^{\theta}}$, where $|D|$ is the database size. The area to designate candidate SVs is set from 255~300m before vehicles leave the RSU's coverage.

We compare the proposed algorithm with MRF (Most Requested First) [21] and SFR algorithms [7]. MRF broadcasts the hottest data item first to serve the maximum

TABLE 1. Simulation statistics under different traffic scenarios

Traffic Volume Level	Mean Arrival Rate (vehicles / h)			Mean Velocity (km / h)			Mean Density (vehicles / km)		
	First Lane	Second Lane	Third Lane	First Lane	Second Lane	Third Lane	First Lane	Second Lane	Third Lane
1	900	800	700	109.44	101.18	91.87	8.79	8.01	8.12
2	1400	1300	1200	103.09	95.20	86.27	14.08	13.44	13.72
3	1900	1800	1700	94.97	86.61	77.95	20.85	21.25	22.04
4	2400	2300	2200	84.01	76.20	67.13	28.31	30.72	32.85
5	2900	2800	2700	69.64	41.44	35.77	41.95	62.30	64.20

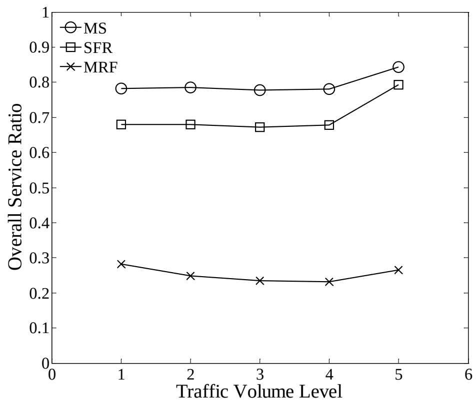


Fig. 3. Overall service ratio under different traffic volume levels

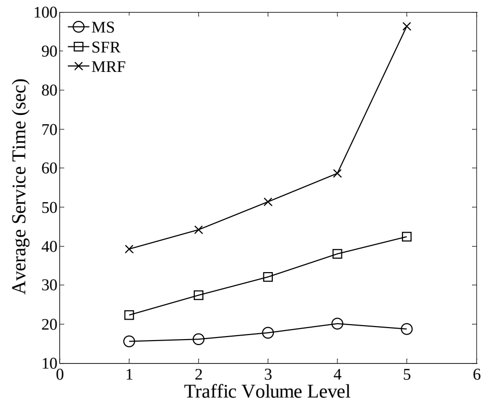


Fig. 4. Average service time under different traffic volume levels

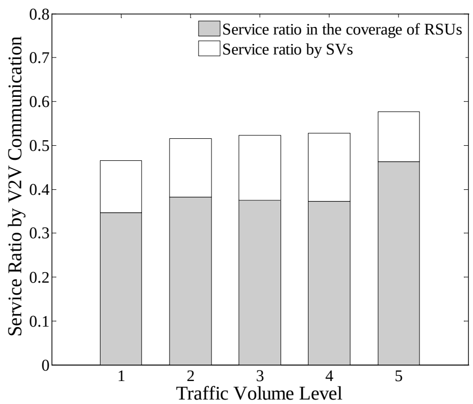


Fig. 5. Service ratio of MS by V2V communication under different traffic volume levels

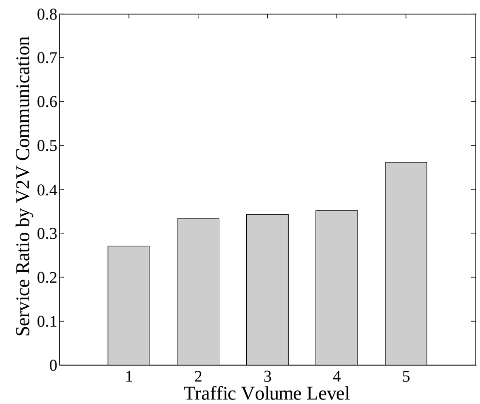


Fig. 6. Service ratio of SFR by V2V communication under different traffic volume levels

number of pending requests via I2V communication. While MRF is not particularly designed for data scheduling in vehicular networks, it has been demonstrated effective in terms of enhancing the bandwidth efficiency in broadcast environments [22], and hence it is adopted for performance evaluation in this work. SFR [7] is the closest solution to the problem investigated in this work, which has been elaborated in Section II. We evaluate the algorithm performance with the following three metrics.

- Overall service ratio: It is computed by the number of served requests over the number of total submitted requests. The higher service ratio implies better overall system performance.
- Average service time: It is the time interval between a request submission and the reception of the corresponding data item. The short average service time represents the faster system responsiveness.
- Service ratio by V2V communication: It is computed by the number of served requests via V2V communication over the total submitted requests. The higher service ratio implies more efficient V2V channel utilization and better offloaded workloads at RSUs.

Fig.3 shows the overall service ratio under different traffic workloads. It demonstrates that MS can achieve higher service ratio than other algorithms in all scenarios. At the volume level 5, the service ratios of MS and SFR increase because the average speed of vehicles decrease significantly due to the higher density. Namely, the vehicles stay within the RSU's coverage for a longer time, so that they can receive more services. From this figure, we can demonstrate that the cooperation among RSUs (i.e., SV designation) improves the overall system performance.

Fig. 4 shows that the average service time of each algorithm increases with the increment of traffic volume levels. MS has less service time than other two algorithms due to the cooperation among RSUs. SFR has a similar service time with MRF in levels 3 and 4 although it has a better service ratio than MRF. Therefore, it is non-trivial for MS to achieve both shorter service time and higher service ratio in all scenarios.

Figs. 5 and 6 show the service ratio by V2V communication of MS and SFR respectively. We observe from these results that, compared with SFR, MS can better exploit V2V communication channels by designating proper SVs outside the RSU's coverage, which further explains why

MS achieves best overall performance in all evaluated scenarios.

VI. CONCLUSION AND FUTURE WORK

In this work, we present the data dissemination system in vehicular networks via the cooperation of I2V/V2V communications. Specifically, we consider a bidirectional road scenario where multiple RSUs are cooperated to provide data services. We propose a data dissemination algorithm which contains three components: a hybrid of I2V and V2V communication strategy for data dissemination within the RSU's coverage, a SV designation strategy for data dissemination outside of the RSU's coverage, and a mechanism to schedule the data items at the RSU for SVs. We have performed a comprehensive simulation study and demonstrated that MS has the best performance with respect to improving the service ratio and reducing the average service time under a wide range of traffic scenarios.

In the future work, we will further investigate data dissemination problems in vehicular networks by considering multi-hop V2V communications and lower layer impacts on data dissemination such as packet loss, signal interference, power control, etc.

ACKNOWLEDGMENT

This research was supported in part by Global Research Laboratory Program (2013K1A1A2A02078326) through NRF, and the DGIST Research and Development Program (CPS Global Center) funded by the Ministry of Science, ICT & Future Planning; in part by the National Natural Science Foundation of China (Grant No. 61572088) and Fundamental Research Funds for the Central Universities (Grant No.106112015CDJZR185518).

REFERENCES

[1] K. Dar, M. Bakhouya, J. Gaber, M. Wack, and P. Lorenz, "Wireless Communication Technologies for ITS Applications," *IEEE Communications Magazine*, vol. 48, no. 5, pp. 156-162, May. 2010.

[2] F. Yang, Y. Tang, and L. Huang, "A multi-channel cooperative clustering-based MAC protocol for VANETs," *Wireless Telecommunications Symposium (WTS), 2014*, Washington, DC, 2014, pp. 1-5.

[3] F. Peng, G. Zhang, X. Huang, X. Ye, and M. Wu, "A Novel TDMA-MAC Protocol for VANET Using Cooperative and Opportunistic Transmissions," *Vehicular Technology Conference (VTC Fall), 2015 IEEE 82nd*, Boston, MA, 2015, pp. 1-2.

[4] F. Malandrino, C. Casetti, C. F. Chiasserini, and M. Fiore, "Optimal Content Downloading in Vehicular Networks," in *IEEE Transactions on Mobile Computing*, vol. 12, no. 7, pp. 1377-1391, July. 2013.

[5] O. Trullols-Cruces, M. Fiore, and J. Barcelo-Ordinas, "Cooperative Download in Vehicular Environments," in *IEEE Transactions on Mobile Computing*, vol. 11, no. 4, pp. 663-678, April. 2012.

[6] M. Sardari, F. Hendessi, and F. Fekri, "Infocast: A New Paradigm for Collaborative Content Distribution from Roadside Units to Vehicular Networks", *IEEE SECON*, Rome, 2009, pp. 1-9.

[7] K. Liu, J. Ng, V. Lee, W. Wu, and S. H. Son, "Towards Scalable, Fair and Robust Data Dissemination via Cooperative Vehicular Communication," in *Embeded and Real-Time Computing Systems and Applications (RTCSA)*, Chongqing, 2014, pp. 1-9.

[8] G. G. M. N. Ali, E. Chan, and W. Li, "On scheduling data access with cooperative load balancing in vehicular ad hoc networks (VANETs)," *The Journal of Supercomputing* , vol. 67, no. 2, pp. 438 –468, Feb. 2014.

[9] P. Fan, Y. Li, G. Zhang, J. Li, and D. Mu, "Packet reachability of VANET in bidirectional road scenario," *Communication Technology (ICCT), 2010 12th IEEE International Conference on*, Nanjing, 2010, pp. 80-83.

[10] M. Akand, M. Rashid, M.T. Nayeem, M. Sumon, R.U. Zaman, and M.M. Alam,"A probabilistic delay model for bidirectional vanets in city environments," *IEEE Conference on Vehicular Technology Society Asia Pacific Wireless Communications Symposium (APWCS)*, 2013.

[11] Y. Liu, J. Niu, G. Qu, Q. Cai, and J. Ma, "Message delivery delay analysis in VANETs with a bidirectional traffic model," *Wireless Communications and Mobile Computing Conference (IWCMC), 2011 7th International*, Istanbul, 2011, pp. 1754-1759.

[12] J. Wang, K. Liu, H. M. Edwin, V. C.Lee, and S. H. Son, (2015), "An efficient cluster-based data sharing algorithm for bidirectional road scenario in vehicular ad-hoc networks," *Proc. of the 15th International Conference on Algorithms and Architectures for Parallel Processing (ICA3PP'15)*, Zhangjiajie, China, Nov., 2015, pp. 537-551.

[13] M. Krohn, R. Daher, M. Arndt, and D. Tavangarian, "Aspects of roadside backbone networks," *in International Conf. on Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology*, Aalborg, 2009, pp. 788–792.

[14] *J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary*, SAE J2735, 2009.

[15] S. Sakai, M. Togasaki, and K. Yamazaki, "A note on greedy algorithms for the maximum weighted independent set problem," *Discrete Applied Mathematics*, vol. 126, no. 2, pp. 313-322, 2003.

[16] D. S. Hochba, "Approximation algorithms for NP-hard problems." *ACM SIGACT News*, vol. 28, no. 2, pp. 40-52, 1997.

[17] H. Schwetman, "Csim19: a powerful tool for building system models," *in Proceedings of the 33nd Conference on Winter Simulation (WSC'01)*. IEEE, Arlignton, VA, 2001, pp. 250–255.

[18] K. Liu, E. Chan, V. Lee, K. Kapitanova, and S. H. Son, "Design and evaluation of token-based reservation for a roadway system," *Transportation Research Part C: Emerging Technologies*, vol. 26, pp. 184–202, Jan. 2013.

[19] Y. L. Morgan, "Notes on DSRC & WAVE Standards Suite: Its Architecture, Design, and Characteristics," in *IEEE Communications Surveys & Tutorials*, vol. 12, no. 4, pp. 504-518, Fourth Quarter 2010.

[20] G. Zipf, "Human Behavior and the Principle of Least Effort: An Introduction to Human Ecology," Cambridge, Mass.: Addison-Wesley Press, 1949.

[21] J. W. Wong, "Broadcast delivery," *Proceedings of the IEEE*, vol. 76, no. 12, pp. 1566-1577, Dec. 1988.

[22] K. Liu and V. Lee, "On-demand broadcast for multiple-item requests in a multiple-channel environment," *Inf. Sci.*, vol. 180, no. 22, pp. 4336–4352, Nov. 2010.