International Journal on Advances in Networks and Services, vol 12 no 3 & 4, year 2019, http://www.iariajournals.org/networks_and_services/

Cooperative V2X for Cluster-Based Vehicular Networks

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Abstract— **Timely data services supported by efficient vehicular communications are essential for connected and autonomous vehicles and future transportation systems. In this paper, a cluster-based two-way data service model is introduced to promote efficient cooperation between Vehicle-to-Vehicle and Vehicle-to-Infrastructure communications, or namely V2X, so that the service delivery performance across the vehicular network can be improved. Our results show that the cluster-based model can significantly outperform the conventional non-cluster schemes, in terms of service ratio, network throughput and energy cost.**

Keywords— V2X communications; clustering; service delivery model; energy cost.

I. INTRODUCTION

The main challenge in the development of smart mobility and intelligent transport systems is how to effectively manage traffic congestion, reduce car accidents and energy consumption with the rapidly increasing number of vehicles and complex road networks. It is vital to make traffic information (e.g., speed and vehicle density) and environmental information (e.g., weather and road condition) timely available for road users and network operators, to ensure road safety and traffic efficiency [1].

The Vehicular Ad-hoc Network (VANET) is an extended version of the Mobile Ad-hoc Network (MANET) and intended for improving driving safety and efficiency through both vehicle-to-vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications. V2V and V2I can be operated cooperatively as V2X, making the VANET play a better role in modern transportation systemes under a complex traffic environment.

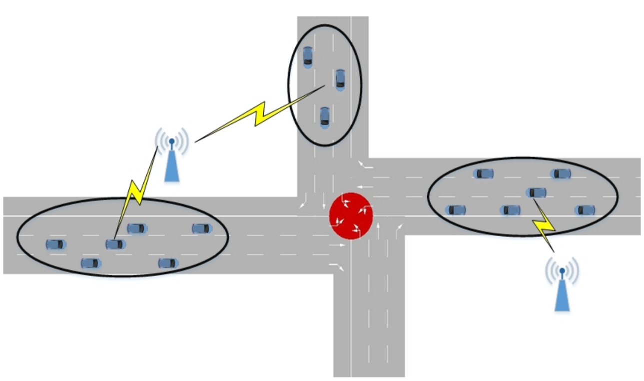


Figure 1. A VANET model with clusters

This paper proposes a V2X-based service system where the clustering technique is applied to improve transmission and energy efficiencies by significantly reducing the number of V2I connections. A cluster is a group of vehicles within the transmission range of each other, as shown in Fig. 1 where cluster heads exchange data with RSU via V2I while the other cluster members communicate with cluster heads via V2V. A data service model with cooperative V2X transmission via clustering is also introduced in this work, for effectively uploading the local information to the database and downloading the required service data from RSUs.

The remaining of the paper is organized as follows. Related work is discussed in Section II. Following the clustering algorithm presented in Section III, the proposed data service model and an energy model for performance analysis are presented in Section IV. Section V explains the simulation results produced by OMNET++, SUMO and MATLAB software tools. Finally, Section V concludes the paper.

II. RELATED WORK

The idea of combining V2I and V2V has been applied in many works on VANET. In [2], Noori et al. explore the combination of various forms of communication techniques, e.g., cellular network, Wi-Fi and ZigBee for VANETs. In [3], a roadside unit (RSU) plays a vital part to provide services and make scheduling arrangements using a simple network coding in a V2X approach. This approach may cost more energy to complete the service and does not consider the packet loss and associated latency caused by the failed services. In [4], multiple RSUs are involved in broadcasting data periodically to vehicles via V2I and forwarded to vehicles via V2V if they are outside the transmission range. This model requires efficient handover mechanisms to ensure stable and in-time data services between the vehicles concerned.

The Dedicated Short-Range Communications (DSRC) technology refers to a suite of standards of Wireless Access in Vehicular Environments (WAVE) [5] and supports both V2V and V2I communications. Vehicles equipped with sensors can collect local traffic and environment information and exchange it for the similar information of other regions (place of interest) with RSUs. A RSU acts as an interface between vehicles and the vehicular network to provide vehicles the service information requested and pass on the collected information to other parts of the network. The high mobility and density of vehicles presents a big challenge in V2X communications, which causes congestion in service delivery in this environment. In addition, moving vehicles will keep exchanging information between them and this will cost a significant amount of energy for continuous data sensing, transmission and processing, especially for V2I as it needs to cover longer distances than V2V.

The Lowest-ID clustering algorithm is a basic method to select cluster head, which uses unique vehicle ID numbers as the selection standard [6]. This algorithm works stably in most MANETs but may not always be suitable for VANET due to higher velocity and more restricted routes for vehicles. The AMAC (Adaptable Mobility-Aware Clustering) algorithm [7] considers mainly the destination as the key factor in forming clusters to improve the stability of clusters and extend the cluster's lifetime. However, the destination may not always be collected from navigation systems as drivers do not always use them for the known routes. A three-layer cluster head selection algorithm based on the interest preferences of vehicle passengers is proposed for multimedia services in a VANET [8]. This scheme is inefficient when the requirements in operations differ too much.

Based on the discussion of V2X related work, a more efficient service delivery method is introduced in this paper by utilizing clusters and minimizing channel congestion caused by excessive V2I transmission in conventional service models. We will show that the cluster model outperforms the non-cluster model at both service and energy performance levels.

III. Clustering Algorithm

In MANETs, moving vehicles can be divided into different sizes of clusters, such as using the "combined weight" algorithm to select cluster heads [9]. The selection takes the current position, number of neighbours, mobility, and battery power of vehicles into consideration. In VANETs, vehicles' mobility is more limited by the road type, traffic signs and other traffic factors. Therefore, the elements involved in forming clusters in a VANET need to be adjusted accordingly.

Clustering in VANET needs to be adjusted in accordance with traffic features such as high mobility of vehicles, regular moving tracks and directions. The clustering algorithm for forming and maintaining clusters should ideally be stable and adaptive to vehicle mobility or sudden changes in network topology, and provide reliable end-to-end communications across the network. The algorithm presented here is focused at the methods for forming a cluster including cluster head selection and cluster operation, which are discussed below.

A. Cluster Head Selection

Clustering in VANET is an extension of clustering in MANET, where the mobility and channels show different features. On the road networks, vehicles equipped with communication devices group themselves into clusters according to certain rules applicable to the road environment and traffic characteristics. Cluster size is not fixed and usually depends on the communication range of vehicles and the traffic environment.

There are three types of nodes (vehicles) in a VANET: Free Node (FN), Cluster Head (CH), Cluster Member (CM). The clustering algorithm considers the one-hop neighbours of each node and the cluster size is decided by cluster head's communication range. CH is responsible for collecting data and service requests from CMs, uploading current driving information (e.g., traffic is normal or congested), and requesting services from the RSUs. This paper defines a new weighting metric for selecting the CH, considering the factors, such as position, velocity, connectivity and driving behavior of the vehicles involved.

The position of each node is obtained from GPS (Global Positioning System) data. The average distance, P_i, between CH and CM should be as short as possible, which is given by

$$P_i = \frac{1}{n}\sum_{j=1}^{n}\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \qquad (1)$$

where n is the number of neighbors of node n_i, x and y are coordinate values of two nodes involved.

The velocity of CH, V_i, is defined to be the difference between the velocity of a candidate node v_i and the average velocity for the current traffic flow, and given by:

$$V_i = \left| v_i - \frac{1}{n}\sum_{j=1}^{n} v_j \right| \qquad (2)$$

where v_j is the velocity of the j-th neighbour of the candidate node.

The connectivity of the candidate node is reflected by the number of its neighbors, N_i. The ideal connectivity is denoted as σ, which represents the maximum number of neighboring nodes within one hop without causing traffic congestion, and is given as:

$$\sigma = 2R_t \times 133 \times n_l / 1000 \qquad (3)$$

where R_t is the transmission range, n_l is the number of lanes. The constant value 133 represents the highest possible density (vehicles/(lane·km) [10]. The actual connectivity, C_i, is used to measure how close the N_i is to the ideal value σ, i.e.:

$$C_i = \left| N_i - \sigma \right| \qquad (4)$$

The last factor is the acceleration of the vehicle, a_i, to reflect the driving behaviour D_i by showing how stable a vehicle is when running along the road, i.e.:

$$D_i = \left| a_i \right| \qquad (5)$$

The weighting matrix is formed by combining the four factors, discussed above, which are considered equally important. After the normalization of the four measurements, as shown below,

$$\text{a)}\ P_i' = \frac{P_i}{P_{\max}},\ \text{b)}\ V_i' = \frac{V_i}{V_{\max}},\ \text{c)}\ C_i' = \frac{C_i}{\sigma},\ \text{d)}\ D_i' = \frac{D_i}{D_{\max}} \qquad (6)$$

the weighting matrix, W_i, is defined as

$$W_i = P_i' + V_i' + C_i' + D_i' \qquad (7)$$

where P_{max} is the distance between the i-th vehicle and the farthest vehicle from it, V_{max} is the speed limitation by traffic rules that a vehicle can reach in the flow, D_{max} is the maximum absolute value of acceleration the vehicle can reach when it is running. A smaller W_i indicates the higher suitability of the candidate for the CH.

B. Cluster Operation

In the environment where vehicles have high mobility, cluster stability is a key factor to consider. In some traffic scenarios, in order to improve the transmission efficiency some vehicles are prevented from joining in a cluster. On a two-way straight road, for example, a vehicle is not allowed to join in the cluster that is running in the opposite direction. To maintain an established cluster in dynamic traffic and environmental conditions, different types of information packets are used for coordinating the operation with the cluster and delivering services, such as:

1) Vehicle Information Packet (VIP): It carries the basic vehicle information, including vehicle ID, velocity and position. VIP is used for starting the cluster forming process. When a vehicle detects itself as a free node (FN), it sends its VIP to its neighbours and enables them to calculate its weight value Wi based on (7), which is the basis of CH selection: the vehicle with the smallest Wi value becomes the CH.

2) Cluster Head Announcement (CHA): When a vehicle considers its weight low enough to be a CH, it will broadcast a CHA together with its weight value Wi. Other vehicles will compare the received Wj with their own weight and send their CHA to argue if theirs have a smaller weight than Wi.

3) Cluster Head Maintain (CHM): A node with the smallest Wi is elected as CH, and it then sends CHM to all its neighbours to declare its identity (CH ID). This packet is broadcast periodically if CH considers its status still suitable to be a cluster head.

4) Service Data Packet (SDP): SDP consists of two parts: head and context. The head includes the packet ID, sender ID and time stamp. The context part carries the actual communication message such as service requests and collected information.

To reduce the transmission cost, CH does not keep the list of its members, every CM stores the CH's ID to identify its cluster. When CH broadcasts the service packets, CMs who have the same CH ID and the targeted service ID will receive the service packets.

IV. Cooperative Service Model

A. Service Delivery

In the pure V2I service model, all vehicles are directly connected to RSUs for service delivery, resulting in transmission congestion due to a limited number of frequency channels and higher transmitting power to cover distance between vehicles and RSUs.

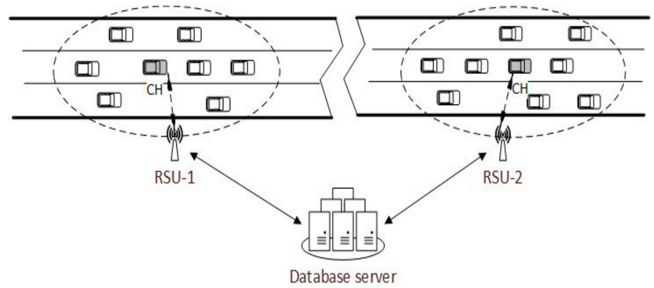


Figure 2. Cluster-based service model

The service model that we have developed utilizes cluster-based V2X communications. In this model, vehicles are grouped into clusters for information exchange between vehicles and RSUs. CHs are selected to gather and aggregate information collected by CMs and disseminate service packets to CMs via V2V. V2I transmissions take place only between CHs and RSUs via V2I directly, including uploading information to the server via RSU and downloading service data from RSU by CHs, as shown in Fig. 2.

This system model enables real-time information sharing. In addition, the cluster-based service model has transferred most of the data delivery from long-range V2I to short-range V2V. In this way, both transmission collision in the vehicle-RSU links and energy consumption can be reduced as RSUs only need to communicate with CHs. The database server shown in Fig. 2 stores service information including the traffic and environmental information such as the velocity of current traffic flow, real-time density of vehicles, weather conditions and road status, which is updated periodically.

This service system follows the standards of IEEE 802.11p and IEEE 1609 family [5], which specifies 7 channels of 10 MHz with each including one control channel and 6 service channels. The transmitting power levels are up to 44.8dBm for RSUs and 33dBm for vehicles. The control channel is used for exchanging control messages and safety information, while service channels are used for delivering service information packets.

Both uplink and downlink transmissions of the proposed service model are described as below.

B. Uplink Transmission

The vehicles on roads have different regions of interest and tend to learn the environmental and traffic conditions in those regions in advance. They also collect current traffic information from their on-board sensors and upload it to the road network for traffic control. Upon generating a message with a high priority (e.g., an accident), it is their responsibility to report it to CH. Each vehicle generates packets including vehicle ID, request ID and CH ID. Every CM submits the requests with the collected information to CH and then set the timer to wait for services. On receiving the packets, CH aggregates the collected information and forward to RSU in uplink transmission.

The traffic/environmental information includes the average speed of current flows, position, weather (rain, fog, lights etc.) and traffic conditions (smooth or congested etc.).

Vehicles within the same cluster may gather similar information, especially the weather and road conditions. In addition, different vehicles may request information for the same regions. Therefore, CH integrates the collected information before forwarding it to RSU. The aggregated data at CH will be less than what it has been collected, so the transmission efficiency of uplink transmission can be improved. Emergent messages (e.g., accidents alerts) will be marked with a higher priority during data aggregation.

Each RSU maintains its own database to store the recent service information collected from different CHs within its coverage. RSUs in different areas will periodically exchange and update information between them. In this case, vehicles in one area can learn the information about a larger range of areas ahead. The information service helps drivers to choose the best routes to reach their destinations and avoid congestion and accidents. They can also be aware of the travelling time they will spend.

C. *Downlink Transmission*

Upon receiving the packets from CH, RSU updates the database with collected information and generates the service packets requested by vehicles. These packets are sent to CH in downlink transmission via V2I and CH will redistribute them to CMs via V2V. Once overhearing the corresponding service ID and CH ID, CM will store the packets and mark the received request as satisfied. If CM is not satisfied (i.e., CM did not receive the requested service data) during a waiting time threshold, this request is considered as failed. In this case, a new request will be generated and sent to its CH again.

It is likely that a service is requested by multiple vehicles (e.g., three cars are interested in the traffic information of the same area), so CH disseminates data to CMs by broadcasting to help reduce the transmission cost. When CH broadcasts service packets, the CMs that are marked with the same CH ID and service ID will receive and save the service packets sent by Ch. Our model can provide real-time services for vehicles and allow drivers to manage their routes and time efficiently.

In addition, through clustering most of the data delivery between RSU and vehicles (i.e., V2I) is now transformed to data exchange between cluster members and cluster head (i.e., V2V). In this way, both transmission collision and energy consumption at the RSUs level can be reduced.

This service model follows the standards of IEEE 802.11p and IEEE 1609 family, which specifies 7 channels including one control channel and 6 service channels. Each channel has 10 MHz. The control channel is used for exchanging control messages and safety information, while service channels are used for delivering service information packets.

D. *Energy Model*

The proposed service model groups vehicles into clusters to improve the service efficiency and reduce energy consumption. Within a cluster we only consider one-hop transmission between neighboring vehicles to ensure the stability of connections between them. The energy model covers transmission in both directions, i.e., uplink and downlink shown in Fig. 3.

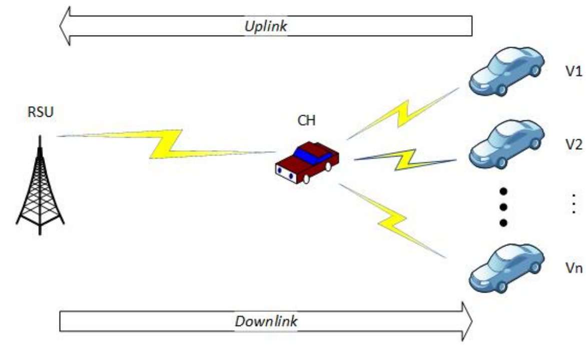


Figure 3. Uplink and downlink scenarios.

For comparison purposes, we consider two different service models: one is to provide services based on clusters (V2X) and the other is to provide services without clusters (pure V2I). In our service model using cluster-based V2X, both V2V and V2I are used for data uploading in the uplink and providing services in the downlink. However, higher transmit power is required in the V2I mode than in the V2V mode as the distances between RSU and vehicles are generally much longer than the distances between vehicles themselves within a cluster. In this subsection, we will discuss the energy performances of the cluster-based service model in comparison with the non-cluster service model where services are delivered through V2I only.

The RSU is up to 8-15 meters high [11] and the distance between a RSU and vehicles is much farther than the distance between vehicles themselves, thus V2I requires higher transmitting power than V2V to deliver data. The transmitting power for V2V mainly depends on the distance between CH and the farthest CM from CH and the maximum transmission distance (d^*) in this case is mainly based on the number of vehicles in a cluster. Denoting the distance between two vehicles as $d_{i,j}$, then:

$$d^* = \max_{i,j \in n} \{d_{i,j}\} \tag{8}$$

With the following definitions: P_{tvi}, - the transmission power of the i-th transmission by a vehicle to another vehicle; P_{tri} - the transmission power of the i-th transmission by a vehicle to a RSU; P_{rv} - the lowest receive power at another vehicle; P_{rr} - the lowest receive power at RSU; L_{pvi} - the path loss of a transmission link between two vehicles; and L_{pr} - the path loss of a transmission link between the vehicle and the RSU, the minimal required transmitting power for this vehicle is:

$$P_{tvi} = P_{rv} \cdot L_{pvi} \tag{9}$$

$$P_{tri} = P_{rr} \cdot L_{pri} \tag{10}$$

where the two path losses in (9) and (10) are defined by (using the two-ray model [12]):

$$L_{pvi} = \frac{{d_{vi}}^4}{{h_{vt}}^2 {h_{vr}}^2 G_{vt} G_{vr}} \quad (11)$$

$$L_{pri} = \frac{{d_{ri}}^4}{{h_{vt}}^2 {h_{rr}}^2 G_{vt} G_{rr}} \quad (12)$$

where G_{vt}, G_{vr} and G_{rr} are the antenna gains of the transmitting vehicle, the receiving vehicle and the RSU, respectively; h_{vt}, h_{vr} and h_{rr} are the antenna heights of the transmitting vehicle, the receiving vehicle and the RSU, respectively; d_{vi} and d_{ri} are the distance between vehicles and the distance between the vehicle and the RSU, respectively.

In the non-cluster service model, only V2I communications take place in both uplink and downlink. Therefore, the total transmitting power, P_{tn}, comprises of the power used for uplink transmission, P_{up}, and power for downlink transmission, P_{down}, i.e.:

$$\begin{aligned} P_{tn} &= P_{up} + P_{down} \\ &= N\sum_{i=1}^{N_{tv}} P_{tvi} + N\sum_{i=1}^{N_{tr}} P_{tri} \end{aligned} \quad (13)$$

where P_{tvi} is the uplink transmitting power of a vehicle for the *i-th* transmission, P_{tri} is the downlink transmitting power of a RSU for the *i-th* transmission, and N is the total number of vehicles that communicate with RSU via V2I, N_{tv} is the total number of uplink transmissions and N_{tr} is the total number of downlink transmissions.

We assume that the transmission time spent on each uplink transmission is unchanged, i.e., t_{tv} and P_{tvi} is constant for all uplink transmissions. Similarly, t_{tr} is defined as the transmission time for each downlink transmission and P_{tri} is constant for all downlink transmissions. Therefore, the total energy consumed in the non-cluster service model is given by:

$$E_n = P_{up} t_{tv} + P_{down} t_{tr} \quad (14)$$

In our proposed model, cluster head aggregates the collected data from each member and these data may be of high similarity when cluster members are in a similar environment but may also differ from each other because of the unique requirement from each vehicle. This leads to different transmission times spent in V2I communications, depending on the level of data aggregation carried out by the cluster head. The similarity level of the data from different cluster members will affect the data size for CH to transmit to RSU. In addition, only the cluster head involves V2I communications.

In the cluster-based model, the uplink transmitting power comprises of power for V2V (CMs to CH), P_{utv}, and power for V2I (CH to RSU), P_{utr}, while the downlink transmitting power is also divided into two parts, i.e., power for V2V (CH to CMs), P_{dtv}, and power for V2I (RSU to CH), P_{dtr}. The total transmitting power, P_{tc}, in the proposed service model can be calculated as:

$$\begin{aligned} P_{tc} &= P_{up} + P_{down} \\ &= [\,P_{utv} + P_{utr}\,] + [\,P_{dtv} + P_{dtr}\,] \\ &= [\,(N-1)\sum_{j=1}^{N_{utv}} P_{utvj} + \sum_{j=1}^{N_{utr}} P_{utrj}\,] \\ &\quad + [\,(N-1)\sum_{j=1}^{N_{dtv}} P_{dtvj} + \sum_{j=1}^{N_{dtr}} P_{dtrj}\,] \end{aligned} \quad (15)$$

where N is the number of vehicles in a cluster, P_{utvj} is the transmitting power of the *j-th* transmission of a CM to the CH (uplink V2V), P_{utrj} is the transmitting power of the *j*-th transmission of the CH to the RUS (uplink V2I), P_{dtvj} is the transmitting power of the *j-th* transmission of the CH to a CM (downlink V2V), P_{dtrj} is the transmitting power of *the j-th* transmission of the RUS to the CH (downlink V2I), N_{utv}, N_{utr}, N_{dtv}, and N_{dtr} are the total numbers of uplink V2V, uplink V2I, downlink V2V and downlink V2I transmissions, respectively.

We also assume that an equal transmission time is spent on each of N_{utv} transmissions and is represented by t_{utv}. This assumption applies also to N_{utr}, N_{dtv}, and N_{dtr}, and represented by t_{utr}, t_{dtv} and t_{dtv}, respectively. Therefore, the total energy consumed in the cluster-based service model is given by

$$E_c = P_{utv} t_{utv} + P_{utr} t_{utr} + P_{dtv} t_{dtv} + P_{dtr} t_{dtr} \quad (16)$$

In uplink V2I transmissions, the transmission time will be reduced as result of data aggregation at the CH. For this reason, t_{utr} is scaled down from the original time duration required for transmitting all the data collected by CH from CMs, which is t'_{utr}, by applying a scaling factor W_s, such that

$$t_{utr} = t'_{utr}\, W_s \qquad (0 \le W_s \le 1). \quad (17)$$

E. Performance Evaluation

In this paper, the following four metrics are applied to evaluate the performance of the proposed system.

- Service ratio (γ). It is the ratio of the number of successful delivered requests n_s to the total number of requested services n. This is a vital metric to evaluate the effectiveness of the V2X system. This performance metric is given by:

$$\gamma = \frac{n_s}{n} \quad (18)$$

- Average service delay (τ). It is defined as the average duration from a vehicle submitting a service request to it finally receiving the service packets, which is expressed by:

$$\tau = \frac{\sum_{i=1}^{n_s} t_{si} + n_{us} \cdot t_p}{n_s} \quad (19)$$

where t_{si} is the time duration of the *i*-th successful service transmission, n_{us} is the number of unsuccessful service requests, and t_p is the waiting time a vehicle spends for the service that is not delivered.

- Throughput (η). It is a widely applied metric to evaluate the transmission efficiency of a system. It is defined as the average size of data successfully delivered over a time unit.

$$\eta = \frac{p_s}{T} \tag{20}$$

where p_s is the total size of delivered service packets, T is the total transmission time.

- Energy Cost (E_C). It is measured as an average amount of energy (Joule) consumed for transmitting one bit of data, or called energy per bit. Given transmitting power P_t and throughput η, the energy cost is given by

$$E_C = \frac{P_t}{\eta} \tag{21}$$

where p_s is the total size of delivered service packets, T is the total transmission time.

Energy cost can also be represented by a ratio of the energy consumption E to the amount of data B transmitted by consuming E Joules.

The energy cost in the uplink (E_{Ub}) is defined as:

$$E_{Ub} = \frac{E_U}{B_U} = \frac{E_{UV} + E_{UI}}{B_{UI}} \tag{22}$$

where B_{UI} is the size of data transmitted in the uplink. B_{UI} is determined by the data loss rate and the aggregation degree, which is shown as below:

$$B_{UI} = (1 - P_{UI}) \cdot B_A \tag{23}$$

$$B_A = (1 - P_{UV}) \cdot (A_I \cdot B_{UV}) \tag{24}$$

where P_{UV} and P_{UI} are the data loss rates in V2V and V2I transmissions in the uplink, respectively; B_A is the aggregated data size, B_{UV} is the size of data transmitted from the vehicles via V2V; and A_I is the aggregation degree, defined as:

$$A_I = \frac{j}{n'} \tag{25}$$

where, $j = 1, 2, \ldots n'$, n' is the number of CMs whose data are successfully received by CH.

The energy cost in the downlink (E_{Db}) has a similar expression to that for the uplink, except there is no need of aggregation as no duplicated data is sent out from RSU, which is represented by:

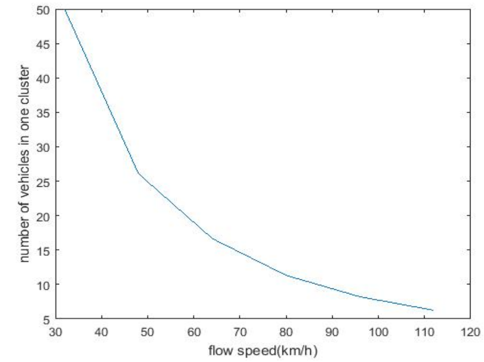


Figure 4. Service ratio under different flow speeds

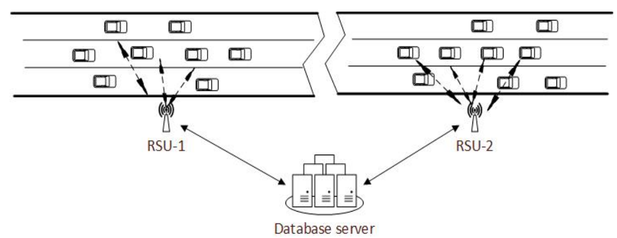


Figure 5. Non-cluster service model

$$E_{Db} = \frac{E_D}{B_D} = \frac{E_{DV} + E_{DI}}{B_{DV}} \tag{26}$$

where B_{DV} and B_{Di} are the sizes of data transmitted by V2V and V2I in the downlink, which are given by:

$$B_{DV} = (1 - P_{DV}) \cdot B_{Di} \tag{27}$$

$$B_{Di} = (1 - P_{Di}) \cdot B_D \tag{28}$$

where P_{DV} is the data loss rate during V2V in the downlink, P_{Di} is the data loss rate during V2I in the downlink.

Overall, the energy cost of the whole system is:

$$E_C = \sum_{i=1}^{n_U} E_{Ub} + \sum_{j=1}^{n_D} E_{Db} \tag{29}$$

where n_U is the total number of uplink transmissions and n_D is the total number of downlink transmissions.

V. SIMULATION AND RESULTS ANALYSIS

A. Simulation Setup

The traffic scenarios and communications models are simulated using SUMO [13] and OMNET++ [14]. SUMO is a powerful traffic simulator and supports multiple road topologies and vehicle attributes. It can cooperate with other network simulators via its Traffic Control Interface (TraCI) modules. OMNET++ is an extensible, modular, and

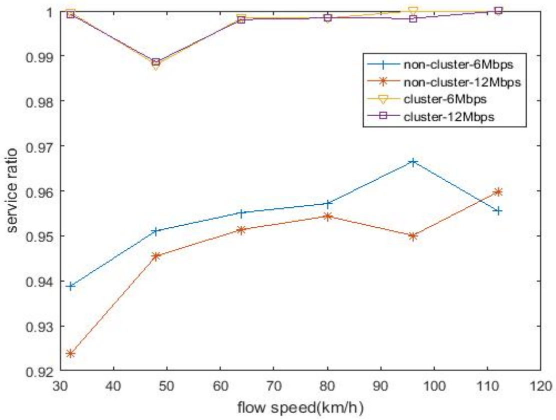


Figure 6. Service ratio under different flow speeds

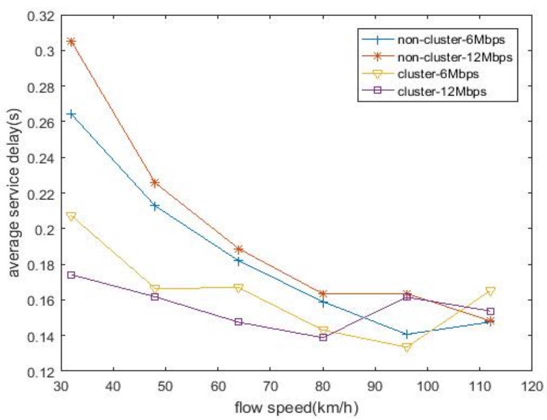


Figure 7. Average service delay under different flow speeds

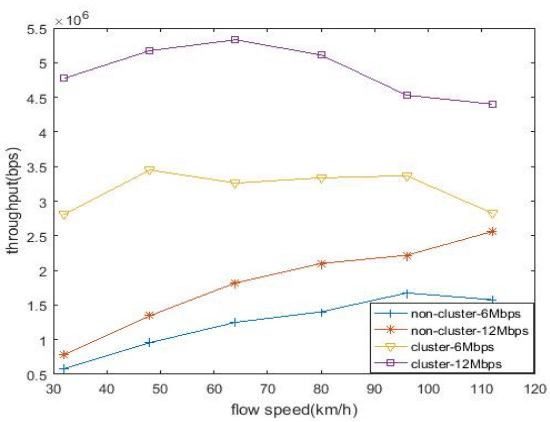


Figure 8. Throughput under different flow speeds

TABLE I. SIMULATION PARAMETERS

Parameters	Value
Frequency band	5.850-5.925 GHz
Channel bandwidth	10 MHz
Receive power sensitivity	-89dBm
Propagation model	Free space model
Data rate	6Mbps, 12Mbps
Number of requests	20-25
Data size	1000 bits
Number of lanes	3
Simulation time	300s

component-based C++ simulation framework, supporting various types of network simulation developments.

We built a one-way straight road with three lanes on SUMO, in which vehicles in each lane are running as a flow and the related service model is shown in Fig. 2. According to the Highway Code [15], the safe stopping distances are related to the driving speed. Considering the transmission range of V2V, which is usually 300 metres, the number of vehicles in a cluster on motorways is related to the flow speed as well.

Based on the safe stopping distance, we define six scenarios in simulation for the flow speed of 32, 48, 64, 80, 96, 112 km/h, respectively. The relationship between the vehicle number and flow speed is shown in Fig. 4.

The transmission model is configured based on the IEEE 802.11p and IEEE 1609 Family. Table I gives the parameters of the physical and MAC (Media Access Control) layers of the vehicular communication system and Table II specifies the transmission power in different modes (V2V and V2I), which are adopted in simulations.

For the purpose of performance comparison, we have also simulated the non-cluster model, as shown in Fig. 5 where the same number of vehicles and vehicle velocity are set in each scenario. Once the vehicles enter the transmission range of the RSU, they communicate with RSU directly via V2I. The two models are evaluated over the same set of performances, featuring the service ratio, average service delay, throughput and energy consumption.

TABLE II. TRANSMISSION POWER IN V2V AND V2I

Flow speed *(km/h)*	32	48	64	80	96	112
V2V *(mW)*	0.802	1.020	0.899	0.867	0.925	0.711
V2I *(mW)*	2.885	2.898	2.890	2.841	2.878	2.821

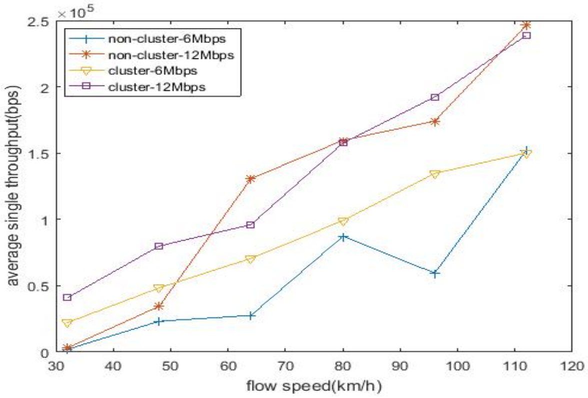


Figure 9. Average throughput of individual vehicles under different flow speeds

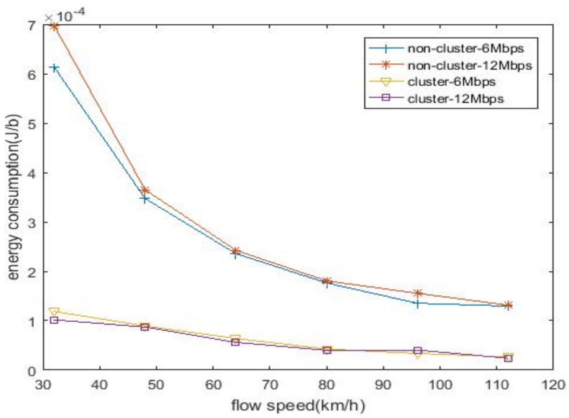


Figure 10. Energy cost under different flow speeds

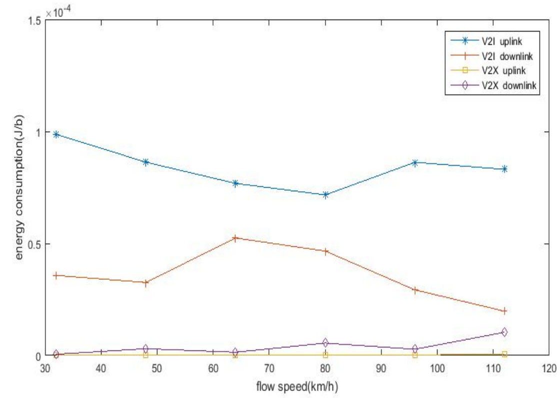


Figure 11. Energy cost in uplink and downlink.

B. *Results analysis*

Fig. 6 shows different service ratios (or successful rate of service delivery) of both Cluster-Based (CB) and Non-Cluster (NC) service models under 6 different scenarios and with different flow speeds and vehicle densities. CB achieves higher and more stable service ratios than NC under all scenarios and at both 6Mbps and 12Mbps data rates. The service ratio of NC also shows a raising trend with the increase of the flow speed. This is due to the lower vehicle density when the flow speed is higher, which reduces transmission collision and congestion.

When the flow speed is low, the distance between vehicles is relatively short and more vehicles are involved within the same transmission range, leading to more service requests and local data collected for transmission. In this scenario, by grouping vehicles into clusters, transmission loads between vehicles and RSUs are reduced, hence less collision events in the CB model than in the NC model.

When vehicles move out of the transmission range of RSU, those without support of clusters will not be able to receive service packets directly from RSU. But in the cluster-based model, CMs can still obtain services from the CH that has stored service data from RSU as long as they are in the transmission range with the CH via V2V.

The average service delay is shown in Fig. 7, which includes the time spent on transmitting service data and the waiting time for re-transmission when the previous service delivery is failed. In the NC model, each vehicle has to wait for downloading service data from the RSU in turn. This delay is reduced in the CB model since only CH is involved in V2I transmissions.

In addition, more time can be saved by using a cluster where CH transmits aggregated sensing data collected from CMs and broadcasts service data from RSU to the CMs that request the same information. The delay profile presented in Fig. 7 is also correlated with the service ratio results shown in Fig. 6.

When the flow speed increases, there will be less collision or congestion cases as a fewer number of vehicles are involved in transmission, thus in this scenario the CB model does not show as much advantages as they have at low flow speeds.

In Fig. 8, it is shown that the CB model clearly outperforms the NC model in terms of the network throughput under all six different scenarios. Throughput in the CB model appears to be more sustainable than that in the NC model, and the gaps between them are data rate dependant. As we can see, the CB's throughput at 6 Mbps is up to 2.3 times higher than that of the NC model, while when at 12 Mbps the difference is increased to up to 5 times. However, the throughput of the NC model also increases with the flow rate as less service requests are generated at high flow speeds or low vehicle densities.

The average throughput of individual vehicles is shown in Fig. 9 versus the flow speed. Generally, the throughput of individual vehicles in all schemes increases with the flow speed. As higher flow speeds correspond to lower vehicle densities according to Fig. 4, lower congestion in data traffic and, as a result, higher throughput will be expected in this situation.

In addition, it also correlates proportionally with the data rate as well. At low flow speeds, the CB model has a clear throughput advantage over the NC model because clustering helps to improve transmission efficiency. But the NC model can achieve competitively high throughput when the flow speed increases and with a higher data rate.

The energy performance in terms of Joule per bit is demonstrated in Fig. 10 for the two service models. Vehicles in a cluster exchange data with a RSU via V2X, i.e., V2V between themselves and V2I between CH and RSU, while when clusters are not used all transmissions rely on V2I. This will make a significant difference in energy consumption between the two service models, as shown in Fig. 10.

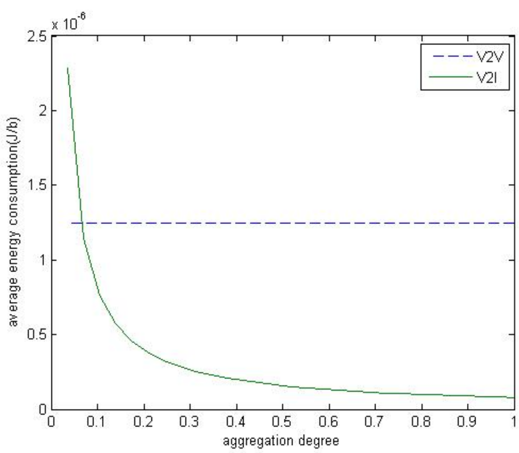
Like the results in other performance figures, the CB model is considerably more energy efficient than the NC model, and this advantage is particularly evident in the low flow-speed regions. The performance gap is closing down as the flow speed increases.

The energy performance can also be displayed separately in uplink as well as downlink, as shown in Fig. 11 where V2X refers to transmission mode in the clustered model while V2I represents transmission mode in the non-cluster model. Clearly, the clustered model is superior to the conventional non-cluster model as much lower energy cost is incurred in V2X than in V2I for both uplink and downlink transmissions.

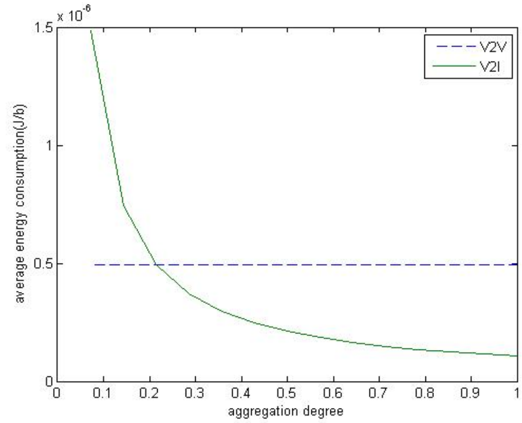
Fig. 12 shows the energy costs for both V2V and V2I (uplink) transmissions under varied aggregation degrees. The aggregation degree value ‘0’ refers to no data aggregation at all as data from different vehicles are all different, and value ‘1’ indicates that all the data from different vehicle are the same, so only one copy of data is needed for V2I transmission after aggregation. And for other values in between it means that data from different vehicles are similarity to some degree.

As shown in Table II, the transmitting power for V2I is much greater than that in V2V. But the energy cost in terms of energy per bit is affected by vehicle mobility (flow speed) and the similarity of data from different vehicles. Given the flow speed of 80 km/h in Fig. 12(a), the crossing point between V2V and V2I is when the aggregation degree A_I is fairly low (around 0.08). This means that V2I transmission can have a lower energy cost than V2V when A_I is greater than 0.08.

When the flow speed is increased to 112 km/h as shown in Fig. 12(b), the crossing point is moved to a higher value of 0.23. In this case, V2I could still be more energy efficient than V2V if more data can be removed through aggregation, i.e., having a higher aggregation degree.



(a) Flow speed 80km/h.



(b) Flow speed 112km/h.

Figure 12. Energy cost vs. aggregation degree at flow speed: (a) 80 km/h and (b) 112 km/h.

VI. CONCLUSION

In this paper, we propose a service delivery model via V2X in a vehicular network to improve the transmission efficiency and reduce energy costs. This model can effectively provide vehicles with real-time traffic and environmental information required for selecting the best routes to their destinations and avoiding traffic accidents or congestions.

A combined weighting metric is introduced in this paper and applied to the formation of clusters. The CH is selected based on the mobility and connectivity of vehicles to ensure the stability and efficiency of data exchange and service delivery. An energy model is also presented in this paper to provide an effective analytical tool for energy performance characterization comprising of both uplink and downlink transmissions.

As only CHs are responsible for direct communication with RSUs and dissemination of service data to other vehicles in the network, the cluster-based V2X approach presented in this work can significantly enhance service delivery efficiency and improve energy performance. This has been shown by simulation results, in terms of service ratio, average service delay, throughput and energy cost, in comparison with the performance of the V2I dominated non-cluster model.

Future work will consider more complicated scenarios in highway settings. The data aggregation method will be extended to develop specific data fusion and integration algorithms based on the information entropy theory. In addition, the two-way service model and associated energy analysis schemes will be established and investigated for developing a more realistic and optimized V2X service delivery platform.

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