Efficient V2X Data Dissemination in Cluster-Based Vehicular Networks

Yongyue Shi, Xiao-Hong Peng
School of Engineering & Applied Science
Aston University
Birmingham, UK
Email: {shiy9, x-h.peng}@aston.ac.uk

Guangwei Bai
Department of Computer Science & Technology
Nanjing Tech University
Nanjing, China
Email: bai@njtech.edu.cn

***Abstract*— Vehicular communications and networking technologies provide essential support for data services across a Vehicular Ad-hoc Network (VANET) and play a key role in the Intelligent Transport System (ITS). In this paper, we introduce a cluster-based two-way data service model that promotes efficient cooperation between Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications, or namely V2X, to improve service performance for vehicles and the network. Our results show that the cluster-based model can significantly outperform the conventional non-cluster schemes, in terms of service successful ratio, network throughput and energy efficiency.**

Keywords*— cluster; V2X communications; VANET; energy efficiency.

I. INTRODUCTION

With the rapidly increasing number of vehicles and complex road networks, traffic congestion, car accidents and large amount of energy consumption are among the main challenges in the development of smart mobility as part of the Intelligent Transportation System (ITS) [1]. To address these problems and ensure road safety and traffic efficiency, 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.

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 ITS in a complex traffic environment.

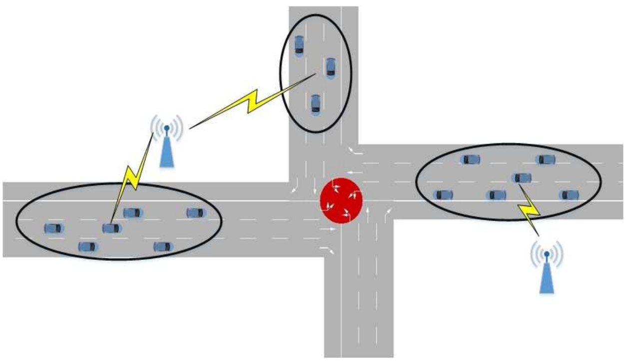

Figure 1. A VANET model with clusters

This paper proposes a V2X-based service system where the clustering technique is applied to improve transmission and energy efficiencies by significantly reducing 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, 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. Section III presents the clustering algorithm and applies it in the proposed data service model. Section IV 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 not inside 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 part 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

 ISBN: 978-1-61208-643-9

exchanging information and this will cost a significant amount 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 the 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] mainly considers 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 efficiency levels.

III. SERVICE MODEL THROUGH CLUSTERING

In MANETs, moving nodes 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 nodes 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.

A. Cluster Head Selection

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 behaviour 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

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

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

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:

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

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 neighbours, N_i. The ideal connectivity is denoted as σ, which represents the maximum number of neighbouring nodes within one hop without causing traffic congestion, and is given as:

$$\sigma = 2R_t \times 133 \times n_l / 1000 \tag{3}$$

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 to measure how close the N_i is to the ideal value σ, i.e.:

$$C_i = \left| N_i - \sigma \right| \tag{4}$$

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.:

$$D_i = \left| a_i \right| \tag{5}$$

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,

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

the weighting matrix, , is defined as

$$W_i = P_i' + V_i' + C_i' + D_i' \tag{7}$$

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.

When a vehicle detects itself as a free node (FN), it sends a vehicle information packet 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. If a vehicle generates a *Wi* that is smaller than a weight threshold, it will send a claim message with its weight *Wi* to the neighbours to announce its suitability for CH. Other nodes will compare the received *Wj* with their own weight and send claim messages to argue if theirs have a smaller weight than *Wi*. Otherwise, it will become the CH after a threshold window time and declare its identity as CH of its neighbours. This process takes place at either a fixed or varied interval(s) depending on traffic conditions given.

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.

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. 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 each including one control channel and 6 service channels. The control channel is used for exchanging control messages and safety information, while service channels are used for delivering service information packets.

B. *Service Delivery*

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 in the V2I links can be improved. Upon receiving the information from CH, RSU updates the database and generates the service packets requested by vehicles. Service packets are then sent via V2I to CH which will redistribute them to CMs via V2V.

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.

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. Denote the distance between two vehicles as $d_{i,j}$, then:

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

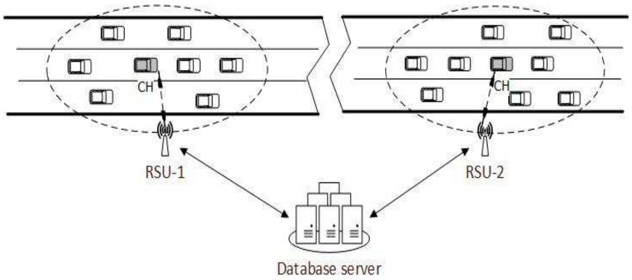

Figure 2. Cluster-based service model

Given the receiver sensitivity P_r, the required transmitting power of the i-th transmission by a vehicle, P_{ti}, is given by

$$P_{ti} = P_r \cdot L_{pi} \tag{9}$$

where L_{pi} is the path loss of this transmission link and represented by (assuming the free-space scenario)

$$L_{pi} = \left(\frac{4\pi d_i}{\lambda} \right)^2 G_t G_r \tag{10}$$

where d_i is the link distance, λ is the wavelength of the signal transmitted, G_t and G_r are transmitting and receiving antenna gains.

For cluster-based service delivery, the total transmitting power, P_{tc}, can be calculated as:

$$P_{tc} = \sum_{i=1}^{n-1} P_{V2V-i} + P_{V2I} \tag{11}$$

where n is the number of vehicles in a cluster, P_{V2V} is the transmitting power for V2V communications, defined as P_{ti} in (9), and P_{V2I} is the transmitting power for V2I communications.

For service delivery without clusters, the total transmitting power P_t, is simply the sum of individual vehicle transmission power all in the V2I mode, i.e.:

$$P_t = \sum_{i=1}^{n} P_{V2I-i} \tag{12}$$

C. *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:

$$\gamma = \frac{n_s}{n} \tag{13}$$

- 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:

$$\tau = \frac{\sum_{i=1}^{n_s} t_{si} + n_{us} \cdot t_p}{n_s} \quad (14)$$

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 which 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.

$$\eta = \frac{p_s}{T} \quad (15)$$

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

- Energy Consumption (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 consumption is given by

$$E_C = \frac{P_t}{\eta} \quad (16)$$

IV. SIMULATION AND RESULTS ANALYSIS

A. Simulation Setup

The traffic scenarios and communications models are simulated using SUMO [12] and OMNET++ [13]. 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 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 [14], 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. 3.

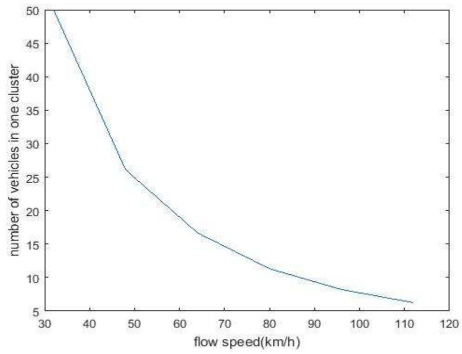

Figure 3. Service ratio under different flow speeds

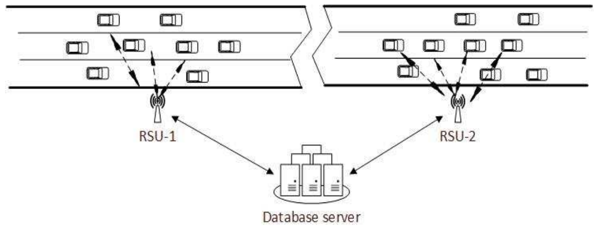

Figure 4. Non-cluster service model

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

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

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

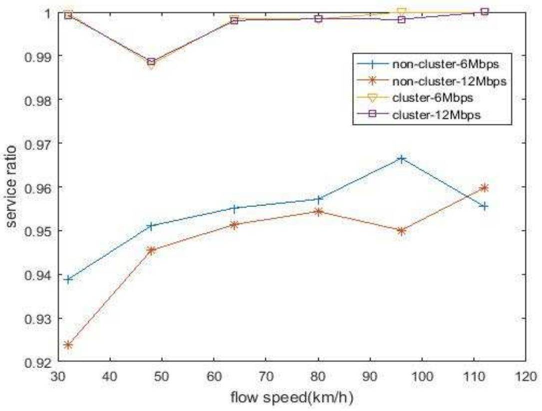

Figure 5. Service ratio under different flow speeds

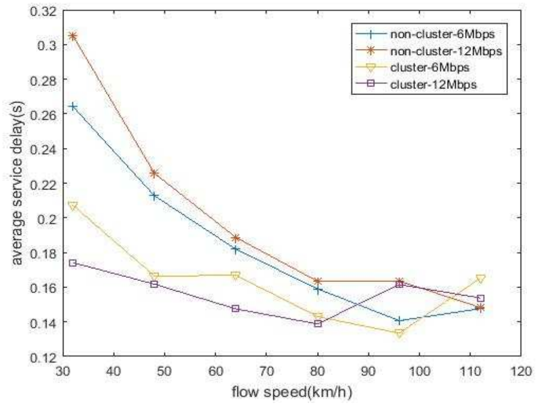

Figure 6. Average service delay under different flow speeds

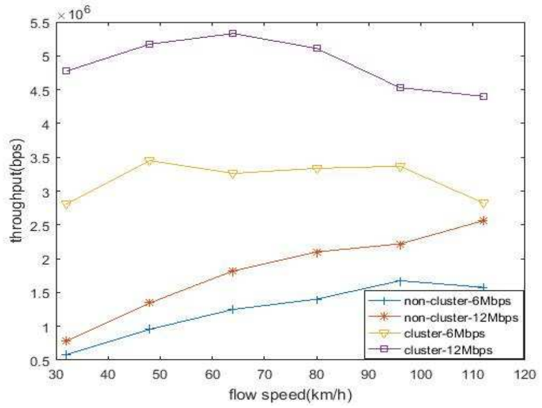

Figure 7. Throughput under different flow speeds

transmission power in different modes (V2V and V2I), which are adopted in simulations.

For the purpose of performance comparison with the proposed service model, we have also simulated the non-cluster model, as shown in Fig. 4 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 for the same set of performances, featuring the service ratio, average service delay, throughput and energy consumption.

B. Results analysis

Fig. 5 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. 6, 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. 6 is also correlated with the service ratio results shown in Fig. 5. 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. 7, 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. 8 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. 3, lower congestion in data traffic and, as a result, higher throughput will be expected in this

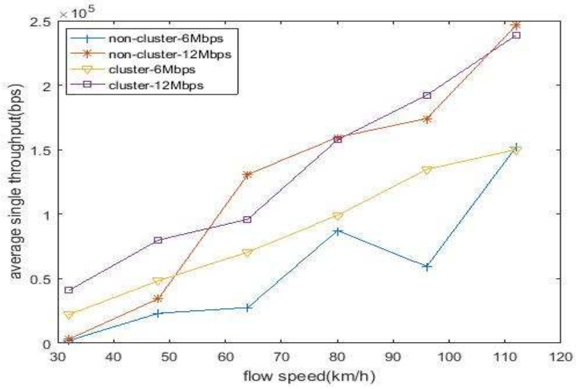

Figure 8. Average throughput of individual vehicles under different flow speeds

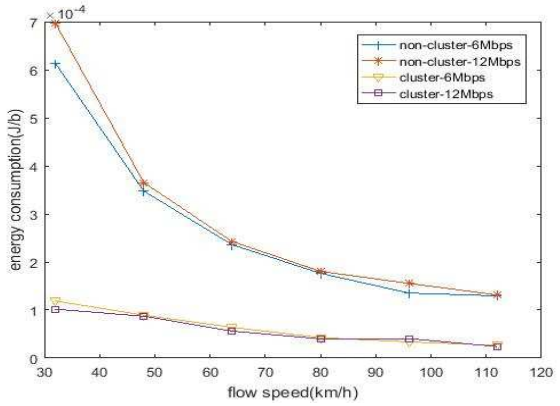

Figure 9. Energy consumption under different flow speeds

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 consumption performance in terms of Joule per bit is demonstrated in Fig. 9 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. 9. 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.

V. CONCLUSION AND FUTURE WORK

In this paper, we propose a service delivery model via V2X in a vehicular network to improve the transmission efficiency and reduce energy consumption. This model can effectively provide vehicles with real-time traffic and environmental information 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 form 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. 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 reduce energy consumption. This has been shown by simulation results, in terms of service ratio, average service delay, throughput and energy efficiency, 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 efficient V2X service delivery platform.

REFERENCES

[1] A. M. Vegni, M. Biagi, and R. Cusani, Smart Vehicles, Technologies and Main Applications in Vehicular Ad hoc Networks, 2013.

[2] H. Noori and M. Valkama, "Impact of VANET-based V2X communication using IEEE 802.11 p on reducing vehicles traveling time in realistic large scale urban area," Proc. International Conference on Connected Vehicles and Expo (ICCVE), 2013, pp. 654-661.

[3] K. Liu, et al., "Network-coding-assisted data dissemination via cooperative vehicle-to-vehicle/-infrastructure communications," IEEE Trans. on Intelligent Transportation Systems, vol. 17, pp. 1509-1520, 2016.

[4] Q. Wang, P. Fan, and K. B. Letaief, "On the joint V2I and V2V scheduling for cooperative VANETs with network coding," IEEE Trans. on Vehicular Technology, vol. 61, pp. 62-73, 2012.

[5] Y. L. Morgan, "Notes on DSRC & WAVE standards suite: Its architecture, design, and characteristics," IEEE Communications Surveys & Tutorials, vol. 12, pp. 504-518, 2010.

[6] M. Jiang, J. Li, and Y. Tay, "Cluster Based Routing Protocol (CBRP). Draft-ietf-manet-cbrp-spec-01," txt, Internet Draft, IETF1999.

[7] M. M. C. Morales, C. S. Hong, and Y.-C. Bang, "An adaptable mobility-aware clustering algorithm in vehicular networks," Proc. Network Operations and Management Symposium (APNOMS), 2011 13th Asia-Pacific, 2011, pp. 1-6.

[8] I. Tal and G.-M. Muntean, "User-oriented cluster-based solution for multimedia content delivery over VANETs," Proc. IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), 2012, pp. 1-5.

[9] M. Chatterjee, S. K. Das, and D. Turgut, "WCA: A weighted clustering algorithm for mobile ad hoc networks," Cluster Computing, vol. 5, pp. 193-204, 2002.

[10] R. D. Kuhne, "Greenshields' legacy: Highway traffic," Transportation Research E-Circular, 2011.

[11] B. Association, Code of Federal Regulations, Title 47: Parts 80-End (Telecommunications): Federal Communications Commission Revised 10/05: Claitors Pub Div, 2006.

[12] D. Krajzewicz, J. Erdmann, M. Behrisch, and L. Bieker, "Recent development and applications of SUMO-Simulation of Urban MObility," International Journal On Advances in Systems and Measurements, vol. 5, pp. 128-138, 2012.

[13] C. Sommer, R. German, and F. Dressler, "Bidirectionally coupled network and road traffic simulation for improved IVC analysis," IEEE Trans. on Mobile Computing, vol. 10, pp. 3-15, 2011.

[14] The Highway Code, https://www.gov.uk/guidance/the-highway-code.

 ISBN: 978-1-61208-643-9