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Software-Defined Management Model for Energy-Aware Vehicular Networks

Elif Bozkaya, Berk Canberk*

Department of Computer Engineering, Istanbul Technical University, Ayazaga 34469, Istanbul-TURKEY

Abstract

This paper investigates the energy efficiency of Road Side Units (RSUs) by proposing a novel flow and energy management model in Software-Defined Networking (SDN)-based vehicular networks. In the considered scenario, high vehicular mobility and limited coverage area of RSUs cause a degradation in Quality of Experience (QoE) of vehicles and this significantly affects the quality of communication by decreasing the percentage of flow satisfied. In addition, the growth in energy consumption of RSUs leads to inefficient network management. Being inspired from SDN, a centralized controller can schedule RSUs by providing a fair share of network resources and reduce the total energy consumption of RSUs by switching on/off. More specifically, in this paper, the controller classifies to vehicles based on QoE and defines unsatisfactory vehicles. Then the controller estimates the right amount of power level of these vehicles to connect a new assigned RSU. In this manner, RSUs can be scheduled by switching on/off so that the growth in energy consumption of RSUs can be managed. The evaluations show that the proposed model provides a better flow satisfied and throughput by guaranteeing energy efficiency in SDN-based vehicular networks.

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1. Introduction

Energy saving technologies for vehicular networks have been widely studied in order to manage increasing data traffic and then decrease total energy consumption. Here, RSUs are the dominant contributing components to the overall energy consumption of the network. It is estimated that the cost of energy will increase in the near future. Therefore, in order to reduce energy consumption of RSUs, the position of RSUs and their coverage areas have a great importance[1].

The expansion of mobile and communication technologies creates both challenges and opportunities. On one hand, vehicles can communicate with each other and provide high quality data. On the other hand, any interruption in a service is essential. In particular, it is a challenge to meet QoE of a task in vehicular networks. Here, high vehicular mobility and limited transmission range of RSUs are two performance limiting factors that affect the quality of communication. Moreover, due to the limited bandwidth of IEEE 802.11p based vehicular communication, providing a fair share of network resources among vehicles brings a crucial problem in terms of flow management.

There is a novel opportunity to address many challenges in vehicular networks: SDN paradigm. SDN overcomes many challenges with a flexible and programmable configurations [2]. Intelligence decisions given by a centralized controller can overcome the complexity of the many task by providing efficient solutions. In SDN-based vehicular networks, a centralized controller has the information to manage RSUs and vehicular nodes so that it can decide whether changing the mode of RSUs (switching on/off) and the transmission power of vehicles according to network conditions. This also enables to reduce interference occurred by transmission of vehicles. Therefore, with the cooperation of SDN and IEEE 802.11p based vehicular communication, a centralized and programmable controller can manage to RSUs by deciding the mode of them and scheduling existing data flows. Then, vehicles can connect to RSUs in order to achieve a higher QoE in vehicular networks. Hence, the characteristics of both wireless technologies,

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*Corresponding author. Email: canberk@itu.edu.tr

[1] Note that this study is an extended journal version of IEEE International Workshop on Advances in Software Defined Radio Access Networks and Context-aware Cognitive Networks 2015 (IEEE SDRANCAN-2015) in conjunction with IEEE Global Communications Conference (IEEE GLOBECOM 2015), entitled "QoE-based Flow Management in Software Defined Vehicular Networks" [1].

IEEE 802.11p based vehicular communication and SDN, are combined to enhance the percentage of flow satisfied by guaranteeing energy efficiency, and then used simultaneously in vehicular networks.

To this end, we concentrate on enhancing flow satisfied and reducing energy consumption of RSUs in SDN-based vehicular networks. To achieve these, we propose a software-defined flow and energy management model with the cooperation of SDN and IEEE 802.11p based vehicular communication. In the network topology, RSUs are modeled by using queuing theory analytics to handle data flows. Each RSU aggregates data flows and serves to vehicles within the transmission range of it. Then controller classifies to each vehicle as unsatisfactory vehicle or satisfied vehicle depending on QoE. Here, we decide minimum number of active RSUs to serve all vehicles in the topology. Depending on the distribution of vehicles within each RSU and the transmission requests of each vehicle, the controller assigns each vehicle to a particular RSU so that RSUs can extend the coverage area and then the number of active RSUs can be minimized. Energy efficiency can be achieved if as many as possible RSUs switch off. To this end, in order to save energy, this paper presents a way to improve total network energy efficiency by managing RSUs with switching on/off.

More specifically, in order to coordinate transmission demand of vehicles with an acceptable QoE level, flow management model is implemented into controller. The proposed flow management model classifies to vehicles and detects to unsatisfactory vehicles. Then it fairly distributes to unsatisfactory vehicles to a particular RSU. In the energy management model, controller estimates the optimal signal levels of the unsatisfactory vehicles with a spatial estimation method. Then the controller decides the mode of each RSU to reduce energy consumption.

Here, Kriging interpolation method is used to estimate the signal level of unsatisfactory vehicles as spatial estimation method in energy management model. This method enables to find optimal prediction by utilizing observed measures. Vehicle informations including position, speed, direction are used to estimate optimal signal level of unsatisfactory vehicles.

Moreover, we redefine flow label field in OpenFlow flow table to transmit obtained results with the presented model so that controller can manage to RSUs in vehicular network.

As a result, this paper makes the following main contributions to provide an effective solution for the energy efficiency in SDN-based vehicular networks.

- We present a novel flow and energy management model to detect unsatisfactory vehicles and then estimate the right amount of power level of these vehicles to assign a particular RSU in SDN-based vehicular networks so that RSUs can be switched off to reduce energy consumption and network throughput can be also enhanced.
- We redefine flow label field in OpenFlow flow table in order to keep the connection between controller and RSUs so that controller can schedule RSUs by switching on/off.
- Our proposed model enables to model highly dynamic vehicular network topology by considering vehicles' speed and direction.

The remainder of this paper is organized as follows: Section II summarizes the related works on SDN-based vehicular networks. Section III defines the proposed network architecture. After that, Section IV gives the proposed system model consisting of flow and energy management model. Section V evaluates the performance of the proposed model and finally conclusions are drawn in Section VI.

2. Related Work

Being a new paradigm in the literature, there exist many efforts regarding the SDN-based vehicular networks. [3] presents SDN-based VANET architecture and gives its operational modes which consists of central control mode, distributed control mode and hybrid control mode. Software-defined VANET benefits and services are defined. The routing protocols and transmission power adjustment of SDN-based VANET and traditional VANET are compared with each other. [4] proposes Type-Based Content Distribution approach by considering the distribution of real-time traffic information and bandwidth-intensive content distribution in SDN-based vehicular networks. According to these two types of content, the presented method takes a push-and-pull pattern in order to transmit to content. The authors aim to minimize the effect of disconnection while vehicles transmit the data and balance reliability and redundancy of the content. [5] proposes a RSU cloud for communication and computational infrastructure by implementing SDN technology. The proposed model consists of RSU microdatacenter and traditional RSU. Based on the demand, RSU clouds can be dynamically reconfigured to meet the quality of service.

Moreover, flow management for vehicular networks has been investigated to overcome the challenge of ineffective resource allocation and system overload. [6] focuses on admission control problem in order to make decisions for new coming flow requests in vehicular networks. Due to the limited transmission range and mobility, a service cannot be achieved in time. By considering overloaded conditions, the authors predict the total data size that can be transmitted to/from a vehicle. However, it is assumed that each vehicle has only one flow request so that highly dynamic vehicular network topology cannot be simulated. [7] presents an analytical model for flow admission control with SDN in 5G network architecture. A load balancing mechanism is proposed to reduce unsatisfied-user percentage based on the user-preference and their priorities so that flow resource allocation is enhanced when compared to no load balancing condition. However, the authors assume that the users move in a random manner. Thus, the proposed model cannot be implemented in SDN-based vehicular networks.

[8] proposes a novel SDN-based vehicular network architecture by combining with Fog Computing. The proposed model aims to optimize resource utility and reduce latency in surveillance services. To optimize resource utilization, SDN controller controls all network behaviors. Here, the solutions for the proposed architecture and the model need to be simulated using a simulator. Therefore, the results should observe in a real test-bed and then evaluate in terms of resource management.

In addition, many approaches have been proposed in the literature for the power management in vehicular networks. [9] presents an interference-based capacity analysis in vehicular networks. The distance between vehicles are considered to model vehicles' mobility and the car-following model is used. The probability density function of SIR at the receiver is derived for a general interfering scenario. However, 1D vehicular environment is considered and this cannot reflect a realistic vehicular environment. [10] proposes a spectrum decision mechanism to decide channel usage. Here, local observation Signal to Noise Ratio (SNR) and decisions of the users are considered to obtain cooperative decision in the presented SNR Tracking System. [11] proposes an analytical model to optimize throughput of VANETs by determining transmission probability. The work models dynamic behavior of vehicles, reduces interference and then throughput is maximized with the obtained optimal transmission probability. However, a simple VANET scenario is considered as a single-lane road with one traveling direction and constant velocity for each vehicle. The transmission is established between adjacent vehicular nodes to mitigate interference. Due to these assumptions, the impacts of vehicular network characteristics cannot be observed with the proposed model. [12] proposes a resource sharing communication mode that vehicles can access the same resources for their individual transmissions. To overcome resource sharing problem for V2V and V2I, two interference graph-based resource-sharing schemes are presented. The authors aim to reduce communication overhead and improve the network performance in terms of network sum rate. Here, resource-sharing communication mode is based on the design of interference management protocol and an efficient interference management protocol can be implemented after proper clustering of both V2V and V2I communication link are achieved. [13] analyzes self similar behavior of the VoIP traffic and models VoIP data using Fractional Gaussian Noise in a heterogeneous wireless network. Hurst parameter that shows the degree of self similarity, is calculated using Hurst estimators. Here, the value of Hurst parameter depends on the correlation between packets. A similar consideration will discuss in the presented estimation methods in the energy management module.

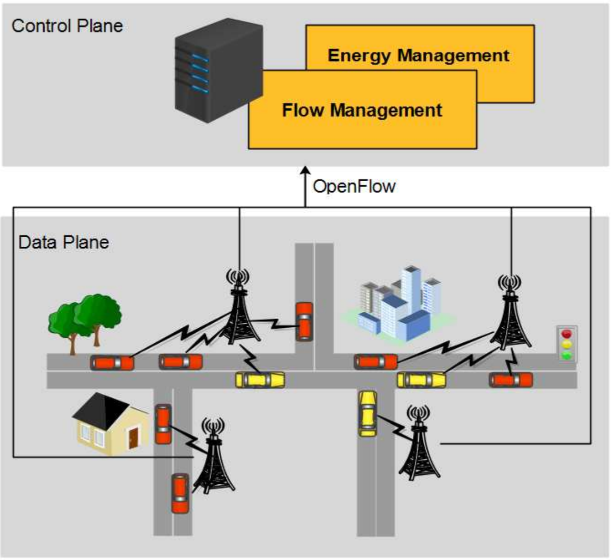


Figure 1. Considered energy-aware vehicular network architecture.

Although many approaches have been proposed in the literature to address flow and energy management in vehicular networks, none of these approaches provides a fair share of network resources among vehicles by providing energy efficiency with the help of SDN paradigm.

3. Network Architecture Overview

This section describes the proposed SDN-based vehicular network architecture that consists of two components named as data plane and control plane as seen in Figure 1.

3.1. Data Plane

In data plane, RSUs are deployed along the road in order to serve the vehicles within the coverage area. The coverage area of RSUs and network resources influence the maximum number of vehicles served. Vehicles can only connect one single RSU at a time. All informations of vehicles including position, speed, direction, distance between vehicle and RSU, signal level are stored in RSUs.

Here, we are interested in the distribution of vehicles within each RSU. Each RSU can handle a limited number of transmission request by keeping the QoE above a threshold. Moreover, QoE of a vehicle is effected from the total number of vehicles that served by a RSU. Therefore, the position of vehicles, the distance between vehicle and RSU, the speed and direction of vehicles effect the flow satisfied. The communication between RSU and vehicles is provided using IEEE 802.11p based vehicular communication.

3.2. Control Plane

Control plane integrates the control and management of multiple-RSUs with the proposed flow and energy management model. The control plane consists of two modules named as Flow Management and Energy Management. The communication between control plane and data plane is provided using OpenFlow protocol.

In the flow management module, controller manages the number of flows in each RSU by keeping the connection between vehicles and RSUs. Here, depending on flow intensity in each RSU, two types of vehicles are defined [1].

- unsatisfactory vehicle: The distribution of vehicles within each RSU specifies the vehicle types. If the QoE of a vehicle is below a threshold, these vehicles are named as unsatisfactory vehicles. Especially, due to the limited network resources and vehicular mobility, QoE of each vehicle may change over time.
- satisfied vehicle: If the QoE of a vehicle is above a threshold, these vehicles can transfer data in an acceptable level and named as satisfied vehicles.

In the energy management module, controller estimates the right amount of transmission power of unsatisfactory vehicles. Then, it presents a way to improve total network energy efficiency by managing RSUs with switching on/off so that total energy consumption of RSUs is reduced. The mathematical notations used in the paper is given in Table 1.

As in [1], we model to RSUs with M/M/1/K queuing model and calculate flow satisfied of each RSU. Then we determine the percentage of total number the vehicles waiting in the queue, which also represents the percentage of unsatisfactory vehicles in the vehicular network topology, as given by Eq.1.

$$E(L^q) = \frac{\sum_{i=1}^{j} E(L_j^q)}{\sum_{i=1}^{j} n_i}100 \qquad (1)$$

Table 1. Mathematical Notations

Notation	Description
n_j	Number of vehicles within the transmission range of RSU_j
j	total number of RSUs
P_0	The probability that RSU_j is idle
$E(L_j^q)$	The number of vehicles waiting in the queue of RSU_j
K	Maximum number of flows that can be served in RSUs
$E(L^q)$	Percentage of unsatisfactory vehicles
U_j	Utilization of RSU_j
$Z(t, x_i, y_i)$	SINR
P_i	Transmission power of vehicle i
P_{no}	Noise power
w_i	Kriging coefficient

where $E(L_j^q)$ is the number of vehicles waiting in the queue of RSU_j and equals to $\sum_{i=1}^{K}(n-1)P_n$. n is the number of vehicles within the transmission range of RSU_j.

Then, utilization of RSU_j is obtained in Eq.2.

$$U_j = Pr\{n_j > 0\} = P_1 + P_2 + P_3 + ... + P_K = 1 - P_0 \qquad (2)$$

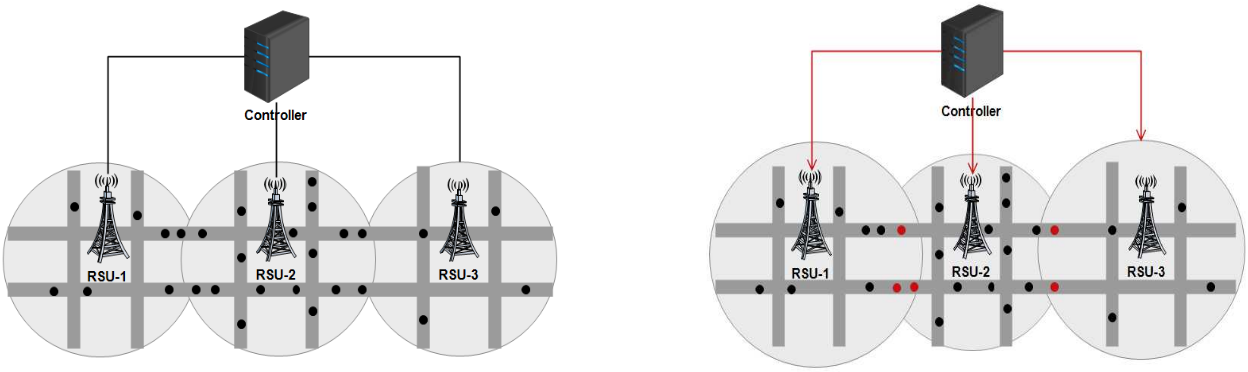
In this paper, our aim is to manage RSUs by controller so that we can schedule the mode of RSUs in terms of switching on/off in such a highly dynamic network topology. Moreover, we also enable a fair share of network resources in vehicular networks. For instance, in Figure 2(a), RSU-2 serves more vehicles at a time when compared to RSU-1 and RSU-3 and this can result with a degradation of QoE of each vehicle within the transmission range of RSU-2. Therefore, the controller evaluates the distribution of vehicles in each RSU and detects the unsatisfactory vehicles. This will be detailed in the next section. Then, as seen in Figure 2(b), vehicles within the RSU-2 can be assigned a new RSU according to their positions. Here, we estimate the power level of vehicles to connect a particular RSU by minimizing the interference.

4. System Model

4.1. Flow Management [1]

In the flow management model, we determine the flows between RSU and vehicle as seen in Figure 3. Flow is defined as a sequence of one control connection between vehicle and RSU to initiate the connection, and then data connection sent from the vehicle to a particular RSU to begin transmission at time interval t_0 and t_1 [1].

Here, controller manages to RSUs in order to schedule of their modes. At first, it is required to



(a) (b)

Figure 2. (a) Each vehicle is served by a RSU in the vehicular network topology (b) The controller manages to RSUs by coordinating vehicles with the proposed model.

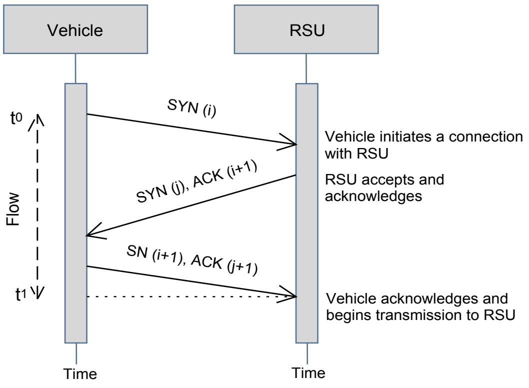


Figure 3. Flow establishment [1].

detect unsatisfactory vehicles and then connect them a particular RSU. To achieve these, flow management algorithm is implemented into controller. The flowchart of proposed flow management algorithm is given in Figure 4.

This algorithm detects unsatisfactory vehicles by evaluating QoE of vehicles within each RSU. Here, each RSU aggregates flow requests within the coverage area and then calculates flow satisfied. If the QoE of vehicles is below a threshold, these vehicles are connected to a new assigned RSU. Hence, RSUs in the topology are determined in order to assign these vehicles with an acceptable QoE. Then new assigned RSU and unsatisfactory vehicle are given to energy management module as an input to adjust their power level.

As seen in Figure 5(a), flow table in conventional OpenFlow protocol defines to each flow and how it should be handled to apply matching packets. The controller is responsible for managing the flow table by handling packets. The flow table contains a set of flow entries including match fields. If a matching field is found, then the instructions related to this specific flow entry is executed. The match fields include a flow label field as shown in Figure 5(b). The flow label defines a flow as a sequence of packets from a source to destination for which the source desires special handling [14]. Relating the flow label field, how it should be used or any specifications about the QoS provisioning is not described [14]. Therefore, this enables more functionalities and flexibility in the network management.

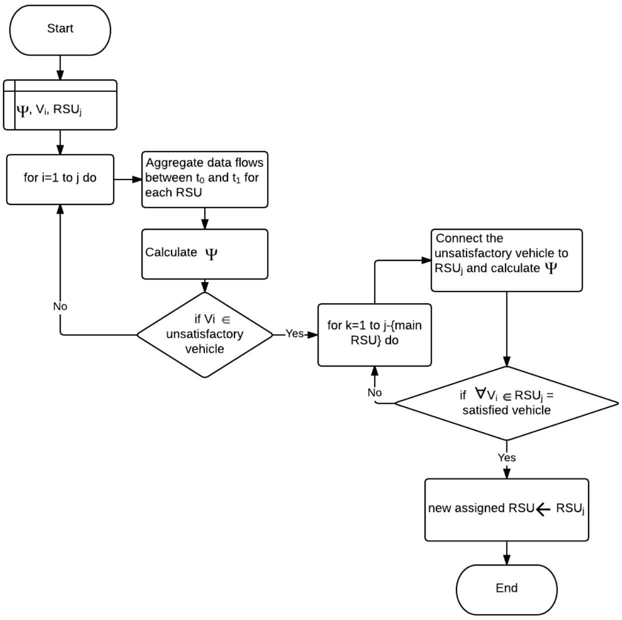
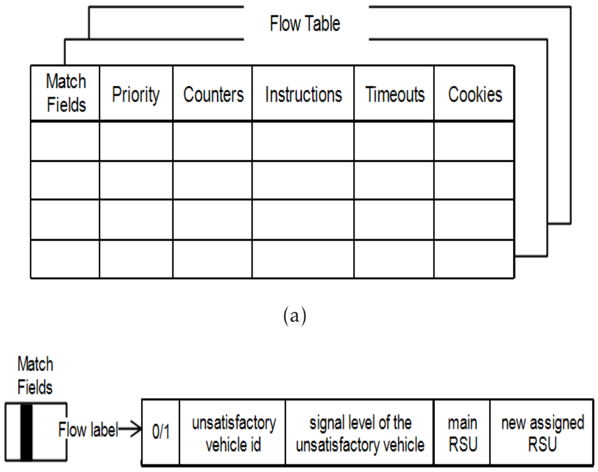


Figure 4. Flowchart of Flow Management Algorithm.

In the proposed architecture, we redefine ”Flow Label” field that divided into 5 parts including the mode of RSU, as represented in Eq.3, unsatisfactory vehicle id, signal level of this vehicle, main RSU and



(a)

(b)

Figure 5. (a) Flow table in OpenFlow (b) Redefined flow label field in match fields.

new assigned RSU. This is determined in order to schedule to RSUs and coordinate the signal level of vehicles by controller. This specification will enable to manage RSUs and then provide more energy efficiency in vehicular networks.

$$a_j = \begin{cases} 0, & \text{if } RSU_j \text{ switched off} \\ 1, & \text{if } RSU_j \text{ switched on} \end{cases} \tag{3}$$

4.2. Energy Management [1]

Energy efficiency can be achieved if as many as possible RSUs switch off. To this end, in order to decrease the energy consumption of RSUs, we schedule to RSUs based on the vehicles' locations. Here, we decide minimum number of active RSUs to serve all vehicles in the topology. Depending on the distribution of vehicles within each RSU and the transmission requests of each vehicle, we assign each vehicle to a particular RSU so that the number of active RSUs can be minimized.

In order to estimate the signal level of unsatisfactory vehicles at the location (x_0, y_0), we use Ordinary Kriging interpolation method as spatial estimation method in energy management model. Kriging is an interpolation technique to estimate a variable at an unknown location from the observed values at nearby locations in geostatistics. In Kriging, the variation and distance between known data points are weighted depending on spatial covariance values and then unknown value is predicted by utilizing the weighted average of the observations. Weights are based on the observed values of surrounding data points. The covariances and obtained Kriging weights are defined based on vehicle configuration and distance between vehicular nodes.

This method uses semivariogram analysis to determine the spatial correlation of two sample locations, does not depend on their absolute location but only on their relative location [15]. For further information about this method, [15], [16] and [1] can be referred.

As in [1], we calculate the spatially estimated SINR of unsatisfactory vehicle at location (x_0, y_0) for three different models, can be expressed as follows:

$$Z^{exp}(t, x_0, y_0) = \sum_{i=1}^{N} w_i^{exp} Z^0(t, x_i, y_i) \qquad \forall i \in N \tag{4}$$

$$Z^{gauss}(t, x_0, y_0) = \sum_{i=1}^{N} w_i^{gauss} Z^0(t, x_i, y_i) \qquad \forall i \in N \tag{5}$$

and

$$Z^{lin}(t, x_0, y_0) = \sum_{i=1}^{N} w_i^{lin} Z^0(t, x_i, y_i) \qquad \forall i \in N \tag{6}$$

where $Z(t, x_0, y_0)$ represents SINR level and w_i is the Kriging coefficient.

Moreover, we define throughput, c, as the number of packets successfully transmitted by all vehicles per unit time for each scheme as given by Eqs. 7, 8 and 9, respectively so that we observe the efficiency of the proposed model.

$$c^{exp} = Wlog_2\left(1 + \sum_{i=1}^{N} (Z^{exp}(t, x_0, y_0))\right) \tag{7}$$

$$c^{gauss} = Wlog_2\left(1 + \sum_{i=1}^{N} (Z^{gauss}(t, x_0, y_0))\right) \tag{8}$$

and

$$c^{lin} = Wlog_2\left(1 + \sum_{i=1}^{N} \left(Z^{lin}(t, x_0, y_0)\right)\right) \tag{9}$$

where N and W are the number of vehicles and channel bandwidth, respectively.

The throughput is also calculated when there is no mechanism to distribute to vehicles to RSUs and then adjust their signal levels as follows:

$$c = Wlog_2\left(1 + \sum_{i=1}^{N} (Z(t, x_i, y_i))\right) \tag{10}$$

As a result, in the proposed flow management model, we detect to unsatisfactory vehicles and then we assign each of them to a particular RSU. In the energy management model, we estimate the right amount of signal level to connect new assigned RSU by minimizing interference. In addition to implementation of these modules, we also propose a solution for the energy efficiency of the network. In this respect, controller

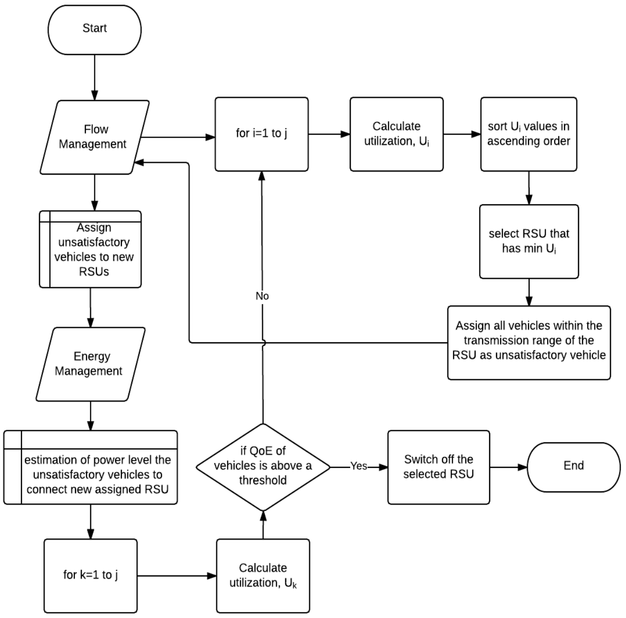


Figure 6. Flow Diagram of Energy Management Module.

calculates the utilization of each RSU as given in Eq.2. Then the obtained utilization values are sorted in ascending order and in each step, controller selects a RSU that has minimum utilization value. Here, the controller defines the vehicles within the transmission range of this RSU as unsatisfactory vehicles so that these vehicles are also given as input in the flow management module. Then the power levels of unsatisfactory vehicles are estimated in energy management model. After that, controller calculates the utilization of each RSU in the topology. If the QoE of vehicles is an acceptable level, then the selected RSU is switched off. Otherwise, the next RSU that has minimum utilization value is selected to apply all these steps again. The system flow diagram is given in Figure 6.

4.3. Mobility Model

This work deals with the weighted linear combinations of the measured data and spatial representation of vehicular environment. Here, we consider 2D vehicular environment and we interest in both distance between vehicles and geographic location of each vehicle. We assume that the distance between vehicles is built as a function the current vehicle positions, velocities and directions of vehicles. The information about vehicular mobility is obtained from the presented spatial estimation method, named as Kriging. Kriging enables to model dynamic behavior of vehicles.

More specifically, Kriging provides a suitable representation for the distinct characterization of vehicular networks such as vehicular mobility. The robustness of Kriging enables to observe the main parameters of mobility including velocity and direction, and the covariance between data values at any two vehicle locations depends on the mobility parameters.

In Kriging, when the covariance between each of sample point increases, the accuracy of the prediction will increase. It means that when the data points are closer to each other, then nearest data samples carry significant weight so that error variance is minimized and optimal and unbiased estimates are obtained. Semivariogram calculates the distance between all vehicle pairs within the range of unsatisfactory vehicle and this information provides the clustering of the available sample data in the topology. Here, w_i is adjusted according to clustering with the help of semivariogram. Therefore, Ordinary Kriging estimates the unknown values based on distance and clustering.

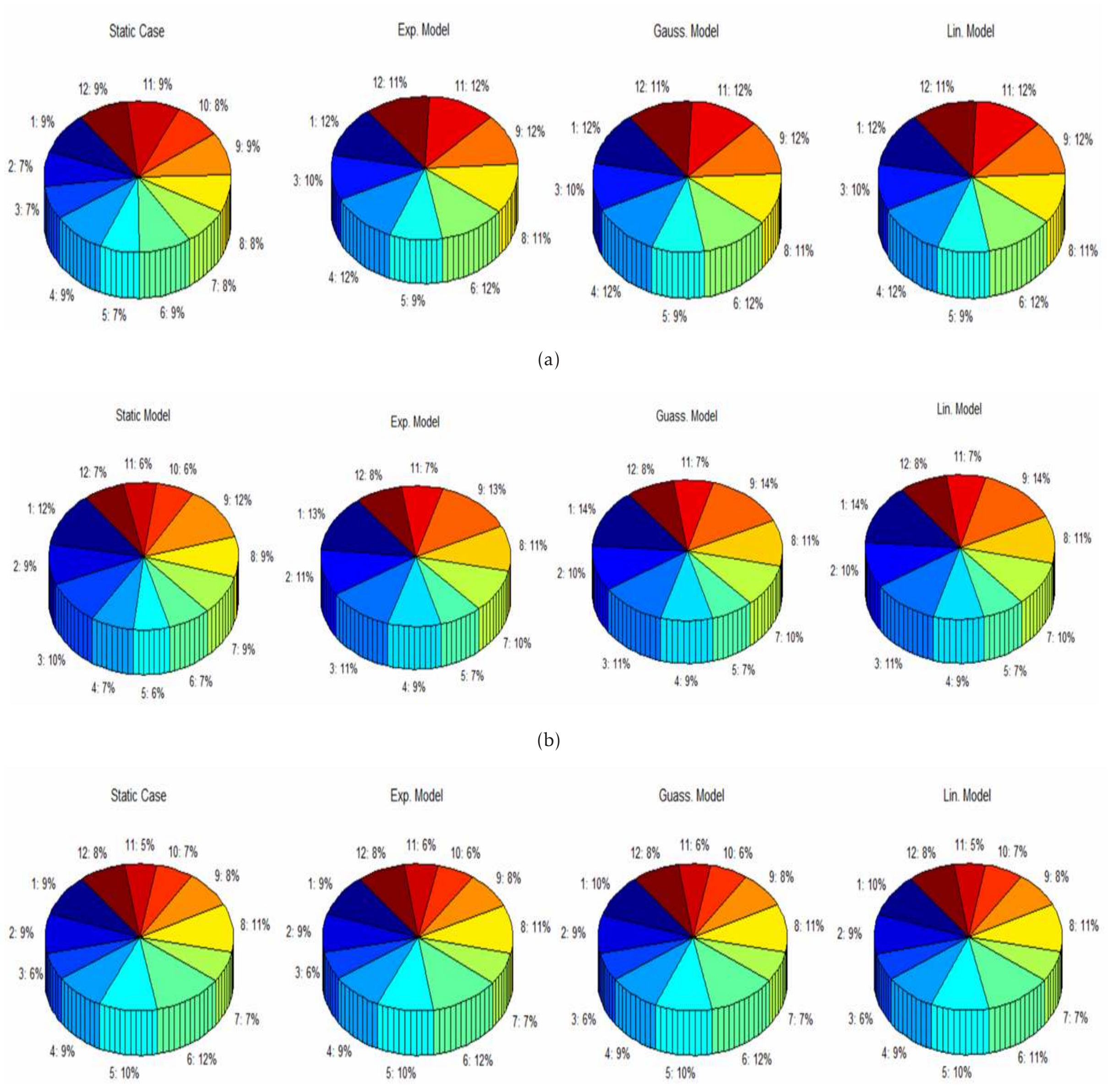
5. Performance Evaluation

The main objective of the proposed model is to maintain a more flow satisfied and more energy efficiency in the network. In this work, two scenarios are considered in SDN-based vehicular network. MATLAB environment is applied for all system modules.

- Static Case: To evaluate the success of the proposed system model, we first observed the Static Case in the network. Static Case means that there is no mechanism to schedule data flows and RSUs with SDN paradigm. When a request arrives at a time, RSU will serve each vehicle without evaluating the QoE of vehicles and this can cause a degradation of QoE the vehicles. Moreover, there is no opportunity to change the mode of RSUs.

- The proposed scheme (SDN paradigm): In this approach, 3 estimation methods which are Exponential, Gaussian and Linear Model, are evaluated in SDN-based vehicular networks. Once the flow for the connection has been established, the QoE of each vehicle is updated. However, if there is no available resource for flow requests to achieve an acceptable QoE at a time, requests are waited in the queue to serve next slots. The controller allows to RSUs to connect any vehicle so that more vehicles can be served by scheduling data flows and RSUs can be switched off to increase energy efficiency of the network.

We assumed that RSUs are deployed along the road with a full coverage of the network topology. We consider a 2D vehicular network environment. In particular, we are interested in the scenario where each RSU can serve a limited number of vehicles which are located on a grid with a mean inter-RSU distance of R=300m at Static Case. All vehicles are distributed according to Poisson distribution with traffic density (vehicles/m), β and each vehicle connects to one



(a)

(b)

(c)

Figure 7. Flow satisfied proportions in percentages w.r.t RSU index (a) Traffic density, $\beta = 0.1$ (b) Traffic density, $\beta = 0.25$ (c) Traffic density, $\beta = 0.5$.

single RSU. RSUs are modeled according to M/M/1/K queuing model.

We consider 12 RSUs with varying number of vehicles with variable velocity between 10m/s and 20m/s according to traffic density. The movement of vehicles is considered normally distributed zero mean and unit variance. At initial situation of simulation, it is assumed that all vehicles have allocated maximum 23 dBm power, and packet size is 64 bytes. Noise power, P_{no}, sets to -99 dBm. Path loss exponent is equal to 2. The channel bandwidth allocates to 10Mhz. Here, RSUs aggregate data flows from the vehicles within the transmission range and handle a limited number of data flows in each time. In flow management model, controller classifies to vehicles based on QoE so that unsatisfactory vehicles are detected in the vehicular network topology. Then, in the energy management model, the optimal signal level is obtained to connect a new assigned RSU and enhance QoE of vehicles so that the number of active RSUs is minimized. To transmit these, flow label in OpenFlow flow table is redefined so that controller manages to RSUs by proposing some behaviors.

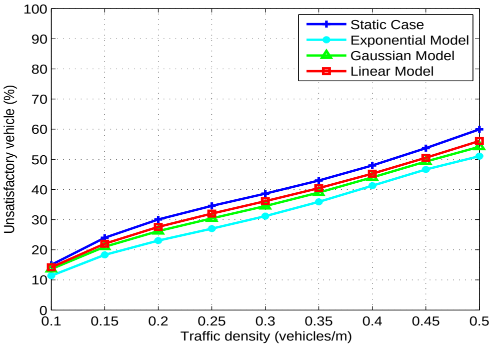


Figure 8. Unsatisfactory vehicle percentage w.r.t. traffic density.

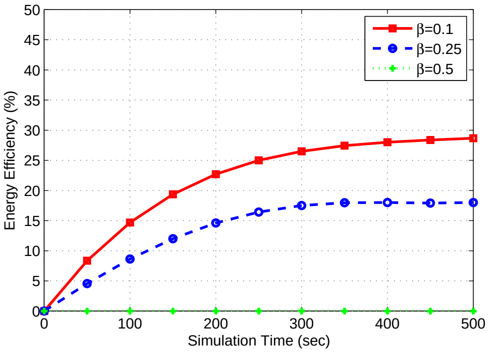


Figure 9. Energy efficiency w.r.t. simulation time.

In this respect, Figure 7 shows the flow satisfied proportions in percentages for each RSU depending on low, medium and high traffic densities, respectively. Flow satisfied is the percentage of number of flows that successfully transmitted to RSU to the number of all flows in the transmission range of a RSU.

In Figure 7(a), RSU-1, RSU-4, RSU-6, RSU-9 and RSU-11 achieve 100% flow satisfied in Static Case due to the low traffic density. After the implementation of the proposed flow and energy management model, unsatisfactory vehicles are detected and the vehicles within the transmission range of RSU-2, RSU-7 and RSU-10 are distributed to new assigned RSUs so that RSU-2, RSU-7 and RSU-10 are switched off in order to decrease total energy consumption of RSUs in the vehicular networks. In Figure 7(b), when the traffic density increases, the flow satisfied decreases. On the other hand, RSU-1 and RSU-9 serve all vehicles within the transmission range with an acceptable QoE. The vehicles within the RSU-6 and RSU-10 are distributed to new assigned RSUs by using flow management algorithm and RSU-6 and RSU-10 are switched off in traffic density, $\beta = 0.25$. However, we observe that when the traffic density is high, there is no guarantee to switch off RSUs as seen in Figure 7(c). In all situations, Exponential model achieves more flow satisfied in each traffic density. The explanation for the observation is that Exponential model estimates more optimal signal level of unsatisfactory vehicles as given in Eq.4 when compared to Gaussian and Linear models as given in Eqs.5 and 6, respectively so that vehicles keep the connection with new assigned RSUs by minimizing interference and more unsatisfactory vehicles will be served in each traffic density.

In addition, Figure 8 shows the percentage of total unsatisfactory vehicles in the vehicular network topology as given in Eq.1. Here, detection of unsatisfactory vehicles and then adjustment of their signal levels with the energy management model enable a degradation in the percentages of unsatisfactory vehicles. Exponential model enables to serve an average of 7% more unsatisfactory vehicle when compared to Static Case.

In this paper, our main goal is to implement a model that can reduce the energy consumption of the network by switching off RSUs. The positions of RSUs on the road and their coverage area effect the number of vehicles that can be served. Here, we are interested in the vehicles that are served in each RSUs so that controller can schedule the mode of RSUs depending on the distribution of vehicles in the topology. We observe that one of the critical factor is the distance between vehicles to minimize interference and it is measured with semivariogram. To achieve a higher energy efficiency, in the proposed energy management model, the spatially estimated SINR of unsatisfactory vehicles is calculated in Eqs.4, 5 and 6 and then the mode of RUSs is scheduled by controller.

In this respect, Figure 9 demonstrates the energy efficiency over the simulation time for each traffic density as described in Figure 6. When the traffic density is equal to 0.1 and 0.25, energy efficiency is achieved 29% and 18% with the proposed flow and energy management model, respectively. However, we also observed that when the traffic density increases such as $\beta = 0.5$, energy efficiency cannot be achieved as seen in the Figure 9. Here, all RSUs need to be active for a full coverage of the vehicular network environment depending on the distribution of vehicles in each RSU. However, it is clear that our model effectively decides the minimal RSU to connect all vehicles in the topology and guarantees a higher flow satisfied in each traffic density.

Moreover, we calculate throughput for the presented schemes and Static Case as given in Eqs. 7, 8 9 and 10, respectively. Recall that throughput is defined as the number of packets successfully transmitted by all vehicles per unit time. Figure 10 demonstrates the throughput over the simulation time when the traffic density is 0.25. The network throughput of the Exponential Model is significantly higher than that of Static Case. It can be clearly seen that the proposed flow

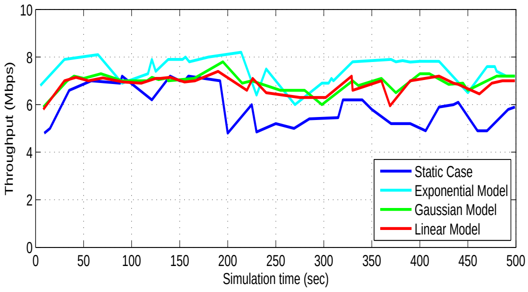


Figure 10. Throughput w.r.t. simulation time ($\beta = 0.25$).

and energy management model performs much better than Static Case.

6. Conclusion

In this paper, we propose a novel software-defined management model for flow control and energy efficiency in vehicular networks. Our goal is to enhance flow satisfied by keeping the QoE above a threshold and reduce the overall energy consumption of RSUs. In the proposed flow management model, we classify to vehicles based on QoE and determine unsatisfactory vehicles. In the proposed energy management model, we use Kriging as spatial interpolation method with three schemes, Exponential, Gaussian and Linear Models. At first, we estimate the optimal signal level of unsatisfactory vehicles so that vehicles connect to new assigned RSUs by mitigating interference. Then RSUs are scheduled depending on the distribution of vehicles and as many as possible RSUs are switched off. Moreover, we redefine flow label field in OpenFlow flow table so that controller manage to RSUs by proposing some behaviors. We observe that an average of 7% more unsatisfactory vehicle is served with Exponential model and energy efficiency is maintained by enhancing the percentage of flow satisfied and throughput.

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