Performance Improvement of Vehicular Ad Hoc Network Environment by Cooperation between SDN/OpenFlow Controller and IEEE 802.11p

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***Abstract*—Vehicular communication has recently become an active research issue in both academic and industry. Vehicular Network, by nature, could possess potential problems in connectivity, intelligence, scalability and flexibility. Networking technology nowadays is moving toward to Software-Defined Networking (SDN) concept where the network is mainly separated into two planes; control plane and data plane. OpenFlow is the most popular open interface for SDN southbound API. In this paper, we proposed the SDN application over Vehicular ad hoc Network (VANET) environment. We believe that the emerging SDN technology and IEEE 802.11p can be used to increase the efficiency and to bridge the gaps in VANET application. We hope to exploit the benefit of SDN by adopting POX/OpenFlow controller to process and perform message routing. A centralized controller is the key player to enable communication between vehicles and roadside unit (RSU). We evaluated the proposed work based on three simulation indicators, such as packet delivery ratio, throughput and packet delay time.**

***Index Terms*—Vehicular Ad Hoc Network; Software-Defined Networking; Openflow; POX; RSU; IEEE 802.11p.**

I. INTRODUCTION

The future world challenges include the affected development and new emerging technologies on information communication and technology (ICT), which need an enormous effort to improve the people's lifestyle to be "smart", such as smart motor systems, smart buildings, smart logistics, smart grids and smart vehicles. Intelligent Transportation System (ITS) application has become an influential tool in the current driving mode of safety road drivers in order to potentially exert the smart vehicles. Vehicle ad hoc network (VANET) is marked as an important element of ITS. VANET architecture consists of two forms of communications i.e., vehicle-to-vehicle (V2V) and vehicle-to-roadside unit (V2R/R2V). These communications are employed to provide safety and comfort for drivers, customers and other nearby users by efficient delivering of informative messages/packets to users' locations [1].

In addition, the improved protocol version of Dedicated Short Range Communication (DSRC) IEEE- 802.11p and Wireless Access in Vehicular Environment (WAVE) IEEE 1609 standard are designed for a wide variety of novel infotainment and road safety applications [2]. This standard is used for supporting GeoNetworking protocol for both V2V and V2R/R2V communication. IEEE 802.11p is promising to address the issues regarding rapidly moving vehicles and non-safety application and to demand the connection efficiency on complex roadway scenario. However, VANET deployments still face many challenges, such as unbalancing flow entry traffic management on multi-path VANET topology. Due to the limitation of IEEE 802.11p bandwidth, the interference and flow transmission are also considered as essential issue to improve vehicular network.

Meanwhile, Software-Defined Networking (SDN) is a recent emerged network that could be a solution to today's limitation of traditional network infrastructure. Generally, control plane and data plane are decoupled in SDN. OpenFlow protocol is a protocol used for interfacing between SDN controller and OpenFlow switch [3]. This separation enables faster configuration and provisioning of network connection. Empowering SDN into wireless communication can improve flexibility, efficiency and programmability, which are required for today's wireless network management and services. Intelligent network is centralized in software-based SDN concept, which could be controlled through standard traditional protocols and underlying network devices.

To bring the benefit of SDN into VANET, we believe that SDN is an appropriate choice to fulfill the gaps of vehicular network and limitation. In vehicular scenario, OpenFlow protocol, however, needs to be extended in order to support VANET requirement. The new architecture, benefits, services, processes and functionalities of software-defined vehicular ad hoc network were proposed. However, it only focuses on centralized control model and SDN-based routing compared to existing routing protocols. The evaluation of simulation result [4] considered packet delivery ratio only by comparing between SDN-based routing versus traditional ad hoc routing protocols and by applying SDN controller based on different velocity of vehicles. The simulation of potential operating systems and fallback mechanisms has been considered as feasibility study for VANET scenarios. In addition, a new routing protocol called Centralized Routing Protocol (CRP) has been proposed [5]. CRP is categorized into three main components i.e., central control, base station and vehicular switch. That reference was just to compare between the proposed CRP and traditional VANET routing protocols. It shows that extended SDN technology to VANET is more useful and CRP is performed with good packet delivery time and routing overhead. However, there is another similar work [6] concept that we consider applying in our work. It aims to focus on SDN technique and Geographic-based broadcast (GeoBroadcast) architecture that implements location management by using the SDN controller. The performance evaluation is performed in various scenarios such as static event, moving event and RSU transmission range overlaps. The results [6] show that the controller overhead and bandwidth consumption are significantly reduced. Meanwhile, our study focuses on IEEE 802.11p to forward messages with neighboring vehicles until it reaches all vehicles at destination location specified in messages, the message forwarding [6] is based on GeoBroadcast scheme. Moreover, Software-Defined Vehicular Network (SDVN) has been introduced [7]. It provides the opportunities and challenges of SDVN and also describes the SDVN system architecture and adaptation of high mobility in VANET based generic SDN. However, the evaluations [7] consider only the partial performance. One is packet delivery ratio in comparison to SDVN, structure-based protocol (optimized link state routing) and structure-free protocol (greedy perimeter stateless routing). The other is the packet delivered in comparison between with and without network slicing of two different scenarios i.e., sparse and dense traffic.

In this paper, we venture into the applicable performance of SDN/OpenFlow controller over VANET scenarios and comparison between VANET with and without SDN support of achieved performance. The cooperation between IEEE 802.11p based VANET and SDN can manage RSUs to achieve better performance. This study reports three performance metrics such as packet delivery ratio, throughput and packet delay time. Moreover, the simulated road network has been applied to an actual road network topology at Sathorn road [12], Bangkok, Thailand.

We present VANET architecture based SDN/OpenFlow concept overview and benefits in Section II. Performance evaluation and discussion are shown in Section III. And then, in Section IV, conclusion and future work are discussed.

II. SOFTWARE-DEFINED NETWORKING OVER VEHICULAR AD HOC NETWORK ENVIRONMENT

This architecture is designed based on the SDN concept. The control plane and data plane are the key components of SDN. OpenFlow protocol is deployed to communicate between these two planes. The abstraction of the existing VANET to integrate with SDN concepts is described as follows.

A. *Control Plane*

It is built to control all vehicles and RSUs in the data plane. It stores and operates the status of all SDN switches. It collects information of every vehicle such as vehicle location, speed, and network connectivity. It results in the topological network information based on localization device like global positioning system (GPS). Controller can use such information to determine forwarding decision. The controller will then find the most appropriate route for packets forwarding to reach destination.

B. *Data Plane*

It is constructed from network components, which provide connectivity. Network components consist of vehicles and RSUs are abstracted as SDN/OpenFlow switches. Vehicles are considered as dynamic data plane elements, while RSUs are supposed to be stationary data plane elements. These SDN switches apply different deployment policies. Configuration of each vehicle is provided via the control interface. In order to optimize the network configuration, status update of each vehicle is sent to SDN controller. IEEE 802.11p is used for V2V and V2R/R2V communication in vehicular network. All of the vehicles information contain position, velocity and direction and then will be stored in RSU based on OpenFlow's flow table.

C. *Openflow Protocol*

OpenFlow can be easily deployed in campus network and is mostly used for communication interface between the data and control plane of SDN architecture [3]. It consists of 3 main components i.e., OpenFlow switch, OpenFlow protocol and OpenFlow controller. OpenFlow switch is a switch located in the data plane or infrastructure layer of SDN model. There are at least 3 parts in OpenFlow switch, including flow table, secure channel and OpenFlow protocol. Each flow table contains at least one flow entry used for processing the flow in the switch. The secure channel is used to provide connectivity between the switch and the controller through OpenFlow protocol. The OpenFlow controller performs an important part to manage all the packets flowing in the network. A flow entry consists of match field, timeout and action. The information in the match field contains source and destination address. Timeout can be calculated by the vehicle's velocity and its distance to RSU.

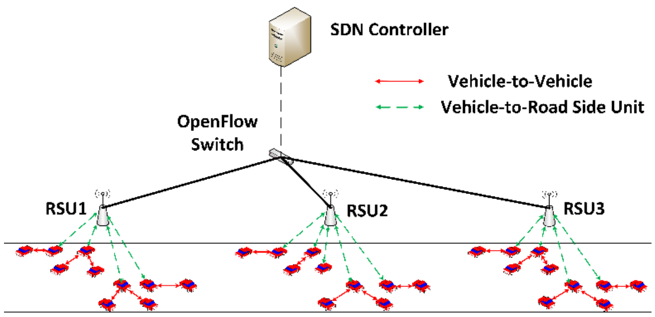

Figure 1: Architecture of VANET based on SDN concept

Our proposed work is to extend the benefit of SDN to bridge the gaps of nowadays' limitation in VANET environment. Figure 1 shows the proposed architecture of VANET based on SDN deployment concept. Moreover, SDN controller communicates with all RSUs by using OpenFlow protocol and RSUs use wireless interface (DSRC IEEE 802.11p) to connect with all vehicles within the coverage area. We assume that the RSUs track position of vehicles by using the GPS. The location information is then delivered to the SDN controller. Thus, we can estimate the distance between vehicles to RSU.

D. *Benefits*

The deployment of SDN technology over VANET environment can offer various benefits such as:

1. Overhead reduction: It can compute the optimal packet routing based on cooperation information network.
2. Extensibility: It refers to the capabilities extension of SDN/OpenFlow standard by supporting status update of each vehicles (i.e., position and speed information) in Flow table.
3. Central networking management: It creates the intelligence of connectivity among vehicles and can control all packet transmission.
4. Wireless adaptation: It can adapt to the different wireless such as DSRC, WiFi, LTE, etc.

E. DSRC IEEE 802.11P

DSRC IEEE 802.11p has a spectrum of 75MHz that occupies 5.850-5.925 GHz frequency band. The band is free but need to be licensed by regulation. Its spectrum is formed into seven 10MHz with one control channel (CCH) and six service controls (SCH) [2]. The periodic beacon transmission, which is used at 5.9GHz CCH is called cooperation awareness message (CAM). Moreover, this standard has a transmission range up to 1000m with the data transmission rate from 3 to 27 Mbps and uses the Orthogonal Frequency-Division Multiplexing (OFDM) modulation. It supports up to node's speed of 100 km/h that is practical for VANET application.

III. PERFORMANCE EVALUATION

To evaluate the effectiveness and feasibility of VANET-based SDN architecture, the simulator OpenNet8 and traffic simulator SUMO have been used in Ubuntu 14.04 LTS-64bit in one computer specification Intel-Core i5-3210M CPU @2.50GHz × 4 and RAM 8GB. To take the benefit of SDN over VANET, we used open source OpenFlow/POX controller [9].

A. Performance Metrics

Our simulation focuses on the performance outcomes of VANET at different speed and number of vehicles. The performance metrics used in this work include:

1. Packet delivery ratio (PDR): the ratio between the successfully received packets at the destination node and the successfully sent packets at the source node.
2. Throughput (TP): the ratio between total number of data packet size and the total simulation time.
3. Packet delay time (E2E): the period from the sending time to the received time of certain packet. One may realize that the performance is better when E2E has a small value.

The performance of VANET-based on SDN architecture is considered by varying some parameters in network density. The simulation parameters are shown in Table 1.

B. Simulation Environment

This section presents the simulation tools to conduct the experiment on VANET based on SDN controller. To evaluate VANET performance, we firstly generate the vehicular traces with SUMO 0.25.0 [10] by extracting the map from OpenStreetMap [11]. Secondly, we utilize OpenNet to simulate our work, which implement POX as SDN controller to manage the vehicles and RSUs spontaneously. The simulation traffic scenarios are located in urban areas and are the real traffic performance from Sathorn road [12], Bangkok, Thailand.

Table 1
Simulation Parameters

Parameters	Values
Emulator	OpenNet (NS3+miniet)
Controller	POX
Simulation Time (s)	200
MAC Protocol	IEEE 802.11p
No. of vehicles	25, 53, 98
Velocity (m/s)	5, 10, 15, 20, 25
Transmission range (m)	250
Packet size (byte)	1024
Mobility Model	SUMO trace (Sathorn Model)
Propagation Model	Propagation Loss Model
No. of RSUs	3

Figure 2: Sathorn Road Model with applied RSUs

OpenNet simulator is combined between mininet [13] and network simulator 3 (NS-3.22) [14]. It has been developed to enjoy the benefit of central controller in mininet and the capability of wireless modeling in NS3. We proposed to deploy 3 RSUs at the intersection along the road as shown in Figure 2.

C. Comparative Study

In our simulation, we compare between applying VANET with and without SDN. In order to discuss the proposed work in detail, we proposed to use an incident scenario. It assumes that there is a car accident or an ambulance located in a RSU's coverage area. The specified vehicle we mentioned above will transmit the warning message periodically to the neighboring RSU and all vehicles within transmission range.

a. VANET with SDN

Based on Figure 1, it is already shown the proposed architecture of VANET with SDN. It uses the 3 proposed RSUs, which are connected to an OpenFlow Switch via wired link. The source vehicle initiates a connection with the nearby RSU. After receiving the RSU replies with acknowledgement, the vehicle sends messages or packets to the RSU. In OpenFlow Switch, a flow entry information consists of match field, timeout and action. The "match field" has the source and destination addresses. A flow may contain many forward actions and different port as well. A flow entry is rejected if a switch cannot find the action list in the specified order. The "action" has many ports connected to all RSUs. Each RSUs inquires the route from the controller through OpenFlow Switch based on action of each flow entry. Moreover, time-out of OpenFlow standard is used as a specified time to remove flow entry. It is significantly useful in frequently changing environment. When messages arrive at the destination RSUs, it will broadcast among vehicles inside that RSUs' coverage area and neighborhood vehicles. The IEEE 802.11p is used for both V2V and V2R/R2V communication in vehicular network. In order to manage topology and routing, the controller is needed to list all RSUs' location or ID. This is particularly helpful to find the shortest routing for transferring messages from source to destination RSU when there are larger number of available RSUs.

b. VANET without SDN

In this scenario, we also proposed 3 RSUs at the same location as in Figure 2. Within these 3 RSUs, it is connected from RSU1 to RSU2 and from RSU2 to RSU3. The source vehicle also broadcasts warning messages or packets to all neighboring vehicles. The IEEE 802.11p is also used for both V2V and V2R/R2V communication. In addition, Ad-hoc On-demand Distance Vector (AODV) routing protocol is now used in this scenario. Every vehicle sends periodically the initiated messages to find its neighbors by broadcasting routing request (RREQ) packets. Vehicle also can communicate directly with RSUs in case there are no path between V2V communications.

D. Simulation Result and Discussion

In our simulation results, we consider only three performance metrics. In order to evaluate the proposed architecture of SDN over VANET environment. We compared the results between two cases; with and without SDN applying into VANET. Figure 1 shows the packet delivery ratio. The results show that the overall PDR decreases when the vehicle's speed is increased and the number of vehicles is decreased. As expected, routing fails when there are no communication link available between transmitter and receiver. At any value of vehicle's density, the PDR of VANET with SDN is higher than VANET without SDN. This is because the cooperation between IEEE 802.11p based VANET and SDN can manage RSUs in packet delivery flow.

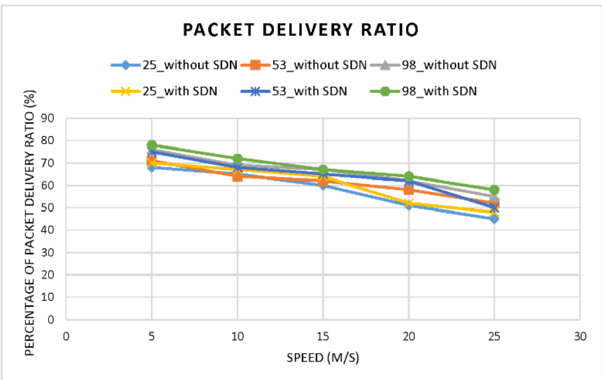

Figure 3: Packet Delivery Ratio Vs Node Speed

Throughput is illustrated in Figure 4. It indicates that VANET with SDN tends to observe more connections as compared VANET without SDN. However, the differences in the result are not significant for higher speed. Its results are slightly higher. With higher number of vehicles and higher speed, vehicles tend to amend its packet reception. It means that successful packet reception results in a better throughput.

The End-to-End Delays are almost the same in these three cases starting from slower speed, as shown in Figure 5. In this case, it notes that the overall packet delay time increases based on the increasing speed of vehicles. Their results show somehow that there is not much difference in this topology when comparing between VANET with SDN and without SDN. At higher speed of vehicles, VANET with SDN suffers more delay than VANET without SDN. This is because the message routing in VANET with SDN requires extra time to communicate with RSU and OpenFlow Switch.

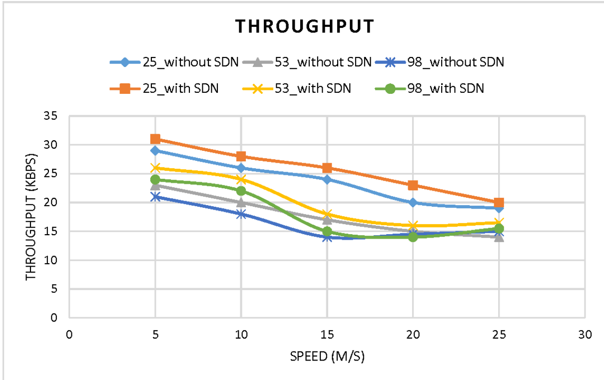

Figure 4: Throughput Vs Node Speed

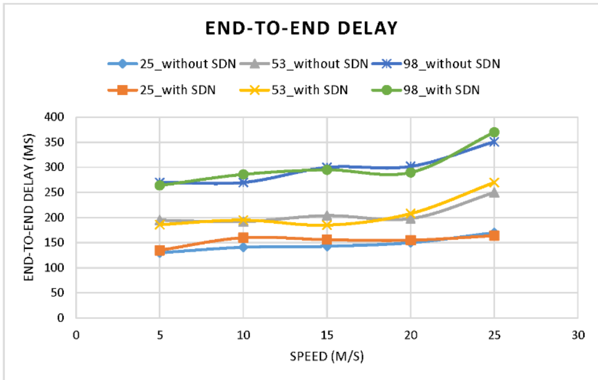

Figure 5: End-to-End Delay Vs Node Speed

IV. CONCLUSION

In this paper, we have proposed and studied the applicability of applying SDN over vehicular network environment. Performance results indicate that VANET with SDN generally performs better than VANET without SDN in term of packet delivery ratio and throughput. It shows the ability of cooperation between IEEE 802.11p based VANET and SDN. On the other hand, as the speed of the vehicle increases, VANET with SDN is performed with slightly higher than VANET without SDN. Based on these performance metrics, SDN is outperformed for VANET in Sathorn model with lower number of vehicles. For future work, the larger number of vehicles should be considered and controller overhead should also be included.

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