CROSS-LAYER NETWORK OPTIMIZATION TECHNIQUE FOR VEHICULAR ADHOC NETWORK

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ACKNOWLEDGMENT

In the Name of Allâh, the Most Beneficent, the Most Merciful.
Read! In the Name of your Lord, Who has created (all that exists),
Has created man from a clot (a piece of thick coagulated blood).
Read! And your Lord is the Most Generous,
Who has taught (the writing) by the pen,
Has taught man that which he knew not.
[AL 'ALAQ:1-5]

Syukur Alhamdulillah, I am most grateful, with all this while, I have been given the time by The Creator ***Ya Malik Ya Alim Ya Hakim Ya Rashid*** to complete the journey with this PhD thesis. Thank you Allahumma ***Ya Wahab Ya Karim***, all families especially my mother Nor Salaniah Harun and my father Abdul Halim Ahmad, all my friends including Rohani Farook, Norazita Marina, 'Aini Syuhada and Nazatul Syima; to my supervisors and not to forget each and every single person that have helped, motivate and encourage me throughout the journey.

Special dedication to slaves of ***Ya Rahman Ya Rahim Ya Wadud***:
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It is the most valuable experience to gain the knowledge and in the process to spread the knowledge to all. I hope with this small ilmu from ***Ya Alim***, it gives benefits and wisdom to others in this life journey here and hereafter. InsyaAllah.

- Amin Ya Rabbal 'Alamin –

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LIST OF ABBREVIATIONS

CF	Control Factor
CFOA	Control Factor Orthogonal Array
DSSS	Direct Sequence Spread Spectrum
FHSS	Frequency Hopping Spread Spectrum
ISM	Industrial, Scientific and Medical
LCF	Level of Control Factor
LNF	Level of Noise Factor
NIC	Network Interface Card
NF	Noise Factor
OA	Orthogonal Array
OSI	Open Systems Interconnection
PF	Performance Metrics

LIST OF SYMBOLS

Σ	Summation of

Teknik Optimasi Rentas-Lapisan Rangkaian untuk Rangkaian Ad Hoc Kenderaan

ABSTRAK

Rangkaian Ad Hoc Kenderaan (VANET) adalah jenis rangkaian ad hoc tetapi berbeza dari segi fungsinya kerana nod atau kenderaan mempunyai kelajuan yang tinggi, kepadatan nod yang pelbagai dan persekitaran komunikasi yang tidak menentu. Terdapat dua aplikasi utama dalam VANET iaitu aplikasi keselamatan dan aplikasi kemudahan. Pengoptimuman rangkaian adalah salah satu cara untuk mengekalkan protokol sedia ada dan parameter terlibat yang lain berbanding merekabentuk dan melaksanakan protokol baru yang lebih baik di mana ia akan melibatkan kos yang lebih tinggi. Dengan motivasi itu, penyelidikan ini membentangkan pengoptimuman rangkaian rentas-lapisan bagi rangkaian ad hoc kenderaan untuk menambah baik prestasi celusan, lengahan dan nisbah penghantaran paket menggunakan teknik yang dicadangkan bernama SOVEA. Teknik SOVEA dibangunkan berdasarkan analisis Kaedah Taguchi. Tiga senario model VANET telah dibangunkan untuk menilai Teknik SOVEA yang dinamakan lebuh-raya luar bandar, lebuh-raya terbuka dan senario bandar berdasarkan peta Perlis. Setiap prestasi yang dinilai menunjukkan faktor yang berbeza dalam penentuan prestasi. Bagi senario lebuh raya luar bandar, faktor sumbangan utama untuk celusan adalah saiz paket, untuk lengahan adalah protokol penghalaan dan untuk nisbah penghantaran paket adalah jarak antara *Road-Side-Units* (RSU). Sebaliknya, senario lebuh raya terbuka yang mempunyai lebih banyak nod atau kenderaan, faktor sumbangan utama untuk celusan dan lengahan ialah protokol penghalaan manakala nisbah penghantaran paket adalah jarak antara RSU. Senario bandar yang dikaji adalah berdasarkan bandar Arau di Perlis, faktor sumbangan utama untuk celusan dan lengahan adalah saiz paket manakala nisbah penghantaran paket adalah bilangan RSU yang ada di kawasan tersebut. Oleh itu, senario yang berbeza mempunyai faktor yang berbeza bagi menyumbang kepada prestasi rangkaian VANET. Setiap senario juga mempunyai set faktor tahap yang berbeza dalam menentukan prestasi jaringan yang optimum yang diperolehi dari teknik SOVEA. Selain itu, teknik SOVEA juga diuji pada parameter lapisan Kawalan Capaian Media (MAC) untuk VANET bagi meningkatkan prestasi celusan, lengahan dan prestasi nisbah penghantaran paket dalam aplikasi kemudahan untuk senario lebuh raya terbuka. Parameter lapisan MAC yang dioptimumkan melalui teknik SOVEA berkesan untuk memastikan kebolehpercayaan yang tinggi dan penyebaran paket aplikasi kemudahan tepat pada masanya. Dari keputusan yang diperolehi, ia menunjukkan teknik SOVEA membuktikan peningkatan terhadap prestasi rangkaian dengan pemilihan parameter lapisan MAC yang terbaik. Oleh itu dapat disimpulkan bahawa sumbangan penyelidikan ini adalah teknik SOVEA yang dapat diaplikasikan sebagai salah satu teknik untuk optimasi rentas-lapisan rangkaian untuk menghasilkan prestasi rangkaian yang lebih baik bagi VANET. Juga teknik ini dapat menjamin paket aplikasi kemudahan dihantar dengan kadar kebolehpercayaan yang tinggi dengan pemilihan parameter optimum pada lapisan MAC.

Cross-Layer Network Optimization Technique for Vehicular Ad Hoc Network

ABSTRACT

Vehicular Ad Hoc Network (VANET) is a type of ad hoc network but different in terms of functionality because of the high mobility of node, variable of node density and unpredictable communication environment. There are two major applications in VANET which are safety applications and non-safety applications. Network optimization is one way to maintain the existing protocols and other network parameter compared to design and implement new improved protocols in which it is very costly. Motivated with the reasons this research presents a cross-layer network optimization of vehicular network to enhance throughput, end-to-end delay and packet delivery ratio performance using the proposed SOVEA Technique. SOVEA Technique is inspired from Taguchi Method analysis. Three VANET model scenarios are selected to evaluate SOVEA Technique which is rural highway, free expressway and city scenario based on map of Perlis. Each performance evaluated shows different cross-layer factors reflects towards the outcome. For rural highway scenario, the major contribution factor for throughput is packet size, for delay is routing protocols and for packet delivery ratio is the distance of the Road Side Units (RSU). On the other hand, free expressway scenario which has more density of nodes, the major contribution factor for throughput and delay is routing protocols, while for packet delivery ratio is the factor of distance of the Road Side Units (RSU). Different form city scenario which was taken based on Arau city in Perlis, the major contribution factor for throughput and delay is packet size while for packet delivery ratio is the number of RSU in the area. Therefore, different scenario resulted different cross-layer factors on contributing towards the performance of the VANET. Each scenario also has different set level of cross-layer factors in determining the optimal network performance derived from the SOVEA technique. Other than that, SOVEA Technique is also tested at Medium Access Control (MAC) layer of VANET model to improve the throughput, delay and PDR performance in non-safety application for free expressway scenario. An efficient optimized MAC is necessary to ensure high reliability and timely dissemination of non-safety messages. From the result obtained, it shows SOVEA Technique proves an enhancement towards the network performance with the best selection of MAC layer parameters. This research shows a contribution on SOVEA technique as one optimization technique for cross-layer to accommodate the demand on highly reliable and prompt system with minimal delay for timely transmission of messages. Also to guarantee appropriate dissemination and high reliability of non-safety messages in efficient optimized MAC layer.

CHAPTER 1

INTRODUCTION

1.1 Background

Advancement in road transportation and inter-vehicle communication has resulted in a large number of vehicles travelling on highways and streets around the world. Wireless communications in a vehicular environment has been drawing much attention due to furnish driver and passenger safety features, in car entertainment and also telecommunications convenience. The interest of industrial and scientific community of vehicle communications has recently switched to more challenging in designing robust wireless networks that deliver the performance necessary to support evolving applications.

A vehicular ad hoc network (VANET) is one type of vehicular communication mechanism which falls into ad hoc network type of communication for vehicle networking. The architecture of a VANET consist of road side units (RSUs) which placed alongside roads and mobile nodes equipped with on-board units (OBUs) in vehicles (Al-Sultan, Al-Doori, Al-Bayatti, & Zedan, 2013). There are two major applications in VANET namely safety application and non-safety application. As such, in vehicular communications simulations studies; either network simulator or physical simulator is used to optimize the performance (Mittag, Papanastasiou, Hartenstein, & Ström, 2011). Normally in network simulators, the physical details such as coding, modulation, radio channel and receiver algorithm is abstracted while in physical simulators such as in MathWork or known as MATLAB (The MathWorks, 2017), the network characteristics, for examples, the topology and network traffics types are not considered. Furthermore, Jarupan & Ekici, (2011) has done survey of cross-layer design for VANET and highlight the benefit of cross-layer design is to allow information to be exchanged and shared across layer boundaries in order to enable efficient and robust protocols.

Optimization in VANET area is quite common and usually focus to a specific layer. Routing protocol optimization in vehicular communication is targeted to improve the network performance and increase the reliability of packet transmission since the nodes and vehicles are high in mobility. A lot of work has been reported in the literature related to routing protocols optimization. The latest research by Daas & Chikhi, (2018) has done optimization on routing protocols for an urban VANET and proves on reducing overhead load reduced the end-to-end delay without deteriorating the packet delivery ratio metric. It is sparse in the literature on optimization of a cross-layer for VANET.

While on the other perspectives, MAC protocols for VANET should be robust and optimized against the intermittent connections because of it is a type of network that is dynamic and scalable. Priya & Malhotra, (2016) study on optimizing the MAC layer to lessen the effect of increased of vehicle mobility for a scenario of VANET.

There are various method of optimization used nowadays including ant colony, genetic algorithm, particle swarm, and also Taguchi method. The target of Taguchi method is to produce high quality product at a lower cost; to reduce the variation in process where a robust experimental design are involved (Mohamed, Lee, Salleh, Sanugi, & Sarahintu, 2011). Taguchi's method is widely used in manufacturing processes, then followed by other engineering fields, such as electromagnetic, power electronics and wireless communications.

1.2 Research Problem

As demands on intelligent transportation system increases it requires to have sufficient VANET analysis on the features of reliable connections and performance in providing services efficiently. Field trials are one of type for VANET analysis but it can be very expensive since the extensive number of vehicles will resulted in high financial cost for the study. As an alternative, VANET analysis can be carried out using simulator as a less expensive effort. Physical simulator such as MathWork or known as MATLAB (The MathWorks, 2017) usually focus on coding, modulation, radio channel, receiver algorithm and study on signal processing algorithms under specific channel conditions. While on the other hand, network simulator usually consider the network topology and traffic; ignoring the physical characteristics such as (channel) effects that later produces an unreliable analysis. Therefore, to overcome these shortcomings, it is imperative to make it a requirement to integrate the detailed physical layer simulator into the network simulator. This would permit a cross-layer simulation studies for vehicular communications or VANET. A cross-layer model in network simulator will allows observation between physical (PHY), medium access control (MAC) and network (NET) layers where it provides a more reliable performance analysis.

Not all studies of VANET incorporate the scenarios into a real map but some have done so and mostly are for foreign countries map such as Atlanta , Rome, New York, San Francisco, Los Angeles, Madrid, London and Korea. Some researchers have developed the scenario for Malaysia but none of them precisely developed for Perlis. It is beneficial to have network analysis for a specific area such in Perlis to know the network performance in help to develop the infrastructure in future.

Designing and implementing a new protocols for VANET will definitely impose high cost and one way to overcome this situation is by optimizing the current available protocols. In conjunction to determine or to select the best of parameters of current available protocols, it is a need on a technique that will provide an optimized setting for each specific scenario. It is necessary to have a method for optimizing a cross-layer parameters in a cross-layer model of VANET. With the optimized setting obtained, it will help in determining the reliable and optimum performance of VANET.

MAC protocols for VANET is also one important issue that captures the research interest since it is supposed to maintain the communication for the highly mobility nodes of vehicles. Many method being proposed to enhance the VANET performance but it is still lacking research in exploring the MAC protocols to improve VANET performance. This research explores the optimization of MAC parameters that can resulted an improvement on the VANET performance.

With this gap in VANET knowledge, this research could contribute in providing a more reliable analysis of vehicular communications with the listed research objectives.

1.3 Research Objectives

1) To design and develop a cross-layer VANET model in network simulator for map of Perlis.
2) To propose a technique for cross-layer network optimization of VANET.
3) To optimize the MAC layer parameters using the proposed technique to enhance VANET performance.

1.4 Research Contribution

1) A cross-layer simulation framework has been established for the design and development of VANET models based on map of Perlis. The quantification of network connectivity is conducted over various types of mobility patterns and variation of network conditions that consist of the rural highway scenario, free expressway scenario and city scenario. A simulation framework validates its functionality and models.
2) An optimized cross-layer factors for three VANET scenarios by using proposed technique named SOVEA in order to overcome the limitation of the classical dependency on ordinary network setting. The scheme quantify the impact of network architecture level to provide improvement in term of higher Packet Delivery Ratio (PDR), as well as throughput, and decreased response in delay.
3) MAC layer parameters of VANET is optimized using proposed SOVEA technique and has been evaluated and resulted in the enhancement and improvement the VANET performance for highway scenario.

1.5 Research Scope

This research is focused on improving the model of VANET by utilizing the physical characteristics in the network simulator platform. The physical characteristic for the model is using orthogonal frequency division multiplexing (OFDM) modulation. Scenario of VANET model involved in this research is reflect to map of Perlis and namely rural highway, free expressway and city scenario. Each scenario have their own characteristic parameters which is uniquely assigned.

The technique proposed named SOVEA is evaluated on the VANET model for cross-layer optimization. The cross-layer factors consideration involves RSU distance, MAC protocol, routing protocol and packet size as determinant factors in VANET performance. SOVEA technique is also evaluated for VANET MAC layer parameters optimization. The parameters are Queue Size, Retry Limit, Basic Bitrate and RTS Threshold.

1.6 Research Framework

Figure 1.1 outline the research framework within the extensive literature survey in the field of VANET. The aim of the process is to understand thoroughly the development of the state-of-the-art technology for ad hoc network specifically for VANET. Relevant information was gathered in order to generate meaningful research problems. Each phase describes the methods, steps and procedures involve in producing an optimized factors for cross-layer network consideration as well as for MAC layer parameters optimization.

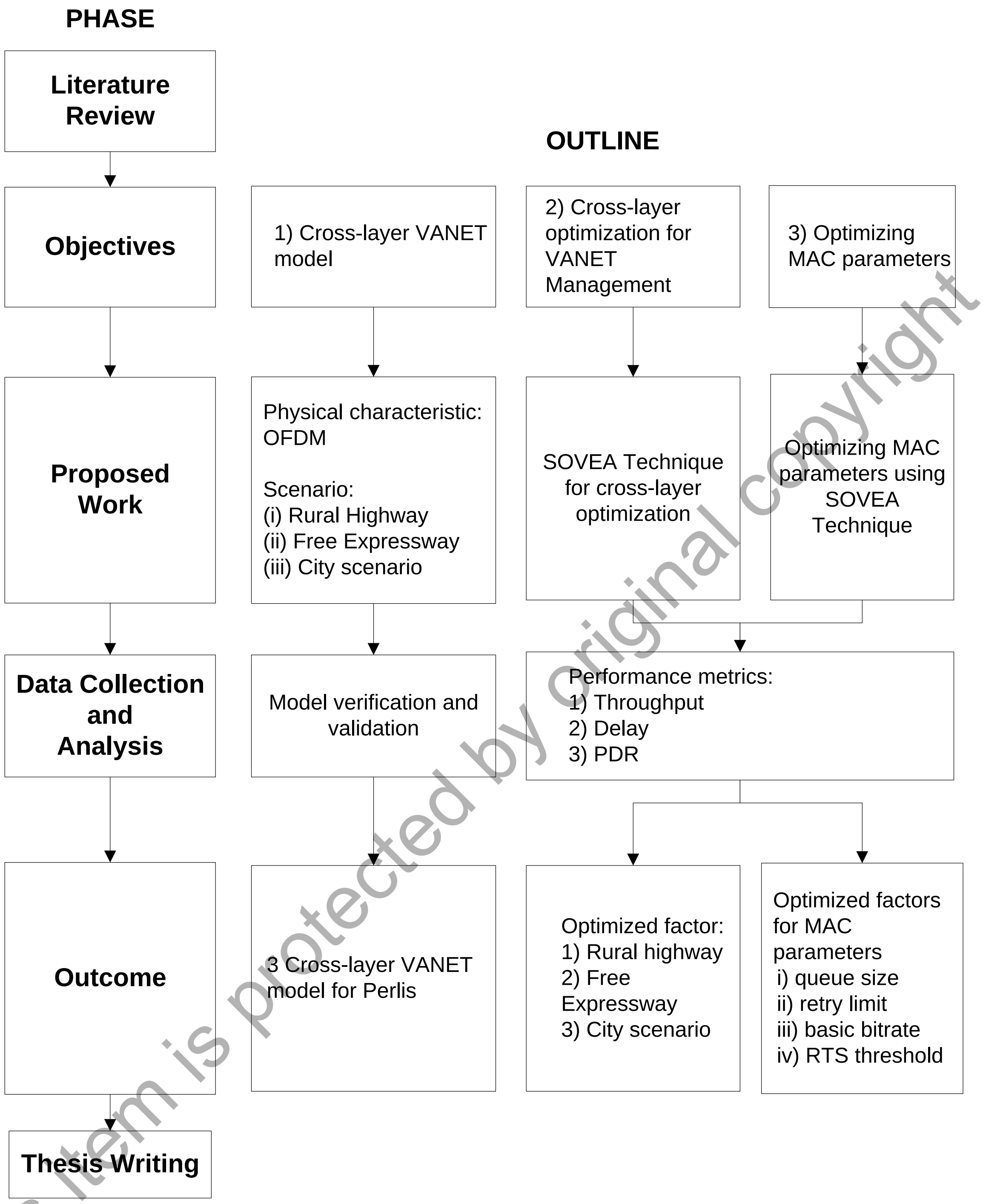

Figure 1.1: Research Operational Framework

1.7 Network Simulators

Research community are widely using network simulators to evaluate new theories and hypothesis. There are several network simulators such as OMNeT++, ns-2/ns-3, JiST/SWAN, OPNET/Riverbed, and GloMoSim. Khan, Bilal, & Mazliza Othman (2012) conclude that OMNeT++, ns-3, and GloMoSiM are capable of carrying out large scale network simulations. In terms of computation time, ns-3 is the fastest simulator.

Parmar & Mehta (2014) has done performance evaluation of ns-2 and OMNeT++ simulator for AODV protocol in MANET. It shows that OMNeT++ is good to work with parameters in which their value is the point of interest and not the form (linear, exponential, etc.) that those values follow when they are plotted.

Based on Table 1.1, OMNeT++ is selected as the network simulator tools because it satisfies the criteria listed.

Table 1.1: Summary of simulation tools

	OMNeT++ (Varga & Hornig, 2008)	**ns-2/ns-3 ("ns-2," n.d.)**	**OPNET/Riverbed ("OPNET/Riverbed," n.d.)**
Interface	C++/NED	C++/OTcl	C or C++
License	Open source	Open source	Free academic license - limited use
Scalability	Large	Large	Medium
Mobility	Support	Support	Support
Available Modules	TCP/IP Ethernet Propagation model IEEE 802.11 ad-hoc model	TCP/IP Ethernet Propagation model IEEE 802.11 ad-hoc model	TCP/IP Ethernet Propagation model IEEE 802.11 ad-hoc model
Documentation and user support	Excellent	Good	Excellent
Development	Active	Active	Active

1.7.1 OMNeT++ Overview

OMNeT++ is a modular simulation framework and an open source discrete event simulation tool. It is a C++ based for modelling communication network, multiprocessors and also distributed or parallel system using hierarchically nested modules (Varga & Hornig, 2008). Network module is the top level module may contains one or more sub-modules. Each sub-module can include more sub-modules and has no limit for depth. Simple modules can be joined together to produce compound module. Modules communicate via messages either through gates or directly to the destination modules. The gates can be an input or output (Malekzadeh, Ghani, Subramaniam, & Desa, 2011; Varga & Hornig, 2008). Figure 1.2 shows the block diagram of hierarchically nested modules. The thick line boxes represent simple module while the thin line boxes is compound module. Arrow connecting small boxes represent gates and connections.

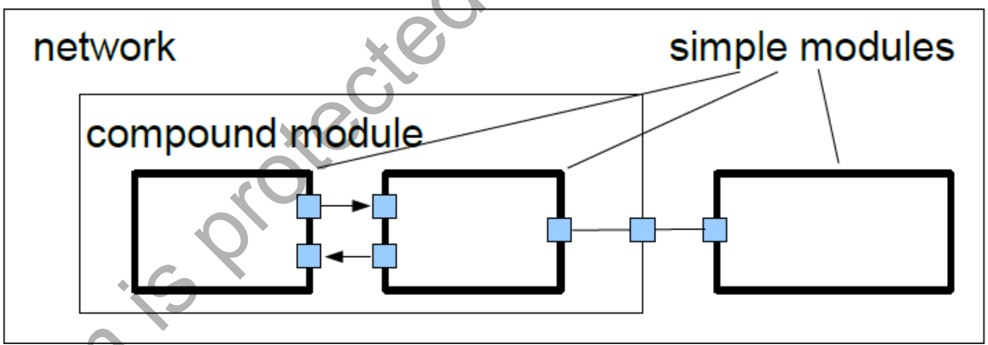

Figure 1.2: Model Structure in OMNeT++ (Varga & Hornig, 2008)

1.7.2 INET Framework

The INET Framework is a set of simulation modules released under the GNU General Public License (GPL) which provides OMNeT++ modules that represent various layers of the Internet protocol suite. The protocol suite includes UDP, TCP, IPv4 and ARP protocols. The INET Framework also features models for wireless radio communication including various MAC protocols. Mobility Framework was introduced into OMNeT++ as mobility modelling and incorporated into INET Framework for modelling spatial relations of mobile nodes. INET Framework contains several application models such as IPv4, IPv6, TCP and UDP protocol implementations. Link-layer models are Ethernet, 802.11, and PPP. Routing can be set up static routing or can use routing protocol implementations. Therefore, INET Framework supports wireless and mobile simulations as well (N. Kumar, Alvi, Singh, & Swami, 2013).

1.7.3 INET-MANET

INET-MANET is based on INET Framework and is continuously developed. It contains additional protocols and components that are especially useful while modelling wireless communication. In other words, OMNeT++ and INET Framework offer all the requirement components for simulating Internet protocols in general and MANET protocols in particular. OMNeT++ is very well suited for the implementation of complex protocols because of its modular architecture and its ability to alter all modules' internal states (N. Kumar et al., 2013).

1.8 Research Outcome Benchmark

From the objectives been outlined, this sub-topic reflect the research analysis outcome with other related works as a benchmark. In first objective, the VANET model design and development are focused for a cross-layer consideration. In this research the characteristics at the physical layer is taken into account for the development. While compared to Bilgin & Gungor (2013) where the study concentrate the model development for highway, rural and urban scenario of VANET using stochastic mobility model with assumption for radio propagation model is ideal.

Second research objectives concentrate on technique development for a cross-layer consideration. Three layers in the OSI is chosen to be optimized using the technique proposed for a better performance outcome which is data link layer, network layer and transport layer. The technique is inspired by Taguchi Method where it is widespread method from manufacturing field to reduce the variation in process with a robust experimental design are involved. The technique proposed is named SOVEA. As compared to study of Bilgin & Gungor (2013) the performance analysis evaluation is stressed to network level where packet size is varies between 256 byte, 512 byte and 1024 byte. The inter-packet gap is selected either 0.1s, 0.05s, 0.033s, 0.025s or 0.02s as the routing protocol is fixed to AODV. The vehicle speed is also varies from 50 km/h to 120km/h. Two MAC protocols are compared in the analysis; IEEE 802.11p and IEEE 802.11b and concluded that IEEE 802.11p performs better results for vehicle-to-vehicle communications.

Third research objectives focus on MAC layer parameters optimization using SOVEA technique. Four parameters involves are Queue Size, Retry Limit, Basic Bitrate and RTS Threshold. The effect factors considered for optimizations are number of nodes, mobility speed and packet generation time. While to compare with the MAC layer optimization by Priya & Malhotra, (2016) only focus on Queue Size with the effect of increased mobility.

1.9 Thesis Outline

This thesis focus on the design and development of cross-layer VANET model and to investigate and evaluate the proposed technique for a cross-layer network optimization. The organization of this thesis is as follows:

Chapter 1 provides the introduction to the domain of the study, the preliminaries of vehicular ad hoc concepts. This is followed by a discussion of the problem statement, research objectives and contributions. The research scope is also been defined as well as the research framework. Review of network simulation tools is provided at the end of the chapter. Research outcome benchmark is also explained in this chapter.

Chapter 2 provides an extensive literature review on area of the study and focuses more on VANET characteristics. This includes the research area, network scenarios, performance metrics, applications in VANET and protocols used in VANET. This chapter also briefly explains optimization concepts and the use of Taguchi Method as an optimization process.

Chapter 3 highlights the details of the research methodology used in this work. This is followed by the problem formulation based on the literature review and simulation set-up. The proposed technique, SOVEA is explained thoroughly in this chapter.

Chapter 4 presents the results obtained from the analysis of SOVEA towards different scenario of VANET model. This chapter also presents the analysis of SOVEA in improving VANET performance by optimizing the MAC protocols parameters.

Chapter 5 summarizes the thesis, the study achievement and re-affirms the contributions of the study. In addition, the suggestions and proposals for future research directions are discussed in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter mainly explains on vehicular ad hoc network or known as VANET. VANET is defined as the network communication between vehicles and vehicles with the roadside infrastructure that enable for data transmission based on the connection with a wireless mobile technology. In general, VANET is a type of ad hoc network where it is part of MANET application and further classified based on the network architecture. This chapter will elaborate in details on the taxonomy of VANET starting from the wireless network point of view. The following subsections will then explain thoroughly on VANET including the research area, applications, scenarios, performance metrics used, transport protocols, wireless access technologies and routing protocols. Lastly, the elaboration of Taguchi Method as one of the optimization procedure.

2.2 Development of Wireless Networks Technology

The challenge in the implementation of wireless communication is an exponential rising segment of the communication industry in particular on network infrastructures, fast growth of cellular network users, the growing availability of wireless applications and the emergence of omnipresent wireless devices. Consequently, nowadays many home and offices that connected using wired networks are replaced with wireless technology. The network is developed wirelessly using access point (AP) where all the devices can connects to it. The AP is responsible in relaying the data among all devices and also can be connected to a wired network. To create a bigger wireless network, where it will function as ad hoc network the AP will be connected together.

Figure 2.1 shows the classification of wireless network that can be done based on the architecture and also application. Network architecture of wireless network can be divided into two categories (Li, 2008) named infrastructure less network and infrastructure-based network.

a) Infrastructure less networks is formed robustly through the cooperation of a random set of independent wireless devices. There is no specific roles for every node and the node is capable on forwarding the data packets to any other nodes. The decision to direct the data packets is depends on the network situation and node decides independently. Two examples of this type of infrastructure less network are wireless ad-hoc networks and wireless sensor networks (WSN).
b) Infrastructure-based networks is a pre-constructed infrastructure network. The examples are wireless local area network (WLAN) and cellular network.

To further categorize the wireless network, the classification of wireless ad hoc network is done based on the application as displayed in Figure 2.1. Several types of application is briefly explained.

2.2.1 Mobile ad-hoc networks (MANET)

Every node in MANET can move freely and independently and therefore it will change the topology or link to other devices frequently (Heni & Bouallegue, 2011). The node in MANET will perform the task as router where they have a properly routing scheme to make sure the packets successfully received by the destination. To be more specific, MANET can be divided to (A. Jenifus Selvarani & Selvam, 2011):

i) Vehicular Ad-Hoc Networks (VANET)

It allows the communication between the vehicles (known as V2V) and also between vehicles and roadside infrastructure (known as V2I).

ii) Internet Based Mobile Ad-Hoc Networks (iMANET)

The nodes in this type of network is connected to a fixed Internet-gateway and it not often applies routing algorithm.

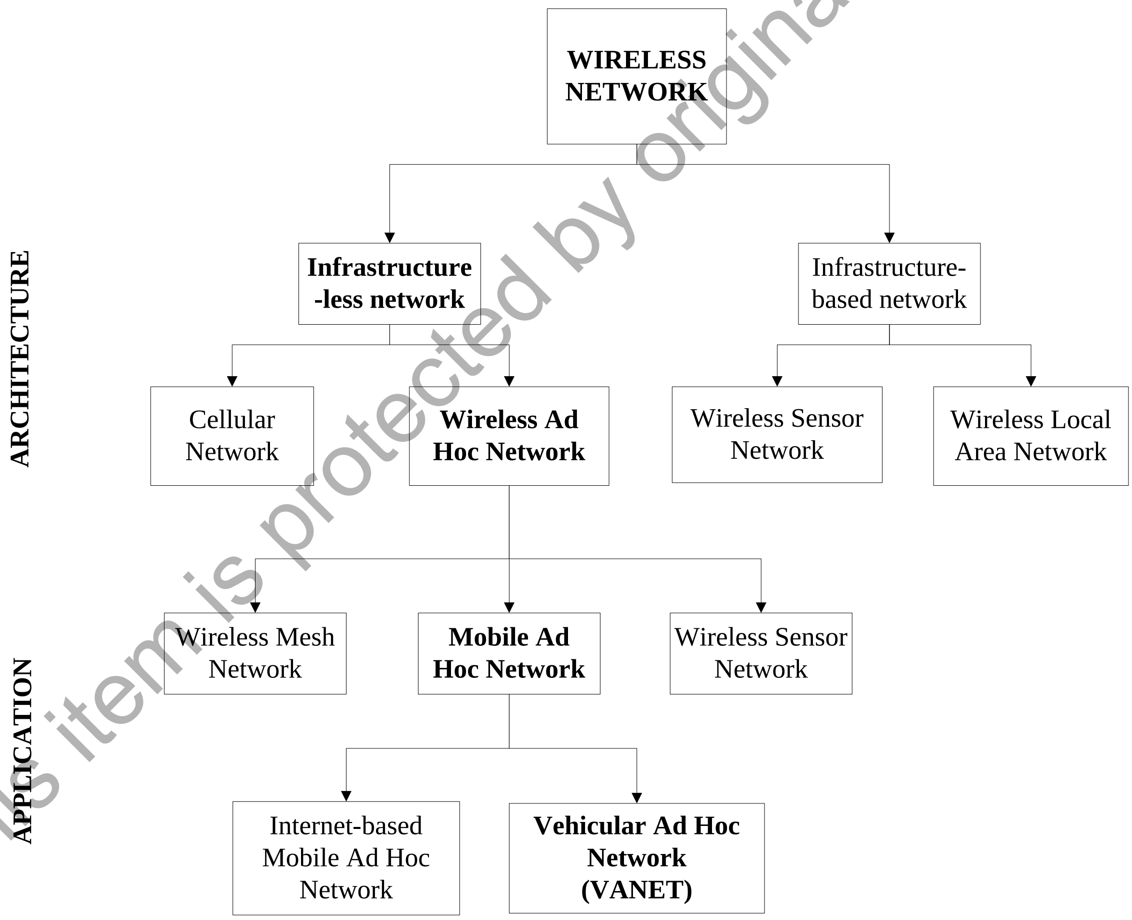

Figure 2.1: Classification of wireless network

2.2.2 Wireless Mesh Networks (WMN)

Wireless Mesh Networks (WMN) consists of gateways, mesh routers and mesh clients. Generally, mesh clients are cell phones, laptops and other wireless devices. While, mesh routers will forward traffic from and to gateways. Accordingly, the gateway might but need not to connect to Internet. Sometimes a single network of radio nodes working in a coverage area is called a mesh cloud. A mesh network is reliable and offers redundancy. Wireless mesh networks can uses several types of wireless technology including the standard of Wireless Local Area Network (WLAN) 802.11, 802.15, Worldwide Interoperability for Microwave Access (WiMAX), cellular technologies or combinations of the wireless technology.

WMN can be seen as a special type of wireless ad hoc network (Xu, Chin, & Soh, 2017) where it is more planned configuration, and may be deployed to provide dynamic and cost effective connectivity over a certain geographic area (Gabale, Raman, Dutta, & Kalyanraman, 2013). On the other hand, an ad hoc network is formed when wireless devices come within communication range of each other. The mesh routers in the composition of mobile, and be moved according to specific demands arising in the network. Regularly the mesh routers are not limited in terms of resources compared to other nodes in the network and thus can be exploited to perform more resource intensive functions. In this way, the nodes in wireless mesh network are often constrained by resources and this differs from an ad-hoc network.

2.2.3 Wireless sensor networks (WSN)

A wireless sensor network (WSN) comprise of spatially distributed independent sensors to observe the physical or environmental conditions and to cooperatively pass their data through the network to a main location (Driss Benhaddou & Al-Fuqaha, 2015).

Each sensor node has typically several parts including a radio transceiver, a microcontroller and electronics circuit to interface between the sensors and energy source. The radio transceiver can be a connection to an external antenna or an internal antenna. The energy source for a sensor node in WSN usually a battery or an embedded form of energy harvesting. A sensor node might vary in size from that of a shoebox down to the size of a grain of dust. The topology of the WSNs can vary from an uncomplicated star network to an unconventional multi-hop wireless mesh network. The propagation mechanism between the hops of the network can be routing or flooding.

2.3 Vehicular Ad Hoc Networks (VANET)

In general, VANET are categorized as an application of MANET (Al-Sultan et al., 2013; Harrabi, Jaffar, & Ghedira, 2016) that have the tendency to develop an Intelligent Transport System (Harrabi et al., 2016; Purohit, Dimri, & Sanjay Jasola, 2016). It provides communications between vehicles by considering the vehicles as nodes with built-in wireless network communication (Anna Maria Vegni, Mauro Biagi, & Roberto Cusani, 2013; A. Kumar & Shree, 2015). VANET has unique characteristics compared to MANET in terms of no power constraints, the nodes have high mobility, the network topology changes rapidly, and it is a large scale network (Al-Sultan et al., 2013; Anna Maria Vegni et al., 2013).

In addition, the architecture of a VANET comprise of road side units (RSU) and vehicles which act as the mobile nodes equipped with on-board units (OBUs) (Al-Sultan et al., 2013). Vehicles with OBUs can communicate with each other by transmitting the data packets and it is known as inter-vehicle communication. While another communication in VANET is named vehicle-to-infrastructure (V2I) where it allows communications between the vehicles with the RSU.

Figure 2.2 shows the illustration of the inter-vehicle (V2V) or known as vehicle-to-vehicle and V2I communication or known as vehicle-to-infrastructure. VANET is expected to offer a broad spectrum of safety and non-safety applications to drivers as well as passengers (Zhu & Minglu Li, 2013). VANETs are visualize to cater long distance communication range up to 1000m for V2V and V2I, at a relative speeds up to 200km/h, regardless the environment (Moustafa & Zhang, 2009).

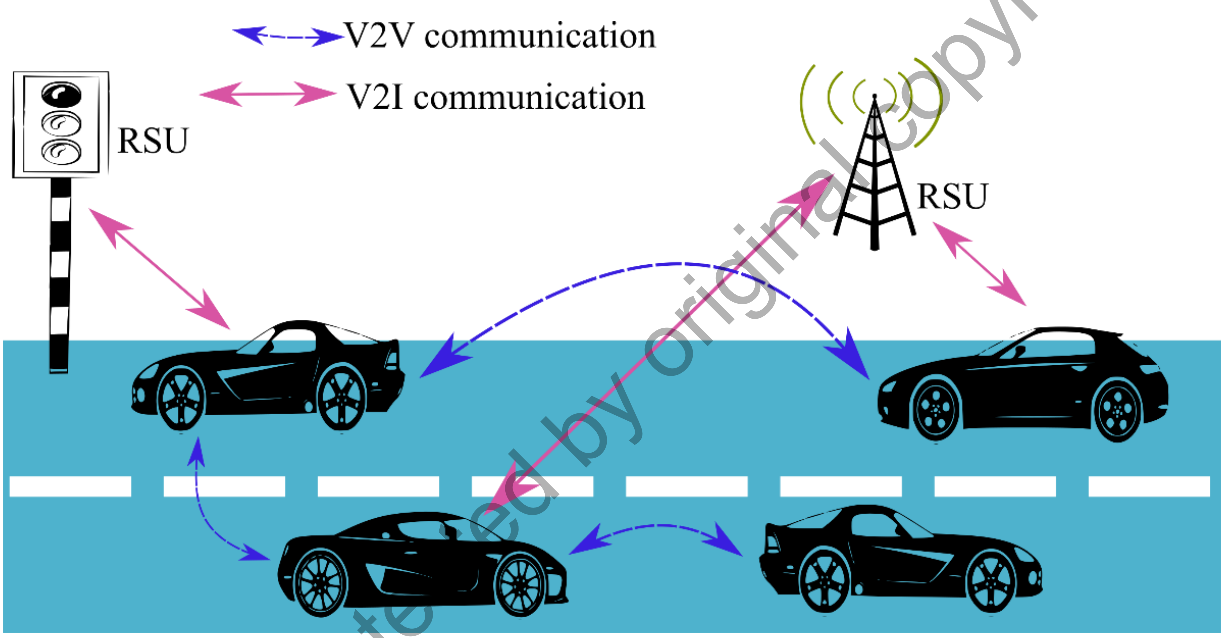

Figure 2.2: Illustration of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication

VANET applications can generally classified into two major categories as shown in Figure 2.3 which are safety applications (Alotaibi & Mouftah, 2017; Hafeez, Zhao, Ma, & Mark, 2013) and non-safety applications (Jiang, Alfadhl, & Chai, 2011). (Elumalai & Murukanantham, 2010). Non-safety application which provide value-added services, for example, entertainment, internet surfing, multimedia applications are also called user applications (Al-Sultan et al., 2013; Gunstone, 2009).

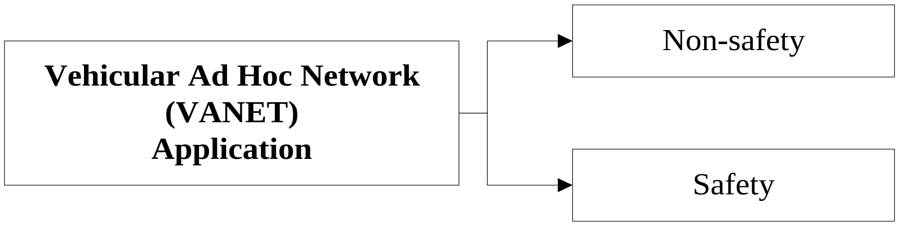

Figure 2.3: VANET applications

Safety applications implemented according to demand of high level quality of service (QoS) and is a delay sensitive, while for non-safety require more to throughput sensitive instead of delay (M.J Booysen, S. Zeadally, & G.-J van Rooyen, 2011).

Zheng, Zheng, Chatzimisios, Xiang, & Zhou (2015) split the safety applications into four categories as shown in Table 2.1 and the maximum latency should be no more than 100ms. The minimum frequency of periodic messages is 1Hz to 10Hz due to the different user cases. In term of non-safety applications, it is also been categorized into two major category that is traffic management and infotainment as referred to Table 2.2. The maximum latency reach up to 500ms for some user cases while the minimum periodic messages is 1Hz and 2Hz only.

Table 2.1: Safety Services and User Cases Requirements (Zheng, Zheng, Chatzimisios, Xiang, & Zhou, 2015)

Safety Services Category	User Cases	Usage	Minimum Frequency of Periodic Message	Maximum Latency
Category I : Vehicle status warning	Emergency electronic brake lights	Warn a sudden showdown of the following vehicle	10 Hz	100 ms
	Abnormal condition warning	Warn the abnormal vehicle state	1 Hz	100 ms
Category II : Vehicle type warning	Emergency vehicle warning	Reduce emergency vehicle's intervention time	10 Hz	100 ms
	Slow vehicle warning	Improved the traffic fluidity	2 Hz	100 ms
	Motorcycle warning	Collision avoidance	2 Hz	100 ms
	Vulnerable road user warning	Collision avoidance	1 Hz	100 ms
Category III : Traffic hazard warning	Wrong way driving warning	Wrong way driving warning	10 Hz	100 ms
	Stationary vehicle warning	Avoid succession of collisions	10 Hz	100 ms
	Traffic condition warning	reduce the risk of longitudinal collision on traffic jam forming	1 Hz	100 ms
	Signal violation warning	Reduce the risk of a stop/traffic violation	10 Hz	100 ms
	Roadwork warning	Reduce the risk of accident at the level of roadwork	2 Hz	100 ms
	Decentralized floating car data	Improved safety and traffic fluidity	10 Hz	100 ms
Category IV : Dynamic vehicle warning	Overtaking vehicle warning	Reduce the risk of accident	10 Hz	100 ms
	Lane change assistance	Active road safety	10 Hz	100 ms
	Pre-crash sensing warning	Accident impact mitigation	10 Hz	50 ms
	Co-operative glare reduction	Avoid the frontal collision	2 Hz	100 ms

Table 2.2: Non-Safety Services and User Cases Requirements (Zheng, Zheng, Chatzimisios, Xiang, & Zhou, 2015)

Non-safety Services Category	**User Cases**	**Usage**	**Minimum Frequency of Periodic Message**	**Maximum Latency**
Category I : Traffic management	Regulatory/ contextual speed limits	Enhance the traffic efficiency/reduce the vehicle' pollution	1 Hz	N/A
	Traffic light optimal speed advisory	Traffic regulation at an intersection	2 Hz	100 ms
	Intersection managements	Road safety and traffic regulation at an intersection	1 Hz	100 ms
	Co-operative flexible lane change	Enhancement of mobility efficiency	1 Hz	500 ms
	Electronic tool collect	Traffic fluidity at the toll collect	1 Hz	500 ms
Category II : Infotainment	Point of interest notification	Driver and passengers comfort	1 Hz	500 ms
	Local electronic commerce	Vehicle driver/passenger comfort	1 Hz	500 ms
	Media download	Passenger entertainment	1 Hz	500 ms
	Map download and update	Efficiency and comfort	1 Hz	500 ms

2.4 Network Scenarios in VANET

In VANETs development, there are various transportation scenarios has been investigate and evaluated. Table 2.3 summarize on some of the type of scenario in previous VANET research which comprise of highway, city or urban area, rural, intersectional, traffic moving in opposite directions, different density and speed and ring road.

In view of vehicular traffic scenario, the observation shown that a highway scenario commonly limited by the available road and the RSU is in irregular distance or position. The relative speed between vehicles is low and vehicles tend to travel in group in same direction.

Dissimilar for city traffic where there are more junctions and the vehicles is tends to be stop-start and vehicles are at a low speed. The density of vehicles in city traffic is higher than highway and there will be more RSUs in city than highway. Therefore, it is very tedious to do routing in city scenario since buildings will be large obstacles, and the driver action is unexpected.

While normally there are more available of RSU at intersectional traffic scenario but another problem should be solve where nonline-of-sight (NLOS) state conditions will occurred (Abumansoor & Boukerche, 2012). Figure 2.4 displays the intersectional traffic scenario while Figure 2.5 shows the traffic is moving in opposite directions scenario.

Zheng et al. (2015) explains on two typical application scenario for VANET which is urban intersection scenario and expressway scenario.

Table 2.3: Network scenario type in VANET

No.	Network Scenario	Author	Year
1.	Highway traffic	Bilgin & Gungor	2013
		~~Omar, Zhuang, & Li~~	~~2013~~
		Sommer & Dressler	2007
		Wei & Qing-quan	2008
2.	City traffic or urban area	Bilgin & Gungor	2013
		Omar, Zhuang, & Li	2013
		Toutouh, García-nieto, & Alba	2012
3.	Rural traffic	Bilgin & Gungor	2013
4.	Intersectional traffic	R. Kaur	2013
		Napit & Trivedi	2011
5.	Traffic moving in opposite directions	Bi, Cai, Member, Shen, & Zhao	2010
		Omar, Zhuang, Abdrabou, & Li,	2013
6.	Different density and speed	Dahiya & Chauhan,	2013
		Harrabi et al.	2016
		Purohit et al.	2016
		Spaho et al.	2012
7.	Ring road	Kuo, Shih, & Chen	2013

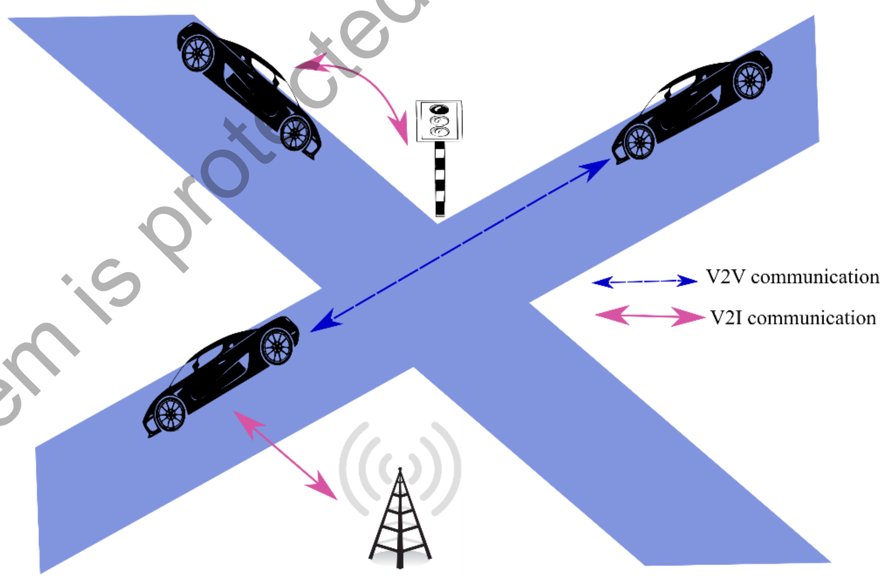

Figure 2.4: Illustration of intersectional traffic scenario

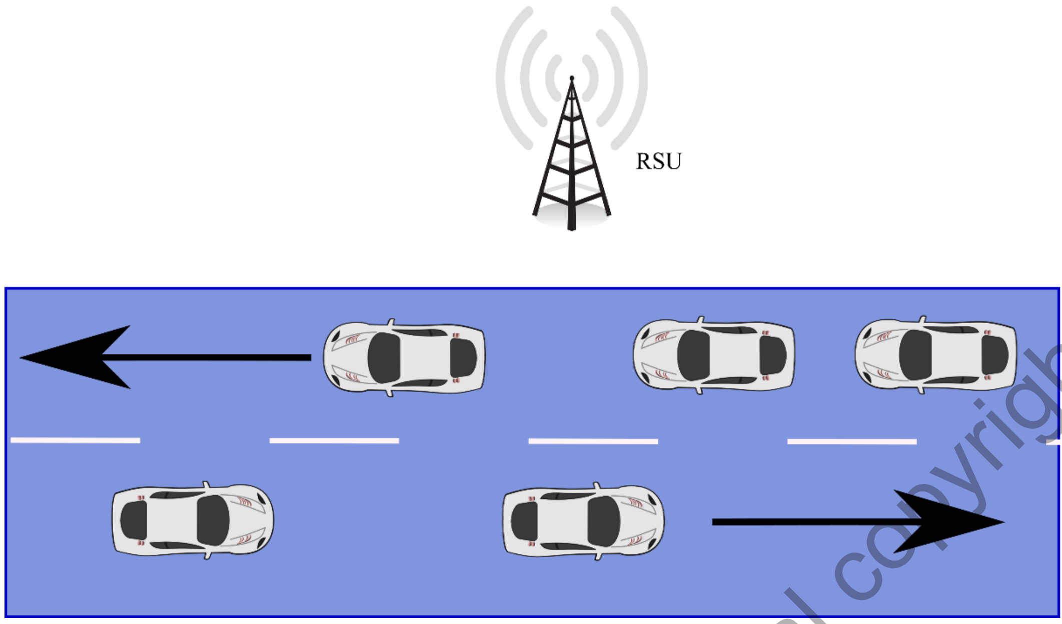

Figure 2.5: Illustration of traffic moving in opposite directions scenario

2.4.1 Performance Evaluation Metrics in assessing VANET

There are various performance evaluation metrics used to assess the performance for VANET which are throughput, delivery delay or latency or also known as end-to-end delay, maximum medium access delay, overhead, and delivery ratio. Majority of the authors analysing VANET performance such as Bi, Liu, Cai, Shen, & Zhao (2009), Bilgin & Gungor, (2013) Hassnawi, Ahmad, Salih, Mohd Warip, & Elshaikh (2014) had uses throughput as the metrics in evaluating the VANET performance. Table 2.4 summarized the performance metrics uses by other researchers in evaluating VANET.