Evaluation of Realistic Mobility Model for Comparative Study of Routing Protocols in IEEE 802.11p (DSRC) Vehicular Ad-hoc Network (VANET)

by

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Abstract

As a countermeasure for rapidly changing topology and high mobility of vehicles, Vehicular Ad-hoc Network (VANET) is emerging as a standard routing protocol. When used efficiently, an ad-hoc routing protocol could play a crucial role in VANET applications, safeguarding both drivers and passengers. In the earlier model, routing protocols were implemented on IEEE 802.11 technology-based environments in which the data was collected from vehicles within the city limit. Communication was among the vehicles themselves, or between vehicles and Road Side Units. This thesis introduces a realistic mobility model using the Auburn University as the venue. Communication is solely between vehicles as not enough Road Side Units are present in the venue chosen.

To evaluate and support scalability and efficiency of protocols for VANET, simulations with realistic mobility models are needed. A plethora of research works and tools were explored to accurately evaluate the models. This thesis proposes to use SUMO to generate realistic vehicle movement based on geographic details of the area by using it in the NS-2 network simulator. To evaluate the efficiency and suitability of mobility models, the paper compares the performance between SUMO and Random Way Point mobility models with the IEEE 802.11p and IEEE 802.11a protocols. Furthermore, this thesis evaluates the performance among different types of ad-hoc routing protocols to find the most suitable one for the IEEE 802.11p environment. This simulation’s result reflects the in-depth comparison between reactive and proactive routing protocol. Results after analysis shows that DSDV is more suitable than AODV protocol for VANET that implemented on IEEE 802.11p.

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Chapter 1

Introduction

1.1 Overview

Wireless Vehicular Ad Hoc Network (VANET) is an innovative wireless network that is rapidly developing accompanied by the advances of wireless and automotive technologies. VANETs are automatically formed between moving vehicles equipped with either same or different wireless interfaces. VANETs are a good example of a real-life application of the ad-hoc network that connects the vehicles with other close vehicles or other infrastructures on the road. It has a variety of usages from private, individual cars to the public transportation such as buses and ambulance vehicles. [1].

Vehicular networking is a core technology used in a plethora of applications that allow communication among vehicles, vehicles traffic, drivers, passengers and pedestrians. These applications are not only the novelties but have handful of usages in real life, and thus satisfying both researchers and companies. Intelligent Transportation Systems (ITS) is not only restricted to the academic accomplishments in the laboratories and test facilities of companies, but already proven practical in supervising the operation of vehicles, managing vehicle traffic, assisting drivers with safety and other information, and providing convenient applications for passengers.

One of the most practical applications of Ad-hoc networking technology is certainly the Vehicular Ad-hoc Network (VANETs). VANETs are not only restricted for commercial uses and entertainment applications but also expanded for the safety and traffic management. In these areas, Quality of Service (QoS) is the most important virtue. Safety information must be carried well-protected in networks that are self-managing with limited degrees of freedom in node movements and high speed variations. This situation will cause a network topology to experience quick and constant changes. Numerous researches with results derived from simulations have been done related to routing, communication sturdiness, and information dissemination to take these points into usable applications such as very simple radio propagation models available in simulation tools [2][3][4].

However, in today's dense urban environment, frequent topology changes cause the quality of the basic radio channels to vary dramatically. QoS is the key factor in delivering messages and sending the parameter during the process of VANET transferring the safety information. QoS is more highly involved in other applications such as communications tools or some entertainment applications.

Although the radio link can be easily found as a common resource in today's given neighborhood, the communication will not take place without satisfying radio link. Fading, time variation, nodes mobility and multi-path effects all combine to cause frequent broken routes, especially when accompanied with high mobility nodes. Subsequently, it is more challenging to provide end-to-end QoS support guarantee because many data packets are lost and failure notifications accompanied with the overhead caused by route repairs increase significantly.

1.2 Applications of VANETs

Vehicular network applications vary from road safety application for the vehicle or the driver, to the entertainment and commercial applications for passengers, using an arsenal of cooperating technologies.

The primary purpose of vehicular networks is real-time and safety applications for drivers and passengers, providing them safety tools and essential tools to decide the best path along the way. The valuable tools including crash warnings, road sign alerts, and in-place traffic views are used by drivers and passengers to decrease the number of accidents and improve the traffic conditions.

These days, vehicular networks are showing some promises in a number of useful applications for drivers and passengers, such as Internet connections facility looking for an available infrastructure only when in demand, electronic tolling system, and a variety of multi media services. A variety of communication networks, such as WLANs, 2~3G and IEEE 802.11 a/b/g/n/p, can be used to expand its use to new, innovative services apart from the safety applications, such as info-mobility and entertainment applications, which can rely on the vehicular network itself.

Considering these applications' potential, vehicular networks create new business chances for car manufacturers, automotive OEMs, network operators, service providers, and integrated operators in terms of infrastructure establishment as well as service provision and commercialization. For safety-related applications, they assure the network operator the authentication of each participant through playing the role of a trusted third party that supervises the participating nodes, or even playing the authority of issuing certificates to each participant in order to prove the authenticity of them later during the communication. While, in non-safety related applications, network operators and service providers, besides services provision and network access, can play the role of authorizing services access and billing users for the consumed services. However, ad hoc systems still require a certain level of penetration and high vehicle density for more safe and reliable communication. Also, the high cost of new communication infrastructure for vehicular networks is another disadvantage, as opposed to the cellular communication system that offers a high coverage along roads and has a reliable authentication and security mechanism. Moreover, a number of technical challenges still remains unsolved for vehicular networks to be ready for wide-scale deployment.

1.3 Characteristic of VANETs

Vehicular ad hoc networks have many common characteristics with general mobile ad hoc networks (MANET). Both VANET and MANET are self-organized wireless ad hoc network that are composed of mobile nodes. However, they are still different in several ways. For example, vehicles can frequently recharge the batteries which usually last much longer than the batteries in regular mobile devices. However, vehicles' movements can be constrained by the road topology and traffic rules. In MANET, nodes cannot recharge their power, and the energy efficiency is also critical, too. In addition, the nodes' movements in MANET are assumed to follow uncontrolled moving patterns. In contrast to other communication networks, vehicular networks have its special, alluring features, such as:

- Unrestricted transmission power: The power issue of mobile devices is usually not a significant concern in VANET as it is in the classical ad hoc or sensor networks. Vehicle itself can provide constant power to computing and communication devices. Usually, the car battery can last much longer than those of hand-held mobile devices.
- More computational capability: Operating vehicles have capabilities of heavy computing, communication, and sensing which can be even more powerful than regular desktops.

- Predictable mobility: Unlike conventional mobile ad hoc networks in which nodes' mobility is hard to predict, vehicles in VANET tend to move more predictably that is usually limited by street topology. Roadway information is often available from navigation systems and map-based applications such as GPS. Given the average number of nodes, average speed, number of lanes, the future position of a vehicle is predicted.

However, to meet its true potential, vehicular networks have to overcome some of the issues such as:

- Large scale: Unlike most of the other ad hoc networks studied in the laboratory that usually predict a limited network size, vehicular networks can be easily used over the entire road network including many participants.
- Fast movement: The environments in which vehicular networks operate are extremely varied, including some extreme situations: for example, on highways, relative speeds of up to 180 km/h may occur, while density of nodes may be 12 vehicles in 1km on less busy roads. Alternatively, in the city, relative speeds can reach up to only 50 km/h and nodes density can be very high, especially during rush hour with a high number of cars.
- Divided network: Vehicular networks can be frequently divided. The rapidly changing traffic situation may result in large inter-vehicle gaps in sporadically populated scenarios, and thus resulting in several isolated clusters of nodes.

- Network connectivity and topology: Vehicular network scenarios differ from traditional ad hoc networks because vehicle are changing and moving continuously and scenarios change rapidly. Thus, as the links between nodes repeatedly connecting and disconnecting, the network topology changes very often, too. Definitely, the degree to which the network is connected is highly dependent on two factors: the range of wireless links and the fraction of participant vehicles, where only a fraction of vehicles on the road could be equipped with wireless interfaces.

1.4 Technical Challenges in VANET

The future deployment of VANET still remains unpredictable as there are a few challenges for vehicular communication. The challenges include information dissemination, security the privacy, and Internet integration. Most importantly, efficient wireless communication is the key factor, so the employed protocols and mechanism should be robust, reliable and scalable to numerous vehicles.

VANET vary from traditional ad hoc networks by having not only rapid changes in wireless links, but also different network densities. For instance, vehicular networks in urban areas are more likely to form more dense networks during heavy traffic. On the other hand, vehicular networks experience more frequent network disconnections in less populated rural highways or during late night hours.

VANET is expected to satisfy a wide range of applications ranging from safety to leisure. As a result, routing algorithm should be efficient and capable of adapting to vehicular network characteristics and applications. So far, lot of research has been focusing on an analyzing routing algorithm in highly dense networks with the supposition that a typical vehicular network is well-connected in nature. Actually, the penetration of vehicles with wireless communication capacity still remains weak. Therefore, a VANET should depend on existing infrastructure supports for large-scale deployment. However, VANET are expected in the future to observe high penetration with lesser infrastructures, and hence it is important to regard the disconnected work problem. Network disconnection in VANET is a decisive research challenge for developing a reliable and better performing routing protocol.

Chapter 2

Motivation and Objectives

This chapter will discuss the motivations and intentions for the proposed protocol for wireless sensor networking.

2.1 Motivation

The Intelligent Transport System (ITS) that uses Vehicular Ad-hoc Network has been established to protect passengers and drivers. It allows vehicles emergency and entertainment information through mobile applications which greatly benefit the travelers [5]. This inter-vehicular communication field has two types of communications: vehicle-to-vehicle communication and vehicle to Road Side Unit communication. Each VANET node contains a Global Positioning System (GPS) device, which identifies the position of each vehicle in the vehicular network [6]. VANET uses this information to alert other vehicles and exchange information, thus decreasing the number of accidents in the highways [7]. This innovative Vehicular Ad-hoc Network communication requires a new type of routing protocol that would provide efficient data transmission.

The IEEE standard 802.11 is not well suited for vehicular environment because the topology of VANET changes more frequently than other networks. Therefore, new standard for VANET model was established. It is known as the Wireless Access in Vehicular Environment (WAVE) with improved version of 802.11 known as 802.11p. The high-speed vehicles are equipped with a communication device known as On-Board Unit (OBU), which allows vehicle to communicate with each other as well as with Road Side Unit (RSU). If there are enough RSU's within the city border, the moving vehicles could receive good data communication among them. However, when they move outside the borders of the city, the communication becomes very weak due to lack of RSU's. Therefore, it is required to establish Ad-hoc routing protocols that is independent of geographical information.

In addition, a network simulator is needed to be combined with mobility models to evaluate scalability and efficiency of a protocol for VANET. Many mobility model tools may be used in simulating VANET. In some cases, vehicular mobility model is a simple random way point mobility model, although a realistic model restricts the movement of vehicles to real roads. A car-following model could be added to make the simulations more reliable and realistic. This will allow computing the vehicle's acceleration, speed, and position according to its neighboring vehicles in the same lane or adjacent lanes.

2.2 Objective

In this thesis, VANET simulation for achieving the following goals is proposed. First, this simulation compares the performance between realistic mobility model and unrealistic mobility model. So, to perform this goal, we propose using the Random Waypoint mobility model and SUMO mobility model. Second, in order to reflect a realistic simulation environment, the experiments is applied to real map scenario. Most of researches deal with various network scenarios. In this paper, we choose real map data from java openstreetmap program, particularly Auburn university area to evaluate Ad-hoc network environment of the area near the university. Third, our research focuses on evaluating proactive and reactive routing protocol to verify the most appropriate one for IEEE 802.11p environment. IEEE 802.11p is developed for VANET, so it can be suitable for this environment.

Chapter 3

Related Work

Various researchers have done the research on improving routing protocols that were used in Mobile Ad-hoc network (MANET) to be compatible with VANET effectively. In VANET, the topology changes all the time and is very dynamic, thus the route for transmitting data also changes often. The congestion due to sending a large amount of various packets (both control and data packet) happens within the network because every node in the same area uses the same access channel. This decreases the efficiency of the communication. Therefore, it is very difficult to find routes in the areas with high congestions. However, there are some differences in performance between IEEE 802.11a and IEEE 802.11p environment.

3.1 Effectiveness of routing protocols in IEEE 802.11a environment

In [8], the paper compares the performance of DSDV and AODV routing protocols by varying the pause time and measuring the metrics such as end-to-end delay, dropped packets, routing overhead, power efficiency, etc. The results indicate that AODV is superior to DSDV. AODV showed consistently lower routing overhead than DSDV's especially when the large number of nodes exist. This is because the number of routing table exchanges increase in DSDV as the number of nodes increases.

Also, in [9], the paper evaluates AODV and DSDV routing protocols based on packet delivery ratio and average delay while varying the number of sources and pause time using IEEE 802.11a and Random waypoint mobility model. The simulation's results indicate that with little node mobility, both protocols deliver greater percentage of the originated data packets, achieving 100% delivery ratio when there is no node motion. The difference shows when the high mobility in nodes exist. The AODV routing protocols showed independence in packet delivery from the number of sources. AODV suffers from end-to-end delays. However, DSDV's packet delivery ratio was very low for high mobility scenarios.

3.2 Effectiveness of routing protocols on IEEE 802.11p environment

The paper [10] proposes the simulation scenario that is designed to evaluate the performance for the normal movement of the vehicles in highways between AODV and DSDV in IEEE 802.11a and IEEE 802.11p environments. The simulation results show that the DSDV with 802.11p yields lower packet latency time than the routing protocol AODV. Also, DSDV protocol is well suited for IEEE 802.11p environment in terms of the packet latency time, broadcasting time and throughput.

In addition, in [11], the paper discusses the comparative analysis of Cluster based Simple Highway Mobility model with DSDV routing protocol and standard 802.11p over the standard 802.11a. The VANET MAC layer standard 802.11p is used to measure the throughput, packet delivery ratio, broadcasting time, and normalized routing load for various clusters. The observations from the simulation indicate that DSDV routing protocol with 802.11p has outperformed the 802.11a.

Chapter 4

Backgrounds

4.1 Realistic Vehicular Mobility Model (SUMO)

Like other types of networks, VANET needs to be simulated to validate protocols and applications. Evaluating the scalability of the VANET is crucial as the number of vehicles in a network could be very huge. We introduce vehicular mobility simulator called, SUMO (Simulation of Urban Mobility). It is a simulator that generates vehicle movement on the real map data and converts the results into a suitable format for ns-2 network simulator. In our case with vehicles moving fast on the road, SUMO is appropriate as an external microscopic traffic simulator [12].

A microscopic traffic simulator computes the position of all the vehicles on road at the same time. These positions could be organized into a graphical user interface (GUI) or saved in a file. Input data can be initials positions, vehicle characteristics such as acceleration and maximum speed, road network, direction, position of destination, speed limits, and etc. SUMO is this type of simulator that supports car-following model.

4.1.1 SUMO (Simulation of Urban Mobility)

SUMO simulates road network traffic the size of a city. As the simulation is multi-modal, it simulates not only the car movements within the city territory, but also public transportations on the street network including train and bus networks. Therefore, the atomic part of the simulation is a human. The simulation follows one's whereabouts such as time of departure and routes one takes that describe a single traffic modality. The simulation figure out if one drives a car and then transfer to the public transportation. Although, walking is not simulated, it will estimate the time the person walks to the other means of transportation. Every second, it records the movement, and these values are updated depending of the vehicle ahead and the street network that the vehicle is on. The simulation of street vehicles is time- discrete and space-continuous.

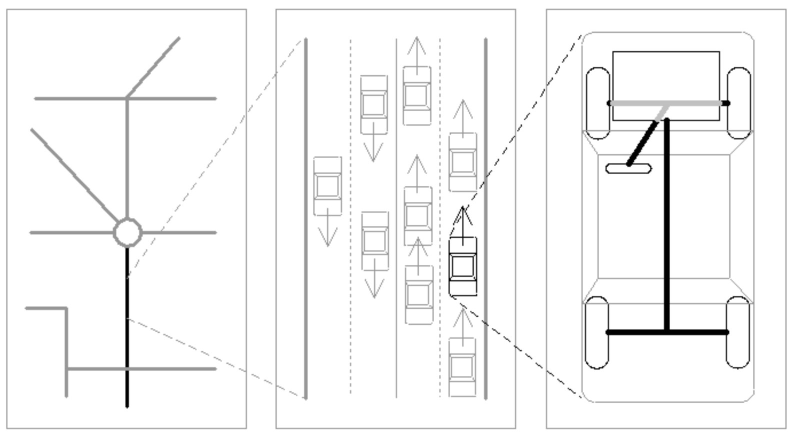


Figure 1: Different simulation classes

SUMO includes the following features:

- Anti-collision vehicle movement
- Supporting lots of type vehicles
- Support lane changing and Multi-lane streets
- Junction-based right-of-way rules (junctions with streets having equal / different priorities, e.g. right-before-left)
- Each Lanes are connected
- XML files has the net state information

- XML files can be convert other format to be better handling

4.1.2 SUMO Additional Tools

SUMO is a combination of more than a single application. There are other modules that help build assigned data that are needed for simulations and research.

4.1.2.1 SUMO - NETCONVERT

Due to high level of complexity, the SUMO’s network cannot be generated by a human. Instead, this tool, which converts common data such as lists of edges and optional nodes into a complete SUMO-network does the job. In this procedure, SUMO-NETCONVERT comprehends the existing data, then calculates the necessary input for SUMO and writes the results into a XML-file.

4.1.2.2 SUMO - DUAROUTER

The simulation not only consists of the stationary part, i.e. the network, but also the mobile part, i.e. moving vehicles. As the quality of simulations increases, more exact modeling of the populations’ mobility is required. As vehicles are not distributed evenly over the network, so a person’s daily route plan and departure times is used instead. From departure times and origin of routes, the routes must be computed. The module called DUAROUTER is used to avoid online computation. This module considers the departure times, starting points and destinations for the humans simulated, and then computes the routes through the network using its Dijkstra routing algorithm (Dijkstra 1959).

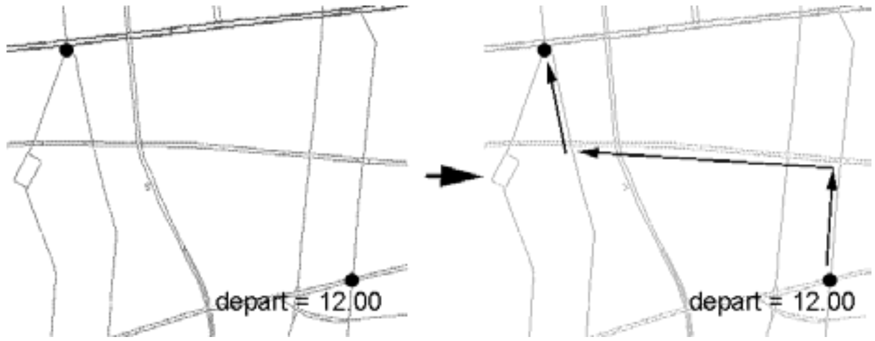


Figure 2 : Routing in a small network

As the speed on the streets changes with the amount of traffic, the computation of routes using a network where the traffic is not yet known does not reflect precise real-world situation. Therefore, the Dynamic User Equilibrium approach was developed by Christian Gawron (Gawron 1998) for routing. This approach repeats the routing and simulation several times to find a real-world behavior of drivers. Additionally, the router supports dynamic network load which depends on the time of the day.

A route file describes both the characteristics of vehicles on the road and the path taken by the cars, the edge sets of roads on the map data. Like net file, road files can be generated with DUAROUTER module from two kinds of input: trip or flow definition. Each trip consists the data of the starting, the ending edge and the departure time. The DUAROUTER computes the shortest path between theses edges. Flow is mostly the same approach as using trip definitions, but one may join vehicles having the same departure and arrival edge using this method. In addition, initial positions of all vehicles are computed randomly.

4.1.2.3 SUMO - TraceExporter

TRACEEXPORTER generates some TCL files for implementing NS-2 simulator. These TCL files contain the scenario description with nodes description such as name, initial vehicles position, speed and direction from the SUMO file.

4.2 Ad-hoc Routing Protocols

Wireless Network could be categorized into 2 types; infrastructure-based and infrastructure-less. Typical wireless network used in cellular phones and wireless local area is a well-known infrastructure-based network. This type of network uses base station or access point as coordinator for communication.

Such as laptops or PDAs is not required to undergo complex routing method, because only one hop communication to a coordinator is needed. Only the coordinator has complex routing procedure.

Technological improvements in wireless communications and electronic devices have allowed the development of sensor nodes that are cheaper, conserve more power, and has more multifunctions. These new sensor nodes that are also smaller in size can communicate without tether in short distances. These small sensor nodes that contain capabilities for sensing, data processing, and communicating components, have revolutionized the field of sensor networks. A sensor network consists of a huge number of sensor nodes that are densely arranged either inside the phenomenon or very close to each other. The position of sensor nodes is not prearranged in advance because this random arrangement of sensor nodes allows more flexible deployment in inaccessible landscapes and disaster relief operations. This also suggests that the sensor network has to be capable of organizing itself without any supervision. This trend is not only restricted to sensor networks, but also exist in other fields such as temporal network for a conference meeting, or certain space consisting various mobile devices.

The key factor in the development of infrastructure-less network is routing protocol that determines how to transfer data from the source to its destination [13]. To solve these problems, different routing protocols were introduced. The two categories of these protocols are proactive (table-driven) and reactive (on-demand).

In proactive routing protocols, each node contains all routes to all the destinations. To instantly update the routes, the protocol use periodic broadcast and instantaneously updates a route if there is any change. This allows every node in the network to maintain up to date routing path information. When up to date route paths are maintained for all the destinations, each node can send packet directly without any delay. However, the downside is the packet overhead for maintaining up to date routes. The overhead problem is more severe for the large scale networks or networks with frequent change. Destination-Sequenced Distance-Vector (DSDV) protocol is a famous protocol of proactive routing.

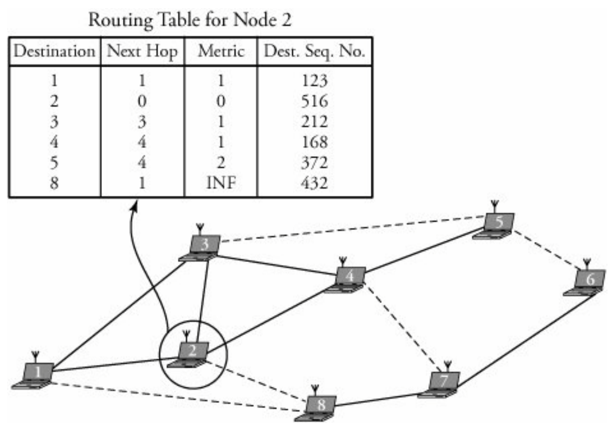
Reactive routing protocols, also known as on-demand protocols, discover routes only when they need to transmit packets. They could reduce the overhead in periodic broadcast packet of proactive protocol. Instead of maintaining the route for all the destinations, the node only discover the route to the destination through route discovery phase only when the transmission is required. Reactive protocols can be categorized into 2 types; source routing and hop-by-hop routing. In source routing, the packet records the path of the delivery, so that complete path information to the destination could be available. In hop-by-hop routing, each data packet only stores the address for the destination and the next hop. Therefore, each node that exists in between the starting point and the destination sends each data packet forward to the destination using its routing table. This strategy has its benefit of more flexible routes in dramatically changing environment of Mobile Ad-hoc Networks (MANETs). Each node can send the data packets over fresher and better routes as it can update its routing table when they receive fresher topology [14].

4.2.1 Proactive Routing Protocols

Proactive routing protocols maintain routes to all destinations even if they are not needed. To update the correct route information consistently, a node must periodically send control packets. As a result, proactive routing protocols use unnecessary bandwidth as control packets are sent out needlessly when there is no data traffic. The advantage of this protocol, on the other hand, is that the nodes can send data with lower delay. DSDV introduced below is a famous proactive routing protocol.

DSDV Routing Protocol

The DSDV described in [15] is a table-driven algorithm based on the classical Bellman-Ford routing mechanism [16]. The improvements have been made to the Bellman-Ford algorithm to allow freedom from loops in routing tables. Every mobile node in the network keeps a routing table, so all of the possible destinations within the network and the number of hops to each destination are recorded as shown in figure 3. Each entry is assigned a sequence number given by the destination node. The sequence numbers allow the mobile nodes to discriminate stale routes from new ones, therefore preventing the formation of routing loops. Routing tables are periodically updated throughout the network to sustain table consistency.


Routing Table for Node 2

Destination	Next Hop	Metric	Dest. Seq. No.
1	1	1	123
2	0	0	516
3	3	1	212
4	4	1	168
5	4	2	372
8	1	INF	432

Figure 3. DSDV Routing Table

The route updates occupy two possible types of packets to lessen the large amount of network traffic that constant updates generate. The first one is a full dump. The full dump carries all available routing information and can require multiple network protocol data units (NPDUs). During the time of infrequent movement, these packets are also transferred occasionally. Smaller incremental packets are used to connect only that information which has changed since the last full dump. Each of these broadcasts need to meet the standard for NPDU’s size requirements, so that the less amount of traffic would be generated. The mobile nodes also contain an additional table which they stack the data sent in the incremental routing information packets. New route broadcasts contain of the sequence number of the information received regarding the destination, the the number of hops to the destination, address of the destination, as well as a new sequence number unique to the broadcast [17]. It automatically uses the route with the most recent sequence number. If the two updates have the same sequence number, the route with the smaller metric is used for the shortest path. Nodes also record the settling time of routes, or the weighted average time that routes to a destination will vary before the route with the best metric is received [18].

The packet is sent without any delay because it keeps up-to-date route information for all the destinations. However, it also produces large amounts of the huge amount of overhead is also created because of periodic messages updates, and the overhead grows according to O (N2). Therefore the protocol is not widely used in large network because a large amount of the network bandwidth is consumed to constantly update the routes [14].

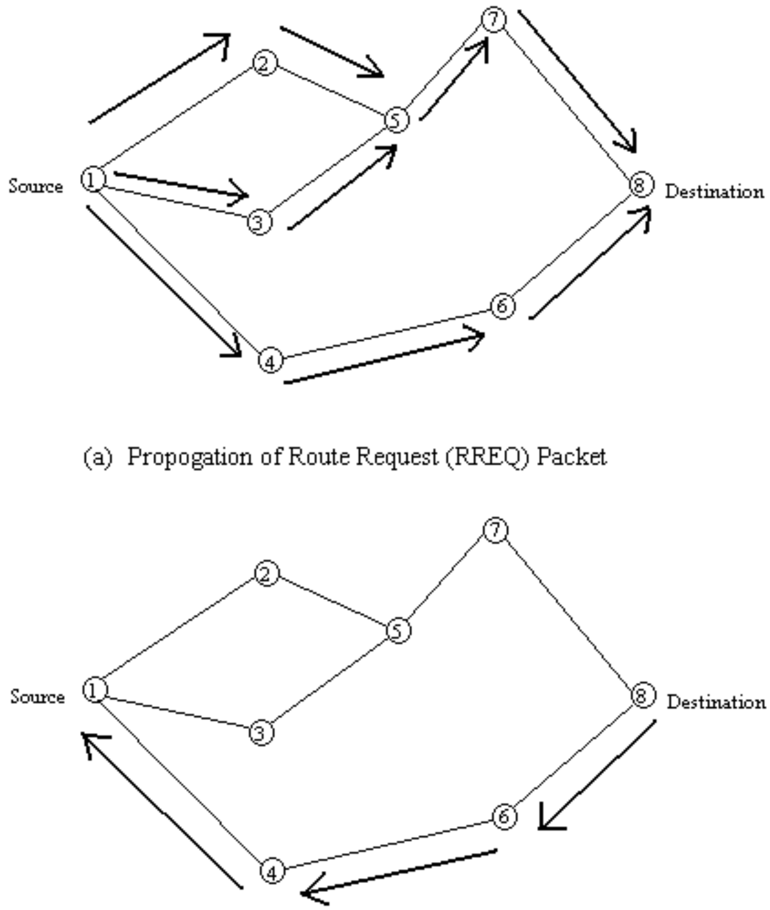
4.2.2 Reactive Routing Protocols

Reactive routing protocols dramatically decrease routing overhead as they do not need to discover or maintain the routes, so there would be no data traffic. This advantage would be very attractive to the resource-limited environment. However, it has its weakness of generating too many packets for route discovery as it frequently sends data. AODV, introduced below, is the famous protocols of reactive routing category.

AODV Routing Protocol

The AODV routing protocol depicted in [19] builds on the DSDV algorithm previously described. AODV is an improved version of DSDV which typically minimizes the number of required broadcasts by creating routes only when needed, as opposed to

DSDV algorithm which maintains a complete list of routes. The authors of AODV categorize it as a pure on-demand route acquisition system because nodes do not store the routing information or exchange routing tables when they are not on the path. A source needs starts the path discovery process and just locates the other nodes right away instead when it needs to send a message to destination nodes and does not have a valid route to them. It broadcasts a route request (RREQ) packet to its adjacent nodes, and these nodes repeat the same process until either the destination or an intermediate node with a "fresh enough" route to the destination is located. Figure 4(a) illustrate the propagation of the broadcast RREQs across the network.



(a) Propogation of Route Request (RREQ) Packet

(b) Path taken by the Route Reply (RREP) Packet

Figure 4: Route Discovery process of AODV

To ascertain that all routes are loop-free and updated with the most recent route information, AODV utilizes destination sequence numbers. Each node stores its own sequence number and a broadcast ID. The broadcast ID is increased for every RREQ the node initiates, and together with the node's IP address, uniquely identifies an RREQ. Other than its the broadcast ID and own sequence number, the source node also contains the latest sequence number that it has for the destination. Intermediate nodes can reply to the RREQ only if they have a route to the destination whose corresponding destination sequence number is greater than or equal to the one that is contained in the RREQ. In the procedure of forwarding the RREQ, intermediate nodes record the routes of the neighbor from which the first copy of the broadcast packet is received in their route tables, so it would establish a reverse path. If additional copies of the same RREQ are later received, these packets are thrown away. Once the RREQ reaches an intermediate or the destination node with a new enough route, intermediate node and the destination node respond by unicasting a route reply (RREP) packet back to the neighbor from which it first received the RREQ as shown in figure 4(b). As the RREP is routed back through the reverse path, nodes along this path create forward route entries in their route tables which point to the node from which the RREP came. These forward route entries mark the active forward route. A route timer is attached to each route to delete the entry that is not used for a certain period of time. Because the RREP is forwarded along the path established by the RREQ, AODV only supports the use of symmetric links. If a source node moves, it discovers a new route to the destination by initiating the route discovery protocol again. If a node transmit along the route, its upstream neighbor node notices the movement and sends a link failure notification message (an RREP with infinite metric) to each of its active upstream adjacent nodes to notice them of the deletion of that part of the route [19]. These nodes in turn transmit the link failure notification to their upstream neighboring nodes, and so on until the source node is reached. The source node then has options to reinitiate route discovery for that destination if a route is still wanted. Additional features of the protocol are the use of hello messages and periodic local broadcasts by a node to inform each mobile node of other nodes in its neighborhood. Hello messages help keep the local connectivity of a node. However, the use of hello messages is not obligatory. Nodes listen for retransmission of data packets to find that the next hop is still within reach. If such a retransmission is not received, the node may use any one of a number of techniques, including the reception of hello messages, to determine whether the next hop is within communication range. The hello messages may list the other nodes from which a mobile has heard, thereby yielding greater knowledge of network connectivity.

4.3 IEEE 802.11p (DSRC)

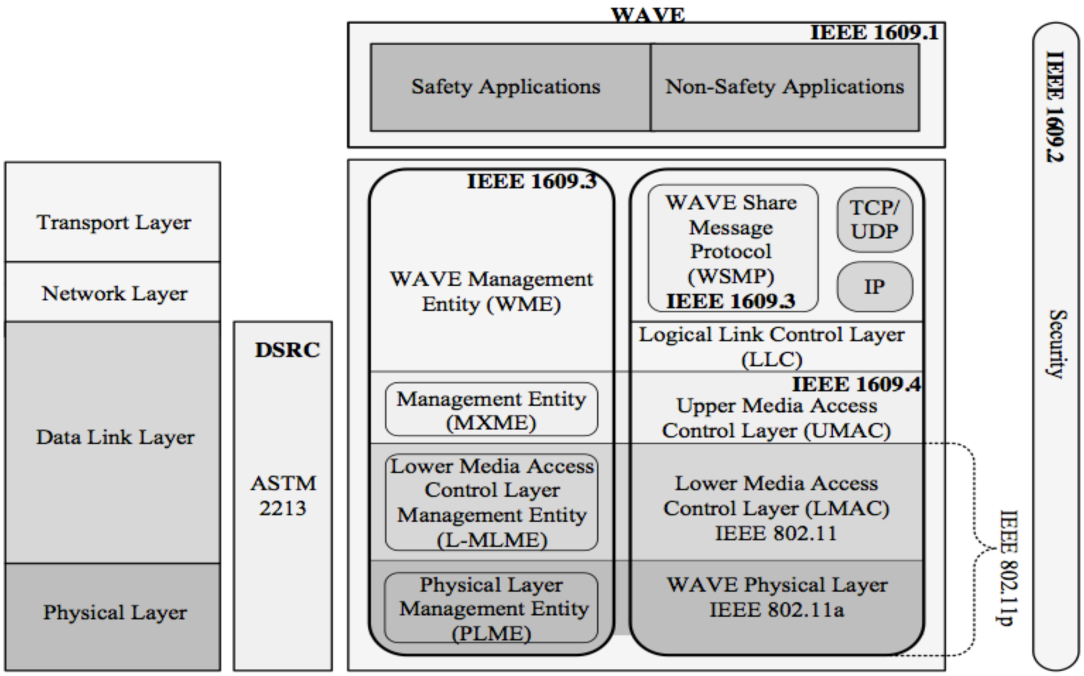
4.3.1 Dedicated Short Range Communication (DSRC)

Dedicated Short Range Communication (DSRC) is a communication service that covers short to medium range. It was developed to aid communications between vehicle and vehicle or vehicle and roadside. Such communications includes a variety of applications such as safety messages between vehicles, road information, toll and drive-through payments, and etc. The purpose of DSRC is to provide large amount of data transfers while having small amount of communication latency. In 1999, the United States Federal Communications Commission (FCC) designated 75 MHz of spectrum at 5.9 GHz as the standard for DSRC. In 2003, The American Society for Testing and Materials (ASTM) agreed the ASTM-DSRC standard which was based on the IEEE 802.11a physical layer and 802.11 MAC layer. DSRC is a free but licensed spectrum. It does not cost to use DSRC, but the usage requires many restrictions. For example, using the channels and all radios that are developed has to meet the standard that FCC requires. The DSRC spectrum has seven channels, and each this channel is 10 MHz wide. All seven channels are reserved for certain purposes. One is used for safety communications, and other two are used for life and high power public safety. The rest are service channels that are freely used in both safety-related and other applications. Higher priority is given to safety applications as avoiding possible performance fall and saving lives from forthcoming hazards are more important than other non-safety applications [20] .

4.3.2 IEEE 1609 - Standard for Wireless Access in Vehicular Environment (WAVE) / IEEE 802.11p

Currently used 802.11a compliant devices with data rates of 54 Mbps provide decent wireless connectivity among mobile vehicles. However, due to the fast and quickly changing velocity, traffic patterns, and driving environments, vehicular traffic scenarios experience more difficulties than fixed wireless networks. Therefore, in the mobile vehicular scenarios, the traditional IEEE 802.11 Media Access Control (MAC) operations suffer from great amount of overheads. This huge amount of overheads is caused because fast data exchanges are needed to make sure safety communications are made in time. In these environments, the scanning of channels for beacon signal from an Access Point along with multiple handshakes required to make communication are associated with too much complexity and high overheads. When a vehicle faces another vehicle coming from the other direction, establishing communications is extremely hard as only a short, limited time is allowed. To address these challenging requirements of

IEEE MAC operations, the DSRC effort of the ASTM 2313 working group migrated to the IEEE 802.11 standard group which renamed the DSRC to IEEE 802.11p Wireless Access in Vehicular Environments (WAVE) [21]. In contrast to DSRC which is standards that are only applicable to regions, WAVE is new standards that could embrace all across the world. As illustrated in Figure 5, it is worth noting that IEEE 802.11p is limited by the scope of IEEE 802.11 which strictly works at the media access control and physical layers . The upper layers of IEEE 1609 standards take care of the operational functions and complexity of DSRC. How applications will utilize in the WAVE environment is depicted by these standards, based on the management activities defined in IEEE P1609.1, the security protocols defined in IEEE P1609.2, and the network-layer protocol defined in IEEE P1609.3. The IEEE 1609.4 is higher in level than 802.11p and it supports the operation of higher layers without the necessity the physical channel access parameters. WAVE defines two types of devices: RoadSide Unit (RSU) which is stationary and OnBoard Unit (OBU) which is mobile. RSUs and OBUs could be either a provider or a user of services. Usually, RSU, the stationary device, hosts an application and provides service to the OBU, the mobile devices. However, there are also applications hosted on mobile devices(OBU) to provide services back to stationary RSU. This WAVE standard explains applications that resides on the RSU but is designed to multiplex requests from remote applications thus providing them with access to the OBU. WAVE uses Orthogonal Frequency Division Multiplexing (OFDM) to divide the signal into several narrowband channels that each provide a data payload communication capability of 3, 4.5, 6, 9, 12, 18, 24 and 27 Mbps in 10 MHz channels.



ASTM: American Society for Testing and Materials
DSRC: Dedicated Short Range Communication
IP: Internet Protocol
TCP: Transmission Control Protocol
UDP: User Datagram Protocol

Figure 5: Wireless Access in Vehicular Environment (WAVE), IEEE 1609, IEEE 802.11p and the OSI Reference Model

4.3.3 Comparison between IEEE 802.11a and IEEE 802.11p

IEEE 802.11p is the new extension of IEEE 802.11 standards, especially proposed for the high vehicular environment. The WAVE documentation represents enhancements to the MAC and PHY layer of IEEE 802.11a to work efficiently in high vehicular environment.

The main system parameters of the 802.11a and 802.11p are shown in Table 2.1, in order to underline the differences between the two standards.

Parameter	802.11 a	802.11 p
Sample rate	**20 MHz**	**10 MHz**
Chip duration	**50 ns**	**100 ns**
Number of fft points	64	64
Number of sub carriers	52 + DC	52 + DC
Number of data sub carriers	52	52
Number of pilot sub carriers	4	4
OFDM symbol period	$T_{Symbols}$ = 80 chips = 4 μs	8 μs
Cyclic prefix	16 chips = 0.8 μs	1.6 μs
FFT Symbol period	64 chips = 3.2 μs	6.4 μs
Modulation scheme	BPSK-QPSK-16QAM-64QAM	BPSK-QPSK-16QAM-64QAM
Coding scheme	$\frac{1}{2}$ industry convolutional	$\frac{1}{2}$
Puncturing	optional puncturing $\frac{3}{4}$ or $\frac{2}{3}$	$\frac{3}{4}$ or $\frac{2}{3}$
Available data rate	6-9-12-18-24-36-48-54 Mbps	3-4.5-6-9-12-18-24-27 Mbps

Table 1: Main system parameters in IEEE 802.11a and 802.11p standard and relative difference

The procedure of frame encoding for IEEE 802.11p has two main differences from the one for IEEE 802.11a in the current version of the standard. The two main differences are the operating frequency band is changed to around 5.9GHz and the duration of OFDM symbols is increased from 4µs to 8µs. The reasons for these changes are to reduce interference with legacy systems and to double the cyclic-prefix-duration by doubling the symbol-time. This change helps decreasing the OFDM inter-symbol-interference (ISI) in outdoor channels.

Chapter 5

Simulation Study of VANET Routing Protocols and Mobility Models

5.1 Configuration Setup SUMO Vehicular Mobility Model

There are many open sources, commercial tools, and software available in market for generating traffic simulation model which features motion of multiple vehicles under the provided conditions. This research uses the OpenStreetmap for extracting road network in form of an OSM file. To execute the command of SUMO for reading and simulating vehicular motion based on road network XML and traffic flow description, the road network was conversed into XML format [22].

The road network file can be generated from various input formats with NETCONVERT module [23]. In our case, we choose OpenStreetmap program to generate OSM file. And NETCONVERT module can generate SUMO network file from the OSM data file. From network to the route files, SUMO module simulates all the positions in numerous times. These positions are, then, recorded in a dump file. The following figure depicts the process of generating vehicular mobility with SUMO.

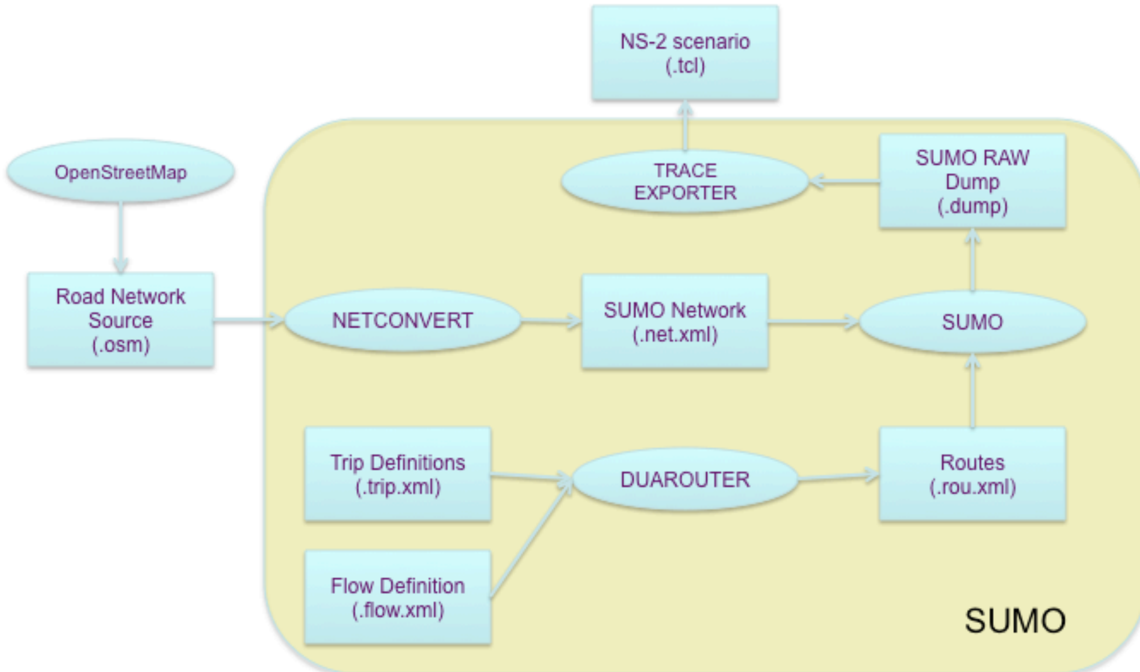


Figure 6: Process to generate vehicular mobility with SUMO

5.2 Configuration Setup for Random Way Point Model

In this model, each node is assigned an initial location, a destination, and speed. The initial location and destination location are planned independently, but uniformly in the region where the nodes move. The speed is chosen uniformly on an interval, not related to both the initial and destination locations. After reaching the destination, the process repeats. A new destination is chosen again from the uniform distribution, and new speed is chosen uniformly on the interval, independent from all the previous destinations and speeds. Nodes may pause upon reaching each destination, or just immediately continue to the next destination. If they do pause at destination locations, the pause times are also chosen independent from speed and locations.

In this paper, we derive the stationary distributions of speed, location, and pause time for a node that moves in a rectangular area under the random waypoint mobility model. To keep the model simple, we made the assumption that the network region is the unit square. This allows flexibility in adjusting the scaling to apply our results to any rectangular network.

In order to compare between realistic mobility model (SUMO) and unrealistic mobility model (Random Way Point), we choose the simulation area size as same SUMO's map size. Also, the number of vehicles is generated as same one.

5.3 Parameters for Ad-hoc Routing Protocols

In our experiments, we use IEEE 802.11a and 802.11p protocol, which are based on the ns-2 network simulator. In this paper, we compare the performance between AODV and DSDV routing protocol on IEEE 802.11p environment. In following table we have summary of parameters of ns-2 network simulator setting.

Parameters	Values
Simulator	NS-2
Mobility Model	SUMO / Random Way Point
Area of map	3217m x 4026m
No. of vehicle	200
Vehicle Speed	0 ~ 16.92 m/s
PHY / MAC	IEEE 802.11a / p
Routing Protocol	DSDV / AODV
Network Traffic	CBR (512Byte/s, rate : 2)
Simulation time	100 ~ 300 sec

Table 2: Simulation Parameters Considered

Routing protocol AODV and DSDV, they can be used in Ad-hoc, network to route packets between mobile and vehicle nodes. The main objective of this paper is evaluating the performance between AODV and DSDV on IEEE 802.11p environment under following metrics:

- Packet Delivery Ratio: The ratio between the numbers of packets arrived at the TCP sink of the final destination and the numbers of packets initiated by the application layer sources. It is a measure of efficiency of the protocol
- Throughput: It is defined as total numbers of packets arrived at the destination. It is a measure of effectiveness of a routing protocol.
- Number of Hops: The difference between the numbers of hops a packet takes to arrive at its destination and the length of the shortest path that physically existed through the network when the packet was initiated.

5.4 Experiments using Vehicular Mobility Model

In this paper, we have selected Auburn University area for mobility model. The stepwise generation of mobility model is given below:

1. Implement OpenStreetMap java program to obtain map data. Search the location and choose the road suitable for the simulation. After choosing the road, use for the map is now done, so select OpenStreetMap XML data and export OSM file.
2. The OSM file will be imported in NETCONVERT which is an additional module of SUMO that provide the tool to convert map data from the OSM file to format

that can be used for road traffic simulator SUMO. The exported result of road network is given to SUMO in XML format.

3. The network and route XML file are generated by SUMO, this XML files are provided to TRACEEXPORTER. It is a tool that help for integrating SUMO and ns-2 for generating realistic scenario. Basically it converts SUMO mobility XML files to .tcl extension files use in ns-2 simulator. Mobility traces are generated for ns-2 from the net and rou XML files. The random and flow-based vehicle routes are generated using duarouter tool from SUMO.

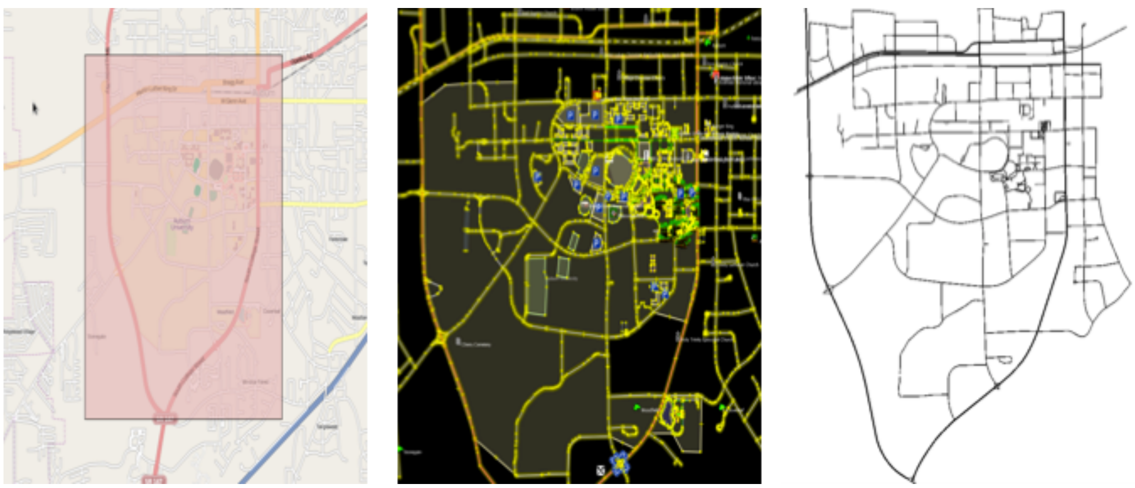


Figure 7: OSM file of AU area convert format for SUMO simulator

Figure 7 shows the process to generate vehicular mobility file and map data file for implementing SUMO. The Auburn University area map scenario is considered 200 realistic vehicles (transmitter and receiver), which were defined with 3217m x 4026m topology until 300 seconds simulation. The node movement was moving only on the roads and in each simulation the speed of each node was variable up to 16.92 m/s. Also Random Way Point mobility model generated vehicular scenario as the same topology size and number of vehicles. However, all the vehicles have variable direction and speed not on the road.

Chapter 6

Performance Evaluation

6.1 Analysis of Packet delivery ratio for various vehicular mobility model using SUMO and Random Way Point

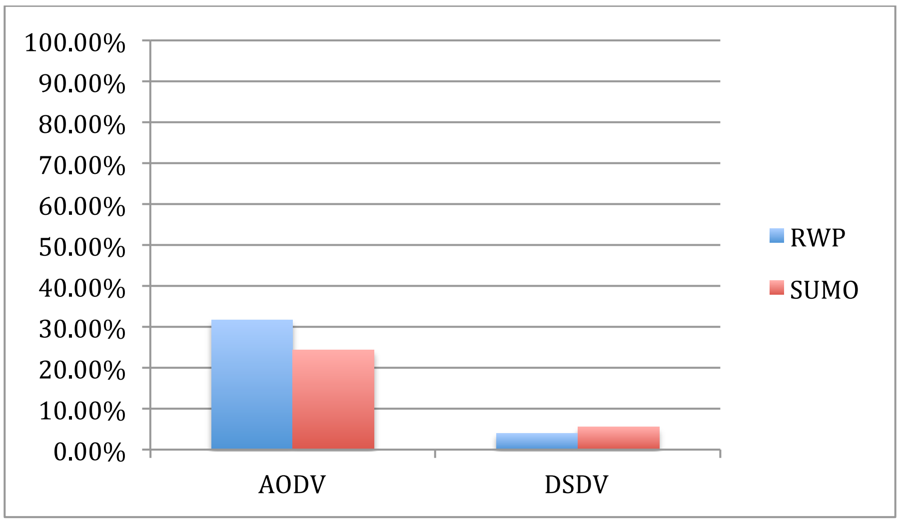


Figure 8: Packet Delivery Ratio vs Routing protocol using IEEE 802.11a

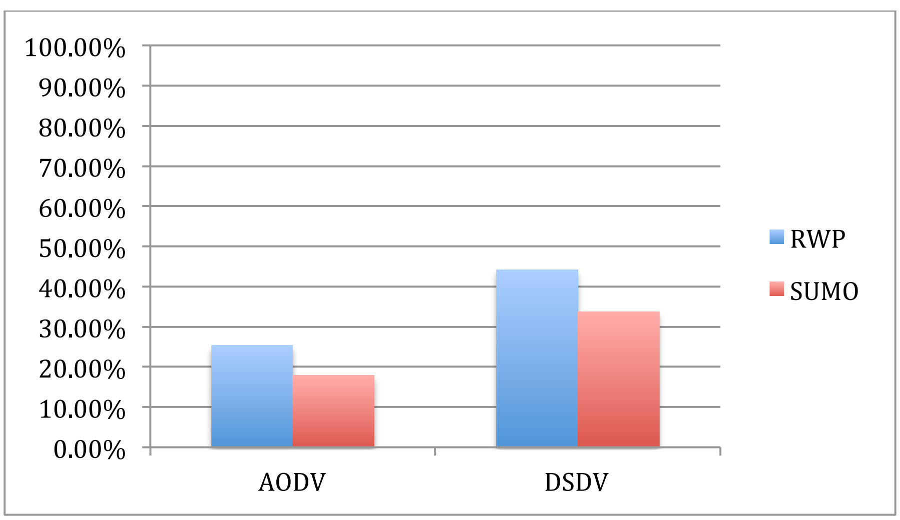


Figure 9: Packet Delivery Ratio vs Routing protocol using IEEE 802.11p

This parameter defines the ratio of successful transmitted packet from source node to destination node. Figure 8 and 9 shows that Packet Delivery Ratio of each routing protocol to compare Random Way Point model and SUMO model. In IEEE 802.11a, AODV routing protocol is more accurate than DSDV routing protocol. However, DSDV is more suitable than AODV in IEEE 802.11p. We will mention the specific analyzing about it in next result.

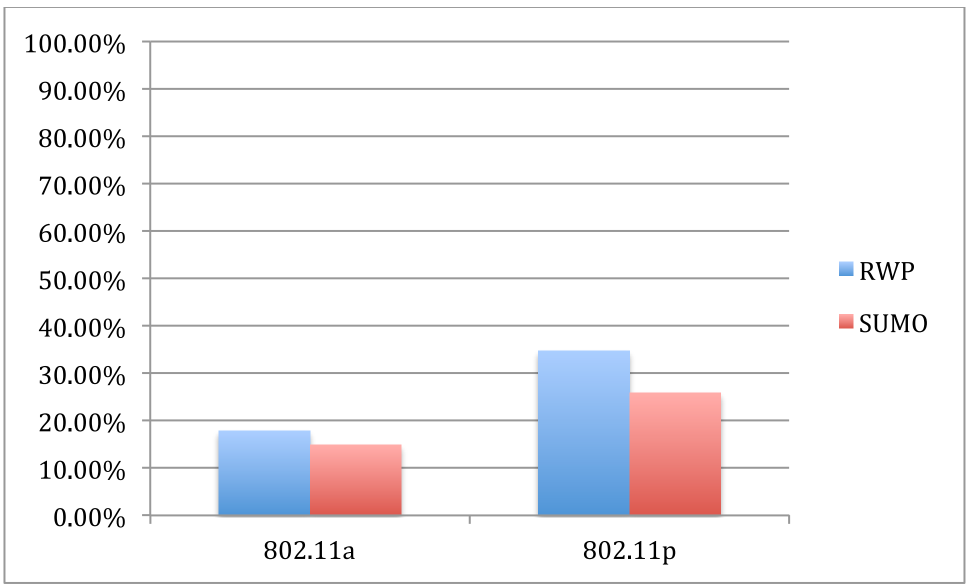


Figure 10: Average PDR(%) of RWP and SUMO with 802.11a/p

Figure 10 presented the average Packet delivery ratio of RWP and SUMO. This graph means that unrealistic mobility model (RWP) supports random vehicle movement. That gives the larger result than using realistic mobility model (SUMO)'s result. The result shows that the RWP network connectivity is more than SUMO's result. In RWP scenario, each vehicle can have more adjacent connections since it can move any directions. But, this phenomenon means that RWP gives not accurate result for VANET simulation.

6.2 Results of the evaluation using IEEE 802.11a protocol

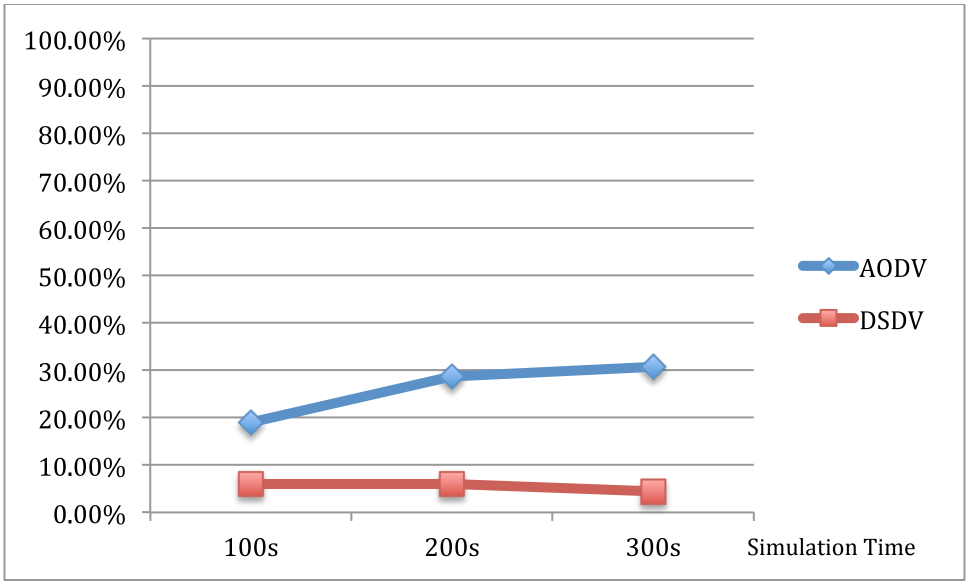


Figure 11: Packet Delivery Ratio with using IEEE 802.11a

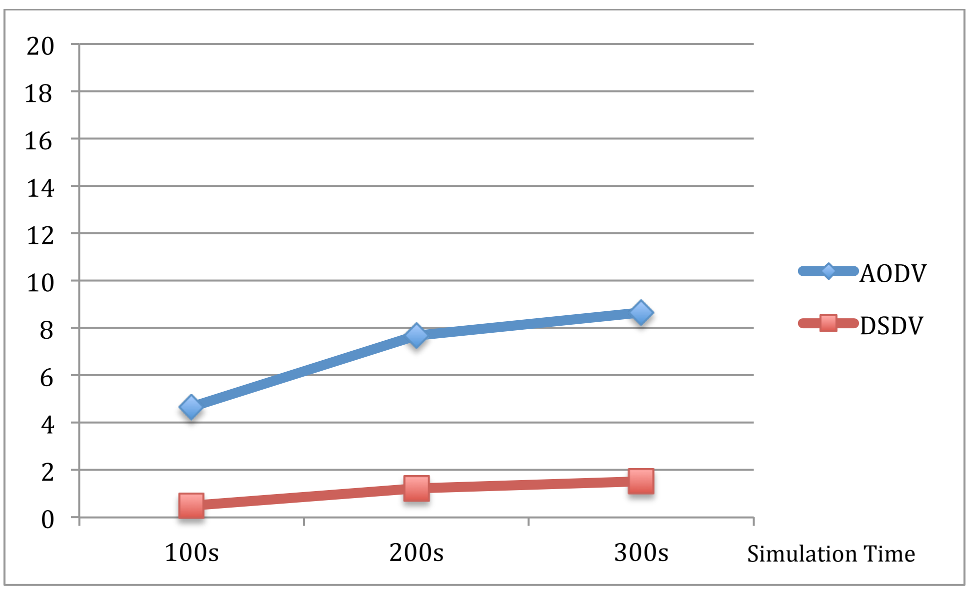


Figure 12: Number of Hops with using IEEE 802.11a

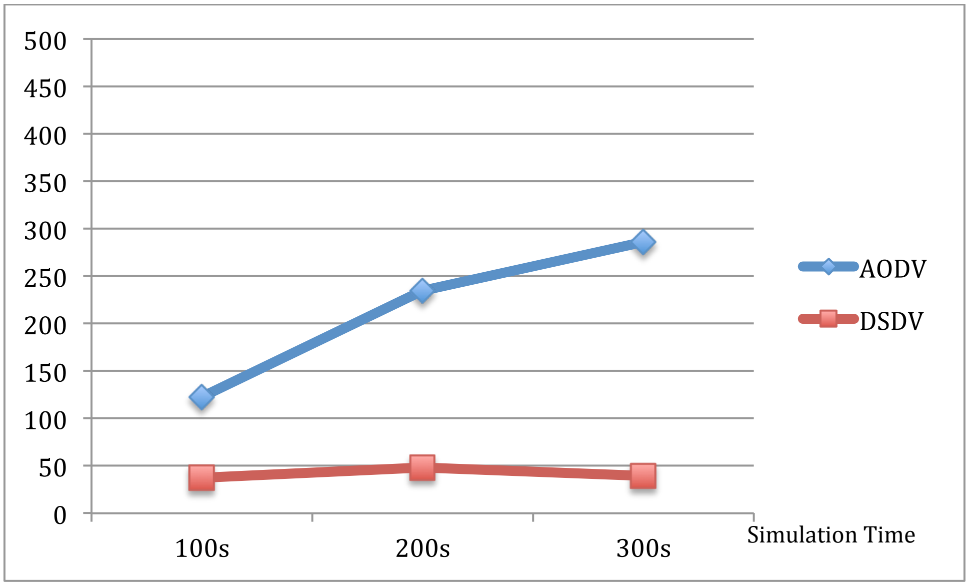


Figure 13: Throughput with using IEEE 802.11a

From figure 12~14, the results shows comparison between AODV and DSDV on IEEE 802.11a environment. The results of this simulation depict the difference between two routing protocols. Frequent link failures happen in existence of high mobility, and each routing protocol responds differently to the link failures. The two protocol's different performances are because these protocols have different mechanisms. When the mobility was high, DSDV failed to respond properly. With the lower pause time, DSDV worked very poorly with the packet delivery ratio under 10%. Most of the undelivered packets are lost because outdated routing table does not update a route that goes over a broken link. DSDV stores only one route per destination, if the MAC layer fails to deliver, the packet gets lost because it does not have any alternative routes. In contrast, AODV maintained the packet delivery ratio up to 30%. The lazy approach used by the on-demand protocols, AODV to build the routing information as and when they are created make them more adaptive and result in better performance.

6.3 Results of the evaluation with using IEEE 802.11p protocol

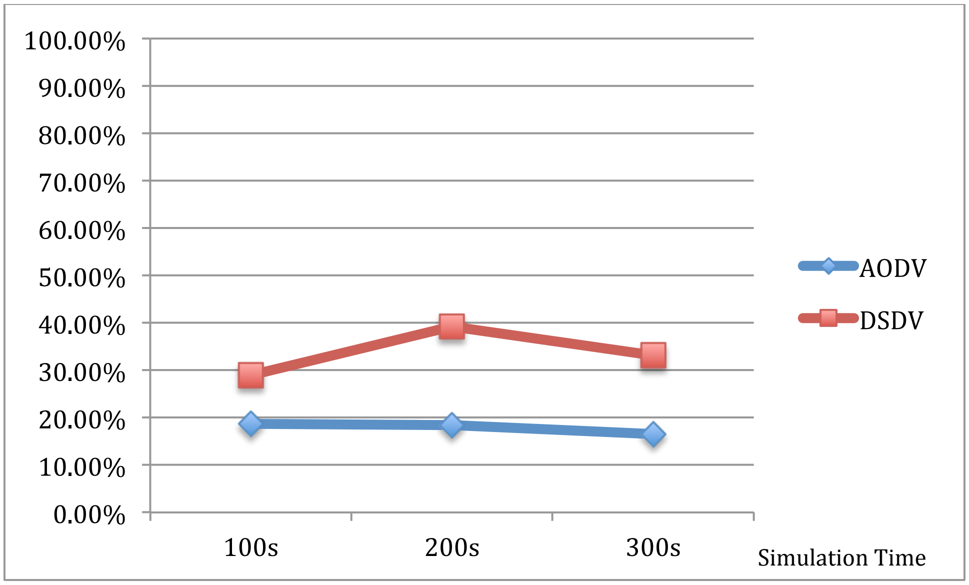


Figure 14: Packet Delivery Ratio with using IEEE 802.11p

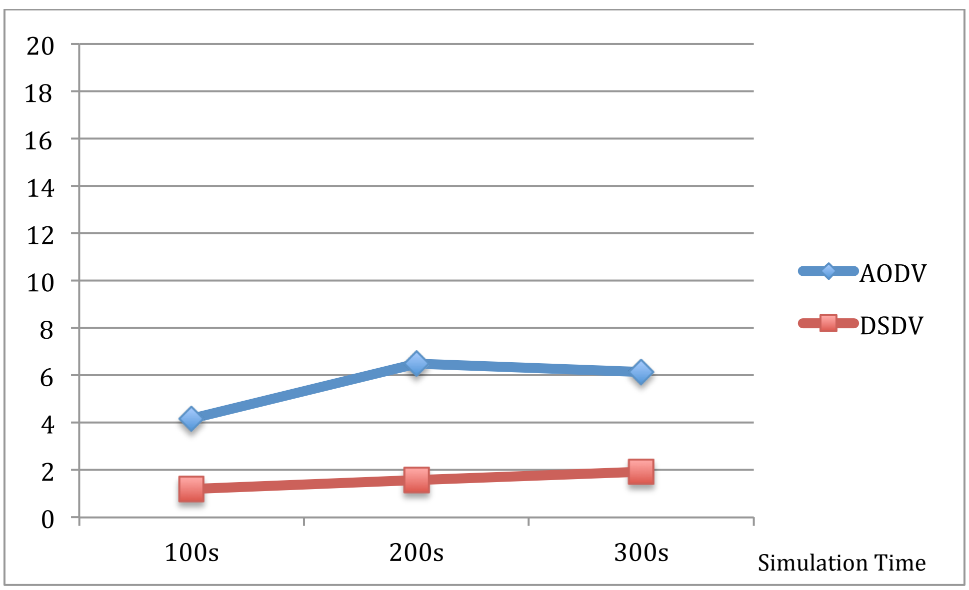


Figure 15: Number of Hops with using IEEE 802.11p

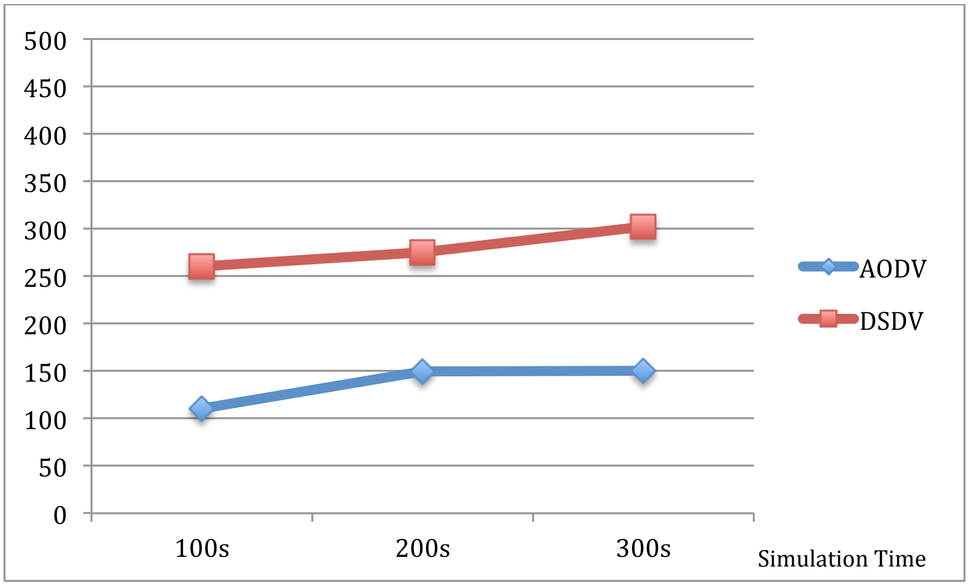


Figure 16: Throughput with using IEEE 802.11p

Figure 14~16 shows that DSDV is more accurate than AODV with using IEEE 802.11p protocol. Especially, figure shows the packet delivery ratio comparison of AODV and DSDV. The graph reveals that DSDV has higher PDR result than AODV. It has been proved that a better performance is received in DSDV for IEEE 802.11p standards. Also, in figure 15 and 16, DSDV has the lower hops and larger throughput that also supports DSDV is more suitable than AODV for IEEE 802.11p. Normally DSDV protocol is well suited for small-scale ad-hoc network. It is noted that the proactive routing protocol DSDV achieves better throughput than the reactive protocol AODV.

Chapter 7

Conclusion

This thesis compared the performance of AODV and DSDV routing protocols for vehicular ad-hoc network using IEEE 802.11p protocol. In addition, we applied vehicular mobility model, which produce more realistic and reliable results. As the result of comparison performance between RWP and SUMO, SUMO is more accurate for VANET simulation. It supports realistic vehicular movement scenario for evaluating routing protocols, it is more suited for the simulation. In the simulations with IEEE 802.11a protocol, AODV shows better performances than DSDV under high mobility scenarios. High mobility results from frequent link failures and overhead from updating all the nodes with the new routing information. DSDV is much more involved than AODV because the route table exchanges increase with the number of nodes. AODV uses only one routing table per destination and also contains destination sequence numbers and a mechanism to prevent loops and determine freshness of routes. However, in the result with using IEEE 802.11p protocol, DSDV shows better performance than AODV protocol in terms of the packet delivery ratio, number of hops and throughput. DSDV has the best packet receiving time and broadcasting time[24]. It is also noted that the proactive protocol DSDV achieves better throughput than the reactive protocol AODV. From this analytical work it has been proved that, when dealing with packet delivery ratio, number of hops and throughput that DSDV for IEEE 802.11p will present better response. Future research can be done in this area to deal with OLSR routing protocol for VANET networks in order to evaluate the most suitable routing protocols. And IEEE can be performed to compare with IEEE 802.11p for VANET simulation.

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