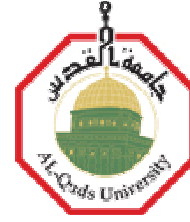


**Deanship of Graduate Studies
Al-Quds University**



**Vehicular Ad Hoc Networks Routing Protocols:
Comparative Simulation Study in City Scenario**

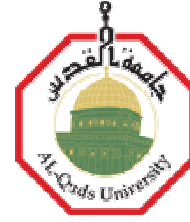
Mohammad Hassan Azouqa

M.Sc. Thesis

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Vehicular Ad Hoc Networks Routing Protocols: Comparative Simulation Study in City Scenario

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**A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Electronic and
Computer Engineering/Faculty of Engineering-
Al-Quds University**

Aug., 2010

Electronic and Computer Engineering Master Program
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Vehicular Ad Hoc Networks Routing Protocols: Comparative Simulation
Study in City Scenario

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Jerusalem / Palestine

Aug., 2010

Dedication

*I dedicate this work to my parents,
my wife,
my sons,
my brothers, sisters, and their families.*

Declaration

I Certify that this thesis submitted for the degree of Master is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signed:

Mohammad H. Azouqa

Date:

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First of all, I would like to thank Allah for the blessing and the opportunity for me to finish this work.

I would like to thank Dr. Samer Bali for his guidance, encouragement, advices and insightful comments during my work period, a special thank to him for reviewing my reports, offering the new ideas, and proposing and commenting on the simulations and results during my whole work.

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I would like to deeply thank my mother and my father for the endless supports, patience and encouragements during my whole life.

Last but not least, I express my sincere gratitude to my wife for her support and patience.

Abstract

The Last decade has seen many advances in wireless networks. Among these networks are the so called mobile ad hoc networks (MANETs) that do not rely on any existing infrastructure. MANETs have no special fixed routers. Instead, the mobile nodes themselves function as routers which discover and maintain communication connections. Thus, a MANET is a self-organizing multi-hop wireless network where all nodes participate in the routing and data forwarding process.

Vehicular Ad Hoc Network (VANET) is special case of MANET where the network is focused on providing vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications. VANET has been one of the hottest research topics in the last few years and is considered one of the most promising types of networks in the future. The main goals of VANET are to increase traffic safety, to increase transportation efficiency, and to reduce the negative impacts of the transportation on environment. VANET has received a wide attention from many car manufacturers, governmental organizations and the academic communities. Due to the mobility of vehicles in VANETs, topology of these networks change unpredictably. Moreover, routing in VANETs work mainly in a distributed manner. These factors make routing one of the main challenging issues to be considered in VANETs.

Simulation is a necessary tool for conducting research in this field for cost and safety reasons. So, simulation tools have a significant role in studying VANETs. The main goal of this thesis is to find the best routing protocol suitable in VANETs city scenario. Our assumed VANET scenario in this thesis consists of vehicles (nodes) approaching a road intersection in urban environment. The scenario focuses on sending information about the intersection from a node existing at the intersection (source node) to other nodes (destination nodes) that are at distance of approximately 1km from the road intersection moving towards it. The information sent to the destination nodes contains the conditions about the intersection. The information may take several types of data such as voice, image, or video. This application assists the driver in dealing with the conditions of intersection, such as traffic congestion and traffic light phase, before his arrival to it. In this thesis, we carried out a comparative simulation study using SUMO and ns-2

simulators to investigate the performance of (V2V) communications based on MANETs routing protocols AODV, AOMDV, DYMO, and DSDV for different parameters such as number of vehicles, maximum speed of vehicles, and number of sent data packets. The simulation results showed that DYMO routing protocol has better performance than other routing protocols in terms of routing overhead and end-to-end delay.

ملخص الرسالة

(router) mobile ad hoc network (MANETs)
(mobile node) .
MANETs .
(multi-hop)
.
Vehicular Ad Hoc Network (VANET)
(vehicle-to-vehicle) MANETs
VANET (Vehicle to infrastructure)
VANET .
.
VANET
VANETs
VANETs
.
VANETs
VANET
VANET
(DSDV, AODV, AOMDV, DYMO) MANETs

()

VANET

1km

()

()

ns-2 SUMO

AODV MANETs

(V2V)

DSDV DYMO AOMDV

DYMO

routing overhead end-to-end delay

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List of Acronyms

AODV	Ad hoc On-demand Distance Vector
AOMDV	Ad Hoc On-Demand Multipath Distance Vector
DCF	Distributed Coordination Function
DL	data load
DSDV	Destination-Sequenced Distance-Vector
DSR	Dynamic Source Routing
DSRC	Dedicated Short Communications
DYMO	Dynamic MANET On-demand
E2ED	Average End-to-End Delay
FCC	Federal Communications Commission
G1	first Generation
G2	second Generation
G3	third Generation
GPS	Global Positioning System
ID	Identity
IETF	Internet Engineering Task Force
IEEE	Institute of Electrical and Electronics Engineers
MAC	Medium Access Control
MANET	Mobile Ad hoc Network
ns-2	Network Simulator 2
OFDM	Orthogonal Frequency-Division Multiplexing
OLSR	Optimized Link State Routing
OH	routing OverHead
OTcl	Object Tool Command Language
PDR	Packet Delivery Ratio
PL	Packet Loss
PHY	Physical
RERR	Route Error
RREP	Route Reply
RREQ	Route Request
SUMO	Simulation of Urban Mobility

List of Acronyms

TH	Throughput
UWB	Ultra-Wideband
VANET	Vehicular Ad Hoc Network
V2R	Vehicle to Roadside
V2V	Vehicle to vehicle
VN	Number of Vehicles
VS	Speed of the Vehicles
WAVE	Wireless Access in Vehicular Environments
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLANS	Wireless Local Area Networks

Chapter 1

1. Introduction

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1.1 Preface

Wireless networks have become increasingly prominent technology in recent years. There are two forms of mobile wireless networks [1]: infrastructure mobile networks and infrastructure-less mobile networks. The latter, also known as ad hoc¹ networks have no special fixed routers. Instead, mobile nodes themselves function as routers which discover and maintain communication connections. Thus, a mobile ad hoc network (MANET) is a self-organizing multi-hop wireless network where all nodes participate in the routing and data forwarding process. Such a network can be easily deployed in situations where no base station is available, and where a network must be built spontaneously. Vehicular Ad Hoc Network (VANET) is special case of MANET where the network is usually formed between vehicles themselves and nearby fixed equipments.

VANET has been one of the hottest research topics in the last few years. The main goals of VANET are to increase traffic safety, to increase transportation efficiency, and to reduce the negative impacts of the transportation on environment [2]. The importance of VANET has been recognized by many car manufacturers, governmental organizations and the academic communities [3]. VANET holds great promises to our future and they have several challenges that need to be addressed. The technical challenges in VANET are not trivial and they are presented in all layers. This thesis will focus on routing protocols in the network layer.

The main goal of this thesis is to find the best routing protocol suitable in VANETs city scenario. To achieve this goal, simulation software has been developed as basis for investigations. In this software, two basic considerations have been taken into account. Firstly, we have considered city scenario that represents the main application in VANET. So we generate simulation environments that could be used as a framework for further studies within the area of VANETs. Secondly, in this scenario, we perform comparative simulation study between exiting routing protocols for MANETs in VANET scenario.

¹ In Latin, *ad hoc* literally means “for this” being further interpreted as “for this purpose only”, It generally signifies a solution designed for a specific problem or task

It is expected that thesis contribution at network layer with other research contributions at other layers will lead to overcome some challenges faced by VANET.

To achieve these goals, the following methodologies are used:

- Define VANET simulation scenario,
- Design VANET scenario using the simulation of urban mobility (SUMO) traffic simulator from German Aerospace Center [54] in order to generate the mobility patterns then apply the mobility patterns in network simulator 2 (ns-2) from Berkeley [53],
- Carry out performance evaluation of routing protocols. This will enable us to specify the basic requirements needed to design a suitable routing protocol for VANET scenario.

1.2 Research Questions

This thesis answers the following questions:

- What are the steps to generate a realistic VANET network scenario?
- Which routing protocol is best for this network scenario?
- How does a routing protocol affect the network performance?

City traffic is a main scenario for VANET applications, and routing for urban VANET faces greater challenges because of potential uneven distribution of vehicular nodes, constrained mobility pattern and difficult signal reception due to radio obstacles. These factors make routing the prominent problem in VANET. Cost and safety factors dictate that simulation is a necessary tool for doing research in this field [3].

1.3 Related Works Studies

MANET working group of the Internet Engineering Task Force (IETF) develops standards for routing in dynamic networks of both mobile and static nodes [27]. There are many routing protocols designed to relay data in MANETs such as Ad hoc On-demand Distance Vector (AODV) [4], [5], Dynamic Source Routing (DSR) [6], Destination-Sequenced Distance-Vector (DSDV) [7], Dynamic MANET On-demand routing protocol (DYMO) [8], [10], Ad hoc on-demand multi-path distance vector [11], Optimized Link State Routing (OLSR) [12], Connectionless Approach (CLA) [13], Contention-based Forwarding (CBF) [14], Greedy Perimeter Stateless Routing (GPSR) [15], Global State Routing (GSR) [16], and Zone Routing Protocol (ZRP) [17].

The principle behind the wireless communication between vehicles has been receiving increasingly attention from researchers. The most comprehensive studies have been performed by the Fleetnet project. Several researches have been published comparing the performance of routing protocols using different mobility models or performance metrics. One of the comprehensive studies was done by the Monarch project [18]. This study compared AODV, DSDV, DSR and TORA and introduced some standard metrics that were then used in further studies of wireless routing protocols. In [19] another study was introduced which compares and evaluates AODV, DSR, FSR and TORA for VANETs, in this study, the mobility was based on free way mobility model. In [1], a comparative study has been performed by using a GloMoSim simulator.

Our study differs from the previous ones in several aspects. Firstly, the study in [18] was on MANETs scenario, but we focus on the VANETs scenario. Secondly, the study in [19] is based on free way mobility model. While our study based on the city scenario mobility model. Thirdly, the study in [1] is based on GloMoSim and do not use any traffic simulator to generate mobility patterns. But our work is based on SUMO traffic simulator to generate the mobility patterns in our study.

1.4 Thesis Organization

This thesis is organized as follows:

In Chapter 2 the origins and evolution of the vehicular Ad hoc networks (VANETs) is explained. Chapter 3 gives an overview on possible MANET routing protocols that may be used in VANETs scenario. In Chapter 4 the design of VANET simulation environments is presented. Particularly, the generation of the mobility patterns using SUMO traffic simulator and using them in network simulator ns-2 are described. Chapter 5 presents and discusses our experimental results. In addition, it presents the performance evaluation of DSDV, AODV, AOMDV and DYMO in order to determine the important requirements needed to design a suitable routing protocol for VANET scenario.

Finally, chapter 6 summarizes and concludes this thesis as well as it provides an outlook for future work.

Chapter 2

2. Vehicular Ad hoc networks

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2.1 Introduction

The past decade has seen many advances in wireless communication technologies. Among these technologies are the so called MANETs and VANETs. This chapter provides a brief overview of the principles of MANETs and VANETs, and their applications and wireless access methods.

2.2 Wireless Networks

In general, the communication networks can be classified according to the medium into two types: wired networks and wireless networks. The latter consist of nodes that communicate over a common wireless channel. This type of networks can be classified based on how the network is constructed, i.e., the underlying network architecture [20].

2.2.1 Infrastructure Networks

An infrastructure-based network is a network that has wireless terminals communicating with each other with pre-existing infrastructure in place (typically, wired network nodes and radio tower). Network services are delivered via these pre-constructed infrastructures. For example, cellular networks are infrastructure-based networks, which are built from public-switched telephone network (PSTN) backbone switches, mobile switching centers (MSCs), Base Stations (BSs), and Mobile Stations (MSs) as shown in figure 2-1. Each node of the network has its specific responsibility in routing the data, and the connection establishment follows a strict signaling sequence among the nodes.

Another example of infrastructure-based networks are wireless local-area networks (WLANs) [20], which are created by means of wireless central device such access point. All nodes such as mobile computer equipped with wireless network card reside in a particular region where all communication must go through the access point. If the connection between a node and the access point is lost, the node cannot transmit any packet. Figure 2-2 shows a WLAN example.

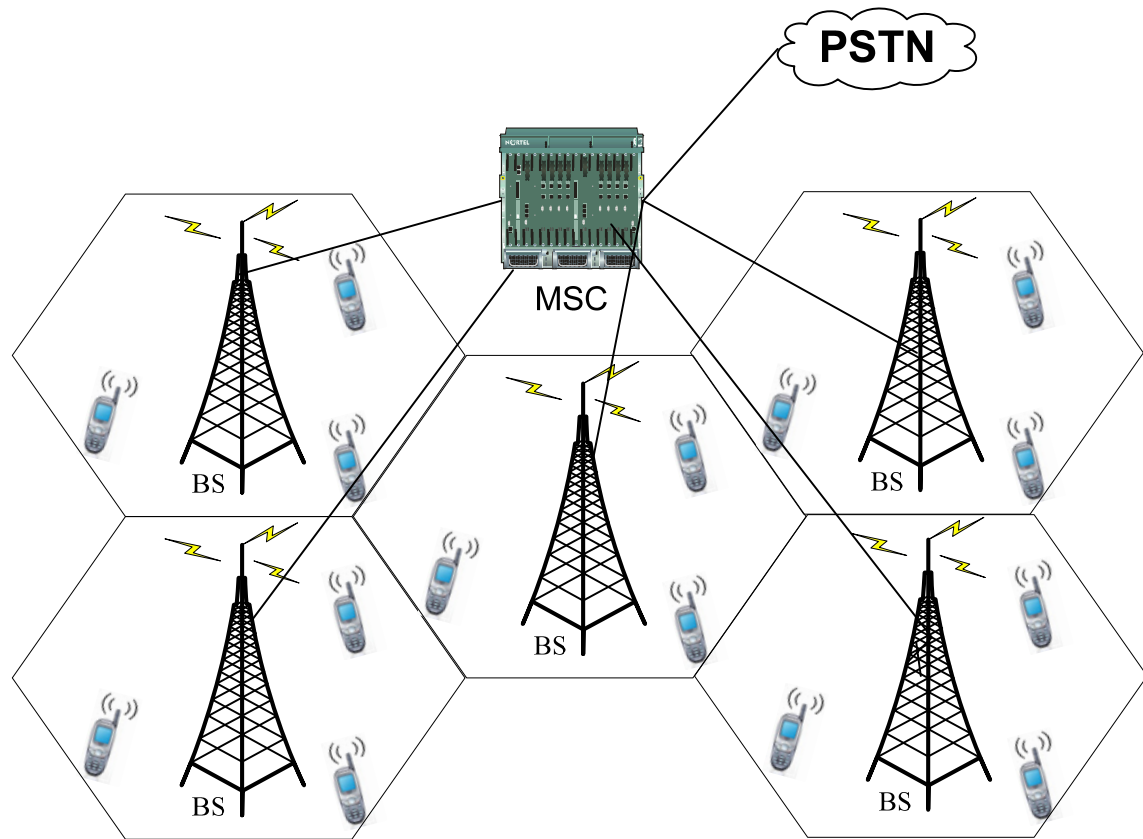


Figure 2-1: An infrastructure wireless network

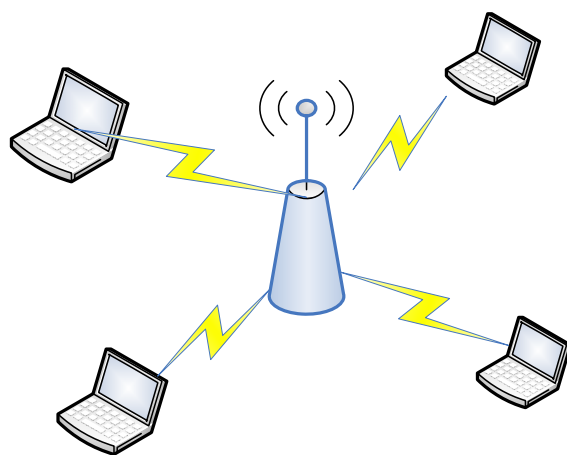


Figure 2-2: An example of infrastructure wireless local area network

2.2.2 Infrastructureless Networks

An infrastructureless network is a network that is formed dynamically through the cooperation of an arbitrary set of independent wireless terminals communicating with one another with no pre-existing infrastructure in place. Typically, each node is assumed to be able to forward data packets for any other node if it is asked to do so. Each node can independently make its own decision based on the network situation. Figure 2-3 shows an example of infrastructureless wireless networks known as ad hoc networks.

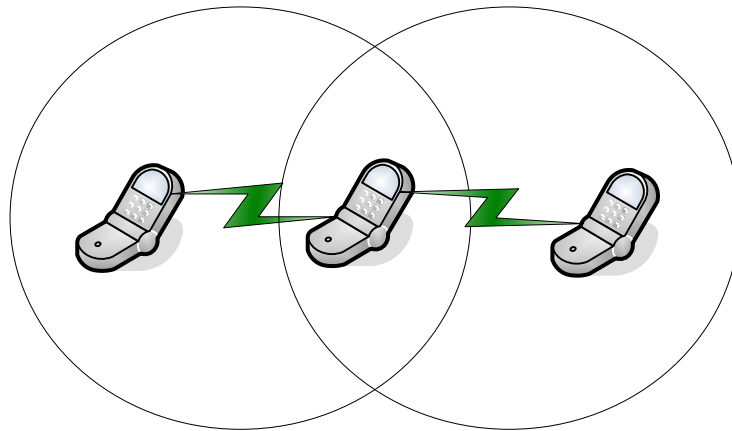


Figure 2-3: An infrastructure-less wireless network

2.3 Ad hoc Networks

The history of ad-hoc networks can be dated back to the US Department of Defense sponsored Packet Radio Network (PRNET) research for military purpose in 1970s, which evolved into the Survivable Adaptive Radio Networks (SURAN) program in the early 1980s [22]. The 1990s witnessed an explosive growth of notebook computers, open source software, and radio equipment, placing the idea that gathering of infrastructureless mobile hosts in the wireless network. As a result, the IEEE 802.11 committee, for the first time, accepted the term “ad hoc network” [23]. After that, the commercial and non-military use of ad hoc networks emerged and resulted in approval of the first WLAN standard in 1997.

Ad hoc networks can be classified, based on their mobility, in mobile ad hoc networks (MANETs) and static or sensor ad hoc network (SANETs) [24]. The Internet Engineering Task Force (IETF) has created a working group (WG) called mobile ad hoc networks (MANET), The primary focus of this working group is to develop and evolve MANET specifications, in order to solve and standardize the routing functionality in mobile ad hoc environment [55] and introduce them to the Internet standard track.

2.4 Mobile Ad hoc Networks (MANETs)

MANETs are formed dynamically by an autonomous system of mobile nodes that are connected via wireless links without using an existing network infrastructure or centralized administration. The nodes are free to move randomly and organize themselves arbitrarily. Thus, the network's wireless topology may change rapidly and unpredictably Figure 2-4 shows an example of a mobile ad hoc network.

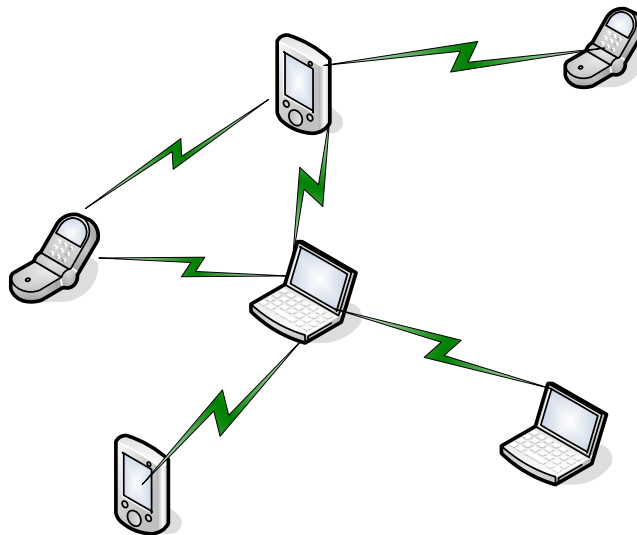


Figure 2-4: A Mobile Ad hoc networks (MANETs)

2.4.1 Characteristics of MANETs

Due to the nature of MANETs, they have different characteristics from other communication networks. Table 2-1 summarizes some of the main characteristics of MANETs.

Table 2-1: The main characteristics of MANETs

Characteristic	Description
Dynamic Topology (Mobility)	Nodes are free to move arbitrarily with different speeds, thus the network topology may change randomly and at unpredictable time, i.e. Node mobility causes frequent change in network topology when new nodes join in, some nodes leave or some links break down. Thus, mobility has had a major effect on the design of routing protocols [25].
Decentralized operation	MANETs generally do not rely on infrastructure for communication and dissemination of information, support for routing, network management, etc. So that MANET self-organizing and self-managing networks [26].
Multi-hop routing	All nodes possess traffic routing and relaying capabilities so that any node can communicate with any other node in the network using multi-hop packet transmissions over other intermediate nodes [27]. So, no dedicated routers are necessary; every node acts as a router and forwards each others' packets to enable information sharing between mobile hosts.
Bandwidth constrained	Wireless links continue to have significantly lower capacity than wired networks. In addition, the realized throughput of wireless communications - after accounting for the effects of multiple access, fading, noise, and interference conditions, etc., is often much less than a radio's maximum transmission rate[28].
Power-constrained	Because nodes can be mobile, they have to rely on battery power, which is a limited resource [29].

2.4.2 Applications of MANETs

MANETs do not need any infrastructure support. So, MANETs are useful in many application environments. Table 2-2 summarizes most distinctive applications of MANETs.

Table 2-2: The Most distinctive applications of MANETs

Application	Description
Tactical networks	Military communication, operations automated battlefields
Sensor networks	Collection of embedded sensor devices used to collect real-time data to automate everyday functions. Data highly correlated in time and space, e.g., remote sensors for weather, earth activities; sensors for manufacturing equipment [27].
Emergency service	Search-and-rescue operations as well as disaster recovery; e.g., early retrieval and transmission of patient data (record, status, diagnosis) from/to the hospital. Replacement of a fixed infrastructure in case of earthquakes, hurricanes, fire, etc [30].
Home and enterprise Networking	Home/office wireless networking (WLAN), e.g., shared white board networking application, use PDA to print anywhere, trade shows Personal Area Network (PAN), Body Area Network (BAN) [22].
Educational applications	Set up virtual classrooms or conference rooms applications Set up ad hoc communication during conferences, meetings, or lectures.
Vehicular Ad hoc Networks (VANETs)	Collision Avoidance, Traffic Optimization, Payment Services, Incident broadcasting [22].

2.4.3 Challenging Issues of MANETs

The technological challenges are not trivial and present at all layers. As a result there are four large areas of research in the field of Mobile ad hoc networks: routing, medium access control, topology and power control, and capacity[31]. In this subsection, we briefly describe the problem in each case as follows:

A. **Routing:** Due to the mobility of the nodes, connectivity between any two nodes in the network is considered Sporadic and often it is very difficult[32], the issue of routing in MANET is considered the main challenge of MANETs.

B. **Medium access control:** Due to limited Bandwidth and multipath propagation, in order to avoid the collision of signals at receivers and their mutual destruction, it is necessary that nodes coordinate, so that simultaneous transmissions are not so close so as to interfere with each other at their intended receivers[31]. It is also important that simultaneous transmissions be packed as close to each other as possible, so that the bandwidth is not wasted, and communication rates between users are maximized. The function of the Medium Access Control (MAC) protocol is to strike the optimum balance between keeping interference levels at a manageable level and utilizing the available bandwidth efficiently.

C. **Topology and power control:** The topology of a wireless network depends on the physical placement of the nodes[31]. Most nodes run on limited battery power, the “energy-efficiency” of the network often determines its lifetime. One way to reduce the power consumption and improve network longevity is topology control, a method to choose a suitable topology to be used for message routing in the network. Reducing interference in the network leads to fewer collisions and packet retransmissions, and therefore reduces power consumption indirectly. Therefore, one important goal of topology control is to reach a topology that gives low interference.

D. **Capacity of MANETs:** Because network topology can change randomly and rapidly, at unpredictable times, wireless links generally have lower capacity[29].

2.5 Vehicular Ad hoc Networks (VANETs)

VANETs, are a form of MANETs, to provide communications between vehicles themselves and nearby fixed equipments, i.e. VANET is an instance of MANET in which network establishes wireless connections between vehicles. This section provides the state of the Art for VANETs. In addition, it presents the characteristic of VANETs, and their potential applications as well as reviewing the wireless access methods.

2.5.1 State of the Art

The concept of deploying wireless communication in vehicles has fascinated researchers since the 1980s[3]. In the last decade, VANET witnessed a large increase in research and development in this area. Several factors have led to this development, including the wide adoption (and subsequent drop in cost) of IEEE 802.11 technologies. The embrace of vehicle manufactures of information technology to address the safety, environmental, and comfort issues of their vehicles. For example, Toyota, BMW, and Daimler-Chrysler have launched some important projects for VANET [33], such as Advanced Driver Assistance Systems (ADAS), Chauffeur, CarTALK2000[35], California Partners for Advanced Transit and Highways (California PATH) and CarNet. This led to the commitment of large national and regional governments to allocate wireless spectrum for vehicular wireless communication such the Federal Communications Commission (FCC) that has allocated spectrum in the 5.8- 5.9-GHz range for VANET [1], [33].

With the availability since the late 1990s of low cost, global positioning system (GPS) receivers and wireless local area network (WLAN) transceivers, research in the field of inter-vehicular communication has received considerable attention such as Dedicated Short-Range Communication (DSRC) [34]. Because of the dynamic nature of the mobile nodes in the network, a fundamental problem in VANET is to develop a routing protocol, which essential to establish suitable routes efficiently for data access between vehicles in a scalable manner and without incurring high control overhead.

2.5.2 Characteristics of VANETs

VANETs formed by radio-enabled vehicles, which act as mobile nodes as well as routers for other nodes. It is also similar to MANETs in some characteristics such as short radio transmission range, self-organization and self-management, and low bandwidth[38]. The Characteristics of VANETs can be distinguished from MANETs as follows:

- Highly dynamic topology: Due to high speed of movement between vehicles, the topology of VANETs is always changing.
- Frequently disconnected network: The connectivity of the VANETs could also be changed frequently. Especially when the vehicle density is low, it is highly probable that the network is disconnected.
- Mobility modeling and predication: Due to high mobility and dynamic topology, mobility model and predication play an important role in network protocol design for VANETs. Furthermore, Factors such as road configuration, traffic laws, safety limits, and physical limits affect the mobility of vehicles. Drivers' behavior and interaction with each other also contribute to the vehicle mobility pattern [40].
- Geographical type of communication: Compared to other networks that use unicast or multicast where the communication end points are defined by ID or group ID, the VANETs often have a new type of communication that addresses geographical areas where packets need to be forwarded (e.g., in safety driving applications).
- Various communications environments: VANETs are usually operated in two typical communications environments. In highway traffic scenarios, the environment is relatively simple and straightforward (e.g., constrained one-dimensional movement); while in city conditions it becomes much more complex. The streets in a city are often separated by buildings, trees, and other obstacles.
- Sufficient energy and storage: A node in VANETs has sufficient energy and computing power (including both storage and processing). Therefore, processing power and storage efficiency are not an issue in VANETs
- Hard delay constraints: In some VANETs applications, the network does not require high data rates but has hard delay constraints. For example, in an automatic highway system, when brake event happens, the message should be transferred and arrived in a

certain time to avoid car crash. In this kind of applications, instead of average delay, the maximum delay will be crucial.

2.5.3 Applications of VANETs

Applications depend on vehicular communication range from simple exchange of vehicle status data to highly complex large-scale traffic management including infrastructure integration[41] several lists of distinctive applications were compiled and assessed by the various projects and consortia [3]. Typical applications include active safety, intelligent transportation, public service, and information/entertainment.

For active safety[35], accident avoidance warnings could quickly notify drivers about conditions that could cause a collision. In case of an accident, communication made to other vehicles prior to collision may allow the accident to be reconstructed more easily. Rescue vehicles could instantly receive exact coordinates of the location of an accident to reach the scene of the emergency faster.

For intelligent transportation, Information about traffic and road hazards could be acquired and fed into vehicle navigation systems in real-time to provide alternate driving routes. Tolls could be automatically paid without the installation of additional hardware to a vehicle. Cooperative driving would allow vehicles to navigate without driver intervention by communicating with other vehicles about velocity, proximity, and other factors.

For public service, includes police or emergency recovery units. Prominent examples of this category are the support of emergency vehicles by virtual sirens or signal preemption capabilities. Using these applications, emergency vehicles may be able to reach their destination much faster than today.

For information/entertainment: a large block of applications can be embraced under this category, such as delivering services to customers, automation of vehicle-related tasks or payment applications, such as music download, fleet management, simpler vehicle maintenance, or payment for parking or road usage.

In our study, we are interested in a road intersection safety. For this application there is a significant role in management and monitor the traffic at the intersection and reducing the congestion of traffic, and preventing the accident in it. In addition, this application will provide the driver with information about the traffic situation on the intersection before his arrival.

2.5.4 Wireless Access Methods in VANETs

The last years witnessed advances in several wireless access methods. VANETs are expected to implement variety of wireless technologies such as Dedicated Short Range Communications (DSRC) which is a type of WiFi. Other candidate wireless technologies are Cellular, Satellite, and WiMAX. VANETs can be viewed as component of the Intelligent Transportation Systems (ITS).

2.5.4.1 The IEEE 802.11 Standard for Wireless LANs

Networking technology has witnessed rapid advances, particularly in wireless local area networks with the popular IEEE 802.11 (WiFi) wireless protocol, which provides an access to a user who is in the physical neighborhood of an access point[42]. The connections are typically within a 100-m range[20].

IEEE 802.11 denotes a set of WLAN standards developed by Working Group 11 of the IEEE LAN/MAN Standards Committee (IEEE 802). The IEEE 802.11 standard places the specifications for both the physical layer and for the medium access control layer. The MAC layer offers two different types of service: a contention-based service provided by the distributed coordination function (DCF) and a contention-free service provided by the point coordination function (PCF). The DCF service provides the basic access method of the 802.11 MAC protocol and is based on the CSMA/CA scheme. These services are made available on top of various physical layers. Three different technologies have been specified in the basic standard: infrared, FHSS, and DSSS. The 802.11 family currently includes six over-the-air modulation techniques that all use the same protocol, the most popular techniques are those defined by a, b, and g amendments to the original standard. The IEEE 802.11a and IEEE 802.11g utilize OFDM modulation technology to achieve the higher data rates[28]. Figure 2-5 show a complete view of the IEEE 802.11 stack with various PHY layers.

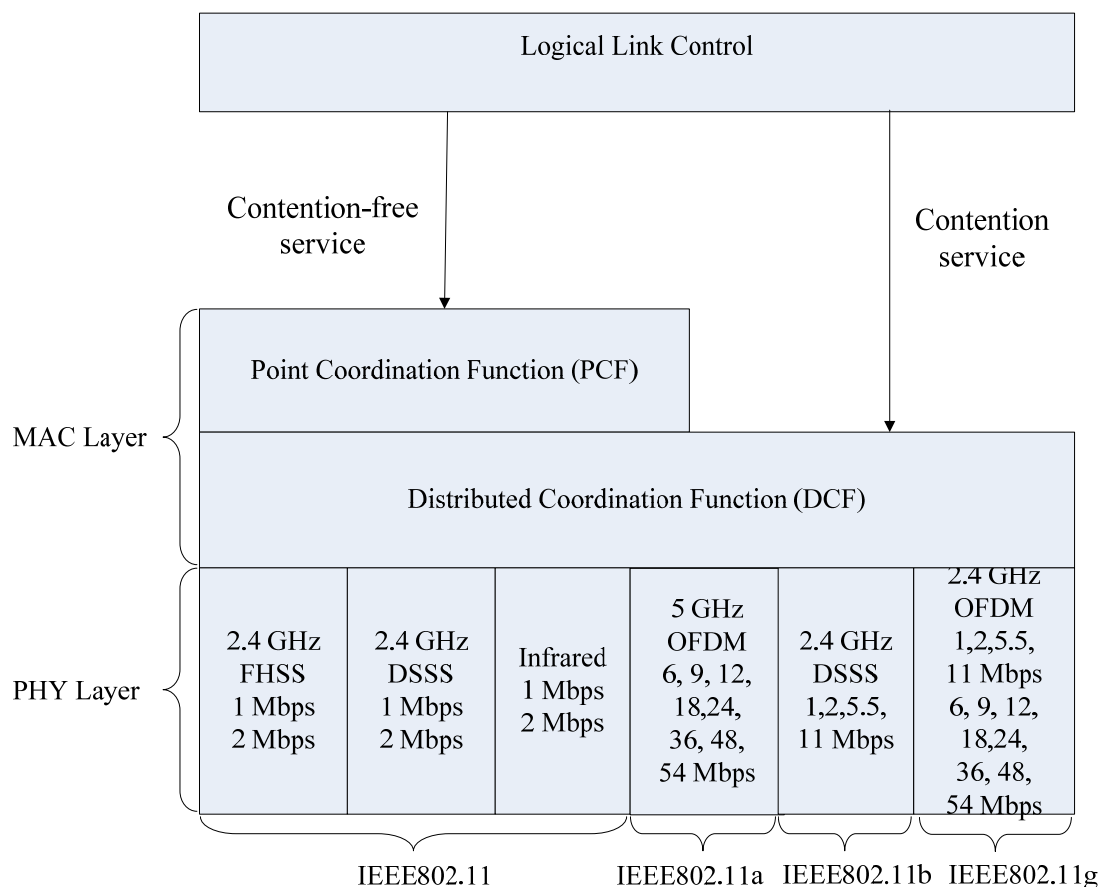


Figure 2-5: A complete view of the IEEE 802.11 stack

2.5.4.2 DSRC/WAVE

The Dedicated Short Range Communications (DSRC)/Wireless Access in a Vehicular Environment (WAVE) refers to a set of emerging standards for mobile wireless radio communications. A radio service that offers significant data transfer capacity in the 5.850 GHz-5.925 GHz range for vehicular ad hoc networks developed by the IEEE standard. DSRC describes a MAC and PHY specifications for wireless connectivity. This standard is based on IEEE standard 802.11a and is meant to be used in high-speed vehicle environments. In fact, the PHY layer of DSRC is adapted from IEEE 802.11a PHY based on orthogonal frequency division multiplex (OFDM) technology. Moreover, the MAC layer of DSRC is very similar to the IEEE 802.11 MAC based on the CSMA/CA protocol with some minor modifications. The DSRC standard utilizes the 75-MHz spectrum, which is allocated by the United States Federal Communications Commission (FCC) in

1999 to provide wireless Vehicle to Roadside (V2R) or Vehicle to vehicle (V2V) communications over short distances. The DSRC spectrum is divided into seven 10 MHz wide channels. Channel 178 is the control channel, which is generally restricted to safety communications only as shown DSRC channels in Figure 2-6.

The two channels at the edges of the spectrum are reserved for future advanced accident avoidance applications and high-powered public safety usages. The rest are service channels and are available for both safety and nonsafety usage[34].

The standard specifies communications that occur over line-of-sight distances of less than 1000 m between roadside units and mostly high-speed, but occasionally stopped and slow-moving, vehicles or between high-speed vehicles. It is expected, with the support of industry and government organizations, that the DSRC system will be the first wide-scale VANET in North America.

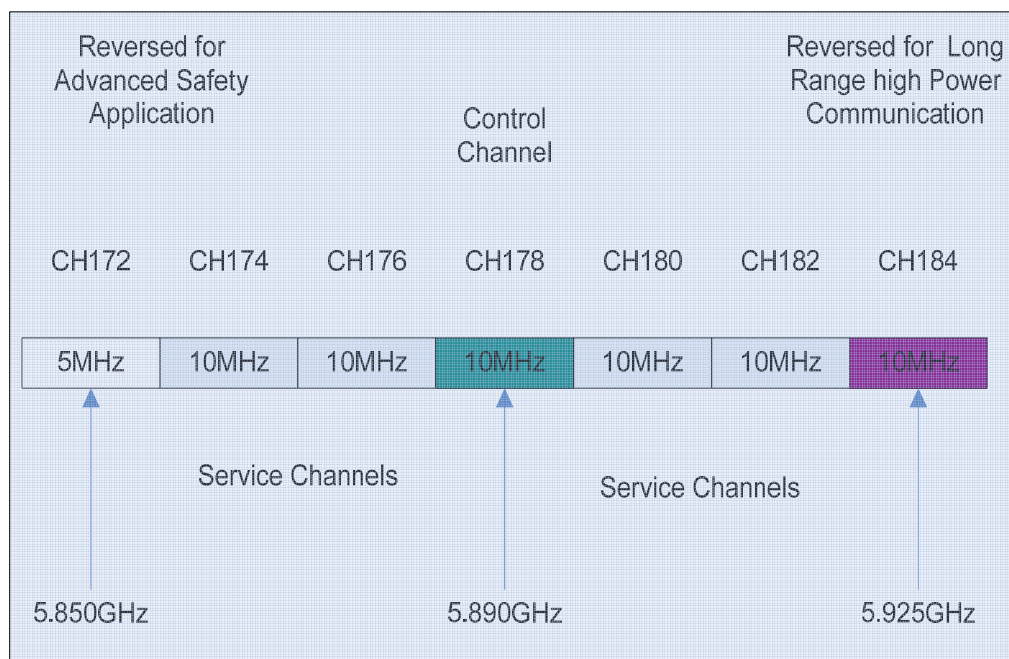


Figure 2-6: DSRC channels.

DSRC is meant to be a complement to cellular communications by providing very high data transfer rates in circumstances where minimizing latency in the communication link and isolating relatively small communication zones are important[56].

2.5.4.3 Cellular Networks

In cellular networks, communications between two mobile nodes completely rely on the wired backbone and the fixed BSs. In a VANET, no such infrastructure exists and the network topology may dynamically change in an unpredictable manner since nodes are free to move. Although cellular networks enable convenient voice communication and simple infotainment services to drivers and passengers, they are not well-suited for certain direct vehicle-to-vehicle or vehicle-to-infrastructure communications, this due to they do not support short range communications.

The main advantages of 2/2.5G technology are coverage and reliable security, while the 3G, systems provide improved capacity and bandwidth. Several telematic and fleet management projects already uses cellular technology (e.g. SMS reports), however the relatively high cost, together with limited bandwidth and latency make it impossible to use as a main communication means [43].

2.5.4.4 WiMAX/802.16e

Worldwide Interoperability for Microwave Access (WiMAX) is an advanced communication technology that provides high speed packet data access on a mobile terminal (laptop, smart phone...). WiMAX is based on the IEEE 802.16 standard, also called Broadband Wireless Access [44].

The emerging standards IEEE 802.16 is considered a potential competitor for the 802.11 standards as well as cellular systems. This standard promises broadband wireless access with data rates on the order of 40 Mbps for fixed users and 15 Mbps for mobile users, with a range of several kilometers.

The WiMAX standard 802.16e provides fixed, nomadic, portable and mobile wireless broadband connectivity without the need for direct line-of-sight with the base station. It is different from the previous versions of the standard in the sense that 802.16e adds the feature of mobility to the wireless broadband standard. 802.16e aims at enabling the delivery of last mile wireless broadband access (<40 Mbps) as an alternative to cable and xDSL, thus providing wireless data over long distances. This will fill the gap between 3G

and WLAN standards, providing the data rate (tens of Mbps), mobility (<60 km/h), and coverage (<10 km) required to deliver the Internet access to mobile clients [35].

IEEE 802.16 supports two modes: the point-to multipoint (PMP) mode and the mesh mode. The first type of network is a PMP network, which is designed primarily for providing the last-mile access to the Internet service providers (ISPs), where the WiMAX network includes one base station and a number of subscriber stations. The WiMAX mesh network, on the other hand, is a multi-hop ad hoc network in which subscriber stations can connect with one another directly [45].

In our study, we use the first one, there are three factors lead to choose this method:

- This technology support the short range wireless data communication between the vehicles,
- The availability of the adoption of the WLAN technologies with use of unlicensed radio spectrum,
- The low cost accompanied with developing this technology.

2.6 Summary

This chapter provides an overview for the origin and development of the MANETs. In addition, it explains the characteristics of the VANETs that distinguish from MANET such as highly dynamic topology, frequently disconnected network, mobility modeling and predication, as well as the potential applications in VANETs that include active safety, intelligent transportation, and information/entertainment. This chapter also gives a brief overview of the possible of wireless access methods that can be deployed with VANETs Applications which are the IEEE 802.11 Standard for Wireless LANs, DSRC/WAVE, Cellular Networks, and WiMAX/802.16e.

The next chapter reviews the MANETs routing protocols which are the core of this work.

Chapter 3

3. MANETs Routing Protocols

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3.1 Introduction

Routing is a process of determining a path from a source to a destination before or after a request for transmission. Based on the network architecture, routing protocols may be logically divided into two classes: distributed and centralized [46]. In centralized protocols, information about the network required to run the protocol (current topology, line capacity, estimated link delays if required, condition of links and nodes, etc) need only be kept by the central supervisor node. Path setup is then accomplished through routing messages sent to each node along the path selected. In the distributed situation, the required information must be exchanged among nodes in the network. This implies some means of disseminating changes in topology (nodes and links coming up or going down), congestion, and estimated time delay information if used in the protocol.

Due to the mobility of nodes in MANETs, topology of these networks change unpredictably. Moreover, routing in MANETs works mainly based on the distributed class. These factors make routing one of the main issues to be considered in MANETs. The main goal of MANET routing algorithm is to correctly and efficiently establish a route between a pair of nodes in the network so a message can be delivered correctly. This chapter provides an overview for different existing MANETs routing protocols like AODV, AOMDV, DSDV, DYMO that are intended to be investigated in assumed VANET scenario as we will see in chapters 4 and 5.

3.2 Classification of the MANETs Routing Protocols

Based on routing information update mechanisms, proposed MANETs routing protocols can be subdivided into two main categories: proactive (table-driven) routing protocols, reactive (on-demand) routing protocols[47]. Figure 3-1 illustrates the classification of MANET routing protocols.

3.2.1 Proactive Routing Protocols

Proactive routing protocols, also called table-driven protocols, have been developed based on the distance vector and link state routing methods. With proactive protocols, each node

in the network needs to maintain an up-to-date route table for all other nodes in the network. Route tables are updated periodically with event-triggered between nodes at specific time intervals regardless of network load, bandwidth constraints, and network size.

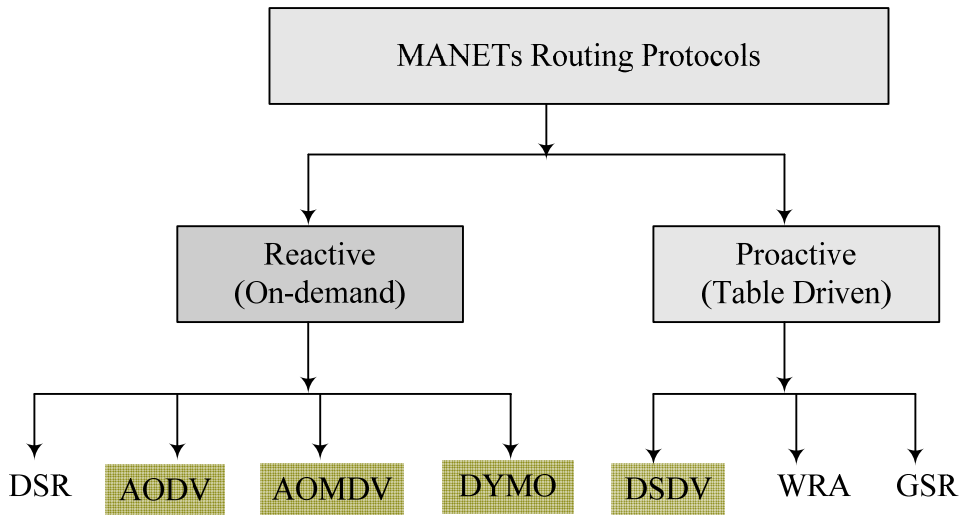


Figure 3-1: Classification of Routing Protocols in MANETs

Whenever network topology dynamically changes, event-triggered updates take place to in response any changes. So, proactive protocols have the advantage that, a source node can get a routing path immediately if it needs one. However, the main disadvantage of these approaches is the addition of significant control overhead in large networks or in networks with rapidly moving nodes.

3.2.2 Reactive Routing Protocols

Reactive routing protocols have been developed as a new solution for routing in MANET. In reactive approaches, a route to a destination node is only discovered whenever it is actually needed. They are also called on-demand routing protocols. In this class of routing protocols, whenever a source node needs to send data packet to a certain destination node, it checks its route table to determine whether it has a route. If no route exists, a route discovery operation is initiated to find a route to the destination node. Hence, route discovery is initiated on-demand only. When a route is discovered, it remains valid for

a certain time and then it is discarded. The benefit of reactive approaches is the reduction of the routing control overhead, particularly in networks with low to moderate traffic loads. However, the primary drawback of these protocols is the introduction of a high initial latency in packet delivery.

3.3 Destination Sequenced Distance Vector (DSDV)

Destination Sequenced Distance Vector (DSDV) routing protocol[7], is a proactive routing protocol, a variant of the distance vector² routing method, and it is a distributed, self-organized, and loop-free routing protocol suitable for dynamic networks by which mobile nodes cooperate to form a mobile ad-hoc network. Each node stores and maintains a routing table containing entries for all the nodes in the network. Nodes periodically advertise their routing information to their neighbors. The packets are transmitted between two nodes in the network using route tables stored at each node. Each route table, at each node, contains lists of all available destinations, the destination node's address, the number of hops to each node, and the sequence number assigned by destination node.

In DSDV, nodes update route table by exchanging routing information with their neighbors, which propagate it periodically to other nodes.

The updating based on the followings rules:

- It is a new route entry.
- The sequence number in the received routing information is higher than it is in the routing table.
- The sequence numbers are equal, but the metric in the received routing information is better.
- Then the updated routing information will be advertised and propagated to its neighbors, and so on.

² Distance vector: In a distance-vector algorithm, a node knows the length of the shortest path from each neighbor node to every network destination, and uses this information to compute the shortest path and next node in the path to each destination.

In DSDV also, each node maintains a “settling time table” to prevent fluctuations of the routing update. A node may receive a new routing update with a worse metric, and later receive a routing update with the same sequence number but with a better metric. This may happen due to network congestion or different advertisement schedules of nodes. It will be a redundant advertisement if a node receives the routing update with a worse metric and propagates it immediately, if it will be overwritten with a better metric later. “Settling time table” stores the history of past update time for each destination, and nodes will calculate the next time to advertise according to the past update history if the routing update is not a significant one that needs to be disclosed immediately. Table 3-1 shows an example of a routing table for node 1 in the mobile ad hoc network topology shown in figure 3-2.

Table 3-1: Possible Routing Table for Node 1

Dest.	Next node	Hop count	Seqno.
2	2	0	22
3	2	1	27
4	5	1	29
5	5	0	130
6	6	0	137
7	2	2	155
8	5	2	163
9	5	2	170

In a MANET, due to dynamic topology network, most of the routing updates may be useless because it will become invalid before the updated routes will be used, which cause more unnecessary wastes. But DSDV provides a simple and distributed routing mechanism, and due to table-driven property therefore provides reasonable initial route delay, so that it can be implemented and deployed, and still works efficiently in some network topologies.

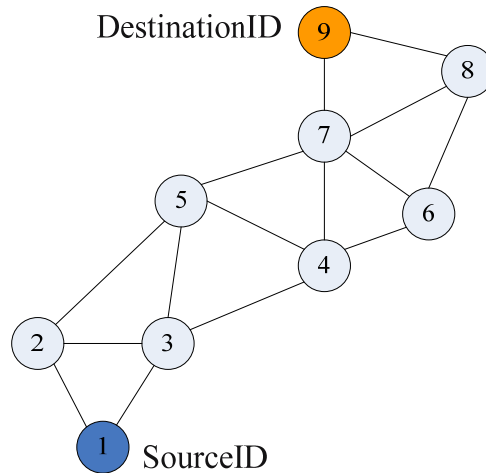


Figure 3-2: A mobile ad hoc network topology.

3.4 Ad hoc On Demand Distance Vector (AODV)

The Ad Hoc On-Demand Distance Vector (AODV) [4] routing protocol is a reactive routing protocol, and it is considered a pure on-demand route acquisition system, based on the distance- vector method. AODV uses destination sequence numbers as in DSDV maintained at each destination to determine whether the routing information is latest and up to date and to ensure loop-free[7]. AODV uses next hop routing approach in which each data packet carries only the next hop address towards the destination. In AODV, each node maintains a single path to each destination. As in the case with all reactive ad hoc routing protocols, AODV consists of two protocol operations: path discovery and Route maintenance operations.

3.4.1 Path Discovery

When a source node (S) needs to communicate with the destination node (D), for which it has no routing information in its table, it will perform a path discovery operation. To start path discovery operation, S creates a route request (RREQ) packet. It places in this packet the destination node's IP address, the last known sequence number for that destination, and the source's IP address and current sequence number. The RREQ also contains a hop count, initialized to zero, and broadcast ID. The broadcast ID is incremented each time

the node sends RREQ packet. In this way, the source IP address, together with the broadcast ID, uniquely identifies a RREQ and can be used to detect duplicates. After creating this packet, S broadcasts the RREQ to its neighbors. Figure 3-3 shows the RREQ packet fields.

source addr	source sequence#	broadcast ID	dest addr	dest sequence#	hop count
-------------	------------------	--------------	-----------	----------------	-----------

Figure 3-3: RREQ Packet Fields.

This RREQ message will be flooded in the network until it reaches the destination node D, or a node with information on a route to node D. Then the node S waits for a reply from its neighbors for certain time. If a node S does not receive a reply, the node may rebroadcast the RREQ with new broadcast ID, or the node will be considered that there is no route for a node D. Figure 3-4a shows the RREQ propagation to discover the path.

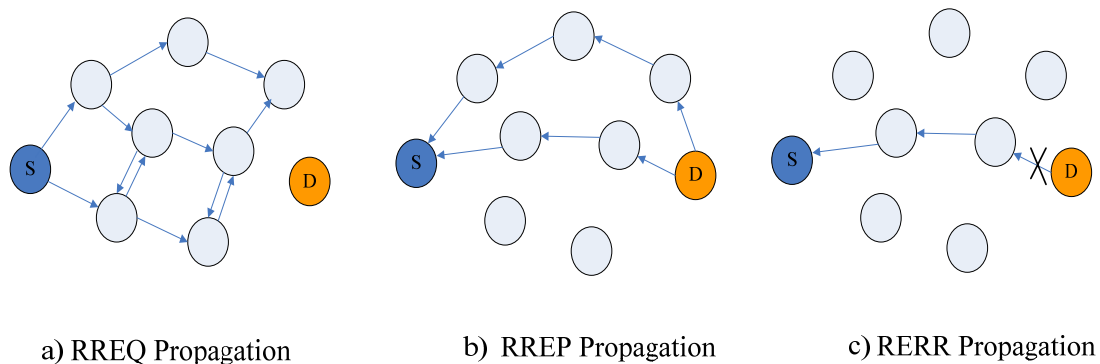


Figure 3-4: The AODV Operations

When the RREQ arrives at a node that possesses a current route to D, it determines whether the route is recent by comparing the destination sequence number in its own route entry to D sequence number in the RREQ. If the RREQ's sequence number for D is greater than that maintained by the intermediate node, the intermediate node does not use its recorded route to respond to the RREQ. Instead, the intermediate node rebroadcasts the RREQ. The intermediate node can reply only when it has a route with a sequence number that is greater than or equal to that contained in the RREQ. If it has a current

route to D, and if the RREQ has not been processed previously, the node satisfies the RREQ by unicasting a route reply packet (RREP) back to the node (S) along the reverse path after incrementing the hop count field. Figure 3-5 shows the RREP packet fields. An example of a RREP packet propagation is shown in Figure 3-4b.

source addr	dest addr	dest sequence #	hop cnt	lifetime
-------------	-----------	-----------------	---------	----------

Figure 3-5: RREP Packet Fields.

3.4.2 Route Maintenance

AODV maintains paths by using hello messages used to detect neighbors that are still in range of connectivity. If a link breaks, the node will immediately initiate a route maintenance operation by means of route error (RERR) packets. When an intermediate node detects a link failure via a hello message, it generates a route error (RERR) packet. The RERR propagates towards all traffic sources having a route via the failed link, and erases all broken routes on the way. A node S upon receiving the RERR initiates a new route discovery if it still needs the route, as shown in figure 3-4c.

3.5 Ad Hoc On-Demand Multipath Distance Vector (AOMDV)

AOMDV[11] protocol is an extension based on AODV. The AOMDV protocol uses the basic AODV route mechanism process, with extensions to create multiple loop-free and link-disjoint paths. AOMDV mainly computes the multiple paths during route discovery process, and it consists of two main components:

- A rule for route updates to compute multiple loop-free paths at each node,
- A distributed protocol to find the link-disjoint paths.

3.5.1 Multiple Loop-free Paths

Multiple loop-free paths in AOMDV are built based on new notions of "advertised hop count", which replaces hop count in AODV, and "route list" which replaces the next hop in AODV. Each node i maintains a variable called advertised hop count for each destination D , which represents the maximum hop count of multiple paths for D available at i . The protocol only accepts alternate routes with hop count lower than the advertised hopcount, while alternate routes with higher or the same hop count are discarded. This is necessary to achieve loop freedom. Figure 3-6 shows the structure of the routing table entries for AODV and AOMDV.

destination	sequence number	hop count	next hop	timeout
-------------	-----------------	-----------	----------	---------

(a) AODV

destination	sequence number	advertised hop count	route list			
			<i>next_hop1</i>	<i>last_hop1</i>	<i>hop_count1</i>	timeout1
			<i>next_hop2</i>	<i>last_hop2</i>	<i>hop_count2</i>	timeout2
		
		

(b) AOMDV

Figure 3-6: Routing table entry structure in (a) AODV and (b) AOMDV.

3.5.2 Link-Disjoint Paths

In addition to maintaining multiple loop-free paths, AOMDV tries to find disjoint alternate paths. AOMDV has two types of disjoint paths: node-disjoint and link-disjoint. Node-disjoint paths do not have any nodes in common, except the source and destination. In contrast, link-disjoint paths do not have any common link. Note that link-disjoint paths may have common nodes. Disjoint paths help in controlling number of forwarding nodes and paths in the network, therefore reducing to some extent overhead in the network such packet duplication.

3.5.3 Route Discovery

AOMDV differs from AODV in the number of the route paths in each route discovery operation. As in AODV, whenever a source node (S) needs to send a packet to destination node (D) it initiates a route discovery by broadcasting a RREQ packet from S to its neighbors, a node may receive several copies of the same RREQ. In AODV, only the first copy of the RREP is preserved to form reverse paths and discard the other RREPs for the same destination. This implies that the routing tables in AODV contain a unique route entry per destination. On the other hand, AOMDV stores many RREPs for each RREQ in the routing table; thereby route tables in AOMDV contain multiple route entries for each destination. So, nodes in AOMDV are provided with alternate routes. Consequently, if a route fails, a node can use another route without broadcasting a new RREQ. As a result, this help in reducing route discovery frequency in AOMDV and therefore minimizes the latency in the routing to some extend.

3.5.4 Route Maintenance

Like AODV, AOMDV also uses RERR packets. A node generates or forwards a RERR for a source when the last path to the destination fails. AOMDV also includes an optimization to salvage packets forwarded over failed links by re-forwarding them over alternate paths.

3.6 Dynamic MANET On-Demand Routing Protocol (DYMO)

DYMO[8] is the successor of AODV, but there are many considerable changes such as a unified packet format, a simplified RERR algorithm, and multiple interface utilization. It offers considerable adaptation to changing network topology. Furthermore, the Internet connectivity is defined in the DYMO Internet-Draft[8], and is the most attractive specification yet towards practical MANET use. In the following, we will review the basic routing operations and Internet connection algorithms of DYMO. As DYMO is a

type of reactive routing protocol, it consists of two operations: route discovery and route maintenance.

DYMO also uses sequence numbers to ensure loop-freedom which enable DYMO routers to specify the order of DYMO route discovery messages, so preventing use of stale routing information, to detect duplicate messages, and to ensure loop freedom, this leads to reduce significantly the overhead of routing control packet. DYMO extends AODV with the source route a path accumulation mechanism on feature of DSR which provides enhanced features in implementing in MANETs scenario.

Figure 3-7 shows the path accumulation mechanism used by DYMO. As shown from the figure all nodes in the path learn about every other node in the path. Information of D, N2 and N1 is increasingly added to the RREP. The same happens in the RREQ Hence, unlike AODV, node S learns about N2, while node D learns about node N1 [9], [10].

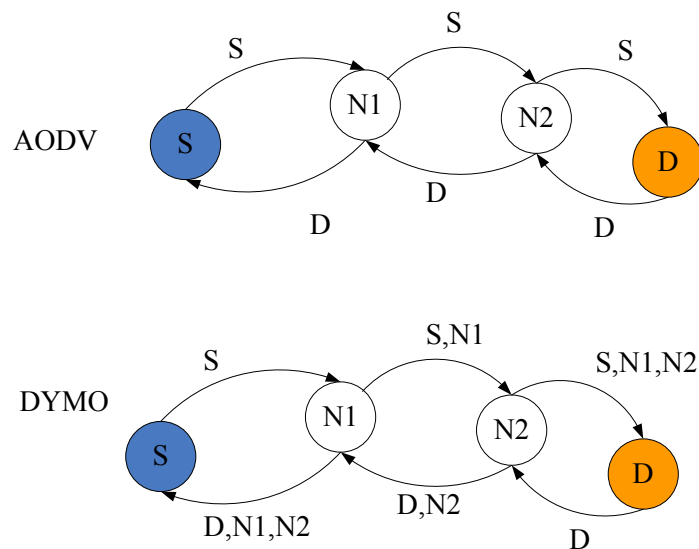


Figure 3-7: Path accumulation mechanism in DYMO

3.6.1 Route Discovery

Whenever a source node (S) needs to send a data packet to a particular destination node (D), and it does not have route information for (D), S issues broadcasts of RREQ packet throughout the network to find the path for D. Each intermediate node records the route to D when receiving the RREQ, responds with RREP packet which is sent in a unicast, hop-by-hop fashion towards the S node. When S node receive RREP packet from the D node, the routes between the S node and the D node are established.

A RREQ packet is flooded in the network. When intermediate nodes receive a RREQ packet, they need to decide if they will update their routing table and if they will further forward the packet. Therefore, it accesses the addresses and the related information found in the packet and responds according to the following rules:

- If the source's sequence number in RREQ packet is lower than the sequence number stored in the node's routing table, then the information in the received packet is considered stale,
- If the routing table does not contain an entry for S, one is created. The next hop entry is the address of the node from which the RREQ was received,
- If an entry exists and is not stale, the entry is updated with the new Information found in the RREQ,
- When D receives a RREQ, it applies the same rules mentioned above. If the information is new, a RREP packet is sent to S, via the reverse path.

3.6.2 Route Maintenance

When a node fails to send a data packet due to link breakage, it sends back to the source node a RERR packet, indicating the broken link. All nodes receiving the RERR invalidate those paths that used the broken link and so does the source. Hence, when a new RERR packet is received by the source's routing agent, a new route request procedure is initiated.

3.7 Summary

In this chapter, Principles of MANETs routing protocols are reviewed. We focused on those we intend to evaluate their performance for VANETs scenario.

In this study, we choose four routing protocols, DSDV that is a proactive type, while other protocols AODV, AOMDV, and DYMO that are a reactive type, with variations in their mechanisms, whereas AODV that uses next hop mechanism, AOMDV that uses multi-path mechanism, and DYMO that uses path accumulation mechanism.

The next chapter deals with the VANETs Simulation Environments, and describes the tools used to design the VANETs scenario.

Chapter 4

4. VANET Simulation Environments

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4.1 Introduction

This chapter provides the description of the assumed VANET scenario in this study. It also presents the simulation environments and explains the steps followed to perform the simulation of the VANET scenario. Then we present an overview about SUMO and ns-2, which are the tools used to design the simulation of VANET scenario. The simulation developed in this chapter is used to carry out a comparative study on the performance of MANETs routing protocols described in the previous chapter, in VANET Scenario.

Simulation[48] is an increasingly prominent and effective tool for analyzing a wide variety of problems that cannot be studied by other means. VANETs have many problems and challenges in all network layers. In order to let VANETs hit real world, a huge number of experiments should be performed to test it. These experiments are very expensive and very difficult to perform. Cost and safety dictate that simulation is a necessary tool for doing research in this field. So the simulation tools have a significant role in studying VANETs[35].

In this study, VANETs scenario is designed using three stages of simulation. These stages are traffic³ model, mobility models, and network model. Figure 4-1 shows the components of the VANETs simulation.

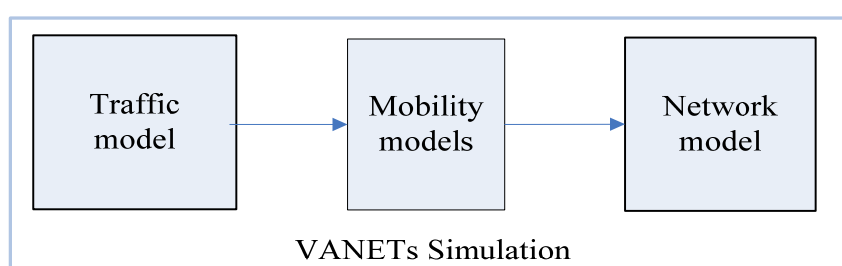


Figure 4-1: VANETs Simulation Components

³ Traffic: when we mention traffic we mean the movement of the vehicles but if we mention data traffic we mean traffic for sending data.

Traffic simulation generates the mobility patterns of the vehicles. These patterns are fed into models and used in the network simulation which generates VANET scenario. The network simulation will be used to evaluate the routing protocols in different applications with different environment parameters.

4.2 VANETs Scenario

The VANET scenario in this study consists of vehicles (nodes) approaching a road intersection in urban environment. Figure 4-2 represents the assumed VANET scenario.

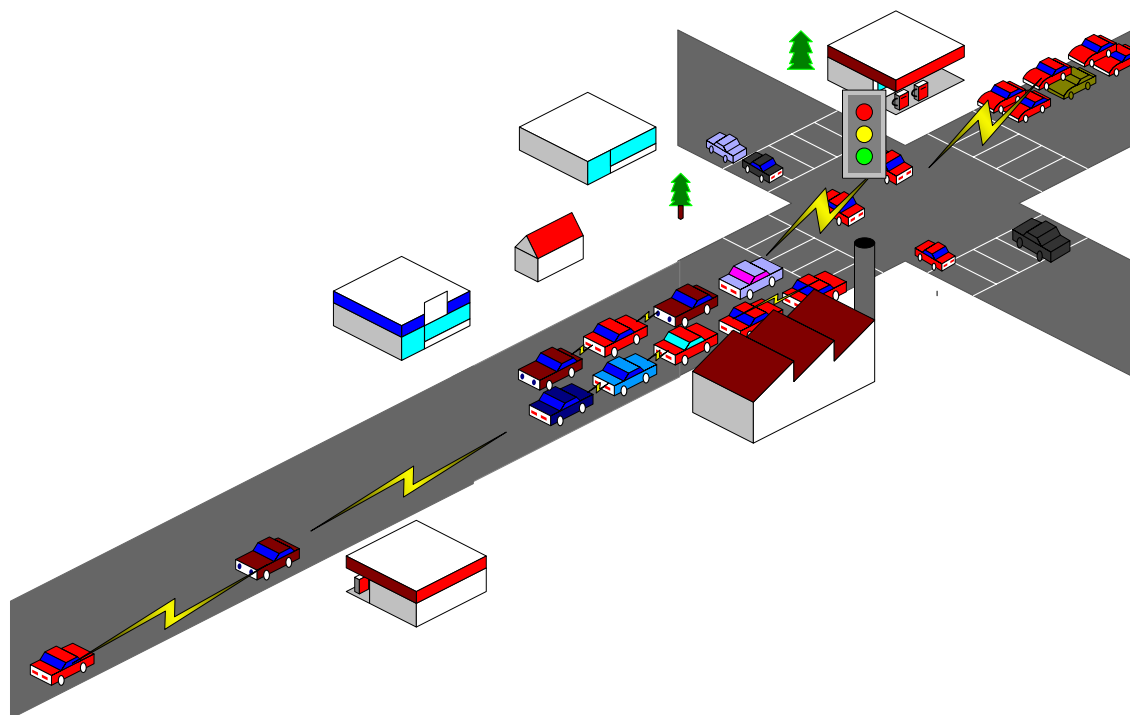


Figure 4-2 : VANET Scenario

As seen from the figure, the assumed VANET scenario is a road intersection consists of two crossed roads: road one is 20m x 1800m and road two is 20m x 1800m. The intersection coordination is at 900m, 900m.

The main idea is the consideration of a critical case in which focuses on sending information about the intersection from a node existing at the intersection (source node) to other vehicles (destination nodes) that are at distance of approximately 1km from the road intersection and they are moving towards it. The information sent to the destination

nodes contains the conditions about the intersection. The information may take several types such as voice, image, or video. This application assists the driver in dealing with the conditions of intersection, such as traffic congestion and traffic light phase, before his arrival to it.

The information delivery to the destination nodes depends on the communication links among the vehicles which are accomplished by forwarding data packets for each other on a multi-hop basis along the current connection between the source node and the destination node.

In this study, we want to investigate the performance of vehicle-to-vehicle communications based on MANETs routing protocols AODV, AOMDV, DYMO, and DSDV for different environments such as number of vehicles, maximum speed of vehicles, and data load.

Therefore, it is intended to design the VANET scenario by means of simulation tools, in order to carry out performance evaluation of several MANETs routing protocols. The steps to implement the simulation are as follows:

- In the first step, we want to determine the simulation environments in order to specify the suitable settings used with the simulation tools.
- In the second step, we need to design the traffic scenario by using one of traffic simulators in order to generate the movement patterns (mobility models). It is significant to use a realistic mobility model in order to obtain accurate simulation results that reflect real-world VANETs scenario. This step is accomplished using a traffic simulator called Simulation of Urban Mobility (SUMO) [54].
- In the third step, we extract the movement patterns as script files.
- In the fourth step, we feed these movement models into the network simulator.
- In the fifth step, we set up the parameters for VANET scenario that are related to each network communication layer such as PHY, MAC, routing protocols, and application.

After performing these steps, we run the simulation scenario with different parameters like number of vehicles, vehicles speed, data load, and so on. Figure 4-3 shows the methodologies and the tools used to design the complete VANET scenarios that will be discussed in the following sections.

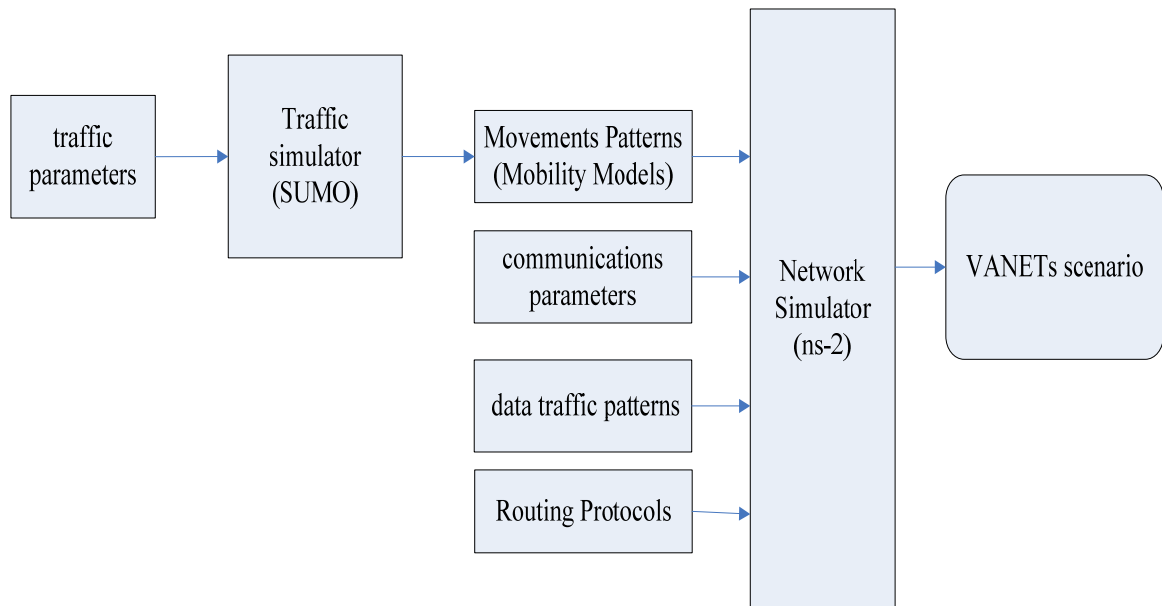


Figure 4-3: The methodologies and the tools used to design the VANETs scenario

4.3 Traffic Simulation

Traffic simulation is considered the first component of the VANETs simulation, which is related to the mobility models for the vehicles on streets. These mobility models in VANETs are distinguished from MANETs, which are constrained by the street map, traffic lights, and laws of the traffic, which made the mobility model one of challenges in VANETs simulation.

Traffic simulation models can be classified as either microscopic, mesoscopic, or macroscopic. These models are distinguished according to the level of detail of the simulation. Microscopic models describe both the vehicles and their interactions at a high level of details. This means that every vehicle moving within the simulated network is modeled individually and has a certain place and speed and interactions. Mesoscopic models describe vehicles at a high level of detail, but describe their interactions at a much lower level of detail than a microscopic model, while macroscopic models describe the vehicles and their activities and interactions at a low level of detail[49].

Several traffic simulators[36] are developed in order to generate the traffic scenario (street map) and the mobility patterns for VANETs scenarios, such as TSIS-CORSIM, VISSIM, PARAMICS, SmartAHS, and SUMO.

In our study we used the SUMO traffic simulator, because it is commonly used to generate mobility models and it used by several large-scaled projects and research community. Furthermore, it is an open source simulator for researchers.

4.3.1 Simulation of Urban Mobility (SUMO)

SUMO is an open-source, microscopic, continuous-space⁴, and discrete-time traffic simulator, which is developed in the year 2000 by the Institute of Transportation Research at the German Aerospace Centre. It is commonly used to generate the mobility model for the vehicles traffic[49]. SUMO uses two different simulation programs, one running using command line in order to allow faster simulations and a second one can show the simulation using the OpenGL-API⁵.

SUMO is very fast; around 100000- 200000 vehicles can be simulated in real time on a desktop PC, including simulation of traffic lights, right-of-way rules and lane changing. Therefore, SUMO can be used with large scenarios.

SUMO is based on a model developed by Stefan Krauss[54]. This model uses discrete time steps of 1s. In each time step, the vehicle's speed is adapted to the speed of the leading vehicle in a way that yields to a collision-free system behavior within the following simulation step(s).

Also, SUMO enables two methods of traffic generation: the first one is importing formats from external database such as NavTeq-databases or TIGER-maps[49]. The second one is generating abstract and geometrical networks by writing own formats in SUMO xml files that will be discussed later. In this study, the second method was used.

⁴ In a space-continuous simulation each vehicle has a certain position described by a floating-point number.

⁵ OpenGL-API: Open Graphics Library- Application Programming Interface which is a standard specification defining a cross-language, cross-platform API for writing applications that produce 2D and 3D computer graphics

4.3.2 Design SUMO Scenario

The first task in this study which is determine the environment parameters of this scenario such as the topology area, number of vehicles, and the maximum speed for the vehicles. These environment parameters for SUMO are illustrated in the Table 4-1.

Table 4-1: Traffic simulation setup parameters

Parameter	Values
Simulation area	1800x1800m
number of vehicles	40,60,80,...300 at max Speed 50Km/h
Simulation time	900s
Maximum vehicle speed	30 - 90 Km/h
Probability distribution	Poisson Function

4.3.2.1 Generation of Vehicular Traffic in the Network

In this study, we built our the vehicular traffic scenario by writing XML files which describe edges (streets), nodes (junctions), types, connections, and routes. Figure 4-4 illustrates the design of the traffic scenarios in SUMO simulator.

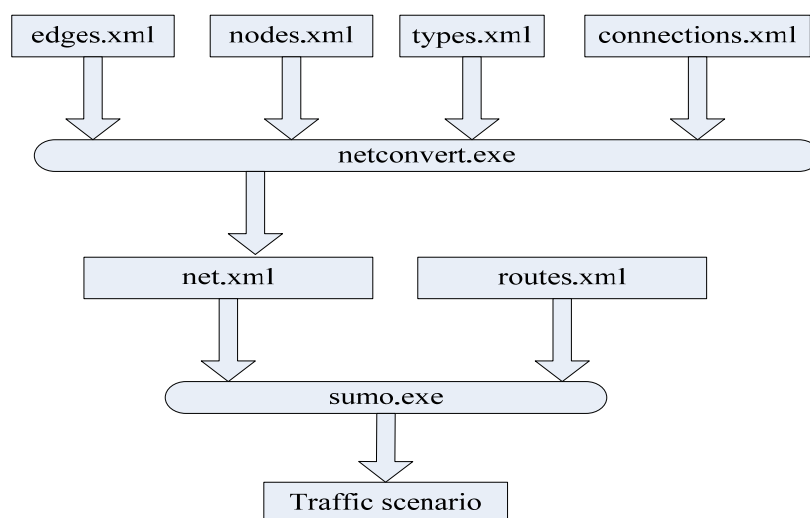


Figure 4-4: Design of the Vehicular Traffic Scenario in the SUMO

As shown in figure 4-4, the first four files used as input files for the netconvert.exe program which converts the user-defined street map (specified in XML files, nodes.xml, edges.xml, types.xml, and connection.xml) into a road-network file (net.xml), then the sumo.exe program takes two input files, net.xml (output from netconvert) and routes.xml to generate vehicular traffic scenario and creates simulation record file (netstate.xml). Appendix B shows these files that build the vehicular traffic scenario.

Figure 4-5 shows the overall for the area of the scenario in SUMO. As we can see from the figure, the road consists of three lanes for vehicles coming to the intersection from the left and two lanes for vehicles leaving the intersection to the right.

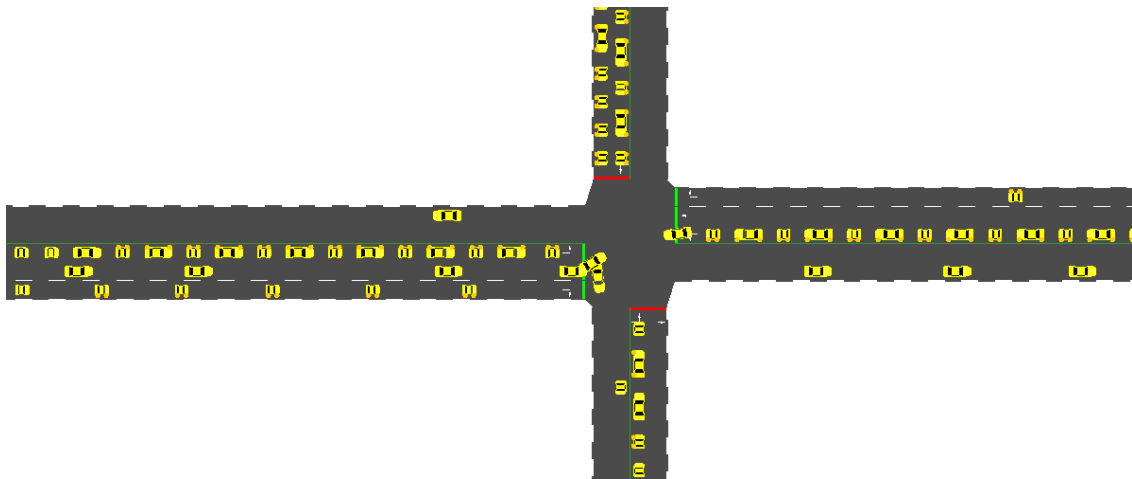


Figure 4-5: The overall for the area of the scenario in SUMO

According to table 4-1, we notice that the number of vehicles takes the values 40, 60... 300 vehicles. The maximum speed of the vehicles takes the values of 30, 40...90 km/h. In order to generate a mobility models with different number of vehicles and maximum speeds, we have to generate different traffic scenarios by repeating the procedure that described in figure 4-4 for each scenario.

4.3.3 Generation Mobility models

After the generation of the traffic scenario, we extracted the movement file patterns (Mobility models) from it. This can be achieved by using the two XML files net.xml (output from netconvert program) and netstate.xml (output from sumo program) which are used as input files for traceExporter.jar program to extract the movement patterns (Mobility models) as mobility.tcl file in order to use it in the network simulator.

Figure 4-6 shows how the mobility model files are generated from the traffic scenarios. Appendix C illustrates an example on how to generate mobility model file from traffic scenario.

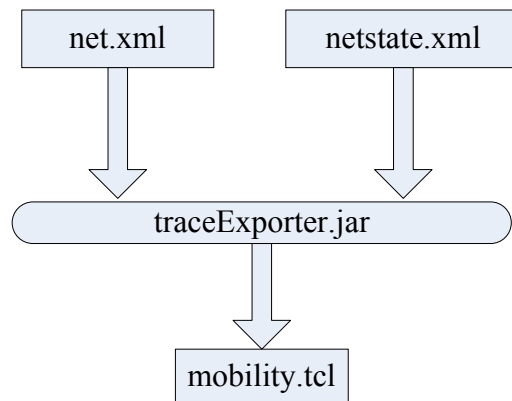


Figure 4-6: Generation Mobility Patterns

We have to perform this procedure for the generation of the mobility model for all traffic scenarios. After this we can use the output file in tcl extension in the network simulator.

4.4 Network Simulation

Wireless network simulations are now widely used in a variety of civilian and military applications to evaluate the performance of network infrastructure or ad hoc wireless network design. There are many software tools like ns-2, OPNET, GloMoSim and QualNet usually used for network simulation. In this study we use ns-2 to perform the

network simulation because it has capabilities for wireless networks, and it is a free source for the researchers.

4.4.1 Network Simulator-2

Network Simulator version 2 (ns-2) is an object-oriented, discrete-event driven⁶ network simulator developed at the University of California, Berkeley, and dedicated for networking research, which has been extensively used by the networking research community. The latest version for ns-2 is the version 2.34 [51]. ns-2 is a powerful network simulator. It supports packet simulation level. It provides substantial support for simulation of TCP, routing, multicast protocols over wired and wireless (local and satellite) networks, etc. Users can define arbitrary network topologies composed of nodes, routers, links and shared medium. A rich set of protocol objects can then be attached to nodes, usually as agents. ns-2 is open-source software and free to use for all users. Due to its open source nature, a user can modify parameters at different layers, create own applications, and develop new protocol. The freeware nature of ns-2 makes it very attractive to students and network researchers and ideal for study and research purpose.

4.4.2 ns-2 Architecture

ns-2[52] based on two programming languages, because the simulator needs to do two different kinds of things. The first language is C++, which is fast to run but slower to change, which can efficiently manipulate bytes, packet headers, and implement algorithms that run over large data sets, making it suitable for detailed protocol implement, Therefore, C++ is utilized for per-packet processing and forms the core of the simulator. The second language is an Otcl interpreter. Otcl is an object-oriented variant of the well-known scripting language tcl, which runs much slower but can be changed very quickly, making it ideal for simulation configurations, so Otcl is used for simulation scenario generation, periodic or triggered action generation and for manipulating existing C++ objects.

⁶ Each event occurs at an instant in time and marks a change of state in the system

The results from ns-2 simulation can be produced in two forms: the visualization trace (as nam file) and ASCII file (as trace file). A graphical visualizer called network animator (Nam) assists the users to get more insights about their simulation by visualizing packet trace data. Appendix D shows one of the VANETs scenarios in nam for our application. The ASCII trace file we used it to analysis the performance of the routing protocols in this study.

4.4.3 Generation of VANETs Scenarios in ns-2

In order to generate VANETs scenario in ns-2, some configurations have to be performed as shown in figure 4-3. The following sub sections describe these configurations

4.4.3.1 Topology and the Movement Patterns:

The intersection consists of two roads; the first road is 20m x 1800m, the second road 20m x1800m. The intersection coordinates is at (900,900). This topology is fed into ns-2 along with the mobility file obtained from traffic simulator (SUMO). The mobility file contains the possible mobility models for vehicles that determine the speed and location of each vehicle every second in the simulation. The following line shows an example of a line in the mobility file.

```
$ns_ at 500.0 "$node_(286) setdest 901.65 1.05 10.05"
```

The line shows that the mobility depends on instruction setdest. Also the line shows the parameter for this instruction: the time, node number, node position, and node speed. Appendix C provides some of these files that used to generated mobility in ns-2 scenarios.

4.4.3.2 Communication Parameters

Every mobile node of VANETs scenario in ns-2 has node configuration parameters, which are communication environments for the ns-2. These parameters are shown in the Figure 4-7.

```
# Communication Environments Configuration for nodes
set val(chan) Channel/WirelessChannel ;#Channel Type
set val(prop) Propagation/TwoRayGround ;# radio-propagation model
set val(netif) Phy/WirelessPhy ;# network interface type
set val(mac) Mac/802_11 ;# MAC type
set val(ifq) Queue/DropTail/PriQueue ;# interface queue type
set val(ll) LL ;# link layer type
set val(ant) Antenna/OmniAntenna ;# antenna model
set val(ifqlen) 50 ;# max packet in ifq
set val(nn) 300 ;# number of mobilenodes
set val(rp) $routing ;# routing protocol
set val(x) 1802
set val(y) 1802
set val(stop) 900
set mobilityfile $nd$density.tcl
set trfilename "city_sce300$a$indx.tr
```

Figure 4-7: Communication parameters for the ns-2

4.4.3.3 Data Traffic Patterns

In our study, we have to perform different sets of simulation experiments. The first simulation set is for the number of vehicles effect. The second simulation set is for the speed of vehicle effect. The third simulation set is for the number of packets effect. For all the simulation sets, the file transfer protocol (FTP) is used as the application that generates the data traffic using the Transmission Control Protocol (TCP) connection. In each scenario of the first and second simulation sets, TCP traffic flows are used with 10 packets per second and data packet size of 1064 bytes. And in third scenario, TCP traffic flows are used with varying in the number of the packets to take the values 1, 2...10 packets per second and the packet size of 1064 bytes.

4.4.3.4 Implemented Routing Protocols

In the simulation of the VANETs scenario, one parameter that has to be specified in ns-2 is the routing protocol being used. In ns-2.34, four ad-hoc routing protocols have been implemented for wireless networks including DSDV, DSR, TORA, AODV, and AOMDV. In our study we used DSDV, AODV, and AOMDV. In addition, we added DYMO routing protocol to ns-2, which is not originally included.

In our study, we are interested in using the most popular classes of MANETs routing protocols which are proactive and reactive classes. We chose three reactive protocols AODV, AOMDV, and DYMO because they have a variety of routing mechanisms. Also we chose one proactive protocols DSDV due to its small initial route delay. Therefore we need to compare the performance of these three reactive protocols and one proactive protocol in the VANET scenario

4.4.4 Simulation Setup Programming

In this study, the simulation settings for ns-2 simulator can be done in two steps. Step one involves the settings of the ns-2 itself, while step two involves the settings that fed into ns-2 such as mobility models from traffic simulation. Therefore, to generate the VANET scenario in ns-2, the following settings have to be programmed in ns-2 tcl file:

- Create a new simulator object
- Turn on tracing
- Open your own trace files
- Create network (physical layer)
- Create link and queue (data-link layer)
- Define routing protocol
- Applying the mobility model
- Create transport connection (transport layer)
- Create data traffic (application layer)

Table 4-2 summarizes the configurations that are set to perform the simulations in our study. And the complete program for scenario ns-2 scenario illustrate in Appendix E

Table 4-2: Network simulation setup parameters

Parameter	Value
Road one	20x1800m (east to west)
Road two	20x1800m (north to south)
Intersection coordinate	900,900
Number of nodes	40,60,80,...300
Transmission range	250 m
Simulation time	900s
Maximum Node speed	velocity 30 - 90 k/h
MAC protocol	IEEE 802.11 DCF
Propagation	TwoRay-Ground
Channel type	Wireless Channel
Queue type	PriQueue
Routing protocols	DSDV,AODV,AOMDV,DYMO
Packet data size	1064 byte
Trace file name	Different Trace file names for each case

4.5 Summary

This chapter provides a description of the VANET scenario which consists of vehicles (nodes) approaching a road intersection in urban environment. Also this chapter gives the steps that we followed to design the VANET scenario and perform the simulation experiments. In addition, it provides an overview about the tools used to design the VANET scenario such as SUMO and ns-2.

The next chapter presents and discusses the results produced from the simulation experiments of the performance of the four MANETs routing protocols used in the VANETs scenario.

Chapter 5

5. Results and Discussions

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5.1 Introduction

This chapter first presents the performance evaluation metrics used in our study to find the best MANETs routing protocol among AODV, DYMO, AOMDV, and DSDV in VANET city scenario, specifically in a road intersection. In addition, it gives an overview of the ns-2 trace files that are produced by the simulations, and gives explanation of their contents, and offers the method that used to analyze it.

Then, we present the results of the comparative simulation study for MANETs routing protocols that are used in the assumed VANETs scenarios. Then, the weakness and strength points in each routing protocols are discussed.

5.2 The Performance Evaluation Metrics

The MANETs routing protocols are evaluated according to the standard metrics suggested by the IETF MANET working group [55], which are routing overhead, average end-to-end delay, packet delivery ratio, the throughput. These metrics are considered because they can describe the interactions and performance of the routing protocols in the network. This section provides an overview of these metrics.

5.2.1 Throughput

Throughput (TH) is measured in Kbit/sec ratio of the total of the data packets delivered to the destinations divided by the time interval. It is also called bandwidth. This metric indicates the effectiveness of a protocol. Mathematically, it can be expressed as:

$$\text{Throughput} = \frac{\sum_{i=1}^N r_i \times ps}{T} \quad (1)$$

Where r: Received Data Packet, T: Time interval, ps: packet size and N: number of the received data packet

5.2.2 Packet Delivery Ratio

Packet delivery ratio (PDR) is the ratio of the data packets delivered to the destinations over the data packets generated by the traffic sources. The routing protocol that has better PDR means that the routing protocol is more complete and correct. In our study, PDR is calculated by dividing the number of packets received by the destination by the number of packets originated by the application layer in the source node. Mathematically, it can be expressed as:

$$\text{PDR} = \frac{\sum_{i=1}^N r_i}{\sum_{i=1}^N s_i} \quad (2)$$

Where r: Received data packets, and s: Sent data packets.

5.2.3 Average End-to-End Delay

Average End-to-End Delay (E2ED) is measured in millisecond. This metric includes processing time, route discover latency, queuing delays, retransmission delay at the MAC, as well as propagation and transmission times. In other words, this metric measures the total delay time from a sender to a destination. Mathematically, it can be expressed as:

$$\text{E2ED} = \frac{\sum_{i=1}^N (tr_i - ts_i)}{\sum_{i=1}^N r_i} \quad (3)$$

Where tr: received time, ts: sent time, and r: received data packet.

5.2.4 Routing Overhead

Routing Overhead (OH) represents the total number of routing control packet transmitted by the routing protocol per distinct data packet delivered to a destination to establish and maintain its routes during the communications. Mathematically, it can be expressed as

$$OH = \frac{\sum_{i=1}^N c_i}{\sum_{i=1}^N r_i} \quad (4)$$

Where c: control packet transmitted, and r: received data packet.

Routing overhead is an important metric that is used to measure the scalability of the routing protocol in networks in terms of consumed bandwidth for control packets such as RREQ, RREP, and RERR.

5.2.5 Packet Loss

Packet Loss (PL) occurs when one or more packets of data fail to reach their destination. PL may occur at both the network layer and the MAC layer, in our study it is interested in the network layer. PL is distinguished as one of the errors that experience wireless communications. It is the ratio of the data packet dropped to the data packets generated by the data traffic sources. Mathematically, it can be expressed as:

$$PL = \frac{\sum_{i=1}^N d_i}{\sum_{i=1}^N s_i} \quad (5)$$

Where d: drop data packet, and s: sent data packet.

5.3 Trace Files

The trace files are text files with extension (.tr) generated by ns-2 simulator. These files contain information about what happened during the simulation. Thus, analyzing these files is considered the main key for measuring the performance evaluation metrics of the routing protocols. This section reviews the contents of the trace files and provides the techniques used to measure the performance evaluation metrics of the routing protocols [51].

5.3.1 Trace File Format

In ns-2 simulator there two types of trace format. One type is normal trace formats which is used with normal wired networks. The other type is wireless trace formats, which is used with wireless networks. To analyze the trace file, the contents of the trace file format should be firstly understood, figure 5-1 shows the format of a wireless trace file and an example for two lines in a trace file.

Event type	Time	Next hop info	Node property tags	Packet info at MAC level	Packet information at IP level	Packet info at "Application level"
s	-t 354.007785645	-Hs 70	-Hd -2 -Ni 70 -Nx 901.65 -Ny 1225.39 -Nz 0.00 -Ne -1.000000 -NI RTR -Nw --- -Ma 0 -Md ffffffff -Ms 36 -Mt 800 -Is 70.255 -Id -1.255 -It AODV -Il 48 -If 0 -Ii 0 -Iv 28 -P aodv -Pt 0x2 -Ph 3 -Pb 1 -Pd 26 -Pds 0 -Ps 100 -Pss 4 -Pc REQUEST			
r	-t 354.007834853	-Hs 55	-Hd -2 -Ni 55 -Nx 898.35 -Ny 1004.54 -Nz 0.00 -Ne -1.000000 -NI MAC -Nw --- -Ma 0 -Md ffffffff -Ms 16 -Mt 800 -Is 22.255 -Id -1.255 -It AODV -Il 48 -If 0 -Ii 0 -Iv 29 -P aodv -Pt 0x2 -Ph 2 -Pb 1 -Pd 26 -Pds 0 -Ps 100 -Pss 4 -Pc REQUEST			

Figure 5-1: Format of a trace file and an example for trace lines

The figure shows that each line in the trace file consists of 7 fields which are explained as following:

- Event type: this field describes the type of event that is taking place at the node and can be one of four types; s: send, r: receive, d: drop, and f: forward. For example, as shown in figure 5-1, the first line begins with s, and the second line begins with r.
- Time: the second field starts with “-t” stand for time.
- Next hop info: this field provides next hop information and the tag starts with the prefix “-H”. As shown in figure 5-1, the first trace line contains –Hs 70 which is the id for the current node, while –Hd -2 is the id for next hop towards the destinations.
- Node property tags: This field relates to the node properties like node-id, the level at which tracing is being done like agent, router or MAC. The tags start with the prefix “-N” which are -Ni which represent the node id, -Nx, Ny, and -Nz for xyz coordinates, -

Ne for the energy level, NI for the trace layer level such as MAC, RTR, and AGT. In this study, we are interested in RTR and AGT levels.

- Packet info at MAC level: this field gives MAC layer information and starts with a leading “-M”. In this study, this field will not be used because we are interested in RTR and AGT levels.
- Packet information at IP level: This tags give start with a leading “-I” which are -Is: source address, source port number, -Id: dest address dest, port number, -It: packet type, -Il: packet size -If: flow id, -Ii: unique id, and -Iv: ttl⁷ value.
- Packet info at "Application level": This field gives the packet information at application level. It consists of tags for the type of application like TCP and UDP, the type of ad hoc routing protocol like DSDV, AODV, AOMDV, and DYMO. The field consists of a leading “-P” and tags differ from routing protocol to another for different applications. It can be noticed from the trace lines for AODV which are -pt :type in hexadecimal, -ph : hop count , -pb :broadcast id , -pd: Destination node -Pds : destination sequence Number -Ps: source node -Pss : source sequence number and -Pc operation REQUEST.

5.3.2 Trace Files Analysis

Trace files produced by ns-2 simulator have a huge number of lines. Therefore, it is nontrivial to deal with these files. Moreover, it isn't interested in all these lines to measure the performance metrics. In our study, two tools used to analyze these trace files. First tool is the Linux command called “grep”. This command is used to extract the interested information from the trace files. Second tool is the m-files in MATLAB program to read the output files from the First tool. Using this technique minimizes the size of the original trace files that should analyzed, make them more convenient to read, and reduce the time for analysis. Appendix D shows how the grep commands are used to produce the greded trace files. Then trace files must be analyzed. M-files in MATLAB program were developed to read the trace files, analyze them, and then calculate the performance metrics for the different MANET routing protocols.

⁷ Time to live (sometimes abbreviated TTL) is a limit on the period of time transmissions in computer network technology that a unit of data.

5.4 Simulation Results

In this study, simulation experiments were performed for different network environments changing the number of vehicles (VN), the speed of vehicles (VS), and the data load (DL). In simulations, the analysis using MATLAB program was performed to investigate the effect of network environments on the four MANET routing protocols AODV, DSDV, AOMDV, and DYMO. This analysis gives the evaluations of the capabilities of each routing protocol in the considered VANET scenario with different environments. In order to ensure the rationality, each simulation experiment was repeated 50 times, and their average is used to calculate the result. Figure 5-2 shows the overall steps of simulation model in this study from the design of VANET scenarios to the simulation results. Notice that nam files are not used in the analysis. They are used only to visualize the movement of nodes.

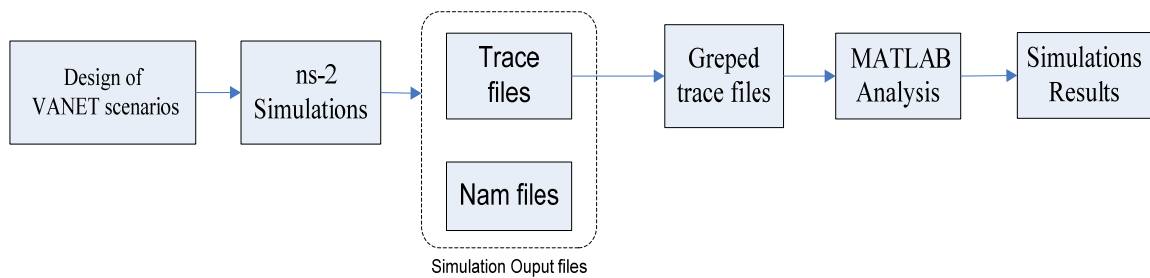


Figure 5-2: The overall steps of the simulation model

5.4.1 Number of Vehicles Parameter

To investigate the effect of the VN parameter on the performance of the routing protocols, simulation experiments were performed with varying VN in the network from 40, 60, 80 ... 300 vehicles (nodes). In this scenario, we take the maximum speed for the nodes to be 50 km/h. TCP data traffic flows are used with 10 packet/s and data packet size of 1064 bytes. Then we analyze trace files for each case. The results and discussions of these simulations are presented in following subsections in terms of TH, E2ED, OH, and PL.

5.4.1.1 Throughput

Figure 5-3 shows TH as a function of VN. In general, it is noticed that at low VN with 40 nodes, the TH is low for all routing protocols. This is because sometimes there are large distances between vehicles and this causes disconnectivity in communication between them.

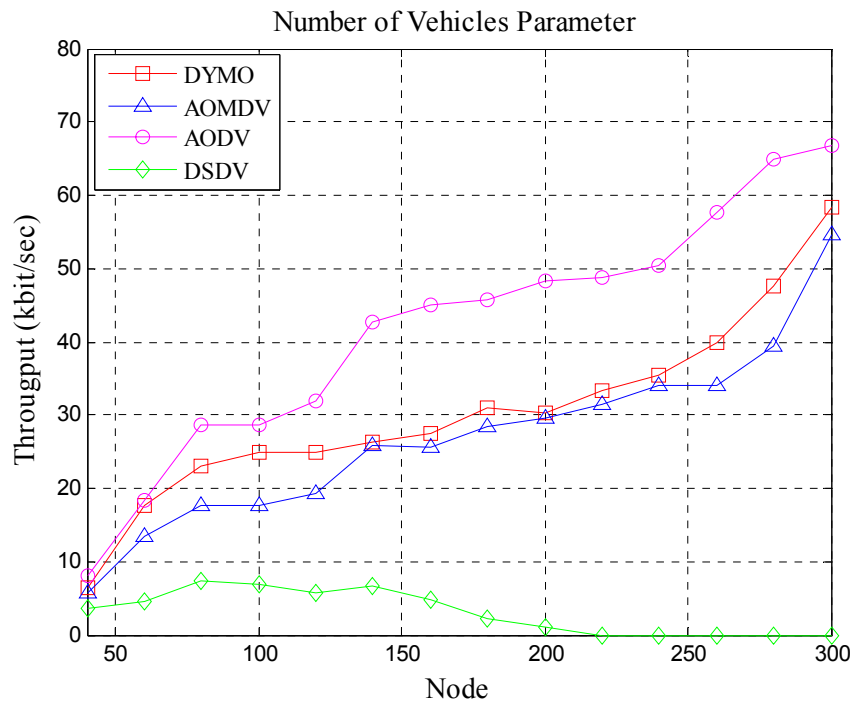


Figure 5-3 : TH with the effect of VN parameter

Also in general the reactive protocols DYMO, AODV, and AOMDV have higher TH than proactive protocol DSDV. This is because DSDV initiates more control packets periodically than reactive protocols to build the routing tables in each node. This reduces the TH of DSDV, while reactive ones issues control packets when it need.

In particular it can be noticed that as the VN increases, the TH in DSDV increases only between 60 to 160 vehicles, then after 180 vehicles TH for DSDV reduces to very low values. This is because of high VN, number of vehicles that are participating in relaying packets increases. Additionally, one can notice that as the VN for all reactive protocols increase, TH value increases due to the increase in the number of vehicles that are participating in relaying data packets. This is because as VN increases, disconnectivity in

the connection between nodes is reduced. Also, figure 5-3 shows that AODV outperforms DYMO, AOMDV, and DSDV. This is because AODV uses an optimal single path mechanism. In the case of DYMO, it uses path accumulation mechanism which may obtain wrong route information from the intermediate routers due to frequent topology changes and this causes more route failure than AODV.

5.4.1.2 End-to-End Delay

Figure 5-4 shows the effect of the VN parameter on the E2ED for the routing protocols. In general, one can notice that the proactive DSDV protocol has the highest E2ED because it spends long time in building routing tables due to its proactive nature. Notice that at low VN, E2ED of DSDV decreases as VN increases. This is because at low VN there are not enough nodes to establish connections between nodes. As VN increases, connections become more stable. However, when VN becomes larger than 100, E2ED starts to increase as VN increases. This is because number of nodes is larger than what is needed to establish connections between nodes. This increase in the number of nodes leads to higher control packets in proactive protocols such as DSDV.

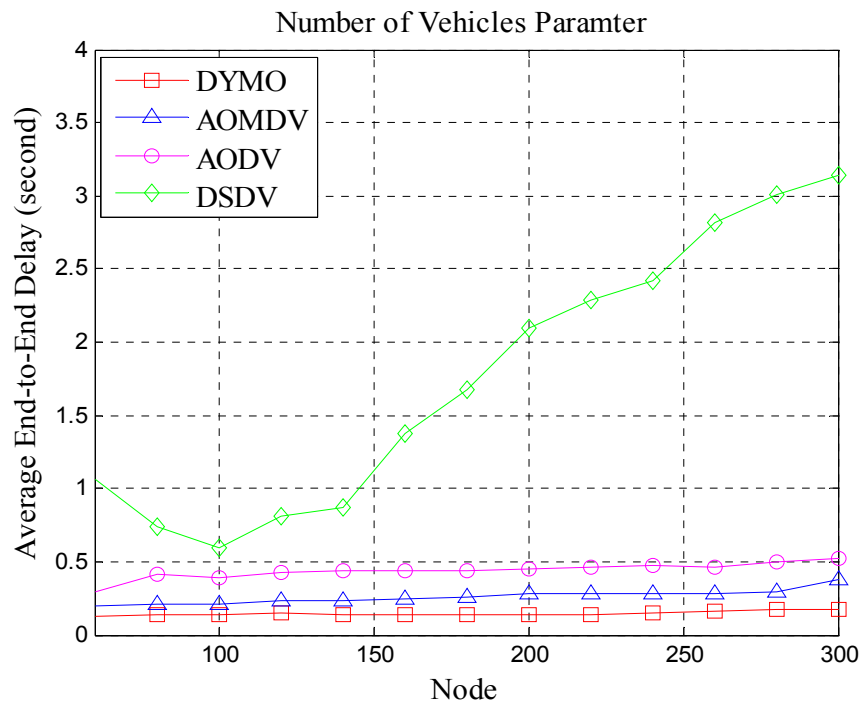


Figure 5-4: E2ED with the effect of the VN parameter

On the other hand, reactive protocols AOMDV, AODV, and DYMO have lower E2ED than DSDV. This is due to their reactive nature which initiates control packets only when they are needed. Furthermore, it can be noticed that E2ED for reactive protocols increases as the VN increases, but it still less than that in DSDV.

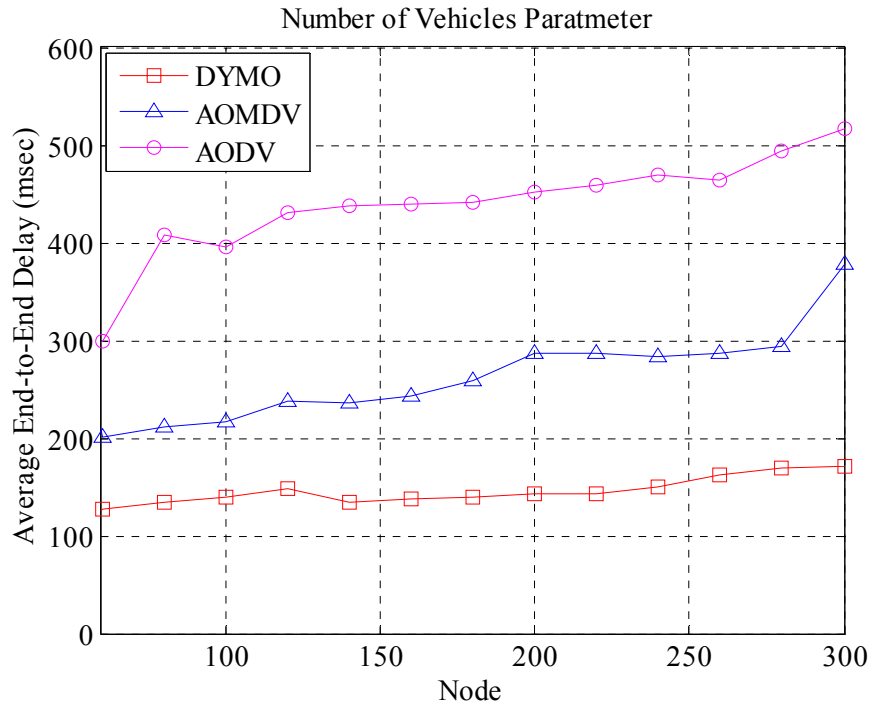


Figure 5-5: E2ED with the effect of the VN parameter for reactive protocols

Figure 5-5 shows the E2ED for the reactive protocols only. According to Figure 5-5, In general it is noticed that E2ED increases as VN increases for all protocols. In addition, one can notice that DYMO has the lowest E2ED. This is due to its path accumulation function mechanism which reduces the path discovery process than AODV, and AOMDV. The AODV has the highest E2ED than the others because it uses an optimal single path.

5.4.1.3 Routing Overhead

Figure 5-6 shows the effect of the VN parameter on OH. In general it is noticed that the increase in VN parameter leads to an increase in the routing overhead because as VN

increases, control packets increases, and hence OH increases as well. In particular, the figure shows the proactive protocol DSDV has the highest OH due to its periodic updates of the routing table which leads to initiate more control packets as VN increases, and hence increasing the OH. Also it can be noticed from the figure that all reactive protocols AODV, AOMDV, DYMO have lower OH compared to DSDV because of their on demand routing nature.

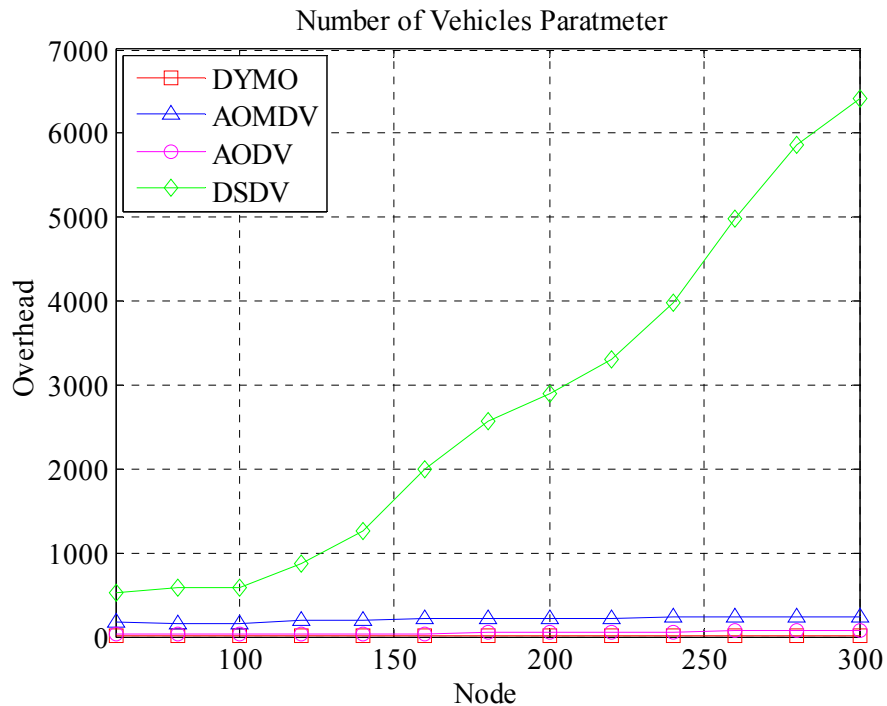


Figure 5-6: OH with the effect of the VN parameter.

To have a closer view, OH of reactive protocols is plotted in figure 5-7. One can notice that DYMO has the lowest OH, and AOMDV has the highest. However, using path accumulation mechanism in DYMO allows the nodes to listen to routing messages in order to obtain knowledge about routes to other nodes without initiating RREQ. On the other hand, AOMDV uses multi-path mechanism in addition it finds a disjoint paths, this initiates more control packets to build the routing tables. Therefore, AOMDV has higher OH than AODV.

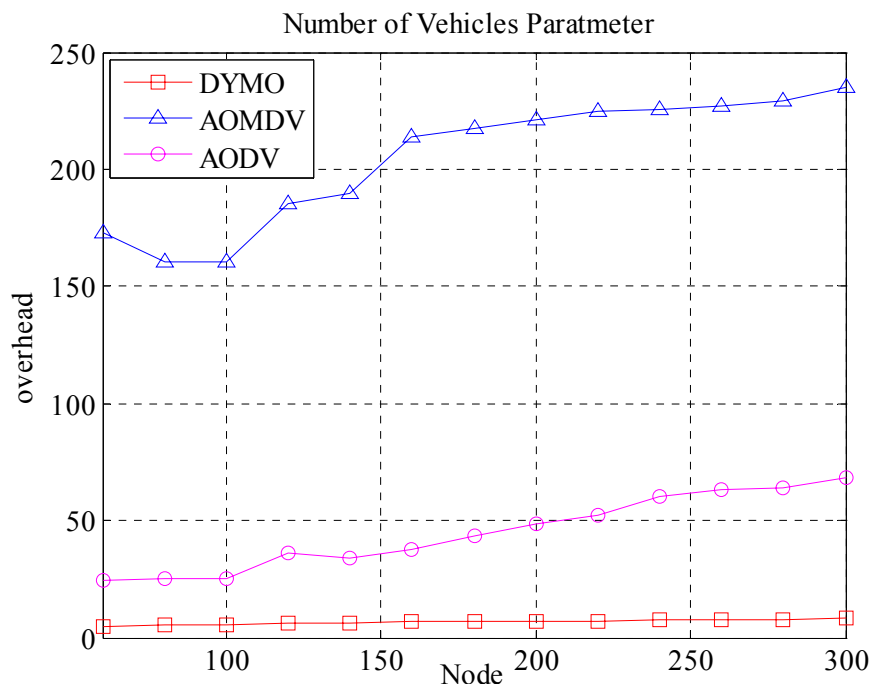


Figure 5-7: OH with the effect of the VN parameter for reactive protocols

5.4.1.4 Packet Loss

Figure 5-8 shows the effect of the VN parameter on PL for the routing protocols. Here one can notice that DSDV has the highest PL. In particular one can see that at low VN, DSDV has high PL due to the large distance between the vehicles. As a result, number of vehicles participating in relaying packets is low, and so PL is high. The PL decreases as VN increases, this is due to the increase in the number of vehicles participating in forwarding the packets, and this increases TH and reduces PL. One can see that this is the case between 60 to 80 vehicles, but after increasing VN more than 80, PL starts to increase as VN increases. This is due to the increase in OH and E2ED. As a result, TH decreases and PL increases.

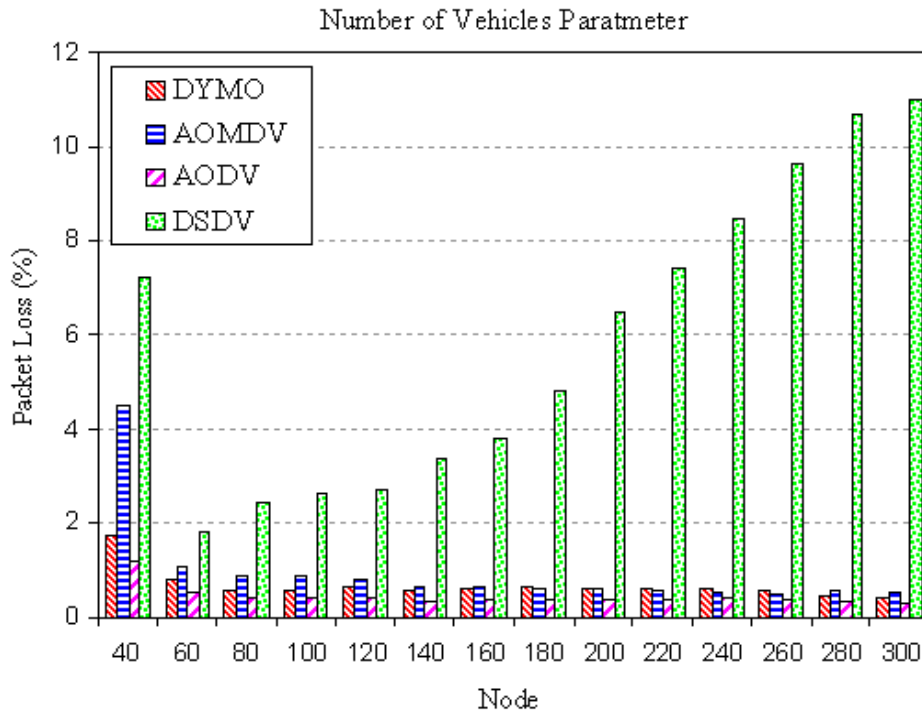


Figure 5-8: PL with the effect of the VN parameter.

From figure 5-8, one can notice that the PL in reactive protocols is close to each other. At low density, AOMDV has the highest PL among the reactive protocols and it is close to that of DSDV, and higher than AODV and DYMO this due to the fact that AOMDV has higher initial E2ED at low density.

According to figure 5-8 and as the VN increases, the PL decreases for all reactive protocols. Moreover, it can be noticed that AODV has the lowest PL among them since it has the highest TH. As a result, as TH increases the PL decreases and vice versa.

Table 5-1 shows a comparison between routing protocols for the VN values of 40, 180, and 300 nodes. The information from table 5-1 represents the effect of VN in three cases: at low, medium and high values. And one can see from Table 5-1 that at 40 nodes, all routing protocols are somewhat close to each other in term of TH, while one can notice small differences in terms of E2ED, OH, and PL.

Table 5-1: comparison of numerical values for VN parameter

VN node	Routing protocol	AODV	AOMDV	DYMO	DSDV
	Performance metric				
40	TH (Kbit/sec)	8.1	5.7	6.3	3.7
	E2ED (sec)	270	357.0	116.1	1364.7
	OH (%)	34.5	317.6	8.4	2041.9
	PL (%)	1.1	6.4	1.7	17.2
180	TH (Kbit/sec)	45.8	28.5	30.8	2.3
	E2ED(msec)	441.1	259	140	1680.3
	OH (%)	43.5	217.1	6.8	2563.8
	PL (%)	0.3	0.6	0.6	6.5
300	TH(Kbit/sec)	66.8	54.6	59.4	0.1
	E2ED(msec)	516.7	378.5	171.6	3138.3
	OH (%)	68.3	234.7	8.4	6416.7
	PL (%)	0.3	0.5	0.4	11.218

For 180 nodes, it can be noticed that the difference between them in all values for TH, E2ED, OH, and PL. According to the table one can notice that AODV has TH of 45.8kbit/s with an increase in E2ED and in OH, while DYMO has 30.8kbit/s with decrease in E2ED and in OH. AOMDV becomes 28.5kbit/s with an increase in E2ED and decrease in OH. While TH of DSDV decreases to 2.3kbit/s and its E2ED and OH increase. According to Table 5-1, one can conclude that DYMO is the best in terms of E2ED as it is consistent with changes topology than other protocols, while DSDV suffers from high E2ED. Also notice that AOMDV has the highest E2ED among reactive protocols. From the above comparison, DYMO is better than other protocol in terms of E2ED and OH. The AODV has good performance in terms of TH but suffers from high E2ED and high OH. The AOMDV has good performance in terms of TH but suffers from higher OH than AODV and less E2ED than AODV. Therefore, the DYMO routing protocol is the best when considering the effect of VN parameter.

5.4.2 Vehicles Speed Parameter

To investigate the effect of the speed of vehicles (VS) parameter on the performance of the routing protocols, we perform simulation experiments by varying the speed of the vehicles to take the values of 30, 40, 50, 60, 70, 80 and 90 km/h. Number of vehicles in these experiments is 60. TCP traffic flows are used with 10 packet/s and data packet size of 1064 bytes to measure the performance of protocols with high data traffic. For this case, four performance evaluation metrics are measured: TH, E2ED, OH, and PL.

5.4.2.1 Throughput

Figure 5-9 shows the effect of VS parameter on TH. The figure shows that as VS increases, TH of the four routing protocols decreases. In particular, AODV has the highest TH at lower speed (30km/h), while DSDV has the lowest TH at this speed and then decreases to very small value as speed increases. This means that DSDV is not suitable for high speed vehicles.

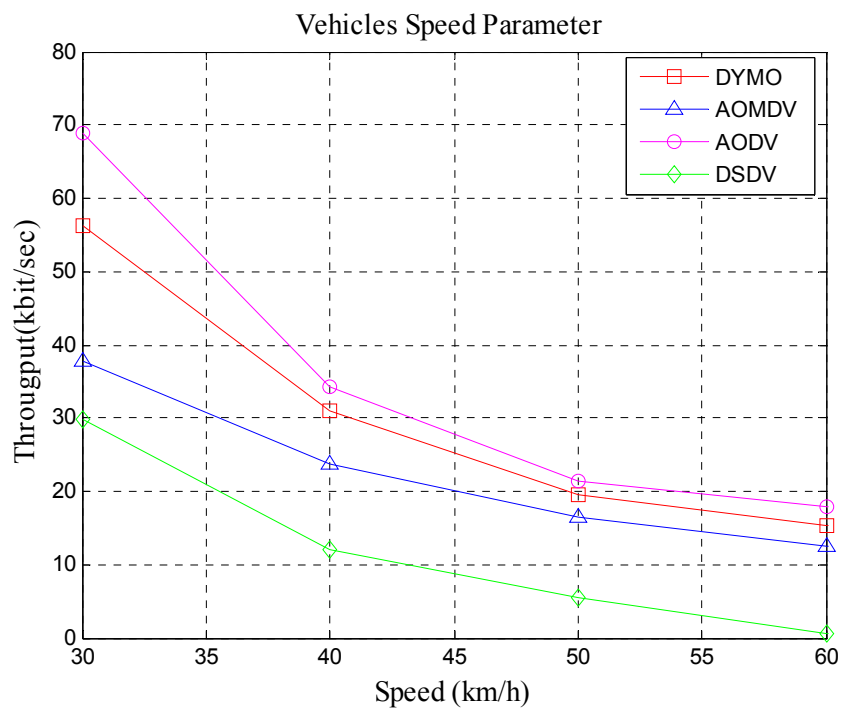


Figure 5-9: TH with the effect of the VS parameter

This is due to the fact that DSDV issues control packets periodically to update the routing table in each node, while the AODV initiates the control packets when needed.

Figure 5-9 shows also that DYMO and AOMDV behave almost identical after 60km/h. TH of DYMO is lower than that of AODV before 60km/h. The reason for this is to the wrong route information given by the intermediate routers using DYMO, because DYMO uses path accumulation which allows the nodes listing to routing messages to acquire knowledge about routes to other nodes without initiating RREQ which causes more route failure in DYMO than AODV.

5.4.2.2 Average End-to-End Delay

Figure 5-10 shows the effect of VS parameter on E2ED. According to Figure 5-11, all routing protocols provide approximately equal performance at the lowest speed (30km/h). However, as VS increases, the E2ED increases as well for all routing protocols with variations between them. DSDV has the highest E2ED with respect to other protocols; this is because increasing the speed of vehicles causes quicker frequent changes in topology. As a result, DSDV initiates control messages to maintain the routes. Therefore, the E2ED for DSDV in high speed is extremely high. But the reactive protocols have much lower E2ED values for this parameter, since the reactive protocols are more adaptive to the frequent changes in topology. Particularly, it can be noticed that DYMO has the lowest E2ED between the reactive protocols because it uses the path accumulation function which reduces discovery path process. Figure 5-10 shows also that AOMDV has less E2ED than AODV. This is because AOMDV uses multi-path routing mechanism which reduces the frequent disconnectivity due to high topology changes, while AODV uses a single path routing mechanism.

5.4.2.3 Routing Overhead

Figure 5-11 shows the effect of the VS parameter on the OH. Firstly, this figure shows that OH of DYMO is the lowest among the protocols due to the path accumulation function that reduces the number of RREQ messages. Secondly, the figure shows that DSDV has the highest OH due to frequent topology changes. This leads to initiate more

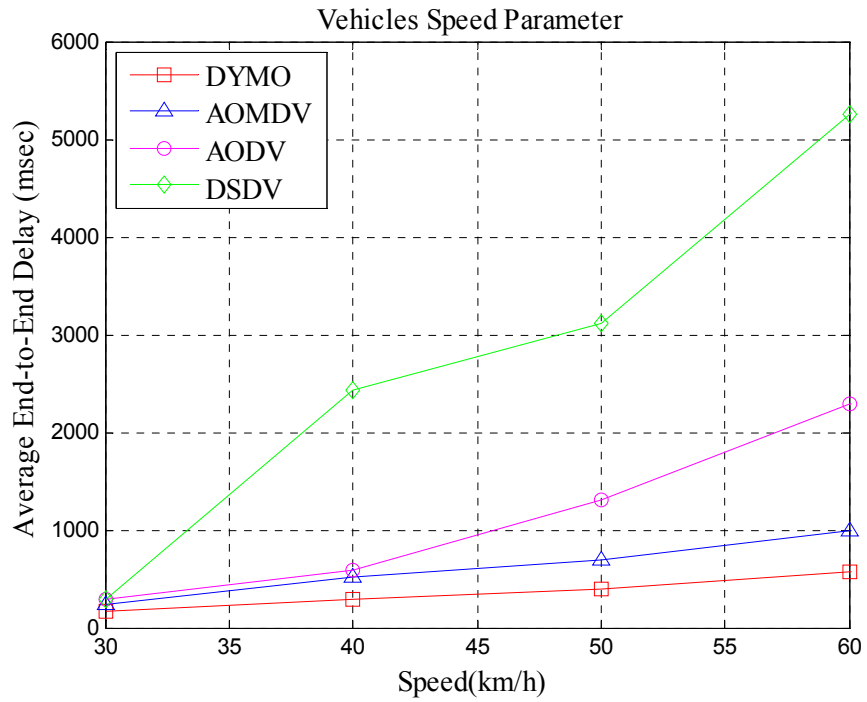


Figure 5-10: E2ED with the effect of the VS parameter

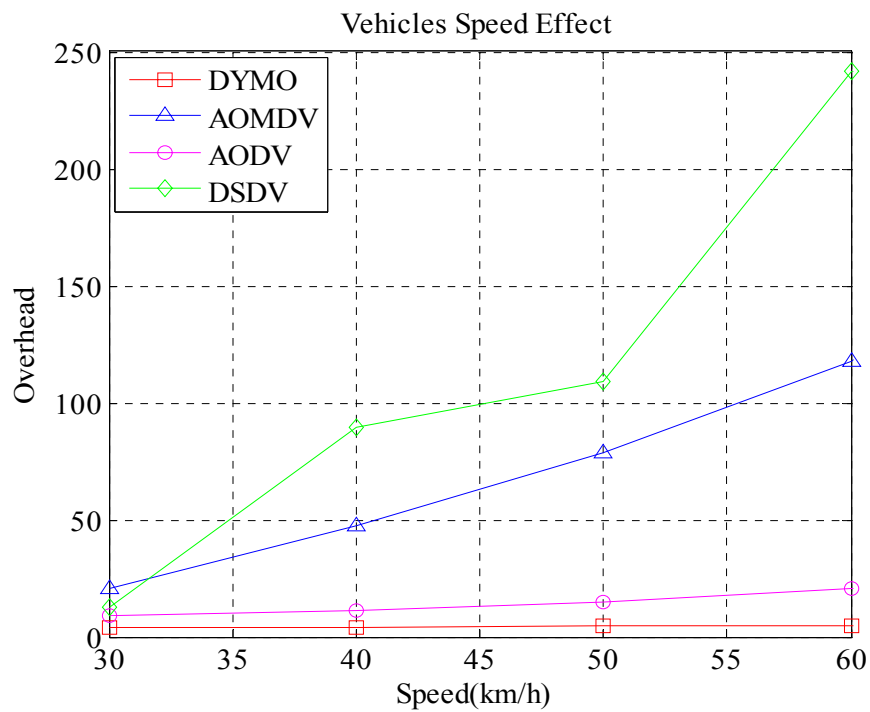


Figure 5-11: OH with the effect of the VS parameter

control messages to build the routing tables periodically which consume time in path building. As a result, TH of DSDV decreases and PL increases rapidly as shown in figures 5-9 and figure 5-12 respectively. Figure 5-11 shows also that AOMDV has the highest OH among reactive protocols. This is due to the multipath mechanism which initiates more RREQ messages than DYMO and AODV to find multiple paths with disjoint paths.

5.4.2.4 Packet Loss

Figure 5-12 plots the PL for the routing protocols as a function of VS. It shows that DSDV has the highest PL among the protocols. This due to frequent topology changes due to the mobility of vehicles which leads to initiate more control packet to update routing tables. Thus OH increases as well as PL. In addition, it can be noticed that the reactive protocols have lower PL than DSDV due to their on demand routing mechanisms. Thus reactive protocols have less OH than DSDV and this leads to decrease packet drop.

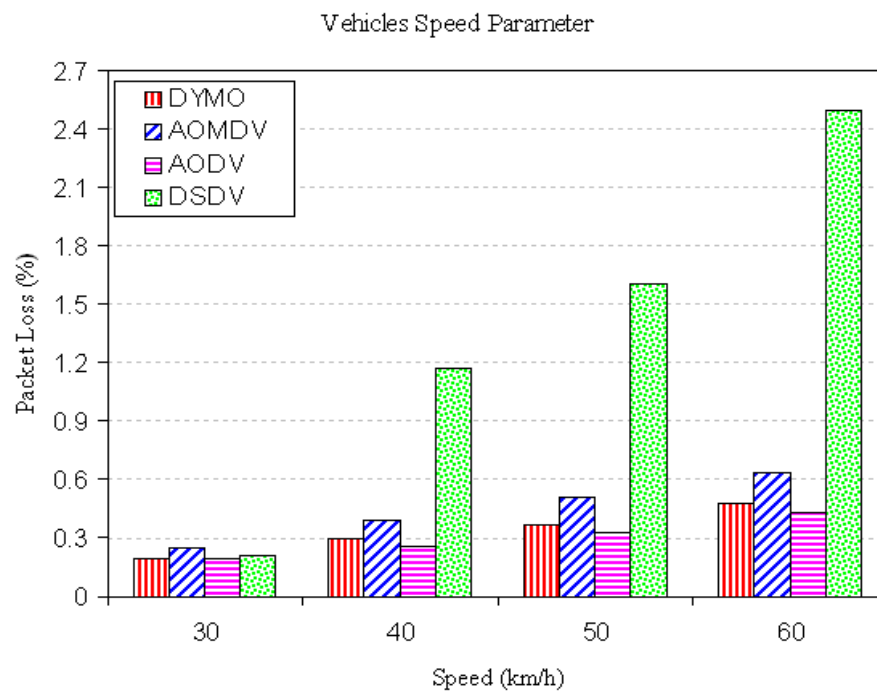


Figure 5-12: PL with the effect of VS parameter

Table 5-2: Comparison of numerical values for VS parameter

VS (km/h)	Routing protocol	AODV	AOMDV	DYMO	DSDV
	Performance metric				
30	TH (Kbit/sec)	68.9	37.8	56.2	29.8
	E2ED (msec)	286.4	245.1	174.8	291.7
	OH	8.8	21.1	3.8	12.4
	PL	0.18	0.25	0.2	0.2
60	TH(Kbit/sec)	17.9	12.5	15.3	0.7
	E2ED(sec)	2235.4	993.6	575.1	5259.3
	OH	20.7	117.9	4.7	241.4
	PL	0.4	0.6	0.5	2.5
90	TH(Kbit/sec)	10.7	5.2	7.4	0.3
	E2ED(sec)	5769.9	3753.3	2004.1	27979
	OH	36.4	505.7	19.3	902.1
	PL	0.8	1.9	1.1	8.6

Table 5-2 shows the effect of VS parameter on the performance of the MANETs routing protocols AODV, AOMDV, DYMO, and DSDV for 30, 60, and 90 Km/h.

As shown in Table 5-2, AODV has a much higher TH than other protocols. For example, TH of AOMDV and DYMO at 30km/h are 0.54 and 0.81 times TH of AODV respectively. This result is expected since AOMDV is based on Multi-path mechanism which increases the OH because it initiates more control packets than AODV. As a result, TH of AOMDV is the lowest. As the speed increases to 60km/h, TH of AOMDV gets 0.68 times TH of AODV. Furthermore as the speed increases to 90km/h, TH of AOMDV becomes 0.48 times TH of AODV, one can notice that the variations between AODV and DYMO in TH in table 5-2, and that the worst TH is for DSDV. According to table 5-2 one can notice also that AODV gives the best performance in term of TH with respect the speed effect regardless other parameters. However, DYMO has the best performance in other terms OH, E2ED, and PL and it has a similar TH value as AODV. Thus it is safe to say that DYMO has also the best performance with VS parameter.

5.4.3 Data Load Parameter

To investigate the effect of the data load (DL) parameter, simulation experiments were performed by varying the number of the data packets between 1, 2... 15 packet/second with data packet size of 1064 bytes. TCP traffic flows are used with each of the varying DL values. Number of vehicles in these experiments is 60, and the maximum speed for the nodes to be 50 km/h is used. The results and discussions of these simulations are presented in following subsections in terms of TH, E2ED, OH, and PL.

5.4.3.1 Throughput

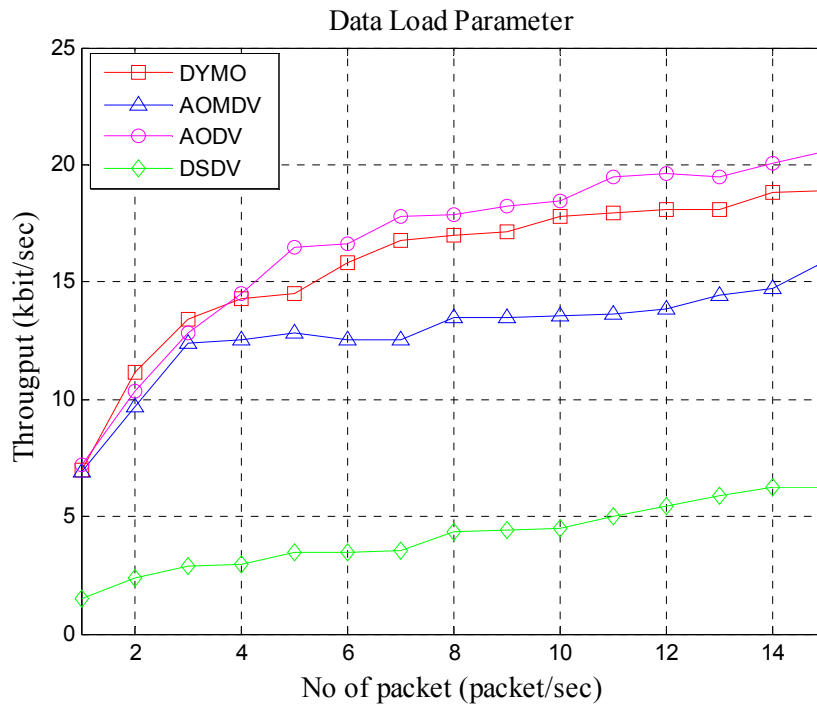


Figure 5-13: TH with the effect of DL parameter

Figure 5-13 shows the effect of the DL parameter on the TH performance for four routing protocols. One can notice that the TH for reactive protocols DYMO, AODV, and AOMDV is higher than the proactive protocol DSDV. One can notice also that the DYMO protocol performs well compared to other reactive protocols AODV and AOMDV. For all routing protocols, the TH value is constant after DL reaches 10packet/s. This is due to the capacity limit of the wireless channel. In addition, DSDV has the lowest

TH because of periodic control messages to build the routing tables due to the frequent topology changes

5.4.3.2 Average End-to-End Delay

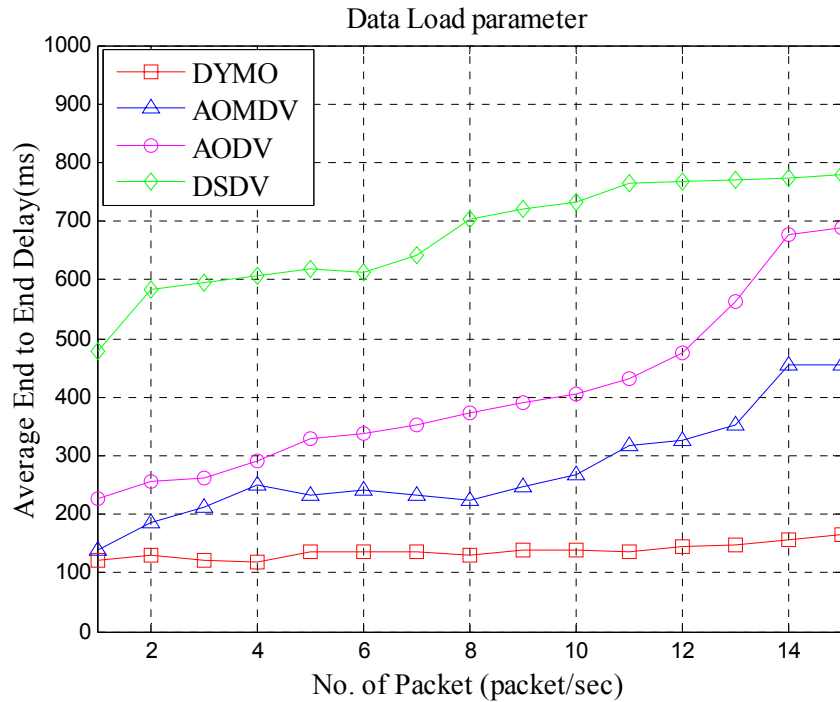


Figure 5-14: E2ED with the effect of DL parameter

Figure 5-14 shows the effect of DL parameter on the E2ED performance for four routing protocols. According to Figure 5-14, one can notice that as DL increases, E2ED of four routing protocols increases. Particularly, it can be noticed that the DSDV has highest E2ED. Due to DSDV spends more time to build a route table periodically and this increase the E2ED. Figure 5-14 also shows that the DYMO and AOMDV have lower E2ED than the DSDV and AODV. This is due to path accumulation function mechanism in DYMO, and multipath with disjoint paths in AOMDV. Furthermore, E2ED of DYMO is almost constant, since route discovery process is optimized. For AODV as the DL increases the E2ED increases and AODV has the highest E2ED among reactive protocols because the source nodes have to frequently re-discover the paths that have been broken. This problem is more sever in AODV since it uses single path routing mechanism.

5.4.3.3 Routing Overhead

Figure 5-15 shows the effect of DL parameter on OH. One can notice that as DL increases, OH of the four routing protocols decreases. In particular it is shown that DSDV has the highest OH at lower DL (1 packet/s), while DYMO has the lowest OH at this DL value.

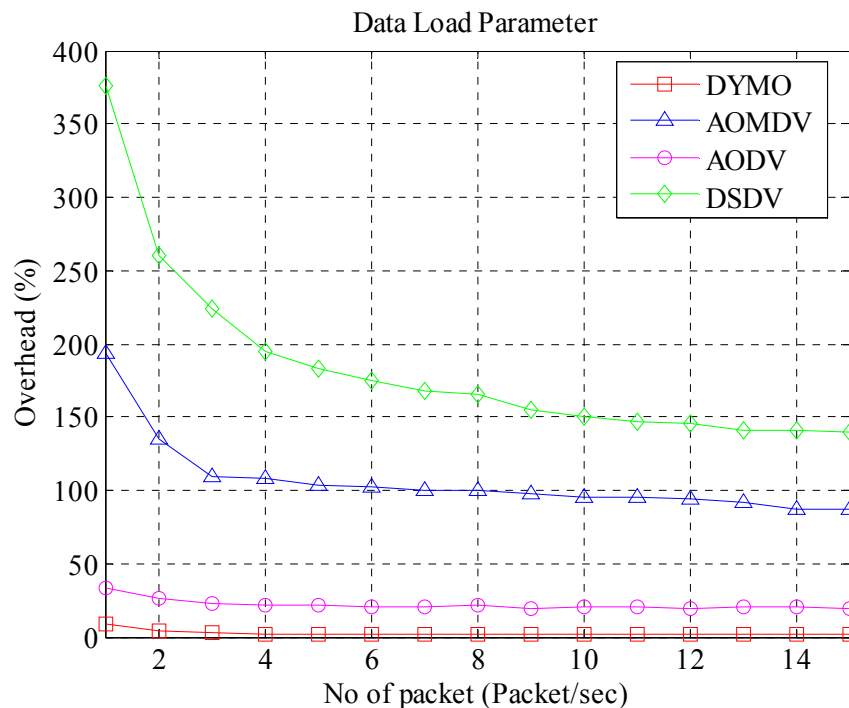


Figure 5-15: OH with the effect of DL parameter

It can notice also from the figure 5-15 that DYMO and AODV have almost constant OH as DL increases. This proves that AODV and DYMO are more efficient than the other protocols with varying DL value.

5.4.3.4 Packet Loss

Figure 5-16 shows the PL for the routing protocols with the DL parameter. As shown from this figure, DSDV has the highest PL among the protocols. This is because DSDV initiates more control packet than reactive protocols and hence suffers from higher OH as shown in figure 5-15.

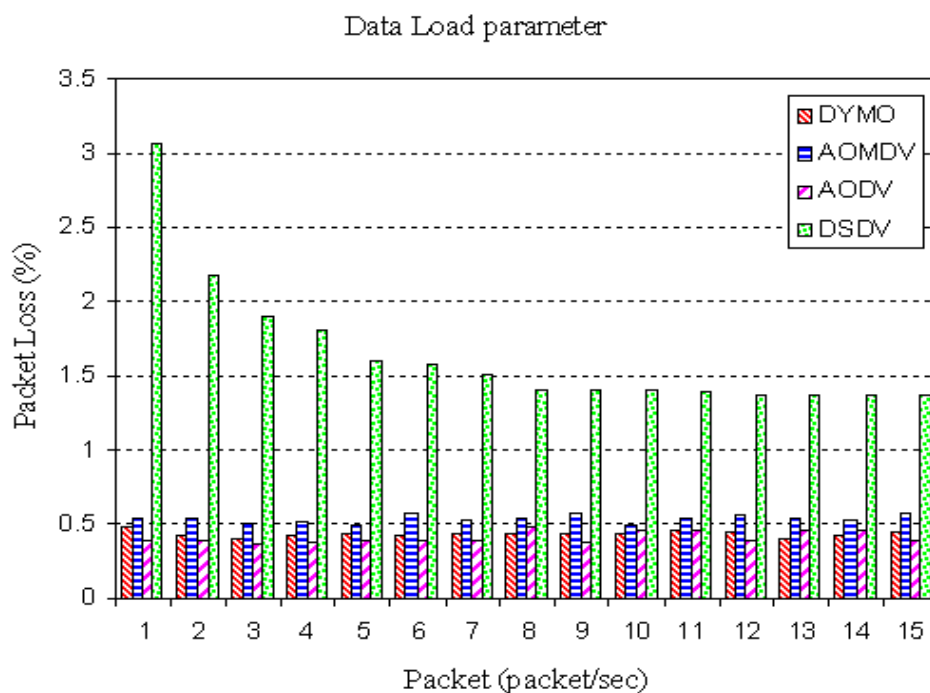


Figure 5-16: PL with the effect of DL parameter.

In addition one can notice that PL of the reactive protocols is somewhat close to each other. Also it can be seen that as DL increases the PL for DSDV decreases exponentially and then becomes consistent at 10 packet/s. This is due to the constant PDR at this point due to the capacity of the channel.

Table 5-3 shows the comparison of numerical values between protocols for the effect of DL parameter on the performance of the MANET's routing protocols AODV, AOMDV, DYMO, and DSDV for 1, 8, and 15 packet/s. One can notice from the table 5-3 that the effect of DL at three different cases which are at low data rate when 1 packet/sec and at medium data rate at 8 packet/sec, and high data rate at 15 packet/sec. For low data rate of DL one can notice the reactive protocols have TH somewhat close to each other ranging between 6.8 kbit/sec and 7.2 kbit/sec and for DSDV has 1.5 kbit/sec. As the DL increases, the TH for all routing protocols increases with AODV having the highest TH and DSDV having the lowest TH among the other protocols.

Table 5-3: comparison of numerical values for DL parameter

DL packet/sec	Routing Protocol				
	Performance metric	AODV	AOMDV	DYMO	DSDV
1	TH (Kbit/sec)	7.2	6.8	7.01	1.5
	E2ED (msec)	225.4	138.7	122.2	477.2
	OH	33.3	193.9	8.5	375
	PL	0.39	0.54	0.47	3.1
8	TH(Kbit/sec)	17.8	13.4	16.9	4.4
	E2ED(sec)	405.8	232.9	131.6	606.2
	OH	22.3	99.6	4.7	165.1
	PL	0.3	0.5	0.4	1.4
15	TH(Kbit/sec)	20.5	15.8	18.8	6.2
	E2ED(sec)	687.4	454.4	164.8	767.7
	OH	19.7	87.1	3.6	139.7
	PL	0.3	0.5	0.4	1.4

In addition, as the DL increases, the OH for all routing protocols decreases. Moreover, DSDV has the highest OH among them and DYMO has the lowest OH. Furthermore, as the DL increases, E2ED for all routing protocols increases while DSDV still has the highest E2ED among them and DYMO has the lowest E2ED. Finally, one can notice that DYMO outperforms other routing protocols in terms of E2ED and OH, and its TH is somewhat close to that of AODV. Therefore, DYMO has better performance than the other routing protocols.

After this discussion, we have to specify the weakness and strength of each of routing protocol with different environments VN, VS, and DL. Table 5-3 summarized the comparison between four protocols for VS, VN, DL effects on different performance metrics.

Table 5-4: The comparison between performance of MANETs rounding protocols with VS, VN, and DL parameters

Parameters Protocol	VN				VS				DL			
	DYMO	AODV	AOMDV	DSDV	DYMO	AODV	AOMDV	DSDV	DYMO	AODV	AOMDV	DSDV
Per. metrics TH ⁸	M	G	M	W	G	G	M	W	G	G	M	F
E2ED ⁹	G	F	M	W	G	F	M	W	G	F	M	W
OH ¹⁰	G	M	F	W	G	M	F	F	G	M	F	W
PL ¹¹	G	G	M	W	M	G	M	F	G	G	G	M

G: Good, M: Moderate, F: Fair, W: Weak

Table 5-4 shows the effects of the different parameters VN, VS, DL on the performance metrics TH, E2ED, OH, and PL for all routing protocols. One can see that the DYMO almost has G in all metrics for all parameters, while AODV has almost G only in TH and PL metrics for all parameters, and it has F always in E2ED for all parameters.

According to Table 5-4, the DYMO routing protocol outperforms the other routing protocols in terms of E2ED, OH, and PL in all environment parameters, while DSDV has the worst performance.

⁸ For TH: Good (G) above 75% of successful rate. Moderate (M) means 75% of successful rate. Fair (F) 50 % of successful rate. Weak (W) means less 50 % of successful rate.

⁹ For E2ED G means 70% less (shorter) delay than the average. M means the average performance compared to other protocols. F means times the average. W delay means longer delay than the fair.

¹⁰ For OH: Good means less than 10 %. Moderate means more than 10%. Fair means more than the average performance compared other. Weak means highly more than the fair

¹¹ For PL : Good means less 1% of Data packet dropped, Moderate means more than 1% of Packets dropped, Fair means more 2 % of packets dropped. Weak means more than 3 % of packet dropped.

5.5 Summary

This chapter provides the description of performance metrics (throughput, average end to end delay, routing overhead, and packets loss) used to evaluate the MANETs routing protocols AODV, AOMDV, DYMO, and DSDV in the assumed VANETs city scenario particularly in a road intersection. In addition, this chapter gives a brief an overview of trace file format and how to analyze this file.

This chapter also presents the results of ns-2 based simulation study that are conducted to investigate the effects of different parameters which are VN, VS, and DL on performance of four MANETs routing protocols (AODV, AOMDV, DYMO, DSDV). It also discusses the weakness and strengths points of routing in terms of TH, E2ED, OH, and PL. From the discussion, it is shown that the performance of routing protocols varies and depends on the environment parameters. According to the comparative simulation study that carried out, it becomes clear that the DYMO routing protocol yields the best performance among other routing protocols.

The next chapter presents our conclusions from the discussion of comparative simulations study results and gives our recommendations for future work.

Chapter 6

6. Conclusions and Future work

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This chapter highlights the main results, provides conclusions and gives directions for future work.

6.1 Summary

The Last decade has witnessed many advances in wireless networks. Among these networks are the so-called mobile ad hoc networks (MANETs). MANET is a self-organizing multi-hop wireless network where all nodes participate in the routing and data forwarding process. Vehicular Ad Hoc Network (VANET) is special case of MANET where the network is focused on providing vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication. The wireless communication between vehicles has been received increasing attention by researchers. Thus VANET has been one of the hottest research topics in the last few years and is considered one of the most promising types of networks in the future. Moreover, VANET has been received a wide attention from many car manufacturers, governmental organizations and the academic communities. VANETs have highly dynamic topology and frequently disconnected network. The potential applications in VANETs include active safety, intelligent transportation, and information/entertainment.

In this study, we focused on a road intersection safety in a city. For this application there is a significant role in managing and monitoring the traffic at an intersection to reduce the congestion of traffic and prevent car accidents. However, routing for urban VANET faces greater challenges because of the mobility of vehicles. Moreover, topology of these networks changes unpredictably. In addition, routing in VANETs works mainly based on a distributed fashion. These factors make the routing the most prominent problem in VANET. For cost and safety reasons, computer-based simulation is a necessary tool for doing research in this field.

In this thesis, a comparative simulation study is has been conducted based on SUMO and ns-2 simulators to find the best routing protocol among four MANETs routing protocols in VANETs city scenario. Theses protocols are DSDV, AODV, AOMDV, and DYMO. The principles of these protocols were briefly reviewed. These routing protocols are classified into two main types: proactive and reactive. DSDV is a proactive protocol that initiates control packets periodically to discover and maintain the routes. The other

protocols AODV, AOMDV, and DYMO are reactive protocols that initiate control packets to discover and maintain a route when it is needed only. However, these reactive protocols have different routing mechanisms. AODV uses next hop mechanism, while AOMDV uses multi-path mechanism, and DYMO uses path accumulation mechanism.

In addition, this study briefly reviewed the possible of wireless medium access methods that can be deployed with VANETs applications, which are the IEEE 802.11 standard for WLAN, DSRC/WAVE, cellular networks, and WiMAX/802.16e. In this study, the first one was adopted for many reasons. Firstly, WLAN technology supports short range wireless data communication between the vehicles. Secondly, LAN technologies can be adopted to be used with unlicensed radio spectrum. Finally, the low cost accompanied with developing this technology.

In this thesis, the assumed VANET scenario was defined as basis for the performance investigation of vehicle-to-vehicle communication based on MANETs routing protocols AODV, AOMDV, DYMO, and DSDV for different environments such as number of vehicles, maximum speed of vehicles, and number of sent data packets.

The assumed VANET scenario in this thesis consists of vehicles (nodes) approaching a road intersection in urban environment. The main idea of the scenario focuses on sending information about the intersection from a node existing at the intersection (source node) to other vehicles (destination nodes) that are at distance of approximately 1km from the road intersection and they are moving towards it. The information sent to the destination nodes contains the conditions about the intersection. The information may take several types of data such as voice, image, or video.

The importance of assumed VANET scenario is to assist the driver in dealing with the conditions of intersection, such as traffic congestion and traffic light phase, before his arrival to it.

The information delivery to the destination nodes depends on the communication links among the vehicles which are accomplished by forwarding data packets for each other on a multi-hop basis along the current connection between the source node and the destination node.

The design of assumed VANET scenario was implemented by means of simulation tools, and it was accomplished in five steps: determine the simulation environments, design the traffic scenario by using Simulation of Urban Mobility (SUMO) traffic simulator in order to generate the mobility patterns, extract the movement patterns as a script files, apply the mobility patterns in Network simulator 2 (ns2), and set up the parameters for VANET scenario that are related to each network communication layer such as PHY, MAC, routing protocols, and application.

In this study, three extensive different sets of simulation experiments were conducted. The first simulation set is for the VN parameter. The second simulation set is for the VS parameter. The third simulation set is for the DL parameter. The performance of the four MANETs routing protocol were measured for each set of simulation experiments using four metrics: TH, E2ED, OH, and PL.

6.2 Conclusions

Our conclusions about performance of routing protocols in the comparative simulation study are as follows.

The simulation results showed that reactive protocols (AODV, AOMDV and DYMO) achieved better performance than the proactive protocol (DSDV) in all simulation experiments. This is because reactive protocols initiate control packets to discover and maintain the routing path when it is needed, while DSDV periodically initiates the control packets to maintain the routing table. This increases the OH and E2ED, and decreases TH in DSDV. Therefore reactive routing protocols are more suitable for VANET than proactive routing protocols.

The simulation results showed that the DYMO achieved the best performance in all simulation experiments in term OH and E2ED. Particularly, in VN simulation set DYMO is better than the other protocols in terms of E2ED and OH. DSDV does not work well in terms of TH, OH, E2ED, and PL. While AODV has good performance in terms TH but suffers from high E2ED and moderate OH. Moreover, AOMDV has good performance in terms of TH but it suffers from higher OH than AODV. As a result, it is concluded that the DYMO is the best routing protocol for VN parameter.

In VS simulation set, DYMO has the best performance in terms of OH and E2ED and it has TH, and PL values close to that of AODV. DSDV also does not work well in all terms of TH, OH, E2ED, and PL. While AODV has good performance in terms of TH and PL but suffers from high E2ED and moderate OH. In addition, AOMDV has TH and PL values close to that of AODV but suffers from high OH and moderate E2ED. Thus, it is safe to say that DYMO has also the best performance when considering VS parameter.

In DL simulation set, DYMO also outperforms other routing protocols in terms of OH and E2ED and it has TH, and PL values close to that of AODV. DSDV has the lowest TH and highest OH and PL with moderate E2ED, while AODV suffers from high E2ED but with good performance in TH and PL, and moderate in OH. Furthermore, AOMDV suffers from high OH and moderate E2ED and it has TH, and PL values close to DYMO. Thus, the more suitable protocol in this set of simulation experiments is also DYMO.

Concerning DL simulation set, DYMO and AODV have approximately constant OH values DL values increases. This proves that the AODV and DYMO have greater ability in dealing with the high data rate than other protocols. Moreover, in simulation set for the DL parameter, it is noticed that all routing protocols reached to approximately constant in TH value when DL reaches 15Packet/s. This is due to the capacity of wireless channel.

To sum up, it is noticed that the PL increases as TH decreases for all routing protocols. DSDV is not suitable to be used in the assumed VANET scenario as it does not work well in terms of TH, E2ED, OH, and PL for VN and VS. It is noticed that DSDV is not able to adapt to the frequent and dynamic changes in topology. This is because DSDV has to initiate control packets periodically to maintain the routing table in each node, which leads to increase OH, E2ED and PL and decrease TH.

The results indicate that the performance of DYMO is the best routing protocol between AODV, AOMDV, and DSDV since it performed well in all environments for the four metrics. Therefore, it is concluded that DYMO is the best routing protocol in the assumed VANETs scenario since DYMO relies on a path accumulation function to maintain the routing information.

6.3 Future Work

The following suggestions for future work can be pointed out:

- Conduct the simulations by using different MAC layers specifically WiMAX IEEE802.16e.
- Perform modification on DYMO protocol to get much better performance. This could be done by using multipath routing with a path accumulation function in forwarding RREQ between the nodes in order to reduce wrong route information from the intermediate routers. This is expected to increase the TH and reduce the PL.
- Conduct the simulations by taking into account the physical layer to increase the capacity of wireless channel.
- Conduct emulation experiments and evaluate the performance of the protocols under realistic information of data types (voice, image, and video) about a road intersection.

References

- [1] Y. H. Ho, A. H. Ho, and K. A. Hua, "Routing protocols for inter-vehicular networks: A comparative study in high-mobility and large obstacles environments", Elsevier Computer Communications, vol. 31, pp. 2767–2780, July, 2008.
- [2] Z. Guoqing, et al., "A Survey On The Routing Schemes Of Urban Vehicular Ad Hoc Networks", In Proceedings Of The 27th IEEE Control Conference, pp.: 338-343, 2008.
- [3] H. Hartenstein, and K. P. Laberteaux, "A Tutorial Survey on Vehicular Ad Hoc Networks", IEEE Communications Magazine, Vol. 46, No. 6, pp. 164-171, June, 2008.
- [4] C. E. Perkins, E. M. Belding-Royer, and S. Das, "Ad Hoc on-Demand Distance Vector (AODV) Routing," Network Working Group, RFC 3561, Jul. 2003.
- [5] C. E. Perkins And E. M. Royer, " Ad-Hoc On-Demand Distance Vector Routing", In Proceedings Of The 2nd IEEE Workshop On Mobile Computing Systems And Applications, Pages 90–100, New Orleans, LA, 1999.
- [6] D.B. Johnson, D.A. Maltz, and Y.-C. Hu, "The Dynamic Source Routing Protocol For Mobile Ad Hoc Networks (DSR)," IETF MANET Working Group, Internet Draft, July, 2004.
- [7] C. E. Perkins, and P. Bhagwat, "Highly Dynamic Destination-Sequenced Distance-Vector (DSDV) For Mobile Computers", In Proceedings SIGCOMM 94, London, England UK, August, 1994.
- [8] I. D. Chakeres, and C. E. Perkins "Dynamic MANET on-Demand Routing Protocol". IETF Internet Draft, Draft-Ietf-Manet-Dymo-19.Txt, March 2010.
- [9] K. Seada, C. Westphal, and C. Perkins, "Analyzing Path Accumulation for Route Discovery in Ad hoc Networks", In Proceedings of IEEE Wireless Communications and Networking Conference (WCNC), 2007, pp.: 4377 – 4382, Kowloon, Hong Kong, 2007.
- [10] C. Sommer, and F. Dressler, "The DYMO Routing Protocol in VANET Scenarios", IEEE VTC-2007 Vehicular Technology Conference, pp. 16-20, Baltimore, US, October 2007.

- [11] M. K. Marina, and S. R. Das, “Ad hoc on-demand multipath distance vector routing”, WIRELESS COMMUNICATIONS AND MOBILE COMPUTING, John Wiley & Sons, Ltd., Vol. 6, pp.:969–988, 2006 .
- [12] T. Clausen, and P. Jacquet, “Optimized Link State Routing Protocol (OLSR)”, IETF Internet Draft, draft-ietf-rfc3626.txt, October 2003.
- [13] Y.H. Ho, A.H. Ho, K.A. Hua, G.L. Hamza-Lup, "A connectionless approach to mobile ad hoc networks", In Proceedings of IEEE Ninth International Symposium on Computers and Communications (ISCC), vol. 1, pp. 188–195, Alexandria, Egypt, July, 2004.
- [14] H. Fubler, J. Widmer, M. Kasemann, M. Mauve, H. Hartenstein, “Contention-based forwarding for mobile ad-hoc networks,” Elsevier’s Ad-Hoc Networks, vol. 1, no. 4, pp. 351–369, 2003.
- [15] J. Bernsen and D. Manivannan, “Greedy Routing Protocols for Vehicular Ad Hoc Networks”, In proceedings of the Wireless Communications and Mobile Computing Conference (IWCMC), pp. 632 – 637, Crete Island, Greece, 6-8 Aug , 2008 .
- [16] T. Chan, M. Gerla, “Global state routing: a new routing scheme for ad hoc wireless networks,” In proceedings of the IEEE International Conference on Communications (ICC), pp. 171-175, Atlanta, GA, United States, 1998.
- [17] Z. Haas, M. Pearlman, and P. Samar, " The Zone Routing Protocol (ZRP) for Ad Hoc Networks ", IETF Internet Draft,draft-ietf-manet-zone-zrp-04.txt, July 2002
- [18] J. Broch et al. " A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols”, In proceedings ACM MOBICOM 98, Dallas, TX, October 1998.
- [19] S. Jaap, M. Bechler, and L. Wolf. “Evaluation of Routing Protocols for Vehicular Ad Hoc Networks in Typical Road Traffic Scenarios”, Proceedings of the 11th Open European Summer School EUNICE 2005, Colmenarejo, Spain, July 2005
- [20] X. Li, “Wireless Ad Hoc and Sensor Networks: Theory and Applications”, Cambridge University Press, New York, United States, 2008.
- [21] S. Wu Y. Tseng "Wireless Ad Hoc Networking: Personal-Area, Local-Area, and the Sensory-Area Networks", Taylor & Francis Group, 2007
- [22] P. Mohapatra, S. V. Krishnamurthy, “Ad Hoc Networks: Technologies and Protocols”, Springer, 2005.

- [23] C. K. Toh, “Ad Hoc Mobile Wireless Networks: Protocols and Systems, Prentice Hall PTR, 2002.
- [24] I. F. Akyildiz et al., “Wireless Sensor Networks: a survey”, *Computer Networks*, Vol. 38, pp. 393-422, March 2002.
- [25] S. G. Glisic, “Advanced Wireless Networks 4G Technologies”, John Wiley & Sons Ltd, 2006
- [26] S. Bandyopadhyay, S. Roy, and, T. Ueda, “Enhancing the Performance of Ad Hoc Wireless Networks with Smart Antennas” , Taylor & Francis Group, LLC,2006
- [27] A. Boukerche, “Handbook of Algorithms for Wireless Networking and Mobile Computing”, by Taylor & Francis Group, LLC. , 2006.
- [28] C. Cordeiro, and D. Agrawal, “Ad Hoc & Sensor Networks: Theory and Applications”, World Scientific Publishing Co. Pte. Ltd. 2006.
- [29] S.K. Sarkar, T G Basavaraju, and C Puttamadappa, “Ad Hoc Mobile Wireless Networks: Principles, Protocols, and Applications”, Taylor & Francis Group, LLC, 2008.
- [30] S. Basagni, M. Conti, S.Giordano, and I. Stojmenovic, “Mobile Ad Hoc Networking”, IEEE Press, 2004.
- [31] S. Toumpis, and D. Toumpakaris, “Wireless ad hoc networks and related topologies: applications and research challenges”, *e & i Elektro technik und Informations technik*, Vol. 6, pp. 232-241, October, 2006.
- [32] A.K. Pathan, and C. S. Hong, “Guide to Wireless Ad Hoc Networks: Routing in Mobile Ad Hoc Networks”, Springer London, pp.59-96, March, 2009.
- [33] S. Xi, and L. Xia-miao, “Study of the Feasibility of VANET and its Routing Protocols”, in proceedings of the IEEE WiCOM, pp. 1-4, Dalian, China, Oct. 2008.
- [34] D. Jiang et al., “Design of 5.9 GHz DSRC-based Vehicular Safety Communication,” *IEEE Wireless Communications Magazine*, vol. 13, no. 5, pp. 36–43, Oct. 2006.
- [35] Weigle, “Vehicular Networks From Theory to Practice,” by Taylor & Francis Group, LLC., 2009.
- [36] F.J. Martinez, et al., “A survey and comparative study of simulators for vehicular ad hoc networks (VANETs)”, *Wireless Communications and Mobile Computing* , John Wiley & Sons, Ltd., vol. 9, no. 10, Oct. 2009

- [37] F. Li and Y. Wang, "Routing in Vehicular Ad Hoc Networks: A Survey", *IEEE Vehicular Technology Magazine*, vol. 2, pp. 12-22, June, 2007.
- [38] Y. Wang, and F. Li, "Guide to Wireless Ad Hoc Networks: Vehicular Ad Hoc Networks", Springer London, pp.503-525 March, 2009.
- [39] Y. Chen, Z. Xiang, W. Jian, and W. Jiang, "An Improved AOMDV Routing Protocol for V2V Communication", *Intelligent Vehicles Symposium, IEEE Conferences* , pp.: 1115 – 1120, June,2009.
- [40] A. Boukerche, "Algorithms and Protocols for Wireless and Mobile ad Hoc Networks", By John Wiley & Sons, Inc., 2009.
- [41] E. Schoch, F. Kargl, M. Weber, and T. Leinmüller, , "Communication Patterns in VANETs", *IEEE Communications Magazine*, Vol. 46, pp. 119-125, November, 2008.
- [42] J. Wu, "Handbook on Theoretical and Algorithmic Aspects of Sensor, Ad Hoc Wireless, and Peer-to-Peer Networks", Taylor & Francis Group, 20006
- [43] J. Jakubiak, and Y. Koucheryavy, "State of the art and research challenges for VANETs", In proceedings of the 5th IEEE Consumer Communications and Networking Conference, pp.: 912 – 916, Jan. 2008.
- [44] H. Liu, and L. Guoqing, "OFDM-Based Broadband Wireless Networks", John Wiley & Sons, 2005.
- [45] K. Lu, Y. Qian, H. Chen, and S. Fu, "WiMAX networks: from access to service platform" *IEEE Network*, Vol. 22, pp. 38 – 45, June, 2008.
- [46] M. Schwartz and T. Stern. "Routing Techniques Used in Computer Communication Networks". *IEEE Transactions on Communications COM-28*: 539–552, April 1980.
- [47] L.Gavrilovska, and R. Prasad, "Ad Hoc Networking Towards Seamless Communications", *Signals and Communication Technology*, Springer, 2006
- [48] B. Liu, et al., "VGSim: An Integrated Networking and Microscopic Vehicular Mobility Simulation Platform" *IEEE Communications Magazine*, Vol.47, pp.: 134 – 141, May, 2009.
- [49] E. Lieberman, and A. K. Rathi, "Traffic Simulation in Traffic Flow Theory A State-Of-The-Art Report", Oak Ridge National Laboratory, Oak Ridge, Tn, 2001.
- [50] D. Krajzewicz, et al., "SUMO (Simulation of Urban MObility) An open-source traffic simulation" , *Proceedings of the 4th Middle East Symposium on*

References

- Simulation and Modeling (MESM2002), SCS European Publishing House, pp. 183-187, Sharjah, United Arab Emirates. Sept. 2002.
- [51] K. Fall, K. Varadhan, “The ns Manual (formerly ns Notes and Documentation), January, 2009.
- [52] R.M. Fujimoto, K. S. Perumalla, and G. F. Riley, “Network Simulation”, Morgan & Claypool. 2007.
- [53] ns-2 home page: <http://www.isi.edu/nsnam/ns>.
- [54] SUMO home page : <http://sourceforge.net>
- [55] IETF Charter home page: <http://www.ietf.org/html.charters/manet-charter.html>
- [56] DSRC home page: <http://www.learmstrong.com/dsrc/dsrchomeset.htm>

Appendix A

Investigation Of Vehicle-To-Vehicle Communication In A Road Intersection

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Abstract—This paper investigates the vehicle-to-vehicle (V2V) communication in a city road intersection using the simulation of urban mobility (SUMO) and ns-2 simulators. More particularly, the proposed vehicular ad-hoc network (VANET) scenario focuses on sending information about the intersection from a node existing at the intersection (source node) to other nodes (destination nodes) that are at distance of approximately 1km from the road intersection and they are moving towards it. The information sent to the destination nodes contains the conditions about the intersection, and may take several types of data such as voice, image, or video. A comparative simulation study is carried out between several mobile ad-hoc network (MANET) routing protocols (AODV, AOMDV, DYMO, and DSDV) for the proposed VANET scenario with different parameters such as the number of vehicles, maximum speed of vehicles, and number of sent data packets. The simulation results showed that the DYMO routing protocol has better performance than other routing protocols in terms of routing overhead and end-to-end delay.

I. INTRODUCTION

The last decade has seen many advances in wireless networks. There are two forms of mobile wireless networks: infrastructure mobile networks and infrastructure-less mobile networks [1]. The latter, also known as ad-hoc networks that do not rely on any existing infrastructure. Moreover, mobile ad-hoc networks (MANETs) have no special fixed routers. Instead, the mobile nodes themselves function as routers which discover and maintain communication connections. Thus, a MANET is a self-organizing multi-hop wireless network where all nodes participate in the routing and data forwarding process. Such a network can be easily deployed in situations where no base station is available, and where a network must be built spontaneously. Vehicular ad-hoc network (VANET) is a special case of MANET where the network is focused on providing vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. VANET has been one of the hottest research topics in the last few years. The main goals of VANET are to increase traffic safety, to increase transportation efficiency, and to reduce the negative impacts of the transportation on environment [2]. The importance of VANET has been received attention from many car manufacturers, governmental organizations and the academic communities [3]. City traffic is a main scenario for VANET applications (see Fig. 1). Typical applications are categorized as safety, transport efficiency, and information/entertainment applications. Many potential applications were compiled and prescribed by the various projects and consortia for V2V and

V2I communication. Several projects have been created in the world to increase safety in a road intersections such as the FleetNet [4], INTERSAFE [5], INTERSAFE-2 [6] and COMeSafety¹ projects. The FleetNet project was initiated by Daimler, automotive suppliers, and research institutes, and was partially funded by the German ministry of education and research (BMBF). The project can be regarded as an initial feasibility study for direct communication among cars. The INTERSAFE project was created to generate a European approach to increase safety at intersections. It combines state-of-the-art sensors and infrastructure to vehicle communication. The INTERSAFE-2 project [6] addresses the shortcomings in INTERSAFE project by investigating geographic routing, multi-hop forwarding, and auto-configuration. The COMeSafety project supports the eSafety forum issues related to V2V and V2I communication as the basis for cooperative intelligent transport systems.

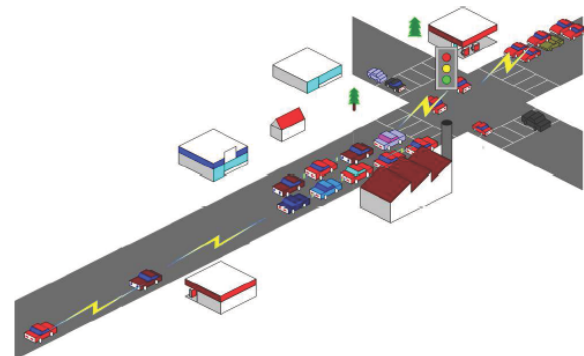


Fig. 1. Application of VANET for a city road intersection traffic scenario.

Due to the mobility of vehicles in VANETs, topology of these networks change unpredictably. Moreover, routing in VANETs work mainly based on the distributed manner. These factors make routing one of the main issues to be considered in VANETs. Several researches have been published comparing the performance of routing protocols using different mobility models and performance metrics. The most comprehensive study has been performed by the Fleetnet project [4]. One of the comprehensive studies was done by the Monarch

¹<http://www.comesafety.org>.

project [7]. This project compared the performance of several routing protocol such as the ad-hoc on-demand distance vector (AODV), destination sequenced distance vector (DSDV), dynamic source routing (DSR) and temporally-ordered routing algorithm (TORA). In addition, it introduced some standard metrics that were then used in further studies on wireless routing protocols. Nevertheless, only MANET scenarios are considered in that project. In [8], another study was introduced which compared and evaluated AODV, DSR, TORA and fisheye state routing (FSR) for VANETs. However, the mobility was based on freeway mobility model, and the city road intersection traffic scenario is not investigated. In [1], a comparative study between several routing protocols have been performed by using a GloMoSim simulator. Nevertheless, this study didn't used any traffic simulator to generate realistic mobility patterns.

In this paper, our purpose is to investigate V2V communications in a typical city road intersection scenario by using the simulation of urban mobility (SUMO) [9] and the ns-2² simulators. The SUMO simulator is used to generate a typical mobility patterns which are then used by the network simulator ns-2 to evaluate the performance of several routing protocols. Based on the proposed VANET scenario, a comparative simulation study is carried out between several MANET routing protocols (AODV, AOMDV, DYMO, and DSDV) for different parameters such as the number of vehicles, speed of vehicles, and number of sent data packets.

The remainder of the paper is organized as follows. Section II introduces the most suitable MANET routing protocols that can be used in VANET scenario. Section III presents the simulation environment and the results. Conclusions are drawn in section IV.

II. MANET ROUTING PROTOCOLS

This section provides a review of several existing MANET routing protocols such as AODV, AOMDV, DSDV, and DYMO. These MANET routing protocols are suitable for the proposed VANET scenario.

A. Destination Sequenced Distance Vector (DSDV)

The DSDV routing protocol [10] is a proactive routing protocol that is a variant of the distance vector routing method. It is a distributed, self-organized, and loop-free routing protocol suitable for dynamic networks by which mobile nodes cooperate to form a mobile ad-hoc network. Each node stores and maintains a routing table containing entries for all the nodes in the network. Nodes periodically advertise their routing information to their neighbors. The packets are transmitted between two nodes in the network using route tables stored at each node. Each route table, at each node, contains lists of all available destinations, the destination node's address, the number of hops to each node, and the sequence number assigned by destination node. DSDV provides a simple and distributed routing mechanism, and due to table-driven property it provides reasonable initial route delay. Thus, it can be

²<http://www.isi.edu/nsnam/ns>.

implemented and deployed, and still works efficiently in some network topologies.

B. Ad-hoc On-demand Distance Vector (AODV)

The AODV [11] routing protocol is a reactive routing protocol that is considered as a pure on-demand route acquisition system and is based on the distance-vector method. Whenever a source node (S) needs to send packet to the destination node (D), for which it has no routing information in its table. Node S broadcasts a route request (RREQ) packet to its neighbors. This RREQ message will flood the network until it reaches the node D or a node with information on a route to node D. If the neighbors possess a current route to D, it satisfy the RREQ by unicasting a route reply (RREP) back to the S, or rebroadcasts the RREQ to its own neighbors after incrementing the hop count field. The node then replies with a RREP message containing the number of hops needed to reach D and a sequence number for D. AODV maintains paths by using Hello messages that used to detect the neighbors that are still in range of connectivity. If a link was lost the node immediately initiates route maintenance operation by sending route RREQ messages.

C. Ad-hoc On-demand Distance Vector (AODV)

The AOMDV [12] routing protocol is an extension of the AODV. However, the performance of AOMDV is much better than AODV. The AOMDV protocol uses the basic AODV route construction process, with extensions to create multiple loop-free and link-disjoint paths. AOMDV mainly computes the multiple paths during route discovery process, and it consists of two main components: (a) a rule for route updates to find multiple paths at each node, and (b) a distributed protocol to calculate the link-disjoint paths. AOMDV also reduces routing overhead by reducing the frequency of route discovery operations.

D. Dynamic MANET On-demand (DYMO)

The DYMO [13] is a type of reactive routing protocol and is a successor of AODV. DYMO extends AODV with a path accumulation mechanism, and there are many remarkable changes such as a unified packet format, a simplified RERR algorithm, and multiple interface utilization. The basic operations of the DYMO protocol are like AODV which are route discovery and route maintenance. DYMO routing protocol enables reactive, multi-hop unicast routing between participating DYMO routers. DYMO as any reactive protocol uses sequence numbers to ensure loop-freedom, each node must maintain its own sequence number. The sequence number is incremented each time the node sends a route request message, which enable DYMO routers to specify the order of DYMO route discovery messages, so preventing use of stale routing information, to detect duplicate messages, and to ensure loop freedom, this leads to reduce significantly the overhead of routing control packet.

III. SIMULATION ENVIRONMENT AND RESULTS

Our VANET scenario in this study consists of vehicles (nodes) approaching a road intersection in urban environment. Figure 1 shows our VANET scenario based on a city road intersection mobility model generated by the SUMO simulator. The main idea of the proposed VANET scenario focuses on sending information about the intersection from a node existing at the intersection (source node) to other vehicles (destination nodes) that are at distance of approximately 1km from the road intersection and they are moving towards it. The information sent to the destination nodes contains the conditions about the intersection. The information may take several types of data such as voice, image, or video. This application assists the driver in dealing with the conditions of intersection, such as traffic congestion and traffic light phase, before his arrival to it. SUMO, an open-source microscopic, space continuous and time discrete vehicular traffic generator package is used to generate the movements of the vehicles. SUMO uses a collision-free car following model to determine the speeds and positions of the vehicles. Figure 2 illustrates a portion from the road intersection traffic scenario generated by the SUMO simulator.



Fig. 2. A portion of the road intersection traffic scenario generated by the SUMO simulator.

In the simulations, SUMO is used to generate the mobility pattern for different number of vehicles with different speeds. This mobility pattern is then used by ns-2, a packet-level simulator specifically designed for ad-hoc networks. The simulation setup settings are shown in Table 1.

TABLE I
SIMULATION SETTINGS.

Parameter	Value
Road one	20x1800m (east to west)
Road two	20x1800m (north to south)
Intersection coordinate	900,900
Number of vehicles	40,60,80, ..., 300
Transmission range	250 m
Simulation time	900s
Vehicle velocity	30 - 90 Km/h
MAC protocol	IEEE 802.11 DCF
Propagation	TwoRay-Ground
Channel type	Wireless Channel
Queue type	PriQueue
Routing protocols	DSDV,AODV,AOMDV,DYMO

In our simulations, a packet-level simulation was performed for different network parameters: the number of vehicles, the speed of vehicles, and the number of sent data packet. Three performance metrics that are specified by IETF³ are used to compare the performance of the routing protocols:

- Throughput (TH): measured in Kbit/sec, is the ratio of the data packets delivered to the destinations by the time interval. This metric indicates the effectiveness of a protocol.
- Average end-to-end delay (E2ED): measured in millisecond, includes processing, route discover latency, queuing delays, retransmission delay at the MAC, and propagation and transmission times. This metric measures the total delay time from a sender to a destination.
- Routing overhead (OH): Measures the number of routing packets transmitted per distinct data packet delivered to a destination. The routing overhead is an important metric for comparing the routing protocols as it measures the scalability of a protocol.

In order to ensure the rationality, each simulation experiment was repeated 50 times for each scenario, and their average was used to calculate the result.

In our simulations, the analysis is performed using MATLAB program to investigate the effect of network parameters on the four routing protocols (AODV, DSDV, AOMDV, and DYMO). This analysis gives the evaluation of the capabilities of each routing protocol in VANETs scenario with different parameters.

A. Effect of the number of vehicles

To investigate the effect of the number of vehicles, simulation experiments were performed with the number of vehicles varying as 40, 60, 80, ..., 300 vehicles. In this scenario, the maximum speed used for the nodes is 50 Km/h. TCP traffic flows are used with 10 packets/s and data packet size of 1064 bytes. The results of these simulations are shown in Fig. 3, Fig. 4, and Fig. 5. According to these figures, one can notice that DYMO routing protocol outperforms the other protocols in terms of E2ED and OH. DSDV yields the worst performance in terms of TH, OH, E2ED. Although the AODV has the best performance in terms of TH, it suffers from high E2ED and provides moderate OH. Therefore, the DYMO routing protocol can be considered the best protocol when varying the number of vehicles.

B. Effect of the speed of the vehicles

To investigate the effect of the speed of the vehicles, simulation experiments were performed with varying the speed of the vehicles from 30, 40, 50, 60, 70, 80 to 90 Km/h with the number of vehicles is fixed at 60 vehicles. The TCP traffic is 10 packets/s with data packet size 1064 bytes. The results of these simulations are shown in Fig. 6, Fig. 7, and Fig. 8. According to these figures, it can be noticed that the DYMO protocol has the best performance in terms of OH and E2ED

³<http://www.ietf.org/html.charters/manet-charter.html>.

and provides TH close to that of AODV. The DSDV protocol yields the worst performance in terms of TH, OH, and E2ED. Although the AODV has the best performance in terms of TH, it suffers from high E2ED and provides moderate OH. The AOMDV has TH values close to that of AODV but suffers from high OH and yields moderate E2ED. Thus it is safe to say that DYMO has also the best performance when varying vehicle speed.

C. Effect of the number of data packet

To investigate the effect of the number of sent data packets, simulation experiments were performed with varying the number of data packets from 1 to 15 packet/sec with data packet size fixed at 1064 bytes. In addition, the number of vehicles is fixed at 60 vehicles with speed of 50 Km/h for each vehicle. The results of these simulations are in Fig. 9, Fig. 10, and Fig. 11. According to these figures, one can also notice that the DYMO protocol outperforms the other routing protocols in terms of OH and E2ED and yields a TH value close to that of the AODV. DSDV has the lowest TH and highest OH with moderate E2ED, while AODV suffers from high E2ED but with good performance in terms of TH and moderate performance in terms of OH. Also AOMDV suffers from high OH and yields moderate E2ED and provides TH close to DYMO. Thus the more suitable protocol in this set of simulation experiments is also the DYMO protocol.

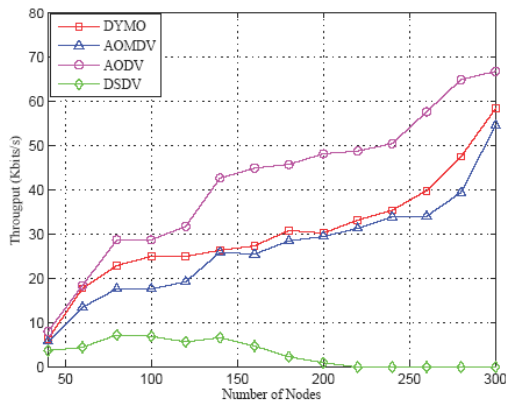


Fig. 3. Throughput versus number of vehicles for the various routing protocols.

IV. CONCLUSION

This paper investigates the vehicle-to-vehicle communication in a city road intersection traffic scenario by using the SUMO and ns-2 simulators. The SUMO simulator is used to generate a typical mobility patterns which are then used by the network simulator ns-2 to evaluate the performance of four MANET routing protocols (AODV, AOMDV, DYMO, and DSDV) for different parameters such as the number of

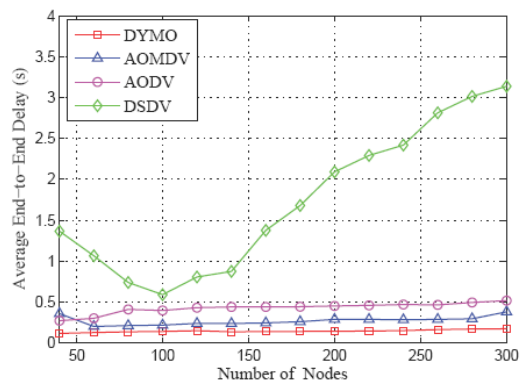


Fig. 4. Average end-to-end delay versus number of vehicles for the various routing protocols.

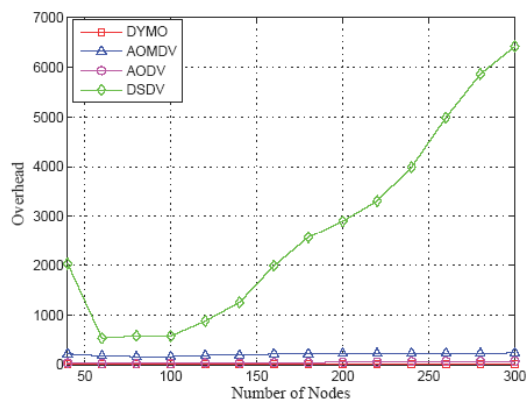


Fig. 5. Routing overhead versus number of vehicles for the various routing protocols.

vehicles, speed of vehicles, and number of sent data packets. The simulation results show that the reactive protocols (AODV, AOMDV and DYMO) achieved better performance than the proactive protocol (DSDV) in all sets of simulation experiments. This is because reactive protocols initiate control packets to discover and maintain the routing path when it is needed, while DSDV periodically initiates the control packets to maintain the routing table. This increases the OH and E2ED, and decreases TH in DSDV. Therefore, reactive routing protocols are more suitable for VANET than proactive routing protocols. The results show also that the DYMO routing protocol is the best routing protocol among AODV, AOMDV, and DSDV, as it performed well for all considered simulation parameters and performance metrics. Therefore, we recommend using the DYMO routing protocol for VANETs.

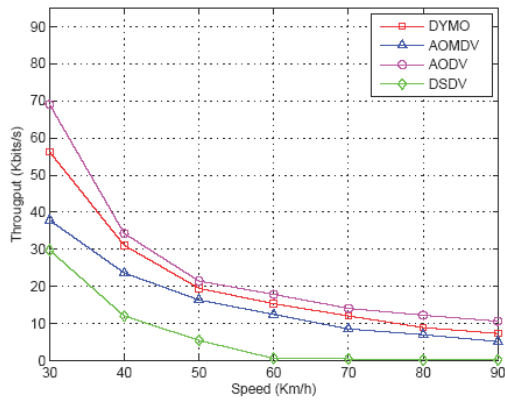


Fig. 6. Throughput versus speed of the vehicles for the various routing protocols.

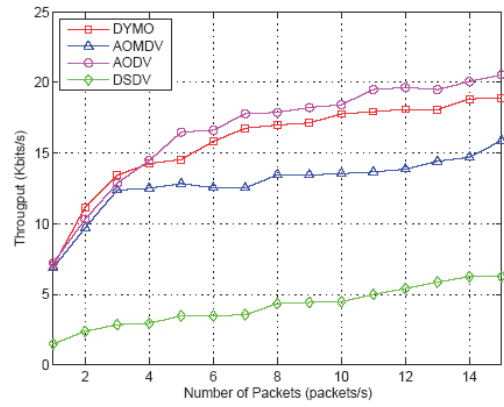


Fig. 9. Throughput versus number of packets for the various routing protocols.

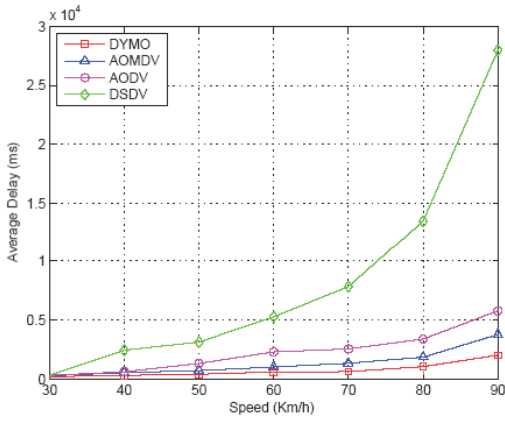


Fig. 7. Average end-to-end delay versus vehicle speed for the various routing protocols.

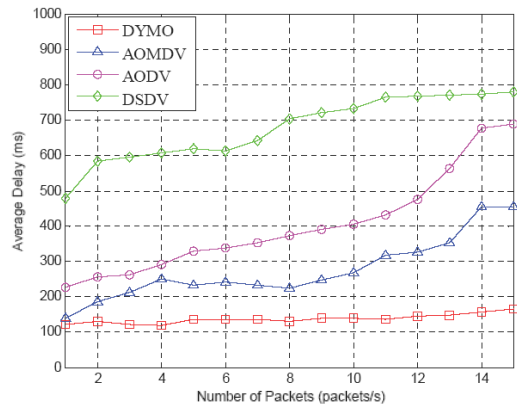


Fig. 10. Average end-to-end delay versus number of packets for the various routing protocols.

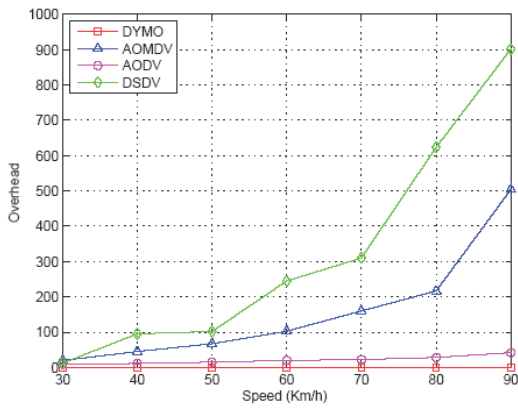


Fig. 8. Routing overhead versus vehicle speed for the various routing protocols.

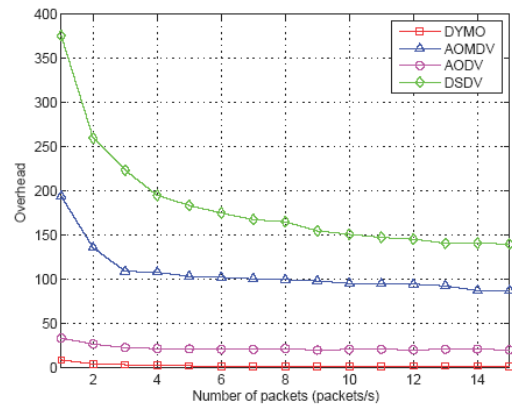


Fig. 11. Routing overhead versus number of packets for the various routing protocols.

REFERENCES

- [1] Y. H. Ho, A. H. Ho, and K. A. Hua, "Routing protocols for inter-vehicular networks: a comparative study in high-mobility and large obstacles environments," *Elsevier Computer Communications*, vol. 31, pp. 2767–2780, July 2008.
- [2] Z. Guoqing, M. Dejun, X.Zhong, Y.Weili, and C. Xiaoyan, "A survey on the routing schemes of urban vehicular ad-hoc networks," in *Proceedings of the 27th Chinese Control Conference*, pp. 338–343, 2008.
- [3] H. Hartenstein and K. P. Laberteaux, "A Tutorial Survey on Vehicular Ad Hoc Networks," *IEEE Communications Magazine*, vol. 46, pp. 164–171, June 2008.
- [4] W. Enkelmann, "FLEETNET - applications for inter-vehicle communication," in *Proceedings of the IEEE Intelligent Vehicles Symposium*, (Berlin, Germany), pp. 162–167, 2003.
- [5] J. .Chen, S. Deutschle, and K. Fuerstenberg, "Evaluation methods and results of the INTERSAFE intersection assistants," in *Proceedings of the IEEE Intelligent Vehicles Symposium*, (Istanbul, Turkey), pp. 142–147, 2007.
- [6] C. Shooter and J. Reeve, "INTERSAFE-2 architecture and specification," in *Proceedings of IEEE Intelligent Computer Communication and Processing*, (Cluj-Napoca, UK), pp. 379–386, 2009.
- [7] J. Broch, D. A. Maltz, D. B. Johnson, Y. Hu, and J. Jetcheva, "A performance comparison of multi-hop wireless ad hoc network routing protocols," in *Proceedings of ACM/IEEE Mobile Computing and Networking*, (Texas, US), pp. 85–97, 1998.
- [8] S. Jaap, M. Bechler, and L. Wolf, "Evaluation of routing protocols for vehicular ad hoc networks in typical road traffic scenarios," in *Proceedings of the 11th Open European Summer School on Networked Applications*, 2005.
- [9] D. Krajzewicz, G. Hertkorn, P. Wagner, and C. Rssel, "SUMO (simulation of urban mobility) an open-source traffic simulation," in *Proceedings of the 4th Middle East Symposium on Simulation and Modelling (MESM2002)*, (Sharjah, United Arab Emirates), pp. 183–187, 2002.
- [10] C. E. Perkins and P. Bhagwat, "Highly dynamic destination-sequenced distance-vector (DSDV) for mobile computers," in *proceedings SIGCOMM 94*, 1994.
- [11] C. E. Perkins and E. M. Royer, "Ad-hoc on-demand distance vector routing," in *Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications*, (New Orleans, LA), pp. 90–100, 1999.
- [12] M. K. Marina and S. R. Das, "Ad hoc on-demand multipath distance vector routing," *Wiley Wireless Communications and Mobile Computing*, vol. 6, pp. 969–988, 2006.
- [13] I. D. Chakeres and C. E. Perkins, "Dynamic MANET on-demand routing protocol," in *IETF Internet Draft, draft-ietf-manet-dymo-12.txt*, 2008.

Appendix B: SUMO – xml programs that build traffic scenario

File1: nodes.xml

```
<nodes>
  <node id="1" x="100.0" y="1000.0" type="priority" />
  <node id="2" x="700.0" y="1000.0" type="priority" />
  <node id="3" x="1000.0" y="1000.0" type="traffic_light" />
  <node id="4" x="1300.0" y="1000.0" type="priority"/>
  <node id="5" x="1900.0" y="1000.0" type="priority" />
  <node id="6" x="1000.0" y="700.0" type="priority" />
  <node id="7" x="1000.0" y="100.0" type="priority"/>
  <node id="8" x="1000.0" y="1300.0" type="priority" />
  <node id="9" x="1000.0" y="1900.0" type="priority" />
</nodes>
```

File2: edges.xml

```
<edges>
  <edge id="L1" fromnode="1" tonode="2" type="c"/>
  <edge id="L2" fromnode="2" tonode="3" type="b"/>
  <edge id="L3" fromnode="3" tonode="6" type="b"/>
  <edge id="L4" fromnode="6" tonode="7" type="c"/>
  <edge id="L5" fromnode="7" tonode="6" type="c"/>
  <edge id="L6" fromnode="6" tonode="3" type="b"/>
  <edge id="L7" fromnode="3" tonode="4" type="b"/>
  <edge id="L8" fromnode="4" tonode="5" type="c"/>
  <edge id="L9" fromnode="5" tonode="4" type="c"/>
  <edge id="L10" fromnode="4" tonode="3" type="b"/>
  <edge id="L11" fromnode="3" tonode="8" type="b"/>
  <edge id="L12" fromnode="8" tonode="9" type="c"/>
  <edge id="L13" fromnode="9" tonode="8" type="c"/>
  <edge id="L14" fromnode="8" tonode="3" type="b"/>
  <edge id="L15" fromnode="3" tonode="2" type="b"/>
  <edge id="L16" fromnode="2" tonode="1" type="c"/>
</edges>
```

File3: type.xml

```
<types>
  <type id="b" priority="3" nolanes="2" speed="11.889"/>
  <type id="c" priority="2" nolanes="1" speed="13.889"/>
</types>
```

File4: connections.xml

```
<connections>
  <connection from="L1" to="L2" lane="0:0"/>
  <connection from="L1" to="L2" lane="0:1"/>
  <connection from="L2" to="L3" lane="0:0"/>
  <connection from="L2" to="L11" lane="1:0"/>
  <connection from="L2" to="L7" lane="0:0"/>
  <connection from="L3" to="L4" lane="0:0"/>
  <connection from="L4" to="L5" lane="0:0"/>
  <connection from="L5" to="L6" lane="0:0"/>
  <connection from="L5" to="L6" lane="0:1"/>
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  <connection from="L13" to="L14" lane="0:0"/>
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  <connection from="L14" to="L15" lane="0:0"/>
  <connection from="L14" to="L3" lane="0:0"/>
  <connection from="L14" to="L7" lane="1:0"/>
  <connection from="L15" to="L16" lane="0:0"/>
  <connection from="L15" to="L16" lane="1:0"/>
```



```
<connection from="L16" to="L1" lane="0:0"/>
</connections>
```

File5: route.xml

```
<routes>
  <vtype accel="3.0" decel="6.0" id="CarA" length="5.0" maxspeed="50.0" sigma="0.5" />
  <vtype accel="2.0" decel="6.0" id="CarB" length="7.5" maxspeed="50.0" sigma="0.5" />
  <vtype accel="1.0" decel="5.0" id="CarC" length="5.0" maxspeed="40.0" sigma="0.5" />
  <route id="route01" edges="L1 L2 L3 L4 L5 L6 L7 L8 L9 L10 L11 L12 L13 L14 L15 L16 L1"/>
  <route id="route02" edges="L5 L6 L7 L8 L9 L10 L11 L12 L13 L14 L15 L16 L1 L2 L3 L4 L5"/>
  <route id="route03" edges="L9 L10 L11 L12 L13 L14 L15 L16 L1 L2 L3 L4 L5 L6 L7 L8 L9"/>
  <route id="route04" edges="L13 L14 L15 L16 L1 L2 L3 L4 L5 L6 L7 L8 L9 L10 L11 L12 L13"/>
  <route id="route05" edges="L1 L2 L11 L12 L13 L14 L3 L4 L5 L6 L7 L8 L9 L10 L15 L16 L1"/>
  <route id="route06" edges="L5 L6 L15 L16 L1 L2 L11 L12 L13 L14 L7 L8 L9 L10 L3 L4 L5"/>
  <route id="route07" edges="L9 L10 L3 L4 L5 L6 L15 L16 L1 L2 L11 L12 L13 L14 L7 L8 L9"/>
  <route id="route08" edges="L13 L14 L7 L8 L9 L10 L3 L4 L5 L6 L15 L16 L1 L2 L11 L12 L13"/>
  <route id="route09" edges="L1 L2 L7 L8 L9 L10 L3 L4 L5 L6 L11 L12 L13 L14 L15 L16 L1"/>
  <route id="route10" edges="L5 L6 L11 L12 L13 L14 L7 L8 L9 L10 L15 L16 L1 L2 L3 L4 L5"/>
  <route id="route11" edges="L9 L10 L15 L16 L1 L2 L3 L4 L5 L6 L11 L12 L13 L14 L7 L8 L9"/>
  <route id="route12" edges="L13 L14 L15 L16 L1 L2 L7 L8 L9 L10 L15 L16 L1 L2 L11 L12 L13"/>
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```

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```

```
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<vehicle depart="54000" id="veh160" route="route01" type="CarA" />
<vehicle depart="54000" id="veh161" route="route02" type="CarA" />
<vehicle depart="54000" id="veh162" route="route03" type="CarA" />
<vehicle depart="54000" id="veh163" route="route04" type="CarA" />
<vehicle depart="54000" id="veh164" route="route05" type="CarA" />
<vehicle depart="54000" id="veh165" route="route06" type="CarA" />
<vehicle depart="54000" id="veh166" route="route07" type="CarA" />
<vehicle depart="54000" id="veh167" route="route08" type="CarA" />
<vehicle depart="54000" id="veh168" route="route09" type="CarA" />
<vehicle depart="54000" id="veh169" route="route10" type="CarA" />
<vehicle depart="54000" id="veh170" route="route11" type="CarA" />
<vehicle depart="54000" id="veh171" route="route12" type="CarB" />
<vehicle depart="54000" id="veh172" route="route05" type="CarB" />
<vehicle depart="54000" id="veh173" route="route06" type="CarB" />
<vehicle depart="54000" id="veh174" route="route07" type="CarB" />
<vehicle depart="54000" id="veh175" route="route08" type="CarB" />
<vehicle depart="54000" id="veh176" route="route09" type="CarB" />
<vehicle depart="54000" id="veh177" route="route10" type="CarB" />
<vehicle depart="54000" id="veh178" route="route11" type="CarB" />
<vehicle depart="54000" id="veh179" route="route12" type="CarB" />
```

```
<vehicle depart="54000" id="veh180" route="route01" type="CarA" />
<vehicle depart="54000" id="veh181" route="route02" type="CarA" />
<vehicle depart="54000" id="veh182" route="route03" type="CarA" />
<vehicle depart="54000" id="veh183" route="route04" type="CarA" />
<vehicle depart="54000" id="veh184" route="route05" type="CarA" />
<vehicle depart="54000" id="veh185" route="route06" type="CarA" />
<vehicle depart="54000" id="veh186" route="route07" type="CarA" />
<vehicle depart="54000" id="veh187" route="route08" type="CarA" />
<vehicle depart="54000" id="veh188" route="route09" type="CarA" />
<vehicle depart="54000" id="veh189" route="route10" type="CarA" />
<vehicle depart="54000" id="veh190" route="route11" type="CarA" />
<vehicle depart="54000" id="veh191" route="route12" type="CarB" />
<vehicle depart="54000" id="veh192" route="route05" type="CarB" />
<vehicle depart="54000" id="veh193" route="route06" type="CarB" />
<vehicle depart="54000" id="veh194" route="route07" type="CarB" />
<vehicle depart="54000" id="veh195" route="route08" type="CarB" />
<vehicle depart="54000" id="veh196" route="route09" type="CarB" />
<vehicle depart="54000" id="veh197" route="route10" type="CarB" />
<vehicle depart="54000" id="veh198" route="route11" type="CarB" />
<vehicle depart="54000" id="veh199" route="route12" type="CarB" />
...
</routes>
```

Appendix C

An example illustrates extract the mobility for 300 nodes.

```
sumo-netconvert -c scenario300.netc.cfg
```

```
sumo -c scenario300.sumo.cfg
```

```
sumo -n scenario300.net.xml -r scenario300.rou.xml --netstate-dump scenario300.netstate.xml
```

```
java -jar traceExporter.jar ns2 -n scenario300.net.xml -t scenario300.netstate.xml -a activity-300.tcl -m
```

```
mobility-300.tcl -c config-300.tcl -p 1 -b 54000 -e 54900
```

Portion of mobility file for 300 nodes

```
$ns_ at 0.0 "$node_(60) setdest 0.0 898.35 0.0"  
$ns_ at 0.0 "$node_(240) setdest 898.35 1800.0 0.0"  
$ns_ at 0.0 "$node_(194) setdest 598.5 901.65 0.0"  
$ns_ at 0.0 "$node_(138) setdest 901.65 0.0 0.0"  
$ns_ at 0.0 "$node_(100) setdest 904.95 601.5 0.0"  
$ns_ at 0.0 "$node_(84) setdest 1800.0 901.65 0.0"  
$ns_ at 1.0 "$node_(60) setdest 2.0 898.35 2.0"  
$ns_ at 1.0 "$node_(240) setdest 898.35 1797.06 2.94"  
$ns_ at 1.0 "$node_(194) setdest 596.19 901.65 2.31"  
$ns_ at 1.0 "$node_(138) setdest 901.65 2.17 2.17"  
$ns_ at 1.0 "$node_(100) setdest 904.95 603.24 1.74"  
$ns_ at 1.0 "$node_(84) setdest 1797.06 901.65 2.94"  
$ns_ at 2.0 "$node_(153) setdest 0.0 898.35 0.0"  
$ns_ at 2.0 "$node_(60) setdest 6.54 898.35 4.54"  
$ns_ at 2.0 "$node_(293) setdest 898.35 1800.0 0.0"  
$ns_ at 2.0 "$node_(240) setdest 898.35 1792.03 5.04"  
$ns_ at 2.0 "$node_(197) setdest 598.5 901.65 0.0"  
$ns_ at 2.0 "$node_(194) setdest 592.03 901.65 4.17"  
$ns_ at 2.0 "$node_(256) setdest 901.65 0.0 0.0"  
$ns_ at 2.0 "$node_(138) setdest 901.65 7.1999993 5.03"  
$ns_ at 2.0 "$node_(286) setdest 904.95 601.5 0.0"  
$ns_ at 2.0 "$node_(100) setdest 904.95 606.87 3.63"  
$ns_ at 2.0 "$node_(227) setdest 1800.0 901.65 0.0"  
$ns_ at 2.0 "$node_(84) setdest 1792.19 901.65 4.87"  
$ns_ at 3.0 "$node_(153) setdest 1.54 898.35 1.54"  
$ns_ at 3.0 "$node_(60) setdest 12.93 898.35 6.39"  
$ns_ at 3.0 "$node_(293) setdest 898.35 1798.54 1.46"  
$ns_ at 3.0 "$node_(240) setdest 898.35 1784.35 7.68"  
$ns_ at 3.0 "$node_(197) setdest 597.03 901.65 1.47"  
$ns_ at 3.0 "$node_(194) setdest 585.77 901.65 6.25"
```

Appendix D ns-2 Main Program

```
#ns-2 Main program for VANETs scenario
# Program for VANETs in a road intersection.
set npkt [lindex $argv 3]
set density [lindex $argv 2]
set routing [lindex $argv 1]
set indx [lindex $argv 0]
set a "-"
set nd ../../all_sce_routing/mobility/mobility
set nd2 ../../all_sce_routing/traffic_patterns/traffic
ns-random [expr $indx]
set val(chan) Channel/WirelessChannel ;#Channel Type
set val(prop) Propagation/TwoRayGround ;# radio-ropagation model
set val(netif) Phy/WirelessPhy ;# network interface type
set val(mac) Mac/802_11 ;# MAC type
set val(ifq) Queue/DropTail/PriQueue ;# interface queue type
set val(ll) LL ;# link layer type
set val(ant) Antenna/OmniAntenna ;# antenna model
set val(ifqlen) 50 ;# max packet in ifq
set val(nn) 302 ;# number of mobilenodes
set val(rp) $routing ;# routing protocol
set val(x) 1802
set val(y) 1802
set val(stop) 900 ;simulation time
set mobilityfile $nd$density.tcl ;# mobility file
set trfilename "city_sce$density$a$indx.tr" ;# trace file
set trafficdata $nd2$density.tcl ;#traffic data patterns
# Initialize Global Variables
set ns_[new Simulator]
$ns_ use-newtrace
set tracefd [open $trfilename w]
$ns_ trace-all $tracefd
set namtrace [open city_sce$density.nam w]
$ns_ namtrace-all-wireless $namtrace $val(x) $val(y)
# set up topography object
set topo [new Topography]
$topo load_flatgrid $val(x) $val(y)
# Create God
create-god $val(nn)
# New API to config node:
```

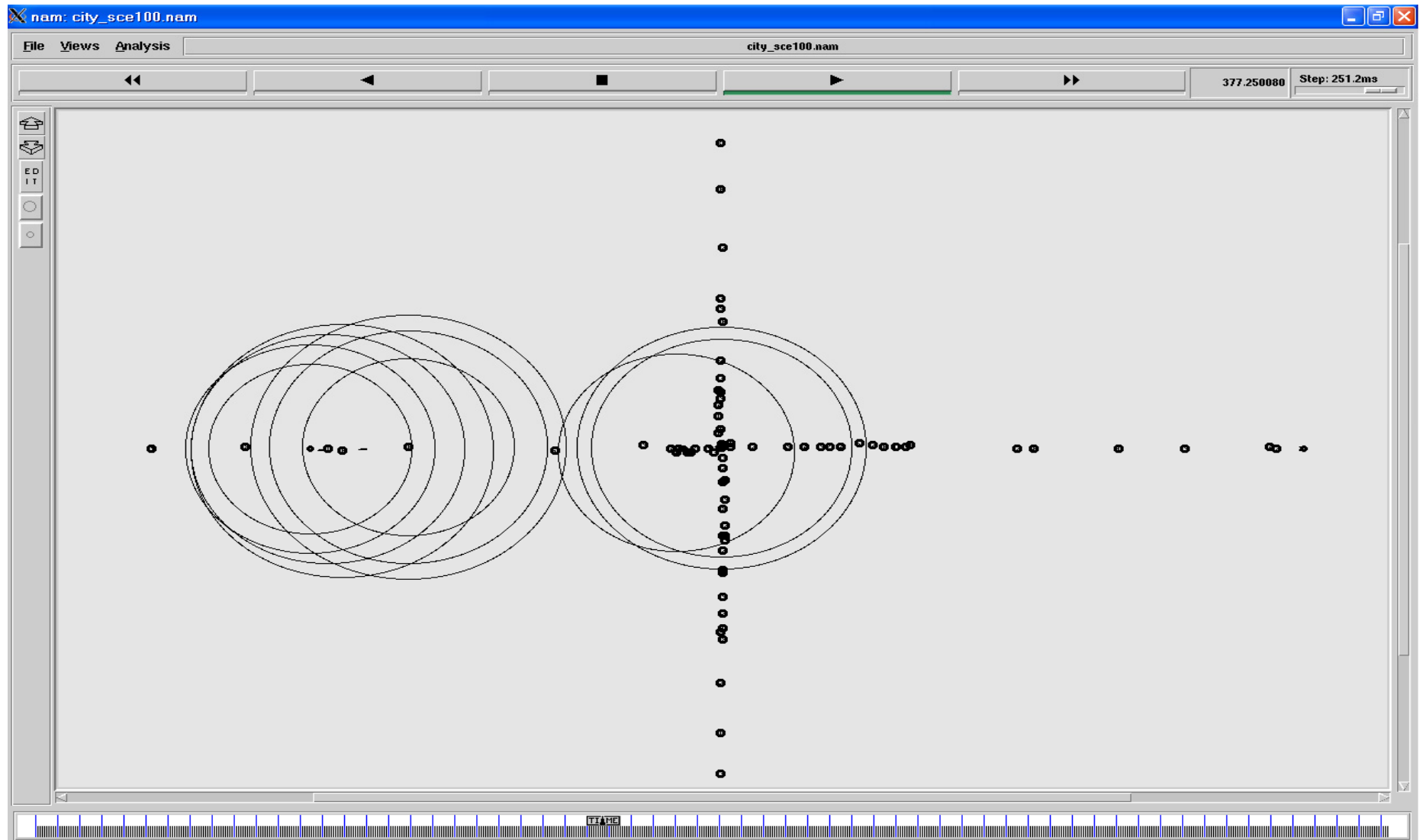


```

# 1. Create channel (or multiple-channels);
# 2. Specify channel in node-config (instead of channelType);
# 3. Create nodes for simulations.
# Create channel #1 and #2
set chan_1_ [new $val(chan)]
set chan_2_ [new $val(chan)]
# configure node, please note the change below.
$ns_ node-config -adhocRouting $val(rp) \
                -llType $val(ll) \
                -macType $val(mac) \
                -ifqType $val(ifq) \
                -ifqLen $val(ifqlen) \
                -antType $val(ant) \
                -propType $val(prop) \
                -phyType $val(netif) \
                -topoInstance $topo \
                -agentTrace ON \
                -routerTrace ON \
                -macTrace OFF \
                -movementTrace OFF \

-channel $chan_1_
# $ns_ node-config \
for {set i 0} {$i < $val(nn)} {incr i} {
    set node_($i) [ $ns_ node $i ]
}
source $mobilityfile
source $traffidata
# Tell nodes when the simulation ends
for {set i 0} {$i < $val(nn)} {incr i} {
    $ns_ at $val(stop) "$node_($i) reset";
}
$ns_ at $val(stop).01 "stop"
$ns_ at $val(stop).02 "puts \"NS EXITING...\" ; $ns_ halt"
proc stop {} {
    global ns_ tracefd
    $ns_ flush-trace
    close $tracefd
}
puts "Starting Simulation..."
$ns_ run

```



Appendix E: An Example for Extraction Useful Information from Trace File

grep is a command line text search utility originally written for Unix. The name is taken from the first letters in global / regular expression / print.

```
ns city_sce.tcl 50 AODV 300 10
grep -e "s -t " city_sce300-50.tr > 300-50-AODV-10-temp1.tr
grep -e "tcp -Il 1104 \| tcp -Il 1124 \| tcp -Il 1176" 300-50-AODV-10-temp1.tr > 300-50-AODV-10-temp2.tr
grep -e "-NI AGT " 300-50-AODV-10-temp2.tr > 300-50-AODV-10-sentdata.tr
grep -e " AODV -Il " 300-50-AODV-10-temp1.tr > 300-50-AODV-10-temp2.tr
grep -e "-NI RTR " 300-50-AODV-10-temp2.tr > 300-50-AODV-10-routdata.tr
grep -e "d -t " city_sce300-50.tr > 300-50-AODV-10-temp1.tr
grep -e "tcp -Il " 300-50-AODV-10-temp1.tr > 300-50-AODV-10-dropped.tr
grep -e "r -t " city_sce300-50.tr > 300-50-AODV-10-temp1.tr
grep -e "tcp -Il 1104 \| tcp -Il 1124 \| tcp -Il 1176" 300-50-AODV-10-temp1.tr > 300-50-AODV-10-temp2.tr
grep -e "-NI AGT " 300-50-AODV-10-temp2.tr > 300-50-AODV-10-recvdata.tr
rm city_sce300-50.tr
rm 300-50-AODV-10-temp1.tr
rm 300-50-AODV-10-temp2.t
```

The first command runs the simulation and it results in one trace file " city_sce300-50.tr "

Where the first four parameters (50 AODV 300 10) are specified in my code in the file " city_sce.tcl". The 1st parameter determines the seed of the simulation, the 2nd parameter determines the routing protocol, the 3rd parameter specifies the number of vehicles, and 4th parameter specifies the number of data packet.

While the grep commands produce a four new trace files which are 300-50-AODV-10-sentdata.tr, 300-50-AODV-10-routdata.tr, 300-50-AODV-10-dropped.tr, and 300-50-AODV-10-recvdata.tr.