Palestine Polytechnic University
Deanship of Graduate Studies and Scientific Research
Master of Informatics

A Scalable Cluster Position-Based Routing Protocol for VANET

Submitted By

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A Thesis Submitted in Partial Fulfillment of Requirements for The Degree of Master's of Informatics

December, 2022

The undersigned hereby certify that they have read, examined, and recommended to the Deanship of Graduate Studies and Scientific Research at Palestine Polytechnic University the approval of a thesis entitled: **"A Scalable Cluster Position-Based Routing Protocol for VANET"**, submitted by Hiba "Mohammed Rashed" Qasrawi in partial fulfillment of the requirements for the degree of Master in Informatics.

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DECLARATION

I declare that the Master's Thesis entitled "**A Scalable Cluster Position-Based Routing Protocol for VANET**", is my original work, and hereby certify that unless stated, all work contained within this thesis is my independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgment is made in the text.

Hiba Qasrawi

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DEDICATION

To My Dear Husband Dr. Ibrahiem,

My Dears Parents Mr. Rashed and Mrs. Dalal,

Sisters Especially My Sister Eng. Hana',

Brothers, and My Husband's Family.

ACKNOWLEDGEMENT

I would like to express my deep gratitude and respect to the people who helped me in completing this work. I would like to express thanks to my supervisor, Dr. Liana Al Tamimi, for her support and guidance throughout the work.

Thanks, are also extended to Dr. Tariq Emad Ali AL-Asfour for his help.

I would like to sincerely thank my husband and parents for their love, patience, and understanding. They never stopped encouraging me, and it gave me the drive I needed to finish this work.

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LIST OF NOMENCLATURE

Symbol	**Description**	**Unit**
	General	
ITS	Intelligent transportation systems	
VANET	Vehicle Ad hoc Network	
MANET	Mobile Ad-Hoc Network	
DSRC	Dedicated Short-Range Communication	
WiMAX	Worldwide Interoperability for Microwave Access	
IVC	Inter-vehicle Communications	
V2V	Vehicle-to-Vehicle	
V2I	Vehicle-to-Infrastructure	
V2X	Vehicle-to-Everything	
OBU	On-Board Unit	
RSU	Road-Side Units	
WLAN	Wireless Local Area Network	
WAVE	Wireless Access in Vehicle Environment	
GPS	Global Position-Pointing System	
DTN	Delay Tolerant Network	
CH	Cluster Head	
CM	Cluster Member	
MAC	Multiple Medium Access Control	
TDMA	Time Division Multiple Access	
AI	Artificial Intelligence	
TA	Trusted Authority	
CA	Certificate Authority	
	Routing Protocols	
AODV	Ad-Hoc On-demand Distance Vector	
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance	
DV-CAST	Distributed Vehicular Broadcast Protocol	
EAEP	Extensible Application Event Protocol	
PBSM	Policy Based Security Management	
PGB	Border Gateway Protocol	
OLSR	Optimized Link State Routing	
DSDV	Destination Sequenced Distance Vector	
MPR	Multi-Point Relay	
DSR	Dynamic Source Routing	
DYMO	Dynamic Manet On-Demand	
ZRP	Zone Routing Protocol	
SKVR	Scalable Knowledge-based Routing Architecture for Public Transport Networks	
VADD	Vehicle-Assisted Data Delivery	
GeOpps	Opportunistic Routing for VANET in a Public Transit System	

GeoDTN+Nav	Geographic DTN Routing with Navigator Prediction for Urban Vehicular Environments	
PPC	Position Based Prioritized Clustering	
DCA	Dynamic Cluster Algorithm	
C-Drive	Modified Clustering Based on Direction	
CGP	Cluster Gathering Protocol	
LICA	Robust Localization using Cluster Analysis	
CBLR	Cluster Based Location Routing	
BDA	Broadcast Decision Algorithm	
RAR	Road side Aided Routing	
SADV	Static Node-Assisted-Adaptive Data Dissemination in Vehicular Networks	
CBR	Cluster-Based Routing	
CRA	Cluster-Based Routing Algorithm	
CBRA	Cluster-Based Routing Protocol	
IBCAV	Intelligent Based Clustering Algorithm in VANET	
CFSR	Clustering-Based Fast and Stable Routing Protocol for Vehicular Ad Hoc Networks	
CRP-TI	Cluster-based Routing Protocol using Traffic Information	
DCCR	Density-Connected Clustering-based Routing protocol	
	Simulators	
OMNeT++	Objective Modular Network Testbed in C++	
SUMO	Simulation of Urban Mobility	
SimMobility	Simulation platform of the Future Urban Mobility	
NS-2	Network Simulator 2	
NS-3	Network Simulator 3	
VEINS	Vehicles in Network Simulation	
	Performance Evaluation Parameters	
APL	Average Path Length	Hop
ARL	Average Route Latency	Sec
PDF	Packet Delivery Fraction	
CPD	Control Packet transmitted per Data Packet delivered	Control Packet/ Data Packet

Abstract

Due to the rapid development of wireless communication technology and the growing demand for services, it is expected that the emergence of Vehicular Ad hoc Networks (VANET)s would enable a variety of applications such as driver assistance, traffic efficiency, and road safety. Frequent changes that occur in the network often leads to major challenges in VANET, such as dynamic topology changes, shortest routing paths and also scalability due to the high dynamic topology where the number of vehicles on the road increases and decreases rapidly. One of the best solutions for such challenges is to divide the network into clusters and then choose a Cluster Head (CH) in each cluster to ensure appropriate message transmission in the VANET. In order to resolve the network scalability issue and accommodate additional applications in VANETs, efficient clustering methods are suggested. Because only the CH communicates with the Road Side Units (RSU) and delivers relevant messages, there is a potential reduction in the communication overhead between RSUs and other VANET components. However, clustering algorithms are necessary to ensure the stability of the cluster because of the dynamic nature of VANETs' network topology. The selection of CH is a crucial step in the clustering process.

In order to improve cluster stability and data transmission efficiency, this thesis proposes a Clustering technique based on Ad hoc On-Demand Distance Vector routing protocol (AODV-C) for VANETs that is cluster position-based. It also implements Vehicle-to-Vehicle (V2V) and CH-to-RSU communication. We also provided an approach for choosing a suitable vehicle to serve as the CH. The distance the vehicle is from the cluster boundary and its average speed are considered when choosing the CH.

Our proposed protocol is implemented using the OMNeT++ 5.5.1 simulator, the simulation results show that the suggested technique enhances some important metrics such as packet delivery fraction, the number of control packets transmitted for each delivered data packets, average path length, and average route latency when compared with the standard AODV in terms of node mobility speed, node density, number of clusters, and network sizes. Where the simulation results show that the AODV-C protocol outperforms AODV in terms of reliability by around 12% for increasing vehicle speed, 23% for increasing vehicle number, 10% for increasing network size and local traffic, and 20% for increasing cluster number. In addition, improved latency by 10% for increasing vehicle speed, 13% for increasing vehicle number, 10% for expanding network size, 11% for increasing local traffic, and 12% for increasing cluster number.

The proposed protocol guarantees scalability by having a good packet delivery fraction and low control packets transmitted for each delivered data packets even when the network size increase and the number of vehicles along with their speeds increase too.

Keywords: Intelligent Transportation Systems (ITS), Vehicular Ad-hoc Networks (VANETs), clustering.

Chapter 1: Introduction

1.1 Overview

This chapter introduces the focus of our work as well as the inspiration behind the study we are conducting. We introduce this work and provide a general idea about the thesis in Section 1.2. Discussions of our issue definition, the goals, advantages, and key contributions are found in Sections 1.3 through 1.4. Finally, we provide a quick summary of the thesis' primary structure in Section 1.5.

1.2 Introduction

Intelligent transportation systems (ITS) are highly advanced systems, including state-of-the-art wireless, electronic, and automated technologies. ITS is designed to provide innovative traffic management solutions for various crossovers transplant methods. The system provides users with instant information. This allows them to obtain information about road conditions within their range and coordinate action within the road network. Many ITS technologies can aid in trip optimization (route guidance), decrease unnecessary miles traveled, boost the usage of other modes of transportation, and shorten congestion-related wait times. ITS depend on the Vehicle Ad hoc Network (VANET), which is a special type of Mobile Ad-Hoc Network (MANET) to improve the efficiency and safety of road transport [1]. In MANET which is a self-organizing network, every node can move freely within the network coverage and stay connected without the need for a fixed infrastructure. In VANETs the highly mobile nodes are vehicles and the mobility of nodes and the rate and speed of network connections change dynamically over time at a higher rate compared to MANETs [2]. VANETs offer telemetric devices, streaming communication between vehicles, and safety measures inside the car. They use Dedicated Short-Range Communication (DSRC), with Wi-Fi, cellular, satellite, and WiMAX (Worldwide Interoperability for Microwave Access) [3].

VANETs are an emerging new technology to combine the capabilities of new-generation wireless networks with vehicles. The goal is to give mobile users, who are already connected to the outside world through other networks at home or at work, ubiquitous connectivity while they are driving, as well as effective vehicle-to-vehicle communications that support ITS [4]. ITS is a major application of VANETs that aimed to reduce traffic congestion, enhance traffic management, reduce environmental impact, and increase the benefits of transportation to commercial users and the general public, ITS includes a variety of applications that process and share information, such as cooperative traffic monitoring, control of traffic flow, blind crossing, collision prevention, and nearby information services. Another vital application for VANETs is providing Internet access to vehicular nodes while on the move so that users can download music, send emails, or play games for backseat passengers [4].

The main purpose of VANETs is to promote and support vehicle-to-vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication [5]. The V2V and the V2I communications in VANETs are made possible by the On-Board Unit (OBU) mounted on vehicles and the Road-Side Units (RSU) strategically positioned on the road network respectively [6]. Both the OBU and the RSU are independent computing units with wireless short-range communication capabilities. The V2V component of the VANET design makes it easier for vehicles within the transmission range to exchange data and information. The V2I architecture, on the other hand, gives vehicles a direct connection to the Internet, allowing them to engage in long-distance communication and gain access to various vehicular and traffic services. VANETs play a pivotal role in promoting critical aspects of road safety, improving traffic efficiency, and providing entertainment to passengers [7]. Applications for VANETs can generally be divided into two broad categories: comfort and safety [8]:

- Comfort Applications: This type of application enhances passenger comfort, and traffic efficiency and/or improves the route to a destination. Traffic information systems, weather reports, gas station or restaurant locations and prices, and interactive communication services like Internet access or music downloads are a few examples of this category [8].
- Safety Applications: This type of application refers to all the features installed in the vehicles to keep the occupants safe [9]. The data is either presented to the driver or used to activate an actuator of an active safety system. Emergency warning systems, lane-changing assistance, intersection coordination, traffic sign/signal violation waning, and road condition warning are a few examples of uses for this class. Due to the strict latency restrictions, applications in this class typically require direct V2V communication [8].

In VANETs, V2V communication experiences delays and packet delivery concerns due to stochastic optimization, dynamic network topology, and frequent network fragmentation, which lowers the reliability of message dissemination [10]. However, with VANETs, factors including vehicle speed, network typologies, network fragmentation, and random selection of messages have an impact on the reliability of safety message propagation [11]. Although it is prone to the broadcast storm problem, where transmission collisions make the usage of the wireless medium inefficient, broadcasting has been found to be a reliable approach to spreading messages in order to minimize these constraints [12]. Therefore, the clustering of vehicles has been adopted to enable broadcasting control among smaller vehicle groupings. In that method, the Cluster Head (CH), of the cluster [13], who will be in charge of receiving data from other clusters and distributing it inside the cluster as well as receiving local data and transferring them to other clusters, is chosen as the most appropriate vehicle.

Scalability is the network's ability to manage increasing workloads without degrading network connection performance by lowering routing overhead to be more efficient. Scalability, which ensures that routing systems maintain high performance even when network properties like node density and network area increase, is a crucial consideration [14].

This thesis proposes a Clustering technique based on Ad hoc On-Demand Distance Vector routing protocol (AODV-C) to be used in VANETs that is cluster position-based, the proposed protocol is a stable structure by using the RSU which is responsible for electing the CH of the cluster. The CH is responsible for the routing process inside the cluster and the RSU is responsible for the communication between the clusters.

We compared the AODV-C with the standard AODV protocol in terms of packet delivery fraction, the number of control packets transmitted per data packets delivered, average path length, and average route latency. The AODV-Cis implemented at different levels of parameters (vehicle speed, node density, number of clusters, network size, and local traffic percentage) with different values. The evaluation of the AODV-C is done using OMNeT++ 5.5.1.

Rustles show that our protocol achieved good scalability by maintaining minimum overhead and having a lower average latency even with a high number of vehicles and high vehicle speeds. Also, maintain a good packet delivery fraction despite increasing network size.

The simulation results showed that, compared to AODV, the AODV-C protocol improves PDF by about 12% for increasing vehicle speed, 23% for increasing vehicle number, 10% for increasing network size and local traffic, and 20% for increasing cluster number. Additionally, as compared to AODV, reduces CPD by around 14% for increasing vehicle speed, 59% for increasing vehicle number, 15% for expanding network size, 3% for increasing local traffic, and 52% for increasing cluster number. Also, as compared to AODV, decreases ARL by roughly 10% for increasing vehicle speed, 13% for increasing vehicle number, 10% for expanding network size, 11% for increasing local traffic, and 12% for increasing cluster number.

1.3 Problem Statement

In order to increase the level of traffic safety and reduce congestion, the ITS (Intelligent Transport Systems) and specifically VANETs (Vehicular Ad-Hoc Networks) are a matter of major importance. Effective routing and congestion control techniques help to alleviate some of these challenges and allow each vehicle to send and receive safety-related messages using V2V communication. To handle such V2V communication. Hierarchical cluster-based routing protocols have demonstrated certain advantages for vehicular communication, in terms of congestion control, security and privacy, routing, and reliability. A cluster can be defined as a group of nodes, which perform some specific tasks under a set of rules and regulations.

The well-known AODV protocol, which is used in VANETs, establishes the route only when necessary. It has a route request-response mechanism that enables it to issue a request for a route and then determine the best way to proceed based on the response it receives. By grouping the network's nodes into clusters and having cluster heads control packet routing, AODV can be made more efficient. The routing process can be narrowed down to just a portion of the network's nodes via clustering.

1.4 Research Objectives

The main purpose of our research is to build a scalable routing protocol for VANET.
Hence our main objectives are:

- Reduce routing overhead.
- Increase reliability.
- Reduce average route latency.
- Improve packet delivery fraction.

1.5 Research Methodology

Our Methodology can be summarized as:

- Studying current position-based routing protocols and identifying their advantages and disadvantages.
- Studying current cluster-based routing protocols and identifying their advantages and disadvantages.
- Proposing a scalable routing protocol to improve VANET network performance.
- Choosing a suitable simulator and simulating the model.
- Assessing the proposed protocol's performance by contrasting it with the standard AODV routing protocol.

1.6 Research Contributions

These are the thesis' main contributions:

- Conducting a detailed study of existing clustering algorithms in VANETs considering different parameters.
- Proposing a scalable routing protocol.
- Suggesting a new CH election and routing strategy.
- Using simulation to evaluate the proposed AODV-C routing protocol's performance and contrast it with standard AODV protocol.

1.7 Thesis Organization

This thesis presented the following topics: an overview of VANET's properties, difficulties, and several routing protocols. A survey on the common position-based and cluster-based routing protocols used in VANETs. A methodology and performance assessment for the AODV-C is also presented. The rest of this thesis is structured as follows:

- Chapter 2
  In chapter 2, a background and literature review are provided. This chapter presents an overview of the VANET routing protocol with a focus on cluster-based routing protocols used in VANETs along with a list of their types.
- Chapter 3
  This chapter presents the details of the suggested routing.
- Chapter 4
  Presents the simulation environment, results, and performance assessment of the suggested protocol.
- Chapter 5
  The conclusion, future work, and summary of the thesis are presented in this chapter.

1.8 Chapter Summary

An overall introduction of the thesis, the motivation behind this research, and the primary goals of this thesis were stated in this chapter. The main contributions were then discussed.

Chapter 2: Background and Literature Review

2.1 Overview

In this chapter, we introduce the VANET, its architecture, VANET technologies, and its routing protocol. Section 2.2 talks about MANETs. Section 2.3 talks about VANETs. Section 2.4 presents VANET architecture. The VANET technologies are presented in section 2.5. An overview of VANET routing protocols is in section 2.6. A literature review is done in section 2.7. Section 2.8 presents an overview of simulation techniques used for VANET. A brief chapter summary is presented in section 2.9.

2.2 Mobile Ad-hoc Network

A wireless self-organizing network of mobile nodes called a Mobile Ad hoc Network (MANET) allows communication without the need for pre-existing infrastructure. MANETs can be topologically flat or hierarchically clustered. Large networks with a flat topology have scalability problems, according to research [15]. Scalability issues occur in large MANETs with a flat topology, where routing causes congestion and the broadcast storm problem [16]. In order to find routes for routing in MANETs, flooding is necessary, and in large networks, this flooding causes severe congestion. As mobility is increased, this issue gets worse since broadcasts must occur often enough to keep neighboring nodes informed of the changing topology in a highly mobile network.

2.3 Vehicular Ad-hoc Network

An important development in the transportation sector is the introduction of the Vehicular Network (VANET) as shown in Figure 2.1 which is a subset of MANETs. It enables automobiles to immediately communicate with infrastructure or other vehicles. On-Board Units (OBU), a type of VANET device, are placed in cars and serve as a node for message transmission and reception through wireless networks. These gadgets give drivers and passengers access to the most recent information on disturbances such as accidents, flooding, rain, and traffic congestion. Having timely access to this information allows drivers to make wise decisions and prevent accidents. [17] Dissemination of safety messages, which depends on broadcast communication, among vehicles, is one of the primary goals of VANETs.

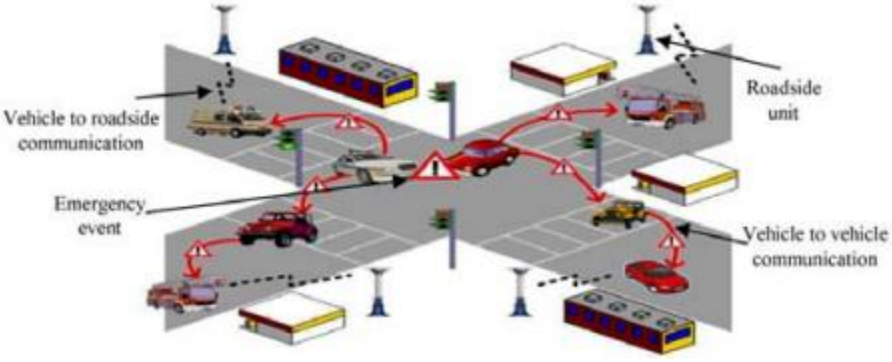


Figure 2.1 Vehicular Ad hoc Network taken from [17]

The features of VANET are generally comparable to the operation technology of MANET in the sense that the self-organization, self-management, low-bandwidth, and shared radio transmission conditions remain the same. However, the main operational challenge of VANET arises from the high speed and hesitant mobility (in contrast to the MANET) of the mobile nodes (vehicles) along the pathways. This fact suggests that for the routing protocol to be designed effectively, the MANET architecture must be improved in order to effectively support the rapid mobility of the VANET nodes. VANET features make the designing of a scalable routing protocol a challenging task for research [17].

Designing a routing protocol for VANETs is considered a major issue [18]. Short communication times with the least amount of network resources are the main goal of routing protocols. Many routing protocols have been designed for MANETs, and few of them can be implemented directly in VANETs [18]. However, the simulation's results demonstrate that, in contrast to MANETs, fast-moving vehicles, active information transfer, and the accompanying high speed of mobile nodes all impair the performance of VANETs. So, for VANETs, discovering and managing routes is a challenging issue. This aspect has ensured that developing a proper routing protocol will provide a number of research obstacles [17].

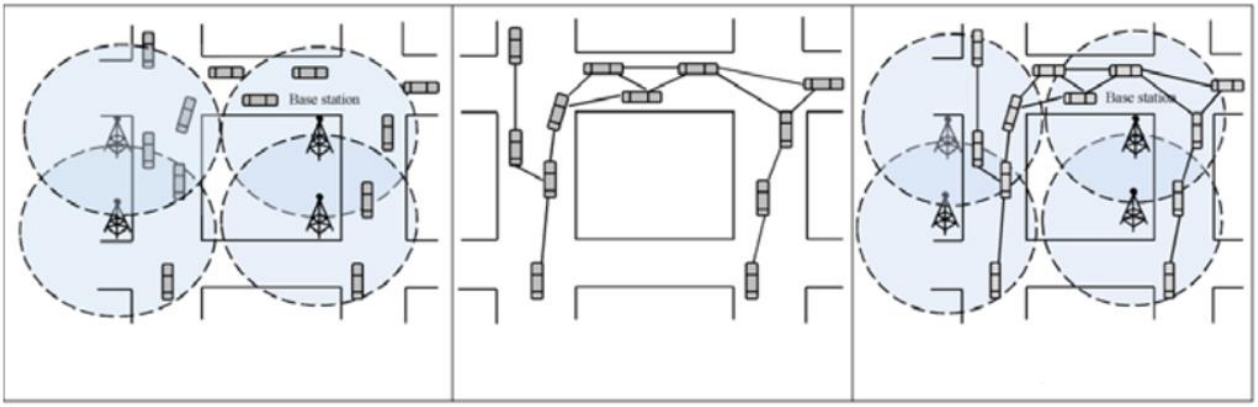
Since VANET routing protocols may be divided into groups, we will go through the routing strategies, advantages, and disadvantages of each group. Due to environmental constraints, position-based routing and geo-casting are more effective than other routing protocols for VANETs, according to a qualitative assessment of the protocols [19]. Furthermore, the most promising routing protocols for VANET communication are those based on infrastructure.

2.4 VANET Architectures

As previously indicated, VANET standards are comparable to those of MANET in that neither rely on a fixed base for communication or information broadcasting. The tremendously vibrant world of road transportation is the subject of VANET. The pure cellular/wireless local area network (WLAN), pure Ad Hoc, and hybrid designs of VANETs are depicted in Figure 2.2. For Internet access, obtaining traffic data, or routing, VANETs may use permanent cellular gateways, WLAN access points, or base stations at traffic intersections in the pure cellular architecture Figure 2.2 (a). The network architecture under these circumstances will either be cellular or WLAN. Vehicle-to-infrastructure (V2I) communication is the name of the VANET architecture that successfully integrates heterogeneous developing wireless technologies like 3G cellular networks, LTE, LTE-Advance, IEEE 802.11, and IEEE 802.16e [20] [21].

The VANET's pure Ad Hoc architecture, also known as vehicle-to-vehicle (V2V) communication, is shown in Figure 2.2 (b). Due to the lack of wireless access points and cell towers in this architecture, the nodes may be forced to communicate with one another. The data acquired from the sensors installed in cars will be very helpful in warning other cars about collisions or other crises and will also help the police find offenders [22]. The nodes in the overall Ad Hoc group that uses the infrastructure-less network design engage in V2V communication.

The hybrid architecture of VANET (V2I and V2V) is shown in Figure 2.2 (c). To enable the connection between automobiles and roadside communication units like cellular towers and access points, wireless networking devices are fixed in the hybrid architecture. Infrastructure communication units have been used for a variety of applications in metropolitan screening, security, driving support, and entertainment [23] to access active and wealthy information outside of their network framework and transmit this information through peer-to-peer Ad Hoc, infrastructure-less communication. Ad Hoc and cellular/WLAN hybrid architecture provide greater flexibility in content sharing and richer content.



(a) Pure cellular (V2I) (b) Pure Ad Hoc (V2V) (c) Hybrid (V2I & V2V)

Figure 2.2: VANET network architectures taken from [17]

Vehicle-to-Everything (V2X) communication as shown in Figure 2.3 refers to communications between vehicles, Road Side Units (RSUs), and infrastructures. Many wireless access technologies can handle V2X communication. Some of these communication systems enable distributed medium- and short-range communications (e.g., DSRC). In contrast, other technologies rely on a centralized infrastructure to facilitate long-distance communications (e.g., Cellular-V2X).

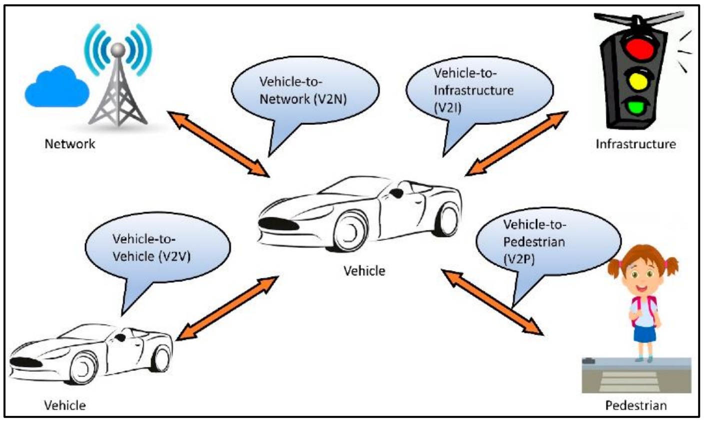


Figure 2.3 V2X communication taken from [24]

2.5 VANET Technologies

VANET based on different wireless access technologies which will be discuses briefly as follows：

1. Dedicated Short Range Communication (DSRC): The US Federal Communications Commission (FCC) designated 75 MHz of spectrum (between 5.850 GHz and 5.925 GHz) for Dedicated Short Range Communication (DSRC) in vehicular applications in 1999. The IEEE 802.11p/1609 Wireless Access in Vehicle Environment (WAVE) standards, which were created specifically to satisfy the needs of vehicular communications, serve as the foundation for DSRC [25]. The communication in DSRC is referred to as "Short Range" and occurs across distances of hundreds of meters (100m-1000m). This "Short Range" communication, for example, is standardized in Europe as ETSI ITS-G5, which is also based on IEEE 802.11p. These two IEEE 802.11p-based technologies (ITS-G5 and DSRC/WAVE) can provide direct V2V and Vehicle-to-RSU (V2I) communication without the need for infrastructure. In this situation, emergency communications can be transmitted with less delay. Without a central controller, however, there are certain restrictions, particularly in the situation of traffic congestion because of the limited throughput and unbounded delay of CSMA/CA under high load [25]. V2V safety warnings, traffic updates, toll collection, drive-through payment, and many other uses are all covered by these communications. High data throughput and minimal communication latency are the goals of DSRC in tiny communication zones.
2. IEEE 1609 Standards for wireless access in vehicular environments (WAVE): In the layers of the WAVE protocol stack the IEEE 802.11p is restricted by the scope of IEEE 802.11 which severely works at the media access control and physical layers. The highest levels of the IEEE 1609 standards address the DSRC operational functions and complexity. These standards outline how applications that utilize WAVE will perform in the WAVE environment, based on the management activities defined in IEEE P1609.1, the security protocols defined in IEEE P1609.2, and the network-layer protocol defined in IEEE P1609.3. Above 802.11p, there is a standard called IEEE 1609.4 that enables higher layers to operate without having to deal with physical channel access parameters. Secure V2V and V2I wireless communications are made possible by the architecture defined by the WAVE standards as well as a complementary set of standardized protocols, services, and interfaces. Although other commercial services are allowed, the main objective was to create public safety applications that could save lives and enhance traffic flow [26].

2.6 Overview of VANET Routing Protocols

Researchers have put out a wide range of routing protocols for VANETs in light of the various architectures, uses, and difficulties. All of these protocols essentially strive to increase throughput while reducing packet loss and managing overhead to create a reliable routing mechanism for message distribution in a VANET with a highly flexible topology. Without concise and efficient routing protocols, vehicles might not be able to exchange crucial information and take advantage of cutting-edge VANET technologies. Numerous VANET routing protocols have been developed to address these problems.

In general, VANET routing protocols can be divided into five categories as follows [27]: broadcasting protocols, topology-based protocols, position-based protocols, clustering-based protocols, and infrastructure-based protocols as shown in Figure 2.4.

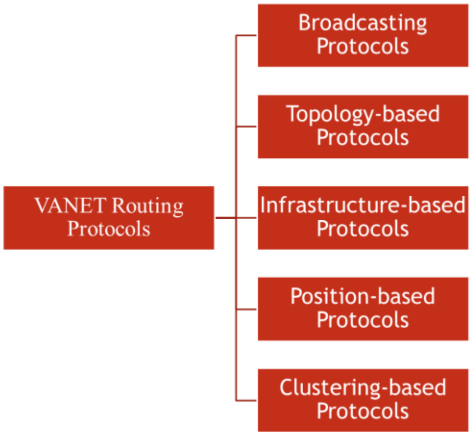


Figure 2.4: Classificatoin of VANET routing protocol

2.6.1 Broadcasting Protocols

Broadcast-based routing is typically used in VANET for advertising and announcements, as well as to exchange information with vehicles about the weather, road conditions, and emergency situations [28], this type of protocols is used for safety applications. In applications relating to safety, it is the routing protocol that is utilized the most frequently. The simple broadcast method is followed by flooding, or using multiple hops, in which each node retransmits the message to other nodes. Although this method has a higher overhead cost due to bandwidth wastage and redundant messages being sent to nodes, it ensures that the message will reach all of its destinations. Blind flooding can lead to a broadcast storm problem [29], which can overrun the constrained channel capacity and lower the reliability of communication. Additionally, it is only appropriate for a small number of network nodes. More message broadcasts cause collisions, more bandwidth usage, and a decline in system performance as a result of higher node density [28]. EAEP is one of the several broadcast routing protocols.

Edge-aware Epidemic Protocol (EAEP) [30]. Based on the highly dynamic VANET protocol, EAEP is a dependable and bandwidth-effective information dissemination technique. By preventing the swapping of additional Hello beacons for transmitting messages between different clusters of vehicles, it reduces the cost of control packets and relieves cluster management. All of vehicles have a topographical position that they can use to send and receive messages and beacon signals. With a fresh rebroadcast message, the EAEP uses several transmission front and rear nodes over a predetermined duration to calculate the deciding whether or not the nodes will resend the message is a possibility.

2.6.2 Topology-Based Protocols

To accomplish packet forwarding, these routing techniques make use of network connectivity information. Additionally, they are separated into Proactive, Reactive, and Hybrid Protocols.

2.6.2.1 Proactive Routing Protocols

In proactive routing, routing details such as next forwarding hopes are kept in the background regardless of communication requests. To maintain the path, packets are continuously broadcast and flooded among nodes. Then, a table is built inside a node to show the next hop node leading to a destination. These protocols make use of the Bellman Ford Algorithm, in which each node stores information about the node next to it. Since the destination route is stored in the background and is known whenever a packet wants to send data, proactive routing protocols have the advantage of eliminating the need for route discovery. However, these protocols have the disadvantage of having low latency for real-time applications and maintaining unused data paths, which reduce the amount of bandwidth that is available. The table-driven routing protocol is another name for the proactive protocol. These protocols operate by periodically exchanging topological information among all network nodes. The Optimized Link State Routing (OLSR) [31] and Destination Sequenced Distance Vector (DSDV) [32] protocols are two examples of these protocols.

OLSR is essentially a refined version of the link state protocol. Link State Protocol has been refined, and OLSR is essentially that. The way link state protocol operates causes any change in a network's topology to be broadcast to every node, increasing network overhead. Two different types of messages, such as hello and a message to manage the topology, are handled by OLSR. The information regarding the status of the connection can be found in hello messages. While using the multi-point relay (MPR) selected list to broadcast its own neighbor information via topology control message. As with pure link state protocol, the overload has decreased as a result of the use of MPR. DSDV protocol is a modified version of the Bellman-Ford Algorithm. By preserving the knowledge about each node's sequence number, this technique avoided routing loops.

2.6.2.2 Reactive Ad Hoc Based Routing

In this type of protocols, the route discovery process is started only when nodes need to send data packets to other nodes. During this phase, a flood of query packets is sent out into the network to search for routing path. These protocols are known as "on-demand routing protocols" since they only have the knowledge of some nodes because they only update the routing table when there is data to convey [33]. However, these protocols involve flooding, which increases routing overhead and has drawbacks with initial route finding, making them unsuitable for safety applications on VANET. Ad-hoc On-Demand Distance Vector (AODV) [34], Dynamic Source Control Routing (DSR) [35], and Dynamic Manet on Demand (DYMO) [36] protocols are examples of reactive protocols.

In VANET, AODV is the protocol that is most frequently used [37]. It is in possession of the destination nodes' next-hop information. Additionally, each routing table has a lifespan. A new route will be defined on demand if there is no route demand within the allotted time. Otherwise, the current route will expire. According to AODV, a source node will check the route in its routing table anytime it wants to deliver data to a destination node. The packet will be forwarded to the destination if the route information is present in the table. If not, the originating node will broadcast the request for route discovery to its neighbors. A mobile ad-hoc protocol with high mobility traffic suitability is AODV. The transmitting overhead was decreased by the aforementioned methods. Additionally, route finding will be done as needed [38]. Four different control message types are included in AODV, including Route Error (RERR), Route Reply (RREP), Route Request (RREQ), and Route Reply Acknowledgement (RREP-ACK). The AODV uses a route detection technique for node-to-node data transfer. To improve the Packet Delivery Ratio (PDR) in the network, this reactive algorithm broadcasts a path failure notification known as RERR to each node in the whole network. Low network utilization and dependability in wireless mesh networks are two benefits of AODV [37].

DSR is an effective routing protocol. Basically, it is designed for multi-hop Wireless Ad Hoc Networks (WANET). It is an administration-free protocol that allows the network to be completely self-organized and configured. Route maintenance and discovery are the claimed protocol's two primary tasks. The aforementioned processes collaborate to maintain routes and find nodes.

Another on-demand protocol designed after AODV is DYMO. Both proactive and reactive implementations of the DYMO routing protocol are possible [37]. Additionally, route discovery methodology is available whenever needed.

2.6.2.3 Hybrid Protocols

Hybrid routing is a composite of proactive and reactive routing protocols that reduces the control overhead of proactive routing protocols and decreases the initial route discovery delay in reactive routing protocols due to the regular sharing of topology information [39]. The hybrid strategy has increased the network's scalability and efficiency. The disadvantage of a hybrid strategy is excessive latency when navigating new routes, on the other side. Zone Routing Protocol (ZRP) [40] is a popular protocol that uses a hybrid method.

2.6.3 Position-Based Protocols

One class of routing algorithms is position-based routing. All nodes recognize their own location and the location of their neighbor nodes using position-pointing devices like GPS, and they all share the property of using geographic positioning information to choose the next forwarding hops where the routing decisions are based on the geographic position of the vehicles [41] [42]. Location service algorithms are used to determine the location of destination nodes before starting the route discovery process. Without any prior knowledge of the map, the packet is sent to the one hop neighbor that is closest to the destination. One important feature of position-based routing protocols is that no need to establish and maintain a global route from the source node to the destination node. There are three types of position-based routing protocols: non-delay tolerant network (non-DTN), delay tolerant network (DTN), and hybrid routing techniques [41].

2.6.3.1 Non-delay Tolerant Networks (non-DTNs) Routing Protocols

The non-DTN position routing techniques are only practical on densely populated VANETs and do not make use of alternating connectivity. These protocols are designed to send data packets as quickly as possible to their destination. The fundamental premise of non-DTN routing protocols that take a greedy approach which is based on forwarding the packet to a neighbor that is near to the destination. However, if the neighbors are not closer to the destination than the node, the forwarding technique may not be successful. Since the packet has experienced the greatest local growth at the current node, we can say that it has reached the local maximum at that node. The routing protocols in this group each have a unique recovery strategy to deal with these failures. Examples of non-DTN protocols include: beacon [43], beaconless [44], and hybrid protocols.

2.6.3.2 Routing Protocols for Delay-Tolerant Networks (DTNs)

An approach to computer network architecture called DTN aims to solve technical problems in heterogeneous networks that might not have continuous network connectivity, which prevents them from having instantaneous end-to-end pathways. Such networks include those that are mobile, operate in harsh terrestrial conditions or are imagined in space. Vehicle routing protocols are created for VANETs, which are a type of DTN. Due to the difficult settings in which this type of network operates, connection loss frequently occurs. The carry-and-forward technique, which is used to address this issue, allows nodes to hold packets when they lose contact with other nodes, carry them a set distance as long as they come into contact with other nodes, and then send them to nearby nodes based on predetermined metrics. Among these protocols, SKVR [45], VADD [46], and GeOpps [47] are the most well-known.

2.6.3.3 Hybrid Position-Based Routing Protocols

Typically, geo-routing is used to route the packets through the greedy and recovery modes. In the greedy mode, a packet is delivered to the destination greedily by choosing a neighbor who, of all the neighbors, is moving faster in that direction toward the destination. A local maximum can be reached by the packet, though, when no neighbor is closer to the destination than it is given the impediments. The recovery mode is used in this situation to retrieve packets from the local maximum before switching back to the greedy mode. Packets are delivered across the obstacles and toward the destination via a planarization process. Similar to this, packet delivery is guaranteed as long as the network is connected, but it's not always safe to assume that the network is functioning. Because VANET is mobile, it is typical for the network to be disconnected or divided, especially in sparse networks. In VANET, the greedy and recovery modes are insufficient. In order to solve this issue, the non-DTN routing strategy, which is represented by the two preview modes, is combined with the DTN routing approach. One of the most well-known hybrid position-based routing protocols is GeoDTN+Nav [48].

2.6.4 Clustering-Based Protocols

In this type of networks, the network is divided into clusters based on neighbourhood's speed, direction or other metrics. There is one Cluster Head (CH) for each cluster, and this CH is in charge of all intra- and inter-cluster administration tasks. The CH is responsible for channel assignment for Cluster Members (CMs), routing, relaying, and scheduling intra-cluster traffic as shown in Figure 2.3. The choice of CH can be influenced by a variety of factors. For instance, compared to other CMs, the node with the best relative average speed may have a higher chance of being chosen as the CH. Direct links are used by intra-cluster nodes to communicate with one another whereas CHs are used for inter-cluster communication.

Additionally, since it is regarded as a local communication, if a vehicle node has to interact with a node within the cluster, the data will travel directly there. Additionally, if a vehicle node has to interact with another node that is outside of the cluster, it needs the assistance of its CH to get there. Depending on the node's transmission range, each cluster has a specific size in terms of both area and nodes [49]. If the clusters are dependable and long-lasting, vehicular node clustering can improve the communication effectiveness of VANETs [50]. The right choice of CH can improve the stability of that cluster.

The construction of clusters and the choice of the CH are crucial issues in cluster-based routing methods. Due to tremendous mobility in VANET, the development of dynamic clusters is a towering process. For large networks, good scalability can be given, but when creating clusters in a highly mobile VANET, network delays and overhead are encountered. In order to provide scalability for cluster-based routing, virtual network architecture must be constructed by clustering nodes [18].

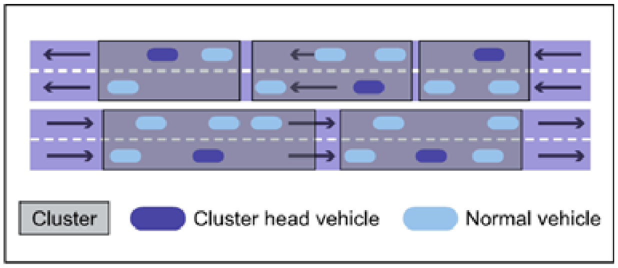


Figure 2.5: Vehicles from multiple clusters in cluster-based routing [51]

Clustering protocols come in a huge diversity, according to the literature. Figure 2.6 depicts a taxonomy of the many clustering techniques now in use.

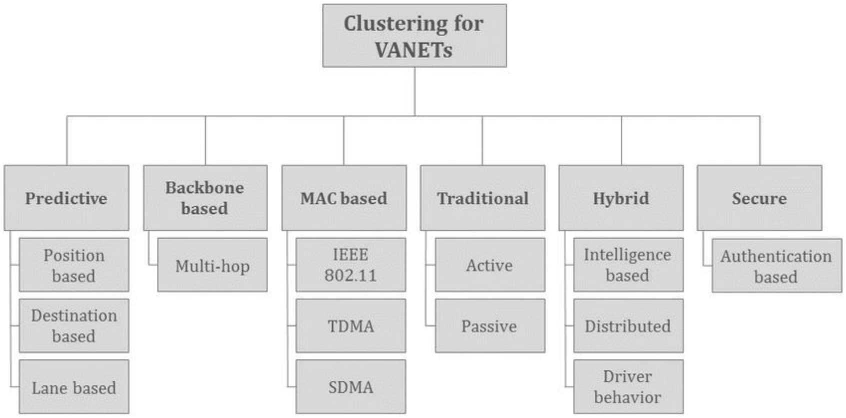


Figure 2.6: Classification of clustering approaches for VANETs according to [52]

The following categories [52] can be used to categorize clustering algorithms:

- Predictive clustering: It is based on the location of the nodes and how they will behave in the future. In VANET, these properties are utilized to create clusters. The most well-known predictive clustering techniques are position-based clustering, destination-based clustering, and lane-based clustering [53].
- Backbone-based clustering: This method of clustering is based on creating a backbone for communication between clusters. After that, the backbone handles communication and aids in CH election among cluster members. This method of clustering, in which hop distance is employed to construct a cluster, is demonstrated by k-hop or multi-hop [53].
- MAC-based clustering: Multiple Medium Access Control (MAC) based clustering strategies have been put forth for the establishment of clusters in VANETs. These methods create clusters using the IEEE 802.11 MAC protocol. IEEE 802.11 MAC, TDMA (Time Division Multiple Access), and SDMA (Spatial Division Multiple Access) clustering algorithms are a few examples of well-known MAC-based systems [52].
- Traditional clustering: It relies on the type of vehicles. It is based on vehicle behavior-related active and passive clustering algorithms. Beacon-based, mobility-based, density-based, and dynamic behavior-based clustering were other divisions of active clustering [52].
- Hybrid clustering: This methodology creates clusters by combining two or more methods, such as the use of artificial intelligence (AI), and fuzzy logic. It is further divided into clustering strategies that are intelligence-based, distributed, and driver behavior-based [52].
- Secure clustering: In order to build clusters in the network, security parameters are used. In this clustering strategy, Trusted Authority (TA) and Certificate Authority (CA) are typically engaged. One example of this type of clustering is authentication-based clustering.

This thesis's suggested method is based on predictive clustering. Therefore, we will examine this strategy in greater detail in this section.

Predictive clustering protocol based on future node behavior and geographic location. We shall now talk about other clustering categories.

1. Position Based Clustering:
   Destination based clustering takes three factors into account when forming clusters. These factors are the destination, speed, and node location. It can benefit from the navigation systems in vehicles to enhance performance. We can predict the final destination of a moving node by using data from navigational devices. Cluster time span can be enhanced due to similar destinations. Table 2.1 provides a relative comparison of some algorithms related to position-based clustering algorithms.

Table 2.1: Comparison of Position-Based Clustering Algorithm

Schemes	Node density	Node speed	Cluster stability	Transmission overhead
Position Based Prioritized Clustering (PPC) [54]	Low	Low	High	Medium
Dynamic Cluster Algorithm (DCA) [55]	Low	High	Medium	High
Modified Clustering Based on Direction (C-Drive) [56]	Low	High	Medium	High
Cluster Gathering Protocol (CGP) [57]	High	High	High	High

2. Destination Based Clustering
   The current location, speed, relative location, and final destination of the vehicle are all taken into account by the destination-based clustering technique while forming the cluster. Using a vehicle's navigation system, the location was known in advance. The cluster stability and message delivery efficiency are thus increased by taking use of vehicular behavior and accounting for the eventual destinations of vehicles, hence extending the cluster time span. The algorithms in Table 2.2 demonstrate destination-based clustering strategies.

Table 2.2: Comparison of Destination Based Clustering Algorithm

Schemes	Node density	Node speed	Cluster stability	Transmission overhead
Robust Localization using Cluster Analysis LICA [58]	Low	Low	High	Medium
Cluster Based Location Routing (CBLR) Algorithm [59]	High	High	High	High

3. Lane Based Clustering
   The availability of lane information with regard to a certain parameter is used by lane-based clustering algorithms to choose stable clusters. Because of the constant layout of the lanes on the road, there may be less variations in the CH selection. Because nodes typically maintain their speed as constant as possible while traveling in the same lane, these systems display low delay overhead and improved transmission efficiency thanks to better broadcasting reachability and good CH lifetime. Two distinct algorithms that used the lane-based clustering technique are shown in Table 2.3:

Table 2.3: Comparison of Lane Based Clustering Algorithm

Schemes	Node density	Node speed	Cluster stability	Transmission overhead
Broadcast Decision Algorithm (BDA) [60]	Medium	Medium	High	Medium
Lane Based Clustering [61]	Low	Low	High	Medium

Cluster stability, which raises the cluster's performance level, can be used to gauge how effective a clustering approach is [62].

2.6.5 Infrastructure-Based Protocols

Because of their high level of dynamicity, vehicular networks frequently undergo topological changes that have an impact on routing and packet delivery ratio. Additionally, traffic density can affect how well vehicular routing protocols operate. Under sparse and dense networks, vehicular routing systems exhibit a large performance variance. VANETs are unable to handle network partitioning due to all the considerations linked to traffic. To improve vehicle communication and eliminate unwanted delays in various vehicular applications, one idea is to place road side units (RSU) along the roads [63]. Energy is not a concern for automobiles because they have a rechargeable energy supply, unlike Ad Hoc and sensor networks. As a result, placing communication infrastructure alongside a road improves packet delivery efficiency and actually reduces on delay.

In infrastructure-based routing protocols, communication occurs between vehicles and RSUs placed along the side of the road. These RSUs serve as a communication link between vehicles. Since the majority of the functionality is already built into RSUs, creating infrastructure units is straightforward. Infrastructure mode is used for the operation of HIPERLAN2 and IEEE802.11 [64].

When the vehicle density is low, the infrastructure mode in the VANET scenario plays a significant role. Since the traffic is controlled at night, the cars may move at speed that enables the two vehicles to quickly move beyond of each other's transmission range. The functionality of RSUs is utilized in this situation. RSUs act as a communication channel for automobiles and transmit traffic alerts.

Road side Aided Routing (RAR) [65] and Static Node-Assisted-Adaptive Data Dissemination in Vehicular Networks (SADV) [66] are the two most used infrastructure-based routing systems. The primary drawback of using infrastructure units for communication is that they are often damaged in dire circumstances like earthquake, storm, and flood.

2.7 Literature Review

VANET clustering has been used in the literature for a variety of tasks, including load balancing, supporting quality-of-service, and disseminating information in high-density vehicle networks [67]. One of the most common cluster-based routing protocols is Cluster-Based Routing (CBR) [68]. The CBR protocol divides the geographic area into grids of six squares each. Based on the geographic information, each node calculates the ideal neighbor CH to transport data to the following hop. Because the route is saved in the routing database and does not need to be discovered, there is reduced routing overhead. The coordinates of its grid and the CH's location are broadcast in a LEAD message by the CH to its neighbors. When an RSU exits in the grid, it transforms into a CH. When a header leaves the grid, it broadcasts a LEAVE message with its grid position. An intermediary node will retain this message until a new CH is selected. This data is used in the new CH's data routing. The important VANET-related variables of velocity and direction are not taken into account by this protocol.

Numerous scalable VANET election techniques have been covered in this section. The CHs are chosen in accordance with the suggested process, and they further watch how vehicles move and interact with one another. Additionally, they communicate verbally and work to maintain a good PDR.

2.7.1 A Cluster-Based Recursive Broadcast Routing Algorithm to Propagate Emergency Messages in City VANETs

A cluster-based recursive broadcast Routing Algorithm to Propagate Emergency Messages in City VANETs (CRB) to propagate emergency message is proposed in [69]. In this protocol the traffic accident vehicle is considered as the first CH that broadcasts emergency message to common vehicles move on same road and same direction with CH. Vehicles that receive messages and decode information correctly in the transmission range with CH, are all considered Cluster Member (CM). Then, the farthest vehicle receiving message in a cluster is the next CH that re-broadcast the received emergency event among the vehicles in the transmission range. Other clusters can be formed using the same steps.

The first CH is considered as the source node that broadcasts emergency message to CM which sends an Acknowledgement (ACK) packet back to the source node. After that, the source broadcast Response packet when it received the ACK packet from the farthest CM which re-broadcast message.

2.7.2 A Cluster-Based Routing Algorithm for VANET

Authors in [70] proposed Cluster-based Routing Algorithm (CRA) based on Cluster-Based Routing Protocol (CBRP). CBRP algorithm divides the nodes into a number of interfering or disjoint 2-hop diameter clusters in a distributed manner. Selecting the CH is based on speed deviation of vehicles as well as the remaining time to destination. Where the vehicle has a long travel time and a small speed deviation, its opportunity is high for being selected as CH.

The vehicle nodes in this protocol are divided to four roles; Cluster Head (CH), Cluster Member (CM), Gateway, and Undecided node. There are also data structures used in the protocol which a Neighbors table, Cluster Adjacency table, and Two-hop Topology database which used in formatting the cluster.

2.7.3 Intelligent Based Clustering Algorithm in VANET

Intelligent Based Clustering Algorithm in VANET (IBCAV) is proposed [71], the RSU is chosen as CH if it is within the confines of the cluster. If it is not, a vehicle with slower speed and an appropriate position is designated as a CH. An artificial neural network using a genetic algorithm is used for CH selection. This algorithm takes the cluster size, velocity, density, bias, and a Vehicle in cluster Flow Position (VFP) as inputs to determine the CH level, vehicle with a higher CH level is chosen as CH. A Store-Carry-Forward concept is used to send a message.

After the CH is chosen, a Store-Carry-Forward concept is used to send a message. When CHs are outside the communication range of the CH that intends to send message, it stores the message inside its buffer and when a CH enter into its communication range it transmits a Hello message to that CH.

2.7.4 A Clustering-Based Fast and Stable Routing Protocol for Vehicular Ad Hoc Networks

In A Clustering-Based Fast and Stable Routing Protocol for Vehicular Ad Hoc Networks CFSR [72], a link quality assessment is proposed where a weight is assigned to each road segment based on connectivity factors. A road segment is split into multiple static clusters. Gateways nodes are selected at road intersections to connect various road segments. The weight of the road segment is used to build the routing path in the sub-zone using Dijkstra algorithm. Then Local Coordinators (LCs), which are special gateway vehicles that contribute to maintaining fast path connectivity, are chosen for each cluster. These LCs are selected on the basis of each sub-zone topology.

The hierarchical cluster structure is divided into three parts. The underlying network consists of CMs within each road segment. The middle level network consists of the CHs of each link and the gateways of the crossroads. The high-level network consists of LCs selected by each subzone topology. After the completion of the cluster structure, source starts to establish the routing path for the data transmission, by assessing link quality and assigning weight to each link. Then, the weight can be directly used as the link quality metric to establish an optimal routing path in every sub-zones.

2.7.5 Cluster-Based Routing Protocol Using Traffic Information

Authors in Cluster-based routing protocol using traffic information (CRP-TI) [73] proposed a clustering routing protocol based on the traffic information to facilitate communication between vehicles and allow the proper routing of packets to their final destinations. Each cluster has only one node as CH and member nodes. The CH is chosen by the longest path in a road. Member nodes belonging to the cluster also build routing paths for the retransmission of packets to other clusters. Authors proposed an ontology to represent information about vehicles and traffic to be used to build and reuse common knowledge. The ontology is integrated directly into each vehicle. Nodes also receive information update on the traffic in real-time from the infrastructure to improve communication between vehicles and facilitate the interpretation of the information collected on traffic and clusters to reduce the overhead and the delay of the communication within vehicles.

2.7.6 Density-Connected Cluster-Based Routing Protocol in Vehicular Ad Hoc Networks

The Density-Connected Clustering-based Routing protocol in vehicular Ad Hoc networks (DCCR) [74] is a position-based density adaptive clustering-oriented routing protocol. The CHs are selected based on the observation that vehicles which are having more homogeneous environments will become the cluster heads and rest of the vehicles in their communication range will be the CMs. Authors used standard deviation of average relative velocity, density of the neighborhood, and homogeneity index for selecting CHs of clusters. When CM wants to send packets to a destination, it passes the packet to the CH. The CH makes sure whether the destination is in its member list or not. If so, then CH sends the message to the destination. Otherwise, the CH forwards the packet by using gateway or next CH or CM towards the destination.

2.7.7 Summary and Disscussion

CRB is an emergency message broadcasting model that has been designed to overcome the flooding strategy and broadcast storm problem. It achieves a high degree of scalability compared to flooding technique in both delay time and delivery ratio in the growth of vehicle density. CRA is based on CBRP algorithm where selecting the CH is based on the lowest-ID algorithm that mean the vehicle with the small speed deviation and long travel time is considered as the CH. In the proposed algorithm, each node broadcasts its neighbour table which contain the ID for the neighbour, role of it, and link statue (unidirectional or bidirectional) information periodically via hello packets. Moreover, CH keeps information about neighbour clusters in cluster adjacency table. Compared to Cluster Based Location Routing (CBLR) algorithm the proposed protocol achieves a good scalability in terms of End-to-End delay since it depends on speed deviation of vehicles and the remaining time to destination when selecting the CH.

In IBCAV algorithm the selection of the CH is done using artificial neural network with genetic algorithm where selecting the CH depends on the place of the vehicle in the cluster and its velocity in addition to the density and the cluster size. Authors show that using this strategy can reduce CH selection operation and reduce the usage of network resources. They also achieve a high scalability compared to Epidemic routing, AODV, and DSR in terms of packet delivery ratio, End-to-End delay, and throughput. CFSR protocol is a clustering technique that uses link quality assessment that can be useful in delay-sensitive applications. CH selection depends on the velocity and the location of the vehicles. The environment is divided into a sub-zone. The CFSR protocol achieves a good scalability compared to AODV and DSDV in terms of End-to-End delay and packet drop ratio.

CRP-TI, to facilitate communication between vehicles, CRP-TI uses ontology to represent knowledge and the information of vehicles and traffic to build and reuse common knowledge. The ontology is integrated directly into each vehicle. That means a learning phase is essential for each vehicle in order to collect information on the infrastructure, and replenish the map and connections between routes to allow the proper routing of packets to their final destinations by improving the communication between vehicles. The proposed protocol was compared to OLSR protocol where CRP-TI achieves higher packet delivery ratio than OLSR as the network size increases. However, it is noticed that the End-to-End delay slightly increase when the network size increases so it achieves lower scalability. DCCR protocol uses the standard deviation of relative velocity, density of the neighbourhood, and homogeneity index for selecting the CH for a cluster. In this way, they guarantee a stable structure that achieves improvement in packet delivery ratio and end-to-end delay by having a more stable clustering so they have a high scalability.

Table 2.4 and table 2.5 summarizes the key points for the mentioned recent studies. All the discussed protocols try to achieve scalability issue in different levels and considering different CHs selection criteria of routing strategy. As tables show, some of these protocols must take into consideration other important points upon electing CHs, some of them must consider more performance metrices to make a comprehensive performance evaluation. Moreover, some of them compared their protocols with somehow old protocols or protocols suggested for different environments.

Table 2.4: Summary of previous studies considering clustering techniques

Routing protocol	Scenario	Objective of clustering	CH selection criteria	Clustering technic
CRB, 2017	City scenario in which has one accident vehicle	Improving delay time and delivery ratio in emergency message broadcasting scenario.	The traffic accident vehicle is considered as the CH.	• The traffic accident vehicle is the first CH. • CH broadcast emergency message to common vehicles (CM). • Farthest vehicle performs a re-broadcasting will be the next CH.
CRA, 2016	NA	Assuming scalable, efficient, and distributed communication.	Travel time and speed deviation.	• Forming the clusters. • Selecting CH based on vehicle having a long travel time and a small speed deviation.
IBCAV, 2013	Highway scenario	Providing reliable communication and increased packet delivery ratio.	Bias, velocity, density, cluster size and vehicle in cluster flow position.	• RSU is chosen as a CH. • If RSU is not present. Vehicle with highest CH level is the CH.
CFSR, 2018	3x3 urban road with an intersection in two-direction carriageway	Supporting delay-sensitive application.	Velocity and location.	• The road is divided into multiple clusters. • Underlying network consists of CMs. • The middle level network consists of the CHs and gateways. • The high-level network consists LCs selected by each subzone topology.
CRP-TI, 2018	City environment	Ensuring the packet transmission in the most reliable manner and in record time.	Path and speed.	• The clustering is based on the traffic information. • CH is chosen by the longest path. • Ontology is used to represent information of vehicles.
DCCR, 2020	Highway scenario	Maintaining the connectivity between two successive forwarders to improve packet delivery ratio and end-to-end delay.	Standard deviation of average relative velocity, neighbourhood density, and Homogeneity index.	• The CH is chosen based on standard deviation of relative velocity, neighbourhood density and Homogeneity index. • The other vehicles in the rang of CH are considered as CM.

Table 2.5: Summary of previous studies considering routing algorithm and performance

Protocol	Performance metrics	Routing algorithm	Scalability	Remarks	Demerits
CRB, 2017	Delay time and delivery ratio	• Source is the first CH and it broadcasts emergence messages to CM. • CM sends ACK packet to source. • Source broadcasts Response packet to the farthest CM to re-broadcast message.	High	Improved PDR over density is increased and reduced communication overhead	It is only compared with flooding technique
CRA, 2016	Average end-to-end delay	• Each node broadcasts its neighbor table periodically via hello packets. • Each CH keeps information about neighbor clusters in cluster adjacency table.	Middle	Substantially reduced End-to-End delay	Other metrices should be considered like PDR
IBCAV, 2013	Packet delivery ratio, end-to-end delay and throughput	• Store-Carry-Forward is used to send the message. • When a CH is outside the communication range of the intended CH, it stores the message. • When a CH enters into the communication range of the intended CH, it transmits a Hello message to that CH.	High	Improved PDR	• PDR decreases as the speed of vehicles increases • Short highway length is considered for performance evaluation
CFSR, 2018	End-to-end delay, Packet drop ratio	• Establish the routing path for data transmission by assessing link quality and assigning weight to each link. • The weight can be directly used as the link quality metric to establish an optimal routing path	Middle	Reduced overhead	• Overhead increases in local coordinator selection • The strength of the algorithm is compared with old schemes
CRP-TI, 2018	End-to-End delay and packet delivery ratio	• Uses ontology to represent knowledge of vehicles and traffic. • Knowledge is integrated directly into each vehicle. • A learning phase is essential for each vehicle. • Collects information and replenish the map to allow proper routing of packets to their final destinations.	Low	Improved PDR	When network size increases, the end-to-end delay increases slightly

DCCR, 2020	packet delivery ratio and end-to-end delay	• CM passes the packet to the CH. • CH checks whether the destination is in its member list or not. • If so, then CH sends the message to the destination, or the CH forwards the packet towards the destination.	High	Significant improvement in PDR and end-to-end delay	It has been compared with a protocol that has been designed for desert scenario

2.8 Simulation Techniques

A simulation approach is a method for simulating real-world scenarios by establishing a system employing both software and mathematical models. It is a mechanism, rather than technological advancement, that aids in providing a clearer perspective into real events by fabricating characteristics from a standpoint of practicality. It can be used to forecast how the system will behave in the future. Additionally, it enables testing in many scenarios without using an actual test system. Researchers can test out scenarios that would be difficult or expensive to model in the actual world using a network simulator. It's very helpful for testing new networking protocols or for making changes to the current protocols in a regulated and repeatable environment. Diverse sorts of nodes can be used to create various network topologies (hosts, hubs, bridges, routers and mobile units). Given that the network topology is just a set of simulation parameters, the routing behavior can therefore be easily explored in various topologies. The vast majority of currently accessible networks simulation toolkits are built on the discrete event-based simulation paradigm [75].

Given the complexity of the VANET infrastructure, it is imperative to create realistic models in order to get acceptable results from VANET simulation. For example, simulators must simulate both mobility patterns and communication protocols. In this section, we go through the core network and mobility components of the most popular VANET simulators.

- Mobility simulators: A mobility model that accurately captures the behavior of vehicles in traffic. It is essential for a simulation study of VANETs. Mobility simulators are mostly used to create a vehicle movement pattern along a predetermined path. SUMO [76], and SimMobility [77] are examples of mobility simulators.
- Network simulators: To model the transmission of messages between linked nodes, a network simulator is utilized. This typically involves wireless communications and, in the case of a VANET, also typically requires vehicles and RSUs. The communication system should ideally have all of its components modeled, and later other important metrics will be added to the simulation. Both network elements and events are described by the network model. The network elements include things like links, nodes, switches, and routers. Also, the network events include packet failures and data transmissions. The output from a network simulator typically consists of network level measurements, link metrics, and device metrics for a specific

simulated scenario. Trace files also use to be existed. Such files can be used for additional studies and provide a record of every simulation occurrence. Examples of network simulators include OMNeT++ [78], NS3 [79], and NS2 [80], some of which are used in VANETs.

- VANET simulators: Network and mobility simulations are used to form VANET simulators [81]. While mobility simulators are in charge of each node's movement, or mobility, network simulators are in charge of modeling communication protocols and the exchange of messages.

2.8.1 NS-3

Network Simulator Version 3 (NS-3) is an open-source discrete event network simulator. It is not a modified version of Network Simulator Version 2 (NS-2) but rather a simulator that was created from the ground up and is still in development [82].

The NS-3 simulator is written in C++ and Python; networks can alternatively be constructed in python, and some simulation components may be performed in pure C++. The object-oriented tool command line (OTCL) APIs used by NS-2 simulators are not used by NS-3 simulators. Hardware can connect to the NS-3 simulator to imitate the network using sockets, and NS-3 supports both simulation and emulation techniques. The generation of traces by NS-3 aids in the debugging of the simulation results. The realistic environment and well-structured source code of the NS-3 simulator are also offered [82].

2.8.2 OMNeT++

OMNeT++ is an open-source discrete event simulator built on C++ [83]. It is a modular, extendable framework that is mostly used to create network simulators. Model frameworks provide several forms of domain support, which are created by distinct projects and include sensor networks, wireless Ad Hoc networks, performance modeling, and Internet protocols. It provides a graphical environment called the Eclipse Integrated Development Environment (IDE). A component (module) architecture for models is provided by OMNeT++ and is based on C++. With the use of a Network Description Language (NED), these modules are combined into larger modules. The modular design of the simulation engine enables integration into any application [83].

2.8.3 SUMO

The Germany Aerospace Center DLR created the open-source road traffic simulator known as SUMO [84]. It offers traffic system simulation for autos, pedestrians, and public transportation. It can be altered to fit our needs in order to create the required simulation map. The files can be altered according to our needs because they are written in extensible markup language (XML). For configuring intersections, edges, connections, and routes for various vehicles, there are numerous files available.

2.8.4 Veins

Veins is an open-source framework for doing simulations of vehicle networks [85]. It is based on SUMO and OMNeT++. For each vehicle included in the simulation, the simulator creates an OMNeT++ node, and then it matches node movements to vehicle movements in the road traffic simulator (i.e., SUMO). In this situation, it is possible to execute in parallel network and mobility simulations. This is made feasible by the Traffic Control Interface (TraCI), a standardized communication protocol that achieves bidirectional coupling [86]. As part of TCP connections, TraCI enables OMNeT++ and SUMO to exchange messages (such as those providing mobility traces) while the simulation is running [87]. In veins, DSRC Channel 178 is designated for CCH, while Channel 174 is designated for SCH. Figure 2.7 illustrates the modular design of Veins.

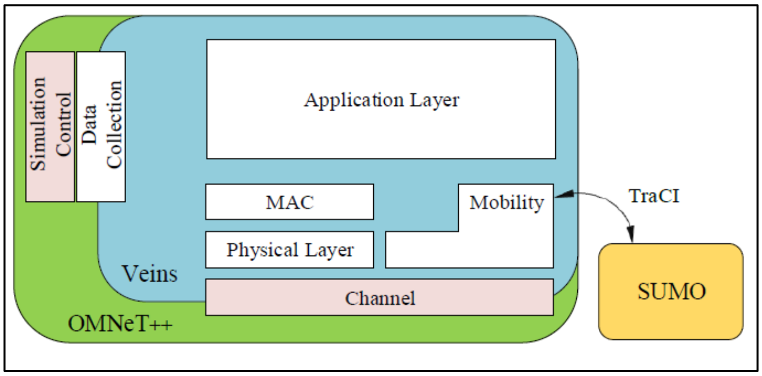


Figure 2.7: Veins Modular Structure [88]

The simulator has numerous extensions that enable simulation of various protocol stacks, including applications and IEEE 802.11p and ETSI ITS-G5. In conclusion, Veins is created to act as an environment in which user-written programs can be executed, making it easier to simulate new environments and applications. The drawback is that it requires the proper operation of SUMO and OMNeT++ in order to get accurate results. Any flaw in one of those can lead to inaccurate results from Veins. Veins is compatible with Mac OS, Windows, and Linux [85].

The SUMO mobility generator and OMNeT++ network simulator are integrated during the simulation run to create the full design view of the network simulator. VEINS was chosen because to the following characteristics: Adapting online car configuration and routing to network simulator, models of the DSRC/WAVE and IEEE 1609.4 network layers in great detail Supporting user comfort, connectivity, and a realistic map with realistic traffic. Through the use of a TCP socket, VEINS permits the concurrent operation of two simulators. VEINS framework was created using MiXiM as a basis. For OMNeT++, full models of wireless channels, connection, mobility, and MAC layer protocols are provided by MiXiM, a framework for simulating wireless channels. Additionally, SUMO is a free, open-source tool for simulating continuous and microscopic road traffic that is made to manage extensive road networks. Additionally, SUMO accepts formats from several sources of maps [85].

2.9 Chapter Summary

This chapter started with an overview and an introduction to MANETs and VANETs. Then this chapter highlights the details of the VANET routing protocols: broadcast routing protocols, topology-based routing protocols, infrastructure-based routing protocols, position-based routing protocols, and cluster-based routing protocols. then a literature review of the clustering VANET routing protocol is done. Finally, the simulation techniques used to simulate VANET were discussed.

Chapter 3: Proposed VANET Routing Protocol

3.1 Overview

In VANET, the scalability is considered a major challenge because of increasing the number of nodes will increasing the node density which means more route breakage occurs due to large number of collisions can happen because of the absence of central coordinator in this kind of network [89]. Many proposed protocols are handling the scalability issue in this kind of network and improve the effectiveness of communication between various VANET components like RSU, OBU. One of the common technics to solve the scalability issue in VANET is the cluster-based routing protocol.

Clustering approach plays an important role in making this highly dynamic topology more stable and improve scalability in VANET [90]. Where a group of vehicles form a cluster with a Cluster Head (CH) which is accountable for intra and inter-cluster communication and the other vehicles consider as the Cluster Members (CM). Any clustering technique must carefully choose its CH, who will be in charge of coordinating communications with other clusters and RSU. For intra-cluster communication within each cluster, the CH is connected through direct link and for inter-cluster communication, the CH is connected through other CHs or gateway nodes [90]. By using clustering, it is the CH responsibility to find the route to destination after formatting the clusters. This means that the routing overhead is reduced and the scalability is increased.

Numerous factors can be taken into account while choosing a CH. In this thesis, we choose the CH based on different factors including the position and the average speed of the vehicle. This selection of the CH can be useful as shown below:

1. Increasing throughput
   Obtaining stable clusters during the transmission is one of the objectives of the clustering technique. It provides consistent connectivity for all CM to its CH, which serves in enhancing the system's overall throughput.
2. Decreasing inter-packet delay
   Increased packet transmission latency may result from increased inter-vehicle communication [91]. By using the clustering technique, we can reduce the inter-packet delay because clustering offers reduced communications within clusters. The inter-cluster and intra-cluster communications by CH are the reason for this.
3. Improving the packet delivery ratio
   Stable clusters, as was previously mentioned, can offer steady links between CH and CMs. In the end, it can decrease data collision and boost bandwidth availability. We can create stable clusters using the fixed cluster technique, which can provide the system more PDR.
4. Study the performance of the network in case of existing of clustering and when no clustering technic is applied.
5. Study the influence of increasing the number of clusters.

3.2 Assumptions

We assume that the VANET is located in a two-dimensional area of (A * B) m^2. N of vehicles node are distributed randomly in this area and moving, as shown in Figure 3.1.

Figure 3.1: Area (A* B) m^2 with N vehicles

In this thesis, we employ a fixed cluster architecture in which the entire road network is split into adjacent segments and is managed by RSUs, as illustrated in Figure 3.2.

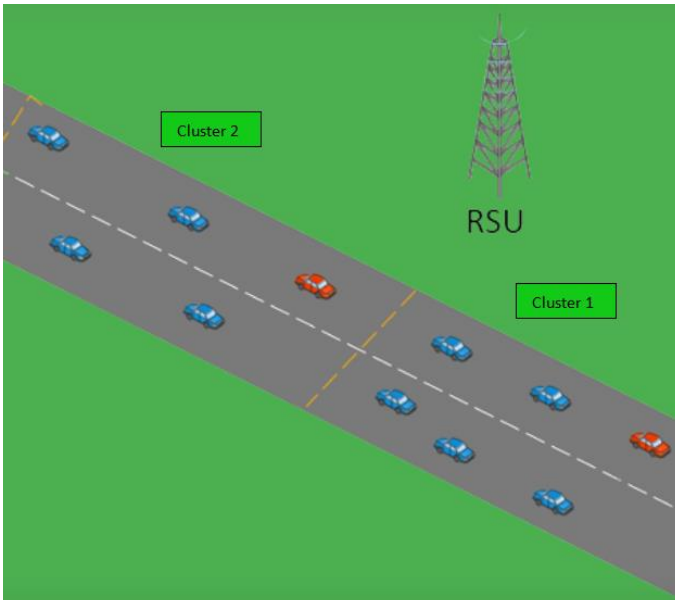
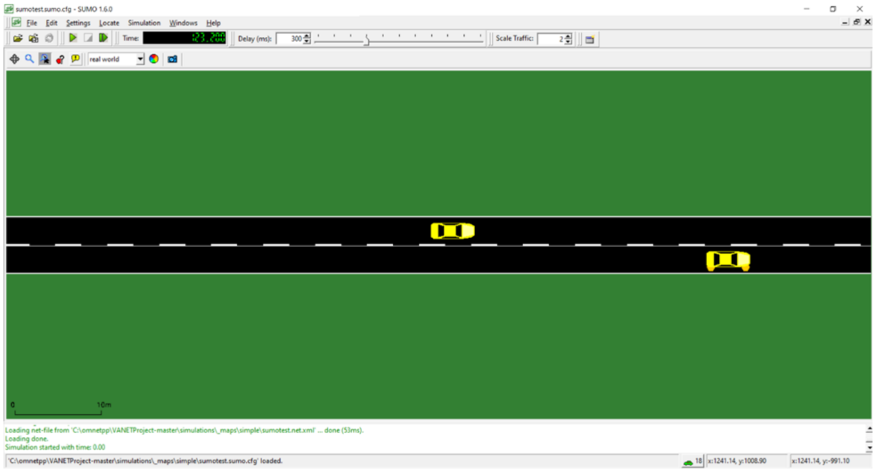


Figure 3.2: Fixed Clusters on the road

In our model we assume the following:

1. There is enough existing infrastructure to separate the road network into adjacent sections without any gaps.
2. Right now, we simply take into account "straight" road stretches.
3. We take into account two-lane, unidirectional traffic, as shown in Figure 3.3.
4. Each vehicle has a satellite positioning system (GPS) that records its position and periodically gathers velocity and direction data.
5. Each vehicle is aware of its geographic information, and the cluster’s boundaries and cluster's own identification information which are periodically broadcast by the RSU.
6. Each vehicle belongs to only one cluster at a time.

7. Every vehicle and cluster have its own individual ID’s.
8. We assume that every deployed RSU has a VANET device for wireless V2I/V2V connection and traffic data gathering. The communication method makes use of 75 MHz of Dedicated Short-Range Communications (DSRC) spectrum at 5.9 GHz that was allotted by the U.S. Federal Communication Commission and is only utilized for V2V and V2I communications [92].



Time: 23.200
Delay (ms): 300
Scale Traffic: 2

```
Loading net-file from 'C:\omnetpp\VANETProject-master\simulations\_maps\simple\sumotest.net.xml' ... done (53ms).
Loading done.
Simulation started with time: 0.00
```

```
'C:\omnetpp\VANETProject-master\simulations\_maps\simple\sumotest.sumo.cfg' loaded.
x:1241.14, y:1008.90
x:1241.14, y:-991.10
```

Figure 3.3: SUMO road structure with vehicles

3.3 Clustering Processes

In this section, we go over the three key procedures for updating and managing clusters. The procedure for joining and departing a cluster as well as the choice of the CH.

A CH is in charge of managing information transit inter-cluster and passing packets. A perfect cluster selection will provide a high level of stability and effective network performance. In order to achieve high cluster stability, we propose a new method in this thesis for choosing the CH that takes into account the position and velocity of the vehicles.

A. Choosing the CH: The CH for each cluster is chosen by the RSU depending on the position of the vehicles and their speeds. Where each vehicle periodically transmits a HELLO message, RSU receives the HELLO message from vehicles and uses this information to determine the CH of each cluster. The first vehicle in the cluster with the lowest speed is regarded as the CH. When a new CH is chosen, the selected vehicle resumes its CH duties.
   - The CH is chosen from the collection of vehicles V currently existing in that cluster.
   - To choose the vehicle as a CH its position (x, y) should be at the beginning of the cluster to stay as long as possible in the cluster to guarantee cluster stability, it can be calculated based on the present positions (x, y) of vehicle V and the cluster boundary that is in behind of the vehicle by taking the difference between the boundary position and the vehicle position.

Where the closer vehicle to the boundary will probably stay in the cluster for longer time than other vehicles. This makes it a better option for CH, as choosing a new CH would require more overhead if the CH were to depart the cluster.

- Vehicles' relative speeds are calculated by the absolute differences in the vehicle speed and the mean average speed of all vehicles in the cluster. Where the maximum absolute difference means that vehicle has the lowest speed compared to other vehicles in the cluster. In general, it is preferable for the CH to travel at a minimum speed that is comparable to other vehicles since it means that it will serve as the CH as long as possible.
- The RSU will depend in electing the vehicle as CH on the minimum CH_i value for each vehicle with different speed and position. Smaller CH_i will be chosen as CH, where the CH_i as below:

$$CH_i = \text{distance from the cluster bounary} + \text{vehicle relative speed}$$

  - Example of selecting a vehicle as CH by RSU:

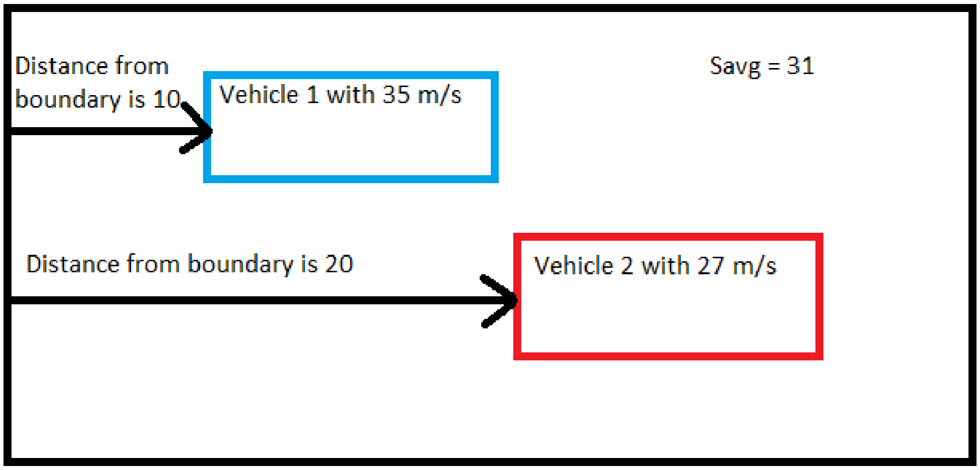


Figure 3.4: Example of CH selection

$CH_1 = |31 - 35| + 10 = 14$
$CH_2 = |31 - 27| + 20 = 24$
The vehicle with CH_1 is will be the selected CH by the RSU, because it has the minimum CH_i value.

B. Joining a cluster: A vehicle will send a HELLO message when it enters a new cluster since it is aware of the limits and identification of each cluster. And it will be regarded as a member of the cluster after CH has acknowledged it. If not, it will ask the RSU to launch a new cluster head election procedure.

C. Departing a cluster: When a vehicle V leaves the cluster, it is not necessary for it to expressly tell the RSU or cluster head, it is considered out of the cluster if:

- No beacons are received from V for a predetermined amount of time, then V is removed from the cluster.
- V's location is outside the cluster even though the CH or RSU gets a beacon from V.

The RSU is going to make the clustering process as shown in Figure 3.5.

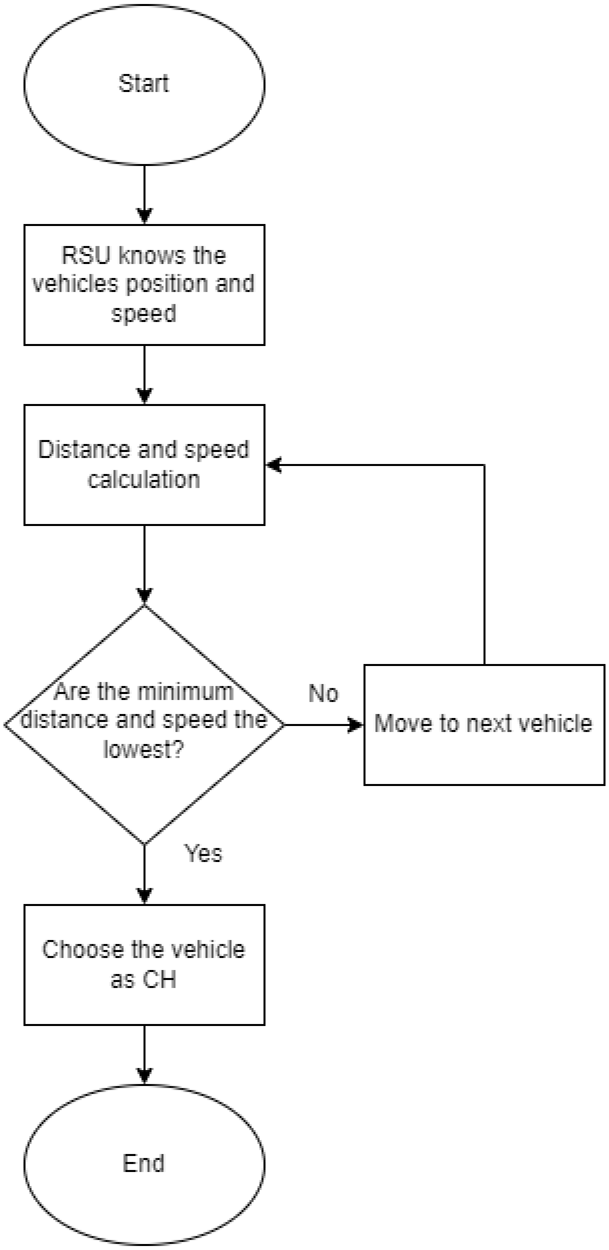


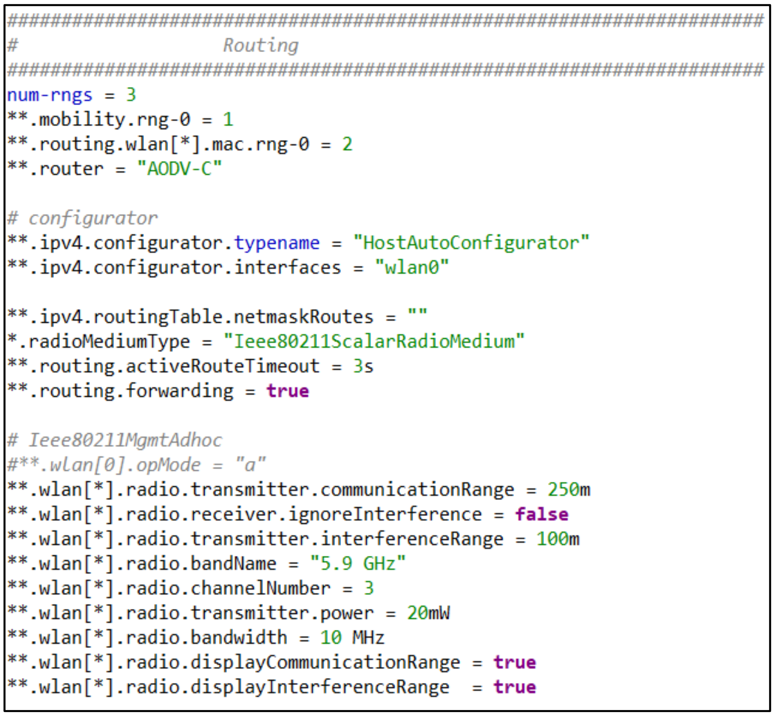
Figure 3.5: Cluster process by the RSU

As shown in Figure 3.5, the RSU constructs the set (V) of all the vehicles in the cluster. The periodic safety beacons that are broadcast by all vehicles can be used to determine this. A few key parameters are being set up, such as the number of vehicles currently exist in the cluster and the average speed of the vehicles. These safety beacons also provide the position (x, y) and speed for each vehicle V.

Every vehicle V in the cluster is assessed the suitability to be CH. Based on its current location and where the cluster boundary is, the vehicle V calculates the remaining distance to the boundary. The RSU is aware of both of these factors, as was already explained. The vehicle with the lowest speed and minimum distance is chosen as the CH of the cluster by the RSU after all the vehicles have been taken into account, and a notification is delivered in that direction.

3.4 Routing Processes

How to route data packets is a significant difficulty because of unpredictable vehicle mobility. Based on the vehicle's position data, a routing strategy is developed. We used the AODV-C for routing packets between V2V and V2I as shown Figure 3.6:



```
######################################################################
#                   Routing
######################################################################
num-rngs = 3
**.mobility.rng-0 = 1
**.routing.wlan[*].mac.rng-0 = 2
**.router = "AODV-C"

# configurator
**.ipv4.configurator.typename = "HostAutoConfigurator"
**.ipv4.configurator.interfaces = "wlan0"

**.ipv4.routingTable.netmaskRoutes = ""
*.radioMediumType = "Ieee80211ScalarRadioMedium"
**.routing.activeRouteTimeout = 3s
**.routing.forwarding = true

# Ieee80211MgmtAdhoc
#**.wlan[0].opMode = "a"
**.wlan[*].radio.transmitter.communicationRange = 250m
**.wlan[*].radio.receiver.ignoreInterference = false
**.wlan[*].radio.transmitter.interferenceRange = 100m
**.wlan[*].radio.bandName = "5.9 GHz"
**.wlan[*].radio.channelNumber = 3
**.wlan[*].radio.transmitter.power = 20mW
**.wlan[*].radio.bandwidth = 10 MHz
**.wlan[*].radio.displayCommunicationRange = true
**.wlan[*].radio.displayInterferenceRange  = true
```

Figure 3.6: AODV-C routing configure

AODV-C defines five types of control messages for route discovery and maintains, HELLO message, route request (RREQ) message, route reply (RREP) message, route error (RERR) message, and route reply acknowledgment (RREPACK) message.

- HELLO message: The network starts with exchanging HELLO message among all vehicles to announce their existence in the network.

Vehicle ID	Vehicle Velocity	Vehicle Position	Neighbour List	Vehicle Status

Figure 3.7: Hello packet structure

- RREQ: The route request message is used by a source vehicle that does not have any routing information for the destination vehicle in its routing table. RREQ messages won't be broadcast to all vehicles; instead, they will be routed to CHs. Therefore, CH will disseminate information about routing among CMs.

Hop Count	RREQ Id	Destination IP Address	Destination Sequence Number	Source IP Address	Source Sequence Number

Figure 3.8: RREQ packet structure

- RREP: If an intermediate vehicle receiving the RREQ has a valid route to the requested address or is the destination itself, it responds with a route reply message. Vehicles will receive RREP packets if CHs do not already have them.

Hop Count	Destination IP Address	Destination Sequence Number	Source IP Address	Life Time

Figure 3.9: RREP packet structure

- RERR: When a vehicle notices a link breakage in an active route, a route error message is used. Each vehicle keeps a list of its neighbours' IP addresses that it is expected to utilize as a next hop to go to each destination. This list is called a precursor list. A RERR message is used to alert other vehicles of a broken link when it is discovered on an active route.
- RREPACK: In response to an RREP message, the Route Reply Acknowledgment RREPACK message must be delivered.

This will result in a significant reduction in the amount of control messages (RREQ) needed to find a route, which will reduce congestion and reduce network overhead across the network. A performance improvement for AODV-C is achievable in this context.

Routing using AODV-C is done by mainly two processes:

- Route Discovery Process:
    - The CH uses the source routing to route packets to destination.
    - When a CM needs to create a link, it contacts the CH with a request RREQ.

  - Following receipt RREP of the request RREQ, the CH confirms whether or not the requested vehicle is a part of the cluster. If both vehicles are in the same cluster, the CH locates the source and destination vehicles' positions in its table before beginning the process of choosing the optimum route based on the source and destination positions.
  - The CH transmits the information to the RSU to route the packets if the vehicle is not a member of the cluster.
  - If the source and the destination in two different clusters with the same RSU, when the CH finds that the destination vehicle is not a part of their CM, it passes the request to its RSU and if it is in the RSU table, then the RSU pass it to the CH with this destination vehicle. If the destination vehicle is not in the RSU table (means that the source and the destination in two different clusters with different RSU) it passes it to the next RSU as shown in Figure 3.10.

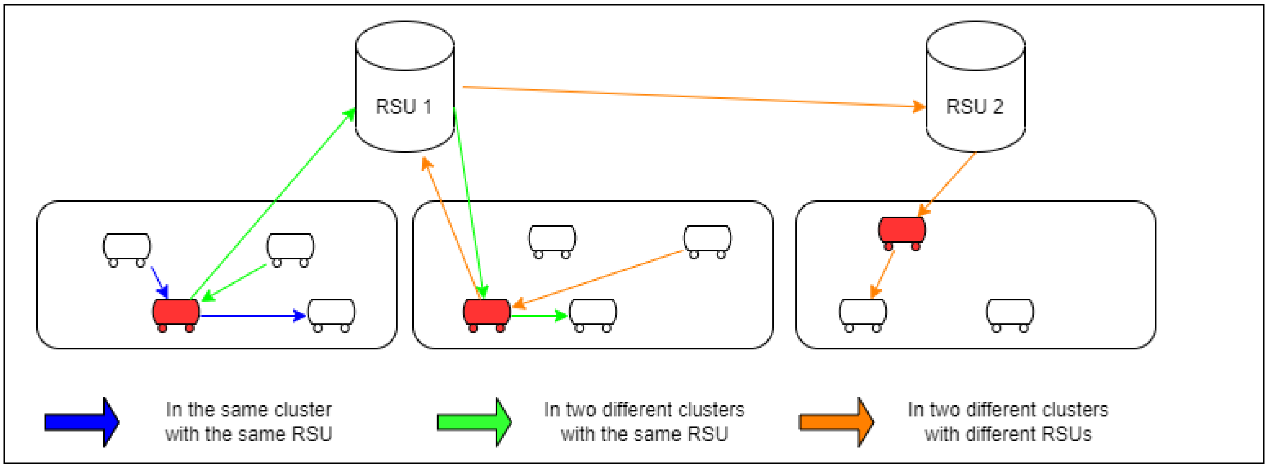


Figure 3.10: Routing process

- Route Maintenance Process:
  When a link breaks, the maintenance process for the route begins. Links can break because the network's vehicles are in moving. A vehicle will detect a connection breakdown and mark the entry for that neighbour in the table as invalid if it does not receive a HELLO message from one of its neighbours for a certain interval of time known as the HELLO interval. To let other vehicles, know about this link breaking, the RERR message will be generated. When a failure happens, RRER notifications alert all vehicles utilizing the network.

3.5 AODV and AODV-C Routing Algorithms

The AODV routing protocol is a reactive routing protocol; routes are established only when needed. AODV uses less bandwidth because it only operates when needed.

Each mobile node in this protocol detects other nearby nodes by flooding or by receiving a local broadcast called an RREQ message. The routing tables of the nearby nodes are now updated with the response time of local movements to give an immediate response to the requester for creating new routes. This routing protocol's primary goals are:

1. To broadcast RREQ packets and get acknowledgement.
2. To distinguish between local connectivity management and overall topology maintenance.
3. To alert nearby mobile nodes to changes that may happen in the local connection.

A large number of control packets are sent throughout the network by AODV during the route discovery process, and as a result, a large number of unused routes between the source and destination are discovered. This turns into a significant flaw in AODV since it increases routing overhead and consumes up node power and bandwidth.

In this thesis, we suggested a more effective AODV routing technique for VANETs by applying clustering approach to AODV where the RREQ message will be sent to CH instead of broadcasted among all vehicles. Clustering maintenance in AODV-C according to two different parameters for CH election: first parameter is the average speed of the vehicle, and the second one is the position of the vehicle. Therefore, CH will disseminate information about routing among CMs. If the route is available, RREP packets will be sent to the vehicles; otherwise, CHs will receive RREQ messages. This will result in a significant reduction in the number of control messages (RREQ) needed to find a route, which will reduce congestion and lower network overhead across the network. In this situation, AODV performance increase is possible.

In Table 3.1 we compare the properties of the AODV and AODV-C.

Table 3.1: Studied protocols characteristics

Performance parameter	AODV	AODV-C
Reliability	Low	High
Latency	High	Low
Energy	High	Medium
Hop count	Medium	High
Control packet	High	Medium

One of the main problems of AODV is that it uses a lot of network bandwidth, generates a lot of control packets when a link fails, and has lower QoS as the network density rises. In AODV-C we reducing the number of control messages sent during the route discovery process, the proposed AODV-C improves AODV. The network nodes are clustered in the optimization approach, and CH control routing. By sending RREQ packets to CH’s instead of broadcasting them, AODV-C successfully lowers the control message flood that occurs during the route discovery process and increases reliability.

3.6 Chapter Summary

This chapter describes the basic model for the proposed routing protocol and how it works. In addition to that, it detailed the how the clustering and the routing will happen.

Chapter 4: Experiments Results and Analysis

4.1 Overview

This chapter, the performance of AODV-C is studied and compared with the benchmark AODV using different metrices. In order to provide a fair comparison, the same scenarios files were executed for the two routing protocols.

Using the OMNeT++ simulator, the AODV-C is tested against AODV routing methods under various networking conditions (mobility speed, node density, number of clusters, network sizes, and local traffic percentage).

The routing performance is measured by calculating the packet delivery fraction, number of control packets transmitted per data packet delivered, average path length and average route latency.

This chapter is organized as follows: Section 4.2 presents simulation environment, Section 4.3 introduces details of performance evaluation metrics, Section 4.4 presents the results of the simulation, Section 4.5 presents the results discussion and a chapter summary is provided in Section 4.6.

4.2 Model for Simulation

OMNeT++ which is a simulator for object-oriented modular discrete event networks is chosen to simulate the AODV-C. Because of its component-based architecture, OMNeT++ may support additional features and protocols through modules. Through the independently created Mobility Framework and INET Framework modules, OMNeT++ enables network and mobility models. Extensions are available for several functions, including real-time simulation, network emulation, database integration, SystemC integration, and others. The international scientific community already uses the open platform OMNeT ++ extensively.

A broad selection of simulation libraries, procedures for controlling these libraries, and a user interface for designing, running, and debugging simulations are all provided by OMNeT ++.

The stages of an OMNeT++ simulation model are as follows:

- Using the NED language, define the topology and structure that will be simulated, including the modules and connections.
- C++ definition of distinct modules, which serve as the model's active components.
- Compiling modules and connecting them to the simulation library.
- Specification of the simulation's specific parameters.

The logical structure of an OMNeT++ simulation program is depicted in Figure 4.1 [93].

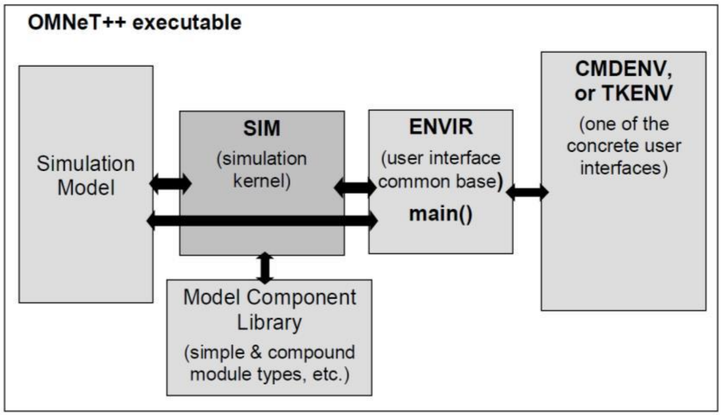


Figure 4.1: Logical Architecture of an OMNeT++ Simulation Program [93]

Packet INET: The INET framework is based on the OMNeT ++ platform and employs the same operating style, i.e., message passing between modules. It includes implementations of the TCP, SCTP, UDP, TCPv4, and IPv6 protocols as well as other application models.

An OMNeT++ modeling framework called MiXiM was developed for fixed and mobile wireless networks (wireless sensor networks, body area networks, ad-hoc networks, vehicular networks, .). It provides thorough radio wave propagation models. With the model, which is utilized in the simulation VEINS framework, it is possible to evaluate the impact that structures and other impediments have on inter-vehicular communication. The model is based on actual measurements using 802.11p/DSRC devices.

SUMO is designed to simulate a city-sized road network with heavy traffic. Since the simulation is multi-modal, public transportation systems on the street network, including alternate train networks, as well as car movements within the city, are also modeled. In the case of SUMO, each vehicle's traffic flow within the simulated network is independently represented and has a specific location and speed. These values are updated every 1 second time step based on the car in front of it and the roadway network it is traveling on. In SUMO, street cars are simulated in a time-discrete and continuous space. The driver-car model is continuous, as well.

Access to a road traffic simulator, in this case SUMO, is provided by TraCI. TraCI enables online behavior manipulation and value retrieval for virtual objects. TraCI, which serves as a server and has OMNeT++ as its client, may be accessed using a TCP client-server architecture. A client connects to SUMO by establishing a TCP connection to the designated SUMO port after SUMO has been started.

A daemon that acts as a proxy is called sumo-launchd. It accepts OMNeT++ and SUMO TCP connections.

The state of the simulation SUMO is controlled by OMNeT++ using the TCP protocol, which also affects how the vehicles behave. The commands are then carried out by SUMO, which responds with information mobility vehicles to simulate OMNeT++. As a result, SUMO only executes commands once OMNeT++ has completed all simulation procedures and terminated the TCP session.

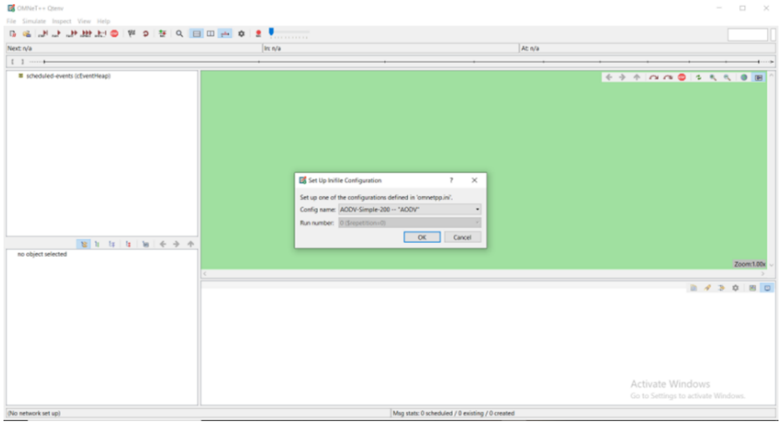
We integrate the Vehicles in Network Simulation (VEINS) framework, OMNeT++ and SUMO. A TCP socket is used to connect SUMO and OMNeT++, enabling simulation that is coupled in both directions. Additionally, VEINS has great DSRC/WAVE standard support. A website repository called OpenStreetMap (OSM) has real-world traffic maps. Road networks are imported using OSM. In our simulations, vehicle communication occurs in two stages: first, broadcast (HELLO) messages are sent, and then, after connecting to CH and CMs, data messages (Request and Reply) are sent.

4.3 Simulation Environment

Running SUMO version 1.6.0, OMNeT++ 5.5.1, Inet 4.2.1, and VEINS version 5.0 allowed us to build up the simulation. The vehicles are randomly distributed in the road. The MAC layer protocol is IEEE 802.11, with transmitter communication Range 250m, transmitter interference Range 100m, radio band of "5.9 GHz" and band width of 10 MHz and radio transmitter power with 20mW.

Five parameters were varied (vehicle speed, vehicle density, number of clusters, network sizes, and local traffic percentage) to examine their effects on the protocols. To compare the suggested technique with AODV, five separate experiments were used in the simulation.

- The first experiment investigated how the nodes' speed (or mobility) affects the studied protocols worked. Four different node speeds have been considered: 14 m/s (50 km/h), 20 m/s (72 km/h), 28 m/s (100 km/h) and 35 m/s (126 km/h) [74].
- In the second experiment, different node densities were used to examine how node density affects the performance of proposed protocol and AODV. The networks used 100, 150, 200 and 300 vehicles.
- The number of clusters have been varied in the third experiment as the 2, 4 and 8.
- In the fourth experiment we change the simulation area size as 2500m * 200m, 3000m * 200m, and 3500m * 200m.
- In the fifth experiment the effect of local traffic percentage has been studied.



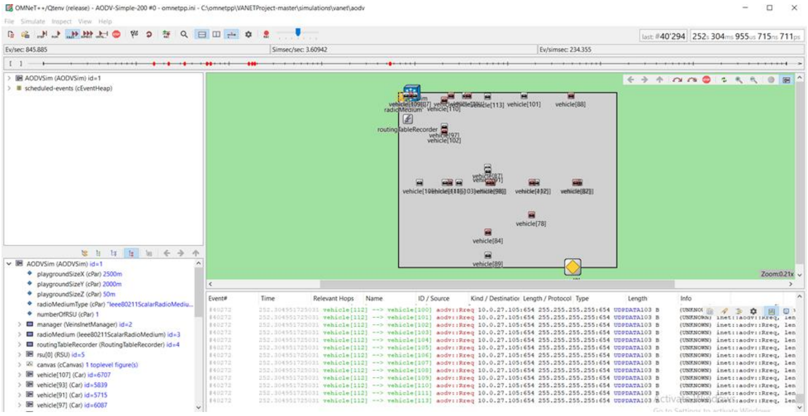
Set Up Inifile Configuration

Set up one of the configurations defined in 'omnetpp.ini'.

Config name: AODV-Simple-200 -- "AODV"

Run number: 0 ($repetition=0)

Figure 4.2: Starting the SUMO scenario



- AODVSim (AODVSim) id=1
  - playgroundSizeX (cPar) 2500m
  - playgroundSizeY (cPar) 2000m
  - playgroundSizeZ (cPar) 50m
  - radioMediumType (cPar) "Ieee80211ScalarRadioMediu...
  - numberOfRSU (cPar) 1
  - manager (VeinsInetManager) id=2
  - radioMedium (Ieee80211ScalarRadioMedium) id=3
  - routingTableRecorder (RoutingTableRecorder) id=4
  - rsu[0] (RSU) id=5
  - canvas (cCanvas) 1 toplevel figure(s)
  - vehicle[107] (Car) id=6707
  - vehicle[93] (Car) id=5839
  - vehicle[91] (Car) id=5715
  - vehicle[97] (Car) id=6087

```
Event#   Time              Relevant Hops                      Name          ID / Source          Kind / Destination      Length / Protocol Type   Length   Info
#40272   252.304951725031  vehicle[112] --> vehicle[100]  aodv::Rreq  10.0.27.105:654  255.255.255.255:654  UDPDATA103 B  (UNKNO
#40272   252.304951725031  vehicle[112] --> vehicle[101]  aodv::Rreq  10.0.27.105:654  255.255.255.255:654  UDPDATA103 B  (UNKNOWN) inet::aodv::Rreq, len
#40272   252.304951725031  vehicle[112] --> vehicle[102]  aodv::Rreq  10.0.27.105:654  255.255.255.255:654  UDPDATA103 B  (UNKNOWN) inet::aodv::Rreq, len
#40272   252.304951725031  vehicle[112] --> vehicle[103]  aodv::Rreq  10.0.27.105:654  255.255.255.255:654  UDPDATA103 B  (UNKNOWN) inet::aodv::Rreq, len
#40272   252.304951725031  vehicle[112] --> vehicle[104]  aodv::Rreq  10.0.27.105:654  255.255.255.255:654  UDPDATA103 B  (UNKNOWN) inet::aodv::Rreq, len
#40272   252.304951725031  vehicle[112] --> vehicle[105]  aodv::Rreq  10.0.27.105:654  255.255.255.255:654  UDPDATA103 B  (UNKNOWN) inet::aodv::Rreq, len
#40272   252.304951725031  vehicle[112] --> vehicle[106]  aodv::Rreq  10.0.27.105:654  255.255.255.255:654  UDPDATA103 B  (UNKNOWN) inet::aodv::Rreq, len
#40272   252.304951725031  vehicle[112] --> vehicle[107]  aodv::Rreq  10.0.27.105:654  255.255.255.255:654  UDPDATA103 B  (UNKNOWN) inet::aodv::Rreq, len
#40272   252.304951725031  vehicle[112] --> vehicle[108]  aodv::Rreq  10.0.27.105:654  255.255.255.255:654  UDPDATA103 B  (UNKNOWN) inet::aodv::Rreq, len
#40272   252.304951725031  vehicle[112] --> vehicle[109]  aodv::Rreq  10.0.27.105:654  255.255.255.255:654  UDPDATA103 B  (UNKNOWN) inet::aodv::Rreq, len
#40272   252.304951725031  vehicle[112] --> vehicle[110]  aodv::Rreq  10.0.27.105:654  255.255.255.255:654  UDPDATA103 B  (UNKNOWN) inet::aodv::Rreq, len
#40272   252.304951725031  vehicle[112] --> vehicle[111]  aodv::Rreq  10.0.27.105:654  255.255.255.255:654  UDPDATA103 B  (UNKNOWN) inet::aodv::Rreq, len
#40272   252.304951725031  vehicle[112] --> vehicle[113]  aodv::Rreq  10.0.27.105:654  255.255.255.255:654  UDPDATA103 B  (UNKNOWN) inet::aodv::Rreq, len
```

Figure 4.3: Running the AODV example

Figure 4.2 and Figure 4.3 show the running process of Veins, SUMO and OMNeT++.

In our simulation, the OMNeT++ parameters listed in Table 4.1 below are used in:

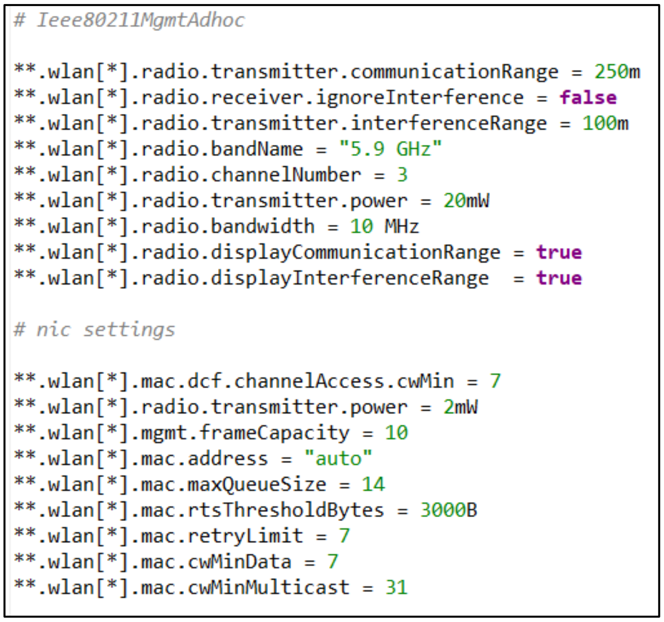
Table 4.1: OMNeT++ parameters value

Parameter	**Value**
Simulator version	OMNeT++ 5.5.1
MAC layer protocol	IEEE 802.11
Channel type	5.9 GHz
Packet size	32 bytes
Transmission Power	20 mW
Transmission Rate	2 Mbps
Simulation time	6000 sec
Radio range	250
Speed of nodes	14, 20, 28, 35 m/s
Number of vehicles	100, 150, 200, 300

Number of clusters	2, 4, 8
Simulation area	2500*200m^2, 3000*200m^2, 3500*200m^2
Local traffic percentages	0%, 40%, 100%

```
##########################################################
#            Simulation parameters                       #
##########################################################
debug-on-errors = true
print-undisposed = false

sim-time-limit = 6000s

**.scalar-recording = true
**.vector-recording = true

##########################################################
#            VeinsInetManager parameters                 #
##########################################################
*.manager.updateInterval = 1s
*.manager.host = "localhost"
*.manager.port = 9999
*.manager.autoShutdown = true

*.manager.moduleType = "vanetsim.simulations.vanet._nodes.Car"
*.manager.moduleName = "vehicle"
#*.manager.moduleDisplayString = ""
```

Figure 4.4: Setting the simulation parameters



```
# Ieee80211MgmtAdhoc

**.wlan[*].radio.transmitter.communicationRange = 250m
**.wlan[*].radio.receiver.ignoreInterference = false
**.wlan[*].radio.transmitter.interferenceRange = 100m
**.wlan[*].radio.bandName = "5.9 GHz"
**.wlan[*].radio.channelNumber = 3
**.wlan[*].radio.transmitter.power = 20mW
**.wlan[*].radio.bandwidth = 10 MHz
**.wlan[*].radio.displayCommunicationRange = true
**.wlan[*].radio.displayInterferenceRange  = true

# nic settings

**.wlan[*].mac.dcf.channelAccess.cwMin = 7
**.wlan[*].radio.transmitter.power = 2mW
**.wlan[*].mgmt.frameCapacity = 10
**.wlan[*].mac.address = "auto"
**.wlan[*].mac.maxQueueSize = 14
**.wlan[*].mac.rtsThresholdBytes = 3000B
**.wlan[*].mac.retryLimit = 7
**.wlan[*].mac.cwMinData = 7
**.wlan[*].mac.cwMinMulticast = 31
```

Figure 4.5: Setting the VANET parameters

Figure 4.4 and Figure 4.5 shows the OMNeT++ parameters setting.

The environments parameters that used to make many scenarios of the network is shown in Table 4.2:

Table 4.2: Parameters values for testing out proposed routing protocol.

Vehicles speed	Vehicle number	Clusters numbers	Network sizes	Local traffic percentages
14 m/s	100	2	2500 m * 200 m	0%
20 m/s	150	4	3000 m * 200 m	40%
28 m/s	200	8	3500 m * 200 m	100%
35 m/s	300	-	-	-

4.4 Performance Evaluation Metrics

This chapter compares the performance of our AODV-C with standard AODV designed specially for VANET using the following metrics. For each parameter four performance metrics were evaluated. These metrics are:

- Packet Delivery Fraction (PDF):
  It refers to the proportion of data packets that all specified vehicles successfully receive. Its definition is the proportion of total data packets received by the target vehicles to total number of data packets transmitted by the source vehicles. PDF should have a higher value to provide better network performance. The calculation looks like this [94]:

$$\text{PDF} = \frac{Total\ Successful\ Packets\ Received}{Total\ Transmitted\ Packets} \qquad (3.1)$$

- Number of Control packets transmitted Per Data packet delivered (CPD) or Normalized Routing Load (NRL):
  To examine how effectively control packets are used in delivering data to the appropriate recipients, we choose to apply a ratio of control packets transmitted to data packets delivered as opposed to a pure control overhead. This is how the computation looks [95]:

$$\text{NRL} = \frac{Number\ of\ Control\ Packets\ Sent}{Number\ of\ Data\ Packets\ Received} \qquad (3.2)$$

- Average Path Length (APL) [number of hops]:
  The average number of nodes involved in successfully forwarding packets from the source to the destination is the definition of this measure. It is defined as the typical number of hops required to send a data packet from source to destination. The end-to-end delay may reflect the path length. The path length can be reflected in the end-to-end delay [96].

- Average Route Latency (ARL) [ms]:
  The typical time it will take to find a route to the destination. Is used to determine the time that is required for the message to be sent from the source node to the destination node. In other words, it is a measurement of the average amount of time that passes between the time the

source node creates a message and the time the destination node receives it [97]. Equation (3.3) presents the calculation method:

$$\mathrm{ARL} = \frac{\text{Average Time Taken to Delivered Packets}}{\text{Total Number of Packets Delivered}} \quad (3.3)$$

We are going to compare our AODV-C with standard AODV based on the above metrics according to different parameters.

4.5 Simulation Results

Several experiments were done, and the results were recorded at various node densities, mobility node speeds, number of clusters, and different network areas size.

4.5.1 Effect of Vehicles Mobility

This section displays the outcomes of our simulation tests upon changing the mobility of the network vehicles. The variables considered in scenarios involving vehicles speed are shown in Table 4.3.

Table 4.3: Parameters values used in the vehicles speed scenario

Parameter	Value
Vehicle speed	14m/s, 20m/s, 28m/s and 35m/s
Cluster number	2
Vehicle number	200
Network area	2500m * 200m

In the first scenario, a fixed number of 200 vehicles, and a variety movement speeds; 14, 20, 28, and 35 m/s were deployed. Figures below shows the impact of mobility on proposed routing protocols based on the selected performance metrics.

- **Packet Delivery Fraction (PDF)**

Figure 4.6 shows that the PDF obtained with the AODV-C is greater than 99% at a vehicle speed of 14 m/sec, greater than 98% at a vehicle speed of 20 m/sec, greater than 97% at a vehicle speed of 28 m/sec, and about 96% at a vehicle speed of 35 m/sec at two clusters with 200 vehicles. This indicates that even in the presence of high node mobility, the AODV-C is quite effective at identifying and maintaining pathways for data packet delivery. From the figure, it is clear that all PDF values decrease as speed rises. This is because link failure is reduced by the low vehicle speed and increases as the speed becomes higher. Higher mobility speeds cause nodes to migrate between clusters more frequently, which causes a slight drop in PDF. In all cases the PDF for AODV-C is much better than the Standard AODV

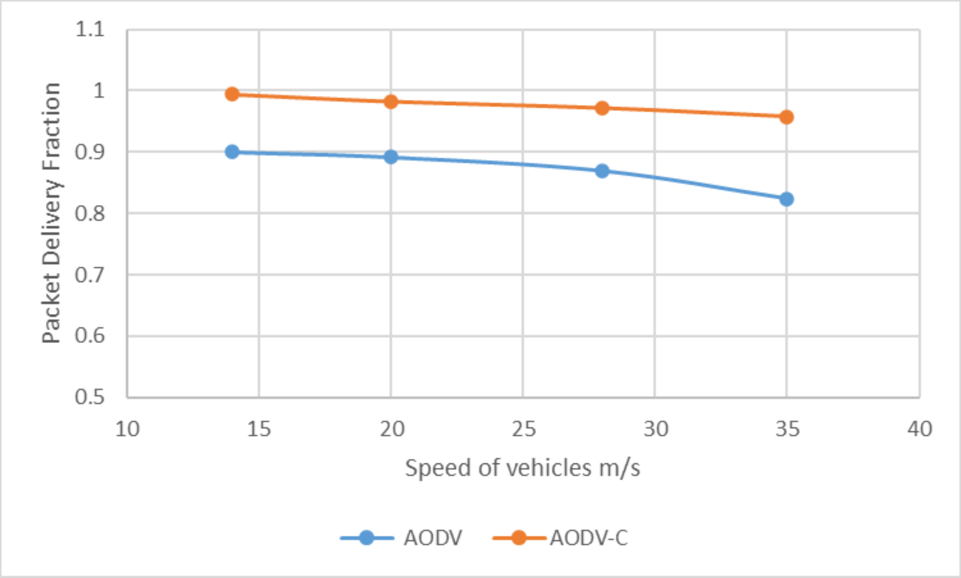


Figure 4.6: PDF versus vehicles speed

- **Number of control Packets transmitted Per Data packet delivered (CPD)**

As the vehicle's mobility speed is increasing, CPD increases. The AODV-C routing protocol with two clusters and 200 vehicles has the best values at low speeds, as shown in Figure 4.7, because the vehicles move slowly and stay in the same cluster, requiring a minimal number of control messages. CPD at high speeds is rising since the network will be under more strain. Additionally, we can see that CPD performs better for AODV-C than standard AODV. This is because stable connections for data delivery are provided by clustering techniques, which can lower the number of packet retransmissions.

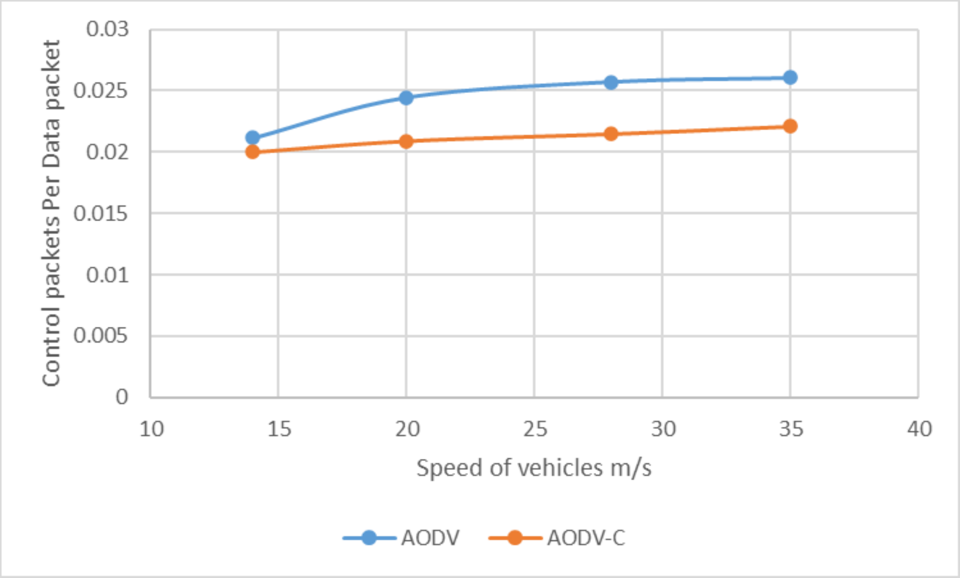


Figure 4.7: CPD versus vehicles speed

- **Average Path Length (APL)**

Referring to Figure 4.8, our protocol shows higher APL compared to standard AODV. In AOD-C the routes must go through the CH, and high vehicle speeds may force the vehicles to move apart and change their positions, producing longer paths. It is clear that as mobility speeds increase, APL values do as well. With the lowest APL setting, the proposed protocol's speed of 14 m/s is still slightly higher than AODV. The APL increases slightly as vehicle mobility speed increases. Additionally, we can observe that the APL for AODV-C is a little bit longer than that for the standard AODV. This is because, in a clustered environment, the message must pass through the CH.

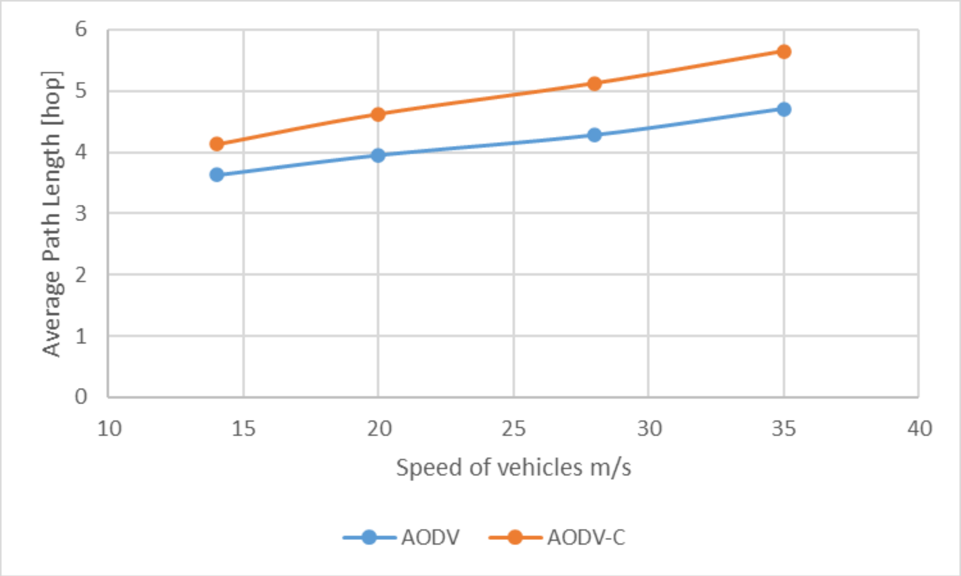


Figure 4.8: APL versus vehicles speed

- **Average Route Latency (ARL)**

Figure 4.9 demonstrates how ARL generally increases as vehicle mobility speeds increase. The AODV-C has the lowest ARL value where the vehicles are close to one another at low vehicle speeds. The ARL value increases when the speed value is high because high speed encourages frequent vehicle movement from one cluster to another. Additionally, we can observe that the ARL for the AODV-C is better than the APL for standard AODV because the route search algorithm is done only once and remains stable until the cluster structure changes. Where the standard AODV requires more time to establish a connection, and the initial communication required for finding a route is high.

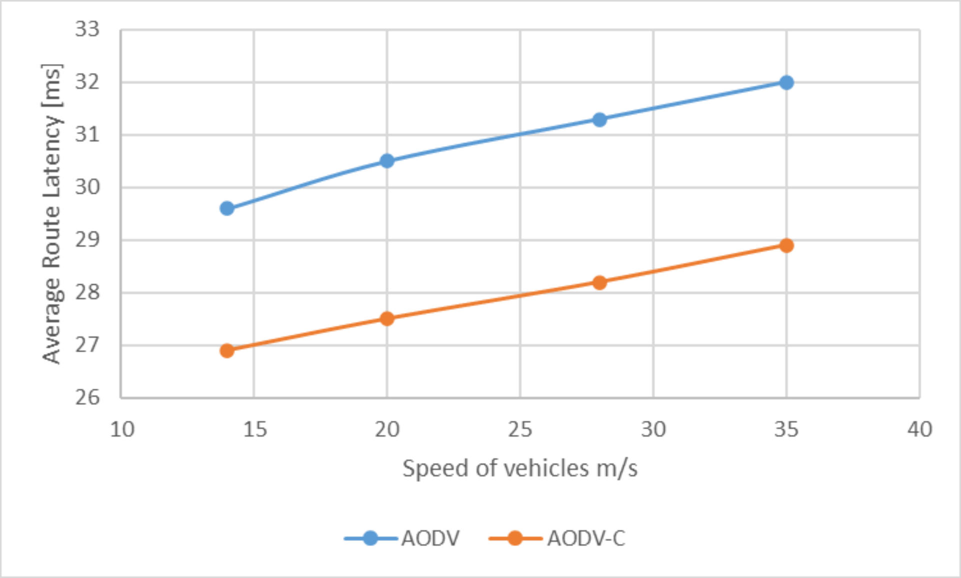


Figure 4.9: ARL versus vehicles speed

4.5.2 Effect of Vehicles Density

The results of our simulation tests, where we altered the number of vehicles in the network, are shown in this section. Table 4.4 displays the variables taken into account in this scenario.

Table 4.4: Parameters values used in the vehicles number scenario

Parameter	Value
Vehicle number	100, 150, 200, and 300
Cluster number	2
Vehicle speed	20 m/s
Network area	2500m * 200m

In this scenario, a variance number of vehicles;100, 150, 200, and 300 are used and all vehicles move with 20 m/s. Figures below shows the influence of vehicles density on the proposed routing protocols based on the selected performance metrics.

- **Packet Delivery Fraction (PDF)**

  Figure 4.10 shows that the PDF obtained with the AODV-C is greater than 98% at 100 vehicles number, greater than 97% at 150 vehicles number, greater than 97% at 200 vehicles number, and more than 96% at 300 vehicles. We can note when the number of vehicles increased the PDF decreased slightly and this is back to the overhead that will happen in the network as the number of vehicles becomes higher. In all cases, the PDF for the AODV-C routing protocol is much better than the standard AODV.

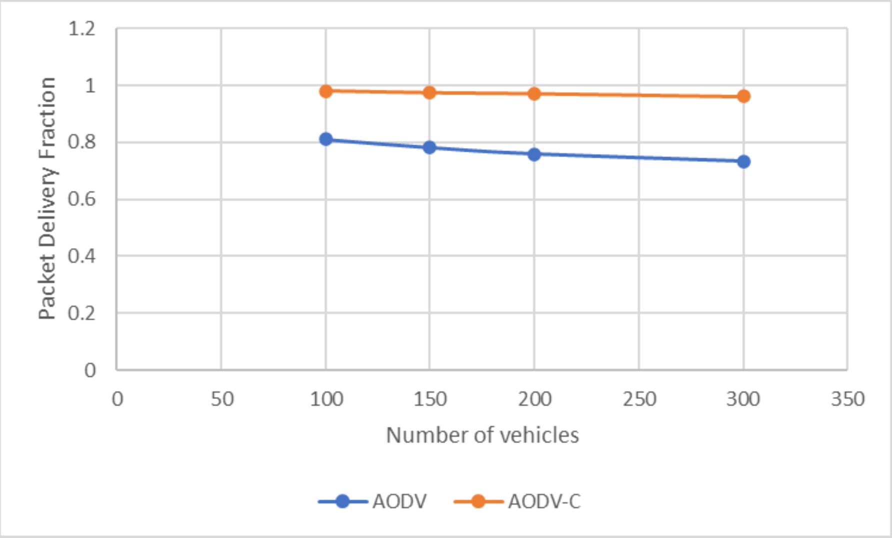


Figure 4.10: PDF versus number of vehicles

- **Number of control Packets transmitted Per Data packet delivered (CPD)**
  From Figure 4.11 we can notice that CPD increases as the vehicle's number increase too, which is related to the network control overheads that will happen. The increasing number of vehicles will increase the number of control messages for route packets so CPD increases. However, the AODV-C routing protocol with two clusters and a vehicle speed of 20 m/s has a lower CPD value than the standard AODV. In dense traffic an increasing in the broadcasted RREQ packet increases the reachability of nodes. However, co-channel interference will rise as RREQ packets are broadcast more frequently and may be required to restart route discovery while limiting the nodes' reachability. This event clearly explains the problem with the standard AODV algorithm's higher overhead so higher CPD.

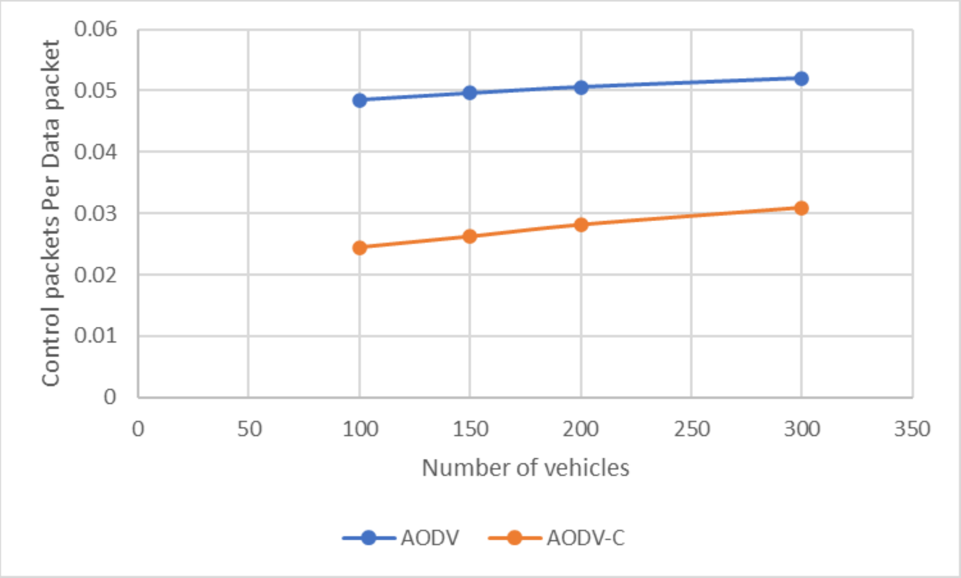


Figure 4.11: CPD versus number of vehicles

- **Average Path Length (APL)**

Figure 4.12 with two clusters and a vehicle speed of 20 m/s the AODV-C routing protocol shows a little higher APL compared to standard AODV, where the routes must go through the CH. As a consequence, we can observe that the APL slightly grows with the number of vehicles due to congestion caused by frequent packet transmission.

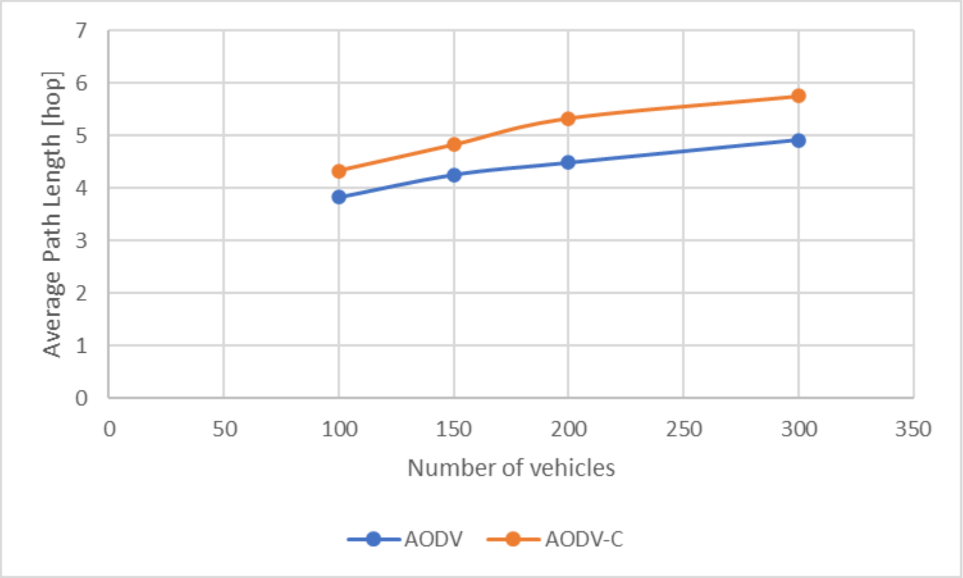


Figure 4.12: APL versus number of vehicles

- **Average Route Latency (ARL)**

Figure 4.13 with two clusters and 200 vehicles, shows how ARL generally increases as vehicle density increases, due to the increasing number of packets transmitted in the network as the number of vehicles increases. Additionally, since the route search algorithm is only used once and is stable until the cluster structure changes, we can see that the ARL for AODV-C is better than the standard AODV. Whereas the initial communication time needed to determine a route is high (higher route discovery time) and the connection establishment time for the standard AODV is longer.

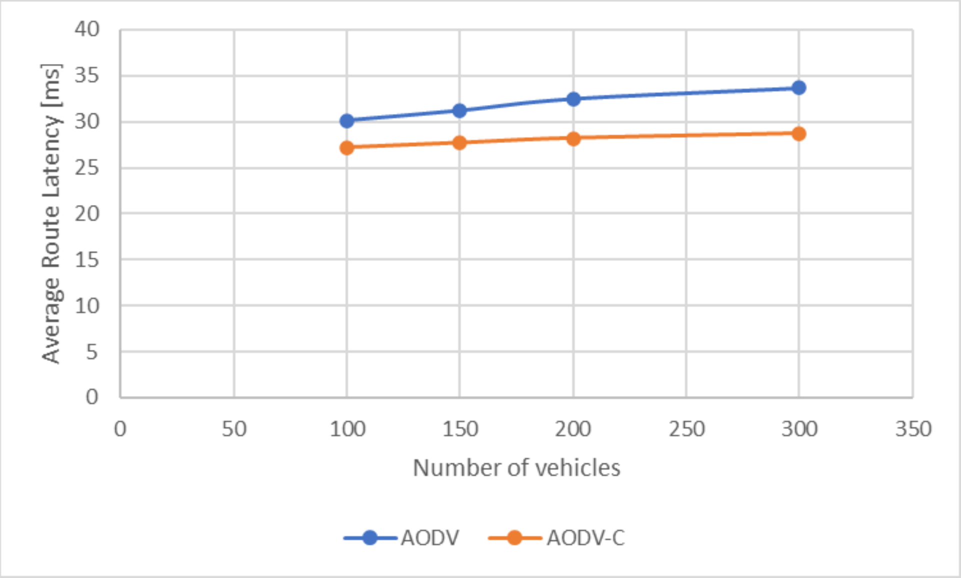


Figure 4.13: ARL versus number of vehicles

4.5.3 Effect of the Number of Clusters

This section displays the outcomes of our simulation tests where we changed the number of clusters formed in the communication range of 500m for the RSU [98]. The variables considered in scenarios involving different cluster numbers are shown in Table 4.5.

Table 4.5: Parameters values used in the cluster numbers scenario

Parameter	Value
Cluster number	2, 4, and 8
Vehicle speed	20 m/s
Vehicle number	200
Network area	2500m * 200m

In the third scenario, a fixed number of 200 vehicles with speed 20 m/s, and variant number of clusters were deployed. Figures below shows the impact of changing the number of clusters for the proposed routing protocols based on the selected performance metrics.

- **Packet Delivery Fraction (PDF)**

Figure 4.14 shows that increases in the number of clusters will cause a slight drop in PDF for the AODV-C due to the increased number of CHs. However, the PDF for the AODV-C is still around 90% which is better than the standard AODV.

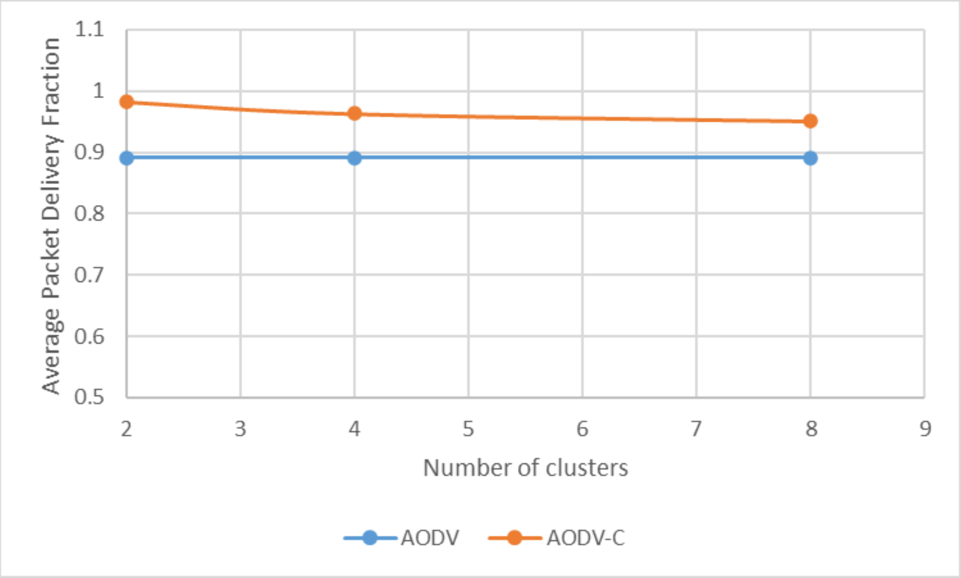


Figure 4.14: PDF versus number of clusters

- **Number of Control packets transmitted Per Data packet delivered (CPD)**

Figure 4.15 shows that the lowest CPD for the AODV-C is at two cluster, that's because increases the cluster numbers means increases the election process of CH which causes more control packet to be transmitted in the network. The CPD for the AODV-C, however, is still lower than the CPD for the standard AODV.

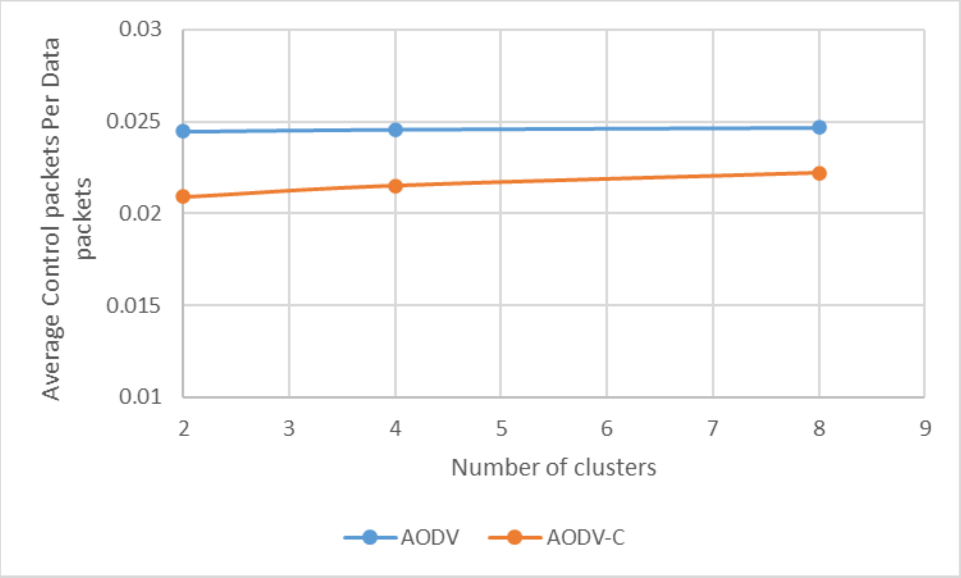


Figure 4.15: CPD versus number of clusters

- **Average Path Length (APL)**

In Figure 4.16 we can see that the lowest APL for the AODV-C is at two clusters, because at two clusters there is two CH's follows to the RSU where increase the number of clusters cause increases the CH’s follows to the RSU which means more CH for the routes to pass through. Even though the APL for the AODV-C is slightly higher than the APL for the standard AODV where the route must pass through the CH in the AODV-C.

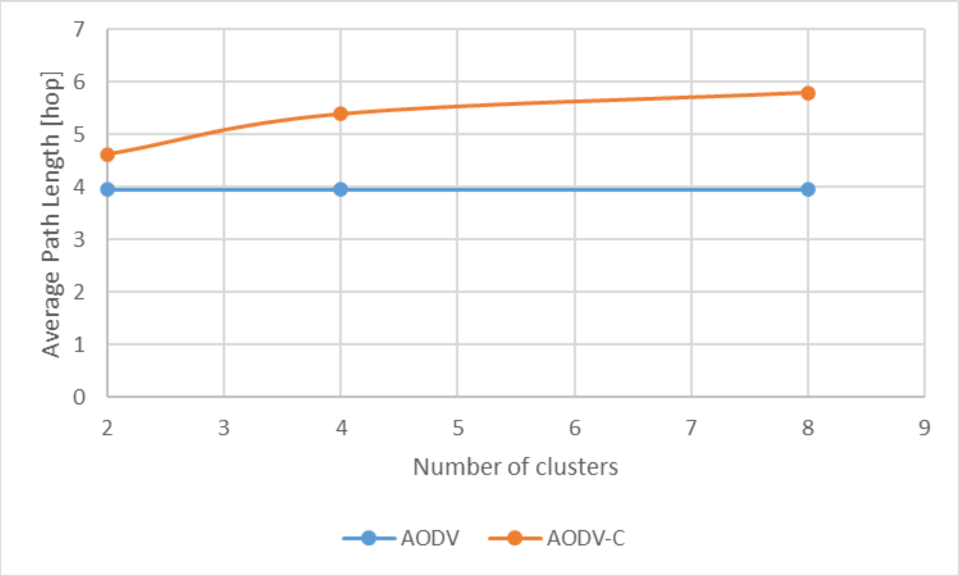


Figure 4.16: APL versus number of clusters

- **Average Route Latency (ARL)**

Figure 4.17 shows that minimum ARL for the AODV-C is in the case of two clusters where increasing the clusters number means higher route path length, higher packet drop and more overhead which causes more average route latency, however still lower than standard AODV.

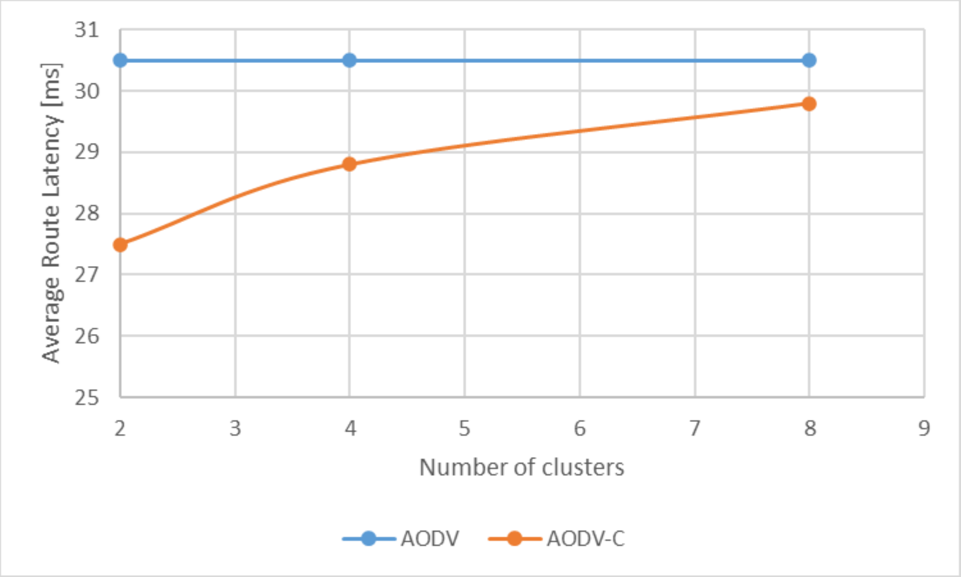


Figure 4.17: ARL versus number of clusters

From the above figures we can conclude that the best number of clusters for a RSU with communication range of 500 m is two clusters.

4.5.4 Effect of Network Area

This section displays the outcomes of our simulation tests where we changed the simulation area of the network. The variables considered in scenario involving different area size are shown in Table 4.6.

Table 4.6: Parameters values used in the size of the area network scenario

Parameter	Value
Network area	2500m * 200m, 3000m * 200m, and 3500m * 200m
Vehicle speed	20 m/s
Cluster number	2
Vehicle density	200

For the fourth set of simulations, we varied the network size in order to evaluate the protocol scalability for larger network areas. Different network sizes have been considered with the same vehicle density. Hence, the studied networks are 2500 × 200 m with 200 vehicles, 3000 × 200 m with 300 vehicles, and 3500 × 200 m with 420 vehicles.

- **Packet Delivery Fraction (PDF)**

  Figure 4.18 shows that as network size increases, the PDF for both the AODV-C and the standard AODV decreases. The PDF for the AODV-C is still about 95%, which is better than the standard AODV since with a larger network size the coverage area of the RSU gets less and that causes packet loss because of a higher probability of link breakages.

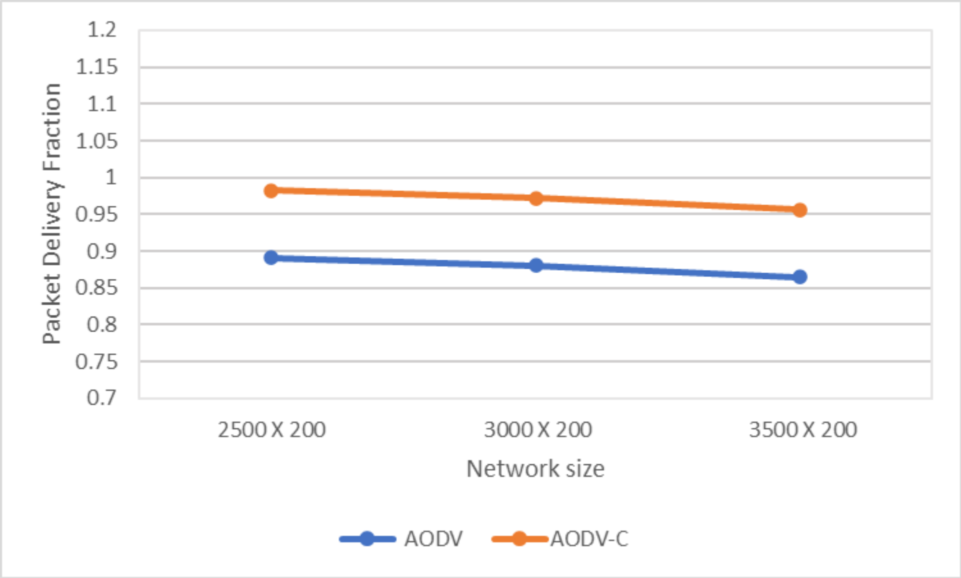


Figure 4.18: PDF versus network size

- **Number of Control packets transmitted Per Data packet delivered (CPD)**

Figure 4.19 illustrates how the CPD increases as the network size increases. A larger network size increases the likelihood that the source and destination nodes would be distant from one another, causing longer routes to be constructed and a higher likelihood of link breakages that require route repairs and more control packets. CPD for standard AODV is still higher than this for AODV-C, due to increased control and data packets.

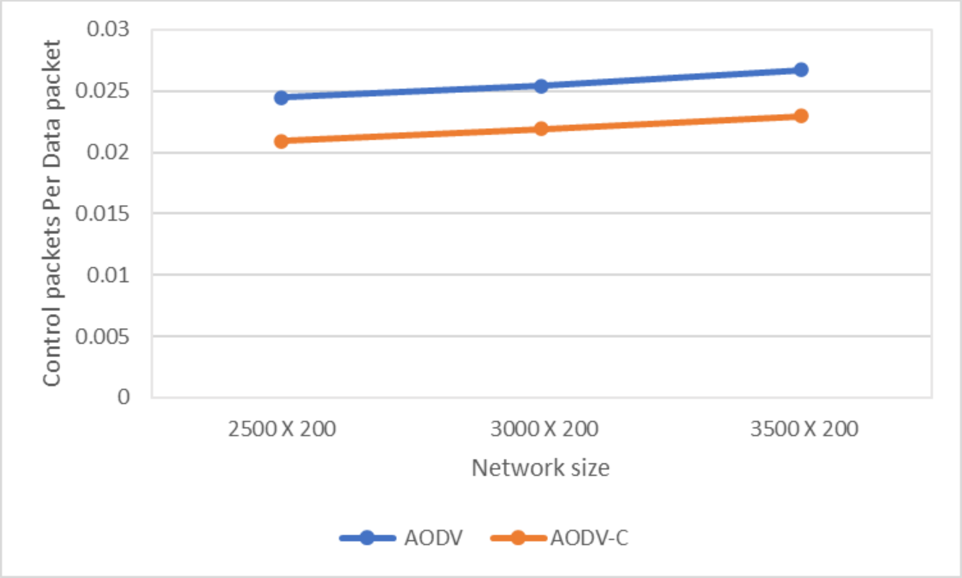


Figure 4.19: CPD versus network size

- **Average Path Length (APL)**

Figure 4.20 shows that as the network size increases, the APL also increases. This is because there is a higher likelihood that the source and destination nodes will be geographically distant from one another, which increases the likelihood that the source will be reached. Due to the routes' passing through CH, the APL of AODV-C is still a little higher than in standard AODV.

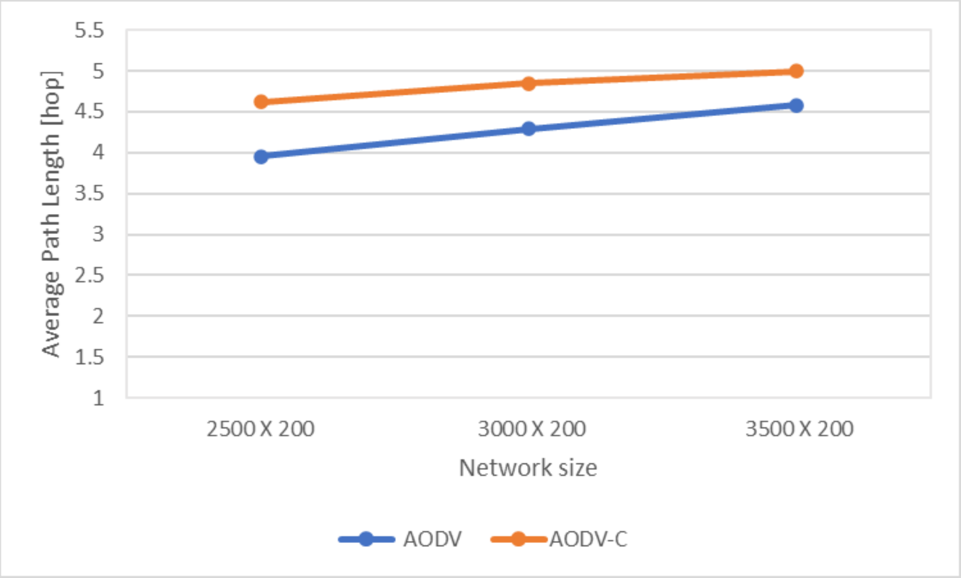


Figure 4.20: APL versus network size

- **Average Route Latency (ARL)**

Figure 4.21 indicates that as the network size increases, so does ARL. Because longer routes and longer setup times are a consequence of a larger network. The ARL for the AODV-C, however, is lower than the ARL for the standard AODV.

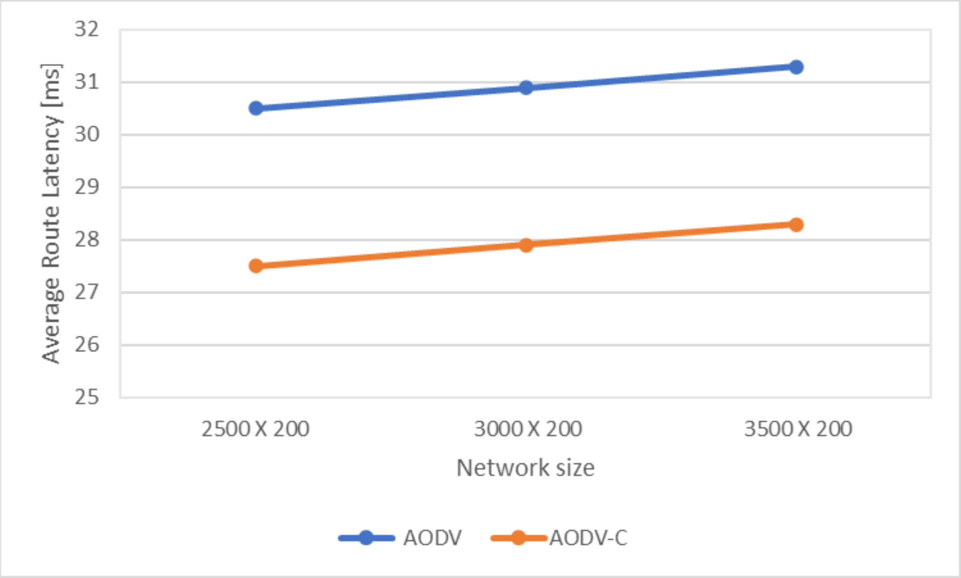


Figure 4.21: ARL versus network size

4.5.5 Effect of Local Traffic Percentage

This section shows the results of our simulation tests where we study the effect of local traffic percentage, a 2500m×200m network was considered. This network contains 200 vehicles and is divided into 2 clusters. These vehicles move at speed of 20m/s. The variables considered in the scenario involving different local traffic percentages are shown in Table 4.7.

Table 4.7: Parameters values used in the local traffic percentage scenario

Parameter	Value
Local traffic percentages	0%, 40%, and 100%
Network area	2500m * 200m
Vehicle speed	20 m/s
Cluster number	2
Vehicle density	200

For the fifth set of simulations, we varied the local traffic percentages in order to evaluate the protocol scalability.

- **Packet Delivery Fraction (PDF)**

  Figure 4.22 shows that as local traffic percentage increases, the PDF for both the AODV-C and the standard AODV slightly increases and closely reaches 100% when all the local traffic are local where the source and the destination are in the same cluster. Larger percentage of local communication means shorter paths means lower probability of having link breakage and data packet drops.

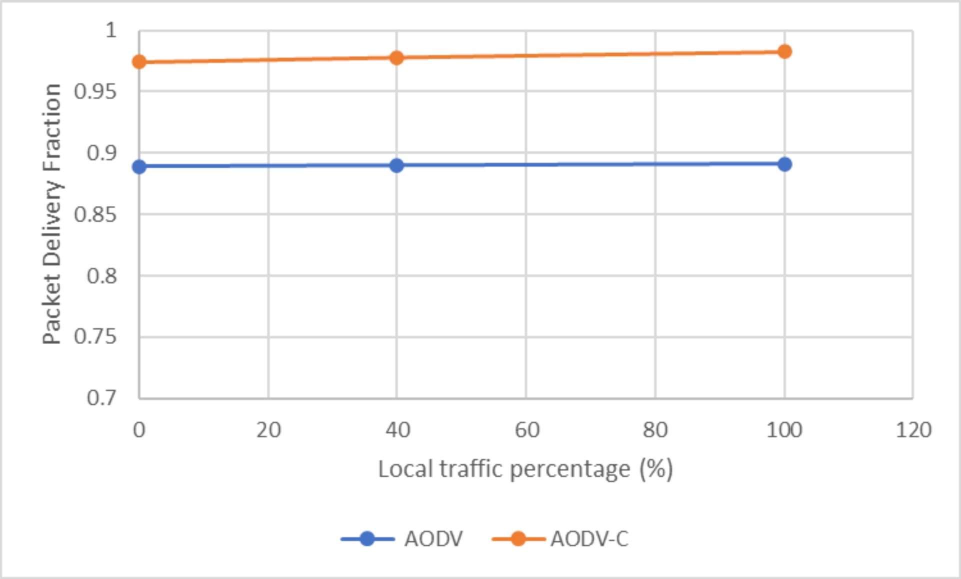


Figure 4.22: PDF versus local traffic percentage

- **Number of Control packets transmitted Per Data packet delivered (CPD)**

Figure 4.23 illustrates how the CPD slightly decreases as the local traffic percentage increases. Where 100% local traffic percentage (the source and destination nodes are in the same cluster) means a shorter route path and fewer control packets. CPD for standard AODV is still a bit higher than this for AODV-C.

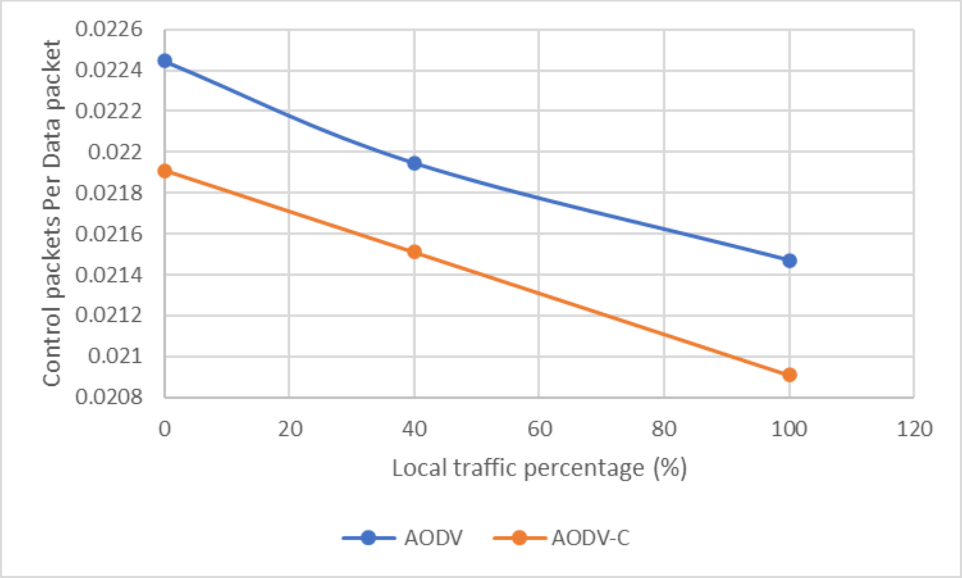


Figure 4.23: CPD versus local traffic percentage

- **Average Path Length (APL)**

Figure 4.24 shows that as the local traffic percentage increases, the APL decreases. This is because the source and destination nodes will be closer to each other, which increases the likelihood that the source will be reached in a shorter route path. The APL of AODV-C is still a little higher than in standard AODV due to the routes must passing through CH.

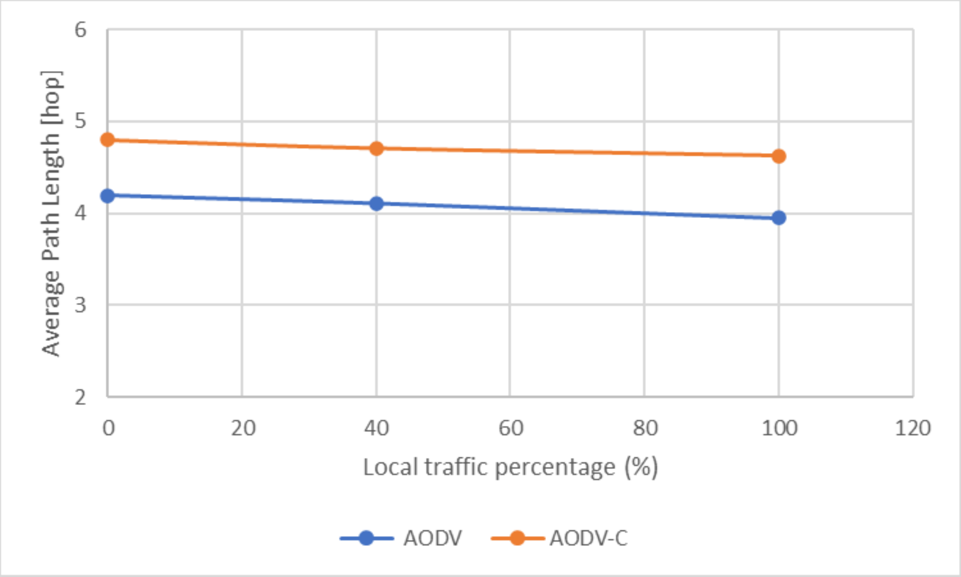


Figure 4.24: APL versus local traffic percentage

- **Average Route Latency (ARL)**

Figure 4.25 indicates that as the local traffic percentage increases, the ARL decreases. Because of shorter routes due to that packets are locally delivered. The ARL for the AODV-C, however, is lower than the ARL for the standard AODV.

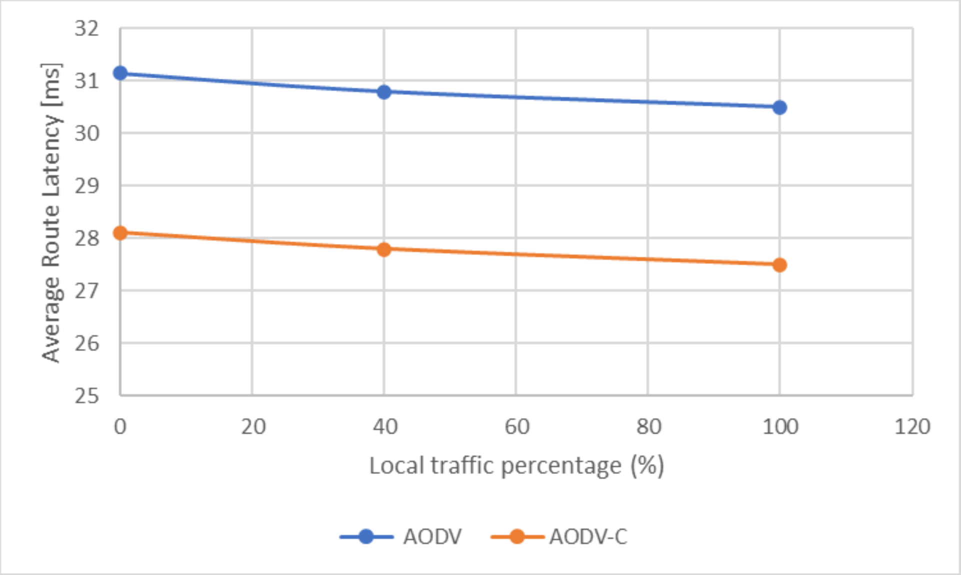


Figure 4.25: ARL versus local traffic percentage

4.6 Results Analysis

This chapter compares the proposed protocol's performance against that of the AODV without cluster routing protocols. The following four metrics have been used: Packet Delivery Fraction, the number of Control packets transferred Per delivered Data packet, Average Path Length, and Average Route Latency. Five different scenarios are used to test these metrics: altering vehicle speeds, varying vehicle densities, varying the number of clusters, having a different network size, and varying the local traffic percentage. With the following findings, the results show that the AODV-C better performance than the standard AODV:

- **Packet Delivery Fraction:**
  The results indicate that in all tested scenarios, the suggested technique provides a higher PDF rate than standard AODV. The number of vehicles as well as the speed affect the performance of PDF which decreases by increasing the number of vehicles as well as the speed. Also, the number of clusters, the local traffic percentage, and large area networks affect the performance of PDF.

  The number of clusters and vehicle speeds have the most effects on how well the suggested protocol works with PDF; at 14 m/s (50 km/h) with two clusters, PDF reached a value of around 100%.

- **Number of Control packets transferred Per delivered Data packet:**
  The results show that the AODV-C offers the lowest CPD rate compared to standard AODV in each of the cases examined. The performance of CPD is affected by both the number and the speed of the vehicles, which rises as the number and speed of the vehicles rise. Additionally, the number of clusters and the different network sizes has an impact on CPD performance since increases the cluster numbers means increases the election process of CH so CPD increases and increases in the network size will cause the source and destination to be far from each other. Therefore, longer routes and a higher likelihood of link failures require route repairs and more control packets. Also, as the local traffic percentage increases, the ARL decreases.

- **Average Path Length:**
  The results illustrate that in each of the scenarios examined, the APL for the AODV-C is slightly greater than the APL for the standard AODV because routes must pass through the CH in case of the AODV-C. The APL for the standard AODV and AODV-C gradually increases when the number of vehicles, vehicle speed, cluster number, and network area size increase, when the local traffic percentage increases the APL decreases because the source and destination nodes will be closer to each other.

- **Average Route Latency:**
  As a result, the ARL for the suggested protocol is consistently lower than the ARL for the standard AODV. The ARL grows as vehicle numbers, speeds, cluster numbers, and network

size increase and ARL decreases as the local traffic percentage increases. However, the ARL for the AODV-C is always substantially lower than the ARL for the standard AODV.

We summed up the percentage difference between AODV-C and AODV in Table 4.8. Using this formula: 100 * |a - b| / ((a + b) / 2) we calculate the percentage difference.

Table 4.8 Percentage Difference between Protocols

Parameters	Vehicles mobility	Number of vehicles	Network size	Local traffic percentage (%)	Number of clusters
PDF (Reliability)	12%	23%	10%	10%	20%
CPD	14%	59%	15%	3%	52%
ARL (Latency)	10%	13%	10%	11%	12%

4.7 Chapter Summary

Using the OMNeT++ 5.5.1 simulator, this chapter simulated the AODV-C under various networking conditions (mobility speed, node density, number of clusters, and network sizes) and compared it to the standard AODV routing protocols.

By evaluating the packet delivery fraction, the number of control packets transferred per delivered data packet, the average path length, and the average route latency, the routing performance is assessed. The results are shown in the section before.

Chapter 5: Conclusion and Future Work

5.1 Overview

In this chapter, Section 5.2 concluded our work on the thesis. Opportunities for improving over research are highlighted in Section 5.3.

5.2 Conclusion

Due to the characteristics of the wireless network, routing in VANETs continues to have obstacles and difficulties. Lack of flexibility, scalability, inadequate connectivity, and continuously changing network topology, result in deployment and management challenging. In VANETs, high node density and high node mobility are two important criteria that significantly affect network performance. Numerous routing protocols have been proposed as solutions to these issues, some of which focus on the concept of cluster-based routing, which has the advantage in scalability, a decrease in routing overhead, and an end-to-end delay.

VANETs are expected to provide a range of applications for traffic efficiency, road safety, and driver assistance. We have suggested a scalable clustering technique in this thesis. The AODV-C guarantees the stability of the network by having efficient V2V and V2I communication where the CH communicates with the Road Side Units (RSU) and delivers relevant messages, there is a potential reduction in the communication overhead between RSUs and other VANET components.

A method for selecting a suitable vehicle to serve as the cluster's cluster head was also described. We considered two factors while choosing the head vehicle: the distance from the cluster boundary and the vehicle's average speed. Our objective was to choose CH in an effective manner that would improve some parameters including PDR, CPD, APL, and ARL. We evaluated our protocol to the original AODV. Our simulation results show that the AODV-C provided a stable cluster and more reliable transmissions in spite of increasing the number of vehicles along with their speeds, increasing the number of clusters, and the network size.

According to simulation results, the AODV-C protocol outperforms AODV in terms of reliability by around 12% for increasing vehicle speed, 23% for increasing vehicle number, 10% for increasing network size and local traffic, and 20% for increasing cluster number. In addition, improved latency by 10% for increasing vehicle speed, 13% for increasing vehicle number, 10% for expanding network size, 11% for increasing local traffic, and 12% for increasing cluster number.

We also conclude that dividing the communication range of the RSU into two clusters is the most effective one, and the AODV-C is more efficient in the urban scenario than the highway scenario.

5.3 Future Work

Future improvements that we can do to improve the performance of the AODV-C include the following:

1. Study the variables associated with the cluster head, such as the cluster head life time.
2. We performed our work in a scenario with only one direction. Future improvements are possible in a two-directional scenario.
3. Improving our protocols in terms of highway roads when a vehicle is traveling at a speed of more than 100 km/h.
4. In the context of a highway, improve the suggested protocol's security and service quality.
5. Comparing the AODV-C with other clustering protocols.
6. Proposing an authentication method to connect the RSU with CH.

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العنوان باللغة العربية: بروتوكول التوجيه القابل للتطوير لشبكة المركبات المخصصة.

نظراً للتطور السريع لتكنولوجيا الاتصالات اللاسلكية والطلب المتزايد على الخدمات، من المتوقع أن يؤدي ظهور الشبكات المخصصة للسيارات (VANET) إلى تمكين مجموعة متنوعة من التطبيقات لمساعدة السائق، وزيادة كفاءة حركة المرور، وضمان السلامة على الطرق. تتمثل إحدى الطرق المقترحة في تقسيم مساحة الشبكة كاملة إلى مجموعات أصغر ثم اختيار رئيس للمجموعة في كل مجموعة لضمان إرسال الرسائل بشكل مناسب في الشبكة وتحسين عملية التوجيه.

من أجل حل مشكلة قابلية توسيع الشبكة واستيعاب التطبيقات الإضافية في هذا النوع من الشبكات، تعد طريقة تقسيم الشبكة إلى مجموعات طريقة فعالة لأن رئيس المجموعة هو من يتصل بالوحدات المثبتة على جانب الطريق ويمرر الرسائل ذات الصلة، هذا يعني انخفاض محتمل في عبء وكمية الاتصال بين الوحدات على جانب الطريق ومكونات شبكة المركبات الأخرى. إن الخوارزميات التي تعمل على تقسيم مساحة الشبكة كاملة إلى مجموعات أصغر ضرورية لضمان استقرار المجموعة بسبب الطبيعة الديناميكية لشبكة المركبات وتحسين أدائها بشكل كبير لذلك يعد اختيار رئيس للمجموعة خطوة حاسمة في عملية التقسيم إلى مجموعات.

من أجل تحسين استقرار المجموعة وزيادة كفاءة نقل البيانات وعملية التوجيه، تقترح هذه الأطروحة منهجية لتقسيم مساحة الشبكة إلى مجموعات صغيرة واختيار رئيس للمجموعة يضمن استقرار الشبكة من خلال إنشاء اتصال جيد بين المركبات مع بعضها وبين رئيس المجموعة مع وحدات الطريق، تعتمد هذه المنهجية عند اختيار سيارة لتكون بمثابة رئيس للمجموعة على المسافة التي تفصل السيارة عن حد المجموعة ومتوسط سرعتها.

تم تنفيذ بروتوكولنا المقترح باستخدام محاكي OMNeT ++ 5.5.1 ومقارنته ببروتوكول (AODV Ad hoc On-Demand Distance Vector)، حيث أظهرت النتائج أن التقنية المقترحة تحسن على بعض المقاييس المهمة مثل نسبة تسليم الحزم، وعدد حزم التحكم المرسلة لكل حزم بيانات تم تسليمها، ومتوسط طول المسار المستخدم لتوصيل الحزم، ومتوسط زمن وصول الحزم بالاعتماد على تغير سرعة حركة المركبات وعددها، وعدد المجموعات التي قسمت الشبكة، ومساحة الشبكة. حيث يضمن البروتوكول المقترح المحافظة على أداء جيد في نسبة تسليم الحزم عندما يزداد حجم الشبكة ويزداد عدد المركبات مع سرعاتها أيضاً.