DEBRE BERHAN UNIVERSITY

COLLEGE OF COMPUTING

# LOAD AWARE AND PRIORITY ADAPTIVE TRAFFIC CONGESTION CONTROL METHOD IN VEHICULAR AD HOC NETWORK

A Thesis Paper Submitted to the Department of Information Technology in Partial Fulfillment of the Requirements of the Degree of Master of Science in Computer Networks and Security

by

ERMIAS MELKU TADESSE

Advisor: SAMUEL ASFERAW (PhD)

December, 2023

Debre Berhan, Ethiopia

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# ADVISOR APPROVAL SHEET

This is to certify that the Thesis entitled: **LOAD AWARE PRIORITY ADAPTIVE TRAFFIC CONGESTION CONTROL METHOD FOR VEHICULAR AD HOC NETWORK** submitted in partial fulfilment of the requirements for the degree of Master's with specialization in Computer Network and Security, the Graduate Program of the faculty of computing and has been carried out by **ERMIAS MELKU TADESSE, ID: PGR/165/12**, under my supervision. Therefore, I/we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

**Advisor:**

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Academic Rank: **Assis Prof**

Signature: __________________

Date: ____________________

# EXAMINATION COMMITTEE CERTIFICATION

We certify to have read the following thesis: **LOAD AWARE PRIORITY ADAPTIVE TRAFFIC CONGESTION CONTROL METHOD FOR VEHICULAR AD HOC NETWORK** and as an examining committee examined the student **(Ermias Melku Tadesse)** in its content and what related to it. We approve that it meets the standards of a Thesis for the Degree of Master of Science in Computer Network and Security.

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| **Dr. Baye Y.** | ____________ | ____________ |
| Chair Holder: Name | Signature | Date |
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# DECLARATION

I declare that the Master Thesis entitled: **LOAD AWARE PRIORITY ADAPTIVE TRAFFIC CONGESTION CONTROL METHOD FOR VEHICULAR AD HOC NETWORK** is my initial 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 acknowledgement is made in the text.

Name: Ermias Melku Tadesse

Signature: ________________

Date: 14/12/2023

# DEDICATION

**Dedicated to:** those who lost their lives in a car accident.

Ermias Melku Tadesse

# ACKNOWLEDGMENTS

I would like to thanks all those who have helped me to accomplish this thesis. First, I gratefully express my deepest thanks to the almighty God for his guidance, help, and support to get strength for thesis accomplishment. Then, I would like to express my deep admiration and gratitude for my esteemed advisor **Samuel Asferaw** (PhD), without him this task could not have been completed. He has been a motivating factor behind my success. He has assisted me at every point, from the conception of the idea to the execution of the experiments, achievement of the results, and finally documentation of the thesis. I am also greatly indebted to all instructors, for their support and guidance during my study. Finally, I want to express my deep gratitude to my parents for providing me with constant support and continuous encouragement during my MSC study in Debre Berhan University. Because these accomplishments have not been possible without the support of them.

**Ermias Melku Tadesse**

December, 2023

# ABSTRACT

Vehicular ad hoc networks (VANET) are a subset of mobile ad hoc networks used to communicate between cars and vehicles and infrastructure. Vehicles act as nodes in a VANET, sending and receiving data without a physical link. Congestion occurs when nodes compete to acquire channels, causing the channels to become saturated. Indeed, when vehicle density rises, the number of channel collisions rises, increasing the likelihood of network congestion. To address this problem, we develop a load aware and priority adaptive traffic congestion control method in vehicular ad hoc networks (VANETs). This research focuses on addressing the problem of traffic congestion by proposing a protocol that takes into account the load factor and adapts to changing traffic conditions. The protocol aims to improve the efficiency of the vehicular environment by utilizing the movement of vehicles with roadside units (RSUs) and sharing the traffic load between them. Simulation results demonstrate the effectiveness of the proposed protocol in reducing congestion and enhancing the overall performance of VANETs.

To validate the proposed algorithm, we have implemented and tested the proposed algorithm using a simulation tool called Network Simulator 3 (NS-3) for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication scenario and computed the performance of the algorithm on different parameters of the network. The simulation result of the proposed load aware and priority adaptive traffic congestion control method in VANET improved the packet delivery ratio, packet lost ration, and end-to-end delay by 96%, 4.1%, and 1102 milliseconds from the previous value of 92%, 5.7%, and 1154 milliseconds respectively for different number of vehicles.



**Keywords: Ad hoc Network, Congestion Control, Load Aware, Priority Adaptive**

# LIST OF ABBREVIATIONS

| ***Abbreviations*** | ***Definitions*** |
|---|---|
| *ACO* | Ant Colony Optimization |
| *AIFS* | Arbitration Inter-Frame Spacing |
| *AODV* | Ad On-demand Distance Vector |
| *AN* | Access Network |
| *AU* | Application Unit |
| *CAR* | Connectivity Aware Routing |
| *CAM* | Congestion Aware Message |
| *NN* | Nearest Neighbor |
| *CRI* | Congestion Route Index |
| *CST* | Congestion Suggestion Table |
| *DTPOS* | Dynamic Travel Path Optimization System |
| *FANET* | Flying Ad hoc Network |
| *GeOpps* | Geographical Opportunistic Routing |
| *GPS* | Global Positioning System |
| *GSR* | Global State Routing Protocol |
| *FFC* | Federal Communication Commission |
| *I2V* | Infrastructure to Vehicle |
| *ID* | Identification |
| *ITS* | Intelligent Transportation Systems |
| *IoV* | Internet of Vehicle |
| *IVC* | Inter-Vehicle Collision |
| *LAPCC* | Load Aware Priority adaptive traffic Congestion Control |
| *LEA* | Law Enforcement Authorities |
| *LOS* | Level of Service |
| *ITS* | Intelligent Transportation Systems |
| *MAC* | Medium Access Control |
| *MANET* | Mobile Ad hoc Network |

| | |
|---|---|
| *NA* | Network Authorities |
| *NTP* | Network Time Protocol |
| *NS3* | Network Simulator 3 |
| *OBU* | Onboard Unit |
| *OLSR* | Optimized Link-State Routing Protocol |
| *PDA* | Personal Digital Assistant |
| *KPI* | Key Performance Indicator |
| *RERR* | Route Error |
| *RREP* | Route Reply |
| *RREQ* | Route Request |
| *RSU* | Roadside Unit |
| *RS* | Road Segment |
| *RSSI* | Received Signal Strength Indicator |
| *RTA* | Regional Transportation Authorities |
| *SUMO* | Simulation of Urban Mobility |
| *TDCCA* | Traffic Density - Based Congestion Control |
| *TOGO* | Topology-assisted Geo-Opportunistic |
| *TTL* | Time to Live |
| *UWV* | Unmanned Water Vehicle |
| *V2I* | Vehicle-to-Infrastructure |
| *V2V* | Vehicle-to-Vehicle |
| *VADD* | vehicle-assisted data delivery |
| *VANET* | Vehicular Ad hoc Network |
| *VS* | Vehicle Speed |
| *WRP* | Wireless Routing Protocol |
| *WAVE* | Wireless Access in Vehicular Environments |
| *ZHLS* | zone based hierarchical link state |
| *ZRP* | Zone Routing Protocol |

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# CHAPTER ONE

## INTRODUCTION

In this chapter, the research background, basic fundamental concepts of VANET, research motivation, statement of the problem, objective, scope, limitation and significance of the study are discussed.

### 1.1. Background

An ad hoc network is a collection of heterogeneous network nodes that construct ephemeral networks without the requirement for a central administration or infrastructure. Using shared wireless channels, nodes on a wireless ad hoc network can connect directly. They do not require extra network infrastructure, such as a base station, access points, switch, router, or other similar devices, when communicating over the network. The connected device on an ad hoc network serves as both an end device and a router. As an end device, each device in the network can request information from another device, and the router distributes the information centrally. For transferring information securely over cabling in such a region, most military organizations use ad hoc networks.

The researchers built their classification for ad-hoc networks into three main categories, Mobile Ad hoc Network (MANET), Vehicular Ad hoc Network (VANET), and Flying Ad hoc Network (FANET), due to the variety and widespread use of ad-hoc networks in many applications, such as complex military system usage applied in resonance and attack roles, and civilian applications such as rescue missions and firefighting, but they didn't discuss in their classification beyond the ad-hoc nodes that operate underwater, i.e. Unmanned Water Vehicle (UWV). Figure 1: shows the new classification for ad-hoc networks, which is divided into four primary categories: MANET, VANET, FANET, and Under Water Vehicular Ad hoc Network (UWVANET)[1].

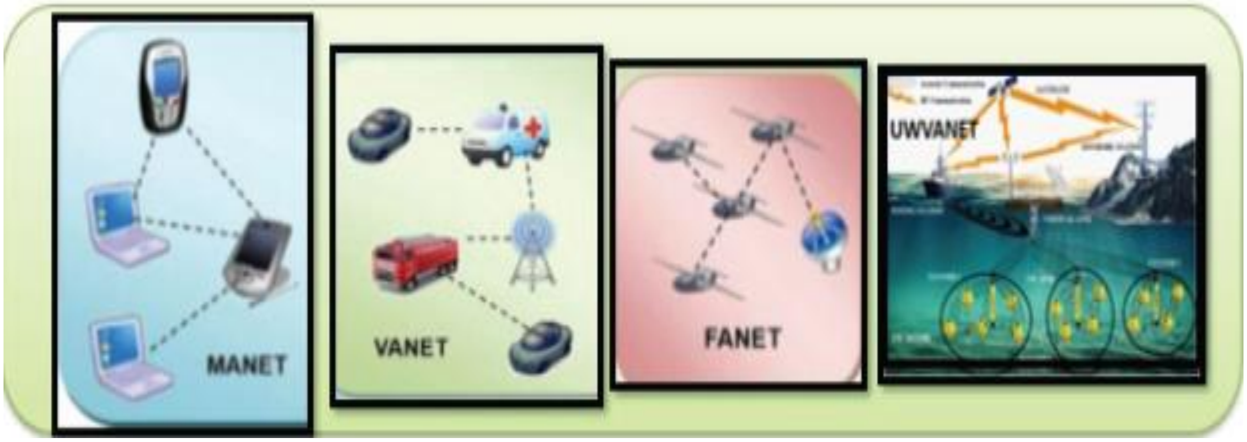



Figure 1:  Four primary categories of ad hoc network[1]

VANETs (vehicular ad hoc networks) are a subset of mobile ad hoc networks (MANETs) that are used to communicate between vehicles and infrastructure. Vehicles act as nodes in a VANET, sending and receiving data without the need of a physical link. The IEEE committee established the IEEE 802.11p standard for VANETs, recognizing the importance of vehicle ad hoc networks for delivering safety-related applications in Intelligent Transportation Systems (ITS). For specialized short-range communication, the US Federal Communication Commission (FFC) has set aside 75 MHz of bandwidth at 5.9 GHz (DSRC)[2].

DSRC can be a single-hop or multi-hop communication channel, with communication modes such as V2V (Vehicle-to-Vehicle), V2I (Vehicle-to-Infrastructure), or a hybrid of V2V and V2I. If a wireless link is available in between, one vehicle communicates directly with another vehicle, which is known as single hop V2V communication. Multi-hop communication is less reliable and takes longer. If there is no direct connection between them, data is transferred from one vehicle to another until it reaches its intended destination, which is known as multi-hop vehicle to vehicle (V2V) communication for long distance communication. This type of communication allows vehicles to transmit many types of information related to any situation, such as safety information for accident prevention and post-accident investigation, or traffic bottlenecks[2].

The DSRC[3] communication range is 100 to 1000 meters, with a data rate of 6 to 27 megabits per second. The DSRC communication strategy was initially based on the IEEE 802.11a physical (PHY) and IEEE 802.11 Medium Access Control (MAC) layers, with a data rate of 54 Mbps [4]

Later, the DSRC standard was renamed Wireless Access in Vehicular Environments (WAVE), which was later shortened to IEEE 802.11p. The IEEE 1609 family expresses the Wireless Access in Vehicular Environments (WAVE) standard. This standard specifies a standardized set of services, architecture, complementary interfaces, and various interfaces for defending vehicle-to-vehicle communication (V2V) or communicating with stationary tools next to the road, referred to as a roadside unit (RSU), forming vehicle-to-infrastructure communication (V2I)[5].

For WAVE, IEEE has created a standalone IEEE 1609-DSRC working group. IEEE 1609.1 for WAVE Resource Management (RM) and IEEE 1609.2 for WAVE Security Services (SS) at the application layer, IEEE 1609.3 for WAVE Networking Services (NS) at the network layer, IEEE 1609.4 for WAVE Multi-Channel Operations (MCO) at the Medium Access Control (MAC) sub layer, and IEEE 802.11p for WAVE Single-Channel Operation (SCO) at the physical layer make up the IEEE 1609 protocol suite and IEEE 802.11p[4]

VANETs are characterized by a lack of central management and a topology that changes rapidly. VANETs face a variety of issues as a result of their network's nature, including network management, congestion and collision control, environmental impact, social and economic challenges, and security[6]. Controlling traffic congestion in VANETs is a crucial concept that is currently attracting the attention of many academics. As a result, VANETs are critical for deploying an intelligent transportation system that allows vehicles to communicate with one another and provides potential applications such as emergency brake alert information, weather forecasting to assist drivers, collision avoidance by reducing road traffic, lane change cautioning to increase traffic safety, internet access, and so on[7].

In different sections of the country, excessive traffic congestion is the leading cause of vehicle accidents in a vehicular environment. Every day, thousands of people are killed or injured while walking down the street. People may not be able to return home if they leave their residences due to vehicle accidents on the road. People have lost their lives and their possessions as a result of these vehicle accidents.

According to[8], one of the World Health Organization's (WHO) latest statistics from 2013 stated that about 1.24 million people die each year as a result of traffic accidents worldwide. If no action is done, these fatalities are predicted to climb to almost 1.9 million people each year by 2020.

According to the survey, poor and middle-income countries account for more than 91 percent of all road fatalities worldwide, even though they only account for around half of all automobiles on the road. Non-fatal injuries, on the other hand, affect between 20 and 50 million people worldwide. As a result of these occurrences, many of which result in disability (WHO, 2013). According to a report published in 2000 by the UK Transport Research Laboratory, the yearly economic costs of traffic accidents are estimated to be $518 billion, with around $65 billion of these expenditures occurring in poor and middle-income nations. Using the World Health Organization's (WHO) statistics on road traffic injuries as a guide, the cost of these incidents is estimated to be 1% of GNP in low-income nations, 1.5 percent in middle-income countries, and 2% in high-income countries.

Congestion occurs when nodes compete to acquire channels, causing the channels to become saturated. Indeed, when vehicle density rises, the number of channel collisions rises, increasing the likelihood of network congestion. Congestion causes increased delay and packet loss (particularly for safety messages), resulting in a reduction in VANET performance. Quality of Service (QoS) should be supported to ensure the dependability and safety of vehicular communications, as well as to increase the performance of VANETs. Controlling congestion is an efficient method for ensuring QoS. Controlling congestion reduces delay and packet loss, and enhanced VANET performance, resulting in a safer and more reliable environment for VANET users [9].

Congestion in VANETs can be managed in a variety of ways, including by adjusting the transmission rate, transmission power, contention window size and Arbitration Inter-Frame Spacing (AIFS), and prioritizing and scheduling messages. High transmission delay, unfair resource consumption, wasteful bandwidth usage, communication overhead, and computing overhead, among other issues, plague congestion control solutions in VANETs. As a result, new solutions for controlling congestion in VANETs should be devised, taking into account these issues, particularly in crucial instances where safety messages must be transmitted without considerable delay or packet loss[9].

In today's industrialized cities, road traffic has become a big issue. Vehicles could be used to accumulate and analyze traffic data and send it to drivers in a way that allows them to make smart decisions to avoid crowded regions, resulting in congestion control, thanks to technological advancements. Because 1.2 million people are anticipated to be killed on the roads each year, road traffic conditions have an impact on population safety. As a result, the automobile industry and governments are investing significant resources to improve road safety and traffic efficiency, as well as to lessen the environmental impact of transportation[10].

Congestion is currently widely regarded as one of the world's most serious issues. As a result of the growing number of modes of transportation and the current low-quality road infrastructure, traffic problems are predicted to become substantially more widespread. Congestion is caused by a variety of circumstances, including rush hour, road construction, accidents, and even adverse weather. All of these causes, as well as a slew of others, can contribute to traffic congestion. Drivers who are unaware of the problem eventually join it, exacerbating the problem. The more severe the congestion, the longer it will take to clear once the source of the blockage is removed. Knowing the traffic conditions on the road ahead of time will allow a driver to seek alternate routes, saving time and money. When a large number of drivers have this capability, traffic congestion will be less severe, with only the vehicles in the congestion region being affected[11].

In this research work, we have presented an important document that can provide detailed information about the main aspects of vehicular ad hoc networks and the challenges related to vehicular ad hoc networks. It covers various subtopics like vehicular ad hoc network architecture, communication domains, challenges, applications, routing protocols, and NS2 simulation tools in VANET.

## 1.2. Motivation of the Study

Peoples move from one area to the other area, whether for work, business, study, research, or pleasure, by various means of transportation. A Vehicle is one of the means of transportation in the world and also they are the source of accidents during transportation when they move from one place to the other place. Due to the shortage of communication between vehicles and other devices on the road, the number of people dying. Currently, congestion is the main issue in many parts of the world, particularly Ethiopia. because the types of vehicles are not appropriate for reducing traffic and there is no sign that indicates the density of vehicles on the road. A number of people are seriously hurt or unable to return home, and several are killed in road accidents[12]. The absence of centralization in VANETs is a major contributing factor to the traffic disaster. At this location, the network may undergo a change in its topology due to the addition or removal of vehicles. Inadequate communication between vehicles and other road equipment is contributing to the growth of traffic congestion. Due to various influencing factors, the issue of traffic congestion has become a significant worry in numerous regions of the globe, with a particular emphasis on Ethiopia. Due to the fact that the current designs of both roads and vehicles do not effectively prevent collisions. We conducted this research because of the traffic gridlock at the junction.

Due to the above local and global problems, we have been motivated to find the solution for traffic congestion on the intersection road in different areas of the country. Purposely to show the traffic congestion prevention mechanism, previous researchers conduct different studies either detecting or preventing traffic congestion over VANET. But they did not consider the load aware and priority adaptive traffic congestion control mechanisms on the crossroads. Therefore, in these papers, we have to propose the load aware and priority adaptive traffic congestion control mechanisms on the crossroads using V2V and V2I communication

## 1.3. Statement of the Problem

In the context of VANET, congestion is the situation where the network becomes overloaded with too much traffic on the road and caused by various factors, including high mobility, dynamic channel conditions, the high density of vehicle, high volume of data traffic, lack of efficient routing protocols. Urban road traffic congestion can happen due to reasons such as high demand, signals, work zones, incidents, weather, or events. Road traffic congestion is classified into recurring and nonrecurring causes. Recurring congestion is often caused by bottlenecks and capacity issues. Bottlenecks happen during peak hours when the number of paths converging on a road, bridge, or tunnel is greater than what these facilities have. A road's capacity refers to its traffic-handling limit, which depends on lane number and width, interchange merging length, and alignment. Nonrecurring congestion happens due to unpredictable events like traffic incidents, work zones, weather, or circumstances[13].

In a vehicular environment, congestion control is a challenging subject. These mainly because of the shared nature of the wireless channel and the frequent changes of the network topology. Indeed, routes changes due to dynamic and mobility of nodes result in unsteady packet delivery delays and packet losses. In addition, the use of a shared channel allows only one data transmission at a time within the interference range of a node. Thus, when too many vehicles try to communicate in a wireless network without a fixed structure, it can cause problems for the entire network, not just particular devices that are receiving too much traffic.

In recent times, congestion control protocols have become increasingly important due to the growing demand for high-speed and reliable network connectivity. As a result, there has been a surge in research efforts to develop more effective congestion control mechanisms. The authors on [14]suggests a V2V-based traffic solution where vehicles share data to select less congested routes through VANET-based Autonomous Management (VAM) Vehicles choose optional routes based on similar neighbor routes, but this causes significant communication overhead. A density-based congestion control method is proposed by[15]  vehicle ID-based congestion aware messages (CAM) for beacon signals in the vehicle environment. The research includes a congestion management method that adjusts the rate of CAM transmitted over the host controller to improve the efficiency of the model parameters. But on CAM-based congestion control mechanisms all vehicles evaluate the digital information before distributing data transfer. Which leads to a payload on the overflow of data on the network.

Generally, there are several studies conducted by previous researchers in congestion control mechanisms. However, there is still a gap in the existing routing algorithm in the selection of the best route, it does not consider the real-time suggestion to vehicles best route depending on the context of the traffic to achieve high message delivery probability and low overhead. Therefore, this research aims to design a congestion control method for vehicular ad hoc networks to control congestion effectively between V2I communications. The algorithm efficiently detects the congestion and suggests the best non-congested route for the vehicles to avoid congestion

**Research Questions**

This study attempts to answer the following research questions:

1. What are the primary factors influencing road traffic congestion in vehicular ad hoc networks (VANETs)?
2. How can a load-aware priority adaptive congestion control algorithm be designed to address current urban traffic congestion issues in vehicular ad hoc networks (VANETs)?
3. How to measure the performance of the load-aware and priority adaptive congestion control algorithm in VANETs?

**Contribution of the Research**

- Design an algorithm based on the load on the network and suggest better non-congested road segments.
- Improve the traffic congestion through route suggestions between neighbors RSU. The proposed LAPCC scheme requires the neighbor RSU to reply with congestion route index to gain the Road segment status.

## 1.4. Objectives of the Study

### 1.4.1. General Objective

The general objective of this research is to design load aware and priority adaptive traffic congestion control technique on vehicular ad hoc network.

### 1.4.2. Specific Objective

To achieve the general objective of the proposal, the following specific objectives are identified;

- To identify the problem of traffic congestion control in VANET.
- To review related works with congestion control algorithm
- To test the proposed algorithm by simulating using network simulation tool.
- To identify appropriate performance metrics for the evaluation of the proposed algorithm against the existing one.
- To conclude the simulation result of the proposed algorithm and give recommendation for future researchers.

## 1.5. Research Approach

This research follows a design science[16] research approach to design, develop and evaluate the proposed routing algorithm in order to meet its intended objectives. Design science approach follows various activities to design artifacts and to solve the observed problem[17]. This study follows activities of design science research life cycle.

**Activity 1: Problem identification and motivation: -** The specific research problem is already defined and discussed in the statement of problems. Which is the lack of a congestion control mechanism which jointly considers the real-time node, and network in the routing decision.

**Activity 2: Define the objectives for the solution: -** The objective is to design and develop a load aware priority adaptive congestion control mechanism on VANET.

**Activity 3: Design and development: -** The architecture design and development of the proposed method done at this phase. The proposed protocol consists of three different stages – initialization, congestion state representation, and congestion route suggestion.

**Activity 3.1: Initialization: -** node and vehicle network environment is initialized to provide good environment.

**Activity 3.2: Congestion state representation: -** we identify the load factor to get the upper limit of the network which causes the road to congest based on different parameters.

**Activity 3.3: congestion route suggestion: -** We suggest the congested node to reach to destination by RSU nodes communicate with neighbors to get the congestion route index of the road.

**Activity 4: Testing and Demonstration: -** after the protocol developed, the effectiveness of the algorithm tested in simulated environment using NS3 and SUMO simulator. To make sure that whether the algorithm meets its objectives.

**Activity 5: Evaluation: -** in this phase evaluation of the proposed routing protocol performed against well-known previous works using metrics packet delivery ratio, packet loss ratio, and delay based on different simulation scenarios such as various number of vehicles, and speed of vehicles,

The summary procedure gone through this research is shown below in the Figure 1.2

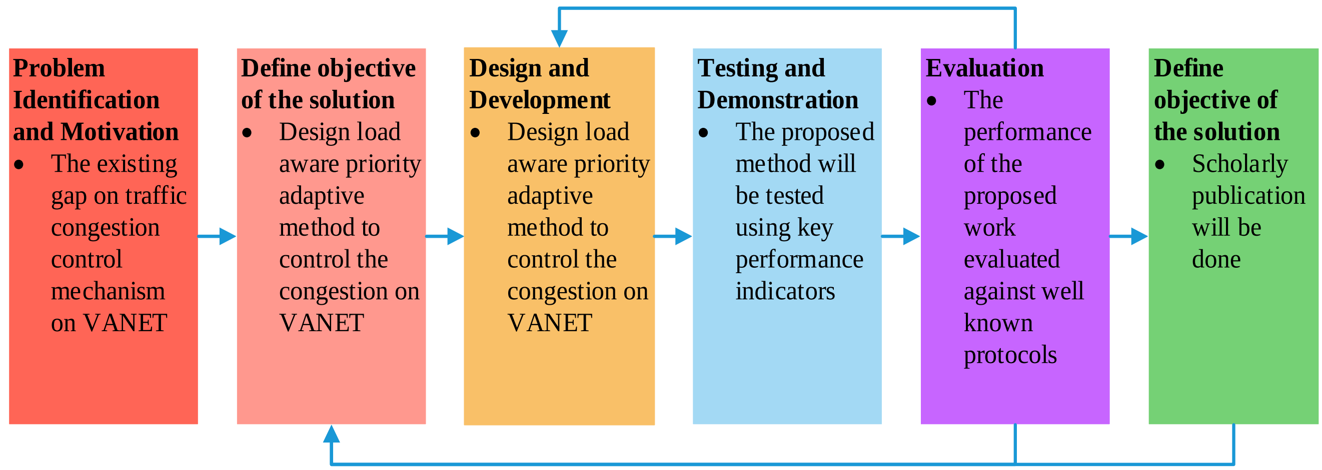



Figure 2: The summary of research process in design science adopted [17]

## 1.6. Significance of the Study

This research will have a lot of implications for various recipient groups. The following are some of the most important groups.

i. **For Drivers:** As we all know, different drivers waste time and fuel as a result of traffic congestion in various parts of the country. The findings of the study will aid in reducing the amount of time and fuel lost due to traffic congestion.

ii. **For Government**: To alleviate traffic congestion, the government is currently paying high salaries to a large number of personnel around the country. The suggested algorithm will assist in reducing the required workforce to the bare minimum required to centrally control all vehicle activities.

iii. **For traffic polices**: These findings will aid in reducing the workload of traffic polices. The traffic polices are always on the go, monitoring the operations of automobiles. The study will aid in reducing their workload by identifying driver behavior and the source of traffic congestion.

iv. **For Researchers**: Once the study is completed, different researchers involved in it will utilize it to refer to for more research on traffic congestion reduction strategies. The study will provide a better understanding of how congestion metrics are determined and will serve as a reference for more research on traffic congestion reduction strategies.

## 1.7. Scope and Limitation of the Study

### 1.7.1. Scope of the Study

According to the study, the scope of the research is to identify the source of traffic congestion on crossroads utilizing VANET and to model the result using the supplied simulation tool. However, the study will not be able to identify false alarm messages during alarm message communication, and non-smart automobiles will be excluded from the study.

### 1.7.2. Limitation of the Study

Because traffic congestion control is such a broad topic, some activities will be excluded from the study. The primary limitation of the study is that it will not be able to identify false alarm messages during alarm message communication. Additionally, non-smart automobiles will be excluded from the study because vehicle intelligence is a crucial condition for establishing vehicle communication.

## 1.8. Organization of the Thesis

The rest of the thesis is organized as follows. Chapter two provides a literature review and related works. From literature review parts, an overview of VANET, characteristics of VANET, the architecture of VANET, communication in VANET, application of VANET, VANET routing protocols, and detail review of related works regarding to congestion control in VANET. Chapter three briefly describes the proposed system that enables to select the best route index. Chapter four deals with the implementation detail of the proposed algorithm. Under the implementation part, a detailed explanation of the simulation tool, implementation of a load aware and traffic congestion control algorithm on an intersection road with their simulation results and comparison with the previous nearest work using tabular and graphical representation would be discussed. Finally, conclusion and future work are discussed in Chapter6.

Generally, the organization of the thesis have been summarized as shown in the following chart.

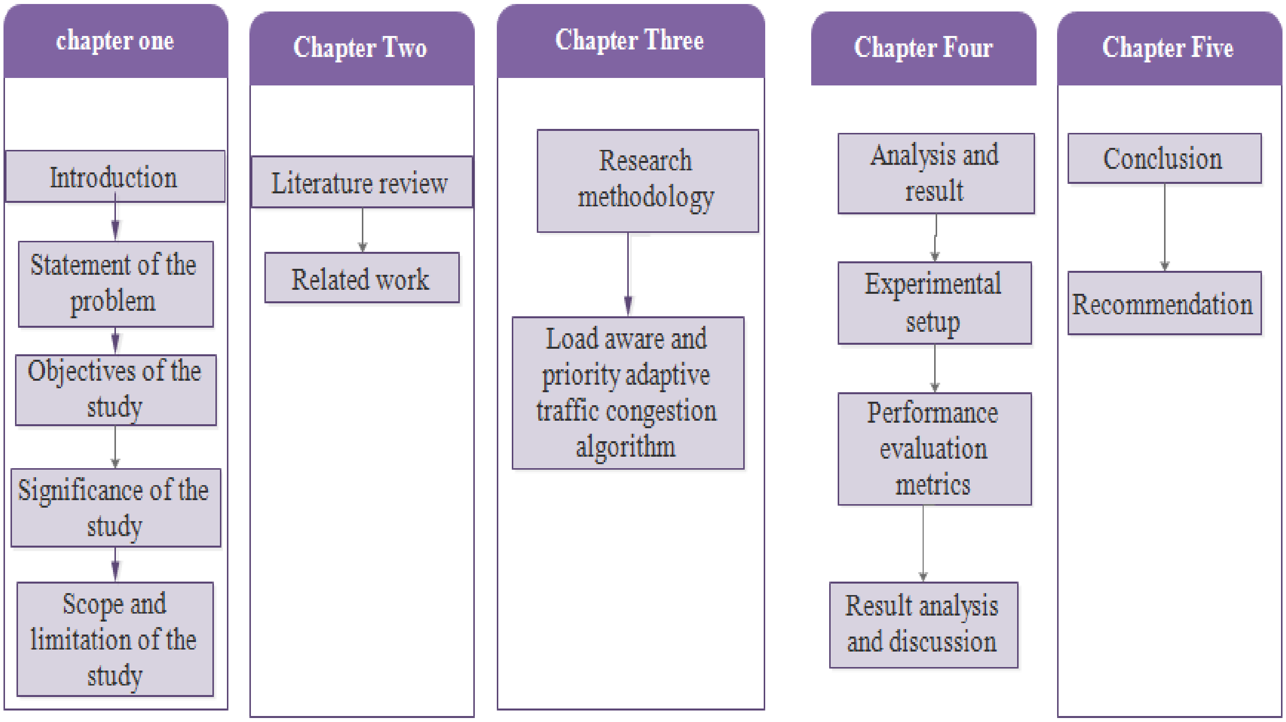



Figure 3: Organization of the thesis

# CHAPTER TWO

# LITERATURE REVIEW AND RELATED WORKS

## 2.1. Overview of VANET

A VANET is a sort of MANET in which moving cars act as nodes, routers, or access points for transmitting messages among vehicles (AP). It can often connect to automobiles within a range of 100 to 900 meters when using 802.11p[18]. Vehicle-to-vehicle and vehicle-to-infrastructure communication is the primary purpose of using a vehicular ad hoc network to connect autos. This interaction between cars and infrastructures resulted in an intelligent transportation system (ITS) that provides a pleasant travel experience for both drivers and passengers. Safety applications such as collision avoidance, pre-crash detection, and lane shifting are aimed at minimizing road accidents by leveraging traffic monitoring and management software. Passengers can use non-safety applications to get internet access, interactive conversation, online games, payment services, and information updates while the car is driving. The primary distinction between safety and non-safety apps is that safety applications can send and process messages in real time. Using wireless access technology, the driver and passengers can effortlessly access both types of services from surrounding infrastructure[19].

Dynamic topology, multi-hop data transfer, distributed architecture, and omnidirectional broadcast are only a few of the commonalities between VANET and MANET. Mobile nodes in both networks are capable of routing or relaying data between nodes. The mobility of a node in a vehicle ad hoc network can be easily anticipated during node mobility. Furthermore, the storage and processing capabilities, as well as the battery power of nodes in a VANET, are unrestricted. The topology of a VANET's generated wireless network is very dynamic due to the quick mobility of nodes. Furthermore, VANET network density changes greatly over time and location. In a mobile ad hoc network, it's difficult to forecast how nodes will move throughout the network[19].

## 2.2. Characteristics of VANET

VANETs are wireless networks using stationary road units or highly mobile vehicles as nodes. In ad hoc mode, nodes connect with one other, and in infrastructure mode, nodes communicate with fixed equipment on the highways. As a result, the characteristics of VANETs are a mix of wireless medium characteristics and topology characteristics in both ad hoc and infrastructure modes. The properties of VANET are listed below, according to information from the researcher[20]

1) **Interaction with on-board sensors:** It is believed that the nodes include onboard sensors that offer information that can be used to build communication links and for routing. GPS devices, for example, are becoming more popular in automobiles and help to provide location information for routing purposes. The nodes are supposed to include on-board sensors that offer information that can be used to build communication links and for routing reasons. GPS devices, for example, are becoming more popular in automobiles and help to provide location information for routing purposes.

2) **Highly dynamic topology:** Due to the fast speed of vehicles, the topology generated by VANETs is constantly changing. Vehicles travel at speeds of up to 90,000 mph (25 m/sec) on freeways. Assume a radio range of 250 meters between two cars. The link between the two vehicles then lasts no more than 10 seconds.

3) **Frequently disconnected network (Intermittent connectivity):** Because the link between two vehicles might abruptly evaporate while the two nodes are transmitting information, the highly dynamic topology results in frequently disconnected networks. Heterogeneous node density, where frequently frequented roads have more cars than non-often traveled roads, helps to solve the problem even more. To provide ongoing communication, a robust routing system must notice frequent interruptions and promptly provide an alternative link.

   The figure 2: shows a graph of the number of disconnections per second in a VANET simulation. The x-axis represents time in seconds, and the y-axis represents the number of disconnections per second. The graph shows that the number of disconnections per second is high, indicating that VANETs frequently experience network disconnections due to the highly dynamic topology resulting from the fast speed of vehicles. The figure highlights the need for a robust routing system that can promptly provide an alternative link to ensure ongoing communication in VANETs

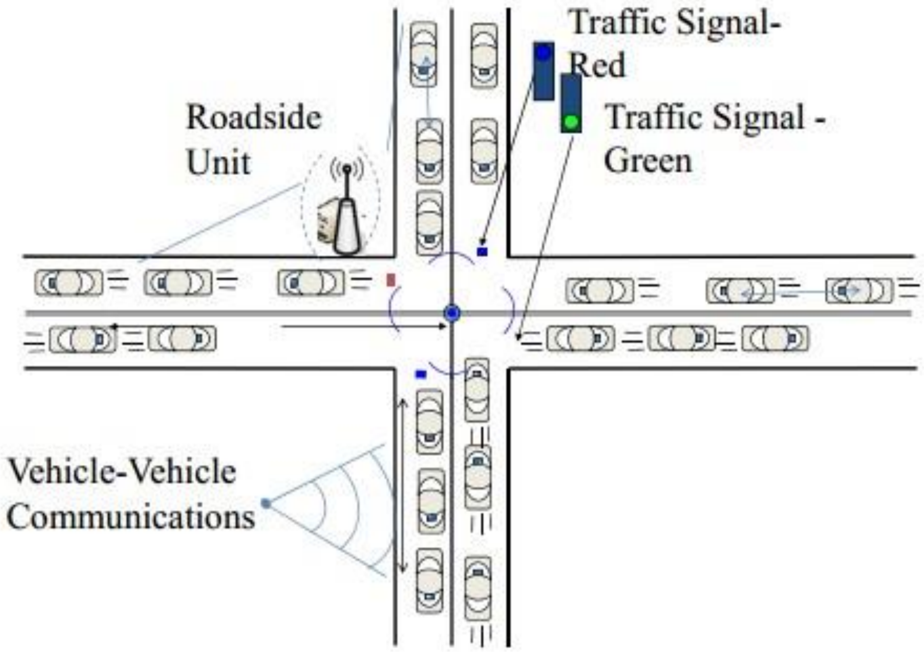



Figure 4:VANET frequent disconnections[20]

4) **Patterned Mobility:** Vehicles travel in a predictable pattern that is determined by the underlying roads, RSUs, speed limits, traffic conditions, and driver behavior. Because of the unique mobility pattern, only traces obtained from the pattern may be used to evaluate VANET routing systems.

5) **Propagation Model in VANET:** Because of the presence of buildings, trees, and other vehicles, the propagation model is rarely believed to be empty space. A VANET propagation model should take into account the effects of free-standing objects as well as the possibility of wireless communication interference from other cars or widely distributed personal access points.

6) **Unlimited Battery Power and Storage:** Unlike sensor networks, where nodes are generally static, nodes in VANETs are not limited in terms of battery power and storage. The energy and computing power of nodes are expected to be sufficient. As a result, optimizing the duty cycle is less important in sensor networks.

7) **Various communications environments:** VANETs are commonly used in one of two communication settings. The setting is relatively simple and easy in highway traffic

scenarios (e.g. constrained one-dimensional movement). When you're in a metropolis, things are a lot more complicated. Buildings, trees, and other impediments frequently separate city roadways. As a result, there isn't always a straight route of connection leading to the intended data transmission[21].

## 2.3. Architecture of VANETs

The architecture of VANETs can be split into three categories based on the contents of components: ad hoc, cellular or WLAN, and hybrid architectures[2]. If a cellular gateway, a WLAN, or a WIMAX access point are present in the vehicle network topology, the vehicular network is classified as WLAN or pure cellular. If no infrastructure is available, the vehicles must connect using a single communication mode, making the vehicular network a pure ad hoc architecture. Several nodes may be able to communicate with infrastructures or directly with one another in some cases. Hybrid architecture refers to this form of vehicle network design[2].

The six most important system components in the VANET architecture are all working together to provide efficient communication services. An onboard unit (OBU), a roadside unit (RSU), an application unit (AU), an access network (AN), the Internet, and communication domains (vehicle to vehicle domain, ad hoc domain, and infrastructure domain) are among these components)[22]. Every vehicle has an OBU, which allows for ad hoc communication with the environment. Each vehicle is equipped with an OBU and a collection of sensors that collect and process data in order to deliver a message through wireless medium to other vehicles or roadside equipment. The roadside unit (RSU) is placed on the roadside on a regular basis to detect nodes. Wireless Access for Vehicular Environment is used to connect vehicles and roadside units for communication (WAVE). This communication system provides a variety of data to vehicle drivers, as well as intelligent safety applications to improve road safety and provide a secure driving experience[23].

The roadside unit links to the internet or another server to allow several application units from different vehicles to connect to the Internet[23]. An application unit is a graphical interface between the operator and the onboard unite, and the access network includes the cellular access network (RSUs and Gateway), as well as the wireless access network, to enable communication between the vehicle and infrastructures as a result of establishing infrastructure domain. The intra-vehicle communication space makes it easier to communicate within a car (among AU and OBU).

The goal of an ad hoc domain is to communicate amongst cars utilizing single or multi-hop communication.

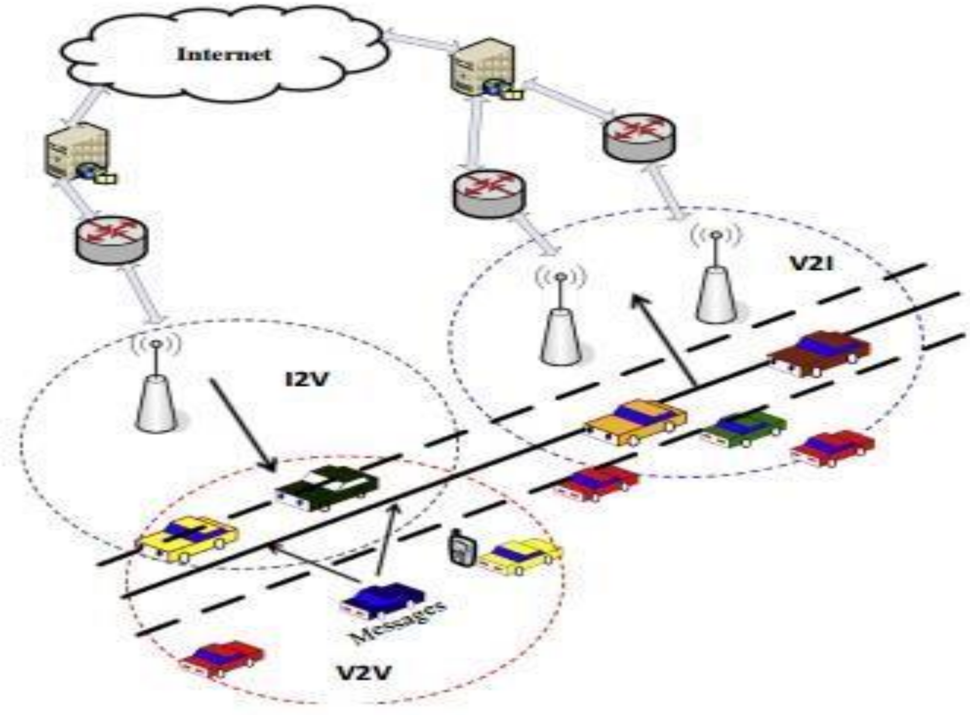



Figure 5:VANET system Architecture[2]

### 2.3.1. On Board Unit (OBU)

The On-Board Unit (OBU) is a device that is frequently mounted on the vehicle's dashboard and is used to transmit data to roadside units or other on-board units. Sensors, processing units, and a communication system are among the on-board units. An OBU broadcasts a traffic-related beacon message every 100–300 milliseconds, according to the 802.11P protocol[24].

To improve vehicular communication, OBU in VANET provides real-time data about each vehicle, such as speed, direction, and position. There's also a resource command processor (RCP), and resources include a read/write memory for storing and retrieving data, as well as a user interface. An interface to connect to other OBUs and a network device for short-range wireless communication based on IEEE 802.11p radio technology are included on board units. It also contains a non-safety network device based on other radio technologies such as IE EE 802.11a/b/g/n. The OBU links to the RSU or other OBUs through a wireless link based on the IEEE 802.11p radio frequency channel and is in charge of communications with other OBUs or

RSUs. It can also provide communication services to the AU and forward data on the network on behalf of other OBUs. Wireless radio access, ad hoc and geographical routing, network congestion control, dependable message transfer, and data security are only a few of the primary tasks provided by the OBU in VANETs[5].

### 2.3.2. Application Unit (AU)

It is the vehicle's gadget that leverages the provider's applications and the onboard unit's communication capabilities to communicate with them. Capabilities (AU) might be a dedicated device for safety applications or a regular device like a personal digital assistant (PDA). The AU can be wired or wirelessly attached to the on board unit (OBU) and can coexist with the OBU in a single physical unit. The distinction between the AU and the OBU is self-evident. The only way the AU communicates with the network is through the OBU, which is in charge of all mobility and networking tasks.

### 2.3.3. Road Side Unit (RSU)

The Road Side Unit (RSU) is a wave device that is normally stationary by the road or in dedicated areas and can be used as a router, access point, or even a buffer point, storing data and providing it when needed. One network device is installed on the RSU for dedicated short-range connectivity using IEEE 802.11p radio technology. It is made up of a sensor unit and a communication unit that receives and sends data to and from other nodes. Figures 6, 7, and 8 depict some of the roadside unit's functions and approaches[5].

1) Figure 6 shows how the Roadside Unit (RSU) extends the range of the ad hoc network of On-Board Units (OBU) in a VANET. The RSU is placed on the roadside and acts as a relay node, receiving data from OBUs and transmitting it to other OBUs within its range. This helps to expand the coverage area of the network and redistribute data to other OBUs. The RSU can also execute various functions in VANET communication, including data distribution, internet access for OBUs, real-time communication, routing path, security traffic management, and route performance analysis

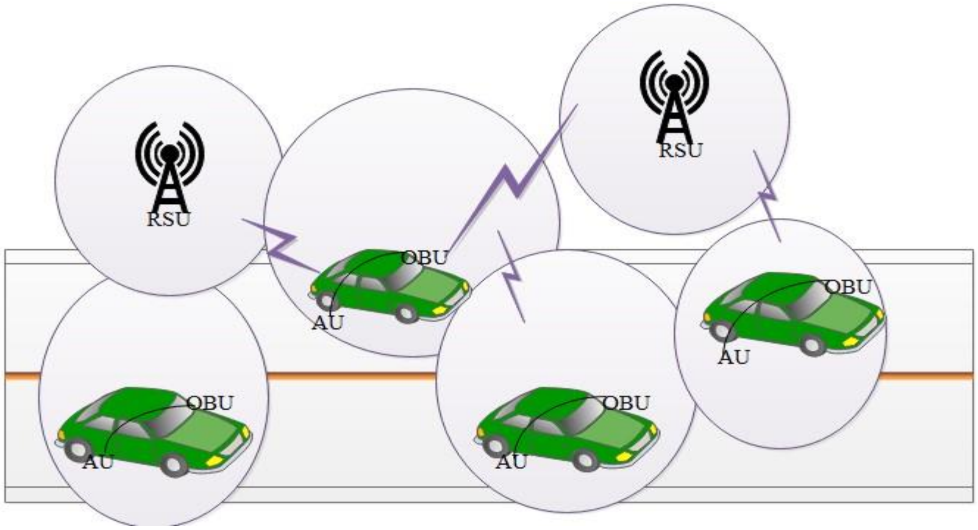



Figure 6: RSU extend range of ad hoc network of OBU[5]

2) Figure 7 shows how the Roadside Unit (RSU) works as an information source in a VANET. The RSU can provide information to the On-Board Units (OBU) about various aspects of the road, such as traffic congestion, road conditions, and weather. This information can be used by the OBUs to make informed decisions about their route and driving behavior. The RSU can also execute safety applications such as low connection warning and accident warning.

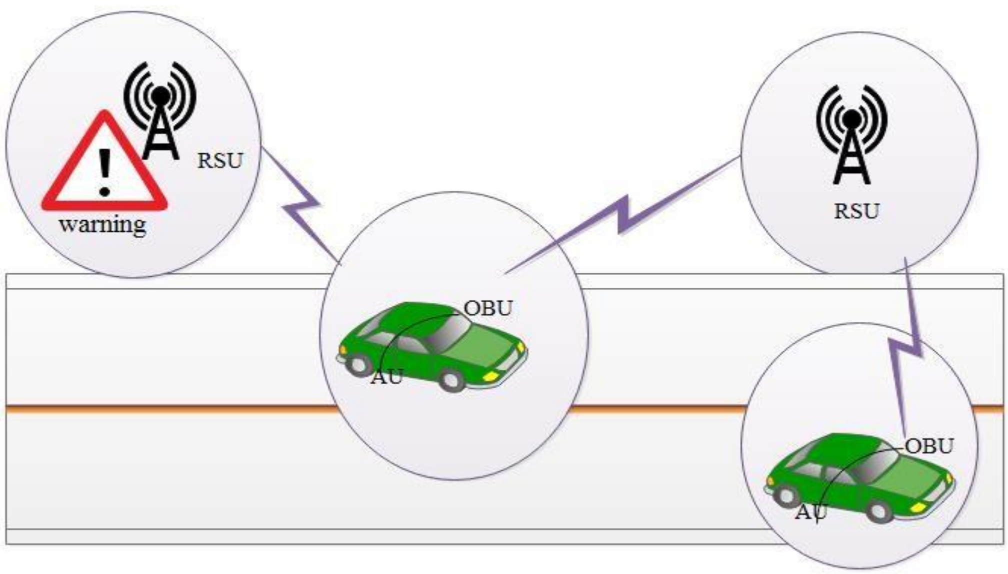



Figure 7: RSU work as an information source[5]

3) Figure 8: shows how the Roadside Unit (RSU) offers Internet connectivity to the On-Board Units (OBU) in a VANET. If the RSU is configured as a router, vehicles can connect to the Internet via the RSU. This provides Internet access to the OBUs, allowing them to access various online services and applications. The RSU can also execute various functions in VANET communication, including data distribution, real-time communication, routing path, security traffic management, and route performance analysis

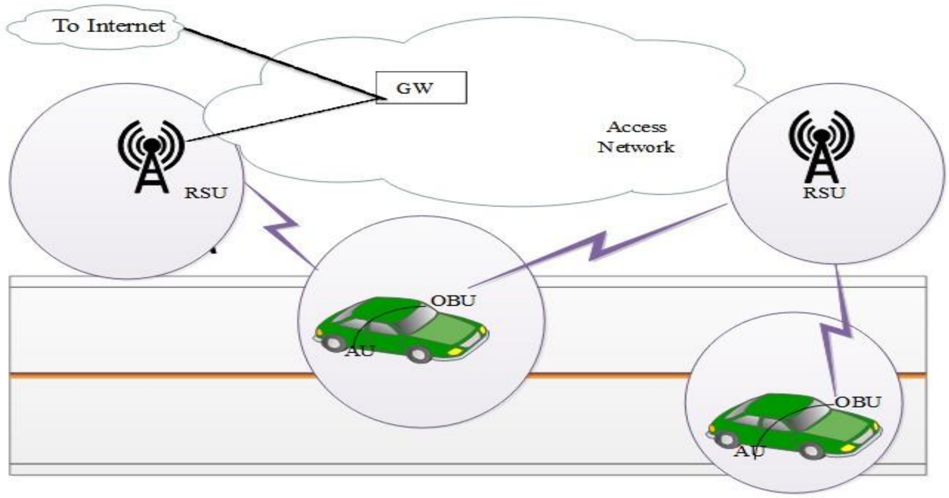



Figure 8: RSU offers Internet connectivity to OBU[5]

## 2.4. Relationship between Vehicles and Infrastructures

Certain articles, such as Regional Transportation Authorities (RTAs), Network Authorities (NAs), Law Enforcement Authorities (LEAs), and roadside infrastructure, such as border road side units (RSUs) for false name management, humble and consistent RSUs for Internet access, and users' vehicles, have been included in the VANET system. As a result, this roadside construction provides network services and infrastructure access. However, in order to function, they require the assistance of third-party service providers. To create access infrastructure in the RTA's state, service providers must enter into commercial agreements with the RTA. As a result, RSUs are not kept by the RTA, whereas border RSUs are kept and administered by the RTA, and they function as the agent's replacement under the RTA's jurisdiction. As a result, both automobiles and RSUs participate in communication in VANETs. Vehicle-to-vehicle communication is used to send out network-wide safety and warning messages. Vehicle-to-vehicle communication can be classified into two types based on the relative positions of the source and destination: There are two types of hops: single-hop and multi-hop[2].

Local vehicle transmission, or single-hop vehicle-to-vehicle communication, is used to direct safety messages. Non-safety messages are frequently transferred through multi-hop V2V communication. Vehicles to roadside unit (V2R) communication allows vehicles and roadside units to communicate[23]. It's utilized to provide services like Internet access and specialized service applications[25]. The communication mechanism between vehicles, RSUs, and infrastructure, or between VANET nodes, is categorized into three domains[24]. Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Infrastructure-to-Vehicle (I2V) are the three vehicular communication modalities, or a blend of V2V and V2.

### 2.4.1. Inter-Vehicle Communication (V2V)

Vehicle-to-vehicle communication is also known as inter vehicle communication. It employs multicast or broadcast to send traffic-related data to a group of recipients over a number of hops. Vehicles in an Intelligent Transportation System must be concerned with activity on the road ahead of them rather than behind them[5]. In V2V communication, there are two types of data forwarding: naive broadcasting and intelligent broadcasting.

#### 2.4.1.1. Naive Broadcasting

Vehicles send out broadcast signals at predetermined times. If communications arrive from a car after it, the vehicles reject the message based on the time it was received. If the message is received from a vehicle ahead of it, the receipt vehicle sends its own broadcast message to the vehicles ahead of it. It confirms in order to allow all forward-moving cars to receive all broadcast signals. The limitations of the naïve broadcasting strategy are that it generates a large number of broadcast messages, which increases the risk of message collision, resulting in lower message distribution rates and longer distribution durations.

#### 2.4.1.2. Intelligent Broadcasting.

It allows for the realization of acknowledgement addresses, as well as the issues inherent with naive broadcasting, by limiting the number of messages broadcast for a known catastrophic occurrence. When an event-detecting car receives identical messages from vehicles behind it, it assumes that at least one of the vehicles in the rear has recognized it and stops broadcasting. The assumption is that the car in the back will be capable of disseminating the message to other vehicles. If a vehicle receives a message from more than one source, it will only process the initial message[5].

### 2.4.2. Vehicle-to-Road Side Communication (V2R)

The major aspect of communication in a VANET is vehicular to roadside unit communication, which includes a single-hop mode of the broadcast system's forward broadcast message to every other vehicle in the surroundings. However, for communication between automobiles and roadside equipment, a very high bandwidth link was used. The range of a high-bandwidth connection is one kilometer or less of neighboring roadside unit. In that instance, it is employed to sustain high data rates for communication and remains stable in any traffic conditions.

### 2.4.3. Inter-Road Side Communication (R2I)

Inter-road side communication is based on routing and is a multi-hop unicast in which a message is disseminated in a multi-hop fashion until the vehicle resounding the intended data is reached. When a request is acknowledged in a vehicle that has the requested piece of information, the request at that vehicle sends a unicast message containing the data to the vehicle that acknowledged the request, which is then charged with sending it to the request source.

## 2.5. Application of VANETs

Vehicle traffic aid communications, such as traffic conditions and traffic flow, information about road conditions, vehicle path change and navigation information, and vehicle post-crash and intersection accident avoidance, are frequently transmitted. However, in non-safety applications such as electronic toll collection, auto parking, streaming, Internet access, entertainment (gaming), and mobile commerce, communication is on demand only. VANET applications that rely on vehicle-to-vehicle or vehicle-to-vehicle communication are divided into four categories[20]. These are the following:

1) Safety Oriented,
2) Commercial Oriented
3) Convenience Oriented and
4) Productive Applications

### 2.5.1. Safety Application

The ultimate purpose of VANET safety applications is to prevent and reduce the number of traffic accidents. This is a delay-sensitive application category. Because a warning message is sent from vehicle to vehicle to alert the accident area, there may be a delay between vehicles. As a result, in this category of applications, vehicle-to-vehicle communication is used to lessen the delay. Another significant criterion of the VANET safety application is that all cars within a certain distance of the hazard must issue a warning. Different sorts of safety applications are explored as follows, based on the researcher's descriptions[26].

1) **Curve speed warning:** In this application, the RSU will be fixed to the curve to send signals to approaching vehicles informing them of the required speed to safely negotiate the curve and the curve's position.
2) **Low bridge warning:** This system notifies the driver of the minimum height of the parking structure they are attempting to enter by sending a warning message to the car via an RSU located near the parking facility, and the OBU can then determine if it is safe to enter the structure.
3) **Violation of RSUs Warning:** his system informs the vehicle when it breaks traffic regulations by moving in the incorrect way. Vehicles that use V2V communication can also send out warning messages to other vehicles moving in the incorrect direction, preventing accidents.
4) **Vehicle-based road condition warning:** This system is based on vehicle-to-vehicle communication, in which the vehicle collects sufficient information about the road status of the vehicle sensors, after which the in-vehicle units process the data to determine the road situation in order to issue a driver warning or send a warning message to other vehicles.
5) **Visibility enhancer:** Poor visibility for drivers is caused by bad weather conditions such as snow, rain, and fog. This system detects inclement weather and alerts drivers, as well as other vehicles on the road, to the situation.
6) **Work zone warning:** This system relies on an RSU positioned near the work zone to deliver warning signals to approaching cars about the work zone region.

7) **Blind spot Warning:** This program warns drivers if they change lanes and there is a car in their blind spot. It sends warning signals to other vehicles on the road using V2V communication.
8) **Intersection collision warning:** This program collects information about road intersections via sensors and sends a warning message to all vehicles if there is a risk of an accident.
9) **Lane change warning:** This application is aimed to prevent accidents from occurring when the motorist changes lanes. The system gathers information about the cars, including their location, speed, and direction. When the driver switches lanes, the system analyzes the data and determines if the action will result in an accident. The technology then delivers a warning to the driver and uses V2V communication to tell other vehicles about the problem.
10) **Highway/rail collision warning:** This program protects automobiles from train collisions by alerting them to train collisions or correcting their judgments based on warning messages received directly from the train. For notifications, RSUs are placed at intersections.
11) **Pre-crash sensing:** The major purpose of this system is to anticipate a condition in which an accident may occur. This technology employs vehicle-to-vehicle communication to improve driver and passenger safety.
12) **Post crashed warning:** When a vehicle becomes disabled due to foggy weather or an accident, this application is meant to transmit warning signals from the disabled car to other vehicles traveling in the same or opposite direction, using both methods of communications (V2V and V2I).
13) **Approaching emergency vehicle warning:** The aim of this application is to make arrangements to provide clear roads to allow emergency vehicles to reach their destinations. This system relies on one way V2V communication between vehicles traveling on the same route.
14) **Emergency vehicle signal preemption:** When an emergency vehicle arrives at a traffic signal, this system uses V2I communication to send messages to all RSUs along the way to the destination, turning all of the lights green.

15) **Left turn assistant:** This application intends to assist drivers in making a safe left turn at an intersection by providing information collected about traffic conditions on the other side of the road to vehicles making the left turn.
16) **Traffic Optimization:** Traffic can be optimized by transmitting jam and accident alerts to other vehicles, allowing them to save time by taking a different route.
17) **In-vehicle signal:** This application uses RSU to deliver alert messages to cars approaching zones such as schools, hospitals, or animal crossing zones.
18) **Real-Time Traffic:** This information is available to vehicles at all times and can be saved on the roadside unit. This is capable of playing a critical role in resolving traffic bottlenecks, avoiding traffic congestion, and in emergency warnings such as accidents.
19) **Co-operative Message Transfer:** Vehicles that are slow or stopped will communicate information and work together to help other vehicles. Although, with a vehicular gadget that alerts emergency braking to avert probable accidents, dependability and delay are important concerns. Similarly, an emergency electronic brake light is another application[20].
20) **Post-Crash Notification:** A vehicle involved in an accident would send out warning information to following vehicles regarding its whereabouts. So that it can make timely decisions on the main road patrol for towing away assistance as defined[20].
21) **Road Hazard Control Notification:** cars alerting other vehicles to information regarding road feature announcements owing to road curves, landslides, and rapid downhills, among other things[20].
22) **Cooperative collision warning:** Notifies two drivers who may be on a collision course so that they might correct their paths[27].
23) **Traffic Vigilance (Traffic awareness):** he cameras can be installed at the RSU as an input and as the latest instrument in a zero-tolerance campaign against traffic violations[28].

### 2.5.2. Commercial Applications

Commercial applications provide internet connection and streaming entertainment services to drivers. Commercial applications are divided into four categories[20]:

1) **Remote Vehicle Personalization or Diagnostics:** It allows for the downloading of customized vehicle settings or the uploading of diagnostic data from or to infrastructure[28].
2) **Internet Access:** If the roadside unit is acting as a router, vehicles can connect to the internet.
3) **Digital map downloading:** Before traveling to a new area, drivers can download a map of the region as needed for trip advice. In addition, downloading the content map database serves as a portal for accessing essential information from mobile hotspots or home stations.
4) R**eal Time Video Relay:** On-demand movie viewing will no longer be limited to the confines of the home, and drivers will be able to request real-time video relay of their favorite films.
5) **Value-added advertising:** This is particularly useful for service providers who wish to draw people to their establishments. Various forms of communication, such as fuel pumps and highway restaurants announcing their services to vehicles, are used. This program will work even if the internet is unavailable.

### 2.5.3. Convenience Application

Convenience applications are largely concerned with traffic management in order to improve traffic efficiency by increasing driver convenience. The convenience applications are divided into four categories[20]:

1) **Route Diversions:** In the event of traffic congestion, route and trip planning can be done.
2) **Toll Payment via Electronic Toll Collection:** Toll payments can be made electronically through a toll collection point. The toll collection purpose must be able to browse the vehicle's onboard unit. OBUs use the Global Positioning System (GPS)[29] as well as the on-board odometer or echography as backups to determine how far the Lorries have traveled using a digital road map and the Global System for Mobile Communication (GSM) to authorize toll payment over a wireless connection. Toll applications are beneficial not only to drivers, but also to toll operators.
3) **Parking Availability:** Notifications on parking availability in major cities assist in locating available slots in parking lots in a certain geographic area.

4) **Active Prediction:** It anticipates the road's impending topography, with the goal of reducing fuel consumption by altering the cruising speed before beginning a descent or ascent.

### 2.5.4. Productive Applications

We named it productive on purpose because it's a companion to the convenience app. The productive applications can be divided into the following categories:

1) **Environmental Benefits:** The goal of the AERIS (Application for Environmental Real-Time Information Synthesis) research program[25] is to develop and obtain ecologically important real-time transportation data. These data enable the creation of actionable information that supports and facilitates transportation users' and operators' "green" transportation choices. The AERIS program will function in collaboration with vehicle-to-vehicle communications, taking a multi-modal approach. The researchers' goal is to better understand how connected[20]vehicle information and applications might help mitigate some of the negative environmental effects of surface transportation.
2) **Time Management:** If a traveler downloads his email, he can turn traffic jams into productive tasks by reading on the in-flight system or reading it oneself if traffic is stalled. When someone is waiting for a friend in a car, they will surf the internet.
3) **Gasoline Savings:** When a car's toll system application collects toll at Toll booth without stopping the vehicle, about 3% of the fuel wasted when a vehicle waits for 2-5 minutes on average is saved[25].

### 2.5.5. Non-Safety Applications

These are also referred to as "comfort" apps. They provide weather and traffic information to drivers and passengers, as well as the location and rates of nearby restaurants, gas stations, and hotels. VANET non-safety applications are explained as follows, according to the discussion on.

1) **Safety recall notice:** When a recall is issued, a message is sent to the driver's car[26].
2) **Just-in-time repair notification:** If a vehicle malfunctions, the OBU sends a message to the infrastructure via V2I communication. Vehicles then receive a response message with advice on how to resolve the issue.

3) **Internet service provisioning:** if Wi-Fi is not available, vehicles can provide internet connectivity options for passengers to use. Passengers in vehicles were able to connect to the internet via an internet service provider to obtain weather information, play games, and make payments.
4) **Instant messaging:** Vehicles can use instant messaging to connect with one another. In other words, the receiver vehicle can send the sender vehicle an acknowledgment message.

Generally, VANET applications are summarized in the following table.

Table 1: Applications of VANET[26]

| **Applications** | **Description** |
| --- | --- |
| Safety | Aimed at preventing and reducing the number of traffic accidents |
| Commercial | Provides internet connection and streaming entertainment services to drivers |
| Convenience | Concerned with traffic management to improve traffic efficiency by increasing driver convenience |
| Productive | Designed to enhance driver productivity and efficiency |
| Non-Safety | Designed to provide comfort and convenience to drivers and passengers |

## 2.6. VANET Routing Protocols

The routing protocols of a vehicular ad hoc network (VANET) are well suited to determining the precise path of the network's next nodes. Protocols are used by each vehicle on the VANET to exchange data. Routing protocols also control how two communication entities share data, including the mechanism for establishing a route, forwarding decisions, and actions for maintaining or recovering from routing failure. Routing protocols in VANET are divided into two categories: topology-based and position-based routing protocols.

### 2.6.1. Topology Based Routing Protocols

The topology of a computer network is an arrangement of nodes and connecting lines, or it is defined as "the way fundamental pieces are interconnected or structured" in the computer network idea. To transport data from the communication parties' source to destination sides, the information must first be recorded. The routing table is used to hold the routing information. The routing protocol distributes information to available nodes by exploiting the network's available links.

Topology-based routing protocols in VANET attempt to determine the shortest path between source and destination. Topology-based routing Protocols are categorized into three kinds, as detailed on[30]**.**

#### 2.6.1.1. Proactive Topology Based Routing Protocols

From a large number of routing paths, the shortest path was determined using the shortest path algorithm. The routing information for the nodes connected to the network is stored in a table by the proactive protocol. In the event of a vehicle accident, the information recorded in the routing table is critical for forwarding information from one vehicle to the other utilizing the shortest way. These proactive methods assist in updating the information of all nodes in the network because the topology of vehicular ad hoc networks changes dynamically over time. The Proactive routing protocol necessitates a substantial amount of resources to keep routing information up-to-date and reliable in highly dynamic network topologies. Routing protocols are classified into several groups. DSDV, Wireless Routing Protocol (WRP), Global State Routing Protocol (GSR), and Optimized Link-State Routing Protocol (OLSR) are examples of such protocols[31].

**WRP:** It is a table-based routing system in which each network node keeps track of a distance table, routing table, link cost table, and message retransmission lists. WRP calculates the distance before a node is able to transmit data from source to destination using the Bellman-Ford algorithm. Each node has the information about the other neighbor node in order to maintain the distance. The distance table uses a matrix to represent a network view of the node's neighbors, with each element containing the distance supplied by a neighbor for a certain destination. The routing table holds an up-to-date view of the network with all destinations, whereas the link cost table is used to calculate the cost of relaying messages for each link between source and destination. Every revised message to be relayed to the relevant nodes is listed in the message retransmission list. When a node receives an update message, it not only changes the distance between transmission neighbors, but it also checks the distance between the other neighbors.

**GSR:** A neighbor list, a topology table, a next-hop table, and a distance table are all maintained by each node in this protocol. A node's neighbor list contains a list of its neighbors. The topology database holds the connection state information supplied by the destination, as well as the timestamp of the information, for each destination node. The next-hop database for each destination contains the next hop to which packets for that destination must be forwarded. The shortest distance to each transmission destination node is listed in the Distance table.

**OLSR:** is a proactive link-state routing protocol for MANET and VANET that employs hello and topology control (TC) messages to identify and disseminate link state information across the mobile ad-hoc network. Using shortest hop forwarding paths, individual nodes use topological information to compute next-hop destinations for all nodes in the network. The OLSR protocol has a lot of advantages. The following are some of the features.

1) It is a proactive routing protocol that improves its suitability for ad hoc networks with high-mobility nodes that generate frequent and rapid topological changes.
2) The state of the links is immediately known while using this protocol. Additionally, additional data about the quality of the links can be included to the protocol information exchanged, allowing the hosts to know the quality of the network routes in advance.
3) The OLSR protocol is well-suited to high-density networks, where the majority of communication occurs between a large numbers of nodes.

**DSDV:** The Bellman-Ford algorithm is used in DSDV, which is a proactive distance vector routing system. It's also a hop-by-hop distance vector routing system with a routing database maintained by each network node. It's a proactive routing protocol that keeps a routing table on each network node. Each item in the routing table includes information on the next-hop node and the number of hops required to reach the destination. Routing changes are disseminated on a regular basis in an attempt to keep the routing table up to date at all times. These protocols use the hope count and sequence number stored on the nodes to help choose the optimum route. A route is deemed to be good for data transmission if it has the highest sequence number and the fewest hops[32].

#### 2.6.1.2. Reactive Topology Based Routing Protocols

These protocols are run with the node's best interests in mind. When data to be transmitted from a source device to a destination device through VANET, a route must be established. When a node wants to exchange information with other nodes, reactive routing protocol performs route discovery unless proactive routing protocol is used. These routing protocols assist in reducing network load. This routing technique has the advantage of saving bandwidth and updating the routing database on a regular basis. A route search is required for every unknown destination on a regular basis. As a result, communication overhead is decreased at the expense of route research time. CBRP, AODV, DSR, and TORA are some of the reactive protocols that are utilized for routing. Because we used the AODV protocol for these investigations, we thought it would be helpful to go over the process in depth.

**AODV:** AODV is a reactive protocol that establishes a route from a source to a destination only when it is required and preserves these routes as long as the sources require them, hence the name "on-demand routing protocol." To ensure the freshness of routes, AODV uses sequence numbers, and Hello messages to detect and monitor links to nearby s. Each active node sends a Hello message to all nodes in its proximity on a regular basis. Because Hello messages are transmitted on a regular basis, a node that fails to receive numerous Hello messages from its immediate area detects a link failure. Every network node keeps track of routing information in a routing table[25].

Route Discovery and Route Maintenance are the two most important activities in on-demand routing technologies. The route discovery method is used when a source node with no routing data in the routing table has to construct a route to a destination node. By flooding, the source node sends routing request packets across the network. The destination node sends a route response packet to the source node after receiving a route request packet. This could have detected a backward path from the source node to the destination node. When a node changes, a link on the activated path may break, which will trigger the route maintenance procedure. In VANETs, bandwidth resources are limited, and the network topology changes regularly[33].

As a result, maintaining routes to each node is unnecessary. The effective time of routing to vehicles is reduced by the dynamic change in topology. Similarly, it lowers the pace at which routing information is used. As a result, on-demand routing methods are preferable in VANETs. VANETs are distinguished from other types of ad hoc networks by their dynamic network designs and vehicle movement features. As a result, routing in VANETs is challenging. The most widely used topology-based routing protocol for VANET is the Ad-hoc On-Demand Distance Vector (AODV) routing protocol[25]. This sort of protocol reduces network overhead. When a source node needs to communicate with a destination node, it begins a route discovery process until it reaches the target node. The destination node then uses unicast communication to deliver a route reply message (RREP) to the source node. In large-scale ad hoc networks with high mobility and dynamic topologies, reactive routing methods are utilized[33]. For Mobile Ad hoc Network, AODV is proposed. In AODV, packet headers are not included for routes. It has a high level of dynamic nature and reduces overhead. Along with active routing in data transmission, routing information is maintained in source, destination, and intermediate nodes. For the communication path in AODV, three processes are involved: route discovery, route establishment, and route maintenance.

**Types of Control Message of AODV Protocol**

Route Request (RREQ), Route Reply (RREP), and Route Error (RERR) packets are used in AODV communication to establish connections and manage routes between sources and destination node[34].

**Route Request (RREQ)**

In order to interact with its target node, a source node with no routing information sends RREQ packets throughout the network to find a valid route[35]. The source node then selects a routing path with a higher sequence range. For communication, AODV also supports multipath routing. Each RREQ has a time to measure (TTL) value that indicates the message's lifespan, or how many hops the message should be forwarded. At the first transmission, this value is set to a predetermined value, and at retransmissions, it is increased. If no responses are received, retransmissions are sent. For transmitting control messages, AODV requires additional bandwidth[36].

**Route Reply (RREP)**

If an intermediate node receiving the RREQ has a valid route to the requested address or is the destination itself, it responds with a route reply message. The unicasted route reply message is sent back to the RREQ originator. This creates a path in the opposite direction between the source and the destination[33].

**Route Error (RERR)**

When a node detects a link breakdown in an active route, it sends a route error message. Each node maintains a precursor list, which contains the IP addresses of the nodes in its immediate neighborhood who are likely to use it as a next hop to each destination. A RERR message is sent when a link breakage in an active route is identified, informing other nodes of the loss of the link. RREP (Remote Response Event Protocol) Message When a destination node receives an RREQ packet, it unicasts RREP as a response. Message from RERR When there is no communication link between the source and destination nodes, intermediary nodes generate this[35]. Table 2[37] generalizes the AODV control message.

Table 2: AODV control message type[37]

| No | Message type | Purpose | Used in stage |
|---|---|---|---|
| **1** | RREQ | Used to find routes and is initiated by a source node | Route discovery |
| **2** | RREP | Response to RREQ message | Route discovery |
| **3** | RERR | Notifies link failures | Route maintenance |
| **4** | HELLO | Provides connectivity information | Local connectivity, may also trigger route update |

**AODV Route Process**

Routing using AODV is primarily accomplished through two processes: route discovery and route maintenance.

**Route Discovery Process**

When a source node does not have routing information for a node to interact with, the route discovery process begins. Because route discovery is based on queries, the response to the current query is utilized to force a routing decision. A RREQ message is issued to start the route-finding process. If any of the nearby nodes has a route to the destination, they respond to the query with a route reply packet; otherwise, the route query packet is replayed. Finally, some query packets make their way to their intended destination. When an RREP message is received, the route is established. Multiple RREP messages with completely distinct pathways could be received by a source node. If and as long as the RREP contains a greater sequence range, i.e. new information, it updates its routing entries.

**Route Maintenance Process**

When a link breaks, the route maintenance process begins. A link can be broken as the network's nodes move. If a node does not receive a HELLO message from one of its neighbors for a period of time known as the HELLO interval, the node will detect a link breakage and mark the record for that location in the table as invalid. The RERR message will be sent to other nodes to notify them of the broken link. When a link fails, RRER alerts are sent to all sources using that link[12].

**DSR:** DSR is a protocol for reactive routing. If a data packet is being forwarded from one node to another in the network, it will first search, route as necessary, and then forward the data from source to destination. By broadcasting RREQ (Route Request) with a unique ID from the source, the node will undertake route seeking. When the packet is received by the network's nodes, they determine where the data packet needs to be transmitted and disseminate it until it reaches the exact destination node. When the destination node receives the data packet, the packet will return to source with a unique ID and broadcast an RREP (Route Reply). This protocol's primary function is to keep track of route information. If a broken connection or unused route is discovered, route maintenance will handle the information, and if a route error is discovered, the nodes will send an RERR (Route Error) message to the network[38].

**TORA:** TORA is a distributed routing method that is loop-free and highly adaptive. This method is based on the concept of link reversal. The upstream and downstream routers are defined using a Direct Acyclic Graph (DAG). The TORA protocol provides better route help when there are more nodes in the network. Although it is a sophisticated protocol, it does support control messages in the event of a link failure. Unlike current protocols, TORA will be able to directly recover the point of failure. It illustrates that small networks have a lot of overhead[39].

#### 2.6.1.3. Hybrid Topology Based Routing Protocols

It combines the advantages of proactive and reactive procedures. The major goal of the hybrid routing protocol is to reduce the delay of the route discovery process in the reactive routing protocol while minimizing the control overhead of proactive routing protocol. As a reactive routing protocol, the hybrid routing protocol also performs route discovery and stores all necessary information in the form of a table for future usage as a proactive protocol. This sort of routing protocol is utilized by vehicle ad hoc networks to assure route discovery, maintenance, and reliability of the information in the network. ZRP (zone routing protocol) and ZHLS (zone based hierarchical link state) routing protocols are examples of hybrid protocols[40].

### 2.6.2. Geographically Based Routing Protocols

Position-based routing protocols are also known as Geographic Based Routing Protocols. Every node has the ability to choose whether or not to transport packets based on the geographical coordinates of surrounding nodes. Due to large dynamic topology changes between mobile nodes, the link may fail in topology-based routing systems. However, a position-based routing strategy can address the issue of node connectivity familiarity. Beacon messages are delivered to adjacent nodes to inform them of their status. The node can respond to the requested component if it is within the coverage region. The key benefit of the position-based routing protocol was its scalability, as well as its capacity to adapt to quickly changing mobility patterns and reduced network overhead during route finding. The downside of position-based routing protocol is that it is difficult to determine an exact location. There may be a roadblock, and there is no guarantee of connectivity between nodes to obtain precise locations. According to the researcher[38], Delay-tolerant, non-delay tolerant, and hybrid position-based routing protocols are described under position-based routing protocols.

#### 2.6.2.1. DTN Geographically Based Routing Protocols

These protocols facilitate communication by taking-into-account difficulties such as poor connectivity, high routing, latency, end-to-end connectivity, and low routing rates. Every activity is carried out by these protocols using the store and forward mechanism. The primary goal of these protocols is to decrease message delay and enhance message delivery rates. These sorts of position-based routing methods cover a wide range of protocols. VADD (vehicle-assisted data delivery) and Geographical Opportunistic Routing are two examples (Geops)[38].

**VADD (vehicle-assisted data delivery):** Transfers packets from a source to a target moving vehicle node using store and forward ideas. This protocol is likewise unable to send a packet unless the receiver nodes give a confirmation message.

**Geographical Opportunistic Routing (GeOpps):** This routing protocol employs a navigation method to determine the position of the link's next node. The mobility patterns on the nodes and the types of topologies generated on the network are used to deliver the packets to the destination nodes.

#### 2.6.2.2. Non-DTN Geographic Based Routing Protocols

The primary goal of Non-DTN protocols is to minimize the time it takes for packets to travel between the source and destination nodes. Min-Delay protocols are another name for it. It uses the shortest way in the network to reduce packet delivery transmission time. HELLO messages are critical in this protocol for discovering the network's neighbor nodes. HELLO, messages are sent on a regular basis to keep the neighbor node's information up to date. Some protocols are found under these types of position-based routing protocols, just as they are under other routing protocols. The Greedy Perimeter Stateless Routing (GPSR), Geographic Source Routing (GSR), and Connectivity Aware Routing (CAR) protocols are examples of such protocols[38].

**GPSR:** Employs the greedy approach, selecting neighbor nodes from which to forward packets. It also employs a perimeter forwarding mechanism to determine the next forwarding node if the greedy technique fails. These procedures also provide a mechanism for recovery via nearby cars.

**GSR:** Protocol searches for the shortest path from source to destination using route maps. The path between the source and destination nodes is found via beacon messages. Route maps are available in GSR, and automobiles are equipped with navigation systems. To transport packets from source to destination cars, GSR employs a greedy forwarding strategy.

**CAR:** Is primarily concerned with inter-vehicle communication in highway scenarios. CAR differs from other position-based protocols in that it determines the location of the destination node as well as the associated hybrid protocols path between the source and destination cars.

#### 2.6.2.3. Hybrid Geographic Based Routing Protocols

Both delay-tolerant and non-delay-tolerant position-based routing protocols were studied in the hybrid position-based routing protocols. Topology-assisted Geo-Opportunistic (TOGO) routing protocol, for example. By maximizing the packet delivery ratio, TO-GO plays a vital role in routing.

## 2.2. Related Works

The increasing quantity of cars on the streets is leading to issues with traffic. To enable a seamless traffic movement, vehicles were under constant surveillance. Smart traffic solutions will be implemented to identify vehicular accidents and mitigate traffic congestions. Numerous technologies are employed to avert traffic accidents.

Various academics attempted to perform various studies in order to solve the problem of traffic congestion by considering vehicle routing. A Traffic Density - Based Congestion Control (TDCCA) Method for VANETs[15] method presents a vehicle ID-based congestion aware message (CAM) for beacon signals on the vehicle environment. However, the algorithm does not consider further traffic conditions as its computation method is based on the current travel time at road segments and the number of queue length on the road. The impacted car, which is involved in the traffic accident, sends the warning message to the other forwarder vehicle and RSU to alert them of the current situation of the lane in Vehicle to Infrastructure (V2I) communication. As a result, the next car on the road makes a different decision to prevent traffic congestion and accidents.

The paper[41] presents a route suggestion protocol to suggest an optimal congestion aware route in the network, taking into account both equipped and non-equipped vehicles. Simulation results showed greater performance and reduced travel time when working with IoV compared to traditional route suggestions protocols. With the passage of time, a surge in congestion occurs and the application of optimum throughput proves to be a more efficacious strategy in comparison to an abrupt reduction. The observed throughput exhibits constancy during non-congested time periods, but manifests variability in response to traffic volume on congested roads.

The HFSA-VANET is proposed on[42] by ensemble-based machine learning technique used to forecast VANET mobility. It uses a hybrid metaheuristic algorithm combined with Ensemble Learning to reduce latency. Comparative analysis between HFSA-VANET and CRSM-VANET showed a 33% drop in delay, 81% decrease in energy consumption, and 8% increase in throughput. It has been implemented in MATLAB and NS2. However, Speed differences affect VANET messaging systems' performance. Two commonly used techniques were analyzed. Both use a sender-oriented relay selection method and aim to optimize channel bandwidth. The connection outperforms the longer distance method in terms of message reachability and speed difference. It is also more resilient to mobility speed disparities.

The issue of avoiding collisions is resolved through the utilization of the Vehicle Collision Prediction System based on VANET. In order to predict the possibility of a crash on highways, a smart control device (ICU) and communication between vehicles were utilized. To improve traffic problems in a city, ant colony optimization was utilized. The utilization of ant colony optimization

(ACO) in a Dynamic Travel Path Optimization System (DTPOS) resulted in the estimation of the most efficient route to a specified destination. This information was gathered from source[43]. Various elements are considered in this strategy, such as the typical velocity of travel, the average amount of time that cars wait, and the quantity of automobiles paused in a line. The DTPOS offers a significant advantage by reducing the average travel time of cars in urban regions. In comparison to alternatives that don't use ACO and allow cars to select their own paths, the mean journey time was decreased by 47%.

Various academics attempted to perform various studies in order to solve the problem of traffic congestion by considering vehicle routing. Among those researchers, I'd like to highlight the following researchers and their contributions to resolving traffic congestion issues. A Distance-Based Routing Scheme was proposed by the researcher[44]. The primary idea behind this routing method is to avoid an accident at the intersection, as anonymous vehicles frequently emerge from the opposite side of the road and cause collisions at the intersection. This accident-prevention technique begins by determining the vehicle's location and estimating the distance between vehicles approaching the intersection. Following the calculation of each vehicle's location, all vehicles will receive information on the location of other vehicles approaching the intersection. As a result, the car with the shortest distance will issue a distance and location notice to other vehicles. Less traffic congestion was obtained as a result of the suggested strategy, which helps to prevent or decrease traffic accidents. However, the proposed routing scheme's reach is limited, and it has scalability concerns. Furthermore, it only works at an intersection and a ring road, where three different routes meet/join at a single point.

Another researcher[45], presented an intelligent vehicular management strategy to avoid traffic accidents. To avoid road congestion, the suggested approach incorporated basic warning safety messages. The traffic signal and management system delivered excellent throughput, a high delivery ratio, and reduced delays. Another researcher[46] considered the Inter-Vehicle Collision traffic avoidance routing protocol (IVC). A secure warning message is broadcast by all vehicles in the cluster to provide additional information to other drivers, such as a traffic bottleneck.

Considered a routing technique called Road Based Vehicular Traffic, according to the researcher[47]. (RBVT). The RBVT strategy creates a road-based intersection with network connectivity and high probability among vehicles by using real-time information based on the vehicular environment. To transfer interest packets between road intersections on the route, the proposed routing strategy employs the geographical forwarding technique. Due to its traffic overhead, the RBVT was able to attain the average packet delivery ratio and average delay.

A congestion detection system was also presented by the researcher[48] in order to reduce road accidents caused by traffic congestion. Drivers of vehicles provide multiple alternatives for the magnitude and location of traffic congestion after recognizing it. This allows them to avoid becoming caught in traffic. The impacted car, which is involved in the traffic accident, sends the warning message to the other forwarder vehicle and RSU to alert them of the current situation of the lane in Vehicle to Infrastructure (V2I) communication. As a result, the next car on the road makes a different decision to prevent traffic congestion and accidents. This technique maximized bandwidth consumption while minimizing message overhead.

As previously said, various researchers conducted various studies utilizing various approaches to alleviate the difficulties linked with traffic congestion.

## Baseline Approach

In these sections, we have discussed the Traffic Density-Based Congestion Control (TDCCA) Method for VANET's[15] baseline method. The TDCCA presents a vehicle ID-based congestion aware message (CAM) for beacon signals in the vehicle environment. However, the algorithm does not consider further traffic conditions as its computation method is based on the current travel time at road segments and the number of queues on the road. The impacted car, which is involved in the traffic accident, sends the warning message to the other forwarder vehicle and RSU to alert them of the current situation of the lane in Vehicle to Infrastructure (V2I) communication. As a result, the next car on the road makes a different decision to prevent traffic congestion and accidents.

In the TDCCA Method, the researchers were not focused on RSU make a different decision to prevent traffic congestion. To fill the gap of this research, we have proposed LAPCC for VANET to design an algorithm based on the load on the network and suggest better non-congested road segments. Improve the traffic congestion through route suggestions between neighbours RSU. The proposed LAPCC scheme requires the neighbour RSU to reply with a congestion route index to gain the Road segment status.

Table 3: Related Works

| Authors | Suggested Method | Strength | Weakness | Year |
|---|---|---|---|---|
| [15] | vehicle ID-based congestion aware message (CAM) for beacon signals on the vehicle environment | solve the problem of traffic congestion by considering vehicle routing | RSU can’t makes a different decision to prevent traffic congestion | 2022 |
| [42] | hybrid metaheuristic algorithm combined with Ensemble Learning | ensemble-based machine learning technique used to reduce latency | Computation Overhead increases as the distance increase | 2022 |
| [46] | Inter-Vehicle Collision traffic avoidance routing protocol (IVC) | A secure warning message is broadcast by all vehicles in the cluster to provide additional information to other drivers | Additional Information become traffic bottleneck. | 2021 |
| [49] | RSU stores network information and keep update regularly and figure out the best routing path. | Control network from congestion occurrence, enhanced performance and QoS of the network. | Congested window is used during sending only one segment at a time which results constant output | 2020 |
| [50] | An Ant Colony hybrid routing protocol to improve the service Quality of intelligent traffic systems. | optimizes routing by improving road-service performance, significantly reducing delivery time. | The protocol focus on V2V communication, | 2020 |
| [51] | By sharing local traffic congestion level estimation between Vehicles on the road segment | reduce the average travel time of vehicles by using vehicle-to-vehicle (V2V) communication. | The protocol is independent of external infrastructures as uses only V2V communication. | 2020 |
| [52] | a combination of data mining historical trajectory data to detect and predict traffic congestion | Aims to achieve congestion detection event and provided congestion prediction | Computational complexity is increased due to the data set used for data mining | 2020 |
| [53] | a route suggestion protocol to suggest an optimal congestion aware route in the network, | reduced travel time when working with IoV | manifests variability in response to traffic volume on congested roads | 2019 |

# CHAPTER THREE

## RESEARCH METHODOLOGY

## 3. Introduction

In this chapter, it is proposed that a traffic congestion control mechanism on VANET. The need for traffic congestion mechanisms in VANETs has kept growing over the past year with the development of versatile congestion control techniques. Congestion control allows safe traffic between vehicles without any compromise. However, congestion control techniques are still vulnerable to compromising the quality of service while routing. Our approach focuses on considering the load on the traffic and suggesting the best routes on the road for the vehicles to avoid congestion.

The scope of this chapter is to first specify the basic models for proposed LAPCC congestion control mechanisms. A model is a simplified representation of a system that aids in the understanding and investigation of the real system. The key point then is the proper choice of some useful properties of model for the VANET for a better designing of efficient congestion control techniques. One of VANET's useful features is that it facilitates communication between cars and surrounding fixed-road infrastructure (V2I) as well as between vehicles and other nearby vehicles (V2V).

### 3.1. Assumptions

The following assumptions are made in this section:

- All participant vehicles are connected in the network topology.
- All the road segments are deployed with road side unit (RSU).
- We assume that nodes communicate through a reliable, authenticated point-to-point channel.
- Each link in the network has the same amount of traffic going in both directions, i.e., Symmetric. This means that a node receives and sends the same amount of information.
- Nods talk to each other using a short distance wireless connection, and we believe the strength of the signal they use is always the same.

- Assume that NTP (Network Time Protocol) is being used to synchronize the time on all participating nodes. Since the Network Time Protocol (NTP), a networking standard for clock synchronization over packet-switched, variable-latency data networks, can aid in ensuring time synchronization above the millisecond level.
- Each participant vehicle on the network knows the upper limit of time synchronization errors.
- Assume that there is at least one participant node working honestly to satisfy the consistency of the algorithm.

## 3.2. Proposed Method

### 3.2.1. Load Aware and Priority Adaptive Traffic Congestion Algorithm

In this study, we propose a load-aware and priority adaptive traffic congestion control (LAPCC) algorithm using congestion route index-based route suggestion techniques, where each vehicle keeps some additional data to balance the congestion among all the vehicles. In a VANET configuration, a vehicle may have the shortest available route through traffic. However, it should be better to choose a route that balances the congestion load and improves traffic congestion on the network. Some vehicles may have better access to RSU at a location where they may have a higher frequency of relaying requests compared to other vehicles. By distributing the load across the vehicles, this condition might significantly decrease the performance of the network. For this purpose, each vehicle forwards road segment information, and the RSU calculates some values for itself that are referred to as the congestion route index. In the proposed work, we divide the overall process into three main stages, as shown in Figure 9.

The first stage is the network model representation of the VANET network. The network model is represented by modelling the communication of the nodes on the road and how they communicate with other components. The second stage is for congestion state representation; on the VANET, not all the network is congested. Thus, to identify whether the network is congested or not, we use the load factor of the information exchange between the vehicle and the V2I. The load factor is calculated based on information such as the speed of the vehicle, the nearest neighbor of the vehicle, and the distance between vehicles. The final stage is the congestion suggestion process, each RSU calculates the congestion route index(CRI) based on the road segment information forwarded by each vehicle. The RSU broadcasts the CRI value to its neighbor RSUs, and the RSUs compare the CRI values to suggest the road segment that has a better index in the network. The algorithm continues a road segment with a good value is suggested for the route.

Generally, the Load Aware and Priority Adaptive Congestion Control algorithm aims to improve the traffic congestion on the network by balancing the load among all the vehicles and suggestion the best route to avoid congestion.

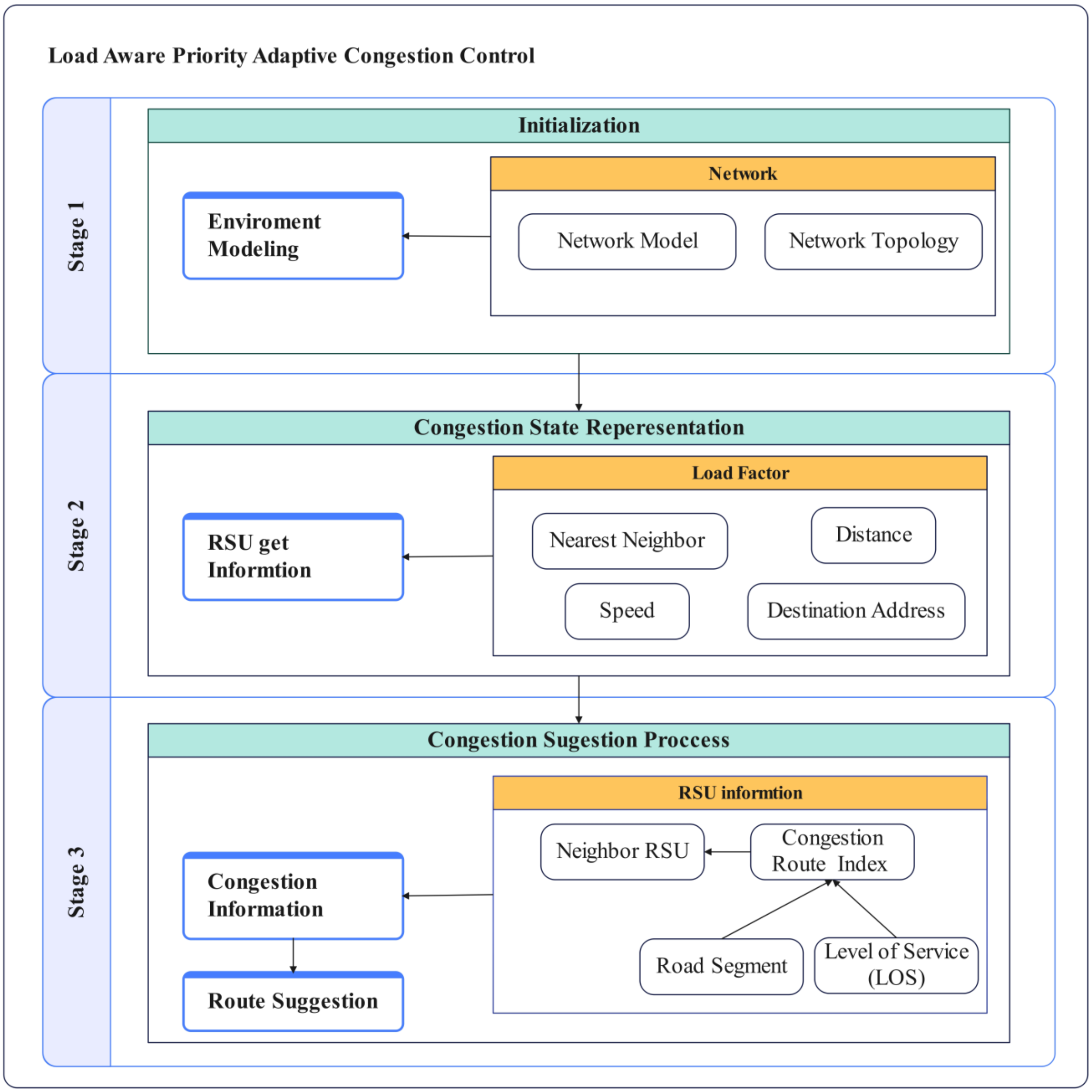



Figure 9: Load Aware and Priority Adaptive Congestion Control

### 3.2.1.1. Stage 1: Initialization

**Network Model and Preliminary**

In order to address the congestion issue in the VANET environment, in this section we discussed a VANET scenario based on the consideration of multiple vehicles on a given congested intersection road. On these roads, multiple vehicles have direct relationships with neighboring nodes in the network. Figure 10 shows the concept of the network model implemented in this proposed work. To identify the nearest neighbors, queue length, RSSI-based distance measurements, and the speed of the vehicles are used. During the communication, two types of messages are forwarded from the vehicle to the RSU and vice versa. i.e., beacon messages and emergency messages. The beacon message ensures that V2V communication and V2I are always in connection. By using beacon messages, the vehicle and the RSU unit exchange information to stay in touch. The emergency message was broadcast when traffic entered a congested state. In addition to this, the RSU communicates with the nearest RSU to get data regarding the VANET network's level of congestion.

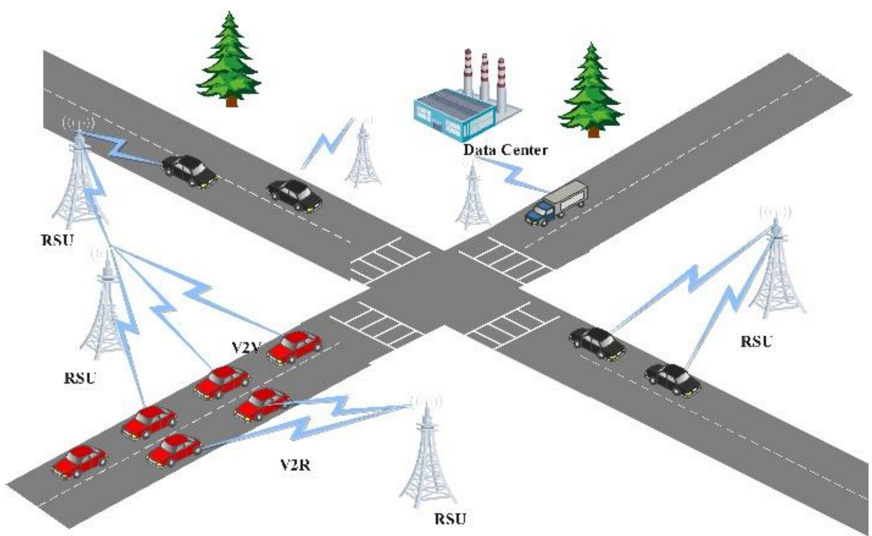



Figure 10: Proposed Communication Architecture

The above figure shows the proposed communication architecture for VANETs. The figure illustrates the communication between vehicles and Road Side Units (RSUs) in the network. The communication is based on beaconing, which is the process of periodically broadcasting status information to nearby vehicles. The sending vehicle broadcasts its location, speed, and identity to nearby vehicles using a special method called "beaconing." The RSUs extract the information from the beacon messages and use it to calculate the load factor for each vehicle in the network. The load factor is used to determine the congestion level of the network and initiate the congestion control process when the load factor exceeds a certain threshold. The RSUs also communicate with each other to exchange information about the congestion level of the network. In addition, emergency messages are broadcasted during traffic congestion to alert nearby vehicles and RSUs about the situation. The proposed communication architecture ensures that the vehicles and RSUs are always in connection and can exchange information to alleviate network congestion.

Beaconing is used to allow nodes in the network to communicate with one another. [54]described beaconing as "the process of periodically and locally broadcasting status information [and] is a key communication pattern in vehicular ad hoc networks.[55] noted, "Beaconing is one of the most important communication modes, which is used to advertise the presence of a car to its neighboring cars." The sending vehicle tells nearby vehicles about its location, speed, and who it is using a special method called "beaconing." It does this so that other vehicles know where it is and what it's doing.[54] investigated the impact of sending messages to vehicles to keep them aware and found that sending directly with a single hop to each other works better and faster than sending through multiple vehicles, i.e., multi-hop.

#### 3.2.1.2. Stage 2: Congestion State Representation

**Load Factor**

Since, the vehicular network channel state is changing continuously, which is affected by the time of arrival of the vehicles, to identify the congestion state, we used a load-based Active Queue Management (AQM) scheme [56]for the detection of congestion level on the network extracted from the *Load_Factor* of each node. The load-based AQM was used to increase high utilization with less delay and packet loss, regardless of the number of nodes. We can determine the load factor by using load-based information to improve or accelerate reaction times by using the link capacity of the route at a specific time with respect to the difference between input rate and output rate. The following equation (1) provides the definition of the load factor.

$$Load\_Factor = \frac{Input\_Rate}{Output\_Rate} \quad \text{Eq. (1)}$$

Where *Input_Rate* is the amount of data that arrived at the node and *Output_Rate* is the link capacity for the queue in the congested network. As the authors [56] stated, "the queue length is a function of load, and queue length gives a more stable congestion indication." The node calculates the *Load_Factor* of the queue. Some of the information, such as traffic accidents, road problems like congestion, and vehicle reversing, is shared between vehicles on the road.

**Load Factor Threshold**

The VANET commonly confront congestion due to road traffic over-burden on links beyond their capacity. The congestion limit value for a load calculate is the upper limit of information allowed for input/output from a total number of vehicles to RSU. During information transfer the *Output_Rate* is fixed based on the link capacity of vehicular network we use around 30Mbps. The acceptable maximum bandwidth on VANET as stated on [4] for a vehicle can move with a speed of up to 200km/h covering a communication extend of 300 m which is amplified up to 1000m with a data rates of 3-30 Mbps. By using these values, the threshold value lies in between 0 and 1. The threshold value as it goes forward to 1, it indicates congestion happen on the road. Thus, on the proposed technique when the load of the network link capacity reach on these limit the congestion process is initiated, when the load reaches to total link capacity it initiates the congestion process by identifying neighbor nodes congestion index as stated on the next stage. For all *Load_Factor* $L_f$ the threshold is shown on Eq. (2)

$$threshold(L) = \begin{cases} L \leq 1, & more\ congestion\ load\ occured \\ L \geq 0, & less\ congestion\ load\ occured \end{cases} \quad \text{Eq. (2)}$$

Figure 11 shows that the proposed method before and after load reduction. The figure illustrates the effect of the proposed load-aware and priority adaptive congestion control (LAPCC) method on the network congestion. The figure shows two scenarios, one with high load and the other with reduced load. The top side of the figure shows the network before load reduction, where the vehicles are congested and the queue length is high. The bottom side of the figure shows the network after load reduction, where the vehicles are moving smoothly and the queue length is reduced.

The load reduction is achieved by reducing the number of nearest neighbors in the network. In VANET communication, the presence of neighboring vehicles plays an important role during communication. However, an increase in the number of neighbors results in higher congestion on the network. In the proposed work, each vehicle in the network keeps a list of all possible neighbor nodes that are in the transmission range. The algorithm reduces the number of nearest neighbors by selecting only the necessary neighbors based on the load factor and the distance between the nodes.

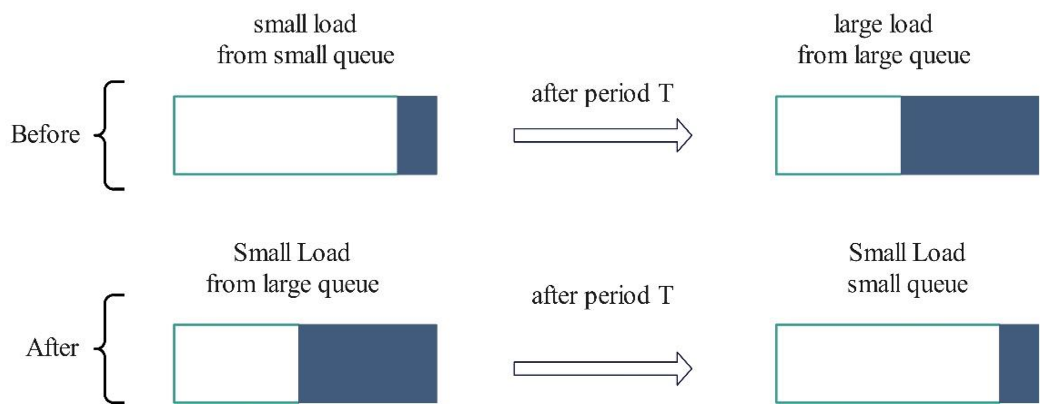



Figure 11: Proposed Method Before and After Load Reduced

**Nearest Neighbors**

In VANET communication, the presence of neighboring vehicles plays an important role. But the increase in neighbors results in higher congestion on the network. In The proposed work, each vehicle in the network keeps a list of all possible neighbor nodes that are in the transmission range. The queue length can be used to define the number of vehicles in a congested network. Eq. (3) shows the hop level for a node within a network of ***n*** vehicles, as follows:

$$1 \leq QL_i \leq n(1) \qquad \text{Eq. (3)}$$

On VANET, neighboring vehicles are placed relatively closer than other neighbors. Such nodes can be considered as Nearest Neighbors (NN). Therefore, to get the physical distance, we consider the received signal strength indicator (RSSI) mechanism. These RSSI mechanism uses Pathloss model Frii's free space propagation model. Because, on VANET environment, there are several causes to occur pathloss such as reflection, absorption, and deflection on the transmission medium. It has significant advantage to measure the transmission from transmitter to receiver. An RSSI-based[57] distance value is calculated and is used to determine the set of neighbor nodes. The RSSI-based distance is calculated based on Eq. (4).

$$P_{i,j}(d) = \frac{\rho_i G_i G_j \lambda}{(4\pi)^2 d^2} \qquad \text{Eq. (4)}$$

Where $\rho_i$ denotes the transmission power, and $G_i$ and $G_j$ denote the antenna gains of nodes i and j, respectively. d denotes the distance between nodes i and j. The transmitter and receiver are represented by nodes i and j, respectively. λ denotes the wavelength of the transmission signal (in metres). The formula shows that the received power at a distance d is proportional to the product of the power density of the transmitting antenna, the gain of the transmitting antenna, the gain of the receiving antenna and the wave length of the signal. In this equation, (4π) ^2 is a constant factor that accounts for the spreading of the signal in three-dimensional space and ensures that the received power decreases with distance squared. It is necessary to accurately calculate the received power at a given distance between nodes in the VANET.

In general, when using RSSI-based distance measurements, compensation values and precision levels can be taken into account to improve the accuracy of distance estimation. Compensation values may be used to account for factors such as signal attenuation, interference, or environmental conditions that can affect the RSSI measurements. Precision levels can indicate the level of uncertainty or error in the distance estimation.

Each node keeps a separate set of Nearest Neighbors (NNs). with their estimated location and speed information. A node has fewer opportunities to become a forwarder of other nodes if it has a high frequency of NNs. Nodes with fewer NNs are vital and can perform better than others.

Every node maintains an individual collection of nearby nodes that have been marked as Nearest Neighbors (NN), along with their approximate positions. If a node consistently has a significant number of connectivity neighbors, this implies that other nodes have fewer chances of selecting the mentioned node as a forwarder. Vehicles with a smaller number of NNs are important and can perform more congestion control by communicating with RSU than other nodes.

As shown on the diagram in Figure 3.5 the proposed VANET environment. The vehicle calculates the distance and Nearest Neighbors (NN) node to ensure the vehicle is congested or surrounded by other vehicles in time and distance relationships. The vehicle forwards NN, distance, destination, and speed to RSU in a beaconing message that the node is connected to RSU via V2I unit. The next step is for RSU to calculate the parameters sent by the vehicle and extract the ratio of *Load_Factor* for preparing the congestion index. During the calculation of the factor by the RSU, it became overloaded by packets shared between the vehicle and the RSU. If the

*Load_Factor* reaches the threshold, the congestion control suggestion process is triggered; otherwise, the RSU keeps on calculating the *Load_Factor* repeatedly.

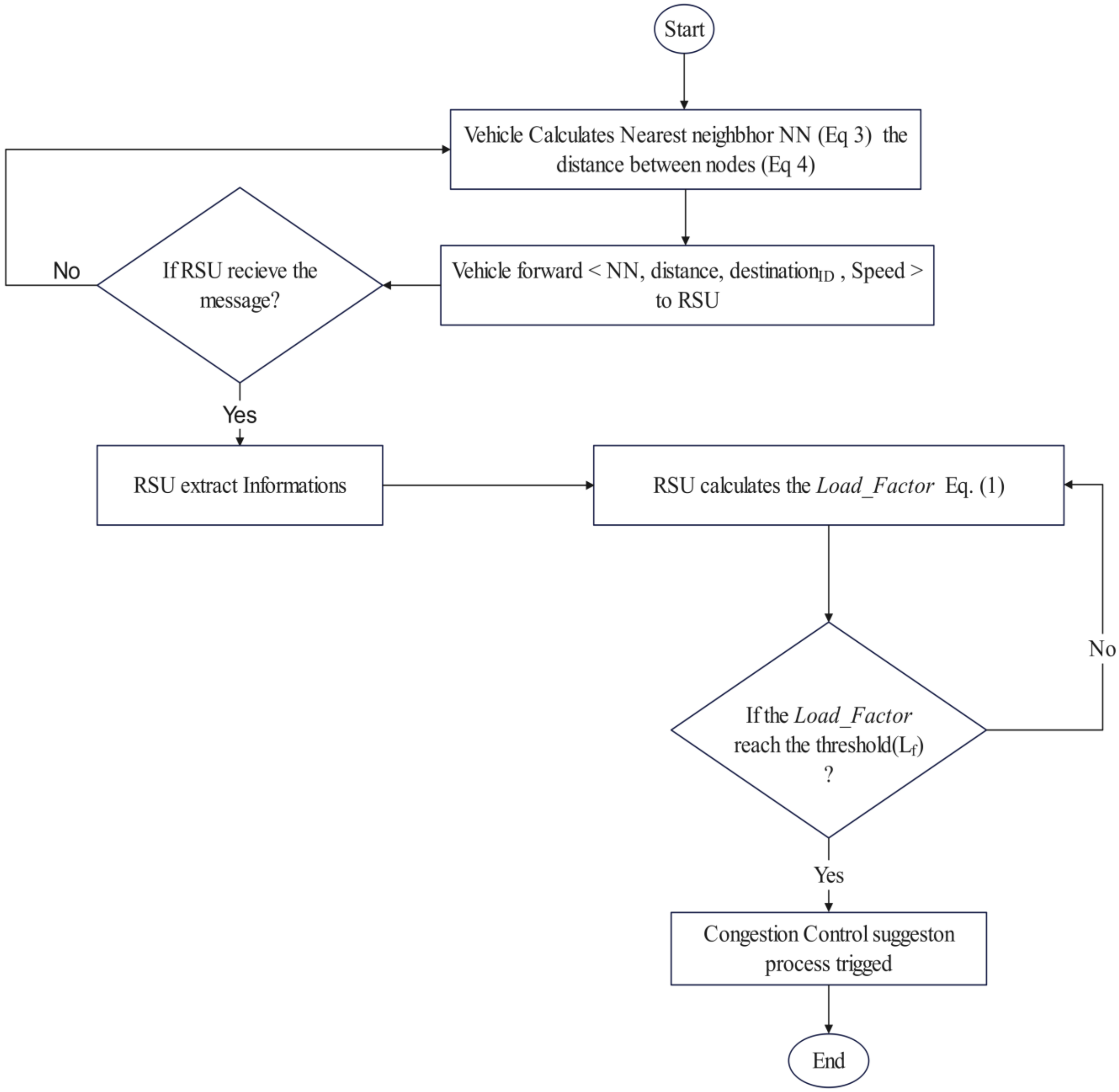



Figure 12: Congestion State Representation Flowchart

**Algorithm 1: Proposed Method Algorithm**

**INPUT:** Vehicle Speed (VS), Nearest Neighbor(NN), distance (d), Road Segment ($RS_{id}$), destination id ($dest_{id}$)

**OUTPUT:** Load_Factor

1: **procedure** LAPCC_Method( VS, NN, d)
2: Vehicle **computes** NN AND distance d between node
3: Vehicle **forward** < NN, d, $dest_{id}$, VS> to RSU
4: RSU extract information
5: **for each** vehicle in $RS_{id}$
6: RSU calculates Load_Factor based on Eq. (1)
7: **if** Load_Factor >=threshold($L_f$) //Maximum threshold is 1 based on Eq.(2)
8: Congestion Control Suggestion Process Trigged ← Algorithm 2
9: **else**
10: goto step 5
11: **end if**
12: **end for**
13: **end procedure**

#### 3.2.1.3. Stage 3: Congestion Suggestion Process

**Road Side Unit (RSU) Component**

The Roadside Units (RSUs) serve as repositories for network information, with their stored data subject to regular updates through communication with neighboring vehicles. Whenever an RSU is presented with any inbound beacon messages emitted from the source vehicles relative to it, it is incumbent upon the RSU to determine the congestion threshold and the optimal routing pathway. The dissemination of information from RSU to other nodes is accomplished through the mechanism of route sharing, which contains essential parameters such as source information, destination, distance, sequence number, route index, and others.

In the algorithm under consideration, upon receipt of a message from the sender, the RSU proceeds to analyze the state of network congestion. In our context, a fixed threshold value equal to half of the assumption of the total capacity of the road was incorporated. As per the algorithm, when the Roadside Unit (RSU) detects that the network is experiencing congestion beyond the defined threshold, it initiates a wait mode for the emergency message until the identification of a network where congestion levels have not exceeded the threshold. When network congestion has not yet occurred, the Roadside Unit (RSU) notifies all other nodes that the network is available and then transmits the packet to the next node on the way to its destination. Table 4 displays the vehicle's free flow speed and the overall standard of road capacity for each lane.

Table 4: Free flow speed (Km/h) and Capacity per Lane(Vehicle/h)

| **Facility Type** | **Free Flow Speed (km/h)** | **Capacity per Lane (veh/h)** |
| --- | --- | --- |
| **Freeway** | 120 | 2000 |
| **Expressway** | 100 | 1800 |
| **Arterial** | 80 | 1200 |
| **Collector** | 60 | 900 |
| **Local street** | 40 | 600 |

RSUs determine the congestion level in the network through *Load_Factor*. The route index finds how long it takes for messages to travel back and forth. If the index value is high, it means there's more traffic on the network. These numbers show how long it takes for information to travel between two vehicles.

**Congestion Route Index**

After the congestion control suggestion process is initiated, as shown in the diagram in Figure 3.6, the RSU is also responsible for analyzing the average speed of the vehicles, destination, and distance by extracting information from the vehicles. Then the RSU estimates the travel time taken to reach the destination. The RSU finds this by forwarding the request to the neighboring node to get information on the congestion route index.  If the congestion route index of neighboring RSUs is less than the expected congestion level, the road segment with less congestion is suggested for the route. Finally, the RSU updates its data and forwards an emergency message to the vehicle.

On the proposed system, each RSU calculates the congestion route index (CRI) probability of the road segment at time t. The CRI is the proportional of parameters taken from the sum d by the

Level of Service (LOS), road segment ratio (RSratio), closed neighbor (CN), and speed as shown in Eq. (5).

$$CRI = \frac{1}{LOS + VS_{ratio} + RS_{ratio}} \qquad Eq. (5)$$

The road segment level of service (LOS) represents the quality of service of the urban road [54] by dividing it up into six level grades. The level of service is described in terms of the free flow speed (FFS) on the road segment during normal hours. The LOS value is derived after calculating the Average vehicle speed ratio ($VS_{ratio}$) from Eq. (5). Based on VSratio, the result falls on one of the LOS scales. The level of service is described in Table 5.

Table 5: Highway capacity manual acceptable speed

| **Typical FFS** | **80 km/h** | **64 km/h** | **56 km/h** | **48 km/h** | | |
|---|---|---|---|---|---|---|
| **Class** | I | II | III | IV | | |
| **LOS** | | | | | LOS scale | Performance |
| **A** | >68 | >57 | >49 | >49 | 5 | Good |
| **B** | 57-68 | 45-57 | 40-49 | 32-49 | 4 | Good |
| **C** | 45-56 | 35-46 | 29-39 | 22-31 | 3 | Acceptable |
| **D** | 36-44 | 27-34 | 22-28 | 16-21 | 2 | Acceptable |
| **E** | 27-35 | 22-26 | 16-21 | 12-15 | 1 | Poor |
| **F** | <26 | <21 | <16 | <11 | 0 | Poor |

Good = Few Traffic Acceptable = Moderate Congestion Poor = Congested

(Source: Highway Capacity Manual 2000[58])

**Vehicle Speed**

The $VS_{ratio}$ is used to identify the ratio between the total delay of a vehicle on a congested road and the total time of the vehicle, which is derived from Eq. (5).

$$VS_{ratio} = \frac{\sum_i D_T(i)}{\sum_i T_S(i)} \qquad Eq. (6)$$

Where $D_T$ is the total travel distance of vehicle i on the road segment and $T_S$ is the total time spent by vehicle i on the road segment. Based on the result obtained from VSratio, we can identify the level of service of the road segment at the current time.

**Road Segment**

The $RS_{ratio}$ is used to calculate the traffic link or capacity during maximum flow conditions at peak hours of the road by using Eq. (7)

$$RS_{ratio} = \frac{Vehicle\_Peack_{volume}}{Road\_Capacity} \qquad Eq. (7)$$

RSU can suggest the least congested path towards the destination based on the CRI value transmitted through the control packet by broadcasting the CRI value to RSU. These processes are done when the suggestion level matches the capacity of the road, and then the RSU calculates the CR value, which is later used to share or exchange between neighboring RSU.

**CRI Threshold**

The CRI result, derived from the $VS_{ratio,}$ RSratio, and LOS as shown in Eq. (5), identifies the threshold. The CRI threshold lies between 0 and 3. For example, let's take an expressway that has capacity per lane at 1800 in a given hour. If the road has 1000 vehicles, then the $RS_{ratio}$ becomes 0.5, and the free flow speed is 50 km/hr. These also have a LOS scale of 1. As a result, the CRI value is 1.9. These indicate that the road segment gets congested because of the CRI threshold. Similarly, by taking the express road supports at the current peak hour of 500 vehicles, the RSratio value becomes 0.2, and the free flow speed is 100 km/hr. These also have a LOS scale of 5. As a result, the CRI value is 0.9. These indicate the road segment is less congested than the previous example. For the CRI threshold, CT, as shown in Equation (8) illustrated, lies in between the two values.

$$threshold(CT) = \begin{cases} CT \leq 3, & the\ road\ segment\ is\ maximum\ congested \\ CT \geq 0, & the\ road\ segment\ is\ minimum\ congested \end{cases} \qquad \text{Eq. (8)}$$

.

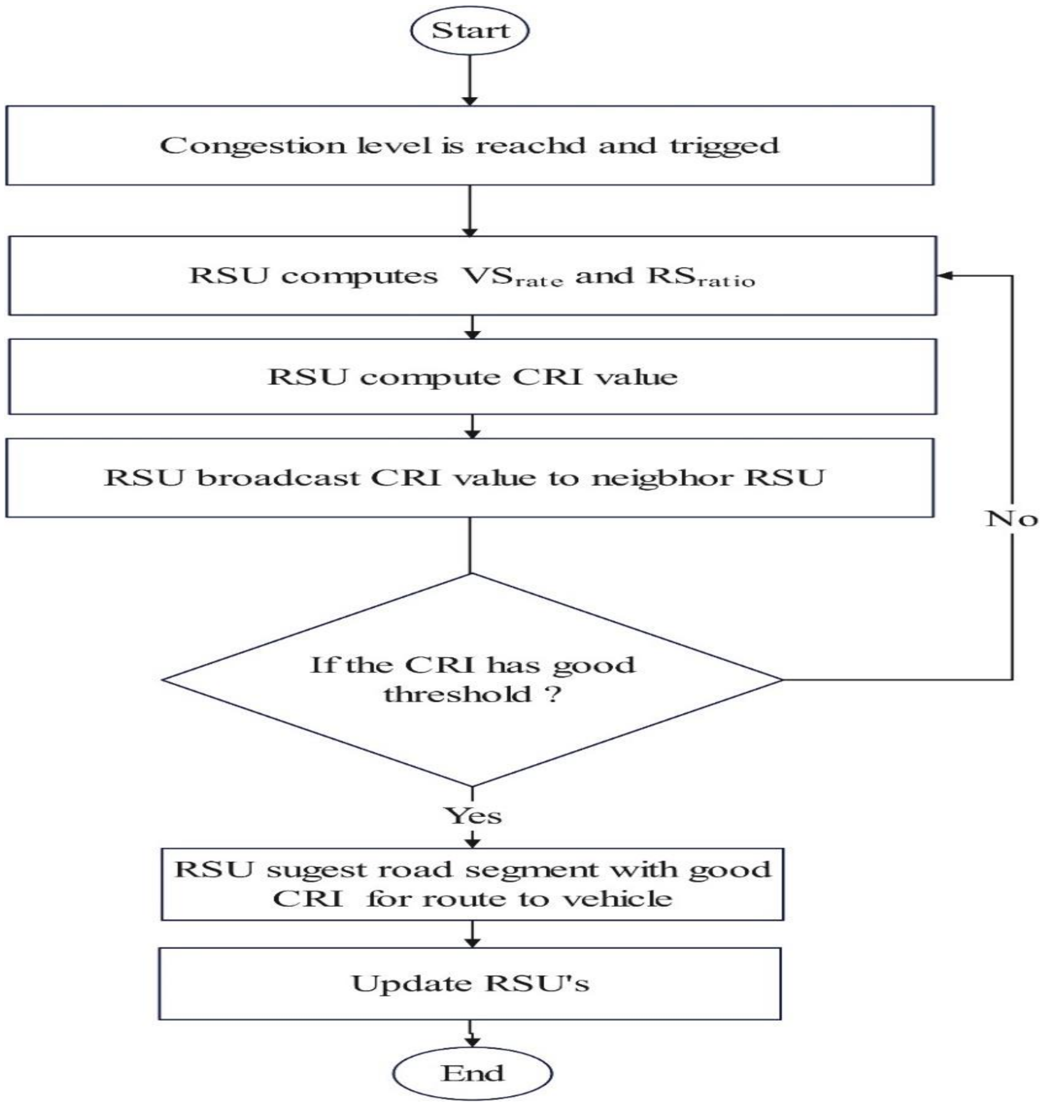



Figure 13: Congestion Suggestion Process Flowchart

Once at the congestion level, the CRI is initiated using the vehicle traffic data, and the route suggestion step begins to calculate an optimal route. The ideal route suggestion is refreshed at each intersection, taking into account the data provided by the RSU. We also consider how busy the roads are and try to choose routes with less traffic to avoid getting stuck. RSU and receive new information from a central location, and they can share their own information with other RSU nearby. The congestion in the VANET is identified by utilizing the communication channel condition. The traffic load in the channel is estimated, and if the level reaches the threshold, the traffic congestion is identified. As a consequence, the congestion condition is transmitted to nearby vehicles to alert them about the traffic congestion. If traffic is detected using the congestion route index (CRI), data can be forwarded to other vehicles and the RSU. When we say “good”, our reference is Free flow speed (Km/h) and Capacity per Lane(Vehicle/h) on Table 4 and the acceptable speed indicated on highway capacity manual on Table 5.

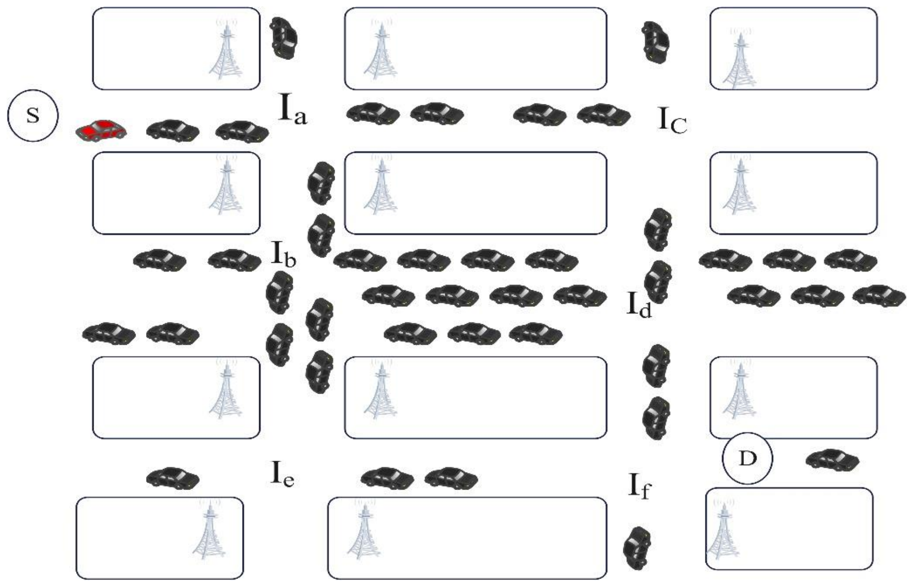



Figure 14: RSU Request for CRI to Neighbor RSU

In the meantime, the RSU finds the congested situation and communicates with the neighboring RSU. As shown in Figure 14, the road intersection from $I_b \rightarrow I_d$ is more congested than the rest of the intersection, and $I_a \rightarrow I_b \rightarrow I_e$ is also relatively congested. After calculating the CRI, the RSU suggests the least congested intersection for source vehicles to destination, i.e., from $I_a \rightarrow I_c \rightarrow I_d \rightarrow I_f$ is an optimal path for the current scenario.

Each vehicle on the road periodically sends a message to their nearby RSU and updates the road segment information at the same time. Each RSU keeps its associated road segment information in the route suggestion table. The RSU exchanges the road congestion index information with other RSUs and sends the road segment information to the data center as well. The Congestion Suggestion Table (CST) includes the optimal route from an origin to a destination, considering travel time and route congestion.

The congestion information exchanged between RSU has the following steps:

**Step 1:** RSU gathers road information from the vehicles on the road segment. Based on our assumption, each road intersection is deployed with a special RSU to gather information, and based on the information, the RSU calculates the CRI value.

**Step 2**: RSU sends a request to its neighbor, RSU. The RSU forwards its CRI value with additional information. The RSU ID, Road Segment ID ($RS_{id}$), CRI and queue delay time qt.

$$\langle RSU_{id}, RS_{id}, CRI, qt \rangle$$

**Step 3:** RSU receives information from neighbors and suggests route path discovery. After the RSU received a reply from the neighboring RSU about road segment information, it suggested the vehicle that had a less congested road segment towards its destination.

**Algorithm 2: Congested route suggestion Method Algorithm**

**INPUT:** $LOAD_{factor}$, Closed Neighbor(CN), Road Segment ($RS_{id}$), destination id ($dest_{id}$)

**OUTPUT:** Congestion Route Index (CRI) value

RSU **compute** $RS_{ratio}$, LOS ← $VS_{ratio}$

RSU **compute** CRI value

RSU **broadcast** $< RSU_{id}, RS_{id}, CRI, qt >$

**for each** neighbor $RSU_{id}$ compare CRI value

    **if** the CRI reaches the threshold

        Road Segment with good CRI value is suggested for the route

        **UPDATE** RSU

    **else**

        goto step 1

    **end if**

**end for**

**end procedure**

## 3.3. Summary

In this chapter, we effectively propose a load-aware traffic congestion control mechanism based on priority adaptive techniques that we developed in order to handle traffic congestion at nodes in VANET. This chapter contains different tasks, mainly divided into three major stages.

In stage one, we initialize our environmental model node, and the vehicle network environment is initialized to provide a good environment. On stage two, we perform Congestion state representation by identifying the load factor to get the upper limit of the network, which causes the road to congest. Based on different parameters.  Finally, describe how congestion route suggestions are used. We suggest the congested node reach its destination by having RSU nodes communicate with neighbors to get the congestion route index of the road.

On the next chapter, we are going to perform an experimental setup and analysis to test our algorithmic design can achieve better performance by comparing it to previously implemented algorithms

# CHAPTER FOUR

## ANALYSIS AND RESULT

In the previous chapters, we defined the problem, introduced the essential background on VANET with related works on the fields, and also proposed the new algorithms. In this chapter, we run various simulation scenarios to test the results obtained after simulation setup.

## 4.1. Experimental Setup

### 4.1.1. Simulation Tool

Simulation is the manipulation of the model of a system to enable the observer to observe the behavior of the system in a setting similar to real-life. By modeling and simulating a vehicular ad hoc network (VANET), it is possible to simplify many difficult real-life problems associated with it. Web chose the popular simulator Network Simulator-3 (NS3) as the simulator of the proposed protocols and a Simulation of Urban MObility (SUMO) simulator[59]. At present there are many simulators in market like Opnet, OMNET++, NS-2, AnyLogic, MATLAB/Simulink etc. There are some problems with one of the mostly used open source simulator ns-2; to overcome them a new simulator is proposed which is called Network Simulator-3. NS3 is one of the most famous network simulation software which funded by the University of Washington (Tom Henderson, Craig Dowell), INRIA, Sophia Antipolis (Mathieu Lacage), and Georgia Tech University (Atlanta) George Riley (main author of GTNetS) and Raj Bhattacharjea partners around 2008[60]. . NS-3 is a discrete-event network simulator in which the simulation core and models are implemented in C++. NS-3 is built as a library which may be statically or dynamically linked to a C++ main program that defines the simulation topology and starts the simulator. NS-3 also exports nearly its entire API to Python, allowing Python programs to import an "ns3" module in much the same way as in C++. NS-3 is a free software simulation platform which aims at network technology and whose source code is open. Researchers can use it easily to develop network technology. NS-3 contains an abundance of modules, almost relating to all the aspects of network technology. SUMO is a free, extremely portable tool for simulating tiny traffic that can handle extensive road networks and various kinds of transportation.

The choice of using SUMO (Simulation of Urban MObility) and NS3 (Network Simulator-3) for simulation purposes in the research paper is likely justified based on objective and scientific reasoning. Here are some common reasons for choosing these tools:

1. **Open-source and extensible:** NS3 is an open-source network simulator that provides a flexible and extensible platform compare to proprietary software like AnyLogic and MATLAB/Simulink for networking research. Researchers can modify and customize the simulator to suit their specific needs, allowing for greater control and flexibility in designing and evaluating their proposed algorithms.
2. **Realistic Traffic Simulation:** SUMO is a widely used tool for simulating urban traffic scenarios. It can handle extensive road networks and various types of transportation. SUMO allows researchers to model realistic traffic patterns, including vehicle movement, traffic lights, and road infrastructure, providing a more accurate representation of real-world scenarios.
3. **Network Protocol Simulation:** NS3 is a popular network simulator that allows researchers to simulate and evaluate network protocols and algorithms. It provides a flexible and extensible platform for networking research and education. NS3 allows researchers to model and analyze the behavior of vehicular ad hoc networks (VANETs) and test the proposed congestion control method in a controlled and reproducible environment.
4. **Integration Capabilities:** SUMO and NS3 can be integrated to create a more comprehensive simulation environment. This integration allows researchers to combine realistic traffic scenarios generated by SUMO with network simulations performed in NS3. By integrating these tools, researchers can evaluate the performance of the proposed congestion control method in a more realistic and holistic manner.
5. **Community Support and Validation: Both** SUMO and NS3 have active user communities and are widely used in the research community. The availability of documentation, tutorials, and support from the community can facilitate the implementation and validation of the proposed congestion control method. Using well-established and validated simulation tools enhances the credibility and reproducibility of the research findings.

6. **Performance:** NS-3 is known for its high performance, allowing for faster simulations large scale VANETs compare to MATLAB/simulink.
7. **Memory usage and computation time:** NS-3 is more efficient in terms of memory usage and computation time compare to other simulation tools.

Generally, the scientific reason for using NS3 and SUMO in this research is to provide a realistic simulation environment where the proposed algorithm can be tested, evaluated, and compared against other existing methods. It allows for a systematic analysis of the algorithm's performance and its impact on traffic congestion control in VANETs.

The simulation was conducted on a computer with the specifications of an Intel i5 processor at 2.50 GHz and 8GB of RAM running Ubuntu 16.04 LTS.

Table 6:Simulation Tools Selection Criteria

| **Parameters** | **Tools** | | | |
|---|---|---|---|---|
| | **NS-2** | **NS-3** | **Vissim** | **MATLAB** |
| **Network Size (Scalability)** | Small | Large | Large | Large |
| **Network Stability** | Unstable | Stable | Stable | Stable |
| **Flexibility** | Not Flexible | Flexible | Flexible | Not Flexible |
| **Source** | Open | Open | Commercial | Open |

Figure 15 shows the relation between SUMO and NS3 in the simulation tool used in the study. SUMO is used for generating mobility traces for the vehicles in the simulation, while NS3 is used for simulating the communication between the vehicles and the roadside units (RSUs). However, Network Animator is a tool that can be used to visualize the simulation results of the communication between the vehicles and RSUs in NS3. It allows for a graphical representation of the network topology and the communication between the nodes. This can help in understanding the behavior of the network and identifying any issues or areas for improvement. The mobility traces generated by SUMO are fed into NS3 to simulate the communication between the vehicles and roadside units (RSUs). This is done using the TraCI (Traffic Control Interface) protocol, which allows SUMO to communicate with NS3 and exchange information about the vehicles' positions and movements.

The .tcl files for SUMO and NS3 are generated separately. The .tcl file for SUMO is generated using the SUMO-GUI tool, which allows for the creation of a road network and the specification of vehicle routes and traffic flow. The .tcl file for NS3 is generated using a text editor.

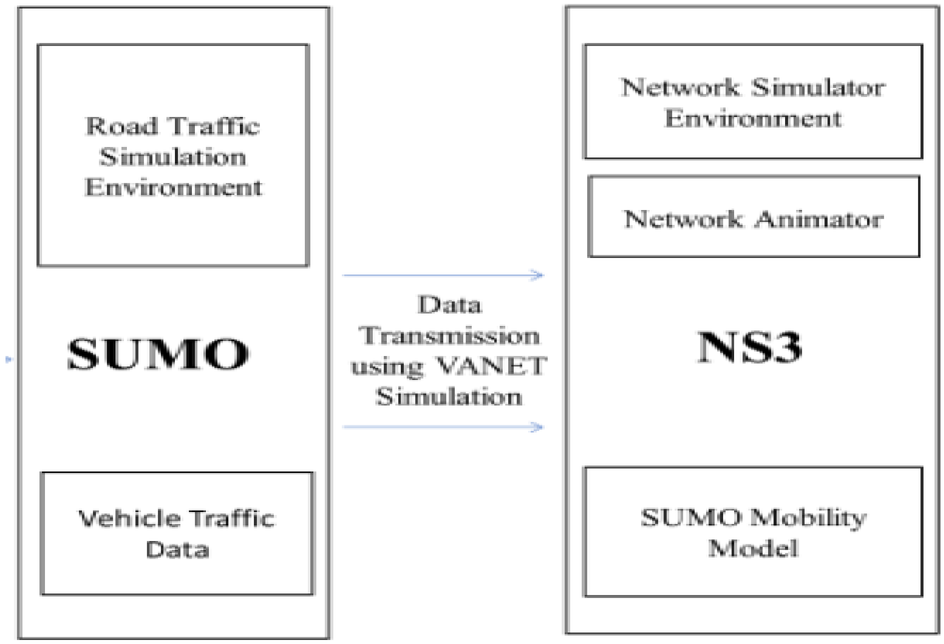



Figure 15: Relation between SUMO and NS3

### 4.1.2. Simulation Scenario

We chose the Manhattan grid topology [61] for our VANET simulations due to its desirable properties. However, our focus lies on the traffic congestion at this particular junction. The Manhattan grid for final simulations in Figure 16 is a 2000x2000 square grid with nine intersections and twelve blocks. Furthermore, it can be observed from Figure 4.2 that the simulation executed in NS3 was subsequent to the incorporation of the mobility model sourced from SUMO. The proposition was made that there were dual lanes for traffic on both sides of the road network. At each junction with priority, the vehicle was afforded the opportunity to advance straight, turn left, or turn right, as depicted. Employing this technique allows us to change the vehicle routes in SUMO during the entirety of the simulation.

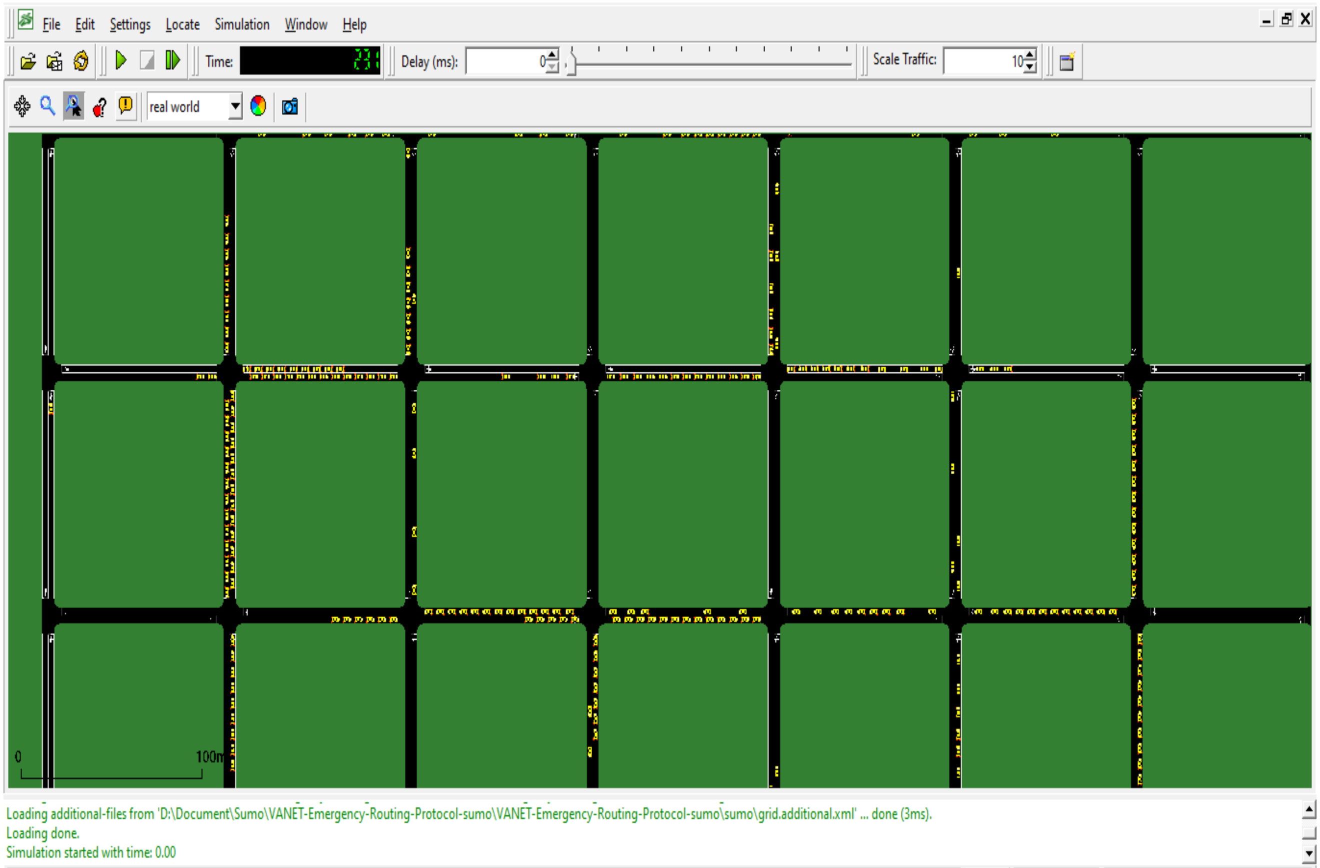



Figure 16: Grid Representation of Proposed Work

### 4.1.3. Network Interface Protocol

In the past ten years, researchers at universities and companies have worked together to create a rul802.11p IEEE 802.11p[4]: This rule helps describe how devices communicate with each other. We used a type of protocol called IEEE 802.11 PHY/MAC to create this idea. The MAC and PHY layers help vehicles talk to each other using a standard called IEEE 802.11a and IEEE 802.11p. Many car companies use this standard all over the world. This method helps devices in a nearby area wirelessly connect. The devices can be stationary, portable, or moving. This gives information on how to use wireless internet on different types of frequencies. The IEEE 802 group created and looks after LAN/MAN standards. We looked at how wireless internet works using a type of technology called IEEE 802.11p, which uses orthogonal frequency division multiplexing (OFDM). It uses a certain frequency band called 60 GHz and a certain amount of space to send information, which we call bandwidth. In this case, we are using 775 MHz of bandwidth. The IEEE 802.11p MAC protocol relies entirely on CSMA/CA to avoid collisions.

In General, the proposed protocol's performance is compared with the existing routing algorithms based on the simulation parameters listed in Table 6.

## Simulation Parameters

On the proposed LAPCC, there are a number of parameters, which were used for simulation purpose on network simulator 3. Those lists of parameters were proposed by the researchers to implement the newly proposed algorithm. To design the proposed algorithm for load aware and priority adaptive traffic congestion control in VANET, we have used different simulation parameters. The simulation parameters have been selected based on the characteristics of vehicular ad hoc networks. We have used the given list of simulation parameters to simulate the proposed algorithm on NS3.

Table 6 shows the experimental parameters used in the VANET simulation scenario. The parameters include area, speed of vehicle, number of lanes, number of vehicles, bandwidth, message size, MAC type, transmission rate, routing protocol, and simulation time.

The simulation tool used in the experiment is NS3 and SUMO. The area of the simulation is 2000x2000 square meters. The speed of the vehicle varies from 50 to 150 km/h, and there are two lanes for traffic on both sides of the road network. The number of vehicles used in the simulation is 200. The bandwidth used is 75 MHz, and the message size is 578 bytes for emergency messages and 500 bytes for beacon messages. The MAC type used is 802.11p, and the transmission rate is between 5.850 and 5.925 GHz. The routing protocol used is AODV, and the simulation time is 1000 seconds. These experimental parameters are used to test the proposed algorithms for traffic congestion control in the VANET simulation scenario.

Table 7: Experimental Parameters

| Parameters | Value | Unit |
|---|---|---|
| **Area** | 2000 x 2000 | $Meter^2$ |
| **Speed of Vehicle** | 50-150 | Km/h |
| **Number of Lane** | 2 | - |
| **Number of Vehicles** | 200 | - |
| **Bandwidth** | 75 | MHz |
| **Message Size** | Emergency (578)<br>Beacon(500) | Byte |
| **Mac Type** | 802.11p | - |
| **Transmission Rate** | 5.850 – 5.925 | GHz |
| **Routing Protocol** | AODV | - |
| **Simulation Time** | 1000 | Second |

The 2000 × 2000-meter square used for the simulation in the simulation area. The reason for using a square area is because it is commonly used in simulation studies to represent the road network and the movement of vehicles in it with a square or rectangular space. As a result, it is possible to represent the road network more simply and define the simulation area's bounds more easily.

## 4.2. Performance Evaluation Metrics

Performance evaluation is the process of measuring the performance of a system under experiment. This evaluation can cover system-wide measures such as packet delivery ratio or measure-specific activities such as time to respond for specific responses. The goal of any performance evaluation is to understand and document the performance of the system being tested. This often involves measuring what happens when the number of nodes is altered; for example, measuring the throughput of the system as the number of nodes is varied. Many researchers want to study how information is shared through VANET. This can be explained as: (a) how information can spread; (b) how quickly the information can be shared with all moving vehicles. To make sure messages are received by everyone they are meant for, it's important to have dependable communication and rules for vehicles and infrastructure talking to each other. The aim of this study is to see how well a new idea works. In this research, we want to know if it does a good job, if it is useful, and if it is efficient based on the following key performance indicator (KPI) [62]:

- **Average End-to-End Delay**: Average End-to-end delay is the time taken by a packet to route through the network from a source to its destination. The average end-to-end delay can be obtained by computing the mean end-to-end delay of all successfully delivered messages. Therefore, end-to-end delay partially depends on the packet delivery ratio. As the distance between source and destination increases, the probability of packet drops increases. The average end-to-end delay includes all possible delays in the network, i.e., buffering route discovery latency, retransmission delays at the MAC, and propagation and transmission delays. Mathematically, it can be shown in the following equation.

$$D = \frac{1}{n}\sum_{i=1}^{n}(T_R - T_S) * 1000 \qquad Eq.(9)$$

where D is the average end-to-end delay, $T_R$ is the reception time, *TS is the* send time, and n is the number of packets successfully delivered.

- **Packet Delivery Ratio**: This is a very important factor to measure the performance of routing protocols in any network. The various simulation parameter selections affect how well the protocol works. The number of nodes, transmission range, and network structure are the three main variables. By dividing the total number of data packets arriving at destinations by the total number of data packets transmitted from sources, the packet delivery ratio can be calculated. In other words, the packet delivery ratio is the proportion of packets delivered from the source to those received at the destination. When the packet delivery ratio is high, performance improves. It can be demonstrated mathematically in the following equation.

$$PDR = total\ succesful\ packet\ recieved / total\ transmitted\ packet \qquad Eq.(10)$$

- **Packet Loss Ratio (PLR):** is the proportion of packets that were sent from a source to a destination but were never received. It can be represented mathematically as Eq. (11).

$$PLR = \frac{(nSentPacket - nRecievedPacket)}{nSentPackets}\, x\ 100 \qquad Eq.(11)$$

## 4.3. Result Analysis and Discussion

Figure 17 shows the communication between Roadside Units (RSUs) and their neighboring RSUs in a VANET. This figure is from a research paper that evaluates the performance of a proposed congestion control mechanism in VANETs. In this figure, the RSUs are represented by circles, and the communication links between them are shown as lines. The RSUs communicate with their neighboring RSUs to exchange information about the traffic conditions and to coordinate their actions to avoid congestion.

The communication between the RSUs is important for the proposed congestion control mechanism to work effectively. The RSUs need to be aware of the traffic conditions in their respective areas to make informed decisions about routing the traffic. The communication between the RSUs is facilitated by the IEEE 802.11p protocol, which is a standard for wireless communication in vehicular networks. This figure is important in understanding the communication infrastructure of VANETs and how RSUs play a critical role in managing traffic flow and reducing congestion.

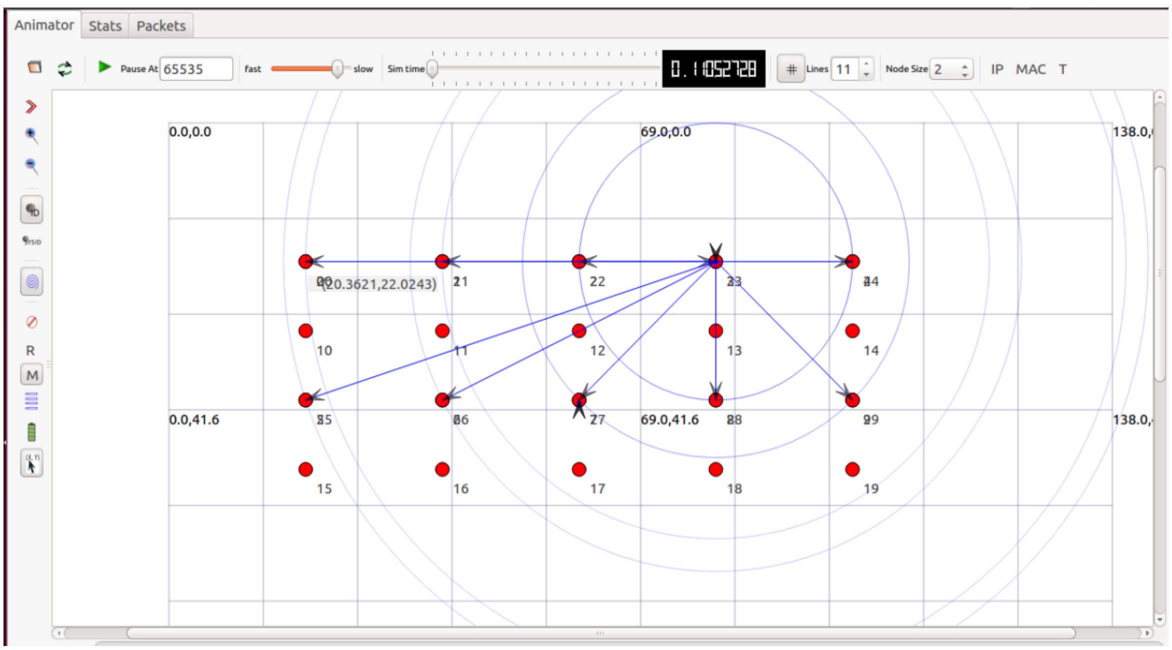
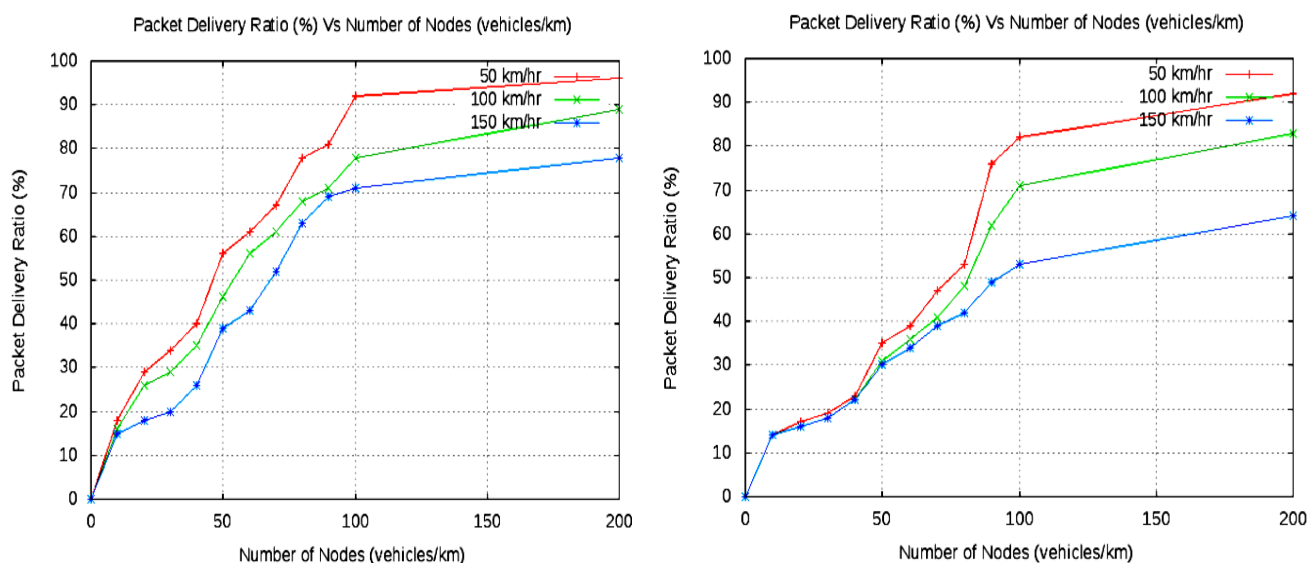



Figure 17: RSU communicate with neighbor RSU

### 4.3.1. Packet Delivery Ratio

Figure 18 shows the Packet Delivery Ratio (PDR) performance of the proposed congestion control mechanism in VANETs compared to the TDCCA method for different numbers of nodes (vehicles/km) and varying speeds. The plot shows the PDR performance with respect to the number of nodes in the network. The x-axis represents the number of nodes, and the y-axis represents the PDR percentage. The plot in Figure 18(a) demonstrates that the proposed method achieves a higher PDR value than TDCCA, with a 96% PDR value when the speed is less than 50km/hr.in congested areas. On the other hand, the plot in Figure 18(b) demonstrates that the existing method achieves a lower PDR value than LAPCC, with a 92% PDR value when the speed is less than 50km/hr.in congested areas. The simulation result shows that the proposed scheme has better performance in terms of PDR under congested network conditions.




**(a) LAPCC** **(b) TDCCA**

Figure 18: Packet Delivery Ratio Vs Number of Nodes

Table 8 shows the Packet Delivery Ratio (PDR) performance of the proposed LAPCC mechanism compared to the TDCCA protocol. The table is from a research paper that evaluates the performance of the proposed LAPCC mechanism in VANETs. The simulation results show that the proposed mechanism outperforms the TDCCA protocol in terms of PDR. The proposed mechanism achieves higher PDR values than TDCCA for all numbers of nodes and vehicle speeds. This table presents the packet delivery ratio (PDR) values for LAPCC and TDCCA for different numbers of nodes (vehicles/km) and varying speeds. The table shows the PDR values for both schemes at speeds of 50 km/h, 100 km/h, and 150 km/h for different numbers of nodes ranging from 10 to 200 vehicles/km. The PDR values are presented as percentages. The simulation results in table indicate that the proposed LAPCC scheme outperforms TDCCA in terms of PLR for all vehicle densities and speeds. For example, at a speed of 50 km/h and a density of 30 vehicles/km, LAPCC achieves a PDR of 34%, while TDCCA achieves a PDR of 19%. Similarly, at a speed of 100 km/h and a density of 200 vehicles/km, LAPCC achieves a PDR of 89%, while TDCCA achieves a PDR of 83%.

Table 8: Packet Delivery Ratio Vs Number of Nodes

| **Number of Node (vehicles/km)** | **LAPCC** | | | **TDCCA** | | |
|---|---|---|---|---|---|---|
| | **50 km/h** | **100km/h** | **150km/h** | **50 km/h** | **100 km/h** | **150 km/h** |
| **10** | 18 | 16 | 15 | 14 | 14 | 14 |
| **20** | 29 | 26 | 18 | 17 | 16 | 16 |
| **30** | 34 | 29 | 20 | 19 | 18 | 18 |
| **40** | 40 | 35 | 26 | 23 | 22 | 22 |
| **50** | 56 | 46 | 39 | 35 | 31 | 30 |
| **60** | 61 | 56 | 43 | 39 | 36 | 34 |
| **70** | 67 | 61 | 52 | 47 | 41 | 39 |
| **80** | 78 | 68 | 63 | 53 | 48 | 42 |
| **90** | 81 | 71 | 69 | 76 | 62 | 49 |
| **100** | 93 | 78 | 71 | 82 | 71 | 53 |
| **200** | 96 | 89 | 78 | 92 | 83 | 64 |

Table 9 provides a comparison between the LAPCC mechanism and the TDCCA protocol in terms of Packet Delivery Ratio (PDR). The table includes different numbers of nodes (vehicles/km) and varying speeds (50 km/h, 100 km/h, and 150 km/h). The PDR values are presented as percentages. The table shows that the LAPCC scheme consistently outperforms TDCCA in terms of PDR for all vehicle densities and speeds. At each speed and density combination, LAPCC achieves higher PDR values compared to TDCCA

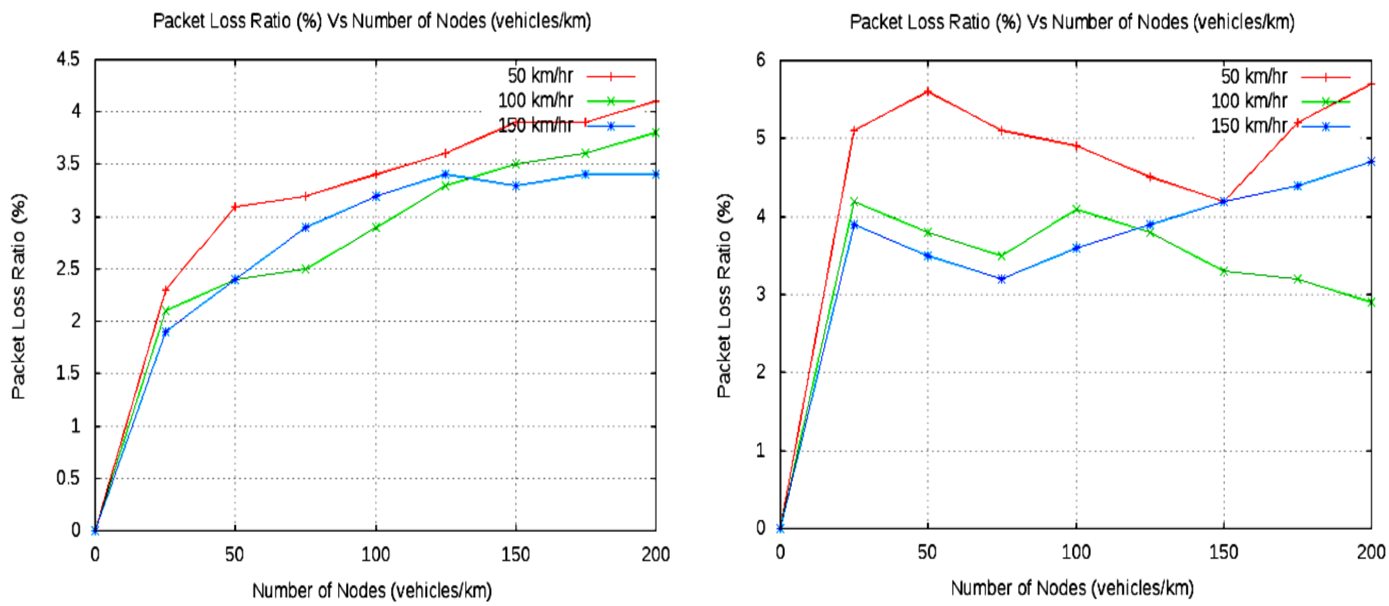
Table 9: Comparison result of PDR

| Number of Node (vehicles/km) | LAPCC vs TDCCA | | |
|---|---|---|---|
| | **50 km/h** | **100km/h** | **150km/h** |
| **10** | 4 | 2 | 1 |
| **20** | 12 | 10 | 2 |
| **30** | 25 | 11 | 2 |
| **40** | 40 | 13 | 4 |
| **50** | 21 | 15 | 9 |
| **60** | 22 | 20 | 11 |
| **70** | 20 | 20 | 13 |
| **80** | 25 | 20 | 21 |
| **90** | 5 | 9 | 20 |
| **100** | 11 | 7 | 18 |
| **200** | 4 | 6 | 14 |

### 4.3.2. Packet Loss Ratio

In VANET, as the density of nodes increases, there are possibilities for collusion. Because of the number of packets transferred between vehicles, the probability of packet loss rises. Thus, analyzing the packet loss ratio is necessary for congestion control mechanisms. In our simulation result, the packet loss ratio performance of the proposed method is illustrated in Figure 19. The figure shows the Packet Loss Ratio (PLR) performance of the proposed LAPCC mechanism compared to the TDCCA method for different numbers of nodes (vehicles/km) and varying speeds. The plot shows the PLR performance with respect to the number of nodes in the network. The x-axis represents the number of nodes, and the y-axis represents the PLR percentage.

The plot in Figure 19(a) demonstrates that the proposed method achieves a lower PLR value than TDCCA, with a 4.1% PLR value when the speed is less than 50km/hr in congested areas. On the other hand, the plot in Figure 19(b) demonstrates that the existing method achieves a higher PLR value than LAPCC, with a 5.7% PLR value when the speed is less than 50km/hr in congested areas. The simulation result shows that the proposed scheme has better performance in terms of PLR under congested network conditions.




**(a) LAPCC** **(b) TDCCA**

Figure 19: Packet Loss Ratio Vs Number Nodes

Table 10 shows the Packet Loss Ratio (PLR) performance of the proposed LAPCC mechanism compared to the TDCCA protocol. The table presents the PLR values for different numbers of nodes in the network and different vehicle speeds. The PLR values are presented as percentages. The table is from a research paper that evaluates the performance of the proposed LAPCC mechanism in VANETs. The simulation results show that the proposed mechanism outperforms the TDCCA protocol in terms of PLR. The proposed mechanism achieves lower PLR values than TDCCA for all numbers of nodes and vehicle speeds. This table presents the packet loss ratio (PLR) values for LAPCC and TDCCA for different numbers of nodes (vehicles/km) and varying speeds. The table shows the PLR values for both schemes at speeds of 50 km/h, 100 km/h, and 150 km/h for different numbers of nodes ranging from 10 to 200 vehicles/km.

The simulation results in table indicate that the proposed LAPCC scheme outperforms TDCCA in terms of PLR for all vehicle densities and speeds. For example, at a speed of 50 km/h and a density of 50 vehicles/km, LAPCC achieves a PLR of 3.3%, while TDCCA achieves a PLR of 5.6%.

Similarly, at a speed of 150 km/h and a density of 200 vehicles/km, LAPCC achieves a PLR of 3.4%, while TDCCA achieves a PLR of 4.7%.

Generally, the results in table demonstrate that the proposed LAPCC scheme is more effective in reducing packet loss in congested vehicular ad hoc networks compared to TDCCA

Table 10: Packet Loss Ratio Vs Number of Nodes

| **Number of Nodes (vehicle/km)** | **LAPCC** | | | **TDCCA** | | |
|---|---|---|---|---|---|---|
| | **50 km/h** | **100km/h** | **150km/h** | **50 km/h** | **100 km/h** | **150 km/h** |
| **25** | 2.3 | 2.1 | 1.9 | 5.1 | 4.2 | 3.9 |
| **50** | 3.3 | 2.4 | 2.4 | 5.6 | 3.8 | 3.5 |
| **75** | 3.1 | 2.5 | 2.9 | 5.1 | 3.5 | 3.2 |
| **100** | 3.2 | 2.9 | 3.2 | 4.9 | 4.1 | 3.6 |
| **125** | 3.6 | 3.3 | 3.4 | 4.5 | 3.8 | 3.9 |
| **150** | 3.9 | 3.5 | 3.3 | 4.2 | 3.3 | 4.2 |
| **175** | 3.9 | 3.6 | 3.4 | 5.2 | 3.2 | 4.4 |
| **200** | 4.1 | 3.8 | 3.4 | 5.7 | 2.9 | 4.7 |

Table 11 presents a comparison between the LAPCC mechanism and the TDCCA protocol in terms of Packet Loss Ratio (PLR). The table includes different numbers of nodes (vehicles/km) and varying speeds (50 km/h, 100 km/h, and 150 km/h). The PLR values are presented as percentages. The table shows that the LAPCC scheme consistently outperforms TDCCA in terms of PLR for all vehicle densities and speeds. At each speed and density combination, LAPCC achieves lower PLR values compared to TDCCA.

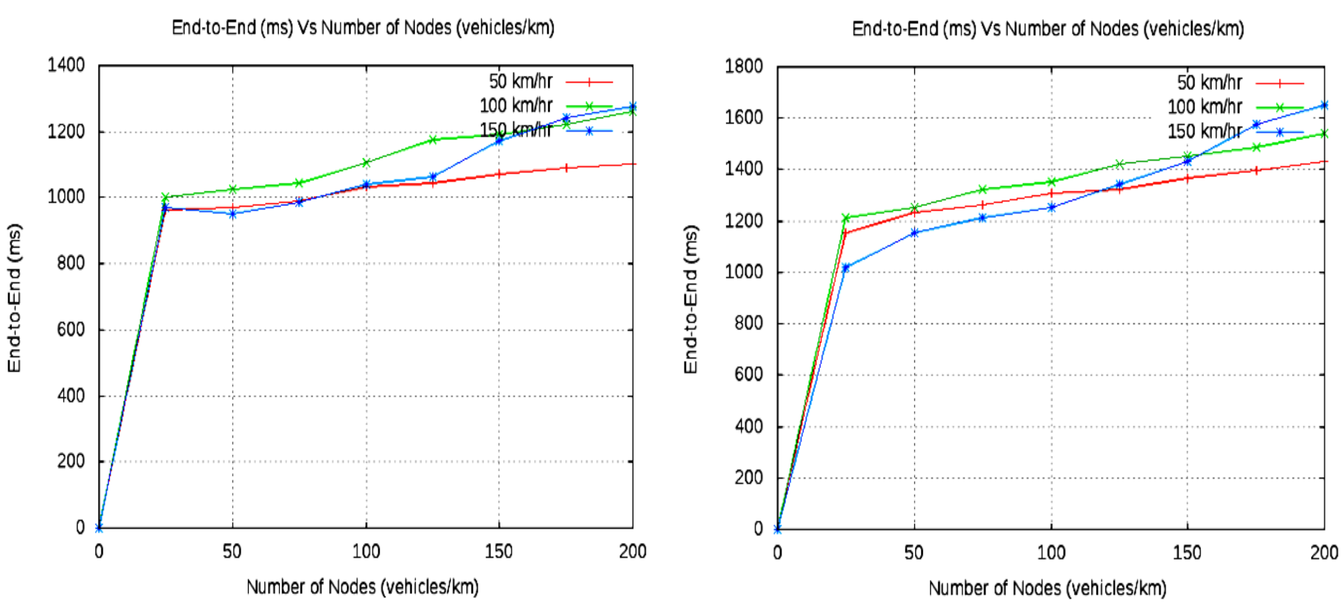
Table 11: Comparison result of PLR

| **Number of Node (vehicles/km)** | **LAPCC vs TDCCA** | | |
|---|---|---|---|
| | **50 km/h** | **100km/h** | **150km/h** |
| **25** | 2.8 | 2.1 | 2.0 |
| **50** | 2.3 | 1.4 | 1.1 |
| **75** | 2.0 | 1.0 | 0.3 |
| **100** | 1.7 | 1.2 | 0.4 |
| **125** | 0.9 | 0.5 | 0.5 |
| **150** | 0.3 | -0.2 | 0.9 |
| **175** | 1.3 | -0.4 | 1.0 |
| **200** | 1.6 | -0.9 | 1.3 |

### 4.3.3. End-to-End Delay

In the simulation scenario, we compare and analyze the end-to-end delay of each scheme in different vehicle density environments. Figure 20 shows the End-to-End Delay (E2E) performance of the proposed LAPCC mechanism compared to the TDCCA method for different numbers of nodes (vehicles/km) and varying speeds. The plot shows the E2E delay performance with respect to the number of nodes in the network. The x-axis represents the number of nodes, and the y-axis represents the E2E delay in milliseconds.

The simulation results show that the proposed mechanism outperforms the TDCCA protocol in terms of E2E delay. The proposed mechanism achieves lower E2E delay values than TDCCA for all numbers of nodes. The plot in Figure 20(a) demonstrates that the proposed LAPCC method achieves a lower end-to-end delay value than TDCCA, with a delay of 1102 ms when the speed is less than 50km/hr in congested areas. On the other hand, the plot in Figure 20(b) demonstrates that the existing TDCCA method achieves a higher end-to-end delay value than LAPCC, with a delay of 1154 ms when the speed is less than 50km/hr in congested area. The simulation result shows that the proposed scheme has better performance in terms of end-to-end delay under congested network conditions.




**(a) LAPCC** **(b) TDCCA**

Figure 20: End-to-End Delay Vs Number of Nodes

Table 12 shows the End-to-End Delay (E2E) performance of the proposed LAPCC mechanism compared to the TDCCA protocol. The table presents the end-to-end delay values for LAPCC and TDCCA for different numbers of nodes (vehicles/km) and varying speeds. The table shows the end-to-end delay values for both schemes at speeds of 50 km/h, 100 km/h, and 150 km/h for different numbers of nodes ranging from 25 to 200 vehicles/km. The E2E delay values are presented in milliseconds.

The simulation results indicate that the proposed LAPCC scheme achieves a lower end-to-end delay value than TDCCA for all vehicle densities and speeds. For example, at a speed of 50 km/h and a density of 25 vehicles/km, LAPCC achieves an end-to-end delay of 962 ms, while TDCCA achieves a delay of 1432 ms. Similarly, at a speed of 150 km/h and a density of 200 vehicles/km, LAPCC achieves an end-to-end delay of 871 ms, while TDCCA achieves a delay of 1021 ms.

Generally, the results demonstrate that the proposed LAPCC scheme is more effective in reducing end-to-end delay in congested vehicular ad hoc networks compared to TDCCA

Table 12: End-to-End Delay Vs Number of Nodes

| **Number of Nodes (Vehicle/km)** | **LAPCC** | | | **TDCCA** | | |
|---|---|---|---|---|---|---|
| | **50 km/h** | **100km/h** | **150km/h** | **50 km/h** | **100 km/h** | **150 km/h** |
| **25** | 962 | 1261 | 1275 | 1432 | 1543 | 1653 |
| **50** | 971 | 1224 | 1247 | 1398 | 1487 | 1575 |
| **75** | 989 | 1191 | 1172 | 1365 | 1453 | 1432 |
| **100** | 1033 | 1174 | 1163 | 1323 | 1421 | 1343 |
| **125** | 1043 | 1105 | 1041 | 1310 | 1354 | 1254 |
| **150** | 1072 | 1044 | 986 | 1265 | 1321 | 1212 |
| **175** | 1091 | 1023 | 953 | 1232 | 1254 | 1154 |
| **200** | 1102 | 1002 | 871 | 1154 | 1213 | 1021 |

Table 13 provides a comparison between the LAPCC mechanism and the TDCCA protocol in terms of End-to-End Delay (E2E). The table includes different numbers of nodes (vehicles/km) and varying speeds (50 km/h, 100 km/h, and 150 km/h). The E2E delay values in the table represent the time taken for a packet to travel from the source to the destination in milliseconds. The results show that the LAPCC scheme consistently achieves lower end-to-end delay values compared to TDCCA for all vehicle densities and speeds. These findings indicate that the proposed LAPCC mechanism has a lower end-to-end delay compared to the TDCCA protocol.

The lower delay values achieved by LAPCC demonstrate its ability to reduce the time taken for data packets to reach their destination, resulting in improved communication efficiency in congested vehicular ad hoc networks.

Table 13: Comparison result of E2E delay

| **Number of Node (vehicles/km)** | **LAPCC vs TDCCA** | | |
|---|---|---|---|
| | **50 km/h** | **100km/h** | **150km/h** |
| **25** | 470 | 282 | 378 |
| **50** | 427 | 263 | 328 |
| **75** | 376 | 262 | 260 |
| **100** | 290 | 247 | 180 |
| **125** | 267 | 249 | 213 |
| **150** | 193 | 277 | 226 |
| **175** | 141 | 231 | 201 |
| **200** | 52 | 211 | 150 |

# CHAPTER FIVE

## CONCLUSION AND RECOMMENDATIONS

After looking at the simulation results in the previous chapter, we came up with some conclusions and suggestions.

### 5.1. Conclusion

Vehicular ad hoc networks (VANET) are a subset of mobile ad hoc networks used to communicate between cars and vehicles and infrastructure. Vehicles act as nodes in a VANET, sending and receiving data without a physical link. Congestion occurs when nodes compete to acquire channels, causing the channels to become saturated. Indeed, when vehicle density rises, the number of channel collisions rises, increasing the likelihood of network congestion. Congestion causes increased delay and packet loss (particularly for safety messages), reducing VANET performance. To address this problem, we develop a load aware and priority adaptive traffic congestion control method based on the movement of the vehicle with RSU and the traffic load shared between them to enhance a vehicle environment's efficiency. This research looks at how to put information together to control traffic congestion on VANET. We suggested a plan to create a system that uses a load factor to improving the congestion on the road. We showed that our new way of organizing algorithm is a good fit with the way data is collected and arranged. We also made a plan to prioritize certain tasks.

The proposed protocol consists of three different stages: initialization, congestion state representation, and congestion route suggestion. To create a favorable environment, nodes and the vehicle network environment must first be setup. Next, we identify the load factor to get the upper limit of the network, which causes the road to congest. The load factor is calculated based on information such as the speed of the vehicle, the nearest neighbor of the vehicle, and the distance between vehicles. Lastly, we recommend that the congested node communicates with its neighbors to determine the road's congestion route index before travelling to the desired location. Thus we design an algorithm that recommends better, less-congested road segments based on the network's load and Reduces traffic congestion by suggesting other routes between nearby Road Side Units (RSUs). To receive the Road segment status under the planned Load Aware Priority Adaptive

Traffic Congestion Control Method (LAPCC) scheme, the neighboring RSU must respond with a congestion route index.

In the results and analysis, the performance analysis of the system-based Network Simulator 3 simulation tool is used. Finally, we discover that our proposed approach LAPCC performs better than other congestion control strategies even in a packed environment. The simulation results demonstrate that, when compared to a Traffic Density-Based Congestion Control (TDCCA) Method for VANETs to a (LAPCC), our suggested method improves the Packet Delivery Ratio, the Packet Loss Ratio, and the end-to-end delay by 96%, 4.1%, and 1102 milliseconds respectively when the speed is less than 50km/hr.in congested areas for different number of vehicles. Therefore, based on the simulation result we observe that, the proposed method shows better performance.

## 5.2. Recommendation for Future Work

In our paper, we found ways to improve how well a network (VANET) works by using a load aware method. This can make the network faster and work better on congested networks. We tested to see if our idea would work on vehicles by varying the density and speed of the vehicles. However, in our thesis, we found out that the current assessment of VANET is not enough. There are some things that need more research and attention in this thesis. Here is a list of some of the issues:

- We need to incorporate traffic lights into our congestion control mechanism. In this aspect of the view, we ought to consider traffic lights as a parameter to enhance traffic congestion on VANET.
- To get deep insight, other performance evaluation metrics should be tested by widening simulation scenarios.
- We need further investigation into the effect of passengers on road traffic congestion.
- We need to add false alarm detection by incorrect observation of vehicles to the trial of communication.

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# APPENDICES

## A. C++ Source Code for the Proposed Method

```
#include <iostream>
#include <vector>
#include <unordered_map>
#include <boost/property_tree/ptree.hpp>
#include <boost/property_tree/xml_parser.hpp>
class LAPCC_RoutingProtocol : public BaseRoutingProtocol {
//Load SUMO XML data
ptree sumocfg, net, rou, bt, vehroute, fcd;
sumocfg = read_xml("sumo/grid.sumocfg");
net = read_xml("sumo/grid.net.xml");
rou = read_xml("sumo/grid.rou.xml");
bt = read_xml("storage/sumo/grid.bt.out.xml");
vehroute = read_xml("storage/sumo/grid.vehroute.out.xml");
fcd = read_xml("storage/sumo/grid.fcd.out.xml");
public:
    int id;
    vector<int> route;
    int CRI_VALUES = 0;
    Road_Segment* _cur_road_Segment = nullptr;
    int speed = 0;
    int cur_pos = 0;
    bool at_intersection = false;
    bool is_cur_fwdr = false;
    int x = 0;
    int y = 0;
    int prev_time = 0;
    vector<Node*> neighbors;
    bool congestion_detected = false;
//Algorithm 1: calculate load factor by RSU
```

```
double calculateLoadFactor(double speed, double distance, double density) {
    double loadFactor = (speed * density) / distance;
    return loadFactor;
}
void LAPCC_Method(double VS, double CN, double d) {
    // Compute CN and distance d between node
    // Forward <CN, d, destid, VS> to RSU
    // Extract information
    vector<double> RSid; // assume RSid is a vector of doubles
    for (int i = 0; i < RSid.size(); i++) {
        double speed = 0.0; // calculate speed based on RSid[i]
        double density = 0.0; // calculate density based on RSid[i]
        double distance = 0.0; // calculate distance based on RSid[i]
        double loadFactor = calculateLoadFactor(speed, distance, density);
        double thresholdmax = 1.0; // set thresholdmax to desired value
        if (loadFactor >= thresholdmax) {
            // Congestion Control Suggestion Process Trigged ← Algorithm 2
        } else {
            continue;
        } } }
    Node(int node_id, vector<int> route) {
        id = node_id;
        this->route = route;
        set_cur_road(route[CRI_VALUES], 0);
    }
    void set_cur_road(int road_id, int pos) {
        _cur_road_segment = get_road_by_id(road_id);
        cur_pos = pos;
        at_intersection = false;
        if (_cur_road_segment->start_node == id) {
            is_cur_fwdr = true;
        } else {
            is_cur_fwdr = false;
```

```
        } }
//Algorithm 2: Congestion Suggestion Process
public: static std::vector<Node> choose_next_RSU(std::unordered_map<std::string,
double> settings, Node f_curr, std::vector<Node> neighbors,
std::unordered_map<std::string, std::pair<Node, Node>> to_and_from_for_edge, int
hop_num) {
        std::vector<Node> ret_lst;
        if (f_curr.at_intersection) {
            std::vector<Node> RSU_neighbors;
            for (Node n : neighbors) {
                if (n.route_contains_rd(settings, f_curr.msg.src_rd)){
                    RSU_neighbors.push_back(n);
                }}
            std::unordered_map<std::string, int> CRI_VALUES;
            for (Node n : RSU_neighbors) {
                if (f_curr.at_intersection) {
        std::unordered_map<Road_Segment, int> CRI_VALUES;
        Road_Segment nxt_rd;
        for (Node n : neighbors) {
            if (n.cur_road == f_curr.cur_road) {
                continue;
            }
            if (CRI_VALUES.find(n.cur_road) == CRI_VALUES.end()) {
                CRI_VALUES[n.cur_road] = 0;
            }
            CRI_VALUES[n.cur_road] += 1;
  if (nxt_rd == NULL || CRI_VALUES[n.cur_road] > CRI_VALUES[nxt_rd]) {
                nxt_rd = n.cur_road;
            }} } else {
      Intersection dst_isect = f_curr.msg.dst_isect;
    Node f_next = _find_node_closest_to(dst_isect, neighbors, f_curr);
        if (f_next != NULL) {
            ret_lst.push_back(f_next);
        }}  }  }
```

```
        return ret_lst;
    }
private: static Node _find_node_closest_to(Node intersection, std::vector<Node>
nodes) {
        Node closest_node;
        double min_dist = std::numeric_limits<double>::max();
        for (Node n : nodes) {
            double dist = n.distance_to(intersection);
            if (dist < min_dist) {
                closest_node = n;
                min_dist = dist;
            } }
        return closest_node;
    }};
```

## B. Performance Evaluation Metrics

```
intj = 0;
floatAvgThroughput = 0;
Time Delay ;
Ptr<Ipv4FlowClassifier> classifier = DynamicCast<Ipv4FlowClassifier
>(flowmon.GetClassifier ());
std:: map<FlowId , FlowMonitor::FlowStats> stats = monitor->GetFlowStats ();
for(std::map<FlowId,FlowMonitor::FlowStats>::const_iterator iter=stats.begin ();
iter!=stats.end();++iter){
Ipv4FlowClassifier::FiveTuple t = classifier->FindFlow(iter->first );
NS_LOG_UNCOND("---- FlowID : "<<iter- >first);
NS_LOG_UNCOND("Source Addr"<<t.sourceAddress<< "Destination Addr"<<t
.destinationAddress );
```

```
NS_LOG_UNCOND("Sent Packets="<<iter- >second . txPackets );
NS_LOG_UNCOND( "Received Packets="<<iter- >second.rxPackets );
NS_LOG_UNCOND("Lost  Packets="<<iter- >second.txPackets- iter->second. rxPackets) ;
NS_LOG_UNCOND( "Packet Delivery Ratio=" <<iter->second.rxPackets*100/
iter->second.txPackets<<"%" ) ;
NS_LOG_UNCOND( " Delay="<<iter->second.delaySum ) ;
NS_LOG_UNCOND( " Througput="<<iter->second . rxBytes*8.0/( iter- >second .
timeLastRxPacket .GetSeconds()-iter-> second.timeFirstRxPacket.GetSeconds())/1024<<
"Kbps" ) ;
SentPackets = SentPackets+( iter- >second.txPackets ) ;
RecievedPackets = RecievedPackets+( iter->second.rxPackets ) ;
LostPackets=LostPackets+(iter- >second.txPackets-iter- >second.rxPackets ) ;
Delay=Delay+(iter->second.delaySum ) ;
j++;
}
NS_LOG_UNCOND( "------ The Total simulation result----- :"<<j ) ;
NS_LOG_UNCOND( " Total Sent Packet : "<<SentPackets ) ;
NS_LOG_UNCOND( " Total Received Packet : "<<RecievedPackets ) ;
NS_LOG_UNCOND( " Total Lost Packets : "<<LostPackets ) ;
NS_LOG_UNCOND("Total Packet Loss Ratio:"<<((LostPackets*100)/ SentPackets)<<"%" ) ;
NS_LOG_UNCOND( " Total Packet Delivery  Ratio : "<<((RecievedPackets*100)/
SentPackets)<<"%" ) ;
NS_LOG_UNCOND( "End␣to␣End␣Delay : "<<Delay ) ;
NS_LOG_UNCOND( " Total␣FlowID : "<<j ) ;
monitor- >SerializeToXmlFile (( tr_name + " . xml " ) , true , true ) ;
```