Swarm Intelligence Based Algorithm for Efficient Routing in VANET

A Thesis submitted to the

University of Petroleum and Energy Studies

For the Award of

Doctor of Philosophy

in

Computer Science

By

GAGAN DEEP SINGH

DECEMBER 2020

SUPERVISOR(s)

Dr. MANISH PRATEEK

Dr. HANUMAT G. SASTRY

School of Computer Science

University of Petroleum and Energy Studies

Energy Acres, P.O. Bidholi via Prem Nagar,

Dehradun, 248007: Uttarakhand, India.

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Supervisor

Dr. MANISH PRATEEK

Professor, School of Computer Science

University of Petroleum & Energy Studies

Co- Supervisor

Dr. HANUMAT G. SASTRY

Professor, School of Computer Science

University of Petroleum & Energy Studies

UPES

School of Computer Science

University of Petroleum and Energy Studies

Energy Acres, P.O. Bidholi, via Prem Nagar,

Dehradun, 248007: Uttarakhand, India

DECLARATION

DECLARATION

I declare that the thesis entitled ***"Swarm Intelligence based Algorithm for efficient routing in VANET"*** has been prepared by me under the guidance of Dr. Manish Prateek, Professor at School of Computer Science, University of Petroleum & Energy Studies, and Dr. Hanumat G Sastry, Professor at School of Computer Science, University of Petroleum & Energy Studies. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

GAGAN DEEP SINGH
School of Computer Science
University of Petroleum & Energy Studies,
Bidholi via Prem Nagar, Dehradun, UK, INDIA

DATE:

CERTIFICATE

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CERTIFICATE

We certify that **Gagan Deep Singh** has prepared his thesis entitled ***"Swarm Intelligence based Algorithm for efficient routing in VANET"***, for the award of the Ph.D. degree of the University of Petroleum & Energy Studies, under our guidance. He has carried out the work at the School of Computer Science, University of Petroleum & Energy Studies.

Supervisor

Dr. Manish Prateek
Professor
School of Computer Science
University of Petroleum & Energy Studies,
Bidholi, via Prem Nagar, Dehradun, UK, INDIA
DATE:

Co-Supervisor

Dr. Hanumat G. Sastry
Professor
School of Computer Science
University of Petroleum & Energy Studies,
Bidholi, via Prem Nagar, Dehradun, UK, INDIA
DATE :

Energy Acres: Bidholi Via Prem Nagar, Dehradun - 248 007 (Uttarakhand), India T: +91 135 2770137, 2776053/54/91, 2776201,9997799474 F: +91 135 2776090/95
Knowledge Acres: Kandoli Via Prem Nagar, Dehradun - 248 007 (Uttarakhand), India T: +91 8171979021/2/3, 7060111775

ENGINEERING | COMPUTER SCIENCE | DESIGN | BUSINESS | LAW | HEALTH SCIENCES | MODERN MEDIA

ABSTRACT

Vehicular Adhoc Networks (VANETs) are the special form of Mobile Adhoc Networks (MANETs) developed for the efficient communication among the vehicles to vehicle (V2V) infrastructure. VANET promotes road safety and is the key to Intelligent Transport System. VANET has emerged as one of the dynamic area of research. VANETs main aim is to improve road safety, optimize traffic flow, reduce traffic congestion, decrease pollution and promotes information dissemination. As per the World Road Statistics, road fatalities are expected to become the world's fifth-largest killer by 2030, i.e. thousands of times more than terrorism or rail/air accidents.

VANET can be used as a driver's assistance for communication and coordination among each other to avoid any critical situation through V2V communication e.g. random braking, obstacles, accidents on road, bumper to bumper jams, random increase in speed, pathways for emergency vehicles like fire, police, and ambulance, etc. Along with these precautionary applications, VANETs are also useful for comfort applications to the drivers and passengers. For example, multimedia applications, internet connectivity, weather forecast, and infotainments during drives.

VANET has its own issues and challenges, like multipath fading and road obstacles, traffic congestion, random change of vehicle speed, its mobility, road topology, traffic diversion model, driver's unpredictable driving behavior, etc. VANET mobility is not as same as that of MANET since in VANET, the vehicle has to strictly follow the rules of traffic laws and this makes node movement even too complex. There are many limitations in VANET and these challenges have to be solved in order to provide reliable services in a network. Hence, reliable and stable routing is one of the major issues in VANET. So, dedicated research in this field is required to implement accurate methods in realistic environments. The vehicles dynamic behaviour and high mobility speed makes routing in VANET even more challenging.

A new area of research has emerged in VANET routing that focuses on reducing the time spent on roads, which also includes waiting and traveling time

for commuters at stoppages and waiting locations. Now, every theory suggests that travel time get reduced by using the shortest path between sources to the destination, but if all the vehicle nodes opt for the shortest routing path, then; this solution will itself become a problem and this results in a congestion for the opted routes. Hence, it is always not true that the shortest path is the optimal route. Therefore, commuters can also choose a longer path because they want to avoid congestions through less frequency of traffic signals and waiting time for much smoother mobility of vehicle nodes.

The focus of the present research work is to study various routing techniques and provide a solution for efficient and optimized Swarm Intelligence based routing in VANET. The presented solution fulfills the requirement that fits for the sparse, dense and real city traffic scenarios. The thesis presents a detailed introduction to VANET and Intelligent Transportation System. The thesis also highlights on the road conditions and deaths caused due to the various transport factors. Further, a detailed literature review has been presented in this work and found that some of the VANET routing techniques proves better in sparse networks while other in dense networks. Rather some are best suited for highway routing and others for urban traffic scenario. Furthermore, it observed that no such routing technique exists in the till yet that proves suitable for sparse, dense and real city traffic scenarios. Hence, in this research a hypothesis proposed with a devised novel Algorithm. This hybrid algorithm is able to bind the features of Ant Colony Optimization (ACO) techniques along with Genetic Algorithm (GA) for efficient routing in vehicular networks. The hypothesis states that the performance of this Swarm Intelligence based routing algorithm is superior then the preexisting standard algorithms like Particle Swarm Optimization (PSO) and ACO.

The thesis also presents the new framework that used to perform simulation experiments using open source software tools. This work also shows that to achieve the best results through VANET simulation, it is necessary to create a realistic mobility model similar to the real road traffic scenarios. The devised novel algorithm tested on simulation experiments performed on three different traffic scenarios i.e. Sparse Traffic Network, Dense Traffic Network and Dehradun city road traffic network. The same also performed for standard routing algorithms like PSO and ACO. This novel algorithm also provides the link stability so that frequent disconnects of the node can minimized. In this thesis, the analysis of the algorithm measured on some of the major metrics of VANET routing protocols such as throughput and packet delivery ratio.

In this research study, the result captured for Packet Delivery Ratio and Throughput for deployed traffic scenarios. The thesis also presents the detailed analysis, which shows that the devised ACO-GA novel algorithm has outperformed in comparison with the preexisting algorithms. To verify the proposed hypothesis *t-test* was performed and proved in mathematical way that the devised novel algorithm is better in performance for all the three traffic scenarios.

Hence, the present research work "*Swarm Intelligence based Algorithm for Efficient Routing in VANET*" provides a novel framework and approach that enhance the Intelligent Transport System for a Better World.

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This acknowledgement is not complete until and unless I thanks my mother-in-law, Mrs. Rama Kaura. Her support in taking care of my family during the completion of my thesis is commendable. Due to her support, I got a peaceful time and the ability to write my Ph.D. thesis.

I want to apologize to those whose names do not figure here but have helped me during my research tenure.

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GAGAN DEEP SINGH

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LIST OF ABBREVIATIONS

ACO	Ant Colony Optimization
ACO-GA	ANT COLONY optimization – Genetic Algorithm
ADASE	Advance Driver Assistance System
AODV	Adhoc on Demand Distance Vector
A-STAR	Anchor based Street And Traffic Aware Routing
BTS	Base Terminal Station
CAMP	Crash Avoidance Matrics Partnership
CLR	Clear
DDN	Dehradun
DSN	Destination Sequence Number
DSR	Dynamic Source Routing
FLEETNET	Fleet Network
FSR	Fisheye State Routing
GA	Genetic Algorithm
GBD	Global Burden of Disease
GDP	Gross Domestic Product
GOI	Government of India
GPCR	Greedy Perimeter Coordinator Routing
GPS	Global Positioning System
GPSR	Greedy Perimeter Stateless Routing
GSM	Global System for Mobile
GUI	Graphical User Interface

HP	Hewlett-Packard
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IRF	International Road Federation
ITS	Intelligent Transportation System
LA	Lion Algorithm
MANET	Mobile Adhoc Network
MCDT	Minimum Calculated Desire Time
MOSPI	Ministry Of Statistical and Program Implementation
MPR	Multi Point Relays
NETSIM	Network Simulation
NP	Non-deterministic polynomial acceptable Problems
NS	Network Simulator
OBU	On Board Unit
OLSR	Optimized Link State Routing
OMNET	Objective Modular Network Testbed
OPNET	Operations Network
OS	Operating System
OSM	Open Street Map
P-AODV	Parallel Adhoc On-demand Distance Vector
PDR	Packet data Delivery Ration
PSO	Particle Swarm Optimization
QRY	Query

RREP	Route Request Replies
RREQ	Route Request
RRER	Route Error
RSU	Road Side Unit
RTS/CTS	Request To Sender / Clear to Sender
RTYB	Road Transport Year Book
RVC	Road Vehicle Communications
STRAW	Street Random Way Point
SUMO	Simulation for Urban Mobility
TACR	Trust Dependent Ant Colony Routing
TORA	Temporally Ordered Routing Algorithm
TSIS-CORSIM	Traffic Software Integrated System Corridor Simulation
TSP	Travelling Salesman Problem
UDP	User Datagram Protocol
UITS	Urban Intelligent Transport System
UPD	Update
UPES	University of Petroleum and Energy Studies
USA	United States of America
VANET	Vehicular Adhoc Network
VENTOS	Vehicular Network Open Simulation
VISSIM	Verkehr In Stadten Simulations Model
WAVE	Wireless Access in Vehicular Environment
WRS	World Road Statistics

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Chapter 1

Introduction and Motivation

1.1 VANET Overview

The advancements in wireless communication technology and devices have opened a new dimension of research capable of repairing and organizing, and rearranging the networks without any centralized authority or infrastructure. Recent enhancements in wireless Adhoc technologies and dedicated short-range communication devices have made vehicle-to-vehicle communications (V2V), and road vehicle communications (RVC) developed using Mobile Ad hoc Networks (MANET). A new network has evolved from this and is called a Vehicular Ad hoc Network (VANET). This newly emerged new technology of VANET is a subset of Intelligent Transportation System (ITS) architecture and is able to provide optimize traffic flow, better road safety, reduction in road congestion, etc. VANETs are evolving from MANETs [1].

VANET can be used as a driver's assistance for communication and coordination among each other that will minimize the critical situation in V2V communication, e.g. random braking, obstacles, accidents on the road, bumper to bumper jams, random increase in speed, pathways for emergency vehicles like fire, police, and ambulance, etc. Along with these preventive applications, VANETs are also useful for comfort applications to drivers and passengers—for example, multimedia applications, internet connectivity, weather forecast, and infotainments during drives. The "Crash Avoidance Matrices Partnership (CAMP), Advance Driver Assistance System (ADASE), FLEETNET, and CARTALK" are some of the famous applications which was developed by various automobile manufacturers and governments through Public-Private Partnerships [2]. Figure 1.1 illustrates the typical VANET structure.

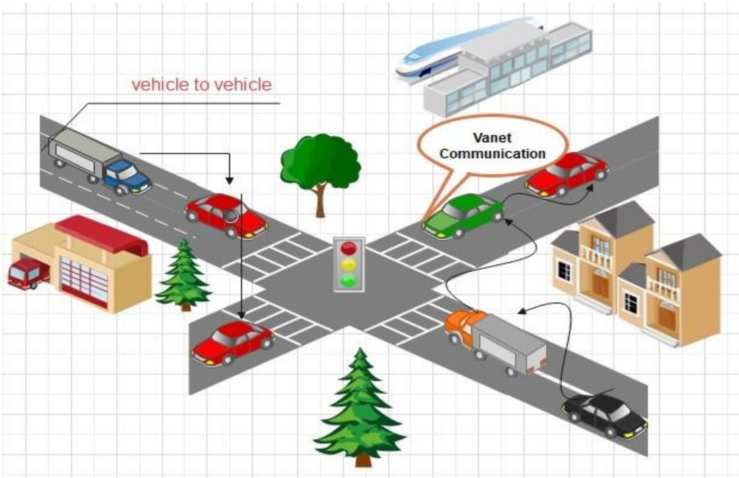

Figure 1.1: VANET Overview

The era of ITS is yet to come. Presently, VANET is in its evolving stage, so industry and researchers are focusing their interest in this domain. VANET has its issues and challenges, like multipath fading and road obstacles, traffic congestion, random vehicle speed change and mobility, road topology, traffic diversion model, driver's unpredictable driving behaviour, etc.

VANET mobility is not the same as that of MANET (mobile ad-hoc network) since in VANET, the vehicle has to follow traffic laws strictly, and node movement sometimes becomes too complex. VANET simulation is necessary to create a realistic mobility model similar to the real road traffic scenarios to achieve the best results. There are many limitations in VANET, and these challenges need to be raised to achieve the reliable and better services in a network. Hence, reliable and stable routing is one of the major issues in VANET. So, dedicated research in this field is required to implement accurate methods in realistic environments. Furthermore, the vehicles have dynamic behaviour, and high mobility speed makes routing in VANET even more challenging.

VANET routing has evolved from traditional MANET routing protocols like DSR (Dynamic Source Routing) and AODV (Ad hoc on Demand Distance

Vector Routing). DSR and AODV are best suited for multihop wireless ad hoc networks [3].

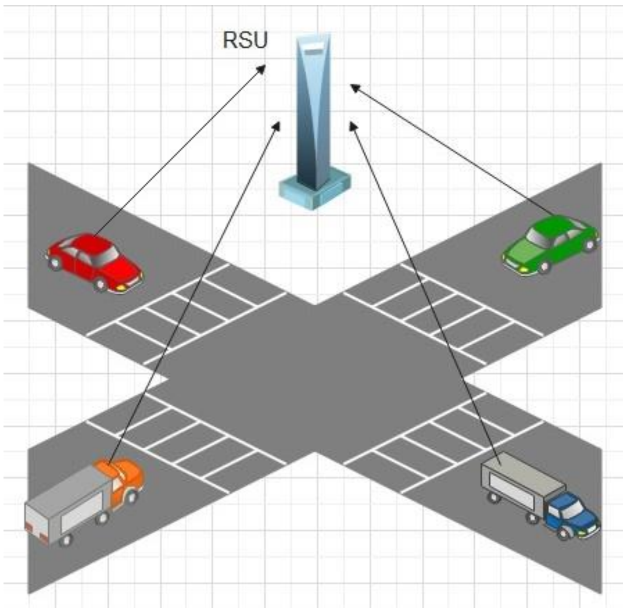

Figure 1.2: Vehicle to Infrastructure

Vehicular Ad hoc Network (VANET) uses wireless communications to communicate among themselves and other vehicles like Mobile Ad hoc Network (MANET). MANET works on Optimized Link State Routing (OLSR) protocol, but the characteristics of OLSR are not best in resources like energy consumption and other hardware [4]. It takes data packets from source to destination while travelling in the OLSR protocol. But consider the same for VANET, then QoS decreases during routing while applying the OLSR protocol in the predefined model and scenarios of urban mobility environments. Hence, to get the best routing process, this needs to revise the configuration setup of OLSR to meet the features of VANET. To reconfigure the parameters like bandwidth, delay, routing network to optimize QoS in VANET using OLSR [5]. Due to the unpredictable nature of vehicles and driver's driving habits, it is almost impossible to apply MANET solutions. That may result in routing and link failures in an environment like urban traffic conditions. Such aspects make it more challenging for eager researchers to develop the best suitable, optimized, and efficient routing protocols for VANET. VANET vehicle nodes use the wireless communication system to disseminate the information among vehicle-to-vehicle, vehicle to infrastructure, and infrastructure-to-infrastructure communications [6].

The working and framework of VANET are entirely different from the MANET. In VANETs, vehicular environments manipulate new issues and need like artificial road topology, traffic flow system, trip models, roadside obstacle, traffic rush, and drivers' behaviour. There are many points from which VANETs differ from MANETs, such as dynamic topology changes and high node mobility. VANETs also vary from various ad hoc networks by compound network architectures, unstable topology, suddenly disconnected networks, and communication [7].

Generally, vehicle nodes mobility patterns are difficult to determine as they move on different traffic scenarios, lights, road or highway structures, and driving behaviour and experience of the person seated at driver's seat [8]. These days, all the vehicles come with Global Positioning System features and other equipped devices/sensors that support providing various information such as signal timings, traffic estimation, fuel consumption, routing decisions best path, shortest route, etc. VANET with intelligence would enhance road safety, fuel efficiency, and even comfort for the drivers as well as for commuters [9]. Therefore, intelligent VANET has made an entirely new area of research for Intelligent Transport System to design unique, automate, and smart transportation system [10]. Every theory suggests that travel time can be reduced by using the shortest path between sources to the destination, but what happens if all the vehicle nodes opt for the shortest routing path, then; this solution will become a problem and result in congestion of opted route. Hence, it is always not true that the shortest path is the optimal route [11]. Therefore, commuters can also choose a longer path because they want to avoid congestions through the lesser traffic signals and waiting time for much smoother mobility of vehicle nodes. Hence, devised a new routing algorithm that binds the features of the Ant Colony Optimization (ACO) technique with genetic characteristics of the Genetic Algorithm (GA). During this research, the other bioinspired algorithmic techniques are also reviewed, but ACO is best suited for VANET because the mobility pattern and behaviour of ants movement in ACO is mainly matched with VANET. Hence, incorporated the methodology through swarm intelligence in VANET to devise a fresh new algorithm.

1.2 Motivation

The "World Road Statistics" (WRS) 2019 [12], issue published by the International Road Federation, (IRF) Geneva, reported that the maximum number of accidents, i.e. 16,30,000 injured in the USA followed by Japan at 7,66,147 and India at 4,84,704 in the year 2018. Whereas India reported the maximum number of fatalities (1,19,860) in road accidents, followed by China (73,484) and the United States of America (37,261) for the year 2018.

As per the data analysis of road accidents reported by the States/UTs, drivers' fault is the major factor for road accidents (78%). Some other important factors causing road accidents are as shown in table 1.1 [13]

Table 1-1 Factors Responsible for Road Accidents with their share

Cyclist fault	1.2%
Pedestrian fault	2.7%
Road conditions	1.2%
Fault in motor vehicle mechanics	1.7%
Non suitable weather condition	1%
All other causes*	14.2%
***Includes other vehicle's fault (driver/vehicle), passenger's faults, poor lighting system, boulders, neglect of civic bodies, stray animals, and causes not known.**	

Government of India gathers the data on Road Accidents in India through The Ministry of Road Transport & Highways. The data analyzed for an annual publication titled "Road Accidents in India", published periodically. The data collected from state police departments frequently. Transport Research Wing is responsible for collecting this data and compiles it to publish it in the 'Road Transport Year Book (RTYB)'. The recently published issue of RTYB reflects the data till 31st March 2018 [14].

The report of MOSPI, GoI, reveals that there were 4,64,910 unfortunate incidences of road accidents during 2017, which claimed 1,47,913 lives and caused injuries to 4,70,975 persons. The national highways, which constitute approximately 2% of the country's total road network, accounted for 30.4% of the total accidents and 36.0% of deaths in 2017. Among vehicle categories, two-wheelers accounted for the highest shares (33.9%) in total road accidents and fatalities (29.8%) in 2017. Most, unfortunately, young adult age group 18 – 45 comprise 72.1% of road accident death victims [15]. http://mospi.nic.in/statistical-year-book-india/2017/189 (Ministry of Statistics and Programme Implementation, GoI)

Table 1.2 indicates the statistics of road accidents, persons killed and injured on all the roads of National Highways in the country: [14]

Table 1-2 Road Transport Year Book Data 2018

Road Category	**2016**			**2017**		
	No. of accidents	**Persons killed**	**Persons Injured**	**No. of accidents**	**Persons killed**	**Persons Injured**
National Highway	1,42,359	52,075	1,46,286	1,41,466	53,181	1,42,622
State Highways	1,21,655	42,067	1,27,470	1,16,158	39,812	1,19,582
Other roads	2,16,638	56,643	2,20,868	2,07,286	54,920	2,08,771
Total	**4,80,652**	**1,50,785**	**4,94,624**	**4,64,910**	**1,47,913**	**4,70,975**

Since India's independence, the population of automotive vehicles has risen around 170 times, but the expansion of roads and its infrastructure has been developed only nine times. India's vehicle population is increasing at a phenomenal rate of 25 lakh per year and automobiles population is increased even more than 5.5 crore. The roads infrastructure is developed around 25% in New Delhi as compared to 4% of Kolkatta city and only 30% in other major cities of the country. Apart from the metro cities, connecting roads and other main roads are always congested and rarely maintained.

Road fatalities are expected to become the world's fifth-largest killer by 2030, thousands of times more than terrorism or rail/air accidents.

It is alarming that the rate of death due to road accidents is highest in India than in any other country in the world. This was highlighted in the World Health Organizations' Global Status report on road safety [16].

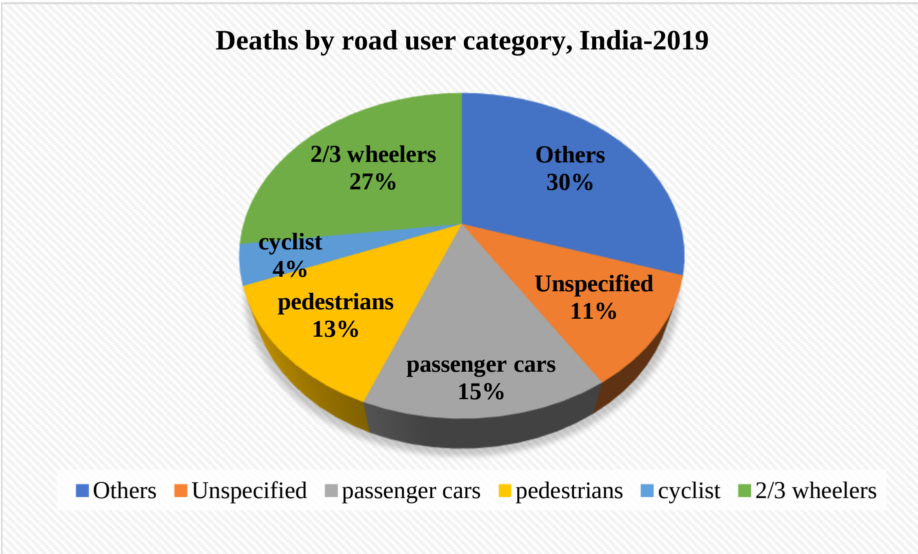

Figure 1.3: Road Accidents - 2019, Ministry of Road Transport, India

Today, metropolitan cities are facing one common problem of bumper-to-bumper traffic on the roads, and this results in congestion. That is the main reason for accidents and as well as vehicles emitting pollution. Therefore, road safety is a must for saving precious human life, and this can also cause a threat to the clean environment. Some features such as airbags, hazard warning systems, and seat belts are available. Still, they cannot resolve the problems that occurred because of driver's incapability to predict the situations before it happens.

At present, the speed of other vehicles is not predictable and cannot respond accordingly. However, with new technologies like wireless sensor communications and other types of equipment, speed can be predicted to broadcast a warning message. These messages can be sent at intervals of a few seconds to reduce the risk of possible accidents [17].

The number of vehicles is increasing at a very fast rate in the last few years. It has been reported by road transport authorities that in the year 2001 there were only 55 million of vehicles get registered. Still, the registration of vehicles increased to 142 million in the year 2011. That is an alarming statistic for traffic management and road safety concerns. Even in the last decade, there was a rise of 219% registered vehicles for one million of the population. The Government of India (GoI) is in the process to expand the national highway network for more than 200,000 km. The GoI has already launched the "Bharatmala Pariyojana", which targets to build 66,100 km of coastal roads, expressways, economic corridors, and borders to boost the highway network as National highways account for 2% of the total road network and carry over 40% of total traffic [18].

1.2.1 **Congestion**

The cities, mostly metropolitan, are facing severe traffic congestion problems because of the rapid growth in private vehicle registration. The average speed of a vehicle is around 17-19 km/h, with the slowest times witnessed during the evening hours in metro cities. The average speed of traffic in key Indian cities is just 17-23km/h, while the average cycling speed is 15-16 km/h [19].

1.2.2 **Road accidents**

A total of 501,423 road accidents and 146,133 death in road accidents were in 2019; this means 1,374 accidents and 400 deaths on India's roads every day. Sadly, 54.1% of people killed in road accidents are in the age group of 15-34 years only. It estimated that around 3% of the GDP economy lost due to road mishaps. [20].

1.2.3 **Air pollution**

The Global Burden of Disease 2018 (GBD) study reported that 'outdoor air' pollution listed in the top 10 risks around the world and the developing countries of Asia is among the top six risks for humans. The developing countries such as India are more effected from air pollutants, approximately 1.4 million of people died because of air pollution whereas from the economic aspects around US$ 505 billion losses towards welfare and US$ 55.4 billion towards labour loss [21].

Hence, research is very much required for V2V, V2I, and V2Hybrid communication to deploy intelligent traffic systems. VANET is a fundamental area of research to overcome the factors mentioned above. Routing plays a vital role here because if the information is not disseminated timely and accurately, then accident disaster may occur in real-time traffic scenarios. VANET is made through random vehicular movements on highways or city drives. These vehicles or nodes are free to move as per their need and speed or as per the driver's mood and driving habits. This uncertain movement of nodes generates newly evolved challenges and problems for the researchers. These problems motivated the researcher to develop and devise a new set of protocols and algorithms that can be more specifically focused on VANETS routings. The VANET can be tested using simulation software to analyze the performance before the implementation in real-world applications. This chapter aims to analyze and present the shortcomings of the present standard routing protocols used and implement for VANET. The following subsection presents the overview of existing VANET standards.

1.3 VANET Standards

Wireless Access in Vehicular Environment (WAVE) standards in figure 1.4 were launched in 2004 and revised in 2006 [22]. That came up with the measurements and demonstrations of the vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications utilizing practical trials. The main aim of these trials was to develop the standards for V2V and V2I communications, assuring greater precision in vehicle location and finding exact mapping using location referencing techniques like satellite navigations [23].

The WAVE architecture is the newly developed standard that relies on IEEE 1609 and IEEE 802.11p standards. The WAVE was majorly used in the research area to develop the MAC and physical (PHY) enhancements of the 802.11

protocol. Here, the IEEE 1609 family's sub-standards are IEEE 1609.1 for services like remote management, IEEE 1609.2 as security services, IEEE 1609.3 for network services, and 1609.4 used in multi-channel operations. The American Society proposed these specifications for Testing and Materials in ASTM E2213-10, and the proposal is adopted in 2004 by FCC.

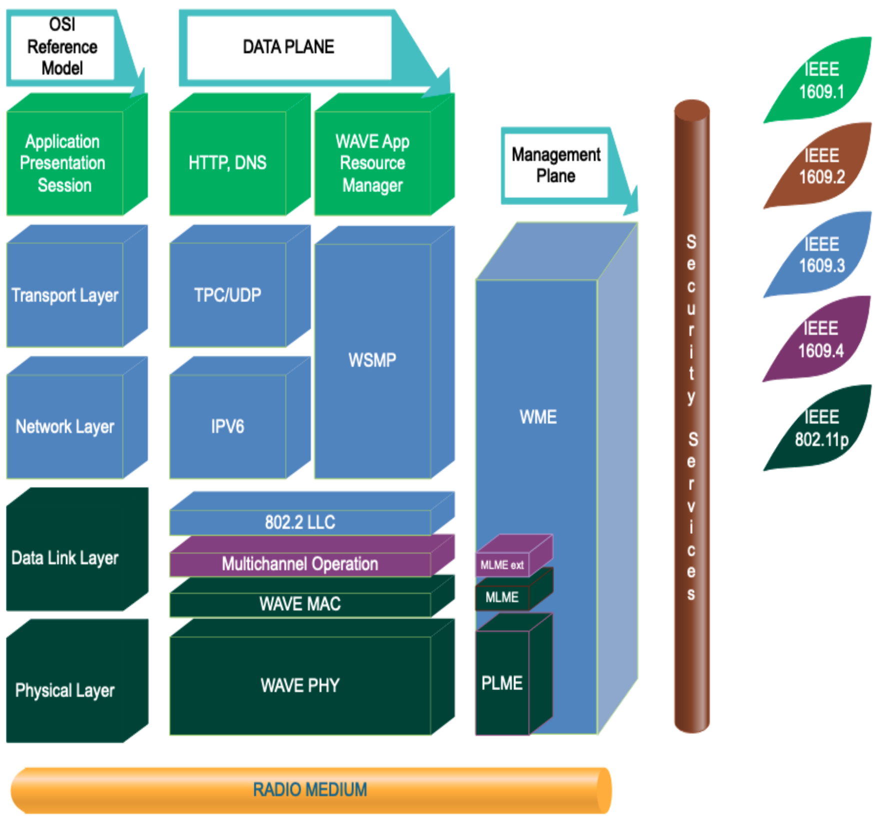

Figure 1.4: WAVE Architecture

There are many wireless access standards used in VANET connectivity, the objective is to give a set of air interface protocols and standards for high-speed vehicular communication by using one or more media. Some core technologies comprised:

a) IEEE 802.11p based technology
b) Combined Wireless Connection Access.

Exchange of data among On-Board Units (OBU) in vehicles is through Road Side Unit (RSU) or roadside help system, mainly based on wireless networking technology. The three wireless radio technology standards for vehicle communication:

a) IEEE 802.11 -WiFi
b) IEEE 802.15.3 - Ultra-Wideband, high data rate
c) IEEE 802.15.4 - ZigBee, low data rate.

All these technologies are used for communicating by using various protocols of wireless communication that analyze different aspects of communication such as rate of data transmission, data transmission range, security, and latency. Data without loss is one of the most desired challenges due to frequent disruption in signal in VANET [24].

1.4 VANET Features and Challenges

The features and characteristics of VANET separate itself from many other Adhoc networks. Some characteristics of VANET, such as huge network size, high speed of nodes, and continuous mobility, make it difficult to stabilize node connectivity. Though, some of the various add-on features of entertainment, internet, payment, and updates are also integrated with the vehicles as a driver's comfort in addition to V2V communication and safety [25].

It is essential to describe the prime challenges that affect VANET. Some of the prime challenges from a technical perception are discussed below:

1.4.1 Signal Fading:

Various objects such as buildings and other vehicles in between two communicating vehicles along roads may act as an obstacle and cause deficiency of network signal [26].

1.4.2 **Bandwidth Limitation:**

The big challenges of VANET are the absence of a central managing device like that of the router for the communication between nodes. Hence, productive use of bandwidth becomes essential in VANET [27].

1.4.3 **Small effective diameter:**

A VANETs small productive network diameter results in weak connectivity in communication among nodes. Therefore, sustaining a network topology for a node for a longer duration is not practical. Hence, the presently available routing algorithms of VANET are not suitable for the larger diameter of networks [28].

1.4.4 **Security and Privacy:**

As the nodes broadcast the information in VANET hence, receiving data from a trustworthy sender is a major concern [29].

All these bring new challenges to VANET communication. VANET-related research challenges need further research and innovative solutions to ensure satisfactory performance of VANET infrastructure, communication, security, applications, and services.

VANET security challenges are still to be addressed in authenticity, driver confidentiality, and availability. Lightweight, scalable authentication frameworks are not able to protect vehicular nodes from inside and outside attackers that can infiltrate the networks using false identities, identifying suppressing attacks, fabricating, altering, or replaying legitimate messages, revealing spoofed GPS signals, and preventing the introduction of misinformation into a vehicular network. These sorts of attacks are still waiting for solutions.

The provision of *reliable* broadcast messages with minimal overheads in VANETs leads to other challenges. That may include a selection of the next forwarding node, maintenance of communications among vehicles. Moreover, they leave or join a group and hidden terminal problems as the broadcast messages do not use Request to Sender/Clear to Sender (RTS/CTS) message exchange as used by IEEE 802.11 [30].

1.4.5 **Autonomous and Infrastructure-less Network**

VANETs are formed by vehicular nodes of the autonomous system connected through wireless links without infrastructure or centralized administration. VANET nodes move randomly, organizing themselves arbitrarily; thus, a network’s wireless topology changes rapidly and unpredictably. In VANETs, a collection of vehicular hosts with wireless network interfaces form temporary networks without fixed infrastructure or centralized administration. A VANET is an infrastructure-less network as networks vehicular nodes set up paths among themselves dynamically to transmit packets temporarily.

VANET is a special ad hoc network of moving cars called nodes, providing a way to exchange information between them without depending on fixed infrastructure. VANETs are autonomous and self-organizing wireless communication networks, where cars called nodes to involve themselves as servers and clients to exchange and share information.

The vehicles acts as a mobile nodes in VANET which is a subclass of MANET. In VANET vehicles are connected wirelessly as an autonomous system on a peer-to-peer communication. VANET’s is separated from MANET through its distinguished characteristics like distributed communication, random mobility, self-organizing capability, restriction on various road patters and non-restricted network size. The challenging characteristics makes it more interesting in designing more efficient routing protocols [31].

Research on VANETs real-time communication enables distributed applications among vehicular nodes in infrastructure-less areas. Cluster-based Routing in VANETs is useful for applications that require better routing and scalability to 1000s of vehicles. Location-based clustering techniques improve routing performance in different mobility scenarios [32].

VANET security differs from wireless and wired networks due to mobility constraints, infrastructure-less framework, and the short duration link between nodes. In wired networks, infrastructure has specific functional components; for example, routers decide destination routes while network hosts send and receive messages.

1.4.6 **Multi-hop Routing**

Emerging MANET and VANET will form network-centric communications. Many mobile nodes communicate through single or multi-hop routing protocols. Though VANET is a classified MANET scenario, its nodes form a highly dynamic network where node density is dense or sparse. Also, vehicle radios have a limited radio range, so communication occurs through multi-hop routing protocols. Urban VANETs, estimate the quality factors of the route based on vehicle position, speed, and trajectory [33].

The relevant perspective analysis services of vehicle networking and mapping requirements shows that the networking infrastructure can clearly outline many VANET services. The “one-to-one,” i.e. single end-to-end path and “one-to-zone” (route till an area and then local geo-referenced broadcast) routing strategies of VANET is reviewed [34].

VANET unicast routing aims to transmit data packets from source to destination using wireless multi-hop transmission, i.e. carry and forward techniques. In the wireless multi-hop transmission technique, called multi-hop forwarding, intermediate vehicles in a route; relay the data from source to destination as soon as possible. In a carry-and-forward technique, a source vehicle carries the data packets as long as possible to reduce these data packets. In wireless multi-hop transmission, delivery delay-time cost is less than the carry-and-forward technique. [35].

Then, multi-hop communication is used when data packets are forwarded from one node to another until they reach the destination. The infrastructure domain provides connectivity to access Internet services, Internet nodes, and servers. It ensures wireless multi-hop communication between two nodes (unicast using 'greedy forwarding') and efficient data packets broadcasting in geographical areas (Geocast) [36].

VANETs enable exchanging information (occurrence of a traffic jam or accident) among vehicles through multi-hop transmissions using intermediate relaying forwarders. But, the effectiveness of such multi-hop transmissions is affected by challenges due to high vehicular mobility and adverse V2V radio propagation conditions. That increases the chances of finding a multi-hop connected path to the final destination with a communications overhead [37].

1.4.7 **Dynamically Changing Network Topology**

VANET works without infrastructure and has a dynamic topology. Communication and routing of transportation networks are challenging due to their short life of communication, high-speed vehicles, unpredictable node density, and city environment characteristics. Topology frequently changes due to speed and vehicle movement. High-speed mobility models and predictions have a significant role in VANETs dissemination and design. Disconnection chances are high due to its dynamic topology. High mobility in VANETs, leads to frequent network partitioning and route disconnection, demanding re-

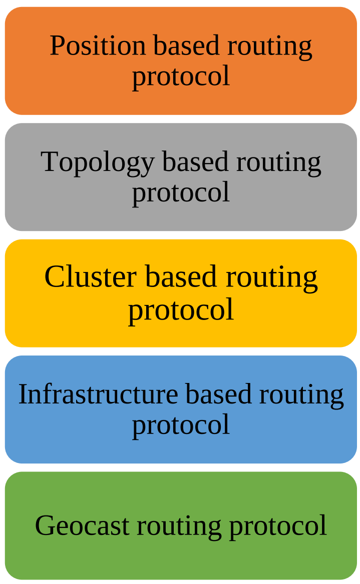

Figure 1.5: VANET Categorization

computation of topology information [38]. Routing protocols in VANETs are categorized into five types: as shown in figure 1.5.

Position-based routing protocol, Topology based routing protocol, Cluster-based routing, broadcast routing, Infrastructure based, and Geocast routing protocol [39].

Designing efficient VANET routing protocols is a challenging task due to the highly dynamic characteristics of topology. The routing protocol in VANETs is classified into Topology based routing protocols and Position-based routing protocols. The routing table is updated periodically by each node of an ad hoc network through broadcast or when new information is available and maintains the routing table consistency with dynamically changing topology of the ad-hoc network. Each mobile node's routing table element changes dynamically to be consistent with an ad hoc network's dynamically changing topology. The consistency level is achieved, routing information advertisements should be frequent or quick to ensure that a mobile node can always locate other mobile nodes in a dynamic ad hoc network.

High mobility and frequent network topology changes are the most challenging issues in VANET. Network topology varies in VANETS when vehicles change their velocity and lanes. These depend on drivers and road situations and are not scheduled in advance [40].

1.4.8 **Network Scalability**

Scalability is a very crucial characteristic in large and especially distributed networks and systems. The network scalability is the property to manage extra incoming nodes without altering or degrading the network performance and additional manageability. The number of active nodes (vehicles) impacts the network connectivity and has the likelihood of congesting wireless channels. Protocol designs also impact scalability [41].

Many base stations are sited throughout a city in order to improve the ad hoc network routing scalability with assured internet connectivity. Nodes communicate over multi-hop paths with the help of these. But, there are other challenges like high node mobility, signal attenuation, and network scalability. With the 750 million vehicles globally increasing daily and the absence of a world-level authority to govern it, network scalability becomes a question mark. The challenge inherent to VANET deployment is the operability with very sparse and highly overloaded networks. Scalability issues are not comprehensively addressed by current approaches, as they focus on parts of the problem alone. Good scalability is ensured for large networks, but network delays and overhead occurs when clusters are formed in mobile VANETs [42].

VANETs comprise potentially multiple vehicles, so protocol mechanisms should be scalable and efficient regarding mobility management-based overhead. Unfortunately, the feature common in topology protocols is degradation as link possibility grows, making scalability difficult.

Limited capacity also leads to scalability concerns for future VANETs. Also, a V2V network with few nodes or low data traffic works well, but networks with many nodes or high data load breaks down. So, new strategies for VANETs data dissemination have to be designed, keeping scalability and capacity in mind [43].

1.4.9 **Bandwidth Constraint**

Position-based protocols, unlike topology protocols, do not need the route maintenance process. Instead, the route is established when needed, thereby reducing undue bandwidth constraint already low in VANETs. This approach results in huge control overheads restricting the use of limited wireless resources like available bandwidth. That ensures information delivery with extensive bandwidth usage.

Periodically, the updates are made regardless of bandwidth constraints, network load, and size. The limitation of such approaches is the undue processing constraints on the network. That already pushed to the limit due to lack of bandwidth. Furthermore, as node density increases, there is an increase in message transmission, leading to bandwidth consumption [44].

Bandwidth constraints wireless links, having lower capacity than wired links. Fading, noise, and interference affect wireless communication throughput. Inter-vehicular communication is at the core of many industries and academic research initiatives that aim to enhance transportation systems' safety and efficiency. The ranking is thus critical and enables the most significant data to be transmitted under bandwidth constraints [45].

A vehicle may have many reports to broadcast but may not do so with all of them due to bandwidth constraints. The number of reports a vehicle broadcast is determined to optimize bandwidth use. Intuitively, if transmission size is too small, then bandwidth is underutilized, and report dissemination suffers.

Facilitating vehicle communication and developing an efficient VANET routing protocol are the challenges due to these reasons: signal fading due to obstacles (buildings), bandwidth constraints, vehicle mobility, and speed which is dependent on traffic signs and other signals. Therefore, this mechanism differs, and the sender does not specify the destination as in traditional forwarding. Here, the information is broadcasted depending on the need and availability of bandwidth challenges in VANET.

1.4.10 **Error-Prone and Shared Channel**

VANET problems should be solved to provide reliable services like routing, security, and Quality of Service (QoS). Dynamic topology, lack of central coordination, hidden terminal problem, error-prone shared radio channel, limited resource availability, and insecure medium render VANETs inefficient to support QoS. VANETs wireless communication is inherently error-prone and suffers from noise, path loss, and interference similar to MANETs. VANETs must also deal with high vehicle mobility and frequent route disruptions. Cross-layer protocol designs should address fundamental VANET problems like high vehicle mobility, topological changes, error-prone wireless channel, and limited channel bandwidth [46].

The radio channel is a broadcast medium. Radio waves during propagation through a wireless medium suffer from attenuation, multipath propagation, and interference (from other wireless devices in the vicinity). Many numbers of wireless channels is an error-prone channel. When a protocol is designed without considering errors, the protocol suffers a degraded performance during the real-time deployment.

A node located farther than a nominal transmission range may not successfully receive long data frames, although it receives short RTS frames sans errors. That happens because real wireless radios do not follow unit-disk assumptions and reason for errors in VANET routing.

1.4.11 **Location-Dependent Contention**

Data transmission rate has to be adaptive in VANETs as wireless channels are time-varying and location-dependent. Location-dependent services are built over a push-pull information model of two earlier scenarios. First, some information like parking zones, fuel stations, entertainment places, restaurants, and markets are accessed through regional transport stations. Second, a vehicle having a Global Positioning System (GPS) ensures the integration of geographical positions in services like the location of facilities like fuel stations, parking zones, entertainment places, and restaurants. That can be further integrated into telemetry (distance to empty) or higher-level recommended systems providing feedback facilities from other VANET nodes (quality/convenience).

In VANETs, a node's information at a real-time position is assumed by most protocols, algorithms, and applications using the GPS receivers. But, when VANETs enter critical areas and become localization system dependent, GPS issues and problems like non - availability or may not be robust enough for some applications. So, there is a need to develop new localization techniques to overcome GPS limitations [47].

VANETs channel conditions are highly dynamic due to the high mobility of vehicles and frequently changing road conditions. To improve system performance, senders selects appropriate communication parameters (like transmission power, data rate) and dynamically adapt their decision to time-varying and location-dependent channel quality. VANET allows the entities to implement a key agreement process and shares the secret session key, ensuring data confidentiality and integrity. It yields authentication during broadcasting and also in high contention environments like VANETs [48].

1.4.12 Security

The simple and effective security mechanism is a big issue for deploying VANETs in public since the security of the VANET system is susceptible to several attacks. These false warning propagation messages are similar to actual warning message suppression, thus leading to accidents. So, security is a major concern in such networks. Moreover, most nodes are vehicles that can form self-organizing networks without knowing each other whose security is very low and very vulnerable [49].

Security requires satisfaction as VANET ensures road safety applications. Among all VANET challenges, security has been receiving limited attention till now. The data packets possess critical information that can impact someone's life also. So this should be careful that such data packets are not hacked or cracked by hackers; here, drivers are liable, and responsibility can be given to them to inform a traffic environment correctly and in time. These security problems are dissimilar to those in general communication networks. Network size, mobility, and geographical factors implement VANET distinct and difficult from other secured networks. [50].

Different techniques have been drawn up to achieve security goals and protect VANETs against attacks. VANET security is an emerging area where many future research lines are indicated. Due to different VANET protocols, mechanisms and applications are also based on different architectures and assumptions. So, a common evaluation framework should compare these differing security research contributions [51].

Different security challenges of the vehicular network are addressed here, with special attention to the application of many known security primitives like symmetric and asymmetric cryptography, data aggregation, strong authentication, and cooperation enforcement. Hence, Security in VANETs is reliant on detecting and correcting malicious data [52].

1.4.13 Energy Efficiency

Vehicle transmitter power control is a mechanism for network connectivity trade-off and reduced interference levels between vehicles. VANETs energy efficiency is not an issue as vehicles are assumed to have unlimited energy reserves, i.e., vehicles' battery. Therefore, despite the availability of many studies in this area, VANET nodes have nearly unlimited power for communication through the battery equipped in them.

Reducing energy for data transmission and improving VANET's energy efficiency are accomplished using a two-tier data delivery mechanism. It also considers energy-efficient roadside access point scheduling. A scheduler capable of satisfying communication requirements of vehicles in the vicinity of an AP while minimizing energy needed using AP power control is considered [53].

As sensor nodes can disappear over time, Wireless Sensor Networks (WSNs) use such methods for replication, yet space and energy-efficient data storage. Also, monitored data has to be encrypted in order to protect it from any unauthorized access.

Unlike MANETs and WSNs, where nodes run on batteries of their own, energy is not a challenge in VANETs as OBUs are continuously charged by car batteries while fixed power cables charge RSUs. So, researchers should shift back to security problems rather than paying attention to energy efficiency.

An optimal schedule of turning on/off the deployed RSUs at a given time is performed to minimize energy consumption while maintaining VANET connectivity [54].

1.5 Routing in VANET

VANET routing is different from MANET routing due to its highly dynamic and changing topologies. The three main protocols as shown in figure 1.6.

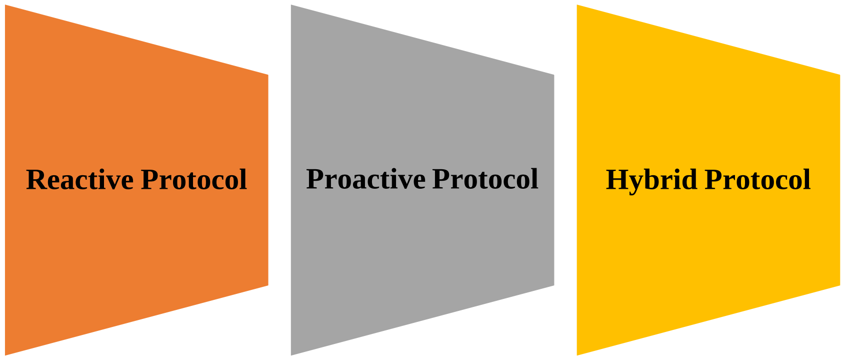

Figure 1.6: Three main MANET protocols for VANET

Reactive, Proactive, Hybrid protocol designed for MANET environments are tested on VANET. A routing protocol governs how two communication entities exchange information among them. It includes a procedure to establish a route, an agreement in forwarding, and action in maintaining a route or recovering from routing failure. Due to a specific mobility pattern, evaluation of VANET routing protocols makes sense from the traces obtained pattern. Various VANET mobility trace generators have been developed for testing VANET routing protocols through simulation [39].

The concern is whether VANET routing protocol performance satisfies the throughput and delay requirements of applications. Road-based VANET routing protocols affect real-time road traffic facts to generate vehicle route information. This protocol also responsible for seamless network connectivity and successions of road intersections and related data.

Unicast routing is an operation for a vehicle to construct a source-to-destination routing in VANETs. The aim of unicast routing in VANET is to transmit data from one source to a single destination through wireless multi-hop transmission or carry-and-forward technique. In the wireless multi-hop transmission technique or multi-hop forwarding as known locally, intermediate vehicles in a routing path should relay data quickly from source to destination. The routing protocols are classified into two categories; min-delay routing protocol and delay bounded routing protocol. The Min-delay routing protocol is used to reduce the delivery delay time from its source to destination. In contrast, the Delay-bounded routing protocol maintains low-level channels within constrained delivery delay time [55].

Temporary network fragmentation and broadcast storm further complicate VANETs routing protocol design. VANET routing protocols should establish routes dynamically and maintain them during communication. VANET should discover alternate routes quickly on-the-fly if they lose the path [45].

1.5.1 Types of Routing in VANET

VANET routing protocols are categorized into two distinctive topologies shown in figure 1.7.

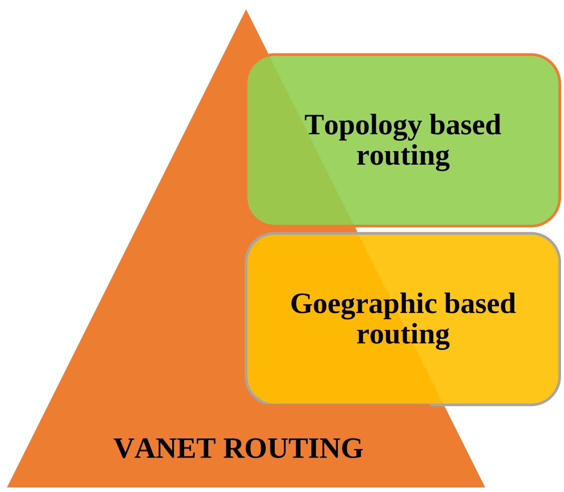

Figure 1.7: Two main routing protocols in VANET

Topology-based and Geographic based routing [39] are on-demand routing protocols, where they update the routing table periodically when any data has to be sent. But, they use flooding for route discovery, causing more routing overhead and suffer from initial route discovery, making them unsuitable for VANET safety applications.

1.6 Topology-based Protocols

Topology-based routing protocols use the link information that is already available in the network. This protocol sends data packets from source-to-destination. The topology based routing protocols are categorized into two i.e. table-drive (proactive) and on-demand (reactive) routing protocols.

1.6.1 **Proactive (table-driven) routing protocol:**

These protocols rely on the exchange of routing tables on a regular basis to construct routes in advance. Proactive routing protocols include Fisheye State Routing (FSR) and Optimized Link State Routing Protocol (OLSR), which are two distinctive protocols of Proactive routing systems.

a) ***FSR***

FSR ignores the change in a faraway topology. It do not consider change in calculation of the local routes in a faraway topology. Hence, the purpose of the function is to update the exchange of routing tables but the network is not flooded with updates. However, all the nodes timely exchange with their neighbour's partial routing update information in a limited duration. Further, all links propagate hop by hop for each send. FSR collects the entire information as per the network map though it is not able to claim the accuracy of farther nodes for all the connections.

b) Optimized Link State Routing Protocol (OLSR)

OLSR optimizes the broadcast route to control messages to save the network bandwidth consumption through the multipoint-relays (MPR) concepts. In this, its neighbour is selected by each node and broadcast its packet at the time of forwarding. As a result of the MPR distribution, all nodes in the network may be reached with fewer repeats. The MPR of node N is the smallest set of its 1-

hop neighbours which covers two-hop neighbours (in the direction of the communication range).

c) Reactive (On-demand) routing protocols:

When it comes to packet routing, the on-demand protocol will look for a route to the destination through the network. The traditional route lookup method involves flooding the network with queries in order to locate the target station which might answer with the reverse path.

d) Ad-hoc On-Demand Distance Vector (AODV):

This protocol is based on the “distance vector routing protocol” principles and is a reactive protocol that adopts a mechanism in dynamic source routing discovery. AODV implies to maintenance of routes, its uses hop by hop routing, and sequence numbers. AODV builds a route by the sequence of queries “route request/ route reply”. AODV uses the Destination Sequence Numbers (DSN) to get every route entry. The destination creates DSN, and the respective route information has to be included by the nodes. At the same time, it is finding the routes to destination nodes. Therefore, routes with the greatest DSN are preferred in selecting the route to the destination. AODV uses the message types Route Request (RREQ), Route Replies (RREP), and Route Error (RRER) in finding the route from source to destination by using UDP (user datagram protocol) packets. A route to a destination is established by a source node when it sends a packet RREQ throughout the network if it does not already have route information.

Nodes that receive this packet update their source information and place pointers in their routing tables for return to the source. Along with source IP, the RREQ consist the sequence number of the destination immediately identified by the source. If it is the destination or if it has a route to the destination with a sequence number higher or equal to that included in RREQ, a node receiving the RREQ packet will forward the RREP. In such case, RREP packets are sent at the source or else RREQ is broadcasted repeatedly. The nodes maintain record for every source IP and RREQ broadcast packet addresses. They erase the RREQ when it gets one that has previously been responded with it.

e) Dynamic Source Routing (DSR):

The DSR protocol works on the basis of source routing. This signifies that the data packet's route information is also added to that data packet's header. And can be retrieved by the routers from the source. Thus, the DSR protocol comprises two distinct mechanisms; the first is used to find the routes on demand, and the other responsibilities to maintain the communication route in progress. The limitation of this protocol is that the route maintenance process is not able to repair the broken link locally, and the performance of the protocol decreases with the increase in mobility.

f) Temporally Ordered Routing Protocol (TORA):

This protocol is based on three phases. The first is the creation of routes. The second is the route restructure, and the third is clear the routes by three distinctive packets CLRS, QRY, and UPD. "TORA" accommodates vehicular network mobility by storing numerous paths to the same destination, ensuring that topology changes do not effect data routing unless all paths linking to the target are lost.

1.7 Geographic (Position-based) routing Protocols

To perform geographic routing in an ad-hoc network, it is necessary to possess access to location information of all nodes, like of GPS and source node must aware of the location of destination node. Some of the position based routing protocols have been discussed below:

a. GPSR – The Greedy Perimeter Stateless Routing: The GPSR algorithm determines the next node to resend the packet based on the position of the nodes as well as the destination. In GPSR, a node operates in greedy mode, forwarding packets to the neighbour who is nearest to the destination. The Beacon message providing the node's address and position is periodically diffused to detect the node's neighbourhood in a topology.

b. GSR – The Geographic Source Routing: In this protocol, a source vehicle sends a data packet to a target vehicle, it uses the geographical information on the road map to compute the shortest routing path to reach the target vehicle. This protocol works on the road topology that gathers information as per the geographical position of the urban area.
c. GPCR – The Greedy Perimeter Coordinator Routing: The GPCR broadcasts the message as per the road network topology through greedy technique that prefers the defined coordinated nodes. The next relay node is chosen at an intersection and preference is given to a non-coordinator node, though it may not nearer to the destination also prevents radio obstacles.
d. A-STAR – An Anchor-based Street and Traffic-Aware Routing: This protocol utilize critical information generally for urban vehicle roads to recognize an anchor path with the best possible connections for packet forwarding. A-STAR works on the geographical position of the Metropolitan Vehicular Environment. The anchor based routing approach is adopted by it as same as of GSR and represents the city street features. The anchor pathways are calculated by the A-STAR protocol based on the traffic and each street is assigned a weight based on its capacity.

1.8 Scalability of routing Protocols

Each node sent the routing traffic which is a significant way to calculate the scalability for the network and routing protocol. It is described as total number of routing packets transmitted over the network and expressed as packets or bits per second. The calculated values are recomputed for each transmission or for the packets that has been received. To determine whether the network is loaded or not, a calculation can be done. The following expression is used to determine the routing traffic:

$$\boldsymbol{T_r = P_n - (P_{nr} + P_{nl})}$$

Where,

$\boldsymbol{T_r}$ **:** Traffic routing

$\boldsymbol{P_n}$**:** number of packets

$\boldsymbol{P_{nr}}$**:** number of received packets

$\boldsymbol{P_{nl}}$**:** number of packets lost

1.9 VANET Routing Challenges:

a. A major challenge in VANET design is developing a dynamic routing protocol to disseminate information from a node (vehicle) to another. The challenge is to reduce the delay associated with passing information from a node to another node. The other issue is to develop an efficient multicast and Geo-cast protocol over VANETs changeable topology. Mobility of a destined zone reveals dissemination of a protocol packet to static or mobile multicast or Geo-cast region. Current protocols consider static multicast or Geo-cast region except for mobicast routing protocols [56].
b. The survey performed over the VANET routing protocols shows the existing challenges and the open research issues in VANET routing. Today's important research area includes the analysis of driver’s behaviour, signal loss, and the interferences that occur due to tunnels and high buildings [57]. Furthermore, designing an efficient VANET routing protocol is challenging due to its high node mobility and mobile node movement constraints.
c. During high mobility and rapid topology change, designing an efficient routing protocol to deliver a packet with minimum time duration having few dropped packets is critical in VANETs. Further, many researchers focusing more on designing and developing a routing protocol to suit rural and dense

environments with high vehicle density and close distance between them. Designing an efficient routing protocol impacts many factors, out of which the first is to enhance system reliability by leveraging between them.

d. The next is to reduce the interference that occurs due to the existence of high buildings. So, there exist new challenges for VANET routing protocols as traditional routing protocols may be unsuitable for VANETs. Researchers are currently designing new VANETs routing protocols by comparing and improving current simulation tests [58]. The major VANET routing challenges is depicted as per figure 1.8.

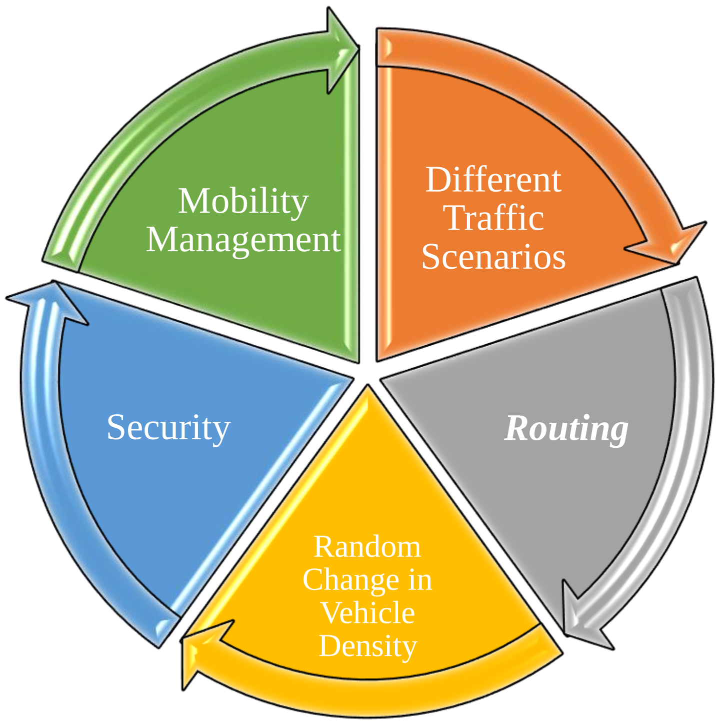

Figure 1.8: Research Challenges in VANET Routing

1.10 Research Gap

The existing routing algorithms for VANET routing are not that robust, which can meet the expectation of various routing scenarios. Many researchers have attained great success in various areas of VANET. But, many challenges are required to be overcome and a few issues that can be investigated [59]. Although, much research has been already available in the areas of VANET routing protocol and its performance [60]. However, due to the emergence of Swarm Intelligence, many fact-findings have yet to be validated [11]. Integration of existing standard routing protocols with Swarm Intelligence shows better results [61]. VANET performance depends on various simulation scenarios, and none of the routings is best suited for every scenario. So, this research is an outcome in developing the optimized solution for optimized routing to get better results in VANET for PDR and Throughput.

1.11 Problem Statement

The efficient routing that is capable of supporting various realistic traffic scenarios is still under investigation. Many pre-existing standard routing protocols are presently available, but they have not integrated Swarm Intelligence for realistic city-based traffic scenarios. So, this problem is taken for the research work and integrated the two best Swarm Intelligence-based routing algorithms to validate the devised algorithm's performance. The performance was verified using three various traffic scenarios on two principle performance factors: Packet Data delivery Ratio and Throughput. The research is the investigation and validation of the devised hybrid algorithm.

1.12 Objectives

The objective of the Research Program is to devise, implement, test, and verify a Swarm Intelligence based algorithm for efficient routing in VANET.

1.12.1 Sub Objectives:

- To study the various existing VANET routing algorithms.
- Identifying the issues in existing routing algorithms.
- Explore the various possibilities to improvise the VANET routing using Swarm Intelligence.
- Devising the efficient VANET routing algorithm based on Swarm Intelligence.
- Implementing the newly devised algorithm.
- Performance testing of the newly implemented algorithm and comparing the existing algorithms to show the efficiency of the newly implemented algorithm.

1.13 Organization of the Thesis

The thesis is organized chapter-wise so that structure of the research work done can be read seamlessly. It is tried to keep the chapters of this thesis in a sequence so the readers' can generate interest in reading and understanding. The research thesis starts with the introduction and government statistics of road accidents and road Infrastructure development. That makes the reader get a

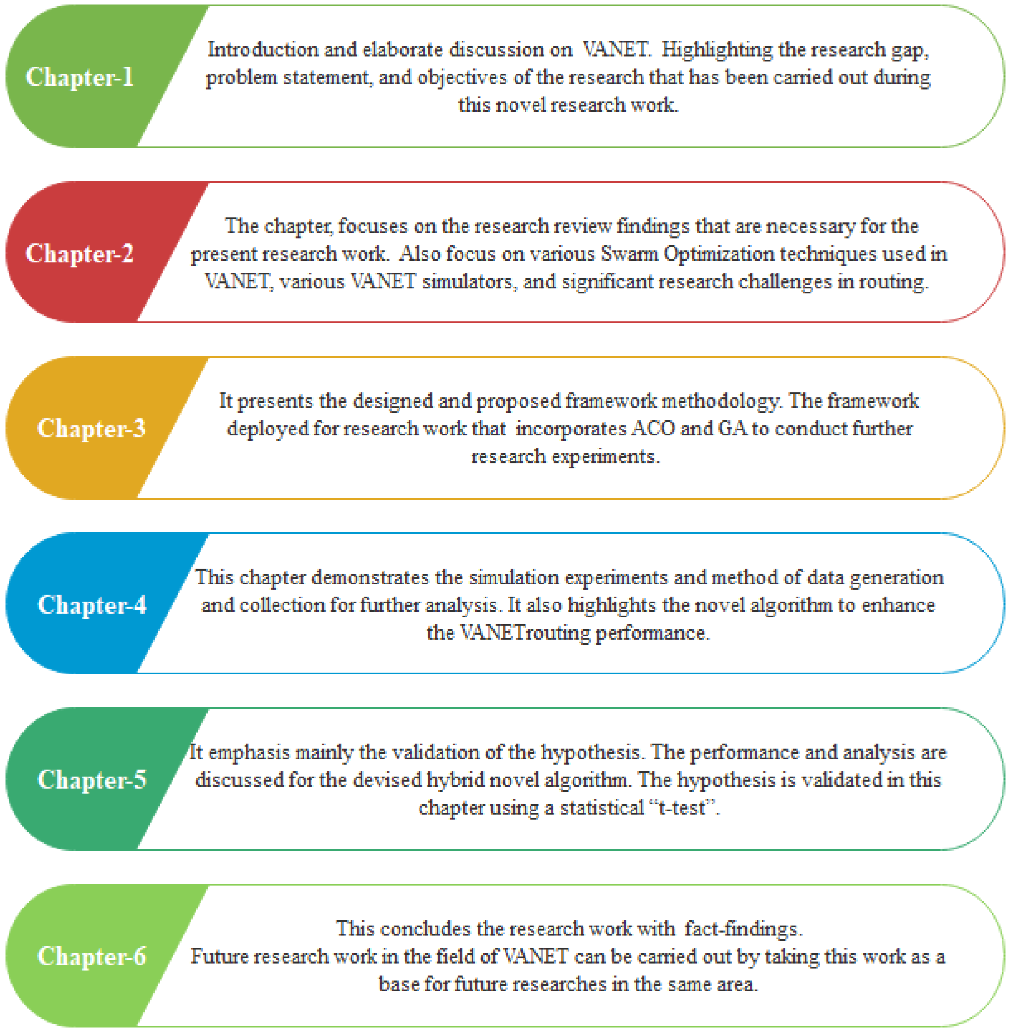

Figure 1.9: Structure of the Thesis

better experience of the requirement of this crucial research work. The remaining chapters mainly focus on the methodology, framework, and experiments conducted to validate the hypothesis. The organization of the thesis is shown as per figure 1.9.

Chapter 1 includes an elaborate discussion on VANET, categorization, and standards of VANET, various routing and challenges in VANET, network scalability, bandwidth constraint, security, energy efficiency, and the other factors affecting mobility VANETS. The chapter highlights the research gap, problem statement, and objectives of the research carried out during this novel research work.

Chapter 2: Deals with a literature survey of VANET. The chapter focuses on the research review findings that are necessary for the present research work. The chapter also discusses various Swarm Optimization techniques used in VANET, various VANET simulators, and significant research challenges in routing.

Chapter3 presents the proposed framework methodology. The proposed framework has been used for research work that incorporates ACO and GA to conduct further research experiments.

Chapter 4 discusses the methodology applied for the implementation of the research simulation experiments. The chapter illustrates the simulation experiments' procedure and method of data generation and collection for further analysis. It also highlights the novel algorithm to enhance the network performance.

Chapter 5 emphasis mainly the validation of the hypothesis. The complete experimental process and result analysis have been done in this chapter. The performance and analysis are discussed for the devised hybrid novel algorithm. The hypothesis is validated in this chapter using a statistical "***t-test***".

Chapter 6 concludes the research work with some of the fact-findings and highlights future aspects. Future research work in VANET can be carried out by taking this work as a base for future research in the same area. The thesis is completed with chapter 6, as it summarizes the concluding remarks and the future enhancements of the investigated work.

Chapter 2

Literature Survey and Findings

2.1 Introduction

Vehicular Networks have evolved as a key solution of Intelligent Transport System, and existing technologies and Swarm Intelligence are also integrating with VANET in the near future to realize its actual purpose. In this chapter, various research issues in VANETs are discussed in detail and followed by the importance of routing in Vehicular Networks. Further, a detailed literature review is presented through the different techniques for VANET routing, and finally discussed the challenges in realizing the Vehicular Networks in real scenarios.

VANET routing protocols is actually evolved from the standard pre-existing MANET protocols like DSR (Dynamic Source Routing) and AODV (Ad hoc on Demand Distance Vector Routing). DSR and AODV were found efficient and best suitable for Multi-hop wireless ad hoc networks [39]. While designing any of the VANET scenarios for Vehicle-to-Vehicle communication must focus on all the aspects of VANET routing. It plays the most significant role in VANET performance and its results. These days the technological upgrades are very frequent and fast. Hence, soon it will be noticed that the deployment of the 5G GSM network invades in Vehicle-to-Infrastructure setup. That results in the inception of V2I and V2V in the Urban Intelligent Transportation System (UITS). VANET is made through vehicles independently communicating among themselves. These vehicles can be assumed as nodes capable enough to establish wireless communication with other nodes, giving birth to entirely a new shared mesh network with the self-organizing property. It generates huge possibilities to develop numerous applications for VANET. These applications can make the road travel experience easy, safe, more entertaining, and efficient. It will also help decrease the travelling time; road traffic congestion helps avoid congested areas, increase road capacity, and be usable during emergency situations, thus resulting in lesser fuel wastage [7]. Ultimately, the environment will be cleaner. At present, various VANET routing protocols and Wireless standards are already available, but none of them is yet able to provide the universal routing solution for VANET realistic Scenarios [62].

2.2 VANET Routing Protocols

The routing protocols are responsible for providing the best suitable route among the nodes within its network.

There are some standard routing protocols designed for VANET routing environments. These protocols are classified in various aspects, like QoS, characteristics of its protocol, network structure, routing algorithm and information dissemination, etc. [39]. The literature review of this research work finds five major VANET routing protocols. They can be distinguished into five classes as below:

- Geographic/Position based routing protocol
- Topology based routing protocol
- Broadcast based routing protocol
- Geocast based routing protocol
- Cluster based routing protocol

Further, in the literature review, the routing protocols in VANET are classified into transmission strategies-based routing protocols and routing information-based protocols [63]. It concluded during rigorous literature finding that routing information-based protocol is suitable for this research development, as this need to devise efficient routing based on Swarm Intelligence. Through the literature review, this also confirmed that not too concern for transmission strategy based protocol, as the research is not focusing on information dissemination issues and challenges in VANET [64].

The information-based routing protocol can be classified into two classes, i.e., topology-based and geographic/position-based VANET routing protocols. Every node is aware of the network layout in topology-based routing, whereas each node knows the location of other nodes while forwarding the packet in position-based routing [65]. The comparative study of Topology based and geographic-based routing is illustrated as per table 2.1.

Table 2-1 Comparative study of Topology and Geographic based Protocol

VANET ROUTING PROTOCOLS	METHODS	STRENGTH	LIMITATION	OBSERVATION
TOPOLOGY BASED ROUTING	Packet forwarding is used to store the link's information in the routing table	Source to destination shortest route	Overheads are more	Best suited for Mobile Adhoc Networks
		Message support for broadcast, multicast and unicast	Discovered routes and delay maintenance	Works best for small networks
		Less utilization of resources	Failure in discovering the complete path	
		Beacon less	Flooding unnecessary	
		Saves bandwidth		
GEOGRAPHIC BASED ROUTING	Beaconing	Creation and maintenance of global routes are not required	Obstacles in highway scenarios	Suitable for VANET; research needs to be done for sparse network and dense network
	Information of Vehicle's position in a network	More stable in the high mobility environment	Issue of deadlock at Server's location	
	Global Positioning	More fitting for distributed network nodes	Failure of position services in absence of satellite signals	
		Minimum overhead		
		Much scalable		

2.2.1 Topology Based Routing Protocol

In this routing protocol, the link information that is available in its routing table is used to broadcast data packets from the source to the destination [66]. The topology based routing protocol has three different categories as per figure 2.1.

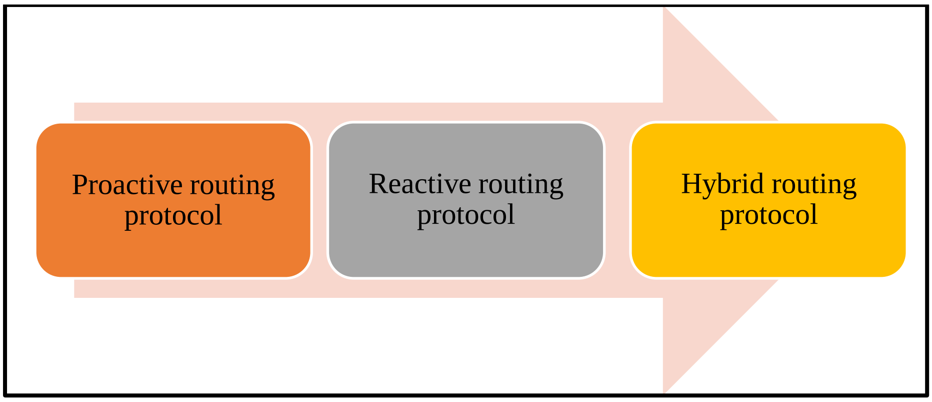

Figure 2.1: Categories of Topology based routing protocols

2.2.2 Proactive routing protocols:

This enables a node in the network to utilize a routing table to store routing information for other nodes. It is based on the periodic exchange of routing tables that establishes the routes in advance. However, more overhead can occur in a high mobility network, but destination routes are always accessible whenever required [67]. It uses distance vector and link state strategy to select the route and depends on the shortest path algorithm.

a) Destination Sequence Distance Vector (DSDV)

This is based on the shortest path technique and distance vector strategy implemented in routing for one route to the destination stored in the routing table. The information of all available nodes is stored in every routing table. And along with the hops required to reach the nodes. The destination node initiates the sequence number that labelled in the routing table for every entry. In this protocol, the routing reliability is maintained by broadcasting the routing table to each neighbouring nodes. In the large network, the overhead increased in DSDV as it unnecessarily updates the broadcast table even there is no change in topology. These constraints of DSDV, Randomized Destination Sequence Distance Vector (R-DSDV) was used to overcome the congestion control problem of DSDV. However, DSDV produces less overhead in comparison to R-DSDV [68].

b) Optimized Link State Routing Protocol (OLSR)

The link state technique is implemented in the OLSR protocol. This maintains the routing table that has the information for all the possible routes. Each node sends its current information whenever the network topology changes and then transmits the information further to the next available node. This is also suitable for dynamic topology where low latency in data transmission is required, such as some of the alarming applications. But due to high frequency of control packets during the change in topology causes network congestion in OLSR. Hence, Hierarchical Optimized Link State Routing (HOLSR) protocol was proposed by few researchers to provide the hierarchy architecture with multiple networks. But, it only supports some low bandwidth applications [69].

c) Fisheye State Routing Protocol (FSR)

In this protocol, the routing tables are updated regularly through the recent information sent by the neighbouring nodes. The entries in the routing table meant for its destination broadcasted at various frequency for the neighbouring nodes. The table entries in a faraway topology are broadcasted in lower frequencies and higher for the near entries. This FSR routing technique not guaranteed lower broadcast overhead in faraway topology. However, it works better when the data packets are near the destination. But, when the network size increases, then the routing tables will also increase and this is the limitation of the FSR and frequent change in topology occurs, then the remote destination route gets faulty [70]. Even when the destination is not in the scope of the source node, the route cannot be discovered in it. FSR attains the complete network map, but all the links between farther nodes cannot be guaranteed.

2.2.3 **Reactive Routing Protocols.**

This is also known as the on-demand routing protocol, and it performs route maintenance whenever required to minimize the network overhead. It floods the network by a route request message when a non-existing route to a destination is needed. This routing protocol is applied to the large size of Adhoc networks that are highly mobile and changes topology frequently [67]. Some of the reactive routing protocols reviewed during this literature survey and discussed below:

a) Adhoc On-Demand Distance Vector (AODV)

This was developed for Mobile Adhoc networks and already implemented in many kinds of research, which shows better results for VANET in comparison to other routing protocols [3]. It works on dynamic source routing and uses sequence numbers and hop by hop routing. The large-scale network and dynamic network topology are adaptable for AODV. But, large delays can be caused by route discoveries. So, a new route is required when a present path is not valid that causes further delays, and this results in increased network overhead and decreases data transmission. This sometimes causes certainly a redundant broadcast in the network that utilizes additional bandwidth and creates a broadcast storm problem. Hence, the researchers suggested many other routing protocols for enhanced AODV protocol as per the need of VANET scenarios [69].

b) Adhoc On Demand Multipath Distance Vector Routing (AOMDV)

AOMDV protocol is an enhancement of AODV protocol that is able to make many path discoveries during a route discovery process from source to destination and hence named as multipath AODV. Its performance is superior in comparison to a single path as it reduces retransmission of route discoveries. It records multipath information to reach the destination during the process of single route discovery. Hence, there is no requirement of discovering a new route in case of a signal path failure. In AOMDV, protocol if all the replicated routes for the destination gets failed, then only a new route discovery is required. That why it is suitable for dense network scenarios in VANET [71].

c) Dynamic Source Routing Protocol (DSR)

It is a multi-hop protocol. It uses periodic messages so that overhead can be reduced. DSR mainly focuses on the discovery and maintenance of the routes. It sends the route request message to the source node when it requires any of the unavailable routes. During this process, all intermediate nodes rebroadcast the same message until it reaches the destination node. Then the route replay message is sent back to the source node and also kept for future use in its source routing table. In case the route is not complete or fails, then a route error message is generated for the source node. When no other route is available, then it starts to search for another route. This gives an advantage at low mobility networks in DSR protocol [72]. But, this DSR protocol mechanism does not suit VANET scenarios because at bigger and dense road networks with high vehicle node strength, the overhead will increase and thus degrade the performance of the VANET routing.

d) Temporally Ordered Routing Algorithm (TORA)

This protocol also uses multi-hop routes and works as a distributed routing protocol. It uses a technique to modulate with frequent change in the network, and thus communication overhead is decreased. TORA protocol does not deploy the shortest path method as in this source node acts as a root of the tree to construct a directed graph. The data packets travel downwards through the tree structure from root to the destination and cannot travel back to the source node, i.e. upwards [73]. This minimizes the control message broadcast and good in offering a route to each node of the network. However, TORA is not suggested for highly dynamic routing in VANET scenarios [74].

2.2.4 **Hybrid Routing Protocols**

The hybrid protocol is constituted by integrating proactive and reactive protocols of VANET. The focus is to decrease the control overhead in proactive protocol and reduce the delay in the route discovery process within on-demand routing protocols. The principle mechanism of this protocol is to create zones of the network by dividing them into parts; this gives better maintenance and a reliable routing process. The node divides its network into inside and outside the region. The proactive routing method is used for maintaining the routes at inside node regions, whereas the outside region nodes are reached by a route discovery technique [75]. This routing protocol is also not fitted for highly dense mobility networks in VANETs.

2.2.5 **Zone Routing Protocol (ZRP)**

ZRP permits nodes to divide their network into various zones depending on different vehicle speed, signal and transmission strength, etc. The outside area is the routing area for the outside nodes in this zone. In comparison, the inside zone is for the routing area for the inside nodes. Hence, at the outside zone, reactive routing schemes are used by ZRP, and for the inside zone, nodes use the proactive routing method. The latest route information is updated periodically inside and outside the zone. The outside and inside zone have their independent protocols that work in ZRP. This makes it more managed and faster. But, the limitation of the ZRP protocol is that it large size network zones it behaves just as a proactive protocol and performs the same as the reactive protocol in small network zones [76]. Hence, ZRP is not suitable for dynamic VANET network environments and in large VANET with dynamic network topology.

The researcher also proposed another Buffer and Switch (BAS) protocol. The researcher found it more suitable for routing on road-based topology for VANET that works in road-to-road transmission than typical node-to-node routing methods. The node's high mobility justified it in the road network and limitation of data delivery due to mesh road networks [77]. However, this technique can cause a delay in the transmission and loss of data packets due to data packets may be expired.

2.3 Position based routing protocol

Geographic or position based routing protocol works on the information of the position of nodes in routing. Here source node does not rely on network address and uses geographic position to send the data packets to the destination. This technique uses Geographic Position System to locate the position of the nodes and their neighbouring nodes in the network. The neighbouring node identified only when they are in the network range. This source sends a data packet with information of the destination's position in its packet header. Therefore, discovery and maintenance of route is not required and directly forwards the data packets [78]. Hence, position-based routing protocols are much preferred and suitable for the large network in VANET routing than the topology-based routing protocols. The three standard position based routing protocols are discussed further.

2.3.1 **Delay Tolerant Network Protocol (DTN)**

This wireless network is designed in such a way that it efficiently performs in a VANET with some distinctive properties such as bandwidth limitations, frequent communication disconnects, large scale and unavoidable long delays, high bit fault rates, and power constraints [79]. DTN uses a store and forward scheme so that data packets are forwarded with the help of all nodes in a network. In this, delays may occur during packet transmissions because of the limited transmission range of the nodes. All nodes in DTN are mobile nodes, so it establishes routes for another node as soon as it comes under its transmission range. This makes it suitable for VANET routing in the sparse network, but more research is yet to be carried for other traffic scenarios.

2.3.2 **Non-Delay Tolerant Network Protocol (Non-DTN)**

This geographic routing protocol does not focus on the link breakage problem of nodes. It works on the assumption that sufficient nodes are always available to establish successful communication. Therefore, it is most suited for dense network scenarios in VANET. However, Non-DTN makes nodes forward the data packets to the closest neighbour of the destination [80]. Hence, this technique not works when there is no closest neighbour available near the destination node. Hence, this protocol not recommended for sparse network scenario in VANET.

2.3.3 Hybrid position based routing

This protocol works on the location information of the neighbour and destination nodes so this will not maintain and create any routing table. In this

Table 2-2 Comparative study of VANET routing protocol

PARAMETER	POSITION BASED	GEOCAST BASED PROTOCOL	PROACTIVE PROTOCOL	REACTIVE PROTOCOL	CLUSTER BASED PROTOCOL	BROADCAST BASED
SCENARIO	URBAN	HIGHWAY	URBAN	URBAN	URBAN	HIGHWAY
Recover Strategy	Carry and forward	Flooding	Multi-hop forwarding	Carry and forward	Carry and forward	Carry and forward
Requirement of Digital Maps	**NO**	**NO**	**NO**	**NO**	**YES**	**NO**
Realistic Traffic Flow	**YES**	**YES**	**YES**	**YES**	**NO**	**YES**
Requirement of Virtual Infrastructure	**NO**	**NO**	**NO**	**NO**	**YES**	**NO**
Method to Prior-forwarding	Heuristic Method	Wireless multi-hop forwarding	Wireless multi-hop forwarding	Wireless multi-hop forwarding	Wireless multi-hop forwarding	Wireless multi-hop forwarding

way control, routing overhead reduces and makes it more scalable to perform better [81]. But these protocols have some limitation which restricts them to be used in VANET routing. The accurate information is not always available hence; its performance may get reduced during such situations. In case it does not find any of the neighbouring nodes closer to the destination, then routing may not be successful.

A comparative study of various routing protocols was performed during the literature review for this research. The extensive literature survey findings are illustrated in table 2.2.

Hence, this extensive literature survey can conclude that existing standard routing protocols are not suitable and fit for VANET routing in all the traffic scenarios—the classification of these routing protocols illustrated in figure 2.2.

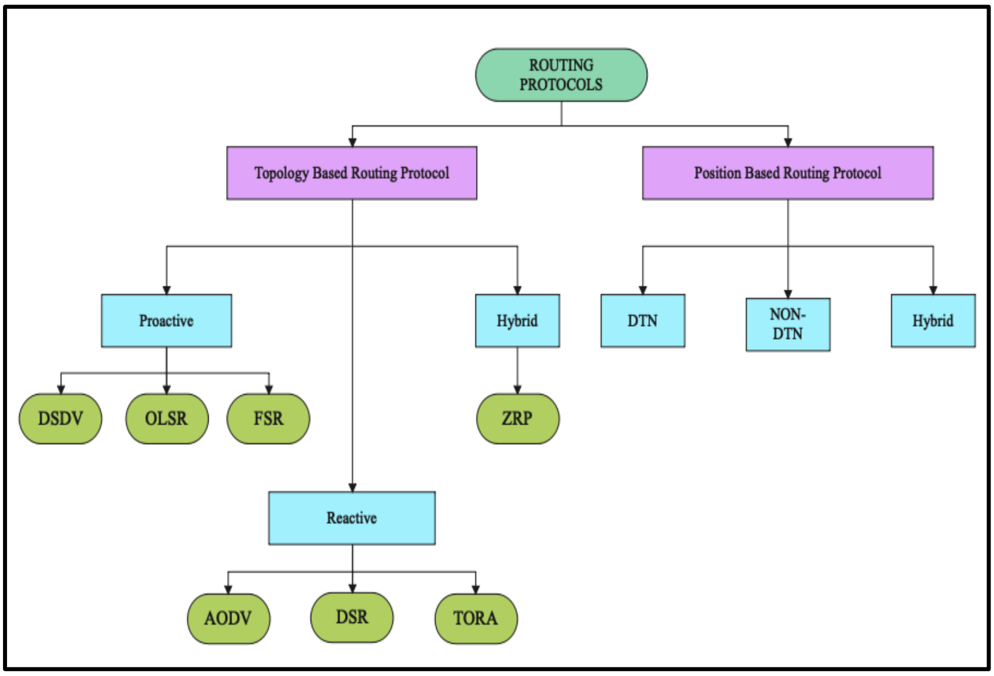

Figure 2.2: Classification of VANET standard routing protocols

The Urban VANETs were also analyzed by focusing on node-level distribution, normal shortest path length, clustering coefficient, and network. It was seen that VANETs are not scale-free networks as Gaussian probability circulations approximate their node degree distributions. However, the conduct of low-density VANETs is the same as to small-world networks, and connectivity is too low even to consider benefitting from the small-world property [82]. The new methodology utilizes a stochastic traffic framework to figure out vehicular density elements in an urban road network through a forwarded built speed profile dependent on the information gathered utilizing the route frameworks introduced in vehicles.

As per the researchers in [83], a navigation methodology that can gather online information of the roads through VANET can be used by the drivers to reach their ideal destination in a distributed manner and real-time situation. The new scheme utilizes real-time road conditions to register a better route, and at the same time, the data source is also verified appropriately. Furthermore, to ensure the driver's privacy, the message broadcasted by the driver for the destination is guaranteed to be unlinked to any other source comprising a trusted authority. From this research, the anonymous credential was achieved.

A new approach of the clustering Mobility Based and Cluster Head algorithms utilized in VANET is introduced by researchers in [84], where various clustering algorithms are investigated. Their highlights, targets, aspects, and impediments are featured for more prominent expansion. The perceptions indicated that the methodologies examined focused on the various performance metric. Most encouraging solutions indicated the importance of reused ideas from public network investigation. The node location in a multi-hop cooperative methodology included numerous safety measures to improve the message integrity. The simulation test result shows that the new protocol increases the vehicle’s rate of local awareness through simulated barriers. Exchanged messages updated the neighbouring vehicle’s records and increased attention to different nodes that cooperatively forwarded demands and solutions.

Inter vehicular interaction that assessed another independent WiMAX framework is proposed in [85]. The broad simulation was acknowledged in the OPNET framework for the design of the WiMAX-mesh framework. That demonstrated VANET portable routing algorithms' relevance and Optimized Link State Routing (OLSR) protocols and Ad hoc On-Demand Distance Vector (AODV).

In [62], represented their platooning algorithm based on swarm-based intelligence. This algorithm applied two different factors to decrease the travel time. It insisted on green traffic signal time that makes traffic free path for the vehicle movement. Second, the proposed the preemptive traffic signal approach is combined with an existing modified Ant Colony Optimization technique to design platooning of the vehicles. These characteristics concluded the platooning algorithm as efficient way to minimize the waiting time of the commuters.

The researchers in [86] introduced an investigation of different simulation instruments accessible for VANET. VANET simulators' taxonomy assists future VANET analysts to pick an ideal simulator, which is most appropriate for VANET scheme objectives. It also talked about certain difficulties that must be addressed for empowering the utilization of VANET technologies, foundations, and administrations cost-adequately, safely, and dependably. Two AODV protocols P-AODV and Improved AODV, are examined and dependent on some parameters [87].

During the literature review and findings, the study was carried out on various routing protocols, wireless standards and found that the available routing protocols is unable to facilitate VANET's with efficient routing in major traffic scenarios [39]. The VANET is dependent of undefined network topology that rely as per road's map. This research work is focused on geographic-based and link-based routing. The both routings are needed as of hypothetical scenarios presented in VANET and also support Swarm Intelligence.

Through the Multi-Point Relays (MPR) approach, the Optimized Link State Routing Protocol (OLSR) can broadcast data packets to the whole network. The link-state routing is also maintained for every node. That results in the reduction of overhead that may occur due to flooding. As the routes have lesser hops hence OLSR is best suited for dense zone. However, OLSR is not recommended since it requires more processing and bandwidth to identify the best network route. [88]. During this research work, it has been observed that multicast routing is handled by computational intelligence using the Genetic Algorithm (GA) [89]. A stable routing protocol resolves the node disconnection in VANET that was tested [90] and alerted the disconnection before occurrence. It is discovered that routing issues of VANET are also determined by Time Windows in a multi-objective local search based optimization techniques and the real time data is used for forty different scenarios in simulation to verify the efficiency of the algorithm [91]. The "Multi-Constrained QoS aware routing algorithm" is also developed using ACO based Swarm Intelligence techniques. As a result, the traffic type data-based QoS network can be achieved. So, security in VANET is also attained through a reliable QoS algorithm [92].

In VANET, the ACO and DSR protocols have also been proposed as routing options that uses stable routing in a variety of VANET scenarios [93]. In order to monitor real-time performance, an eco-friendly ACO-based routing method was presented that shares roadway linkages. The novel feedback and cost updating technique is used to resolve the weakness of VANET routing [94]. The most important element for optimal routing in VANET is smooth connectivity and link dependability. For that the standard GPSR protocol is modified to derive a reliable and new technique with "Greedy Parameter Stateless Routing (GPSR)" is also proposed. Hence, GPSR-R in comparison to standard GPSR is more efficient because "Packet Delivery Ratio (PDR)" and maximum throughput is found to be increased in VANET routing [95]. However, it does not fits for the hypothesis due to significance delay in calculations and its complex computations.

2.4 Swarm Optimization in VANET

The Genetic Algorithm (GA) application in VANET is proposed by the researcher in [96] and located the best generation of vehicles to be generated and managed a data flow while reducing the wireless network bandwidth consumption. Using random values of £, P, and z, the initial population size is reduced based on corresponding effect coefficients (a1, a2, a3).

In [61] researcher proposed a PSO approach for hybrid VANET-sensor networks for the two-lane placement problem is proposed and implemented. An Integer Linear Program (ILP) model for a 2-lane problem is first established. Then, a Center PSO approach is proposed for the problem, and theoretical analysis is also derived for the same. Results showed that this approach performed well for moderate problems. Future work must consider heterogeneity, other objective functions, constraints, and hybrid methods in practice. Another challenge dealt with is to propose a cross-layer design of the hybrid network.

A double-head clustering algorithm is implemented to select the most appropriate Cluster Head (CH) by considering a real-time updated position and trust value of vehicles is proposed by the researcher in [97]. With evolutionary-based routing being a predominant research theme, an efficient, trust-based, ant colony routing technique is used for a simple highway scenario-based VANET. Simulation results show that the new Trust dependent Ant Colony Routing (TACR) performed better than Mobility-aware Ant Colony Optimization Routing (MAR- DYMO) algorithm compared to routing overhead.

In this research, a metaheuristic procedure is used to get the appropriate solution in minimum time duration, i.e. low computation time. These population-based techniques evolved to browse the optimum solutions to generate a new population through the iterative process of natural selection. The bio-inspired evolutionary algorithm and swarm intelligence majorly used techniques in population-based metaheuristics. Here, GA is the evolutionary algorithms, whereas PSO and ACO are swarm intelligence based algorithms. The algorithms are most exciting and mainly used to solve the problems that persist in the real world.

The survey presented in [98] highlights the bio-inspired approach in VANET routing. It is shown that the bio-inspired routing in VANET can adapt to the network disruption and is robust enough. That ensures efficiency in data packet delivery along with low complexity for larger VANET scenarios. The improved Genetic Algorithm-based Routing Optimization Technique (IGAROT) is presented in [99]. This GA variant replaces the selection technique with the K-Means clustering method adopting from the same concept of a novel clustering-based genetic algorithm for the route optimization technique proposed in another approach [100].

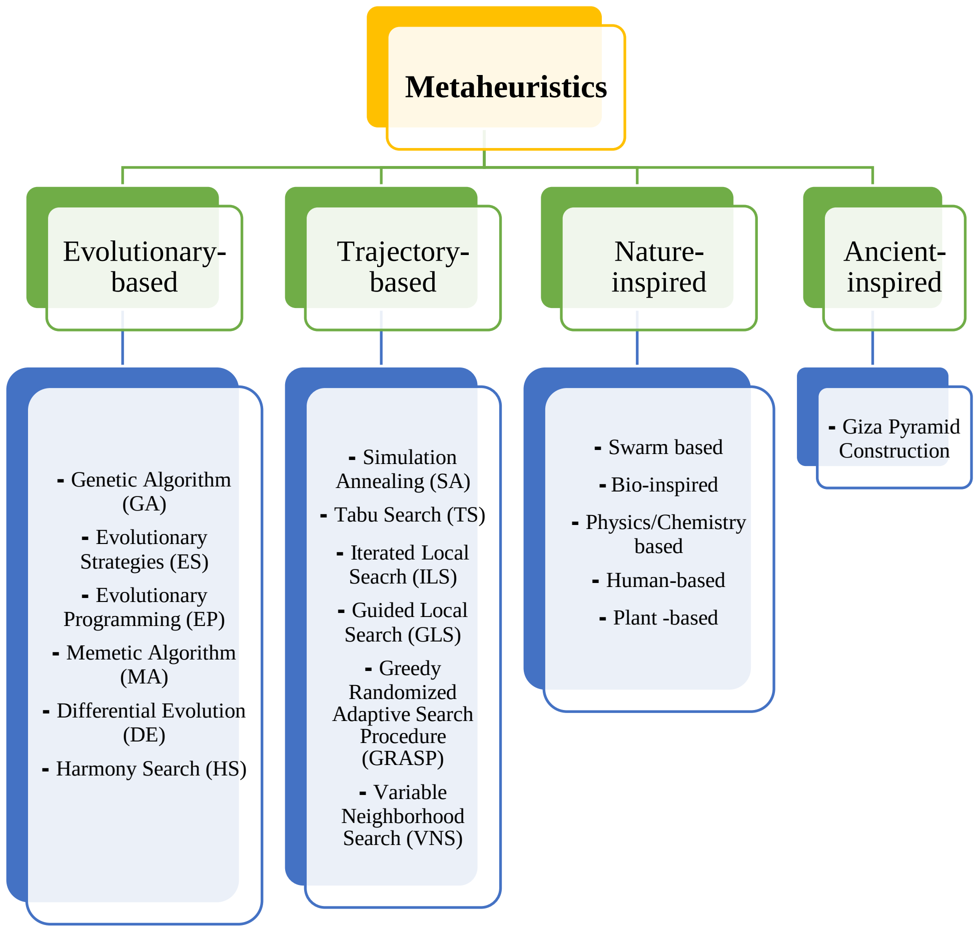

Figure 2.3: Classification of Metaheuristics based algorithms

IGAROT utilize the vehicle density required in communication for VANET scenarios that randomly initialize individual population. That provides the initial solution for the defined search space. Likewise, in a low-density VANET communication scenario with 20 vehicles, this makes a randomly generated initial population size of 1 by 20. In this way, IGAROT creates unique generations by selecting the best solutions from the initial population. That comes after many generations to give the best solution.

A new metaheuristic Giza Pyramids Construction (GPC) algorithm is presented in [101]. This new metaheuristic population-based algorithm has been inspired by past ancient history and can deal with many problems of that era. It helped to review the technologies, best optimum methods, and strategies of that time. The classification of the metaheuristics algorithm is shown in figure 2.3.

VANETs are unable to meet the exact needs and applications of all users. For example, in real-time situations the emergency signals has to be forwarded with minimum latency and high priority; however, messages like of infotainment and hello/hi can be put up in queue and latency. Hence, in sparse and dense network the "Minimum Calculated Desire Time (MCDT)" technique is suggested and data dissemination is performed using a context-aware congestion resolution protocol. Here, the MCDT determines the node connectivity through a peak-stable link [102] [103]. “Modified Lion Algorithm (LA)” is also used to compare with GA and performance analysis was done for cost, complexity and convergence. The simulation analysis of modified LA in respect to standard GA and LA proved the efficiency of modified is better in comparison with others [45]. In this literature study, the analysis of the last ten years related work was presented and then reviewed. Through that, the research approach is formed for efficient routing in VANET. This is also verified and presented later by devised new Novel Algorithm. To validate the experimental test is performed on realistic simulation environment using open source software tools.

2.5 VANET Simulators

The review of various publicly available VANET simulators currently in use by the research community is also presented in this chapter. In this research study, the proprietary VANET mobility generators or network simulators, such as TSIS-CORSIM [104], Paramics [105] [106], VIS-SIM [107], QualNet [108] were excluded. The research focuses on freeware and open source tools that allow free access to simulator source code.

Figure 2.4 presents the taxonomy of VANET simulation software. The existing VANET simulation software is classified into three distinctive categories.

(a) Vehicular mobility generators
(b) Network simulators, and
(c) VANET simulators.

The Vehicular mobility generators are used to make a realistic traffic mobility environment during VANET simulations. So, that it can be used for the input while simulating the realistic traffic scenarios.

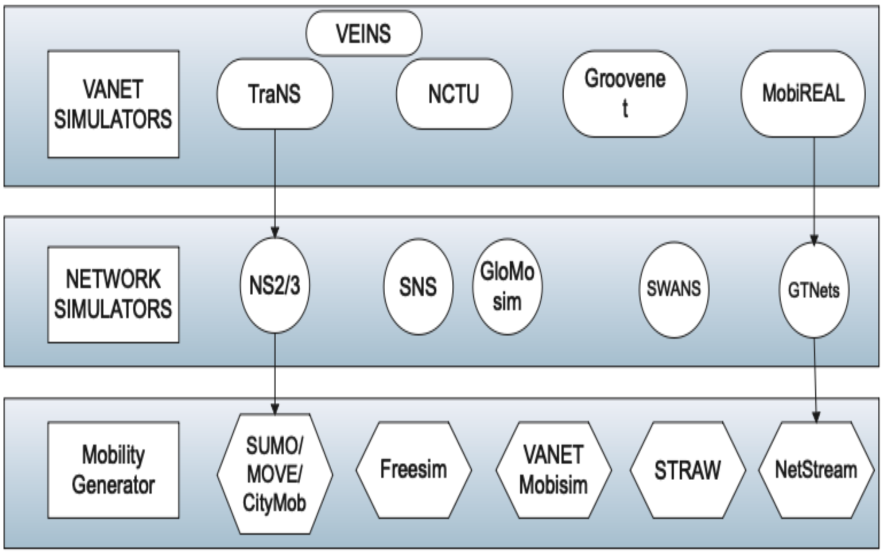

Figure 2.4: Taxonomy of VANET Simulators

The few mobility generator inputs used during the simulation were sparse and dense road model, the maximum speed of vehicles, rate of vehicle's arrivals and departures, etc. The output gathered from this trace is the location details of each vehicle at every time during the complete simulation period and their mobility profiles. Examples are SUMO [109], MOVE [110], CityMob [111], STRAW [112], NetSIM [113], and VanetMobiSim [114].

The Network simulators are used to process the data packet-level simulation of data traffic transmission, source and destinations, channel links, reception, routes, and background load. Examples are ns-2/3, GloMoSim, SNS, JiST/SWANS, and GTNetS [115].

Mainly the network simulators were developed for MANET and to be used for VANET they need special extensions like that of vehicular mobility generator so that they can be used for VANET simulations.

So that VANET simulators can be used for both i.e. network simulation and traffic flow simulation. Such as GrooveNet, TraNS, MobiREAL, and NCTUns. Table 2.3 shows the comparison of VANET GUIs based simulators [116].

Table 2-3 Comparison table of VANET GUI simulators

GUI	User friendly	Topology view	Parameters input	Output
TraNS	Good	Google Earth	Streetmap file	ns-2 trace
		With zoom ability	Mobility file	.kmz file (Google Earth)
		Without obstacles	Graphical input	
		Street view	Streetmap file	Simulation file
Groove Net	Good	With zoom ability	Simulation file	Animation view
		Without obstacles	Graphical input	
		User defined	Topology file	Simulation file
NCTUns	Moderate	With zoom ability	Graphical input	Animation view
		With obstacles		
		User defined	Streetmap file	
Mobi REAL	Moderate	With zoom ability	Mobility models	Trace file
		Without obstacles	Density and routes file	Animation view
			Graphical input	

2.6 Research challenges in VANET Routing

Figure 2.5 presents the identified routing research challenges in VANET. The present research program aimed to address the identified challenges and provide an effective routing mechanism focusing on performance throughout and PDR in VANET routing.

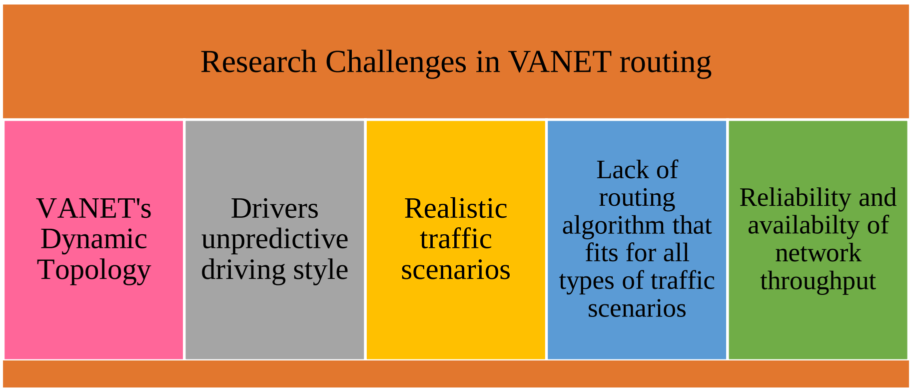

Figure 2.5: Research Challenges in VANET Routing

2.7 Chapter Summary

In this chapter, the discussion on various research areas of VANET was presented, and a detailed review has been done on the solutions designed for efficient routing and various simulators. There has been a considerable amount of work done in the field of VANET routing, but such works are limited to specific scenarios and routing. They are also not able to fulfil the present research challenges in various traffic routing scenarios.

Some techniques proved better in sparse networks while others in dense networks. Similarly, no such technique exists in the literature that can provide a solution to VANET routing for realistic traffic scenarios with the hybrid algorithm that incorporates Swarm Intelligence and features of a Genetic Algorithm.

The following chapters of the thesis aim to build the research lines based upon these findings. The next chapter mainly focuses on design and implementation of the framework that has been carried out during this research work.

Chapter 3

Proposed Framework for Efficient Routing

3.1 Introduction

Mobile Ad hoc Networks (MANET) evolved into Vehicular Ad hoc Networks (VAN) with its own set of characteristics. Many consortiums are already active in this area around the globe. However, the outcomes are not satisfactory for realistic implementation. Message alerts during emergencies, as well as improving road safety features, monitoring live traffic, and information distribution, are all key concerns in realistic scenarios. Hence, the significance of efficient and effective routing cannot ignored in such aspects. That implies on vehicle-to-vehicle communication, vehicle-to-infrastructure communication, infrastructure-to-vehicle communication, and now vehicle-to-internet-cloud communication is also rising as the new domain of research. This also requires Roadside units (RSUs) for precise management and public safety in the real-world implementation of an Intelligent Traffic System (ITS). However, these requirements cannot be met presently in developing countries. But in near future, "Base Terminal Stations (BTS)" and Street Lights could be used to install ITS technology for Smart Traffic Management and VANET.

Though several routing protocols has been tested and implemented for VANET on simulations for analysis. Few approach demonstrated the robust adaptive mobility clustering, connectionless geographic forwarding, Q-learning routing protocol and distance-based estimated routing protocol [48]. All of these protocols were unable to withstand computational complexity and had significant flaws. The vehicle can also communicate with RSUs through Dedicated Short Range Communications (DSRC) that can be used in ITS and traffic management [117]. In real time traffic scenarios the complete, accurate, and prompt information to the vehicles is the most important feature in VANET that cannot be compromised. This vehicular network must trustworthy enough to prevent road traffic accidents caused by missed or delayed messages being broadcast and received. Otherwise, a huge calamity of traffic accidents could takes place. Hence, flawless VANET communication Intelligent and smart transportation aims at optimized, reliable, multi-hop scalable and efficient routing algorithms. VANET deals in dynamic topology, many times drivers' driving behaviour is uncertain, and there are chances of frequent route disconnects due to obstacles/stoppages. These factors degrades the performance and reliability of VANET. In unicast multi-hop the selection of optimize path is truly significant for message forwarding from source node to others. However, the congestion and broadcast storm problem may be caused due to broadcasting transmissions. In this chapter, proposed hypothesis is capable of determining the most efficient and reliable route for transmission of data from a node to node in VANET. The optimized route discovery is similar to a "non-deterministic Polynomial time (NP)" hard problem, "Traveling Salesman Problem (TSP)", shortest path problem, etc. [118]. Though, "Dijkstra's" and "Bellman-ford model" are untrustworthy for such a vast and dynamic VANET network.

The VANET is ideally suited for meta-heuristic optimization since it allows for automatic parameter tweaking in a dynamic environment of vehicular network. There are many techniques such as "Ant Colony Optimization (ACO)" [119], "Particle Swarm Optimization (PSO)" [120], "Genetic Algorithm (GA)" [121] which are global search-based heuristics methods. The statistical comparisons of GA and PSO have revealed that PSO is just as successful as GA at calculating the routing path with greater efficiency [122]. But in contrast with GA, ACO is advantageous in various VANET parameters. In comparison to GA, ACO is simple to construct in a VANET that can be implemented with lesser factors. There are other available algorithms as discussed previously that can also be used to resolve the discrete-continuous search space problem but as ACO [62] is capable of self-tuning and easy to deploy in VANET, hence ACO is selected to implement this novel algorithm. To achieve this the encoding/decoding technique of ACO with GA is tuned the position update equation in ACO [123]. In this approach the ants are considered as nodes with several solutions and GA decoding phase is used to create optimum routes.

3.2 Methodology

This research work uses the stepwise approach to prove the presented hypothesis, as shown in figure 3.1. Firstly, the analysis and review of work done and approach applied in the similar area. The review of the testing of various algorithms for the VANET solutions. As per the analysis the selection for the

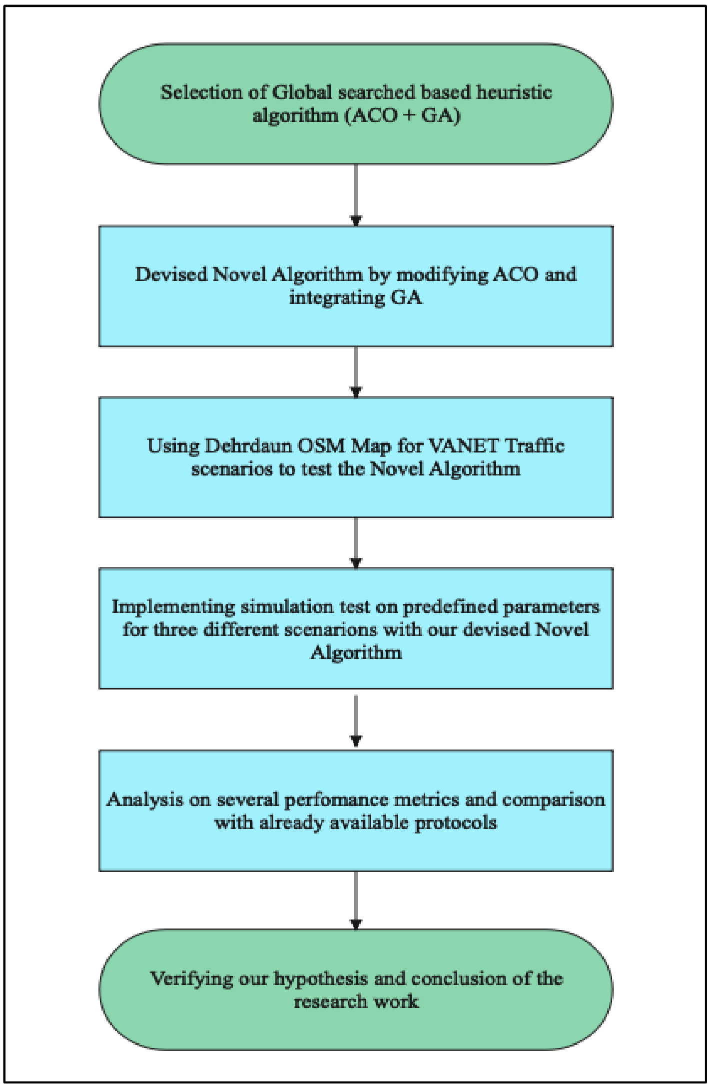

Figure 3.1: Methodology followed

best two global-searched-based heuristic algorithms, i.e. ACO and GA was made. Then a new algorithm is devised as the requirement analysis, by changing the position and updating the preexisting ACO which includes the encoding and decoding features of GA. Hence, the research outcome proposed new Novel "Swarm Intelligence based efficient routing algorithm" through assembling the ACO and integrating it with GA algorithm. The research work confirms the positive results of the algorithm by simulation tests done on "Clock Tower" to "Mussoorie Diversion" route picked from "openstreetmap.org" [124]. The screenshot of the map is shown in figure 3.2.

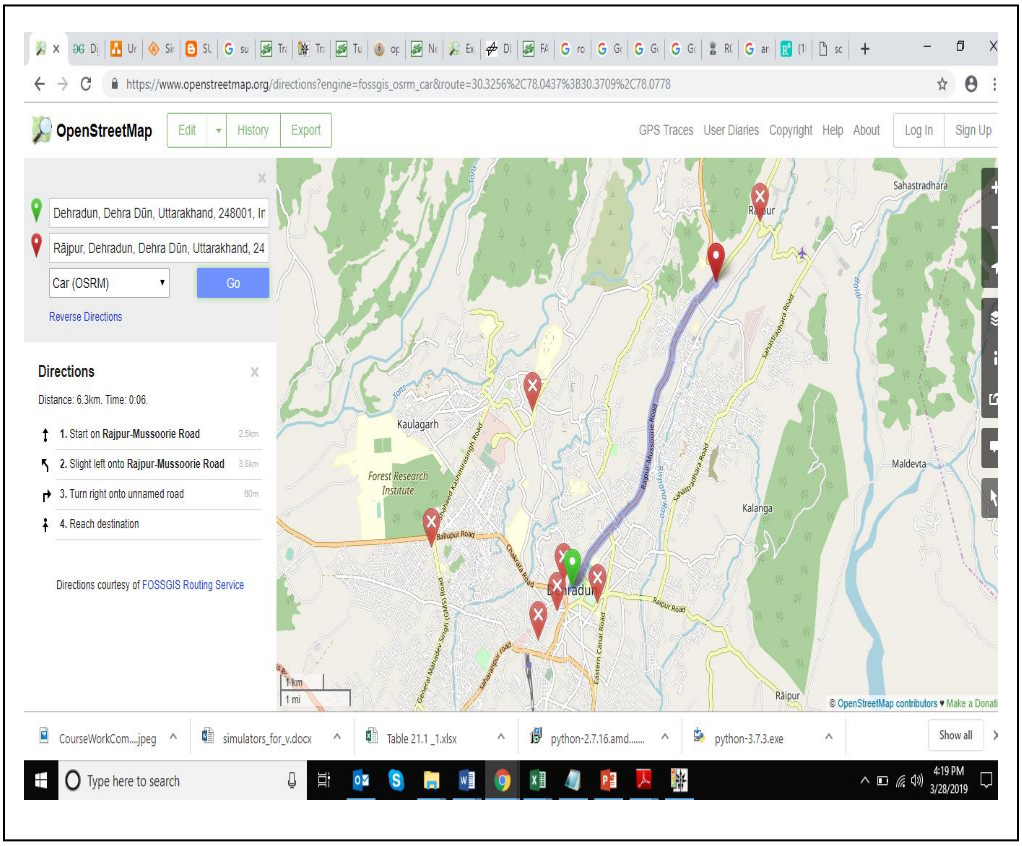

Figure 3.2: Dehradun city openstreet map

For this research experiment, the simulation setup was experimented on an HP system. For this Oracle Virtual Box is used to create virtual machine on the host Operating System (OS) and assigned two dedicated processors with 4 GB of memory. The guest OS used is Ubuntu. From experience, this can be concluded and commented that a minimum of 4GB memory is a must for performing these types of VANET simulations.

The experimental results also reflect the limitation of the newly devised hybrid algorithm. This hybrid algorithm only works for a defined scenario (i.e.

sparse and dense network) at a time with accurate results. It cannot adopt the change of its routing behaviour when there is a sudden or random changeover of a VANET traffic scenario. That can be an entirely new area of research to be conducted in future.

3.3 Ant Colony Optimization (ACO) Algorithm for VANET

The GA approach is suitable with Swarm Intelligence to tackle the real-time tough problems. The integration of these two best suited for self-adaptation and optimization as per the requirements of the problem. ACO is a biological swarm of ant species that is best for routing because of its intelligent, self-contained engagement without supervision. The ACO is a metaheuristic

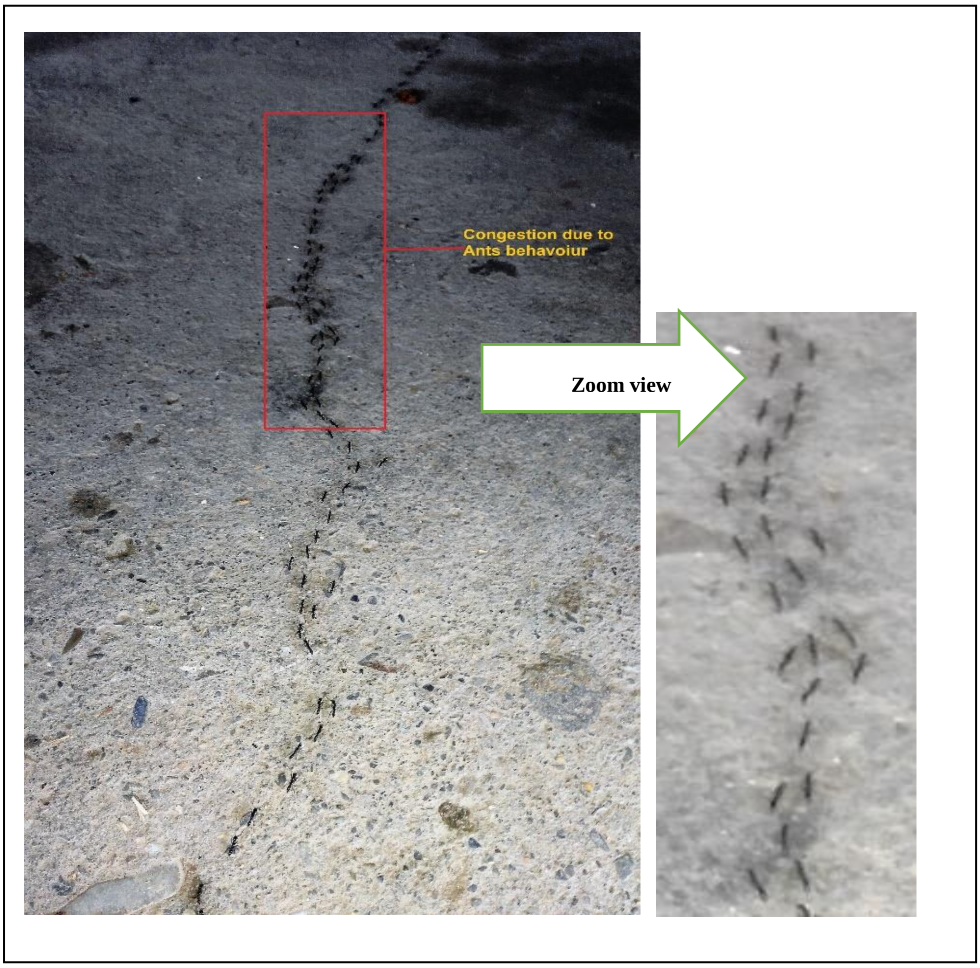

Figure 3.3 Ant behaviour (photo captured on 02-06-2018)

algorithm that is adopted from the ant's behaviour of searching pheromone trail.

Efficient VANET may decrease the travelling and waiting time of the commuters. However, the shortest paths can always be opted to reduce the traveling time. But, if the bandwidth of the road is not enough to cope with the increased random numbers of the vehicles for these shortest paths, there will obviously be congestion that occurs like the same that of Ants behaviour as shown in figure 3.3. From this, it can be rigidly concluded that the selection of shortest path is not always the fastest route.

Algorithm 1: ACO representation

Input: Initial Ant Population (ANT), Initialize ACO Parameters

Output: Cost Evaluation

```
Calculate Euclidean distances between all the vehicles;
while
  no. of iteration ≠ total_iteration OR terminate_iteration==20
    do
      for ANT_i= 1 : number of ants
          cost_evaluation(ANT_i);
          ANT_i++;
          update(Pheromone);
          cost_evaluation(ANT_best);
          iteration ++;
      end for
  iteration ++;
end while
```

In this research work, the novel routing algorithm is devised that is used in VANET's Vehicle-to-Vehicle communication. The assumption to test the hypothesis considered are no obstacles on roads due to any road maintenance, civil works, accidents, etc. The On-Board Units (OBU) and Global Position System (GPS) are installed on vehicles to locate the vehicle location and to update them frequently. In VANET the topology is represented in graph G (V, E) for ACO. Where, V is a set of vertices in a graph, and communication link is represent as E and Euclidean distance metrics is used to measure the distance between two nodes [45]. The ants drops a special chemical called pheromone while traveling and thus their movement depends on pheromone. Hence, the edges of the graph are linked through pheromone value and thus Ants' movement is guided by it. Ant depicts the best solution by guiding each other with subsequent iterations. Therefore, the best solution of the edge is concluded by the maximum pheromone value. Hence, the ant searches the best-optimized route/solution through this method. The ACO representation shown as pseudocode illustrated in Algorithm1.

The ACO is also represented using a flowchart, and the same is demonstrated as per figure 3.4. It is shown the states of the ants how it

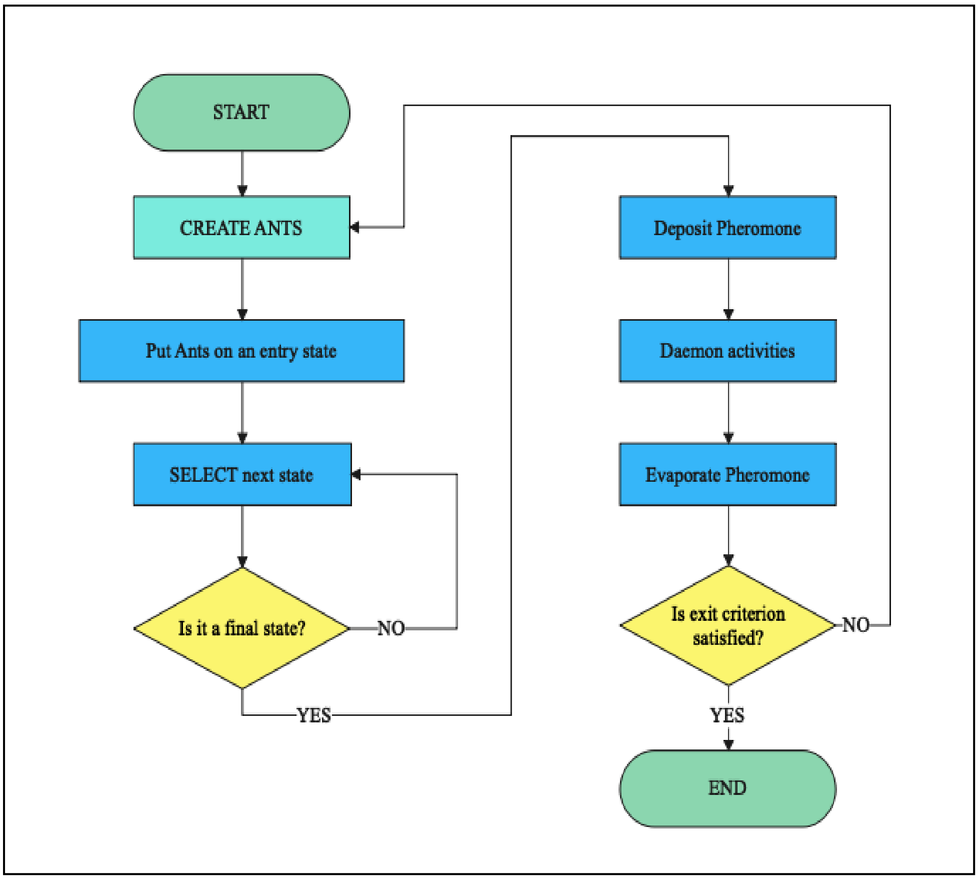

Figure 3.4 ACO Flowchart

3.3.1 Genetic algorithm (GA)

In this research work, GA is used to bind with tweaked ACO because of the metaheuristic technique. GA is best suited to integrate with ACO as it is a subclass of evolutionary algorithms (EA) and has natural selection properties. Genetic Algorithm is also explored to find the optimized path in the network [125]. The three genetic operators used by GA when an initial population is generated,

- Selection: evaluation of survival of the fittest.
- Crossover: performs mating and reproduction between individuals.
- Mutation: presents arbitrary modifications.

The pseudocode illustrated in Algorithm 2 shows the GA representation.

Algorithm 2 : GA representation

Input: Initialize number of iterations, Initialize the GA parameters

Output: Final optimized cost

```
Calculate final best cost using GA
    for i = 1 : no_iterations
        random_select(P1, P2);        // Select Parents
        crossover (P1, P2);      // Apply crossover
        calculate(offspring)
        mutation(Pi);
    end for;
return(optimized cost);
```

The selection of the population, crossover, and mutation is used for the VANET routing with ACO. In each iteration, a new population of the same size can be generated from the current population using three basic operations on the individuals of the population. This working of GA is best suited for ACO techniques with road traffic scenarios in VANET.

The principle of the GA algorithm is illustrated in figure 3.5 to show the standard flow chart for GA working.

3.4 Proposed Solution for the Research work

The devised new ACO technique is applied to derive the solution for optimized path and then, basic GA operators including mutation, selection, and crossover were imposed on it with a termination condition. The applied method derives the optimized path and efficient routing in VANETs. In this process, the

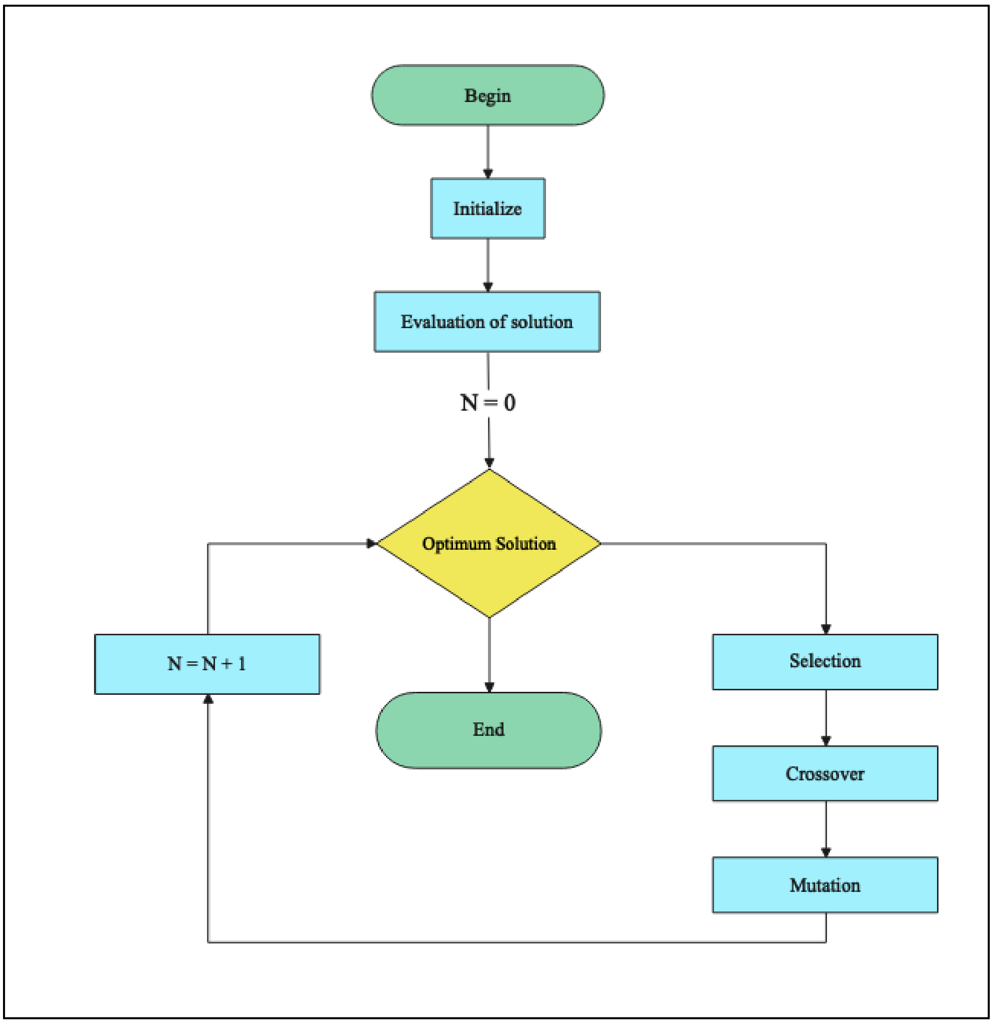

Figure 3.5 Working of Genetic Algorithm

data is transmitted from the source to all the nodes in the network to find an efficient routing in VANETs; the most optimized path is calculated using multi-valued functions. Where, Given V = { v 1 , v 2 , ... v n } set of vehicles/nodes in a network and E = { e 1 , e 2 , ...e n } set of routes or links connecting the vehicles/nodes. For n numbers of vertices, there are n x (n −1) / 2 number of possibilities to connect the vertices with each other.

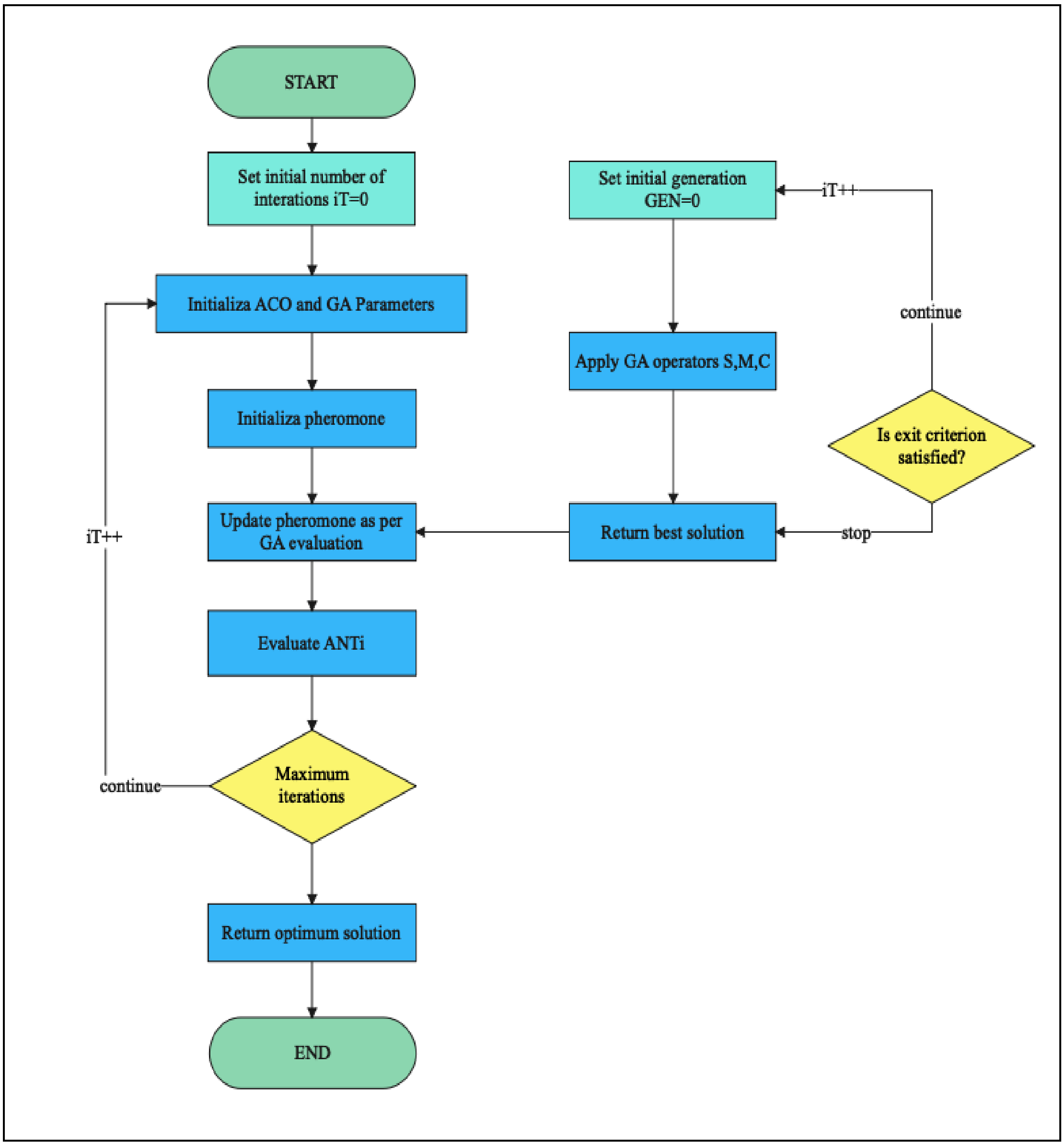

Figure 3.6 Binding process ACO+GA flowchart

The major routing work is performed by ACO, which is better suited for VANET routing and easier to construct using simulation tools comparing to GA. Similarly in contrast to GA technique, ACO took less time in computation. Hence, it is more suitable to simulate on a workstation. The devised algorithm starts the process to generate a swarm for ACO. The low pheromone values are assigned to edges and get updated on every iteration. The binding procedure of ACO with GA is shown in figure 3.6.

The proposed hypothesis is verified by validating the simulation results for three different road scenarios [62]. The algorithm devised for the research work is presented the Algorithm3.

Algorithm 3: Optimized result based on the output of GA and ACO evaluation

Input: Initial Ant Population (ANT), Initialize GA and ACO Parameters

Output: Optimized result

```
Set Itr = 0, Gen = 0;
Initialize ANT, GA, ACO
    for Gen = 0 : n
        apply(selection, crossover, mutation)
        max(generation)
        Gen++
        continue;
    end for
Initialize Pheromone
    for  Itr = 0 : m
        ANT_i++;
        update(Pheromone);
        iteration ++;
    end for
return optimized_solution;
```

Further, the devised Algorithm3 was tested using simulation experiments. The pseudocode illustrated in Pseudocode 1 is deployed for confirming the results generated through it. The methodology applied for simulation tests is elaborated as per Pseudocode 1. The three different scenarios created for simulation environment. The Spare Road Network, Dense Road Network and Dehradun City Road Network for realistic traffic scenario. The Three scenarios tested for ACO, PSO and as per the devised novel algorithm.

The pseudocode mentioned is deployed for all the simulation experiments tested to validate the proposed hypothesis for this research work. The details have been discussed and elaborated in the further chapters of this thesis.

Pseudocode 1: Implemented for Simulation Experiments of different traffic scenarios.

Input: S_1= Sparse Network1 (Sparse Road), S_2 = Dense Network2 (Dense Road), S_3 = Network3 (Dehradun Road Network), deployed from www.openstreetmap.org, *Particle Swarm Optimization Algorithm* = PSO Algorithm, S_{ACO} = Standard Ant Colony Optimization, GA_{ACO} = ACO-GA Novel Algorithm, Ћ ∈Threshold Value, $\mathcal{N}$= Number of iteration

Output: $\Re$ (Result secured after using novel algorithm for VANET)

1. Set value of S_1, S_2, S_3 for VANET simulation criteria
2. Set common parameters, for all the three scenarios S_1, S_2, S_3 and implementing PSO, S_{ACO}, and GA_{ACO} correspondingly
3. for $i = 0$: $\mathcal{N}$
4. $S_1, S_2, S_3 \leftarrow PSO$
5. $\Re_1 \leftarrow Result$
6. $S_1, S_2, S_3 \leftarrow S_{ACO}$
7. $\Re_2 \leftarrow Result$
8. $S_1, S_2, S_3 \leftarrow GA_{ACO}$
9. $\Re_3 \leftarrow Result$
10. *if congestion = = high && congestion* > Ћ
11. $S_1, S_2, S_3 \leftarrow GA_{ACO}$
12. $\Re_4 \leftarrow Result$
13. *then*
14. *continue*
15. $\Re \leftarrow \Re_1, \Re_2, \Re_3, \Re_4$
16. end for
17. return $\Re$

3.5 Computational Complexity

The computational complexity is determined for the proposed solution through a Big-Oh representation. It is an asymptotic notation and lies for the set of *"$1<logn<\sqrt{n}<n<nlogn<n^2<n^3<\ldots\ldots<2^n<3^n<\ldots\ldots n^n$"*

The big O is the upper bound of the function and is represented as below:

The function f(n) = O(g(n)) if f ∃ +ve constants c and number such that

$$f(n) \leq c * g(n) \ \forall\ n \geq n_0$$

So, $f(n) \leq c * g(n)$, c is constant.

The time complexity and space complexity are taken to determine the computational complexity of the algorithm. The time complexity of the developed algorithm comprises the computational complexity of the fitness function and the run time of the algorithm. Therefore, the computational complexity reflects the cost of fitness function *(cost_f)* for the size of the complete population, i.e. (*n*).

Therefore: *Computation Complexity* = O (*cost_f * n*) -------- (1)

In this the dimension of the scenario taken i.e. problem is (*d)* considering for population size (*n)*.

Therefore: *Run Time* = O (*d * n*) --------------------------------------- (2)

So, at each iteration, the time complexity of an algorithm is formulated below:

Time Complexity = O (*cost_f * n + d * n*) ---------------------------- (3)

For multiple iterations, say (*t*), we can formulate the time complexity as below:

Total ***Time Complexity = O* (*t* * (*cost_f * n + d * n*))** ----------------------(4)

Hence, from equation 1, 2, and 3 we can drive the time complexity of the algorithm and is represented through Big O notation as below:

Time Complexity = O (t * (cost_f * n + d * n))

3.6 Chapter Summary

The chapter has discussed the framework design and developed methodology for stepping further on this research work. Then, the chapter presented the algorithms that have been devised for this research work. It also explains the swarm intelligence techniques like ACO and GA. That focused mainly on the optimization of VANET routing problems. Finally, the real-time city scenario of Dehradun was taken to be carried out for simulation experiments in different VANET scenarios. The next chapter of the thesis elaborates the methodology that has been used to perform the simulation experiments through available open-source tools. Then its also emphasize performance analysis of the results obtained for three various traffic scenarios.

Chapter 4

Implementation of Simulation Experiments

4.1 Introduction

Vehicular Ad hoc Network (VANET) is one of the fastest evolving research in the domain of Intelligent Traffic Systems (ITS). When closely looked at the taxonomy of ITS, it can be seen that the major concern is VANET routing and security. However, many international consortiums are already working on it with their own agendas and products. As high cost involved in real-time testing hence simulation software used to get proposed results. So, none of the research consortiums is directly testing their hypothesis on the field. Instead, they first create real-time scenarios using various software tools and then test them using simulation experiments. After getting the desired results, they test that with actual hardware in real-time fields [126]. Presently due to the emergence of cloud services and the Internet of Things, there will be a revolutionary change in the architecture of today's traffic and transportation system in the near future. VANET performance depends on various routing protocols and wireless standards. Otherwise, timely communication and delay in data packets may cause accidental disasters in real-time ITS implementation [39]. For testing various routing protocols, simulation tools are also used to verify the analysis of the results. Many open-source and proprietary tools are already available, but none of the standard simulation software can fulfil all the real-time scenarios.

In this chapter, some major VANET simulations are discussed, followed by simulation experiments performed to show the validity of the proposed methodology.

4.2 Methodology used in the research work

In this section, the methodology is presented and verified during the various research simulation implementation and experiments. This approach helps in performing the research test in a much simpler and faster way. The result analysis is also instant as data can be saved in .csv format and viewed as per need. From the present experience, this can be stated that the computing resource must be robust enough so that no lagging or outages come during the execution of any simulation task. For all the experimental setups, the test deployed on the computing machine with Corei7-8700 3.2 GHz. of processor and a minimum of 4GB RAM is required. That was the HP workstation used from UPES Computer Laboratory, IT Tower, ITLab102_PC35. Previously the test was tried on Corei3 Laptop, but the results were not satisfactory and took too long to run, even when it stopped responding. There was a need to repeat the simulation tests multiple times to verify the results, as reading may vary due to the machine's poor performance.

Figure 4.1 of this chapter illustrates the methodology of the process followed for all the research simulation tests. The below-designed framework was implemented for repetitive simulation tests on an HP workstation machine through the open-source operating system Ubuntu 16.04 release [127]. The traffic simulator used is Simulation of Urban Mobility (SUMO 0.32) [6] and Network Simulator NS-3.29 [128] for all the research tests. The simulations carried by importing the real city scenario map of Dehradun city from OpenStreetMap as per the URL given here https://www.openstreetmap.org/search?query=dehradun#map=15/30.3257/78.0602 [129] for a realistic approach. Then this was converted for the SUMO network. The region from Clock Tower to Mussoorie diversion Rajpur Road is selected as it is the most congested route because of the heavy traffic going to Mussoorie from various regions during peak season times.

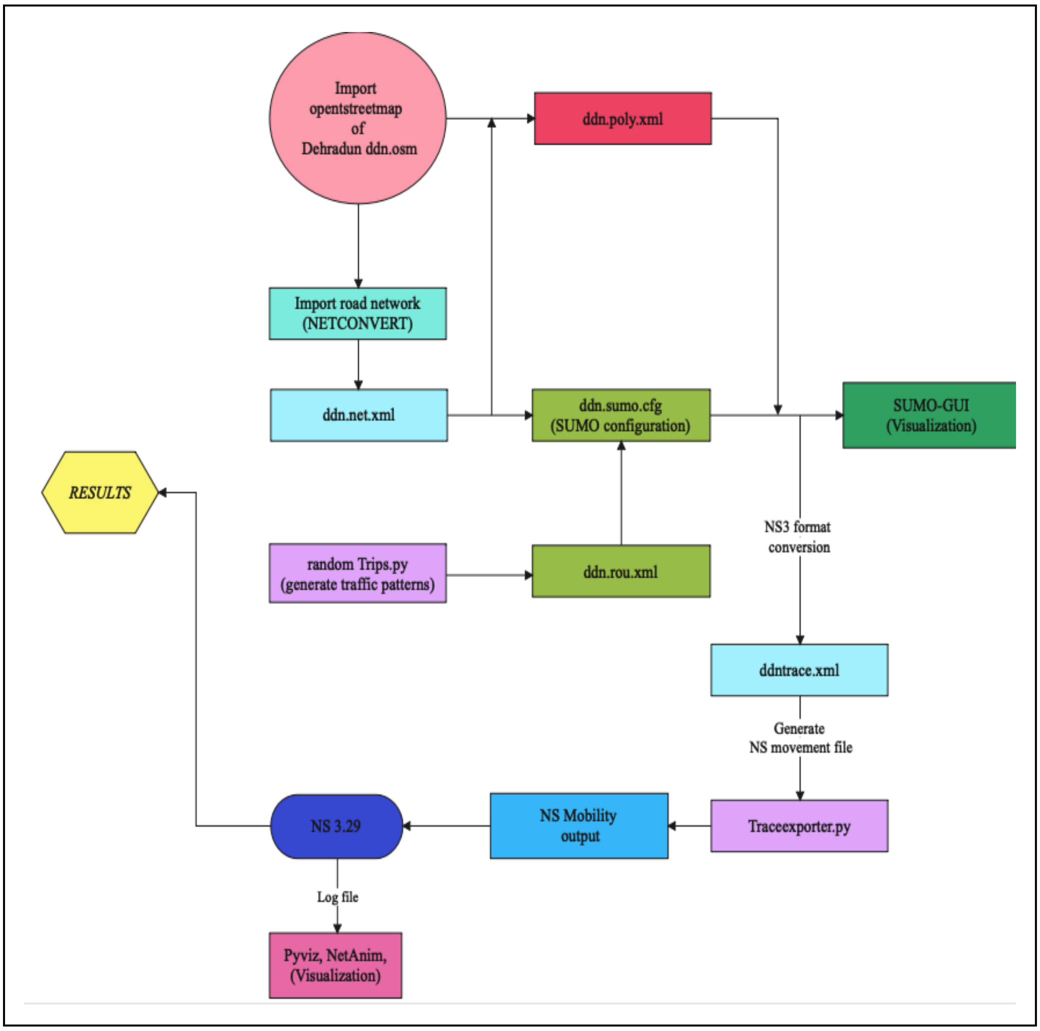

Figure 4.1 Framework used for simulation tests

The imported OSM map is converted through netconvert command: "netconvert --osm-ddn.osm –o ddn.net.xml". Then randonTrips.py is used for adding the desired trip and routing in the network through the python scripts. This random trip script randomTrips.py applied through the command: "py randomTrips.py –n ddn.net.xml -r ddn.rou.xml –e 50 –l –e" to generate the route, and this generates an automatic file with extension .rou that was named as ddn.rou.xml. This completes the research simulation process at this stage. The route of the vehicle is defined as a set of edges. The separate file for the trip is also generated with the departure and end node. Next, run the network using SUMO configuration file ddn.sumo.cfg. This generates the traffic flow and road map for the real city scenario imported from opensteetmap.org. The road map generated is shown in figure 4.2. At last, python script execution through "*$./waf --run ddn.py –visualize*" command at NS3 shell prompt and *netanim-module.h* is included as a header file for network animator in NS3.

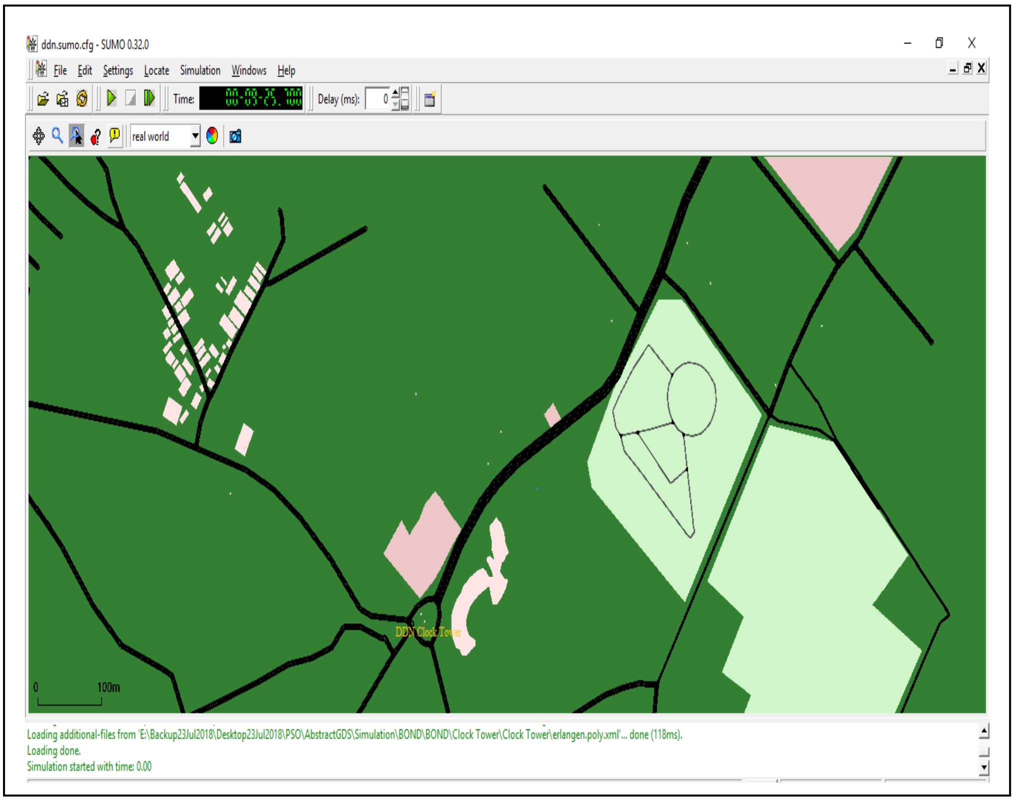

Figure 4.2 Generated Road map for Dehradun City

The same methodology is used in many other research works to predict the routing issues in VANET using swarm intelligence techniques and validation. However, other methods were also found during this research work but found it more fast and feasible compared to others.

4.3 Major VANET Simulators

Many network simulators are already available to implement VANET research experiments. Some proprietary VANET simulators such as QualNet, Carisma, Daimler-Chrysler, OPNET, TSIS-CORSIM, Paramics, and VISSIM [130]. These closed source tools are not available to those who are not associated with these projects. Hence, researchers in academia are dependent on only open-source software tools for all the experimental works. The VANET simulation software can be classified into three distinguished categories: Standard Network simulator, VANET Simulator, and Mobility Generator, as illustrated in figure 4.3.

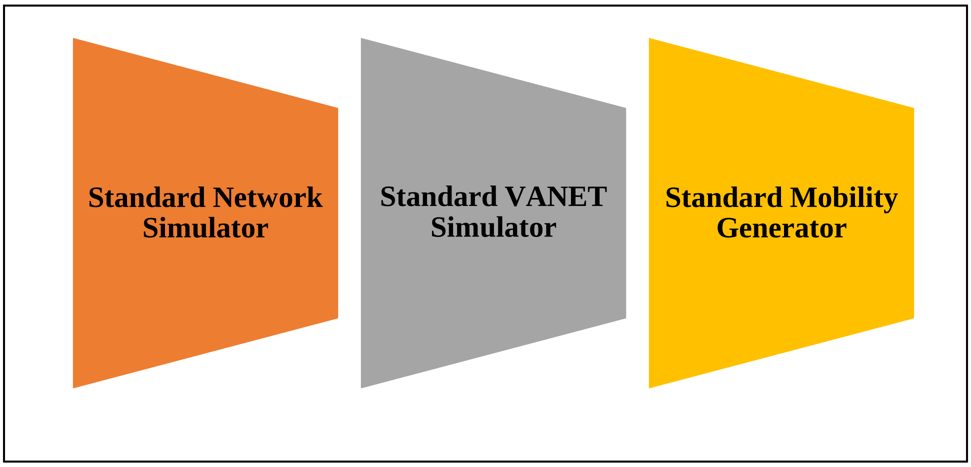

Figure 4.3 Categories of VANET Simulation

Vehicular mobility generators provide real city road network traces as input for the network simulator. It includes vehicle speed, road model, and increase/decrease of vehicle counts. Some of the most popular open-source mobility generator tools are MOVE, STRAW CityMob, SUMO, FreeSim, VanetMobiSim, and NETstream [131].

Standard network simulators like NETSIM and NS are used for Mobile Ad hoc Network simulations, but VANET's mobility generator extension can also be used for VANET simulations. These are GTNetS, SNS, GloMoSim, and NS2 [115]. Network simulation and traffic simulation can be performed using VANET simulators such as VENTOS, VANETsim, GrooveNet, TraNS, MobiREAL, and NCTUns. Now Veins is also getting popularity. It is an open-source simulator designed for VANET. It is the integration of SUMO and OMNET++ [132]. But none of the VANET simulators is best suited for all types of simulation tests. VANET simulation depends on various scenarios that cannot be verified through any of the above-discussed tools. So the designed framework in this research is used to perform the simulation test on a real city scenario. The performance analysis and measurement of the average throughput using the AODV routing protocol are carried out during these tests.

4.4 Simulation Test Performed using the above discussed Methodology

This section illustrates the result of the simulation tests performed during this research work. The mentioned details in table 4.1 illustrates the characteristics of the simulation parameters.

Table 4-1 Simulation Parameters with specifications

PARAMETERS	SPECIFICATION DETAILS
Open Source OS Open Source Network Simulator	Ubuntu 16.04 NS3.26
Open Source Traffic Simulator	Simulation of Urban Mobility (SUMO-0.32)
Open Street Map for Dehradun City vehicle traces	www.openstreetmap.org
Model Transmission network range	Manhattan Mobility Model 150 to 200 m
Size of data packets Interval	200 bytes 0.02 seconds
Data rate	2 mbps
Protocol	MAC Layer 802.11p
Velocity	20 to 80 km/h (above 80 is not permitted in DDN)

During this research work, many of the major performance metrics already analyzed and compared, but this section will present only the results obtained by one performance metric, i.e. average throughput. The others will be discussed in the next chapter. The simulation was performed for three VANET scenarios. The first is sparse network, the second is the dense network, and the third is for real city scenario route network taken from osm. The above-discussed methodology is followed and tested the Ad hoc On-demand Distance

Vector (AODV) routing protocol only to verify the performance of AODV as comparing of protocols is not in the scope of research in this chapter. That proves that the methodology and framework developed in this research work are easier to perform simulation of VANET using specified open-source tools. The data considered to calculate average throughput in kbps for AODV protocol is as per table 4.2 and performance analysis shown in figure 4.4 in the graph.

Table 4-2 Data for Simulation Experiments

Number of Vehicles	**Average Throughput**		
	Sparse Network	**Dense Network**	**DDN Network**
100	200	140	90
200	160	125	100
300	140	115	110
400	130	100	90
500	125	110	95

This chapter is not focusing on the performance issues of routing protocols. Instead, this work presents the methodology to perform simulation in VANET using open source tools like Ubuntu, SUMO, NS3, OSM, and python. However, it can be concluded from the above analysis that AODV performed superior in parse networks, and the performance is least in real city scenarios. The same is used for the devised Novel Algorithm Simulation tests.

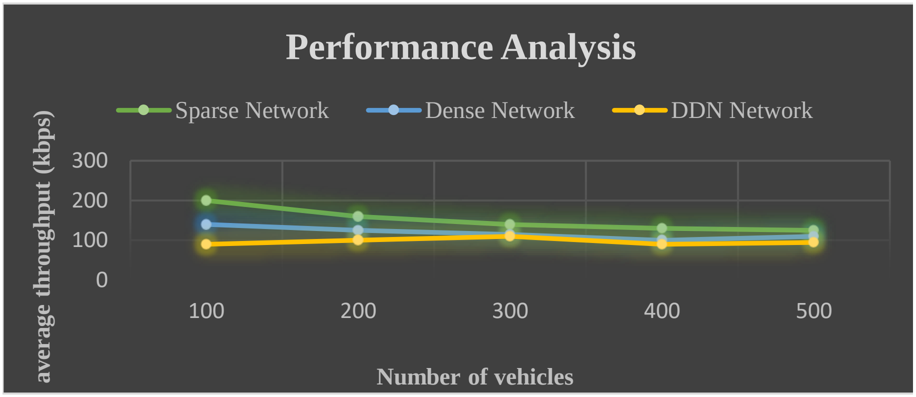

Figure 4.4 Performance analysis of average throughput for three VANET networks scenarios.

4.5 Chapter summary

This chapter has presented some of the primary open-source software tools widely accepted by the research community for realistic simulation tests. The VANET has emerged as a dynamic platform to perform simulation tests and verify the results based on various parameters, including routing protocols. The chapter focuses on developing the new optimized methodology for testing VANET simulations and is discussed in this chapter. It has been concluded that the community would surely get results faster and easier by adopting this methodology for research. The same has been demonstrated in this chapter by showing AODV routing protocol performance analysis of average throughput. In the next chapter, the same methodology and framework will be deployed to verify the simulation performance analysis of Swarm Intelligence-based routing algorithms. Hence, it can be confidently stated that the open-source VANET simulation tools are a boon to the research community.

Chapter 5

Validation of Devised Algorithm

5.1 Introduction

In VANET, many contemporary researchers are attempting to optimize the routing solutions. Though still there are possibilities to find the approach that is able to provide the solution for all the VANET traffic scenarios. Hence, VANET has emerged as region of analysis, research, and improvements for optimization. Many researchers and industry groups have proposed hypotheses and solutions based on predetermined scenarios, but no complete solution has yet been developed till present. This study found that bioinspired solutions can function in conjunction with VANET to provide a more precise and better solution. However, the performance of VANET is dependent on a variety of conditions, and no definitive answer can be given at this time because of the unpredictable nature of vehicle movement. Hence, the Ant Colony Optimization technique used to add Swarm Intelligence into VANET, and it was discovered that the performance of VANET was improved by avoiding the entire congested path as it sensed the pheromone trail. The open source tools like Instant Veins, Simulation of Urban MObility (SUMO), and MObility model generator for VEhicular networks (MOVE) were used in this study to implement and the test findings. The traffic simulation was tested with SUMO, and the model was designed with MOVE. The script was written in Python. The OSM project used to take a map of Dehradun. When the experimental setup was completed, the result indicates that the outcome reduced node travel time, making nodes speedier and more manageable, as well as saving hydrocarbon fuels.

Hence, in this research work deployment of Swarm Intelligence through Ant Colony Optimization [ACO], a multi-valued discrete approach was used to find the optimized path for routing. The Genetic Algorithm (GA) features are combined with ACO to develop the algorithm. This innovative approach also ensures link stability thus reducing the number of node disconnections. The algorithm's concreteness is confirmed using open-source simulation tools. The technique was examined in terms of throughput, packet delivery ratio, and normalized routing head, which are all important parameters in VANET routing protocols. During this research approach, the newly devised novel algorithm, as presented in Chapter 3 of this thesis, has improved the current Ant Colony Optimization technique and found that by using this research approach, the average node trip time is reduced.

5.2 Experimental- Process and Results

In this chapter, the details of the experimental setup are discussed. The same setup was used for generating the simulation results during this entire research. So, as per the devised novel algorithm that was already discussed in chapter 3, implemented to compare with algorithms that are used for VANET routing. The packet delivery ratio and average throughput are examined as parameters for the analysis of the devised algorithm.

5.3 Experimental Setup for Simulation Tests

In this research, simulation experiments an HP 6 core 8th Generation workstation with two dedicated Corei7-8700 3.2GHz processors and four GB of memory is used. The past simulation exercise confirms that the research community should not deploy a computing machine with less than four GB of memory. Only open-source software tools, as shown in Table 5.1, were used for all research experiments. The details of the same are already discussed in chapter 4. This software tool was installed on the HP workstation for repeated simulation tests and two distinct routing algorithms, including the newly developed ACO+GA binding innovative approach, were used to test diverse scenarios.

Table 5-1 Open Source Software tools for Simulation Setup

Operating System	Ubuntu 16.04
Network Simulator	NS 3.26
Traffic Simulator	Simulation of Urban Mobility (SUMO-0.32)
Open Street Map for Dehradun vehicle traces	www.openstreetmap.org
Model	Manhattan mobility model

Table 5-2 Simulation Parameters with specifications

PARAMETERS	**VALUES**
Dimension of the area	12000 m X 12000 m
Time to run a simulation	500s
Iteration for each simulation	10
Vehicles/Nodes	20 to 500
Velocity	20 to 80 km/h (as per DDN)
Transmission range	150 to 250 m
Size of data packets	200 bytes
Interval	0.02 s
Data rate	2 mbps
Protocol	Mac Layer 802.11p
Model	Manhattan Mobility Model

During this research experiment, the simulation area of 12000 m X 12000 m dimensions was created. SUMO is used with three distinctive scenarios such as sparse road network, dense road network, and Dehradun city road network. The hypothesis considered that the two lane roads are in well maintained conditions without any stoppages. The variation of 10 to 20 is considered as needed for an urban cities like Dehradun. The 2 mbps data rate and packet size of 200 bytes are deployed with 10ms of interval as a standard. The vehicle movements were carried out according to the widely known Manhattan mobility paradigm. The research simulation experiments parameters are illustrated in Table 5.2.

5.4 Performance Analysis

The final performance analysis is performed by computing and comparing the results of two primary performance metrics: PDR and throughput. The data is gathered and computed in MS-EXCEL/XLSTAT and arranged in a tabulated form. The field taken is the number of vehicle nodes with respect to PDR percentage. The PDR is computed against the number of vehicle nodes for each algorithm result viz; ACO-GA, ACO, PSO. Similarly, the same is done for PDR with respect to the speed of the vehicle against every speed range used in the simulation test. The simulation result data is computed in the same manner for average throughput with respect to the vehicle nodes and the speed of the vehicles. Then the line graph is plotted for each tabulated data in MS-EXCEL for review of the performance analysis, and XLSTAT is used to validate the hypothesis via t-test.

From the research test results and its analysis of the devised novel algorithm, it has been seen that the PDR ratio is high as compared to others. That means the performance of the devised algorithm is improved in contrast with other preexisting standard protocols. The total number of data packets received at a certain one time is the average throughput. Hence, as a result, it may ensure that a high data transmission rate in the network. The dissemination of the total number of routing packets per data packet is routing overhead. As data packets and routing packets utilize a similar bandwidth channel, all routing packets are taken as routing overheads in a simulation network. The PDR is retrieved as a ratio of the total number of packets received at the assigned destination to the total number of packets sent by the source. Here, higher the PDR means lesser the packet loss, which justifies that the hypothesis is effective from the perspective of data delivery.

Average throughput is defined as the number of data packets received per unit time. It takes into account the rate of successful data delivery over a defined scenario in simulation. The average throughput of the devised algorithm is determined by varying the speed and number of vehicles. The average throughput decreases as the number of vehicles and speed increases. That is because, at high density, it is difficult to maintain the connection between vehicles. The PDR and Throughput analysis is presented further.

5.5 Observations and results

The simulation was performed for verifying the performance of the devised novel algorithm to compare it with existing standard protocols like PSO and ACO. The performance of these protocols has been observed for getting data of PDR and average throughput for two scenarios as per the proposed hypothesis. The observation of the performance analysis retrieved is represented in the graphs as per figures 5.1 to 5.14. So, this analysis shows that the devised novel ACO-GA algorithm well performed in all the VANET network scenarios. The Performance Analysis 1 to 10 has been demonstrated that in the DDN City network scenario ACO-GA algorithm has outperformed as compared to preexisting standard algorithms like ACO and PSO. Later, it is also validated the proposed research hypothesis through a statistical t-test. The results of the t-test also justified that the hypothesis is also valid through mathematical evaluations.

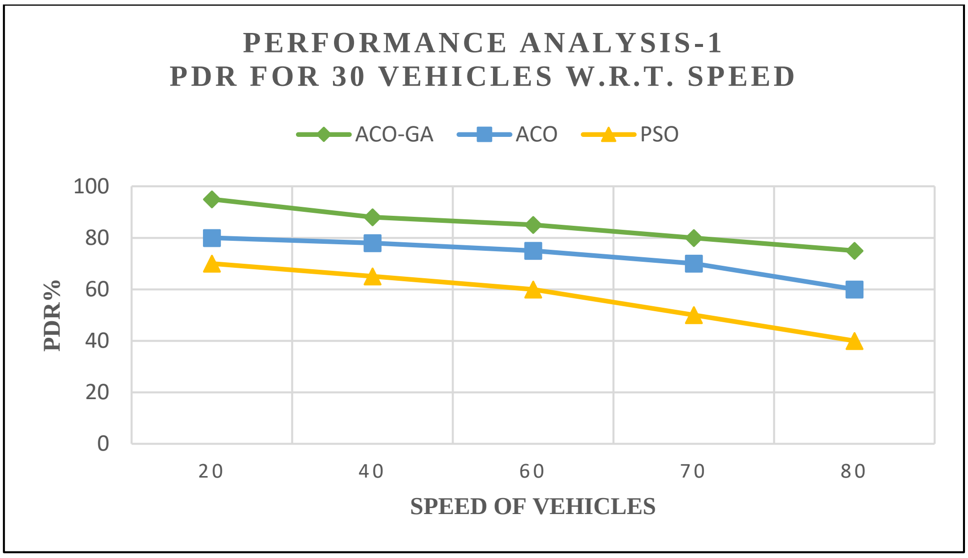

Figure 5.1: Performance analysis of PDR for 30 vehicles w.r.t. speed.

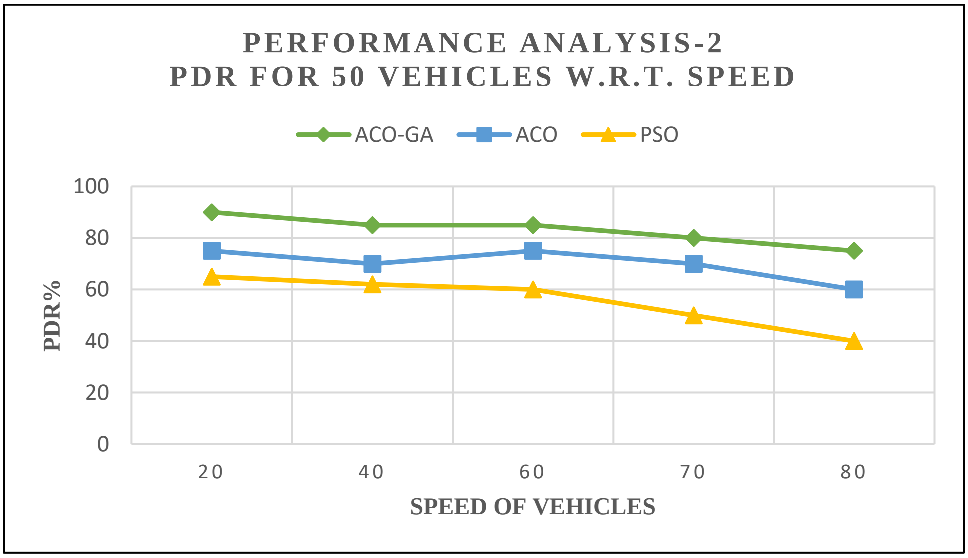

Figure 5.2: Performance analysis of PDR for 50 vehicles w.r.t. speed

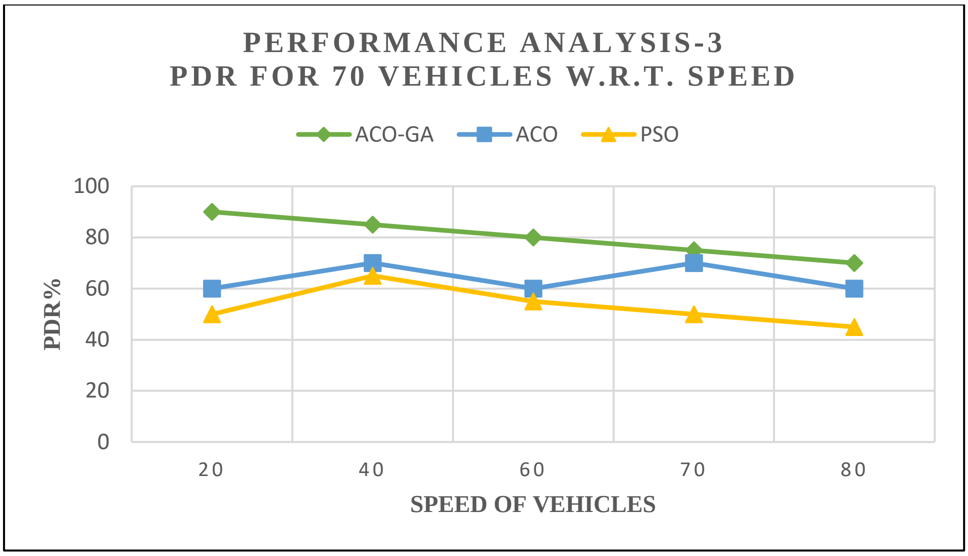

Figure 5.3: Performance analysis of PDR for 70 vehicles w.r.t. speed.

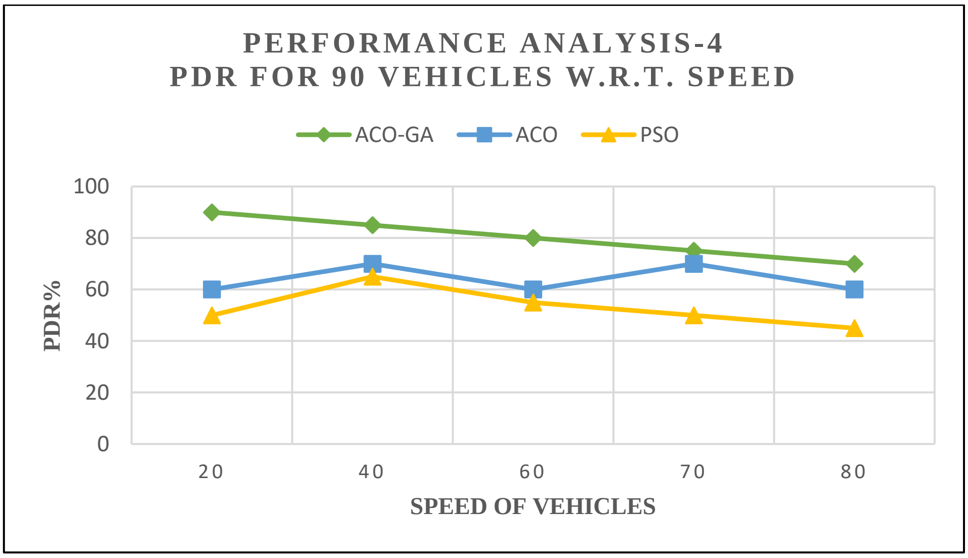

Figure 5.4: Performance analysis of PDR for 90 vehicles w.r.t. speed

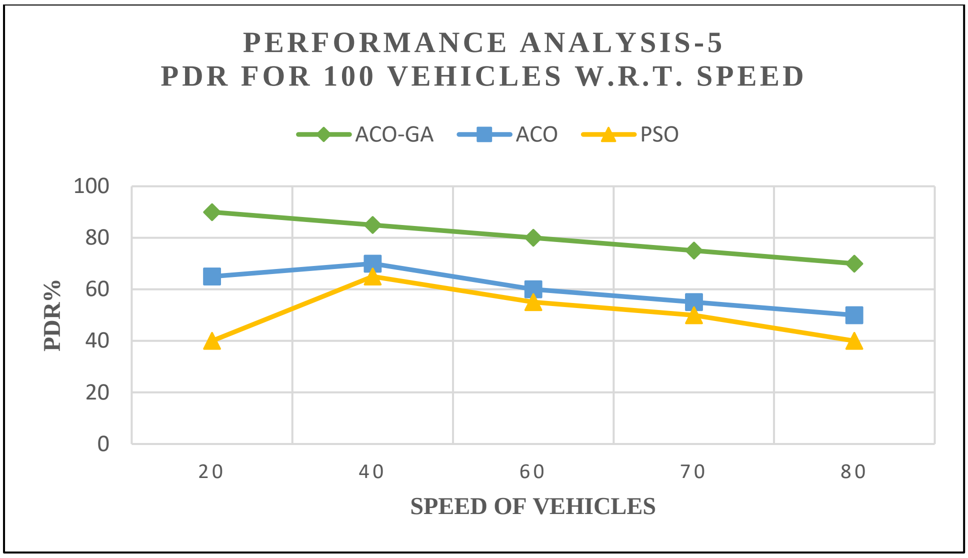

Figure 5.5: Performance analysis of PDR for 100 vehicles w.r.t. speed

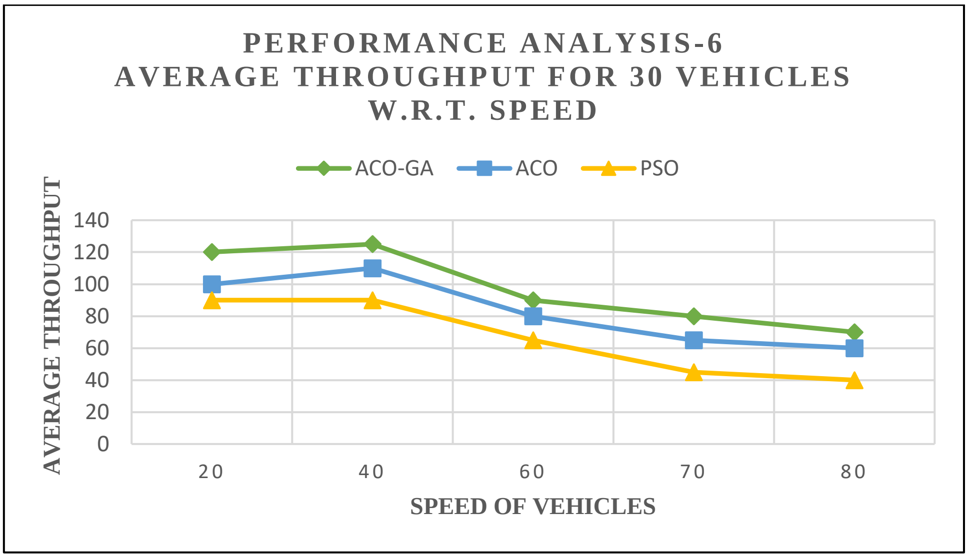

Figure 5.6: Performance analysis of throughput for 30 vehicles w.r.t. speed.

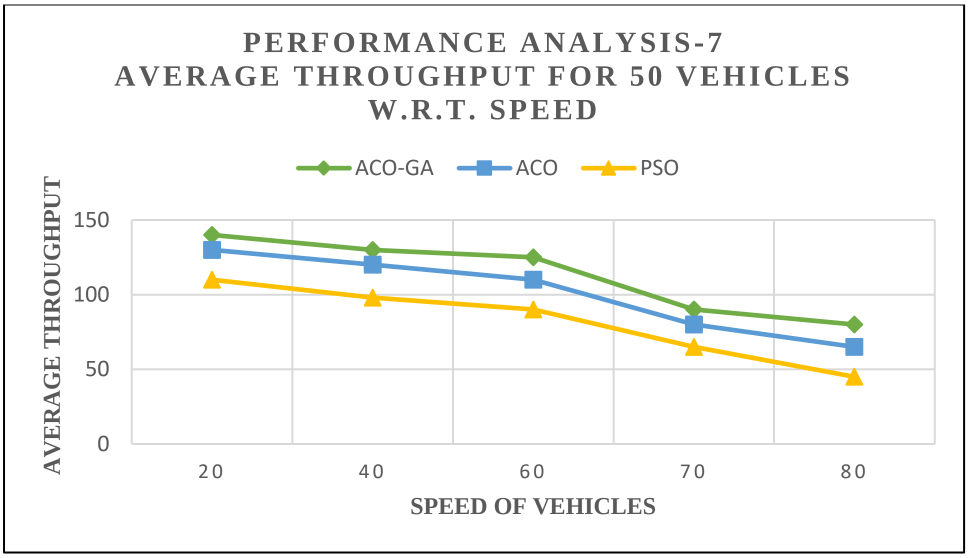

Figure 5.7: Performance analysis of throughput for 50 vehicles w.r.t. speed.

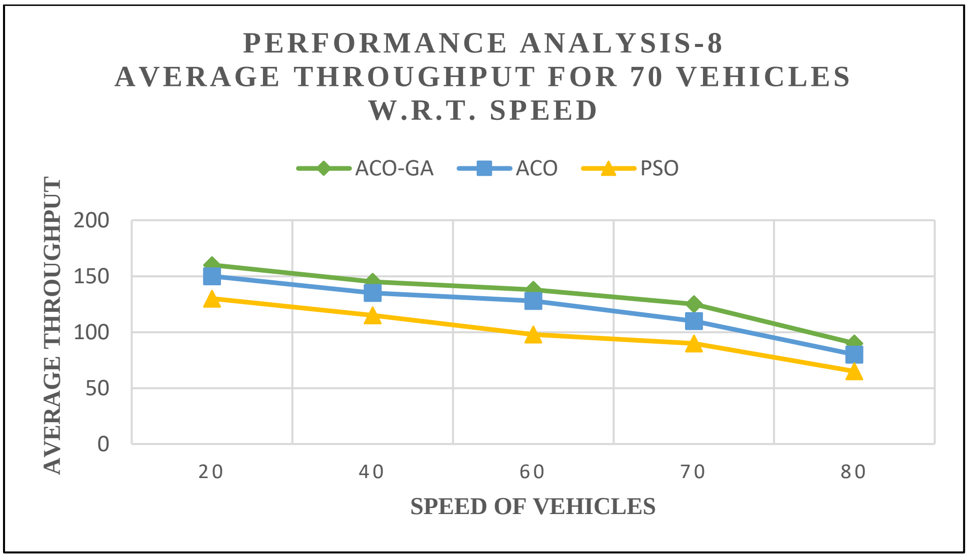

Figure 5.8: Performance analysis of throughput for 70 vehicles w.r.t. speed.

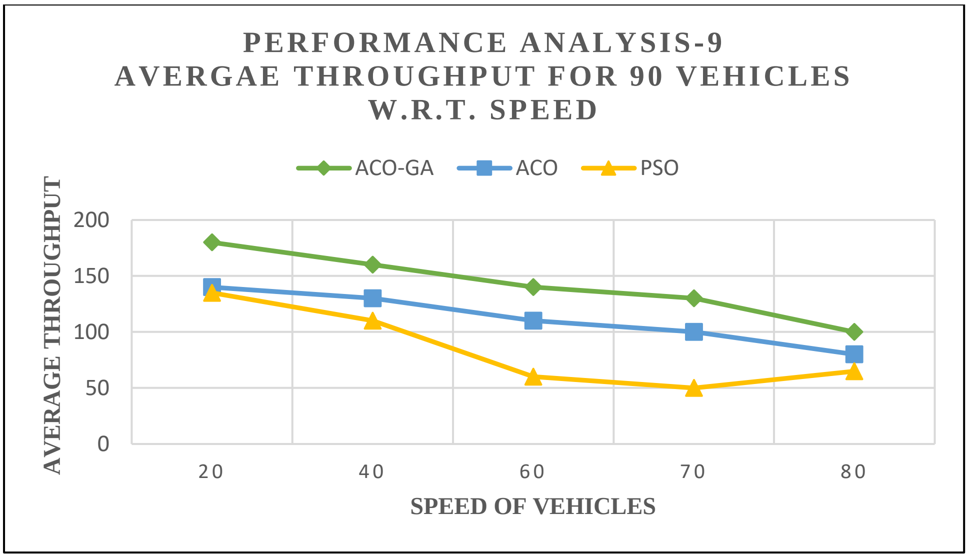

Figure 5.9: Performance analysis of throughput for 90 vehicles w.r.t. speed.

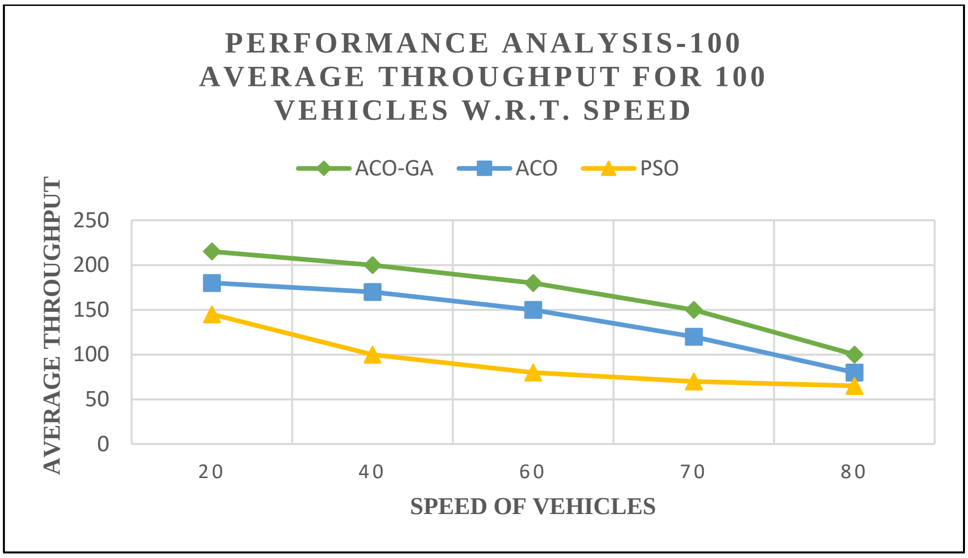

Figure 5.10: Performance analysis of throughput for 100 vehicles w.r.t speed.

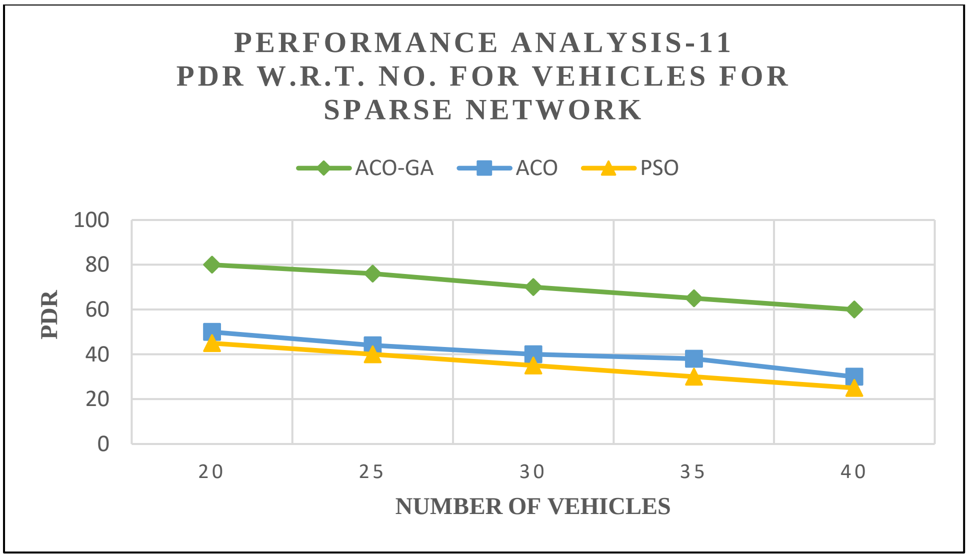

Figure 5.11: Performance analysis of PDR for sparse network w.r.t. vehicles at random speed.

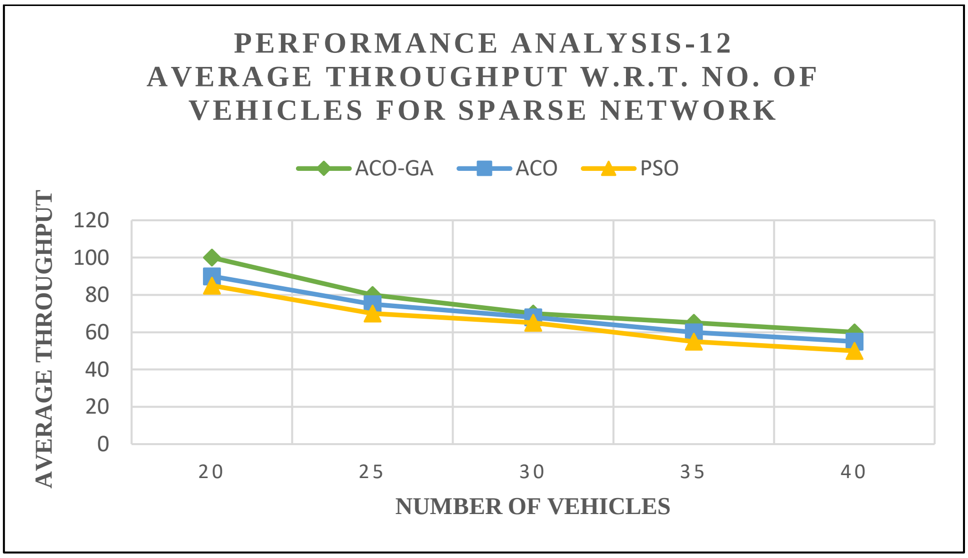

Figure 5.12: Performance analysis of throughput for sparse network w.r.t number of vehicles at random speed.

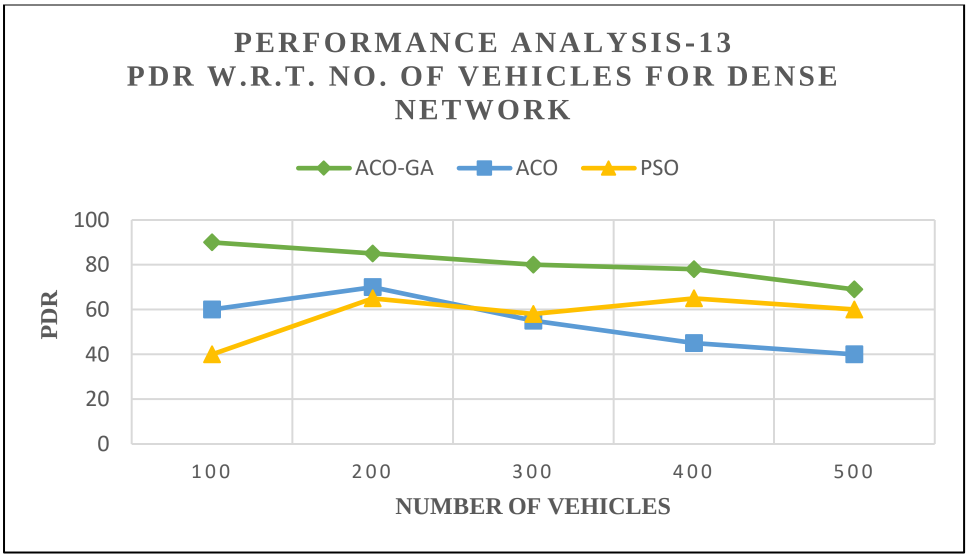

Figure 5.13: Performance analysis of PDR for dense network w.r.t. number of vehicles at random speed.

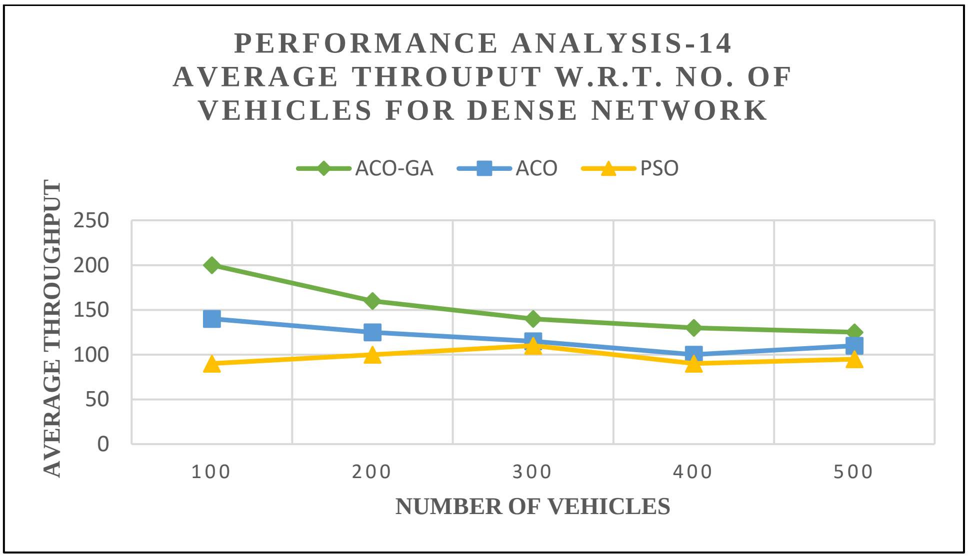

Figure 5.14: Performance analysis of throughput for dense network w.r.t. number of vehicles at random speed.

The comparative performance analysis presented in the above graphs depicts the proposed novel algorithm's better efficiency. In addition, the performance of the novel algorithm is compared with ACO and PSO to observe

PDR and average throughput with respect to vehicle density and vehicle speed for Sparse and Dense simulation network also.

5.6 Detailed Analysis as per data captured are represented in tabulated form

The comparative data is presented in a tabulated form to present the PDR and throughput values generated after simulation. Tables 5.3 to 5.16 illustrates the PDR and throughput comparative values of DDN scenario. The PDR and throughput values are considered for vehicle density of 30 to 100 and a speed variation from 20 to 80 only as it is a limit for DDN city. The same task is respited for sparse and dense network to cross verify the performance of the devised algorithm. The comparative tables show comparison of ACO-GA along with standard ACO and PSO. These data is also taken for statistical validation of the hypothesis.

Table 5-3: PDR for 30 vehicles w.r.t. speed for DDN scenario

PDR for 30 Vehicles w.r.t. speed			
SPEED	ACO-GA	ACO	PSO
20	95	80	70
40	88	78	65
60	85	75	60
70	80	70	50
80	75	60	40

Table 5-4: PDR for 50 vehicles w.r.t. speed for DDN scenario

PDR for 50 Vehicles w.r.t. speed			
SPEED	ACO-GA	ACO	PSO
20	90	75	65
40	85	70	62
60	85	75	60
70	80	70	50
80	75	60	40

Table 5-5: PDR for 70 vehicles w.r.t. speed for DDN scenario

PDR for 70 Vehicles w.r.t. speed			
SPEED	ACO-GA	ACO	PSO
20	90	60	50
40	85	70	65
60	80	60	55
70	75	70	50
80	70	60	45

Table 5-6: PDR for 90 vehicles w.r.t. speed for DDN scenario

PDR for 90 Vehicles w.r.t. speed			
SPEED	ACO-GA	ACO	PSO
20	90	60	50
40	85	70	65
60	80	60	55
70	75	70	50
80	70	60	45

Table 5-7: PDR for 100 vehicles w.r.t. speed for DDN scenario

PDR of 100 Vehicles w.r.t. speed			
SPEED	ACO-GA	ACO	PSO
20	90	65	40
40	85	70	65
60	80	60	55
70	75	55	50
80	70	50	40

Table 5-8: Average throughput for 30 vehicles w.r.t. speed for DDN scenario

Average Throughput for 30 Vehicles w.r.t. speed			
SPEED	ACO-GA	ACO	PSO
20	120	100	90
40	125	110	90
60	90	80	65
70	80	65	45
80	70	60	40

Table 5-9: Average throughput for 50 vehicles w.r.t. speed for DDN scenario

Average Throughput for 50 Vehicles w.r.t. speed			
SPEED	ACO-GA	ACO	PSO
20	140	130	110
40	130	120	98
60	125	110	90
70	90	80	65
80	80	65	45

Table 5-10: Average throughput for 70 vehicles w.r.t. speed for DDN scenario

Average Throughput for 70 Vehicles w.r.t. speed			
SPEED	ACO-GA	ACO	PSO
20	160	150	130
40	145	135	115
60	138	128	98
70	125	110	90
80	90	80	65

Table 5-11: Average throughput for 90 vehicles w.r.t speed for DDN scenario

Average Throughput for 90 Vehicles w.r.t. speed			
SPEED	ACO-GA	ACO	PSO
20	180	140	135
40	160	130	110
60	140	110	60
70	130	100	50
80	100	80	65

Table 5-12: Average throughput for 100 vehicles w.r.t. speed for DDN scenario

Average Throughput for 100 Vehicles w.r.t. speed			
SPEED	ACO-GA	ACO	PSO
20	215	180	145
40	200	170	100
60	180	150	80
70	150	120	70
80	100	80	65

Table 5-13: PDR w.r.t. vehicles at random speed in sparse network

PDR w.r.t Vehicles at Random Speed in Sparse Network			
Vehicles	ACO-GA	ACO	PSO
20	80	50	45
25	76	44	40
30	70	40	35
35	65	38	30
40	60	30	25

Table 5-14: Average Throughput w.r.t. no. of vehicles at random speed in sparse network

Average Throughput w.r.t no. of Vehicles at Random Speed in Sparse Network			
Vehicles	ACO-GA	ACO	PSO
20	100	90	85
25	80	75	70
30	70	68	65
35	65	60	55
40	60	55	50

Table 5-15: PDR w.r.t. vehicles at random speed in dense network

PDR w.r.t Vehicles at Random Speed in Dense Network			
Vehicles	ACO-GA	ACO	PSO
100	90	60	40
200	85	70	65
300	80	55	58
400	78	45	65
500	69	40	60

Table 5-16: Average throughput w.r.t. vehicles at random speed in dense network

Average Throughput w.r.t vehicles at random speed in Dense Network			
Vehicles	ACO-GA	ACO	PSO
100	200	140	90
200	160	125	100
300	140	115	110
400	130	100	90
500	125	110	95

5.7 Validation of Hypothesis

The validation of the proposed hypothesis is done through a statistical method for analyzing the performance of the devised algorithm. The two-sample test, i.e. t-test, is deployed to compare it with previously available algorithms. In this way, it can be confirmed that the proposed hypothesis is valid, as sample results are compared with the existing algorithms for validation of the performance of a newly implemented algorithm. Second, the t-test is used to check the acceptance of the alternate hypothesis. The two sample t-test is opted in this research work. The test is based on the Null hypothesis (H_0) and alternate hypothesis (Ha) as explained below:

$$\boldsymbol{H_0: \mu_1 - \mu_2 < D \quad and\ H_a: \mu_1 - \mu_2 > D}$$

where μ_1 is calculated as the mean of overall throughput and PDR for the first algorithm whereas μ_2 is calculated as the mean of overall throughput and PDR for another algorithms in this statistical *t-test*. The t-test is performed to evaluate the data samples to verify the hypothesis. To check for the data samples and in case of major variation as compared to computed hypothetical values, it rejects the null hypothesis; else, the null hypothesis is accepted. The *t-test* statistic is performed by applying Equation (1) demonstrated below. Where n_1 and n_2 are taken as sample sizes of two selected algorithms, s_1 and s_2 are taken as standard deviation, and μ_1 and μ_2 are the means taken for solving the equation.

The standard online tool is used for getting the result of a statistical *t-test* https://www.graphpad.com/quickcalcs/ttest1.cfm [133] and xlstat used in MS Excel.

Equation 1: *t-test*

$$\frac{(\sum \boldsymbol{D})/\boldsymbol{N}}{\sqrt{\dfrac{\sum \boldsymbol{D}^2 - \left(\dfrac{(\sum \boldsymbol{D})^2}{\boldsymbol{N}}\right)}{(\boldsymbol{N}-\boldsymbol{1})(\boldsymbol{N})}}}$$

The implementation of the statistical t-test is elaborated as in algorithm 4

Algorithm 4 : To perform validation of t-test

Input: $X = \{Sample_1\}$ and $Y = \{Sample_2\}$, N = Population Size

Output: Hypothesis testing

Step 1: $X = \{Sample_1\}, Y = \{Sample_2\}$

Step 2: D = subtract($X_i - Y_i$)

Step 3: $sum = \sum D$

Step 4: $Square = \left(\sum D\right)^2$

Step 5: $calculate(t), \quad where\ t = \frac{(\sum \boldsymbol{D})/\boldsymbol{N}}{\sqrt{\frac{\sum \boldsymbol{D}^2 - \left(\frac{(\sum \boldsymbol{D})^2}{\boldsymbol{N}}\right)}{(\boldsymbol{N}-\boldsymbol{1})(\boldsymbol{N})}}}$

Step 6: $DoF = N - 1$, where DoF = degree of freedom

Step 7: $calculate(p - value)$ # Find *p-value* in the t-table using the degree of freedom in Step7; if it don't have a specified *alpha level* then use *0.05 i.e. 5%.* (For this sample problem)

Step 8: $compare(p - value)$ # Compared the t-table value from Step8 to the calculated value. The calculated t-value is greater than the table value at an alpha level 0.05. If, the p-value is less than the alpha level: p<0.05. This can reject the null hypothesis that there is no difference between means.

5.8 Implementation of t-test for proving of the hypothesis

The performance of the devised novel algorithm is verified; in contrast, to present ACO and existing PSO algorithms. The t-test is selected in this research for statistical validation of the proposed research hypothesis as the sample size of the data collected is less than 30. Hence, the data is gathered for three algorithms, i.e. ACO, standard PSO, and developed ACO-GA novel algorithm. The t-test was performed for two distinct algorithms at a time. The first t-test was done for ACO-GA to compute $\boldsymbol{\mu_1}$ and existing ACO for $\boldsymbol{\mu_2}$ and similarly for ACO-GA and PSO. So, the validation of the proposed hypothesis was confirmed to validate the performance of a newly devised ACO-GA algorithm compared with ACO and standard PSO algorithm. In t-test μ_1 is the ACO-GA mean computed for throughput and PDR. Similarly, μ_2 is the computed mean for ACO and PSO. Through this mathematical procedure, the means for all the algorithms in respect to PDR and throughput is calculated.

The two independent samples/upper-tailed t-test is performed as per the need of the sample data with a 95% confidence interval on the difference between the means. This statistical t-test can be interpreted as:

H_0: The means difference ≤ 0.
H_a: The means ≥ 0.

The null hypothesis can be accepted only when there is a significant difference in the computed hypothesized data values compared to data sample values gathered through simulation experiment results. The alternate hypothesis is accepted if the devised algorithm's performance is better compared to other standard algorithms. As the significance level alpha value i.e. 0.05 is greater than the computed p-value is hence, reject the null hypothesis **H_0** is being rejected and the alternative hypothesis **H_a** has been accepted.

Here, the significance level for α is 0.05, and the p-value found is always less than α; hence the alternate hypothesis is accepted, and the null hypothesis is rejected. The experimental simulation process is used to design a real-time Dehradun City network, sparse network, and dense network to deploy in simulation for ACO, PSO, and ACO-GA algorithms. The t-test was performed on the data gathered through these simulation tests. A large number of data samples gathered multiple times from the performed experiments. During this statistical hypothesis verification probability, p is accepted and rejected by the proposed hypothesis. It checked the value of p with significance levels, i.e. α, the value equals 0.05. Hence, if the value of p is lesser than these α values, then reject the null hypothesis; else can accept the alternate hypothesis with a confidence level of 95%. The t-test of DDN network scenario with respect to speed is considered for PDR and throughput. Similarly, the t-test is also performed for sparse network and dense network scenarios in reference to PDR and throughput. The results are tabulated as per figures 5.15 to 5.28 for concluding this hypothesis. For all test results the significant answer is *"Yes"*. Hence, the hypothesis is accepted for **H_a** and rejected for **H_0**.

Research Question: **Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning Packet Delivery Ratio w.r.t. speed in DDN Scenario?**

µ1: mean (Packet Delivery Ratio of ACO-GA)
µ2: mean (Packet Delivery Ratio of ACO/PSO)

Hypothesized difference (D): 0
Significance level (%): 5
Population variances for the t-test: Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	75.000	95.000	84.600	7.635
ACO	5	0	5	60.000	80.000	72.600	7.987
ACO-GA	5	0	5	75.000	95.000	84.600	7.635
PSO	5	0	5	40.000	70.000	57.000	12.042

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	**Research Answer**
ACO	12	2.428	1.860	8	0.021	H0	**Significantly YES**
PSO	27.600	4.328	1.860	8	0.001	H0	**Significantly YES**

Figure 5.15: t-test results for 30 vehicles w.r.t. speed in DDN Network Scenario

Research Question: **Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning Packet Delivery Ratio w.r.t. speed in DDN Scenario?**

µ1: mean (Packet Delivery Ratio of ACO-GA)
µ2: mean (Packet Delivery Ratio of ACO/PSO)

Hypothesized difference (D): 0
Significance level (%): 5
Population variances for the t-test: Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	75.000	90.000	83.000	5.701
ACO	5	0	5	60.000	75.000	70.000	6.124
ACO-GA	5	0	5	75.000	90.000	83.000	5.701
PSO	5	0	5	40.000	65.000	55.400	10.286

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	**Research Answer**
ACO	13	3.474	1.860	8	0.004	H0	**Significantly YES**
PSO	27.600	5.248	1.860	8	0.000	H0	**Significantly YES**

Figure 5.16: t-test result for 50 vehicles w.r.t. speed in DDN Network Scenario

Research Question: Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning Packet Delivery Ratio w.r.t. speed in DDN Scenario?

µ1: mean (Packet Delivery Ratio of ACO-GA)
µ2: mean (Packet Delivery Ratio of ACO/PSO)

Hypothesized difference (D): 0
Significance level (%): 5
Population variances for the t-test: Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	70.000	90.000	80.000	7.906
ACO	5	0	5	60.000	70.000	64.000	5.477
ACO-GA	5	0	5	70.000	90.000	80.000	7.906
PSO	5	0	5	45.000	65.000	53.000	7.583

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	**Research Answer**
ACO	16	3.720	1.860	8	0.003	H0	**Significantly YES**
PSO	27	5.511	1.860	8	0.000	H0	**Significantly YES**

Figure 5.17: t-test result for 70 vehicles w.r.t. speed in DDN Network Scenario

Research Question: Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning Packet Delivery Ratio w.r.t. speed in DDN Scenario?

µ1: mean (Packet Delivery Ratio of ACO-GA)
µ2: mean (Packet Delivery Ratio of ACO/PSO)

Hypothesized difference (D): 0
Significance level (%): 5
Population variances for the t-test: Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	70.000	90.000	80.000	7.906
ACO	5	0	5	60.000	70.000	64.000	5.477
ACO-GA	5	0	5	70.000	90.000	80.000	7.906
PSO	5	0	5	45.000	65.000	53.000	7.583

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	**Research Answer**
ACO	16	3.720	1.860	8	0.003	H0	**Significantly YES**
PSO	27	5.511	1.860	8	0.000	H0	**Significantly YES**

Figure 5.18: t-test result for 90 vehicles w.r.t. speed in DDN Network Scenario

Research Question:	Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning Packet Delivery Ratio w.r.t. speed in DDN Scenario?

µ1: mean (Packet Delivery Ratio of ACO-GA)
µ2: mean (Packet Delivery Ratio of ACO/PSO)

Hypothesized difference (D): 0
Significance level (%): 5
Population variances for the t-test: Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	70.000	90.000	80.000	7.906
ACO	5	0	5	50.000	70.000	60.000	7.906
ACO-GA	5	0	5	70.000	90.000	80.000	7.906
PSO	5	0	5	40.000	65.000	50.000	10.607

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
ACO	20	4.000	1.860	8	0.002	H0	**Significantly YES**
PSO	30	5.071	1.860	8	0.000	H0	**Significantly YES**

Figure 5.19: t-test result for 100 vehicles w.r.t. DDN Network Scenario

Research Question:	Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning average throughput w.r.t. speed in DDN Scenario?

µ1: mean (Packet Delivery Ratio of ACO-GA)
µ2: mean (Packet Delivery Ratio of ACO/PSO)

Hypothesized difference (D): 0
Significance level (%): 5
Population variances for the t-test: Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	70.000	125.000	97.000	24.393
ACO	5	0	5	45.000	90.000	68.000	20.187
ACO-GA	5	0	5	70.000	125.000	97.000	24.393
PSO	5	0	5	40.000	90.000	66.000	23.822

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
ACO	29	2.048	1.860	8	0.037	H0	**Significantly YES**
PSO	27.600	4.328	1.860	8	0.001	H0	**Significantly YES**

Figure 5.20: t-test result for 30 vehicles w.r.t. average throughput in DDN Network Scenario.

Research Question:	Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning average throughput w.r.t. speed in DDN Scenario?

µ1: mean (Packet Delivery Ratio of ACO-GA)
µ2: mean (Packet Delivery Ratio of ACO/PSO)

Hypothesized difference (D):	0
Significance level (%):	5
Population variances for the t-test:	Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	80.000	140.000	113.000	26.363
ACO	5	0	5	50.000	100.000	79.000	22.472
ACO-GA	5	0	5	80.000	140.000	113.000	26.363
PSO	5	0	5	45.000	110.000	81.600	26.274

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
ACO	34	2.195	1.860	8	0.030	H0	**Significantly YES**
PSO	31.400	1.886	1.860	8	0.048	H0	**Significantly YES**

Figure 5.21: t-test result for 50 vehicles w.r.t. average throughput in DDN Network Scenario.

Research Question:	Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning average throughput w.r.t. speed in DDN Scenario?

µ1: mean (Packet Delivery Ratio of ACO-GA)
µ2: mean (Packet Delivery Ratio of ACO/PSO)

Hypothesized difference (D):	0
Significance level (%):	5
Population variances for the t-test:	Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	90.000	160.000	131.600	26.463
ACO	5	0	5	70.000	120.000	100.000	20.310
ACO-GA	5	0	5	90.000	160.000	131.600	26.463
PSO	5	0	5	65.000	110.000	92.600	16.994

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
ACO	31.600	2.118	1.860	8	0.034	H0	**Significantly YES**
PSO	39	2.773	1.860	8	0.012	H0	**Significantly YES**

Figure 5.22: t-test result for 70 vehicles w.r.t. average throughput in DDN Network Scenario.

Research Question:	Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning average throughput w.r.t. speed in DDN Scenario?
µ1:	mean (Packet Delivery Ratio of ACO-GA)
µ2:	mean (Packet Delivery Ratio of ACO/PSO)
Hypothesized difference (D):	0
Significance level (%):	5
Population variances for the t-test:	Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	100.000	180.000	142.000	30.332
ACO	5	0	5	70.000	120.000	96.000	18.507
ACO-GA	5	0	5	100.000	180.000	142.000	30.332
PSO	5	0	5	50.000	135.000	84.000	36.640

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
ACO	46	2.895	1.860	8	0.010	H0	**Significantly YES**
PSO	58	2.727	1.860	8	0.013	H0	**Significantly YES**

Figure 5.23: t-test result for 90 vehicles w.r.t. average throughput in DDN Network Scenario.

Research Question:	Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning average throughput w.r.t. speed in DDN Scenario?
µ1:	mean (Packet Delivery Ratio of ACO-GA)
µ2:	mean (Packet Delivery Ratio of ACO/PSO)
Hypothesized difference (D):	0
Significance level (%):	5
Population variances for the t-test:	Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	100.000	215.000	169.000	45.607
ACO	5	0	5	75.000	150.000	105.000	28.284
ACO-GA	5	0	5	100.000	215.000	169.000	45.607
PSO	5	0	5	65.000	145.000	92.000	32.519

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
ACO	64	2.667	1.860	8	0.014	H0	**Significantly YES**
PSO	77	3.074	1.860	8	0.008	H0	**Significantly YES**

Figure 5.24: t-test result for 100 vehicles w.r.t. average throughput in DDN Network Scenario.

The research answer for all the t-tests performed for DDN Network Scenario illustrates that the hypothesis is significantly yes for all. Hence, the alternate hypothesis i.e. **H$_a$** is accepted with 95% of confidence for the parameter PDR and average throughput.

The performance analysis shows that the ACO-GA is better even in Sparse and Dense Network Scenario. To validate this the t-test is also performed for all the simulation results captured for PDR and average throughput in both the network scenarios.

Research Question: Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning Packet Delivery Ratio w.r.t. sparse network?

µ1: mean (Packet Delivery Ratio of ACO-GA)
µ2: mean (Packet Delivery Ratio of ACO/PSO)

Hypothesized difference (D): 0
Significance level (%): 5
Population variances for the t-test: Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	60.000	80.000	70.200	8.075
ACO	5	0	5	30.000	50.000	40.400	7.403
ACO-GA	5	0	5	60.000	80.000	70.200	8.075
PSO	5	0	5	25.000	45.000	35.000	7.906

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	**Research Answer**
ACO	29.800	6.083	1.860	8	0.000	H0	**Significantly YES**
PSO	35.200	6.965	1.860	8	<0.0001	H0	**Significantly YES**

Figure 5.25: t-test result for PDR w.r.t. vehicles at random speed in Sparse Network Scenario.

Research Question:	Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning average throughput for Sparse Network?

µ1: mean (Packet Delivery Ratio of ACO-GA)
µ2: mean (Packet Delivery Ratio of ACO/PSO)

Hypothesized difference (D): 0
Significance level (%): 5
Population variances for the t-test: Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	60.000	100.000	75.000	15.811
ACO	5	0	5	40.000	80.000	55.000	15.811
ACO-GA	5	0	5	60.000	100.000	75.000	15.811
PSO	5	0	5	35.000	80.000	54.000	18.507

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	**Research Answer**
ACO	20	2.000	1.860	8	0.040	H0	**Significantly YES**
PSO	21	1.929	1.860	8	0.045	H0	**Significantly YES**

Figure 5.26: t-test result for average throughput w.r.t. vehicles at random speed in Sparse Network Scenario.

Research Question:	Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning Packet Delivery Ratio Dense Network Scenario?

µ1: mean (Packet Delivery Ratio of ACO-GA)
µ2: mean (Packet Delivery Ratio of ACO/PSO)

Hypothesized difference (D): 0
Significance level (%): 5
Population variances for the t-test: Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	69.000	90.000	80.400	7.893
ACO	5	0	5	40.000	70.000	54.000	11.937
ACO-GA	5	0	5	69.000	90.000	80.400	7.893
PSO	5	0	5	40.000	65.000	57.600	10.310

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	**Research Answer**
ACO	26.400	4.125	1.860	8	0.002	H0	**Significantly YES**
PSO	22.800	3.926	1.860	8	0.002	H0	**Significantly YES**

Figure 5.27: t-test result for PDR w.r.t. vehicles at random speed in Dense Network Scenario.

Research Question:	Is ACO-GA (µ1) better than ACO/PSO (µ2) concerning Average Throughput for Dense Network Scenario?

µ1: mean (Packet Delivery Ratio of ACO-GA)
µ2: mean (Packet Delivery Ratio of ACO/PSO)

Hypothesized difference (D):	0
Significance level (%):	5
Population variances for the t-test:	Assume equality

t-test for two independent samples / upper-tailed test:

t-test for two independent samples / upper-tailed test: 95% confidence interval on the difference between the means

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
ACO-GA	5	0	5	125.000	200.000	151.000	30.496
ACO	5	0	5	100.000	140.000	118.000	15.248
ACO-GA	5	0	5	125.000	200.000	151.000	30.496
PSO	5	0	5	90.000	110.000	97.000	8.367

H0: The difference between the means is greater or equal to 0, i.e. µ1 - µ2 <= 0.
Ha: The difference between the means is lower than 0, i.e. µ1 - µ2 > 0
Significance Value 0.05

Research Conclusion

ACO-GA	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	**Research Answer**
ACO	33	2.164	1.860	8	0.031	H0	**Significantly YES**
PSO	54	3.818	1.860	8	0.003	H0	**Significantly YES**

Figure 5.28: t-test result for average throughput w.r.t. vehicle speed in Dense Network Scenario.

The t-test confirms the validation of the hypothesis with 95% confidence. Therefore, the developed ACO-GA algorithm shows better performance as compared to standard ACO and existing PSO. Hence, through a statistical approach, it is proved that the performance of the proposed ACO-GA is better, which is required as per the aim of the research objective, i.e., devise an optimized routing algorithm in VANET.

5.9 Chapter summary

This chapter mainly elaborates on the simulation experiments performed during this research work. It illustrates the experimental process, system setup, and tests performed on three specific VANET traffic scenarios. Further, the hypothesis is confirmed and validated using a statistical one-tailed t-test. Hence, this concludes that the derived novel algorithm is far better when compared with preexisting standard algorithms like PSO and ACO. The next chapter of this thesis ends with the conclusion of this research work. It also discusses the possible future scope that can be carried out on highway scenarios like NH108 and Intelligent Transportation Systems.

Chapter 6

Conclusion and Future Direction

6.1 Conclusion of the Research Work

These novel research findings verify and prove that the hypothesis is valid by comparing best suited VANET algorithms with the performance of the devised novel algorithm. The most significant feature of VANET is reliable links and efficient routing but due real-time scenarios and its dynamic topology of makes it almost impossible to eliminate link breakage. Therefore, the GA approach is applied and integrated with existing standard algorithm from the most reputed swarm intelligence-based techniques. The new algorithm was developed and implemented in this research work. The swarm intelligence technique ACO was deployed with the features of GA in it. The experimental and statistical results depicted that the performance of PDR and average throughput is better in a newly devised algorithm when compared to pre-existing standard swarm intelligence based algorithms. In this way, the ACO-GA hybrid algorithm may also reduce the fuel consumption in real-time traffic because the waiting period will get reduced at intersections. In the same way, the total journey time will also get reduced, avoiding the congested stretch. Ultimately, the pollution contribution of the vehicles will also get reduced, and it will be a huge contribution towards the environment and people's health living in the nearby area and commuters.

The resultant of the devised novel algorithm outperformed in comparison with the pre-existing ACO and PSO. Moreover, the hybrid ACO-GA swarm intelligence algorithm performed superior on critical metrics like PDR and average throughput in three different scenarios in VANET. Hence, on comparative analysis of the results and *t-test* validations, it is concluded that the hypothesis was verified and proved.

6.2 Future Scope of the Research Work

In V2V and V2I routing, VANET has emerged as one of the most critical research areas in routing, and it is yet to be supported with one standard protocol that can fit all urban traffic scenarios. VANET routing differs in urban and highway traffic scenarios, which has been observed that during urban traffic scenarios, the density of the vehicle nodes may vary and dynamic, which can be used to compute various routes across the network. However, investigations need to be carried out to find the robustness of the proposed algorithms on urban traffic scenarios with more vehicle nodes in different city scenarios such as Mumbai, Bengaluru, Delhi, etc.

Similarly, sometimes the vehicle stalling problem is faced by the drivers, and this pause time can affect the Quality of Service in VANET routing. So, the future scope of this research can be fact-finding for urban traffic scenarios with various parameters because due to traffic jams and frequent traffic signals, and high congestion on the roads, vehicles tend to slow down and may stop regularly. That results in congestion in the VANET routing protocol, so the same parameters may not be sufficient. Hence, as an enhancement for this research work, investigations can be performed in this direction by studying the simulation results of vehicle pause time for realistic city traffic scenarios.

Other metaheuristics algorithms like Bee Optimization, Firefly optimization, PSO, Tabu search, etc., can also be tried to bind with any of the new evolutionary algorithms for future research in the domain of VANET routing. But this research focused on ACO behaviour as it best suits the scenario-based traffic environment. The ACO optimization technique binds with genetic properties like mutation. The ant/node/vehicle can mutate depending on the network environments like sparse, dense, and real-time city traffic scenarios. The same is tested through simulation and applied to other metaheuristic algorithms for further study and observations.

Future research can also be carried out on highway scenarios, as vehicles move at very high speeds and may not be distributed uniformly, e.g. Eastern Peripheral Expressway in plain areas and Gangotri Chardham Highway NH108 at hills. Similarly, vehicles may be at a bumper-to-bumper distance at toll stations, while on the roads, the vehicles may be uniformly spaced. The future work of this research can also be focused to investigate the opportunity of developing even more optimized algorithms that may be used to develop a shared framework for the store and forward concept. Toll stations will be used as the storage point for VANET data collection, and data can also be forwarded to the vehicles that are reaching afterwards. Hence, toll stations can be best suitable for V2I setups. Further research investigations can be carried out in this direction also.

Similarly, research can also be performed in multimedia streaming that can be very useful in vehicular communication to identify the route condition through VANET, and even video streaming can be integrated through VANET over the GSM network. That can be considered as part of future research in the Intelligent Transportation System for a Better World.

REFERENCES

[1] R. J. Hall, "An improved geocast for mobile ad hoc networks," *IEEE Transactions on Mobile Computing*, Vol. 10, No. 2, pp. 254–266, 2011.

[2] J. Luo and J. P. Hubaux, "A survey of research in inter-vehicle communications," in *Embedded Security in Cars: Securing Current and Future Automotive IT Applications*, Springer Berlin Heidelberg, 2006, pp. 111–122.

[3] P. Kaleeswari, N. M. J. a, and P. G. Student, "SURVEY ARTICLE A Survey on Routing Protocols in VANET," Vol. 2, No. 3, pp. 383–388, 2013.

[4] P. Muhlethaler, A. Laouiti, and Y. Toor, "Comparison of Flooding Techniques for Safety Applications in VANETs," in *2007 7th International Conference on ITS Telecommunications*, 2007, pp. 1–6.

[5] K. C. Lee and M. Gerla, "Opportunistic vehicular routing," *2010 European Wireless Conference, EW 2010*, pp. 873–880, 2010.

[6] R. Tomar, H. Sastry, and M. Prateek, "Establishing Parameters for Comparative Analysis of V2V Communication in VANET," *Journal of Scientific and Industrial Research (JSIR)*, Vol. 79, No. 01, pp. 26–29, 2020.

[7] R. Tomar, M. Prateek, and G. H. Sastry, "Vehicular Adhoc Network (VANET)- An introduction," *International Journal of Control Theory and Applications*, Vol. 9, No. 18, pp. 8883–8888, 2016.

[8] G. G. Suresha, "Internet Access in Vehicular Ad-Hoc Networks Based on Infrastructure and LTE Communications Masters Thesis in Communication and Signal Processing," No. January, 2017.

[9] R. Tomar, M. Prateek, and G. H. Sastry, "Vehicular adhoc network (vanet)-an introduction," 2016.

[10] S. Panichpapiboon and W. Pattara-Atikom, "Connectivity requirements for self-organizing traffic information systems," *IEEE Transactions on*

Vehicular Technology, Vol. 57, No. 6, pp. 3333–3340, 2008.

[11] G. D. Singh, M. Prateek, and H. S. G, "Swarm Intelligence Based Algorithm for Efficient Routing in VANET," *International Journal of Innovative Technology and Exploring Engineering*, Vol. 9, No. 5, pp. 1124–1136, 2020.

[12] "WRS Data – World Road Statistics." [Online]. Available: https://worldroadstatistics.org/wrs-data/. [Accessed: 21-Dec-2020].

[13] "Overview of Road Accidents in India | PRSIndia." [Online]. Available: https://www.prsindia.org/policy/vital-stats/overview-road-accidents-india. [Accessed: 27-Oct-2020].

[14] "MOTOR VEHICLES - Statistical Year Book India 2018 | Ministry of Statistics and Program Implementation | Government Of India." [Online]. Available: http://mospi.nic.in/statistical-year-book-india/2018/189. [Accessed: 27-Oct-2020].

[15] "MOTOR VEHICLES - Statistical Year Book India 2017 | Ministry of Statistics and Program Implementation | Government Of India." [Online]. Available: http://mospi.nic.in/statistical-year-book-india/2017/189. [Accessed: 27-Oct-2020].

[16] "WHO | Global status report on road safety 2009," *WHO*, 2015.

[17] "Intelligent Transportation Systems - Benefits of Intelligent Transportation Systems Fact Sheet." [Online]. Available: https://www.its.dot.gov/factsheets/benefits_factsheet.htm. [Accessed: 27-Oct-2020].

[18] "Roadways in India - Road Industry, Network, Projects & FDI." [Online]. Available: https://www.investindia.gov.in/sector/roads-highways. [Accessed: 07-Dec-2020].

[19] "(No Title)." [Online]. Available: https://olawebcdn.com/ola-institute/ease-of-moving.pdf. [Accessed: 27-Oct-2020].

[20] "Road Accidents in India | Ministry of Road Transport & Highways, Government of India." [Online]. Available: https://morth.nic.in/road-

accident-in-india. [Accessed: 27-Oct-2020].

[21] "Over 7 billion people face unsafe air: State of Global Air 2018 | Institute for Health Metrics and Evaluation." [Online]. Available: http://www.healthdata.org/news-release/over-7-billion-people-face-unsafe-air-state-global-air-2018. [Accessed: 27-Oct-2020].

[22] S. Din, A. Paul, and A. Rehman, "5G-enabled Hierarchical architecture for software-defined intelligent transportation system," *Computer Networks*, Vol. 150, pp. 81–89, Feb. 2019.

[23] K. Zheng, Q. Zheng, P. Chatzimisios, W. Xiang, and Y. Zhou, "Heterogeneous Vehicular Networking: A Survey on Architecture, Challenges, and Solutions," *IEEE Communications Surveys and Tutorials*, Vol. 17, No. 4, pp. 2377–2396, 2015.

[24] S. D. Sudarsan, V. Kumar, and R. Tomar, "IEEE France Section," 2018.

[25] A. M. Vegni, "Smart Vehicles, Technologies and Main Applications in Vehicular Ad hoc Networks," M. Biagi, Ed. Rijeka: IntechOpen, 2013, p. Ch. 1-Ch. 1.

[26] C. He, K. Zhang, and S. Wei, "Analysis of the Channel Capacity with Shadowing Fading in VANET," in *2018 14th International Wireless Communications and Mobile Computing Conference, IWCMC 2018*, 2018, pp. 577–581.

[27] N. Haouari, S. Moussaoui, S. M. Senouci, A. Boualouache, and M. A. Messous, "An efficient management of the control channel bandwidth in VANETs," in *IEEE International Conference on Communications*, 2017.

[28] L. Qiao, Y. Shi, and S. Chen, "An empirical study on the temporal structural characteristics of VANETs on a Taxi GPS Dataset," *IEEE Access*, Vol. 5, pp. 722–731, 2017.

[29] F. Qu, Z. Wu, F. Wang, and W. Cho, "A Security and Privacy Review of VANETs," *IEEE Transactions on Intelligent Transportation Systems*, Vol. 16, No. 6. Institute of Electrical and Electronics Engineers Inc., pp. 2985–2996, 01-Dec-2015.

[30] S. Wang, B. Yang, F. Gu, and X. Shi, “A novel reliable broadcast protocol for VANET’s safety applications,” in *ICEIEC 2016 - Proceedings of 2016 IEEE 6th International Conference on Electronics Information and Emergency Communication*, 2016, pp. 282–286.

[31] R. Hussain and S. Zeadally, “Autonomous Cars: Research Results, Issues, and Future Challenges,” *IEEE Communications Surveys and Tutorials*, Vol. 21, No. 2. Institute of Electrical and Electronics Engineers Inc., pp. 1275–1313, 01-Apr-2019.

[32] A. Vladyko, A. Khakimov, A. Muthanna, A. A. Ateya, and A. Koucheryavy, “Distributed Edge Computing to Assist Ultra-Low-Latency VANET Applications,” *Future Internet*, Vol. 11, No. 6, p. 128, Jun. 2019.

[33] Q. Yang and L. Shen, “A Multi-Hop Broadcast scheme for propagation of emergency messages in VANET,” in *2010 IEEE 12th International Conference on Communication Technology*, 2010, pp. 1072–1075.

[34] A. Festag, P. Papadimitratos, and T. Tielert, “Design and performance of secure geocast for vehicular communication,” *IEEE Transactions on Vehicular Technology*, Vol. 59, No. 5, pp. 2456–2471, 2010.

[35] P. Singh, “Comparative study between unicast and Multicast Routing Protocols in different data rates using vanet,” in *Proceedings of the 2014 International Conference on Issues and Challenges in Intelligent Computing Techniques, ICICT 2014*, 2014, pp. 278–284.

[36] F. Dressler, F. Klingler, C. Sommer, and R. Cohen, “Not all VANET broadcasts are the same: Context-Aware class based Broadcast,” *IEEE/ACM Transactions on Networking*, Vol. 26, No. 1, pp. 17–30, 2018.

[37] C. Wu, X. Chen, Y. Ji, S. Ohzahata, and T. Kato, “Efficient Broadcasting in VANETs Using Dynamic Backbone and Network Coding,” *IEEE Transactions on Wireless Communications*, Vol. 14, No. 11, pp. 6057–6071, 2015.

[38] S. S. Manvi and S. Tangade, “A survey on authentication schemes in VANETs for secured communication,” *Vehicular Communications*, Vol. 9, pp. 19–30, 2017.

[39] G. D. Singh, R. Tomar, H. G. Sastry, and M. Prateek, “A review on VANET routing protocols and wireless standards,” in *Smart Innovation, Systems and Technologies*, Vol. 78, 2018, pp. 329–340.

[40] M. H. Slovenská akadémia vied. Institute of Informatics., H. Abdy, and S. H. Zahiri, *Computing and informatics.*, Vol. 35, No. 1. 2016.

[41] M. Al-Rabayah and R. Malaney, “A new scalable hybrid routing protocol for VANETs,” *IEEE Transactions on Vehicular Technology*, Vol. 61, No. 6, pp. 2625–2635, 2012.

[42] T. Taleb, E. Sakhaee, A. Jamalipour, K. Hashimoto, N. Kato, and Y. Nemoto, “A Stable Routing Protocol to Support ITS Services in VANET Networks,” *IEEE Transactions on Vehicular Technology*, Vol. 56, No. 6, pp. 3337–3347, 2007.

[43] M. Chaqfeh and A. Lakas, “A novel approach for scalable multi-hop data dissemination in vehicular ad hoc networks,” *Ad Hoc Networks*, Vol. 37, pp. 228–239, Feb. 2016.

[44] P. Misra and V. Kulathumani, “RoAdNet: A Multi-Resolution Transmission Strategy for Long Range Information Diffusion in VANETs,” in *2019 IEEE 90th Vehicular Technology Conference (VTC2019-Fall)*, 2019, pp. 1–6.

[45] M. B. Wagh and N. Gomathi, “Route discovery for vehicular ad hoc networks using modified lion algorithm,” *Alexandria Engineering Journal*, Vol. 57, No. 4, pp. 3075–3087, Dec. 2018.

[46] A. A. Almohammedi, N. K. Noordin, A. Sali, F. Hashim, W. A. Jabbar, and S. Saeed, “Modeling and analysis of IEEE 1609.4 MAC in the presence of error-prone channels,” *International Journal of Electrical and Computer Engineering (IJECE)*, Vol. 9, No. 5, pp. 3531–3541, 2019.

[47] K. Na Nakorn and K. Rojviboonchai, “Non-GPS data dissemination for

VANET," *International Journal of Distributed Sensor Networks*, Vol. 2014, No. 1, p. 906084, Jan. 2014.

[48] A. Srivastava, A. Prakash, and R. Tripathi, "Location based routing protocols in VANET: Issues and existing solutions," *Vehicular Communications*, Vol. 23. Elsevier Inc., p. 100231, 01-Jun-2020.

[49] A.-S. K. Pathan, *Security of Self-Organizing Networks: MANET, WSN, WMN, VANET*, 1st ed. Auerbach Publications, 2019.

[50] A. Rawat, S. Sharma, and R. Sushil, "VANET: SECURITY ATTACKS AND ITS POSSIBLE SOLUTIONS," *Journal of Information and Operations Management*, Vol. 3, No. 1, pp. 301–304, 2012.

[51] J. M. De Fuentes, L. González-Manzano, A. I. González-Tablas, and J. Blasco, "Security models in vehicular ad-hoc networks: A survey," *IETE Technical Review (Institution of Electronics and Telecommunication Engineers, India)*, Vol. 31, No. 1. Medknow Publications, pp. 47–64, 2014.

[52] A. M. Malla and R. K. Sahu, "Security attacks with an effective solution for dos attacks in VANET," *International Journal of Computer Applications*, Vol. 66, No. 22, 2013.

[53] P. Deshmukh, "Improving Energy and Efficiency in cluster based VANETs through AODV Protocol," Vol. 5, No. 3, pp. 4788–4792, 2014.

[54] M. Elhoseny and K. Shankar, "Energy Efficient Optimal Routing for Communication in VANETs via Clustering Model," in *Studies in Systems, Decision and Control*, Vol. 242, Springer International Publishing, 2020, pp. 1–14.

[55] A. Khan, D. W. Kum, J. C. Nam, and Y. Z. Cho, "Minimum delay routing protocol for DTN-enabled VANETs," in *APCC 2012 - 18th Asia-Pacific Conference on Communications: "Green and Smart Communications for IT Innovation,"* 2012, pp. 534–538.

[56] A. Ahamed and H. Vakilzadian, "Issues and Challenges in VANET Routing Protocols," in *IEEE International Conference on Electro*

Information Technology, 2018, Vol. 2018-May, pp. 723–728.

[57] E. R. Cavalcanti, J. A. R. de Souza, M. A. Spohn, R. C. de M. Gomes, and A. F. B. F. da Costa, "VANETs' Research over the Past Decade: Overview, Credibility, and Trends," *SIGCOMM Comput. Commun. Rev.*, Vol. 48, No. 2, pp. 31–39, May 2018.

[58] H. Bello-Salau, A. M. Aibinu, Z. Wang, A. J. Onumanyi, E. N. Onwuka, and J. J. Dukiya, "An optimized routing algorithm for vehicle ad-hoc networks," *Engineering Science and Technology, an International Journal*, Vol. 22, No. 3, pp. 754–766, 2019.

[59] J. A. Volpe, "The Smart/Connected City and Its Implications for Connected Transportation."

[60] P. P. Rajendra, K. S. Santosh, K. K. N. Sunil, S. Majumdar, and Shivashankar, "An efficient routing algorithm based on ant colony optimisation for VANETs," in *2016 IEEE International Conference on Recent Trends in Electronics, Information and Communication Technology, RTEICT 2016 - Proceedings*, 2017, pp. 436–440.

[61] B. Ranjan Senapati and P. Mohan Khilar, "Optimization of performance parameter for vehicular ad-hoc NETwork (VANET) using swarm intelligence," in *Studies in Computational Intelligence*, Vol. SCI 871, Springer, 2020, pp. 83–107.

[62] G. D. Singh, M. Prateek, and G. Hanumat Sastry, "Swarm intelligence based efficient routing algorithm for platooning in VANET through ant colony optimization," *International Journal of Innovative Technology and Exploring Engineering*, Vol. 8, No. 9, pp. 1238–1244, 2019.

[63] S. Singh, "A closer look through routing protocols in vehicular ad hoc networks (VANETs)," *IOSR Journal of Engineering*, Vol. 4, No. 6, pp. 58–64, Jun. 2014.

[64] M. Chaqfeh, A. Lakas, and I. Jawhar, "A survey on data dissemination in vehicular ad hoc networks," *Vehicular Communications*, Vol. 1, No. 4, pp. 214–225, 2014.

[65] C. Ksouri, I. Jemili, M. Mosbah, and A. Belghith, "VANETs Routing Protocols Survey: Classifications, Optimization Methods and New Trends," in *Communications in Computer and Information Science*, 2020, Vol. 1130 CCIS, pp. 3–22.

[66] A. Roy, B. Paul, and S. K. Paul, "VANET topology based routing protocols & performance of AODV, DSR routing protocols in random waypoint scenarios," in *1st International Conference on Computer and Information Engineering, ICCIE 2015*, 2016, pp. 50–53.

[67] S. Hayat, X. Liu, Y. Li, and Y. Zhou, "Comparative analysis of VANET's routing protocol classes: An overview of existing routing protocol classes and futuristic challenges," in *2019 2nd International Conference on Electronics Technology, ICET 2019*, 2019, pp. 1–7.

[68] B. Paul, A. Roy, and S. K. Paul, "Comparison of DSR, AODV, and DSDV routing protocols with varying pause time & Node density over tcp & Cbr connections in VANET," in *Proceedings - 2014 6th International Conference on Computational Intelligence and Communication Networks, CICN 2014*, 2014, pp. 374–379.

[69] A. K. Basil, M. Ismail, M. A. Altahrawi, H. Mahdi, and N. Ramli, "Performance of AODV and OLSR routing protocols in VANET under various traffic scenarios," in *2017 IEEE 13th Malaysia International Conference on Communications, MICC 2017*, 2018, Vol. 2017-November, pp. 107–112.

[70] N. Javaid, A. Bibi, S. H. Bouk, A. Javaid, and I. Sasase, "Modeling enhancements in DSR, FSR, OLSR under mobility and scalability constraints in VANETs," in *IEEE International Conference on Communications*, 2012, pp. 6504–6508.

[71] T. K. Araghi, M. Zamani, and A. B. T. Abdul Mnaf, "Performance analysis in reactive routing protocols in wireless mobile Ad Hoc networks using DSR, AODV and AOMDV," in *Proceedings - 2013 International Conference on Informatics and Creative Multimedia, ICICM 2013*, 2013, pp. 81–84.

[72] D. A. Maltz and D. B. Johnson, "The Dynamic Source Routing Protocol (DSR) for Mobile Ad Hoc Networks for IPv4."

[73] Priyanshu and A. K. Maurya, "Impact of node density on the performance of GSR & TORA routing protocols," in *Proceedings - 5th IEEE International Conference on Computer and Communication Technology, ICCCT 2014*, 2015, pp. 251–255.

[74] A. Sharma and R. Kumar, "Performance comparison and detailed study of AODV, DSDV, DSR, TORA and OLSR routing protocols in ad hoc networks," in *2016 4th International Conference on Parallel, Distributed and Grid Computing, PDGC 2016*, 2016, pp. 732–736.

[75] B. Pete and P. Jaini, "Continuous connectivity aware routing in VANET using hybrid protocol," in *2nd International Conference on Electronics and Communication Systems, ICECS 2015*, 2015, pp. 223–226.

[76] D. Lin, J. Kang, A. Squicciarini, Y. Wu, S. Gurung, and O. Tonguz, "MoZo: A Moving Zone Based Routing Protocol Using Pure V2V Communication in VANETs," *IEEE Transactions on Mobile Computing*, Vol. 16, No. 5, pp. 1357–1370, May 2017.

[77] T. Willke, P. Tientrakool, and N. Maxemchuk, "A survey of inter-vehicle communication protocols and their applications," *IEEE Communications Surveys and Tutorials*, Vol. 11, No. 2, pp. 3–20, 2009.

[78] H. Ghafoor and K. Aziz, "Position-based and geocast routing protocols in VANETs," in *2011 7th International Conference on Emerging Technologies, ICET 2011*, 2011.

[79] S. S. Magdum, M. Sharma, S. M. Kala, A. Antony Franklin, and B. R. Tamma, "Evaluating DTN Routing Schemes for Application in Vehicular Networks," in *2019 11th International Conference on Communication Systems and Networks, COMSNETS 2019*, 2019, pp. 771–776.

[80] S. Zeadally, R. Hunt, Y. S. Chen, A. Irwin, and A. Hassan, "Vehicular ad hoc networks (VANETS): Status, results, and challenges,"

Telecommunication Systems, Vol. 50, No. 4, pp. 217–241, Aug. 2012.

[81] A. D. Devangavi and R. Gupta, “Routing protocols in VANET-A survey,” in *Proceedings of the 2017 International Conference On Smart Technology for Smart Nation, SmartTechCon 2017*, 2018, pp. 163–167.

[82] J. Bhatia, R. Dave, H. Bhayani, S. Tanwar, and A. Nayyar, “SDN-based real-time urban traffic analysis in VANET environment,” *Computer Communications*, Vol. 149, pp. 162–175, Jan. 2020.

[83] T. W. Chim, S. M. Yiu, L. C. K. Hui, and V. O.k. Li, “VSPN: VANET-based secure and privacy-preserving navigation,” *IEEE Transactions on Computers*, Vol. 63, No. 2, pp. 510–524, 2014.

[84] J. Alonso-Zárate, C. Crespo, C. Skianis, L. Alonso, and C. Verikoukis, “Distributed Point Coordination Function for IEEE 802.11 wireless ad hoc networks,” *Ad Hoc Networks,* Vol. 10, No. 3, pp. 536–551, 2012.

[85] P. D. Dorge, G. H. Raisoni, and M. B. Chakole, “Implementation of MIMO and AMC Techniques in WiMAX Network based VANET System Implementation of MIMO and AMC Techniques in WiMAX Network based VANET System Dr. Sanjay S. Dorle,” *Article in International Journal of Information Technology and Computer Science*, Vol. 2, pp. 60–68, 2016.

[86] V. Patel, M. Chaturvedi, and S. Srivastava, “Comparison of SUMO and SiMTraM for Indian Traffic Scenario Representation,” in *Transportation Research Procedia*, 2016, Vol. 17, pp. 400–407.

[87] R. Cumbal, X. Calderon, R. Hincapie, L. Urquiza, and G. Arevalo, “Performance analysis of a VANET with optimal infrastructure location in setting urban,” in *2018 IEEE Colombian Conference on Communications and Computing, COLCOM 2018 - Proceedings*, 2018.

[88] F. Goudarzi, H. Asgari, and H. S. Al-Raweshidy, “Traffic-aware VANET routing for city environments-a protocol based on ant colony optimization,” *IEEE Systems Journal*, Vol. 13, No. 1, pp. 571–581, Mar. 2019.

[89] C. H. Lee, K. G. Lim, M. K. Tan, R. K. Y. Chin, and K. T. K. Teo, "A genetic algorithm for management of coding resources in VANE T," in *Proceedings - 2017 IEEE 2nd International Conference on Automatic Control and Intelligent Systems, I2CACIS 2017*, 2017, Vol. 2017-December, pp. 80–85.

[90] Y. He, W. Xu, and X. Lin, "A stable routing protocol for highway mobility over vehicular ad-hoc networks," in *IEEE Vehicular Technology Conference*, 2015, Vol. 2015.

[91] Y. Zhou and J. Wang, "A Local Search-Based Multiobjective Optimization Algorithm for Multiobjective Vehicle Routing Problem with Time Windows," *IEEE Systems Journal*, Vol. 9, No. 3, pp. 1100–1113, Sep. 2015.

[92] M. Hashem Eiza, T. Owens, and Q. Ni, "Secure and Robust Multi-Constrained QoS Aware Routing Algorithm for VANETs," *IEEE Transactions on Dependable and Secure Computing*, Vol. 13, No. 1, pp. 32–45, Jan. 2016.

[93] M. Rajesh Kumar and S. K. Routray, "Ant Colony based Dynamic source routing for VANET," in *Proceedings of the 2016 2nd International Conference on Applied and Theoretical Computing and Communication Technology, iCATccT 2016*, 2017, pp. 279–282.

[94] A. Elbery, H. Rakha, M. Y. Elnainay, F. Filali, and W. Drira, "Eco-routing: An Ant Colony based Approach."

[95] C. Wang, Q. Fan, X. Chen, and W. Xu, "Prediction based Greedy Perimeter Stateless Routing Protocol for Vehicular Self-organizing Network," in *IOP Conference Series: Materials Science and Engineering*, 2018, Vol. 322, No. 5, p. 052019.

[96] M. Jafer, M. A. Khan, S. Ur Rehman, and T. A. Zia, "Optimizing Broadcasting Scheme for VANETs Using Genetic Algorithm," in *Proceedings - Conference on Local Computer Networks, LCN*, 2016, pp. 222–229.

[97] G. H. Alsuhli, A. Khattab, and Y. A. Fahmy, "Double-head clustering for resilient VANETs," *Wireless Communications and Mobile Computing*, Vol. 2019, 2019.

[98] B. Dappuri, M. Amru, and A. M. Venkatanaga, "A stable routing algorithm based on link prediction method for clustered VANET," in *Intelligent Systems Reference Library*, Vol. 172, Springer, 2019, pp. 85–95.

[99] H. Bello-Salau, A. M. Aibinu, Z. Wang, A. J. Onumanyi, E. N. Onwuka, and J. J. Dukiya, "An optimized routing algorithm for vehicle ad-hoc networks," *Engineering Science and Technology, an International Journal*, Vol. 22, No. 3, pp. 754–766, Jun. 2019.

[100] A. M. Aibinu, H. Bello Salau, N. A. Rahman, M. N. Nwohu, and C. M. Akachukwu, "A novel Clustering based Genetic Algorithm for route optimization," *Engineering Science and Technology, an International Journal*, Vol. 19, No. 4, pp. 2022–2034, Dec. 2016.

[101] S. Harifi, J. Mohammadzadeh, M. Khalilian, and S. Ebrahimnejad, "Giza Pyramids Construction: an ancient-inspired metaheuristic algorithm for optimization," *Evolutionary Intelligence*, pp. 1–19, Jul. 2020.

[102] M. L. Chiang, "Eventually Byzantine Agreement on CDS-based Mobile Ad hoc NETworks," *Ad Hoc Networks*, Vol. 10, No. 3, pp. 388–400, 2012.

[103] R. Tomar, M. Prateek, and H. G. Sastry, "A novel approach to multicast in VANET using MQTT," *Ada User Journal*, Vol. 38, No. 4, pp. 231–235, Dec. 2017.

[104] "CORSIM." [Online]. Available: https://mctrans.ce.ufl.edu/featured/tsis/version5/corsim.htm.

[105] G. D. B. Cameron and G. I. D. Duncan, "PARAMICS—Parallel microscopic simulation of road traffic," *The Journal of Supercomputing*, Vol. 10, No. 1, pp. 25–53, 1996.

[106] "Quadstone Paramics | Traffic and Pedestrian Simulation, Analysis and

Design Software.” [Online]. Available: http://links.giveawayoftheday.com/paramics-online.com/. [Accessed: 02-Nov-2020].

[107] “PTV Group.” [Online]. Available: ptv simulation - VISSIM.

[108] “QualNet - Network Simulation Software | SCALABLE Networks.” [Online]. Available: https://www.scalable-networks.com/products/qualnet-network-simulation-software-tool/. [Accessed: 02-Nov-2020].

[109] Institute of Transportation Systems (DLR), “Eclipse SUMO – Simulation of Urban MObility,” 2019. [Online]. Available: https://www.dlr.de/ts/en. [Accessed: 02-Nov-2020].

[110] W. Xp *et al.*, “Rapid Generation of Realistic Simulation for VANET Manual,” 2011. [Online]. Available: https://lens.csie.ncku.edu.tw/index.php/research-projects/past/18-rapid-vanet. [Accessed: 02-Nov-2020].

[111] B. Boukenadil, “Importance of Realistic Mobility Models for Vanet Network Simulation,” *International journal of Computer Networks & Communications*, Vol. 6, No. 5, pp. 175–182, Oct. 2014.

[112] “STRAW - STreet RAndom Waypoint - vehicular mobility model for network simulations.” [Online]. Available: http://oldaqualab.cs.northwestern.edu/projects/144-straw-street-random-waypoint-vehicular-mobility-model-for-network-simulations-e-g-car-networks. [Accessed: 02-Nov-2020].

[113] “NetSim-Network Simulator & Emulator | Vehicular Adhoc Networks (VANET) Specifications.” [Online]. Available: https://www.tetcos.com/vanets.html. [Accessed: 02-Nov-2020].

[114] J. Härri, M. Fiore, and F. Filali, “Vehicular Mobility Simulation with VanetMobiSim 1.”

[115] V. Nampally, “Simulators for VANET,” *International Journal for Research in Applied Science and Engineering Technology*, Vol. V, No.

IX, pp. 1723–1735, Sep. 2017.

[116] S. A. Ben Mussa, M. Manaf, K. Z. Ghafoor, and Z. Doukha, “Simulation tools for vehicular ad hoc networks: A comparison study and future perspectives,” in *International Conference on Wireless Networks and Mobile Communications, WINCOM 2015*, 2016.

[117] E. Moridi and H. Barati, “RMRPTS: a reliable multi-level routing protocol with tabu search in VANET,” *Telecommunication Systems*, Vol. 65, No. 1, pp. 127–137, May 2017.

[118] G. Lancia and P. Serafini, “Traveling Salesman Problems,” Springer, Cham, 2018, pp. 155–164.

[119] “Advances in Swarm Intelligence for Optimizing Problems in Computer Science - Google Books.” [Online]. Available: https://books.google.co.in/books?hl=en&lr=&id=BidxDwAAQBAJ&oi=fnd&pg=PT97&dq=related:-xsi-mtYhuwJ:scholar.google.com/&ots=6duPSMvNHW&sig=qQAcncvXPhNDeJTJjVC7BgXhzdo&redir_esc=y#v=onepage&q&f=false. [Accessed: 23-Nov-2020].

[120] M. R. Bonyadi and Z. Michalewicz, “Particle swarm optimization for single objective continuous space problems: A review,” *Evolutionary Computation*, Vol. 25, No. 1. MIT Press Journals, pp. 1–54, 01-Mar-2017.

[121] G. Zhang, M. Wu, W. Duan, and X. Huang, “Genetic Algorithm Based QoS Perception Routing Protocol for VANETs,” *Wireless Communications and Mobile Computing*, Vol. 2018, 2018.

[122] R. Hassan, B. Cohanim, O. De Weck, and G. Venter, “A comparison of particle swarm optimization and the genetic algorithm,” in *Collection of Technical Papers - AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference*, 2005, Vol. 2, pp. 1138–1150.

[123] M. Chahal and S. Harit, “Optimal path for data dissemination in Vehicular Ad Hoc Networks using meta-heuristic,” *Computers and*

Electrical Engineering, Vol. 76, pp. 40–55, 2019.

[124] Webpage, "OpenStreetMap." [Online]. Available: https://www.openstreetmap.org/#map=18/30.32427/78.04188.

[125] A. Norouzi and A. H. Zaim, "Genetic algorithm application in optimization of wireless sensor networks," *The Scientific World Journal*, Vol. 2014, 2014.

[126] M.-A. Lèbre, F. Le Mouël, E. Ménard, J. Dillschneider, R. Denis, and R. Denis VANET, "VANET Applications: Hot Use Cases."

[127] S. Jain, S. Sharma, and R. Tomar, "Integration of wit API with python coded terminal bot," in *Advances in Intelligent Systems and Computing*, Vol. 814, Springer, Singapore, 2019, pp. 397–406.

[128] "Download | ns-3." [Online]. Available: https://www.nsnam.org/releases/ns-3-29/download/. [Accessed: 23-Nov-2020].

[129] "dehradun clock tower | OpenStreetMap." [Online]. Available: https://www.openstreetmap.org/search?query=dehradun clock tower#map=15/30.3321/78.0542&layers=N. [Accessed: 23-Nov-2020].

[130] T. K. Bhatia, R. K. Ramachandran, R. Doss, and L. Pan, "A review of simulators used for VANETs: The case-study of vehicular mobility generators," in *2020 7th International Conference on Signal Processing and Integrated Networks, SPIN 2020*, 2020, pp. 234–239.

[131] P. V. D. Khairnar and D. S. N. Pradhan, "Comparative Study of Simulation for Vehicular Ad-hoc Network," *International Journal of Computer Applications*, Vol. 4, No. 10, pp. 15–18, Aug. 2010.

[132] M. J. Haidari and Z. Yetgin, "Veins based studies for vehicular ad hoc networks," in *2019 International Conference on Artificial Intelligence and Data Processing Symposium, IDAP 2019*, 2019.

[133] "GraphPad QuickCalcs: t test calculator." [Online]. Available: https://www.graphpad.com/quickcalcs/ttest1.cfm. [Accessed: 23-Nov-2020].

LIST OF PUBLICATIONS

[1] **G. D. Singh**, M. Prateek, and G. H. Sastry, "A Novel Algorithm for efficient routing in Vehicular Ad hoc Network using Swarm Intelligence optimization techniques", International Journal of Advanced Science and Technology, 29(7), Vol. 29, No. 7, pp. 1132–1143, 2020.

[2] **G. D. Singh**, M. Prateek, and G. H. Sastry, "Methodology to perform Simulation experiments for realistic VANET scenarios using Open Source Software Tools," International Journal of Psychosocial Rehabilation, Vo. 24, Issue 6, May 2020, Page 1017-10175" Vol. 24, No. 06, pp. 10170–10175, 2020.

[3] **G. D. Singh**, M. Prateek, and G. H. Sastry, "Swarm Intelligence Based Algorithm for Efficient Routing in VANET," *International Journal of Innovative Technology and Exploring Engineering*, Vol. 9, No. 5, pp. 1124–1136, 2020.

[4] **G. D. Singh**, M. Prateek, and G. H. Sastry, "Swarm intelligence based efficient routing algorithm for platooning in VANET through ant colony optimization," *International Journal of Innovative Technology and Exploring Engineering*, Vol. 8, No. 9, pp. 1238–1244, 2019.

[5] **G. D. Singh**, R. Tomar, G. H. Sastry, and M. Prateek, "A review on VANET routing protocols and wireless standards," in *Smart Innovation, Systems and Technologies*, Vol. 78, pp. 329–340, 2018.

[6] R. Tomar, **G. D. Singh**, M. Prateek, and G. H. Sastry, "Modelling and Simulation of Vehicle to Vehicle Communication," *International Journal of Control Theory and Applications*, Vol. 10, No. 15, pp. 245–253, 2016.

CERTIFICATE OF PLAGIARISM

1. We _***Dr. Manish Prateek***_ (Internal Guide)____ ***Dr. Hanumat G Sastry***__ (Co Guide) certify that the Thesis titled " Swarm Intelligence based Algorithm for Efficient Routing in VANET" submitted by Scholar Mr._____***Gagan Deep Singh***__ having SAP ID **500024037**__ has been run through a Plagiarism Check Software and the Plagiarism Percentage is reported to be__**1 (one)**_% .

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Analysis address	gagan.upes@analysis.urkund.com

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