EFFICIENT INFORMATION DISSEMINATION ON VEHICULAR AD-HOC NETWORKS USING INTELLIGENT MULTICASTING

A thesis submitted to the
University of Petroleum and Energy Studies

For the Award of
Doctor of Philosophy
in
Computer Science and Engineering

By
RAVI TOMAR

December 2019

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Declaration

I declare that the thesis entitled **"Efficient Information Dissemination on Vehicular Ad-Hoc Networks using Intelligent Multicasting"** has been prepared by me under the guidance of Dr. Hanumat G Sastry, Associate Professor at School of Computer, University of Petroleum & Energy Studies and Dr. Manish Prateek, 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.

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Certificate

We certify that **Ravi Tomar** has prepared his thesis entitled **"Efficient Information Dissemination on Vehicular Ad-Hoc Networks using Intelligent Multicasting"**, 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.

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Abstract

Vehicular Adhoc Networks (VANETs), are the special class of Mobile Adhoc Networks (MANETs) to enable communication between vehicles. VANET promotes road safety and serves as a crucial component for autonomous vehicles. VANETs promising applications are not only restricted to road safety but span from vehicle traffic optimization like flow congestion control to commercial applications like file sharing and internet access. The applications in VANETs need real-time and quick information to realize the usefulness of VANETs.

Efficient information dissemination is extremely important in VANETs. Vehicles gather, process and disseminate relevant data to the other vehicles to realize the applications of VANETs. Information dissemination is paramount to support the development of safety applications and other applications of VANETs.

The main focus of the present research work is to study data dissemination solutions for vehicular environments and provide an efficient information dissemination approach that fulfils the requirements of both safety and other applications of VANETs.

The thesis presents a detailed introduction to VANET and the importance of information dissemination in VANETs. Further, a detailed literature review has been conducted and found some techniques proved better in sparse networks while other in dense networks. Furthermore, it has been observed that no such technique exists in the literature that utilizes the prioritization of messages and makes use of V2V and V2I approach accordingly. And hence, we proposed a novel framework for efficient information dissemination in vehicular networks for V2V and V2I communications. The framework prioritizes the messages and assigns the suitable classID based on the nature of the message and its direction for dissemination. Based on, messages' classID, the framework selects the appropriate dissemination approach. Class 1-4 messages employ the V2V approach and Class-5 messages employ the V2I approach. For effective

dissemination on V2I, a novel information dissemination mechanism is being proposed using Message Queue Telemetry Transport (MQTT) protocol, and this proposed approach is tested in real-time implementation and the results are encouraging. Further, to improve the information dissemination efficiency on V2V, a novel protocol i.e. Priority Based Efficient Information Dissemination Protocol (PBEID) is being developed. The newly developed PBEID protocol is tested on both sparse and dense network scenarios. Further, PBEID protocol is compared with standard information dissemination protocols and found encouraging results. In a gist, the present research program "Efficient Information Dissemination on Vehicular Ad-hoc Networks using Intelligent Multicasting" provided a novel framework along with approaches to leverage the benefits of both V2V and V2I based information dissemination efficiently in vehicular networks.

Acknowledgment

Ph.D. journey is a confluence of multiple learnings, my success in this journey has become possible only because of continuous guidance and help received from many individuals, I am extremely grateful to all of them.

I express my deep sense of gratitude to my research supervisor, Dr. Hanumat G Sastry, for his unconditional support and motivation during the entire journey. I still remember how courteously he has accepted my request to mentor me in this work. His guidance helped me in all the times not only in research but also in real life. He gave me the chance to release my potential in research and taught me how to do research. His simplicity, positivity and discipline have been an inspiration for me, I wish and try to be as humble and disciplined as he is for my entire life.

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I am extremely grateful to the distinguished authors whose precious works have been consulted and referred in my research work.

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I am blessed to have a very loving and supportive family, I cannot express my gratitude in words towards my affectionate parents, for their blessings and constant efforts to make me what I am today. I am thankful to my wife Manu and two lovely daughters, Kritika and Vedika who have shown so much patience and confidence in me.

Above all, I owe it to all almighty God for granting me the wisdom, health, and strength to undertake this research task and to shower his blessings on me to complete my thesis.

Ravi Tomar

Table of Contents

List of Abbreviations

3G	Third Generation
ACK	Acknowledgement
AL	Access Layer
ASTM	American Society for Testing and Materials
AWS	Amazon Web Services
BSM	Basic Safety Message
CALM	Communication Access for Land Mobiles
CBDRP	Cluster-Based Directional Routing Protocol
CBLR	Cluster-Based Location Routing Protocol
CCH	Control Channel
CI	Communication Interface
CID	Class ID
COIN	Clustering for open IVC Network
CORSIM	Corridor Simulation
CRCP	Collision Ratio Control Protocol
CSMA/CA	Carrier-sense multiple access with collision avoidance
CTB	Clear to Broadcast
CW	Contention Window
DB	Deterministic Broadcast
DDCDS	Dynamic Directional Connected Dominating Set

DECA	Density-Aware Reliable Broadcasting Protocol
DRG	Distributed Robust Geocast Protocol
DSR	Dynamic Source Routing
DSRC	Dedicated Short Range Communication
DTSG	Dynamic Time-Stable Geocast Routing Protocol
DVCAST	Distributed Vehicular Broadcast Protocol
EAEP	Edge Aware Epidemic Protocol
EDB	Efficient Directional Broadcast
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
GPS	Global Positioning System
GPSR	Greedy Perimeter Stateless Routing
HCB	Hierarchical Cluster routing Protocol
I2I	Infrastructure to Infrastructure
IaaS	Infrastructure as a Service
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IF	Irresponsible Forwarding
IP	Internet Protocol
IPV6	Internet Protocol Version 6
ISO	International Standards Organization
ITS	Intelligent Transportation System

ITSC	Intelligent Transport System Communications
IVC	Inter Vehicular Communication
LDMB	Link-based Distributed Multi-hop Broadcast
MAC	Medium Access Control
MANET	Mobile Ad-Hoc Networks
MDDV	Mobility-centric Data Dissemination Algorithm for Vehicular Networks
MHVB	Multi-hop Vehicular Broadcast
MLME	MAC Layer Management Entity
MPLS	Multi-Protocol Label Switching
MPR	MultiPoint Relay
MQTT	Message Queue Telemetry Transport Protocol
MRP	Mobicast Routing Protocol
OAPB	Optimized Adaptive Probabilistic Broadcast
OBU	On-board Unit
OSI	Open Systems Interconnection
PaaS	Platform as a Service
PARAMICS	Parallel Microscopic Simulation
PBEID	Priority based efficient Information Dissemination Protocol
PHY	Physical
PLME	Physical Layer Management Entity
QoS	Quality of Service

RBLSM	Reliable Broadcasting of Life Safety Messages Protocol
RMDSI	Reliable Method for Disseminating Safety Information
ROVER	Robust Vehicular Routing Protocol
RS	Random Selection
RSU	Road Side Unit(RSU)
RTB	Request to Broadcast
SaaS	Software as a Service
SCH	Service Channel
SNIR	Signal-to-interference-plus-noise ratio
SODAD	Segment Oriented Data Abstraction and Dissemination
SRB	Selective Reliable Broadcast
STRAW	STreetRAndom Waypoint
SUVNET	Shanghai Urban Vehicular Network
SWANS	Scalable Wireless Ad hoc Network Simulator
TCP	Transport Control Protocol
TRANSIMS	Transportation model Simulation
UMB	Urban Multihop Broadcast Protocol
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VADD	Vehicle-Assisted Data Delivery
VANET	Vehicular Ad-hoc NETworks
VDEB	vehicle-density-based broadcast scheme

VISSIM	VERKEHR IN STÄDTEN – SIMULATIONSMODELL
VPS	VICINITY PRIORITY SELECTION
VPSQ	VICINITY PRIORITY SELECTION WITH QUERIES
WAVE	WIRELESS ACCESS IN VEHICULAR ENVIRONMENTS
WSM	WAVE SHORT MESSAGE
WSMP	WAVE SHORT MESSAGE PROTOCOL
WT	WAITING TIME
WWM	WEIGHTED WAYPOINT MODEL

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Journal

1. R. Tomar, M. Prateek, and G. H. Sastry, *"Vehicular Adhoc Network (VANET) -An Introduction",* Int. J. Control Theory Appl., vol. 9, no. 18, pp. 8883–8888, 2016. https://hal.archives-ouvertes.fr/hal-01496806/document **(SCOPUS), (Published)**
2. R. Tomar, M. Prateek, and H. G. Sastry, *"A novel approach to multicast in VANET using MQTT",* Ada User J., vol. 38, no. 4, pp. 231–235, 2017. **(SCOPUS), (Published)**
3. R. Tomar, H.G. Sastry, M. Prateek, *"Establishing parameters for comparative analysis of V2V communication in VANET,"* J. Sci. Ind. Res., vol.79 , no.1 , p.26-29 , 2020. **(SCI) , (Published)**
4. R. Tomar, H.G. Sastry, M. Prateek, *"V2I Based Approach to Multicast in Vehicular Networks",* Malaysian J. Comput. Sci. vol. x , no. , p. , 2020. **(SCI) , (Accepted)**
5. R. Tomar, H.G. Sastry, M. Prateek, "Priority Based Efficient Information Dissemination Protocol (PBEID) in VANETs", Veh Net J.,vol. , no. , p. , 2020 **(SCI) (Submitted)**

Conference

1. R. Tomar, M. Prateek, and H. G. Sastry, *"Analysis of beaconing performance in IEEE 802.11p on vehicular ad-hoc environment",* in 2017 4th IEEE Uttar Pradesh Section International Conference on Electrical, Computer and Electronics, UPCON 2017, 2018, vol. 2018-January. **(SCOPUS), (Published)**
2. R. Tomar, H.G. Sastry, M. Prateek, *"A Novel Protocol for Information Dissemination in Vehicular Networks"* BT - Internet of Vehicles. Technologies and Services Toward Smart Cities, in: C.-H. Hsu, S. Kallel, K.-C. Lan, Z. Zheng (Eds.), Springer International Publishing, Cham, 2020: pp. 1–14. **(SCOPUS), (Published)**
3. R. Tomar, H.G. Sastry, M. Prateek, *"A Novel Framework for Efficient Information Dissemination for V2X",* in 2020 IEEE 92nd Vehicular Technology Conference: VTC2020-Fall will be held 4 – 7 October in Victoria, BC Canada. **(SCOPUS), (Submitted)**

Chapter 1

Introduction and Motivation

Transportation has a great impact and contribution in human civilization. Human discovered ways to travel from one place to another using animal-powered carts and steam engines. Before the arrival of the steam engine, raw materials and finished goods were hauled and distributed via horse-drawn wagons, and by boats along canals and rivers. The industrial revolution was a significant catalyst to transform the transportation industry. In today's world, transportation has evolved into fast cars, trains, airplanes, and even inter-planet spaceships. According to the report[1], the number of vehicles has increased from 500 million in 1986 to around 1 billion in 2010, another report [2] shows the number of vehicles operating on road in the world was 1.2 billion in 2014 and are expected to be 2 billion by the year 2035. This immense growth of vehicles on roads have bought comfort on the road but also have led to 1.25 million death in a year [3]. This growth not only impacted safety but also increased the CO_2 emissions and wastage of time due to traffic congestions [4]. These problems have led to a new area of research, i.e. Intelligent Transportation System (ITS). ITS has been developed to resolve congestions and save human lives, further the technological developments in artificial intelligence and networks are promising autonomous vehicles. To realize the ITS and autonomous vehicles, a special class of networks are essential for communication between vehicles. This special class of networks are known as VANETs or Vehicular Networks. The Figure 1.1 presents the holistic communication scenario in Intelligent Transportation Systems.

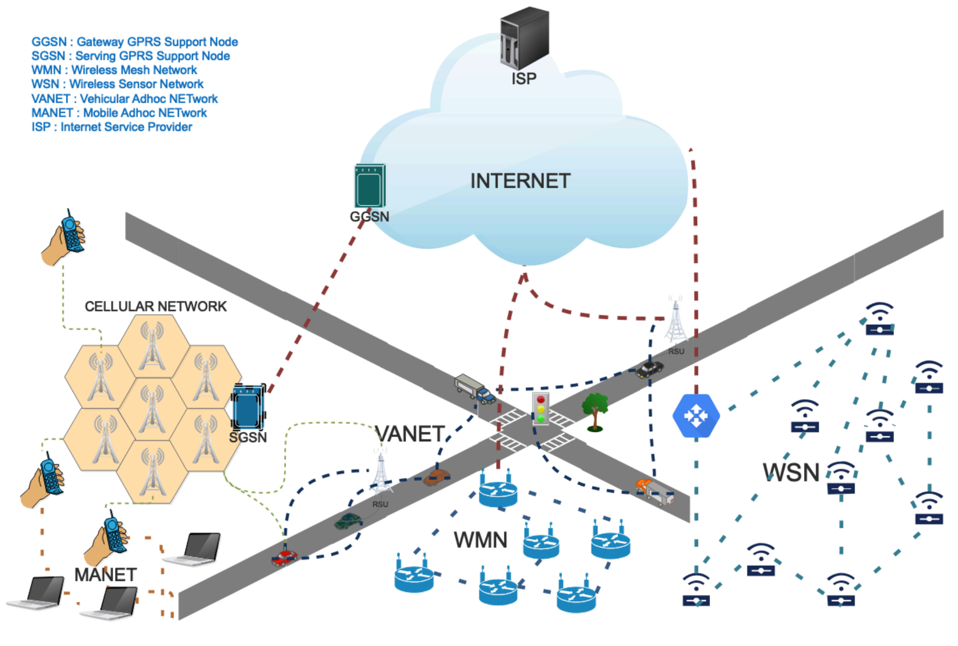

Figure 1.1: Wireless Communication Scenario

Information exchange among vehicles is one of the crucial parameters for the successful deployment of vehicular networks. The present thesis proposes an efficient information dissemination mechanism in vehicular networks, in the context of evolving information and communication technologies.

1.1 Vehicular Ad-hoc Network

Vehicular Ad-hoc Networks, or vehicular networks are a particular class of Mobile Ad-Hoc Networks to establish the communication between the vehicles so that a cooperative environment of vehicles can be realized for various applications. In VANETs vehicles are treated as mobile nodes, and it carries unique characteristics of network topology due to frequent mobility of nodes(vehicles). In general, communication in VANETs takes place using the following mechanisms, i.e.

1)Vehicle to Vehicle (V2V).

2) Vehicle to Infrastructure (V2I).

The V2V communication takes place between the vehicles and no additional infrastructure is required. V2I communication takes place between infrastructure and vehicles. The Figure 1.2 shows a typical VANET scenario with all possible ways of vehicular communications, i.e. Road Side Unit (RSU) to management, Vehicle to RSU, V2V, V2I and RSU to RSU.

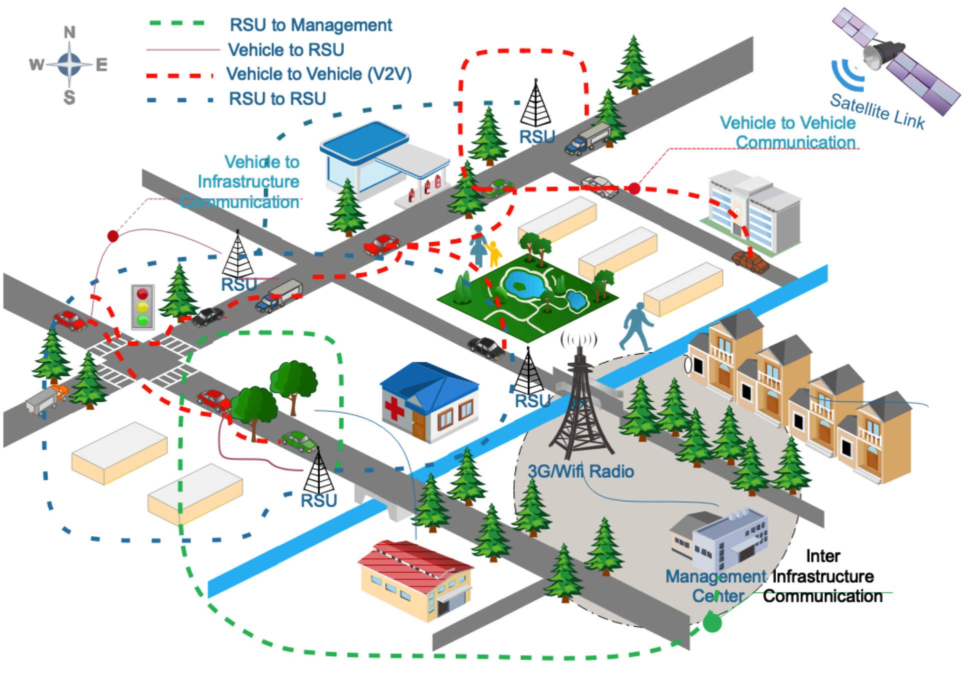

Figure 1.2: Overall VANET Scenario

VANETs being the special class of MANETs possesses special characteristics to develop collaborative services for ITS. The rapid data dissemination is highly essential in vehicular communications, and this generally requires broadcasting. Internet architecture is crucial for VANET deployment, and almost all VANET architectures are built in consideration with Internet architecture with the enablement of Internet Protocol Version 6(IPV6), to facilitate the vehicle to infrastructure connectivity. Delay, bandwidth and QoS are crucial parameters in VANET and these crucial parameters make the difference between VANETs and other network models. The critical differences between VANET and MANET is presented in Table 1.1.

Table 1.1: MANETs vs VANETs

METRIC	MANET	VANET
Deployment cost	Lower	Higher
Level of Mobility	Low	Very High
Frequency	2.4 GHz	5.9 GHz
Range	100 meters	1000 meter
Network partitioning	Low	Very frequent
Mode of operation	Infrastructure less	Infrastructure less and Infrastructure based
Movement of nodes	Random	Constrained by Road, but highly mobile

The following subsection details the VANET characteristics to establish the need for further research in VANETs and its allied communication architectures.

1.1.1 VANET Characteristics

Vehicular Networks possess unique characteristics and challenges in comparison with other classes of Ad-hoc networks[5]. In VANETs, node mobility is quite higher in comparison with MANETs. However, the nodes in VANET follows the predictable pattern while moving. The Figure 1.3 presents VANET characteristics and is detailed in the subsection.

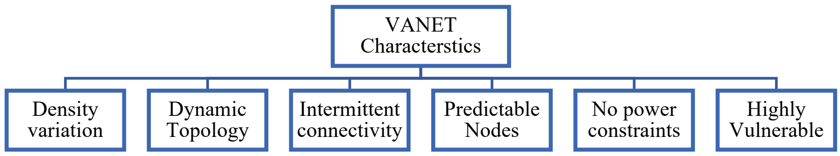

Figure 1.3: VANET Characteristics

a) Density Variation

In vehicular networks, network density varies dynamically. Traffic flow in cities on busy roads is different from traffic flow in rural areas. Further, traffic flow changes dynamically, less traffic flow creates a sparse network and high traffic flow creates a dense network. Optimal algorithms are highly required to meet out the dynamic situation in unpredictable scenarios [6].

b) Dynamic Topology

Vehicular networks possess a special characteristic i.e. dynamic topology. In dynamic topology, nodes association and disassociation take place very frequently. In vehicular networks vehicle(nodes) moves with unpredictable speed, this change in speed makes the vehicle to join and leave the network frequently. The frequent disconnection leads to unstable and dynamic network topology [7].

c) Intermittent Connectivity

The density variation leads to intermittent connectivity. If the road traffic is low, the average vehicle speed would increase, and it eventually leads to intermittent connectivity[8].

d) Predictable Nodes

In VANETs, nodes movement is predictable, and (Global Positioning System) GPS and digital road maps facilitate to identify the vehicle location. Mobility patterns can easily be generated with the help of modern analytics [9].

e) Power Constraints

The VANETs, unlike MANETs, possess a distinctive characteristic, i.e. the abundance of energy and computational power. This is due to the gasoline engine powering the vehicle and hence there is no constraint for battery and computational capability in VANETs[10].

f) Highly Vulnerable

The VANETs being a special class of MANETs is prone to the security challenges, by design VANETs are highly vulnerable to events like false messages [11].

As detailed above, VANET special characteristics pose the demand to create VANET specific architectures and network standards. Various organizations have developed VANET specific architectures to support its effective implementation, among them Open Systems Interconnection(OSI)[12], European Telecommunications Standards Institute (ETSI)[13], Institute of Electrical and Electronics Engineers (IEEE)[14] and Internet Engineering Task Force(IETF) are popular. The following sub-sections present the standard VANET architectures.

1.2 VANET Architecture

VANET architecture defines the underlying wireless techniques and the complete layered protocols to enable the processing of data at various layers. The first ITS services in the USA like automated toll collection used a frequency spectrum between 902 MHz to 928 MHz. The spectrum was minimal to cater to the needs of ITS. Thus, in 1997 the National ITS Architecture urged the Federal Communications Commission (FCC) for a frequency bandwidth of 75MHz in the 5.9GHz frequency range to support Dedicated Short Range Communication(DSRC). Then in 1999, the 75MHz frequency band between 5.85-5.925 GHz was allotted for DSRC based ITS. This section describes the VANETs standard layered architectures developed by organizations like IEEE, OSI, and ETSI.

1.2.1 WAVE Architecture

The American Society for Testing and Materials(ASTM) proposed the specifications in ASTM E2213-10 [15] based on IEEE 802.11[16] . The FCC adopted this proposal in 2004. Based on the specifications proposed in ASTM E2213-10 [15], the task group named p at IEEE in 2004 started to make amendments in 802.11[16] to include vehicular support, and this amendment is known as IEEE 802.11p [14]. The IEEE 802.11p [14] standard was suitable for Medium Access Control (MAC), and Physical (PHY) layers only and higher layers of protocol IEEE working group 1609[17] specified additional standards: IEEE 1609.1[18], IEEE 1609.2[19], IEEE 1609.3[20] and IEEE 1609.4[21]. These IEEE WG 1609 [16]standards, along with IEEE 802.11p[14], are collectively known as Wireless Access in Vehicular Environments(WAVE)[22] architecture. The typical WAVE architecture is presented in Figure 1.4.

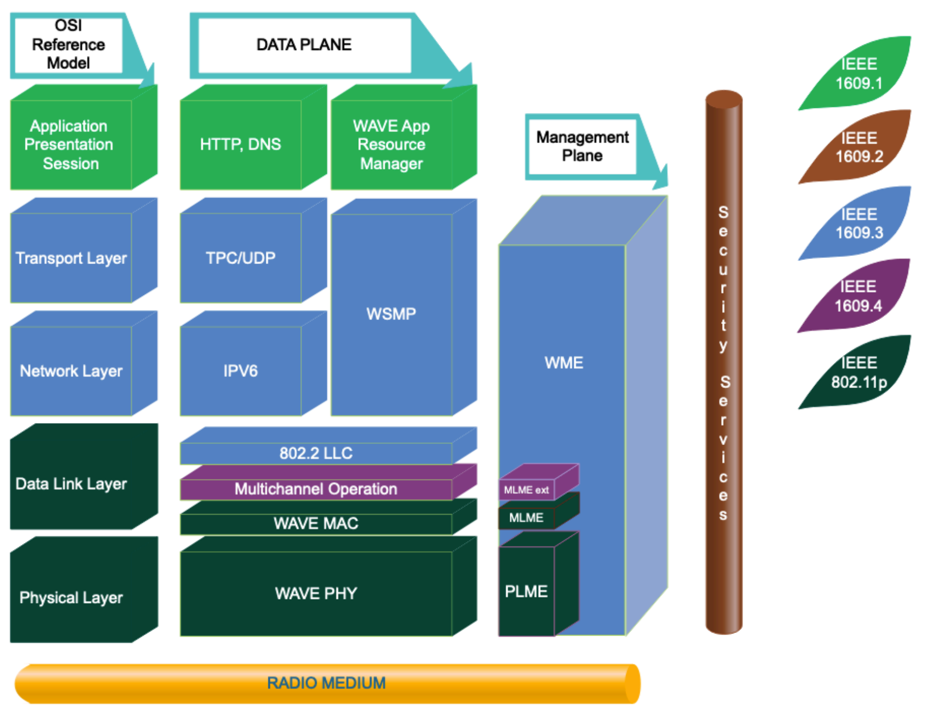

Figure 1.4: WAVE Architecture

The WAVE protocol suite is described and compared with OSI reference architecture in Table 1.2.

Table 1.2: Comparison of OSI reference architecture and WAVE architecture

OSI Layers	**IEEE Standards**	**Description**
Application Layer	IEEE 1609.1	Describes the format of message exchanged with other applications on On-board Unit(OBU), RSUs and neighbourhood nodes
Across all Layers	IEEE 1609.2	These standards specify the WAVE security mechanism across all layers by defining secure message formats.
Transport Layer and Network Layer	IEEE 1609.3	Provides routing and addressing services required for WAVE communication and describes the WSMP(WAVE Short Message Protocol). This WSMP replaces (Transport Control Protocol/Internet Protocol) TCP/IP with broadcast and is capable of prioritizing messages. The special WSM(WAVE Short Message) are used in WSMP, Safety Messages are delivered with low latency and are transmitted over Control Channel(CCH) while non-safety messages are transmitted over Service Channel(SCH).
Datalink Layer	IEEE 1609.4	It provides multi-channel operation between the nodes. One CCH is reserved for the system and critical messages while six SCH are available for non-safety applications. According to this standard, all vehicles have to monitor CCH and have to switch to SCH if any non-safety message has to be transmitted.
Physical and Data Layer	IEEE 802.11p	This protocol specifies MAC and PHY features for the vehicular environment. It also defines the Physical Layer Management Entity(PLME) and MAC Layer Management Entity(MLME). It is based on the Carrier-sense multiple access with collision avoidance (CSMA/CA) mechanism as the

	basic medium access scheme for link sharing and uses one control channel to set up transmissions and to send emergency messages. It also uses service channels for non-sensitive delay applications

1.2.2 CALM Architecture

In 2010, the International Standards Organization (ISO) specified the architectural communication framework for ITS. These specifications in ISO 21217:2010[23] are known as Communication Access for Land Mobiles (CALM) concepts and revised to ISO 21217:2014[24]. The architecture is designed by following the ISO OSI [12] principles. The purpose of CALM architecture is to develop a standardized networking protocol suite for connecting vehicles and roadside systems continuously and seamlessly. Since inception CALM targeted to incorporate all existing, current and future communication technologies. CALM architecture is compatible with 2G cellular, 3G cellular, satellite, infrared, 5GHz microwave,60 GHz millimeter and wireless broadband technologies. The CALM protocol provides the interfaces to work with various wireless technologies. The Figure 1.5 presents the CALM reference architecture[24] [25] along with the access layer communication interfaces.

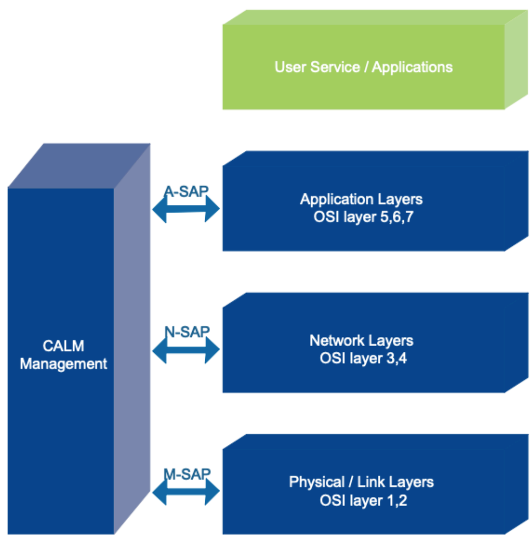

Figure 1.5: CALM Architecture, based on [25]

The Access layer in CALM architecture is responsible for handling various communication standards supported by CALM. The CALM architecture along with various access layer interfaces is described in Table 1.3.

Table 1.3: AL interfaces of CALM architecture

Interface	Description
CALM 2G/2.5G/GPRS Cellular [26]	Determines the air interface parameters for CALM communications via 2G/2.5G cellular networks
CALM 3G [27]	Determines the air interface options applicable to CALM using third-generation (3G) cellular networks
CALM infrared [28]	Determines the air interface using infra-red systems at 820 nm to 1 010 nm.
CALM M5, IEEE 802.11p and WIFI [29], [30]	Provides specifications of the access layer (OSI layers 1 and 2 and the related management functionality) of a communication interface (CI) named "CALM M5", operating in the 5 GHz microwave frequency range.
CALM millimeter, 62-63 GHz [31]	Covers the OSI Layer 1 PHY air interface for a communications medium operating in the 60 GHz millimetric frequency range.

CALM for IEEE 802.16/WiMAX[32]	Additional specifications which wireless devices adhering to the mobile wireless broadband IEEE 802.16 standards must also meet to be CALM compliant.
CALM for IEEE 802.20[33]	Specifies the options appropriate for CALM using mobile wireless broadband (MWB) techniques conforming to the IEEE 802.20 air interface and protocol specification recommended by ITU-R M.1801, and specifies the management interface requirements.
CALM satellite[34]	Provides definitions and procedures for the establishment, maintenance, and termination of an ITS communications session within a CALM system environment using bi-directional satellite communications.

1.2.3 ETSI ITSC Architecture

ETSI developed vehicular communication architecture under the name of Intelligent Transport System Communications (ITSC)[13]. The lowest protocol layer in the ITSC is the Access Layer (AL). The AL contains the slightly adapted version of the IEEE 802.11p amendment at the PHY and MAC levels. The ITSC AL provides its services to the Networking and Transport layer. This layer provides the OSI networking functionality through the set of protocols such as IPv6 with Mobility, UDP/TCP and GeoRouting protocols. The Network and Transport layer provides services to the facilities layer, the facilities layer provides Application, Session and Information support. The facilities layer serves as the pool of services for the applications. The application layer is at the top level in the architecture. The management and security cross-layer components are the orchestrator of the ITSC and both of these components interface with all the other layers in the architecture. This architecture comprises six components and is presented in the Figure 1.6 [35].

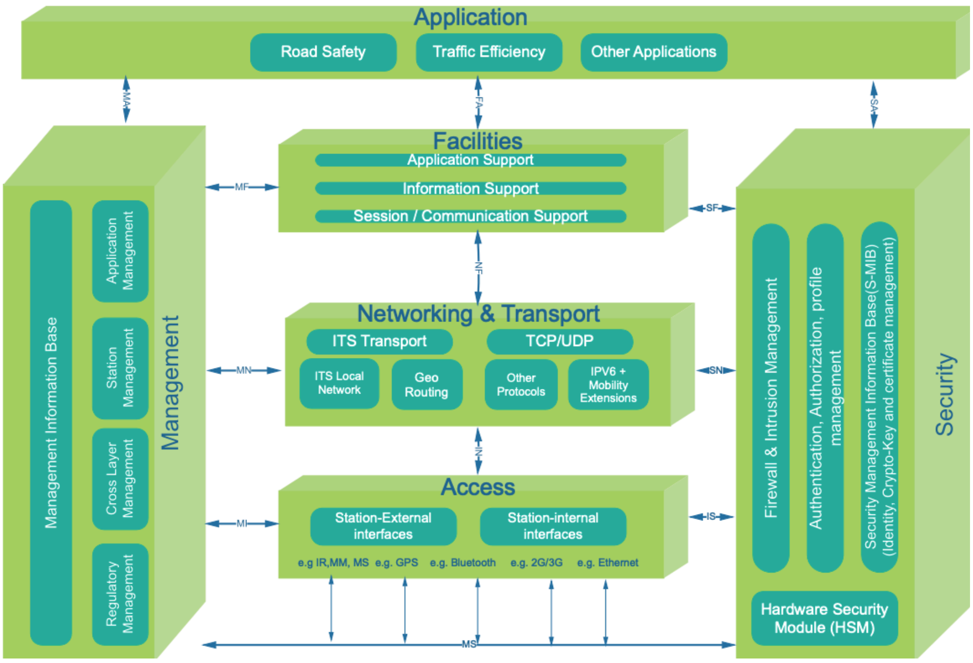

Figure 1.6 : ETSI Networking Architecture for ITS, based on [35]

1.3 Applications of VANETs

VANET has various applications to cater, such as safety, traffic info, red light warning, and infotainment etc. [36]. VANETs become relevant and important in terms of road safety and critical weather updates. The integration with other latest technologies would extend its services in various dimensions as well. Broadly, VANET apps are classified into three categories, i.e. Safety, Traffic and Infotainment Applications.

1.3.1 Safety Applications

The safety application of VANET aims to provide critical alerts to the vehicles to foster road safety. These applications are critical and real-time. Some of the VANET safety applications are detailed below.

a) Location Warning Applications

These applications notify the user about dangerous places beforehand. This information helps the user to take preventive actions, For example, a stretch of the bad road, an oversized speed breaker, a busy road with numerous pedestrians, a sharp turn or a slippery section of the road.

b) Emergency Electronic Brake Lights

In the event of sudden brake applied by leading vehicle, the following vehicle may not observe the sudden break, which leads to an accident.

c) Lane Changing Warning

These applications help users to exchange information about lane changing on highways. This prior information ensures neighboring vehicles to stay alert for such an event.

d) Intersection Collision Warning

These applications are used at intersections of the road. The vehicles coming from different roads must be aware of approaching the vehicle to the intersection and blind turns. These applications use either V2V or V2I based communication.

e) Vehicle to Vehicle Emergency Service application

This kind of application provides information about the approaching nearby emergency vehicle, so that vehicle on the road making way for emergency vehicles to pass the road in minimum possible delay.

f) Rollover Warning

The rollover warning applications are crucial in hilly areas. The fixed roadside infrastructure is used to inform the vehicles about the curve parameters. For example, driving on hilly areas where the turns on the road are not smooth, these applications inform the user about the curve degree, angle and width of the road by using the RSUs.

g) Work Zone Warning

These applications provide upcoming work zone information to the vehicles so that that vehicle can take appropriate action.

Other such services include stationary vehicle warning, wrong-way driving warning, co-operative merging assistance, pre-crash sensing warning, rear-end collision warning, signal violation warning, collision risk warning, and hazardous location warning.

1.3.2 Traffic Management Applications

Traffic Management application of VANET aims to provide traffic-related information to the vehicles. These applications help in the overall coordination and management of traffic. These applications are non-critical and real-time. Some of the VANET Traffic Management applications are detailed below.:

a) Traffic Awareness

In these kinds of applications, vehicles in the network share information among one another to optimize the traffic flow at every road section. This awareness leads to intelligent traffic flow. The moving vehicles collect data and transmit to the RSU. The RSU then sends the collected data to other vehicles coming in the same direction.

b) Sign Extension

In such services, if the traffic signal at the next road segment is jammed due to heavy traffic, the application can notify to the following vehicles. The receiving node can decide the optimal speed for itself depending upon the input being provided by other nodes.

c) Coupling and Decoupling

For vehicles traveling on long and identical routes such as truck drivers and cargo vehicles. The user can couple them together to minimize the latency and traffic overhead. This coupling can be done when the information is available about the driver's route in the earlier phases and is more suitable to be implemented for longer journey routes.

d) Electronic Toll Collection

The vehicle to infrastructure type of communication makes it possible for vehicles to pay the toll electronically. This facility increases operational efficiency and reduces the time overhead for the driver.

e) Route Information

By using the navigation facilities, the travel time can be used by optimizing the routes repeatedly as per traffic and road quality information. This information will also lead to a decreased level of fuel consumption and pollution levels.

1.3.3 Infotainment Applications

The word infotainment is made up of two words, information, and entertainment. Thus, this field of services is meant to provide luxury services to the users which they can enjoy during their journey on the road. Such services include file sharing, video streaming, online songs, internet access, and customized services. However, these services can tolerate a small or medium level delay when being provided to the users as they are not critical, so they are comparatively treated as lower priority services.

a) Co-Operative Local Exchange

Such types of services provide informative entertainment via locally available services such as local stock market exchange, local electronic commerce data, uploading and downloading of data using some stationary infrastructure.

b) Global Internet Services

Such services demand the availability of the internet as a pre-requisite for functioning. Parking zone management, ITS station life cycle management are examples of global internet services.

1.4 Research Challenges of VANETs

VANET is still at its inception stage, and its unique characteristics like density variation, dynamic topology (decentralized nature and self-organization), self-management of high mobility nodes have posed various research challenges like Mobility Management, Security, Quality of Services, Routing, Interoperability and Information Dissemination.

1.4.1 Mobility Management

In general, nodes in VANET possesses a high degree of mobility. Therefore, the probability of link disruption is relatively high, and end-to-end connectivity cannot be easily guaranteed. This leads to many technical challenges in mobility management such as frequent hands-off, selection of optimal rebroadcaster, and integration of multiple access technologies [37].

1.4.2 Security and Privacy

Security and data privacy are leading challenges in VANET. In general, vehicular communication happens over the infrastructure-less mechanism, and the infrastructure-less mechanism is highly prone to network vulnerabilities. In the article “Threat of Intelligent Collisions” [38], authors ask an essential question: “A wireless network of intelligent vehicles can make highway travel safer and faster. But can hackers use the system to cause accidents?”. The question is very well suited to the VANETs because human lives are always at stake. In addition to traditional network security issues like confidentiality, integrity, and availability, VANET has to deal with the security of information about the vehicles and the drivers. The Figure 1.7 presents the major threats and attacks in VANETs[39].

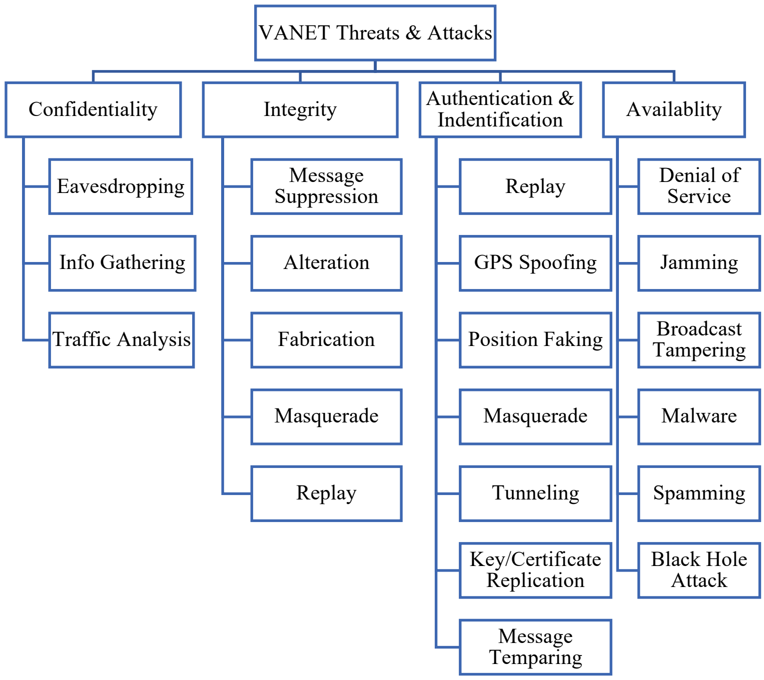

Figure 1.7 : VANET Attacks, Classification and Examples. [39]

Most importantly, these security issues need to be addressed in real-time with the constraint of time. However, the computational capability and battery life is not a bottleneck in VANETs.

1.4.3 QoS

The applications in VANETs need the data in real-time and with minimum latency. This demands proper algorithms to guarantee Quality of Service (QoS). Various researchers worked on QoS related architectures for VANET and proposed some effective schemes to address the issues [40]. However, QoS is an open research area of VANETs.

1.4.4 Routing

In VANETs, wireless communication has been a critical technology to support the achievement of many applications and services. However, due to the characteristics of VANETs, such as high dynamic topology and intermittent connectivity, the existing routing algorithms of MANETs are not available for most application scenarios in VANETs, and this made routing an open research area, having the scope for improvement always.

1.4.5 Interoperability

Efficient VANET deployment requires heterogeneous networks such as Vehicle to Vehicle, Vehicle to Infrastructure, and Infrastructure to Infrastructure environments. This communication between heterogeneous networks creates Interoperability issues. Various standards have been proposed for VANETs and these standards are highly dependent on cooperative standards for interoperability [41].

1.4.6 Information Dissemination

There are different applications and services provided by the VANETs; all applications need information exchange at some point or other to perform their intended task. This information exchange is referred to as information dissemination. The Safety and emergency messages should reach the vehicles as soon as possible with a minimum possible delay. The proper methods and techniques remain an open challenge to deal with proper information dissemination. The research is done in controlling the packet generation rate, utilization off the channel, guaranteed delivery and most important is timely delivery. The present research program is focused to improve the information dissemination in VANETs.

1.5 Research Gap and Direction

The existing Information dissemination algorithms on VANET are not that matured enough to meet its vision [42], [43], [44]. Any generated information has to be quickly distributed among nodes [45]. Moreover, there is no intelligent mechanism to prioritize the crucial type of information, which has to be disseminated without any delay.

1.5.1 Problem Definition

Information dissemination in VANETs can be perceived as multi objective optimization problem. Information priority, information direction, network size, network evaluation parameters are the decision variables and constraints are limited bandwidth, and dynamic vehicle movement. We formulated the research problem on efficient information dissemination using intelligent multicast mechanism in VANETs, and is defined below:

$$\text{solution set } \vec{\mathrm{X}} = \{\overrightarrow{\mathrm{x}_0}, \ldots\ldots, \overrightarrow{\mathrm{x}_3}\} \text{ such that:}$$

$$\overrightarrow{x_0} \textit{ is to be minimized}$$
$$\overrightarrow{x_1} \textit{ is to be minimized}$$
$$\overrightarrow{x_2} \textit{ is to be minimized}$$
$$\overrightarrow{x_3} \textit{ is to be maximized}$$

Where, $\vec{\mathrm{X}}$ is the efficient information dissemination mechanism, $x_0$is the total packet loss, x_1 is propagation time, x_2 is the number of retransmissions and x_3 is the reachability ratio.

1.5.2 Research Objective

The objective of the present research program is to “Design & Implement Efficient Information Dissemination on Vehicular Ad-Hoc Networks using Intelligent Multicasting”

Sub-Objective:

- To study the various existing Information Dissemination algorithms with special emphasis on VANET.
- Identifying the issues in existing Information dissemination algorithms of VANET.
- Explore the various possibilities to prioritize the Information Dissemination mechanism according to the need of the situation.
- Devising the intelligent multicast protocol for efficient information dissemination in VANET.

- 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

1.6 Research Contribution

The present research work is focused on “Efficient Information Dissemination in Vehicular Ad-hoc Networks using intelligent Multicast” and its major contributions are summarised below.

1.6.1 Framework For Efficient Information Dissemination

As a part of the present research program, a novel framework for Information Dissemination over VANET is being proposed, the framework is designed to prioritize the generated information and to disseminate the messages as per priority over the network. The framework leverages the V2I communication and V2V communication approach to efficiently disseminate the information. The framework is detailed in Chapter 3.

1.6.2 A Novel Approach To Multicast in VANETs Using MQTT

As a part of the present research program, a novel approach to multicast in Vehicular Ad-Hoc Networks using the MQTT protocol is being proposed. The purpose of this approach is to disseminate the information in the network in minimum time. This approach makes use of infrastructure and MQTT based communication. This proposed approach is detailed in Chapter 4.

1.6.3 Priority-based Information Dissemination in VANETs (PBEID)

The main goal behind this contribution is to establish a V2V approach for efficient Information dissemination. The proposed technique PBEID takes a multi-level approach to reduce the number of packets generation and still providing a better reception of information in the network. This efficient Information dissemination is achieved by classifying the messages based on their type and later calculating rebroadcasting probability based on the density of the neighbourhood. PBEID protocol is detailed in Chapter 5.

1.7 Thesis Navigation

The remainder of the thesis is organized as follows. Chapter 2 gives an overview of various research areas in VANETs followed by state-of-the-art data dissemination solutions provided in the literature with a detailed description of their characteristics. Chapter 3 provides a detailed description of the proposed novel framework for efficient information dissemination for VANETs. Chapter 4 deals with the novel approach for V2I based information dissemination. Further, this chapter presents detailed experimental results of the proposed approach. Chapter 5 presents the V2V approach for information dissemination in vehicular networks. In this chapter, a novel protocol PBEID has been proposed. Further, this chapter also presents the proposed PBEID protocol evaluation details. Finally, Chapter 6 concludes this thesis with a summary and directions for future work.

Chapter 2

Background and Literature Survey

Vehicular Networks are evolving to realize the ITS, and contemporary technologies have given an opportunity to evolve VANET in the near future to realize its actual purpose. In this chapter, we detailed the various research issues in VANETs followed by the importance of information dissemination in Vehicular Networks. Further, a detailed literature review is presented through the different techniques for information dissemination, and finally outlined the challenges in realizing the vehicular networks in real essence.

2.1 VANET Research Areas

Vehicular Ad-hoc Networks are still at the infancy stage, and researchers are working from various dimensions in Vehicular Networks to realize ITS. This sub-section presents contemporary and comprehensive research in VANET happened so far, and Figure 2.1 presents the major VANET research areas.

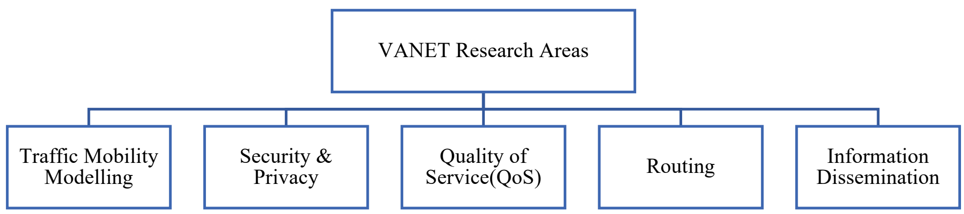

Figure 2.1: VANET Research Areas

2.1.1 Traffic Mobility Modelling

Traffic mobility models play a significant role in designing various VANET routing protocols to meetup real-world traffic scenarios. There are four categories of mobility models that exist [42], i.e., synthetic models, survey-based models, trace-based models, and traffic simulator-based models. The synthetic models are the mathematical models, and further divided into five categories, i.e., stochastic models, traffic stream models, car-following models, queue models, and behavior models. The Figure 2.2 presents the various types of traffic mobility models.

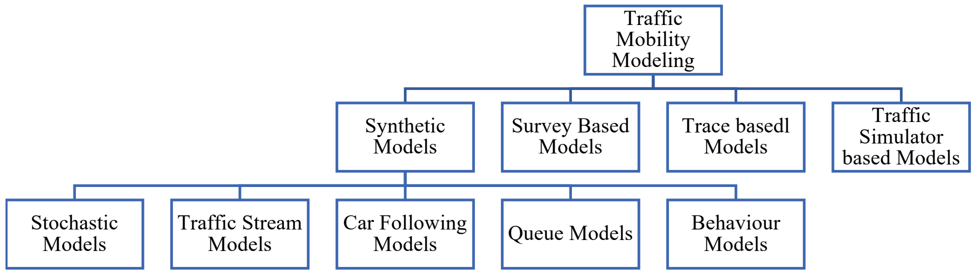

Figure 2.2: Types of Traffic Mobility Modelling

The Weighted Waypoint Model (WWM)[43] and HWGui [44]models are examples of Synthetic models. Survey-based models collect the data from various sources and build the real-life behavior models, the UDeI model[45] is an example of the survey-based model. Further, the trace-based models capture the traces of vehicles and create a realistic depiction of traffic. The projects ETH MMTS [46], CrawDaD[47] , UMASSDieselNet [48], USC MobiLib [49] or MIT Reality Mining [50] are built upon trace-based models. Various researchers have combined various traffic mobility models and developed realistic traffic simulators. Some of the traffic simulators are PARAMICS [51], CORSIM [52], VISSIM [53] or TRANSIMS [54].

2.1.2 Security and Privacy

The intrinsic characteristics of VANETs, such as the high mobility of nodes and short connection times and real-time communication, exhibit it to critical security and privacy issues[55]. The conventional security mechanisms in VANETs are not always effective[39] and Vehicular Networks are vulnerable to all the attacks such as availability, authentication, identification, integrity, non-repudiation, and confidentiality. Consequently, this opens up a broad area to research for making VANETs safer and secure. The cryptographic solutions are proposed in the literature to deal with security issues[39]. The researcher in

[56] proposed the frequency hop technique to address the jamming attack, which compromises the availability. The researcher in [57] developed certain solutions for eavesdropping and traffic analysis. Researchers in [58]–[60] proposed a novel solution to ensure the message authenticity and addressed the message tampering attack.

In addition to the security issues, vehicular networks are also prone to the privacy issues[11]. In order to provide a rich experience, the modern vehicles collect the various information such as habit patterns of users, their mobility, their trajectories, travel companions, and travel stops, etc. This critical information demands proper security policies to protect the privacy. Various researchers[61][62][63] are working to address the privacy issues of VANET. The researchers in [64]proposed a novel and effective privacy scheme for VANETs.

2.1.3 Quality of Service (QoS)

Quality of Service (QoS) is the description or measurement of the overall performance of the service, whereas in networking QoS refers to the mechanism that manages data traffic to reduce packet loss, latency and jitter on the network[65]. QoS controls and manages network resources by setting priorities for specific types of data on the network. QoS in VANET is a critical requirement due to the diverse applications of the network[66]. Although in literature, the researchers have proposed, various architectures and schemes for VANET, but the issues like providing QoS during hands-off remains an open challenge[67][40], [68]. The research is going on in finding an optimal solution to cater to the need of the networks. The researchers in [40] proposed a Multi-Protocol Label Switching (MPLS) based solution for providing better QoS and showed significant results. Another researcher in [69] proposed a novel transport and network layer protocol on VANET aiming to reduce the processing overhead and provide Quality of Service in vehicular networks. The researchers in [66] used Bee inspired QoS routing protocol to improve QoS in VANETs using the bee' mobility behavior.

2.1.4 Routing

Routing is a prime requirement for any network, efficient routing protocols aiming at providing the optimal and shortest path between the nodes. The MANETs have well established routing protocols while VANETs being their special class lacks in utilizing those protocols. Various researchers are working towards efficient VANET Routing protocols aiming to improve the throughput and packet delivery ratio. The Figure 2.3 presents various VANET routing techniques proposed in the literature.

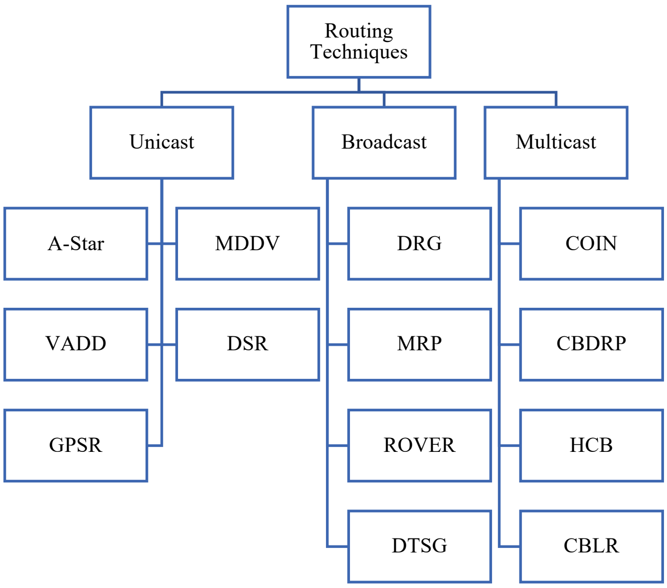

Figure 2.3: Routing Techniques in VANETs

Routing techniques can be classified into three categories, i.e. Unicast, Broadcast, and Multicast. The researchers in [70][71][72][73] [74] proposed different unicast routing techniques A-Star [70], Mobility-centric Data Dissemination Algorithm for Vehicular Networks (MDDV)[71], Vehicle-Assisted Data Delivery(VADD) [72], Dynamic Source Routing(DSR) [73] and Greedy Perimeter Stateless Routing(GPSR) [74] respectively.

The researchers in [75] [76] [77] [78] used geographical information and proposed broadcast-based routing technique as, Distributed Robust Geocast Protocol (DRG)[75], Mobicast Routing Protocol(MRP) [76], Robust Vehicular

Routing Protocol (ROVER) [77] and Dynamic Time-Stable Geocast Routing Protocol (DTSG) [78]

The researchers in [79] [80] [81] [82] used clustering approach and proposed multicast-based routing techniques as, Clustering for open Inter Vehicular Communication(IVC) Network Protocol (COIN)[79], Cluster-Based Directional Routing Protocol (CBDRP) [80], Hierarchical Cluster routing Protocol (HCB) [81] and Cluster-Based Location Routing Protocol (CBLR)[82].

2.1.5 Information Dissemination

Information dissemination in VANET is a prominent research area. The emergency messages have to be disseminated to the farthest node as soon as possible. Effective information dissemination mechanisms are extremely important in VANETs due to its dynamic characteristics such as network size, speed, delivery ratio, intermittent connectivity, etc. The present research program is focused on designing effective information dissemination for vehicular networks, and a detailed literature review on VANET information dissemination is presented in the following sections.

2.2 Information Dissemination in Vehicular Networks

In VANETs, information dissemination is crucial and highly challenging. Unicasting, multicasting and broadcasting are popular mechanisms for information dissemination in VANETs. Unicasting is not that much appropriate in VANET scenarios as it delivers information in one to one mechanism. The information in VANETs is mostly of public interest, and therefore, it becomes more reasonable to broadcast the packets instead of unicasting them. Broadcasting is the most popular mechanism for information dissemination in VANETs. In broadcasting, the flooding mechanism sends the packets to all the neighboring nodes of transmission. This way, it is ensured that the maximum number of nodes have received the transmitted information.

At present, information dissemination majorly relies on infrastructure-based communication. However, in future information exchange among vehicles will be majorly in infrastructure-less mode, and this facilitates the vehicles to join and move out of the network on the fly in order to exchange information swiftly and reliably. The Figure 2.4 presents the various broadcast-based information dissemination protocols of VANET.

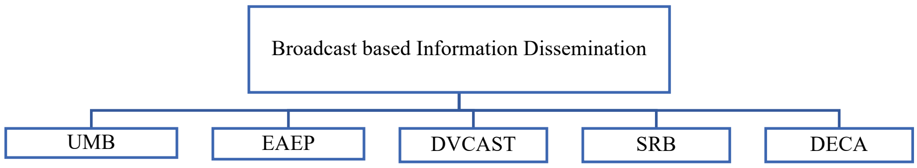

Figure 2.4: Broadcast based Information Dissemination

The Urban Multihop Broadcast Protocol (UMB)[83], Edge Aware Epidemic Protocol(EAEP)[84], Distributed Vehicular Broadcast Protocol (DVCAST) [85], Selective Reliable Broadcast(SRB)[86], and Density-Aware Reliable Broadcasting Protocol (DECA) [8] are some of the broadcast routing protocol proposed in the literature. The next section presents the VANET specific broadcasting techniques in detail.

2.3 Techniques for Information Dissemination

Broadcasting is the more suitable and reliable information dissemination technique for vehicular communication. The Figure 2.5 presents various broadcasting protocols for information dissemination over VANETs, and the following subsection presents contemporary and comprehensive research in this area.

2.3.1 Single-hop Broadcasting Protocols

The single-hop protocols broadcast the updated information to the vehicles in one hop transmission range. Single hop broadcasting protocols rely primarily on the mobility of the vehicle, high mobility of vehicles would spread the information to the farthest node[87]. Broadcast interval value is a key parameter and its setup is crucial. Broadcast intervals with high values would miss the relevant information and low value would cause the redundant packet over the network and packet collision. Optimal broadcast interval value improves the efficiency of the protocol. There are two popular ways to set up the interval value, i.e. Fixed broadcast interval and Adaptive broadcast interval[88].

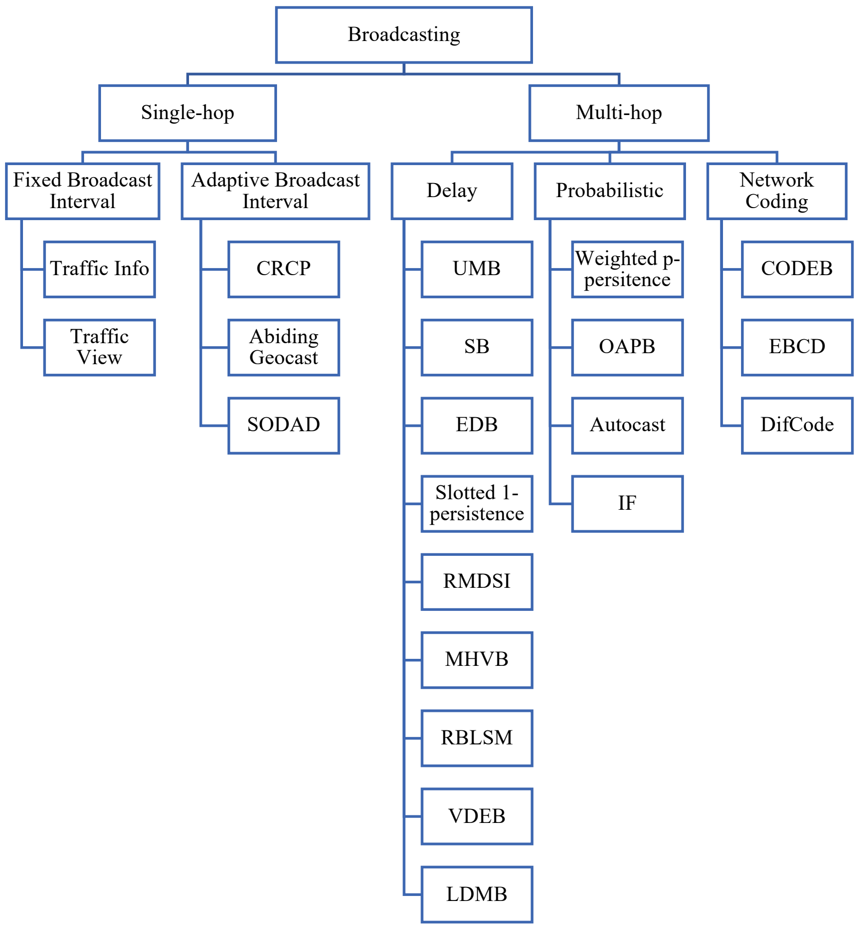

Figure 2.5: Broadcasting protocol for Information Dissemination

a) Fixed Broadcast Interval Single Hop Broadcasting Mechanism

This type of single-hop broadcasting protocol focuses on the selection and aggregation of the critical information to broadcast. The packet receiving vehicle process the received packets and synchronizes its stored database, selection and aggregation procedures updates the packets with the changed information in order to broadcast in the next broadcast cycle.

The researcher in [89] proposed TrafficInfo algorithm, in this single hop fixed broadcast interval algorithm, each vehicle periodically broadcasts information from the onboard database. Broadcasting in TrafficInfo is done by assuming that every vehicle has a digital map of the road segments it travels, and every vehicle has equipped a GPS. The digital map contains various road segments, with each having a unique identification number. Vehicles would exchange the onboard database information among themselves. The onboard database contains the information of the current road segment, speed of the vehicle with a timestamp. This protocol uses a ranking algorithm to rank the information, the first *n* records from the ranked information get selected for broadcasting. The ranking algorithm primarily depends on the current location of the vehicle on a road segment and current time. The information is ranked such that information related to closer road segments are given priority as compared to the farther ones.

The researcher in [90] proposed the TrafficView framework to disseminate and gather information about the vehicle on the road, it broadcasts information based on results of the ratio-based algorithm and cost-based algorithms. In this framework, vehicles store the received packets in its onboard database and shares the information related to speed and position in broadcast cycles. The researcher claims that the results of TrafficView, with the ratio-based algorithm, shown greater flexibility and with the cost-based algorithm shown greater accuracy.

b) Adaptive Broadcast Interval Single Hop Broadcasting Mechanism

The adaptive broadcast interval considers the broadcast interval in addition to the selection and aggregation of the critical information.

The researcher in [91] proposed a Collision Ratio Control Protocol(CRCP), CRCP is a single-hop broadcasting protocol, and it broadcasts information periodically, and this information includes location, speed, and the road ID. This protocol is adaptive to the network density and controls the number of packet collisions in the network by adjusting the broadcast interval value. CRCP sets the broadcast interval with the logic presented in the Algorithm 1.

Algorithm 1: Mechanism for setting Broadcast Interval

If ($CollisionRatio_{estimated}$ > $Transmission_{threshold}$) and ($BandwithEfficiency_{estimated}$> $Bandwidth_{threshold}$)

    extend dissemination interval twice;

else

    shorten dissemination interval one second;

CRCP comprises of the following methods to select the information to broadcast, i.e. Random Selection (RS), Vicinity Priority Selection (VPS), and Vicinity Priority Selection with Queries (VPSQ).

The researchers in [92] proposed the Abiding Geocast protocol, and this protocol enables the dissemination of safety information to the geographically required areas. The packet generated on emergency events contains the coordinates of the area of importance, and the receiving vehicle continues to broadcast it to till the required area. On information dissemination to the required area, this protocol drops the packet and stops its broadcasting. This protocol dynamically adjusts its rebroadcast interval in order to keep the number of packet collisions to a minimum. The rebroadcast interval is dependent on multiple factors such as transmission range, speed, and distance between the vehicle and the emergency site.

The researchers in [93] proposed Segment Oriented Data Abstraction and Dissemination (SODAD) technique, SODAD divides the entire road into segments, and vehicles are aware of segment lengths. The vehicles traveling on a road segment would sense and collect information either on their own or by observing the other vehicle's information. Each vehicle determines its rebroadcast interval based on information related to the road segment of its travel. The information received by the vehicle on a road segment is categorized into two events: provocation and mollification. The event of provocation leads to a reduction in the rebroadcast interval until the next cycle begins, whereas the event of mollification leads to an increase in the rebroadcast time until the next broadcast cycle. On reception of the packet by vehicle, packet information gets compared with an onboard database, if a new message is received higher weight would be assigned otherwise a lower weight. Assigned packet weight identifies the event type occurred, i.e., provocation or mollification in order to decide the rebroadcast interval.

2.3.2 Multi-hop Broadcasting Protocols

This category of protocols spread the information via flooding. In flooding the source vehicle sends the packet to other vehicles in the vicinity, and later, the vehicles that received the information would flood over the network in the next broadcast cycle. Similarly, broadcasts happen over and over, and the packet reaches to the faraway vehicles. However, pure flooding has scalability and packet collision issues, and in case of dense network, these issues are much serious. To address these issues, various researchers have proposed improvements[94] over multi-hop broadcasting protocols as detailed below.

a) Delay-Based Multi-Hop Broadcasting Mechanism

In this approach, a delay is assigned to nodes before they rebroadcast the packet and the vehicles with minimum waiting delay, i.e., the function of the distance between transmitter and vehicle, gets a higher priority and is allowed to rebroadcast the packet. Once the packet rebroadcasts, other vehicle stops rebroadcasting of the same packet. Thus, in order to maximize the packet forwarding, the farthest vehicle is assigned the shortest delay, by providing it with the highest priority to rebroadcast the packet. The various protocols proposed in the literature for delay-based multi-hop broadcasting are discussed as follows.

The researcher in [83] proposed Urban Multi-Hop Broadcast(UMB) protocol, in UMB, the vehicle divides the area under its transmission range into smaller segments, and it assigns the highest priority to the vehicle in the farthest segment. There are two types of packet forwarding in UMB, i.e., directional broadcast and intersectional broadcast. In the directional broadcast, a vehicle divides the road into segments and sends a packet called Request to Broadcast (RTB) to all the vehicles in its transmission range. RTB contains the location of the source vehicle and the direction of the propagation of the message. Different vehicles on receiving RTB start transmitting a jamming signal called black burst, and its duration will be calculated using Eq. (2.1).

$$B = \left(\frac{S}{T} \times N\right) \times S \tag{2.1}$$

Where *B* is the duration of the black burst, *s* is the distance between vehicle and source, *T* is transmission range of the source, *S* is time slot duration, and *N* is a maximum number of road segments.

All the vehicles emit the jamming signal as per their black burst duration and start sensing the channel. If the channel is idle, the vehicle starts rebroadcasting the packet else it aborts its rebroadcasting process. This way the farthest vehicle from the source, gets the highest black burst duration and it becomes the next rebroadcast vehicle, and thus it sends Clear to Broadcast (CTB) packet back to its source. After receiving CTB, the source starts transmitting the packet (DATA) and the next broadcast vehicle sends an ACK back on receiving the packet. In case of a collision, the whole process of RTB-CTB-DATA-ACK starts over again. The second type of forwarding in UMB is intersectional broadcast, and it deals with rebroadcast at road intersections using infrastructure. UMB was designed to address broadcast storm and hidden node problems.

UMB has a limitation due to its long black burst durations to overcome the UMB limitation the researcher in [95] proposed Smart Broadcast (SB) protocol. Smart Broadcast designates the node having the shortest waiting delay as the next rebroadcast vehicle. The source vehicle sends the RTB packet to all the vehicles in its transmission range. The vehicles decide their contention delay based on the sector they are present, by using the set as described in Eq. (2.2).

$$W = \{ (\mathrm{r}-1)\,\mathrm{CW}, (\mathrm{r}-1)\,\mathrm{cw}+1, - - - - - - - -, \mathrm{rcw}-1 \} \tag{2.2}$$

Where r = 1,2,- - - - - N_s refers to the sector number, (r = 1 being the outermost, cw refers to the contention window size. Using this set, the vehicle in the outermost sector gets the minimum delay and thus becomes the next rebroadcast vehicle. Vehicles residing in the same sector chose their waiting times randomly. This mechanism helps to reduce the packet collision rate, and address the latency issue as well.

The researchers in [96] proposed the Efficient Directional Broadcast (EDB) protocol, this protocol uses the directional antennas and works upon the receiver based decision approach, the receiving vehicle decides to rebroadcast the packet in opposite direction. Each vehicle calculates its waiting time using a function described in Eq. (2.3).

$$W = \left(1 - \frac{d}{R}\right) \text{maxWT} \tag{2.3}$$

Where R is the transmission range of the vehicle, W is the waiting time, $maxWT$ is the maximum waiting time, and d is the distance between the transmitter and the vehicle.

The researcher in [97] proposed Slotted 1-Persistence Broadcasting, in this technique, the farthest vehicle from the transmitter is assigned the highest rebroadcast priority and is marked as the next relay vehicle to rebroadcast the packet, and other vehicles discards their rebroadcast process. The rebroadcasting happens w.r.t. the time slot, and it is calculated using the function given in Eq. (2.4) of the distance between the transmitter and the next rebroadcast vehicle.

$$T_{S_{ij}} = S_{ij} \times \tau \tag{2.4}$$

Where $T_{S_{ij}}$ is the time slot duration, S_{ij} is the slot number, and τ is the one-hop propagation and medium access delay. The calculation of the slot number depends on the density of the network, a number of slots N_s, transmission range R, and distance D_{ij} between the transmitter and the vehicle. The slot number is calculated using function provided in Eq. (2.5).

$$S_{ij} = N_s \left(1 - \left\lceil \frac{\min\,(D_{ij}, R)}{R} \right\rceil\right) \times \tau \tag{2.5}$$

The value of N_s keeps on varying with changes in network density and might also lead to multiple vehicles broadcasting the same packet and resulting in the packet collision. Therefore, the number of slots made impacts the performance.

The researcher in [98] proposed a Reliable Method for Disseminating Safety Information (RMDSI) protocol, this delay-based protocol designed to provide a solution for the reliability problem in case the network disconnection. It calculates a waiting time for the next rebroadcast vehicle in a way similar to EDB. The assigned rebroadcast vehicle broadcasts the packet on completion of its waiting time. On reception of the nearby vehicles receive the packet, they abort their own rebroadcasts. This protocol provides a mechanism to address the network fragmentation problem and showed better performance results against UMB protocol.

The researcher in [99] proposed Multi-hop Vehicular Broadcast (MHVB), this delay-based protocol assigns the next rebroadcast priority to the farthest vehicle from the source Vehicles broadcast the packets once its waiting time expires, the rest of the vehicles within the network cancel their broadcast process for that packet.

The researcher in [100] proposed Reliable Broadcasting of Life Safety Messages Protocol (RBLSM), this delay-based protocol provides a reliable way to select the next rebroadcast vehicle. Contrary to the conventional way of assigning the farthest vehicle as to the next rebroadcast vehicle, this protocol assigns the nearest vehicle as to the next rebroadcast vehicle. Selecting the nearest vehicle as the next rebroadcast vehicle is done to ensure reliability as it is more dependable than the farthest vehicle. It uses the mechanism of RTB-CTB-ACK-DATA like other delay-based multihop protocols.

The researcher in [101] proposed a Vehicle-Density-based Broadcast Scheme(VDEB) for emergency message forwarding. This scheme designed to resolve the issue of high overhead and longer delays, and it uses a receiver-oriented contention mechanism along with the density measurement component. In addition, this scheme limits the number of forwarders by the ring width which is calculated by the vehicle density and neighbor information. The simulation results show that the VDEB scheme provides a good delay performance.

The researcher in [102] proposed Link-based Distributed Multi-hop Broadcast (LDMB) forwarding scheme, this scheme is completely distributed, and each vehicle receiving the emergency message estimates its link status before computing the waiting time to forward the message. The parameters distance between sender and receiver, transmission power, transmission rate, and vehicular traffic density are used to compute the waiting time and the packet forwarding scheme is based on the link status. The simulation result shows the equal performance with distance-based multi-hop broadcast and has lower latency.

b) Probabilistic-based Multi-Hop Broadcasting Mechanism

In the probabilistic based multi-hop broadcasting protocol, the probability distribution function is used to assign the rebroadcast priorities. This assignment of different broadcast priorities to vehicles leads to a reduction in the number of redundant packets and the reduction of the number of packet collisions[87].

The researcher in [97] proposed Weighted p-persistence[97] technique. This technique computes the probability to rebroadcast for each vehicle and decides its broadcast priority. A vehicle, that receives the packet for the first time uses the Eq. (2.6) to compute its probability to rebroadcast.

$$p_{ij} = \frac{D_{ij}}{R} \tag{2.6}$$

Where p_{ij} is the probability to be calculated, D_{ij} is the distance between the transmitter and the vehicle, and R is the transmission range of the vehicle. Based on the value calculated for p_{ij} the farthest vehicles get the highest probability to rebroadcast. The major drawback of this protocol is that not considering network density into an account. In a dense network, this protocol may result in an increased number of packet collisions due to the supply of redundant packets.

The researchers in [88] proposed the Optimized Adaptive Probabilistic Broadcast (OAPB) scheme. In this scheme, the density of the network adjacent to it calculates the forwarding probability. The vehicle determines the number of its neighbors and uses Eq. (2.7) to calculate its forwarding probability:

$$\overline{\emptyset} = \frac{P_0 + P_1 + P_2}{3} \tag{2.7}$$

Where P_0 is the function related to the number of one-hop neighbors, P_1 is the function related to the number of two-hop neighbors and P_2 is the function related to the set of two-hop neighbors, it can only be reached using a particular one-hop neighbor. This protocol addresses the flaw of the weighted p-persistence protocol by accounting the network density into the function to calculate probability.

The researcher in [103] proposed the AutoCast protocol. In this protocol, the forwarding probability is calculated using a function dependent on the number of neighbors in the vicinity of that vehicle. This protocol accounts for the density of the network; that is, it changes the forwarding probability according to the density of the network. The Eq. (2.8) is used to calculate the forwarding probability.

$$p = \frac{2}{N_h \times 0.4} \tag{2.8}$$

Where p is the forwarding probability and N_h is the total number of neighbors that are reachable in one hop. The protocol has a limitation that the function cannot work when the number of vehicles in a transmission range is less than 5. However, the protocol provides a mechanism to enhance reachability by adjusting the rebroadcast interval of using the function in Eq. (2.9).

$$t = \frac{N_h}{\alpha} \tag{2.9}$$

Where t is the rebroadcast interval, N_h corresponds to the number of vehicles in the vicinity of the transmitter and α is a constant specifying the number of packets broadcasted per second. This protocol considers the network density and dynamically sets the broadcast interval value, these mechanism helps in reduction of packet collision and increase the packet delivery ratio.

The researcher in [104] proposed Irresponsible Forwarding (IF) scheme, this scheme assigns the rebroadcast priority by a probability function using the distance between the vehicle, the transmitter and the density of the network. This scheme uses a nonlinear function to calculate the probability to rebroadcast. The Eq. (2.10) is used to determine the forwarding probability of each vehicle:

$$p = e^{\frac{-\rho_s(z-d)}{c}} \tag{2.10}$$

Where p is the forwarding probability, ρ_s is the density of the vehicles, z is the transmission range of the vehicle, d is the distance between the vehicle and the transmitter and c is a coefficient ≥ 1, it is used to shape the forwarding probability. The value of forwarding probability is directly proportional to the value of the coefficient. If the value of c increases, the probability also increases. Every vehicle calculates its forwarding probability periodically as per the changes in the network. This scheme was designed to adapt to network density and to reduce the packet collision.

c) Network coding based Multi-Hop Broadcasting Mechanism

The networking coding-based approach reduces the total number of transmissions and thus, increases the throughput of the system, resulting in utilizing the bandwidth to make the network more efficient. The network coding-based protocols designed for mobile ad-hoc networks, and so far, limited research has been taken place in VANET.

The researcher in [105] proposed CODEB, and the CODEB is an extension of the COPE protocol. The CODEB uses opportunistic coding to determine whether a node can handle encoded packets or not while the COPE uses unicast routing. The opportunistic coding is more natural as it sends the encoded packet to one node only, and therefore has to make sure that only that particular node can handle the encoded packet. Whereas the CODEB performs the broadcasting, and thus it has to ensure that all its neighbors can process the encoded information. This process adds another layer of complexity in the functioning of this protocol.

The researcher in [106] proposed the Efficient Broadcasting Using Network Coding and Directional Antennas (EBCD) protocol. This protocol combines the functionality of network coding with directional antennas. This network coding based protocol works similar to CODEB as it also finds a set of forwarder list deterministically. This list contains a set of nodes to be used to broadcast the packet in order to make sure that all nodes in the network receive the packet. However, it uses a different algorithm, i.e. Dynamic Directional Connected Dominating Set (DDCDS) to generate a directional virtual network backbone. EBCD applies network coding in each of the outgoing edges or sectors of the directional antennas. The researchers claim that EBCD performs better in terms of a total number of transmission as compared to protocols using only network coding or the ones using none of these.

The researcher in [107] proposed the DifCode algorithm, the Difcode aims at decreasing the total number of transmissions required to flood the packet in the ad-hoc wireless network. This protocol also functions similar to CODEB, where it selects a set of nodes deterministically and creates a forwarder list for every node. Difcode uses the algorithm based on MultiPoint Relay (MPR) where each node selects only the nodes in its one-hop neighborhood that are covering the two-hop neighbors.

The Table 2.1 presents the synopsis view of the above discussed VANET broadcasting protocols.

Table 2.1: Broadcasting protocols for VANETs.

Comparison of Various Broadcasting Data Dissemination Protocol in VANET S. No.	*Protocol Name*	*Hoping Level*	*Rebroadcast strategy*	*Simulation Platform*	*Evaluation Metrics*	*Focus Area (Algorithm)*	*Simulation Mobility Scenario*	*Algorithm Compared With*

1.	*TrafficInfo*[108][89]	*Single-Hop*	*Fixed Broadcast Interval*	*STRAW / SWANS (Scalable Wireless Ad hoc Network Simulator) [15]*	*Packet Delivery Ratio* *DIK*	*rank-based store-and-forward algorithm*	*Downtown Chicago map modeling in STRAW (STreetRAndom Waypoint)*	*Grassroot*
2.	*TrafficView* [109]	*Single-Hop*	*Fixed Broadcast Interval*	*NS-2*	*Propagation Distance*	*Data aggregation and information dissemination using 802.11b wireless standards.*	*Own developed random-way point mobility model developed at Carnegie Mellon.*	*Non Aggregation, Ratio Based, Cost-Based, Brute Force*
3.	*Collision Ratio Control Protocol (CRCP)*[91]	*Single-Hop*	*Adaptive Broadcast Interval*	*NETSTREAM*	*Packet Drop Ratio*	*RS,* *VPS,* *VPSQ*	*realistic traffic models obtained from Toyota Central R&D Lab*	*RS,* *VPS,* *VPSQ*
4.	*Abiding Geocast*[110]	*Single-Hop*	*Adaptive Broadcast Interval*	*OMNeT++*	*Broadcast Overhead*	*Use of Opposite vehicles and dynamic wait time of individual relay vehicles*	*Static 6km road model with random traffic*	*Different density in the same algorithm*

5.	*Segment-Oriented Data Abstraction and Dissemination (SODAD)*[93]	*Single-Hop*	*Adaptive Broadcast Interval*	*NS-2*	*Packet Drop Ratio, End to End Delay*	*Dissemination of data with a spatial component in sparsely connected mobile ad hoc networks.*	*microscopic traffic simulation using a cellular automaton approach*	*SOTIS and packet density*
6.	*Urban Multi-hop Broadcast (UMB)*[83]	*Multi-Hop*	*Delay*	*Own Developed WS based on CSIM*	*Load Generated Per Broadcast Packet, Packet Delivery Ratio, Dissemination Speed*	*Segment road based on Transmission range & choose farthest to rebroadcast*	*Generated based on MATLAB*	*802.11-distance and 802.11-random*
7.	*Smart Broadcast (SB)*[95]	*Multi-Hop*	*Delay*	*MATLAB*	*One Hop Progress, Rebroadcast Latency, Dissemination Speed*	*Contention resolution procedure is performed to select the relay node.*	*Highway Scenario in MATLAB*	*GeRaF, UMB, MCDS-based, and mathematically acquired results*
8.	*Efficient Directional Broadcast (EDB)*[96]	*Multi-Hop*	*Distance*	*Proprietary/ Shanghai Urban Vehicular Network (SUVnet),*	*Forward Node Ratio, Packet Delivery Ratio*	*Use of directional antennas*	*real mobility model generated by live GPS data of taxis in the city of*	*SDB,RDDB*

							Shanghai	
9.	*Slotted 1-Persistence Broadcasting*[97]	*Multi-Hop*	*Delay*	*OPNET*	*Link Load, Reception Rate, Packet Drop Ratio, No. of Hop Propagated, End to End Delay*	*Assigns time slots based on a computational formula.*	*Single lane and Multilane highway model*	*Slotted 0.5p, weighted p-persistent*
10.	*Reliable Method for Disseminating Safety Information (RMDSI)*[111]	*Multi-Hop*	*Delay*	*NS-2*	*Packet Delivery Ratio, End to End Delay*	*Establish the connectivity in gaps of a new vehicle by sending small messages periodically*	*straight 5 km long highway with 2 Lanes using Freeway traffic model.*	*UMB*
11.	*Multi-hop Vehicular Broadcast (MHVB)*[99]	*Multi-Hop*	*Delay*	*NS-2*	*Packet Delivery Ratio, Packet Drop Ratio*	*Congestion detection and backfire algorithm to select the best receiver based on distance*	*Micro traffic simulator using an intelligent driver model and lane change*	*Own scenarios*
12.	*Reliable Broadcasting of Life*	*Multi-Hop*	*Delay*	*MATLAB*	*Dissemination Speed*	*Prioritization of emergen*	*unspecified*	*UMB, SB and multiple*

	Safety Messages (RBLSM)[112]					*cy packets*		*segments.*
13.	*Vehicle-density-based Emergency Broadcasting (VDEB)*[101]	*Multi-Hop*	*Delay*	*NS-2*	*Redundancy Rate, End to End Delay*	*Vehicle density-based approach.*	*8 km, three lanes, single direction moving highway*	*MCDS, DBS*
14.	*Link Based Distributed Multi-hop Broadcast (LDMB)*[102]	*Multi-Hop*	*Delay*	*Not Specified*	*Packet Delivery Ratio, End to End Delay*	*Calculate waiting for time-based on link-state and do not require a handshake*	*Not Specified*	*DMB*
15.	*Weighted p-Persistence* [97]	*Multi-Hop*	*Probabilistic and distance*	*OPNET*	*Link Load, Reception Rate, Packet Drop Ratio, No. of Hop Propagated, End to End Delay*	*Adjusts probability to broadcast based on computation*	*Single lane and Multilane highway model*	*Slotted 0.5p, weighted p-persistent*
16.	*Optimized Adaptive Probabilistic Broadcast (OAPB)*[88]	*Multi-Hop*	*Probabilistic*	*UC Berkley modified NS-2*	*Broadcast Overhead, Packet Deliver*	*Adaptive rebroadcasting*	*Custom model of 5Km*	*DB with changed P_r*

					y Ratio, End to End Delay			
17.	*AutoCast*[103]	*Multi-Hop*	*Probabilistic*	*NS-2*	*Packet Delivery Ratio, Dissemination Speed*	*The trade-off between data dissemination speed, communication overhead, and delivery ratio.*	*dynamic highway scenario with varying network density, generated using SUMO*	*Theoretical model, mile, flooding*
18.	*Irresponsible Forwarding (IF)*[113]	*Multi-Hop*	*Probabilistic*	*MATLAB*	*Redundancy Rate, Reception Rate, Saved Rebroadcast, End to End Delay*	*Adjust probability based on distance from origin and neighborhood density*	*a straight road with calculated N vehicles.*	*Variable hops*
19.	*CODEB*[105]	*Multi-Hop*	*Network Coding*	*NS-2*	*Packet Delivery Ratio*	*Opportunistic listening , forward selection , and pruning, opportunistic coding*	*random waypoint mobility model with zero pause time*	*PDP, CODEB : XOR, CODEB : RSCode*
20.	*Efficient Broadcasting Using Network Coding and Directional*	*Multi-Hop*	*Network Coding*	*NS-2*	*Redundancy Rate, Packet Delivery Ratio*	*Usage of directed antennas in network*	*n nodes are randomly placed in a*	*Coding, CDS*

	Antennas (EBCD)[106]					*coding based.*	*restricted area.*	
21.	*DifCode*[107]	*Multi-Hop*	*Network Coding*	*OPNET*	*Redundancy Rate*	*Using Multi-Point Relay and Network coding*	*randomly on a square network area*	*Probabilistic NC, Flooding*

2.4 Research challenges in VANET Information Dissemination

The Figure 2.6 presents the identified information dissemination research challenges in VANET. The present research program aimed at to address the identified challenges and to provide an effective information dissemination mechanism over VANET.

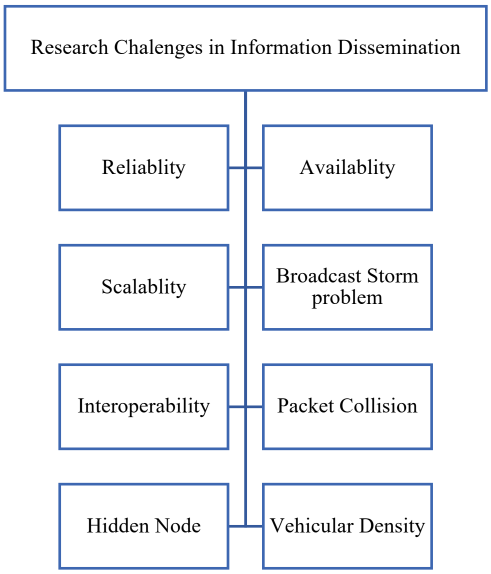

Figure 2.6: Research Challenges in Information Dissemination

2.5 Chapter Summary

In this chapter, we have reviewed various research areas in VANETs, and a detailed review has been done on the solutions designed for information dissemination. There has been a considerable amount of work done in the field of information dissemination, but such works are limited to specific scenarios. Some techniques proved better in sparse networks while others in dense networks. Similarly, no such technique exists in the literature that can utilize the prioritization of messages and make use of V2V and V2I approach accordingly. The following chapters of the thesis aim to build our research lines based upon these works.

Chapter 3

Proposed Framework for Efficient Information Dissemination

In this chapter, we first discuss the need for information dissemination and propose a novel framework for efficient information dissemination. The proposed framework utilizes the benefits of V2V and V2I approaches to deliver messages to the maximum nodes in optimal time. The proposed approach prioritizes the messages and chooses the appropriate approach for dissemination.

3.1 Need of Information Dissemination

Information dissemination is crucial in Vehicular Networks, a lot of utility can be facilitated with the information exchange between vehicles in a real-time manner. Because of this, VANET has been able to support a wide range of applications ranging from road safety to vehicular traffic optimization. The kind of value which this information generates has made VANETs popular in the fields of research, government and the worldwide industry [114]. The Figure 3.1 depicts the overall scenario of vehicular communication.

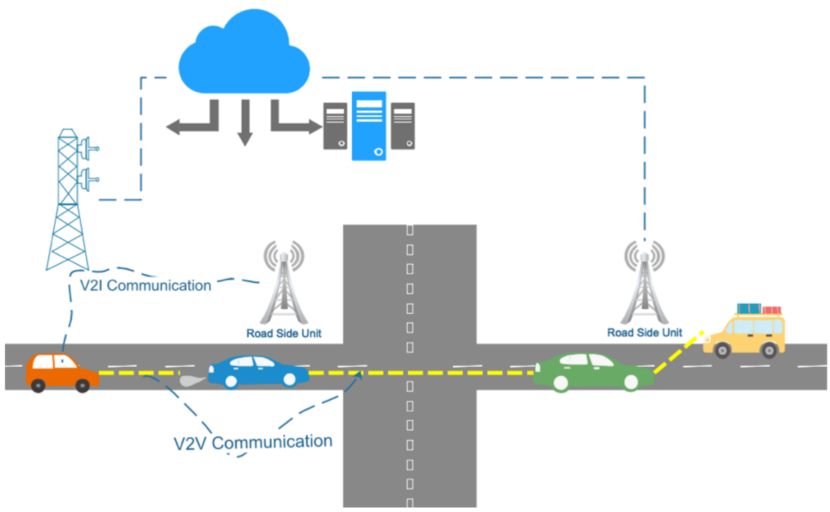

Figure 3.1: Communication modes in VANETs

Information dissemination between components of a VANET can be categorized into two categories broadly, i.e. Vehicle to Infrastructure(V2I) and Vehicle to Vehicle(V2V). The following subsection explains them in detail.

3.1.1 Vehicle to Infrastructure Based Approach

Vehicle to Infrastructure dissemination refers to the information dissemination between the vehicles and various types of the infrastructure of VANETs such as Roadside Units, Cellular Towers, WiMAX etc. V2I primarily employed to disseminate safety and operational information. The vehicle to infrastructure approach possesses a big advantage to do complex processing on data using high-end backend servers and real-time data analysis.V2I can also be used to establish communication with the Internet via the RSUs. There are two key approaches in V2I dissemination i.e. Push based and Pull based approach. [5] In the push-based approach, the infrastructure (RSU) sends out the data to all the vehicles in the range. It is best suited for data that is needed for all the vehicles such as critical event information or public interest data. It works similar to broadcasting and generates lesser contention and collisions, and the Figure 3.2 presents the push-based information dissemination scenario.

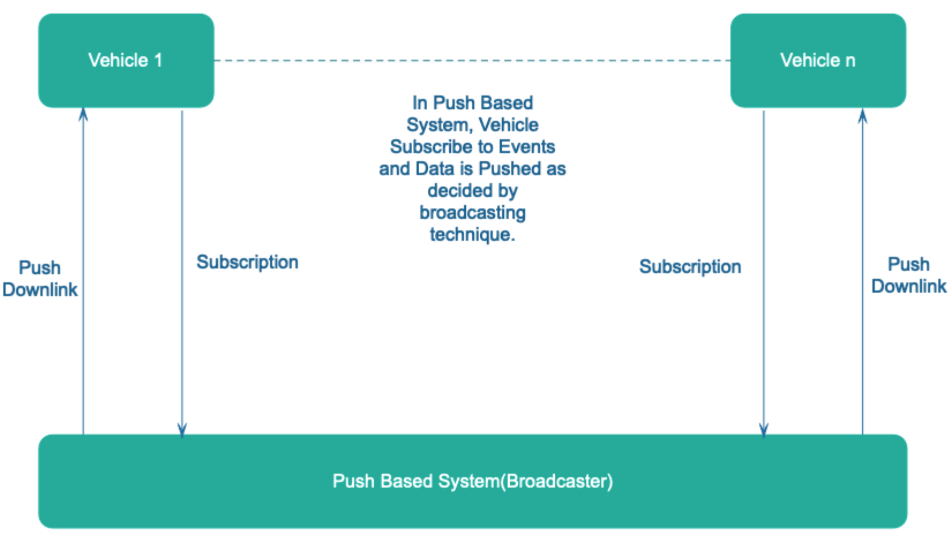

Figure 3.2: Push Based Information Dissemination

In the pull-based approach, a vehicle can query-specific data that it needs. This approach increases the contention and collisions in the network due to constant query and servicing of the queries by the infrastructure. The Figure 3.3 presents the pull-based information dissemination scenario.

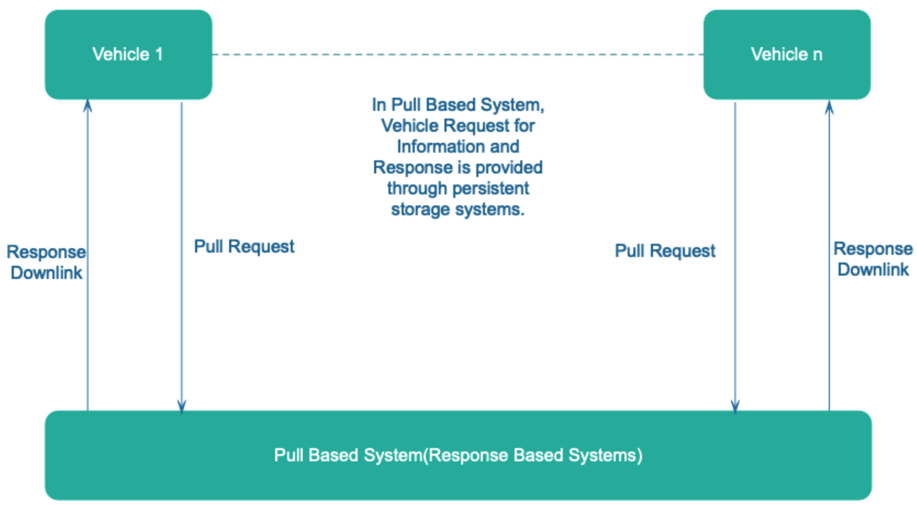

Figure 3.3: Pull Based Information Dissemination

3.1.2 Vehicle to Vehicle Based Approach

Vehicle to Vehicle dissemination refers to the information dissemination between the vehicles using the cooperation of the vehicles. V2V primarily employed to disseminate safety and immediate information when there is no infrastructure available. The vehicle to vehicle approach possesses a big advantage of creating an ad-hoc network on the go and allow information exchange between the vehicles. In this type of information dissemination, the information is sent to the nearby vehicles using the DSRC protocol. The basic data packet being exchanged contains information such as current location, speed, the direction of motion, acceleration etc. This packet is called as Basic Safety Message (BSM) or a beacon. This enables the vehicle to make better-informed decisions by making use of this information [115]. The information dissemination can follow either flooding or relaying based approaches [116]. Flooding involves broadcasting the message to nearby vehicles. It is best suited for sparse networks and for emergency information which required latency. Relaying approach involves selecting a relay node, the relay node is used for relaying the message on the basis of some conditions or rules. This approach is suited for dense networks as the overhead is comparatively less. And hence, the V2V approach is applicable for real-time and zero delay-tolerant applications. The V2V approach incurs much less cost as compared to V2I as no infrastructure is needed. The V2V also has the benefit of creating an ad-hoc network on the go and leave it when not required. The limitations of V2V are more concerned towards establishing a reliable network that can communicate without having lot of collision. The latency is very less in V2V as compared to V2I, but V2V is best suited for short range communication.

V2V and V2I are both equally important to disseminate information over VANET. A novel information dissemination framework is presented in the next section. The proposed framework utilizes both V2V and V2I approaches.

3.2 A Novel Information Dissemination Framework for VANET

The existing information dissemination approaches are based on either V2V or V2I, the proposed framework leverages both V2V and V2I approaches for efficient information dissemination. This framework works in two phases, at first phase, the message will be generated and prioritized along with direction and in the second phase, the information will be disseminated using the V2I or V2V approach. The Figure 3.4 shows the complete framework and the following section explains the various components of the framework.

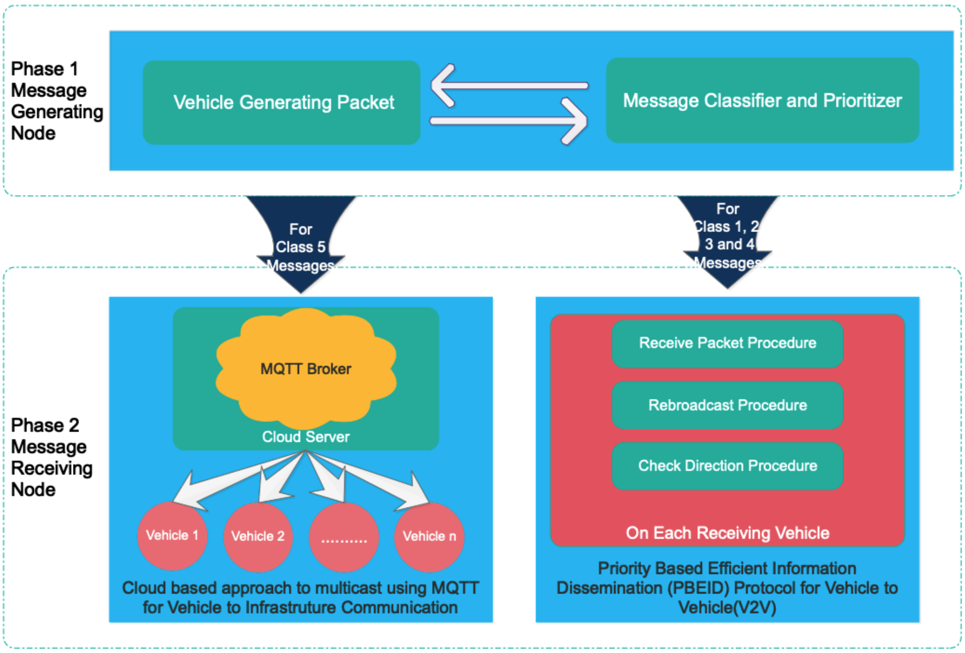

Figure 3.4: A Novel Framework for Efficient Information Dissemination over VANET

3.2.1 Message Generating Node Phase

The generating node phase consists of two components, i.e. the vehicle generating a packet and the message classifier and prioritizer. Various research studies have focused on message classification to prioritize crucial information for effective dissemination, and this approach has given encouraging results [19][20]. The vehicle in phase 1 generates the message using the predefined set of message rules and assigns a classID according to the need of the application. This is achieved by the generate packet component that generates a packet of the information to be disseminated over the network and the message prioritization component that comprises priority, direction, class and details of farthest neighbors. The generated packet is disseminated over the network using the V2V or V2I approach. The following subsections explain both the components.

a) Generate Packet Component

The generate packet component comprises of the GENERATEWARNINGPACKET procedure. If the vehicle encounters any situation such as an emergency, traffic info, sudden brake, accident etc. a packet is generated through this procedure. The generated packet consists of relevant information such as priority, direction, class and farthest neighbor. The packet also contains the maximum distance to broadcast parameter(M_{db}), this parameter defines the area of coverage and is kept to infinity in this work in order to cover the maximum area to disseminate. The generated packets will be broadcasted using the V2V approach or V2I approach based upon the assigned classID. GENERATEWARNINGPACKET procedure is presented in **Algorithm 2**.

Algorithm 2: Generate Warning Packet

```
procedure GENERATEWARNING PACKET
    Farthest Neighbor (Fn) ← GetFarthestNeighbour
    Class (CID) ← AssignClassID
    MaxDistance (Mdb) ← Max Distance to Broadcast(∝)
    AddFarthestNeighbourAndClassAndMaxDistance (Fn, CID, Mdb)
    Broadcast(P) or Publish(P)
```

b) Message Prioritization

In general, the broadcast mechanism spread the information circularly without any direction specific. However, in real-world scenarios, specifying the direction to messages would improve the dissemination efficiency, e.g. Ambulance information needs to be propagated to forward vehicle and sudden brake information required by the following vehicles. Based on this logic, in this step messages are classified by propagation direction along with its priority. Messages are classified into five classes, and each class adopts a specific broadcast policy, and Table 3.1 presents the priority and direction with example.

Table 3.1: Class of Message based on Priority and Direction

Class	Priority	Direction	Example	Approach
1	High	Backward	Accident, Sudden Brake, Bad Road	V2V
2	High	Forward	Ambulance, Fire Vehicle	V2V
3	Medium	Backward	Traffic Updates, Infotainment	V2V
4	Medium	Forward	Other Infotainment	V2V
5	Low	Both	General Broadcast	V2I

- **Class 1 Messages:** Class 1 message indicates an emergency message with backward direction dissemination, e.g., accident, sudden brake detection, etc. These messages are of zero tolerance and should be disseminated as early as possible to all the following vehicles. To understand in a better way, a scenario is presented in Figure 3.5, in this scenario red colored vehicle generated an emergency message due to the sudden occurrence of an event and passed it to the proposed framework. That sudden event could be either an accident or an application of sudden break, and this information is extremely important to the vehicles that are behind the red coloured vehicle. The proposed framework will assign Class 1 to the generated message to facilitate immediate dissemination in backward direction.

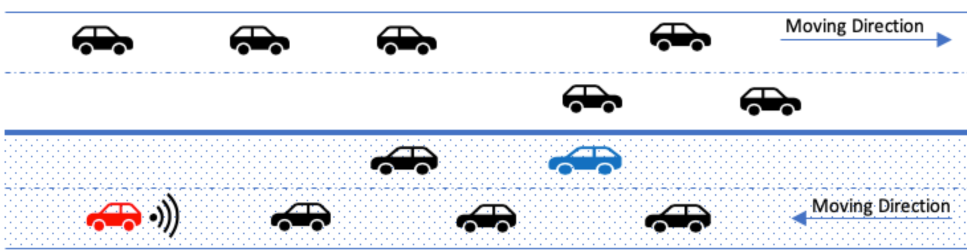

Figure 3.5: Class 1 Message, Backward Broadcast, High Priority

- **Class 2 Messages:** Class 2 message indicates an emergency vehicle trying to overtake vehicles in front, and this message needs to be disseminated in the forward direction, e.g., ambulance, fire vehicle, etc. These messages are also of high priority and should be disseminated as early as possible to all ahead vehicles. To understand in a better way, a scenario is presented in Figure 3.6 , in this scenario red colored vehicle is an emergency vehicle and it requires the road clearance to commute as much as fast. Red colored vehicle generated an emergency message and passed to the proposed framework, then the proposed framework will assign Class 2 to the generated message to facilitate the forward direction dissemination on high priority basis.

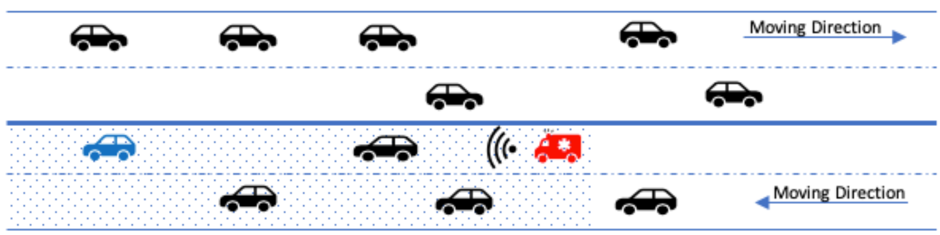

Figure 3.6: Class 2 Message, Forward Broadcast, High Priority

- **Class 3 Messages:** Class 3 message indicates a message with medium priority and backward direction dissemination, e.g., traffic updates, infotainment applications. These messages are of medium priority and possess less critical information. The Figure 3.7 presents the dissemination scenario for Class 3 messages. The red colored vehicle in the figure intend to provide information such as traffic update, infotainment message etc. The event is generated by the red colored vehicle and is passed further to the proposed framework for dissemination. As the message is of medium priority and the information is required to the following vehicles, the proposed framework will assign Class 3 to this message.

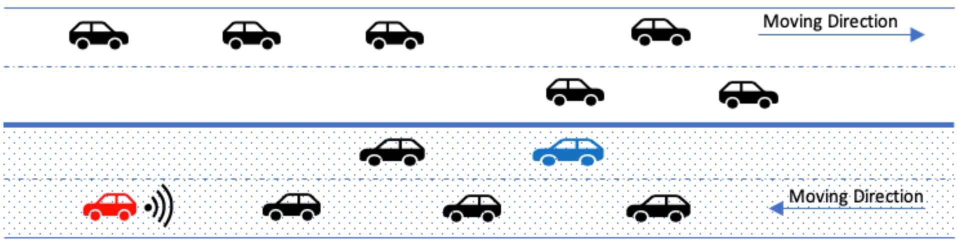

Figure 3.7: Class 3 Message, Backward Broadcast, Medium Priority

- **Class 4 Messages:** Class 4 message indicates message with medium priority and forwards direction dissemination, e.g. lane migration, traffic signal token, advertisement and infotainment. These messages are of medium priority and possess less critical information, for example to share traffic information among nodes and finally updating this information to traffic monitoring applications. The Figure 3.8 presents the dissemination scenario for Class 4 messages. In the scenario, the red colored vehicle generated a medium priority message for forwarding vehicles, and the generated message is passed to the proposed framework. The proposed framework will assign Class 4 to the message to facilitate the forward direction dissemination with medium priority.

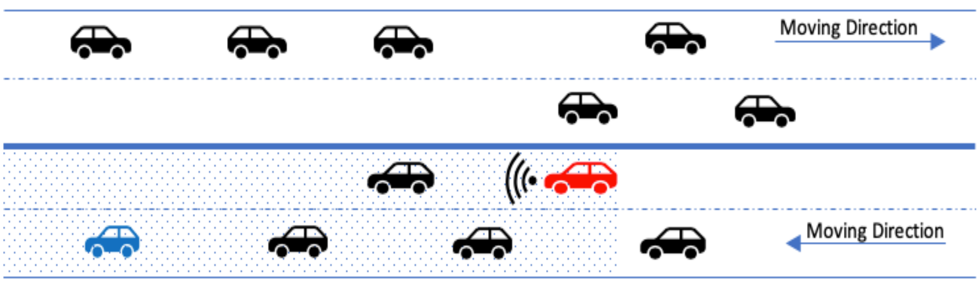

Figure 3.8: Class 4 Message, Forward Broadcast, Medium Priority

- **Class 5 Messages:** Class 5 message indicates a general message, e.g., point of interest, advertisement service, weather information, etc. These messages are of low priority and can be disseminated separately (with permissible latency), the Figure 3.9 depicts the scenario for Class 5 messages. The red colored vehicle in the scenario intend to provide general information to all the vehicles and generated a message. The generated message is passed to the proposed framework, the proposed framework will assign Class 5 to this message in order to facilitate message dissemination to all the vehicles in the network with permissible latency.

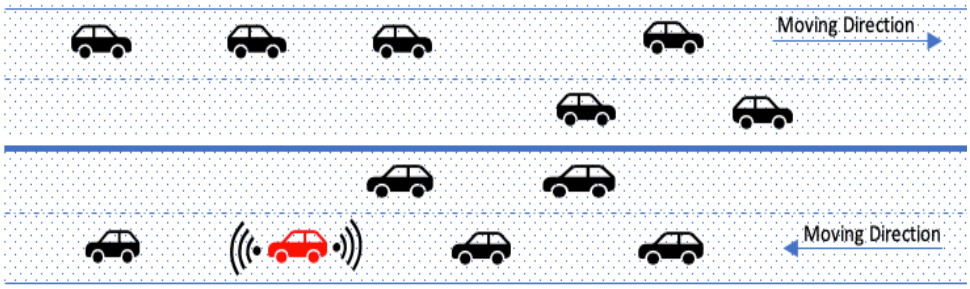

Figure 3.9: Class 5 Message, General Broadcast

3.2.2 Message Receiving Node Phase

In this phase, an appropriate message dissemination mechanism will be selected out of V2V and V2I approaches. The message with class 1-4 uses V2V approach and class 5 message uses V2I approach. The framework is proposed to overcome the limitations of using any single approach such as the V2V approach provides minimum latency in information dissemination but has a limited distance threshold, along with various network issues like collision, hidden terminal, whereas the V2I approach provides marginal latency requirement and QoS but suffers due to high cost of infrastructure. In this phase, the approach is selected based on the application requirements.

a) A Novel Approach to Multicast in VANET using MQTT- A V2I approach.

This approach is operational when the class of message is assigned to 5 during Phase 1. These types of messages are general broadcast messages and are targeted for larger geographical coverage. This is based upon V2I based communication. A central server is deployed on the cloud infrastructure and over this server, a MQTT server is deployed which is accessible through the proper authentication mechanism. The approach follows PUB-SUB architecture. The message generated by the source node is published to the road topic and all the subscribed vehicles receive the message through the MQTT delivery architecture. Chapter 4 presents the complete description of this approach along with the deployment details.

b) Priority based efficient Information Dissemination Protocol (PBEID)- A V2V approach.

This approach is intended for the messages with class ID 1,2,3 and 4. The messages which need real-time delivery in limited geography utilizes this approach. The communication is established using the Ad-hoc network and possesses several issues discussed previously like broadcast storm problem, hidden node and collision. PBEID has been developed to maximize the radio channel utilization and message transmission to maximum nodes in minimum time. Network density and message priority are the significant factors which influence the information dissemination. This protocol is fully compatible with IEEE 802.11p standards[21]. Chapter 5 presents the complete architecture and working procedure of PBEID protocol.

3.3 Chapter Summary

In this chapter, we proposed a novel framework for efficient information dissemination that is capable of working with both V2V and V2I approaches. In addition, the proposed framework consists of an algorithm that assigns classID to the packets based on its type and priority. Further, based on the priority the message is disseminated using one of the two proposed approaches specifically for V2I and V2V respectively. The upcoming Chapter 4 and Chapter 5 detail the novel information dissemination approaches based on V2I and V2V respectively.

Chapter 4

A Novel Approach to Multicast in VANET (V2I)

In this chapter we propose a novel approach for efficient information dissemination in Vehicular Networks using V2I based communication. This approach is developed to disseminate Class 5 messages, and the Class 5 messages has been explained in the previous chapter. This approach makes use of V2I communication to establish the connectivity between the cloud server and the vehicle. The foundation of this work relies on the MQTT protocol, IoT and IaaS. The sections following discuss the various technologies used in this approach, the detailed explanation of the proposed approach and concludes with the experimental setup of the proposed approach.

4.1 Multicast in VANET

In multicast Information dissemination techniques for VANETs, the messages travel from a single sender to a group of interested vehicles[117]. Multicasting reduces the transmission overhead, control overhead and power consumption by sending the copies of messages to various vehicles simultaneously. The MANET based multicast approaches are not well suited for VANETs due to its characteristics like unpredictable topology, and high mobility etc., and hence multicast information dissemination is the most active research area due to their efficiency and mobility within a dynamic environment like VANET. The present research made use of the latest technologies such as Infrastructure as a Service(IaaS)[118], Internet of Things(IoT)[119] and MQTT [120] to implement the multicasting in VANETs. The following section explains the background technologies used specifically in this work.

4.2 Background Technologies

In this section, we discuss the background technologies which are used in this work.

4.2.1 Cloud Computing

Cloud computing is the on-demand delivery of computing power, database, storage, applications, and other IT resources via the internet with pay-as-you-go pricing[121]. Cloud computing provides user access to servers, storage, databases, and an expansive set of application services over the Internet. The typical cloud computing architecture is presented in Figure 4.1.

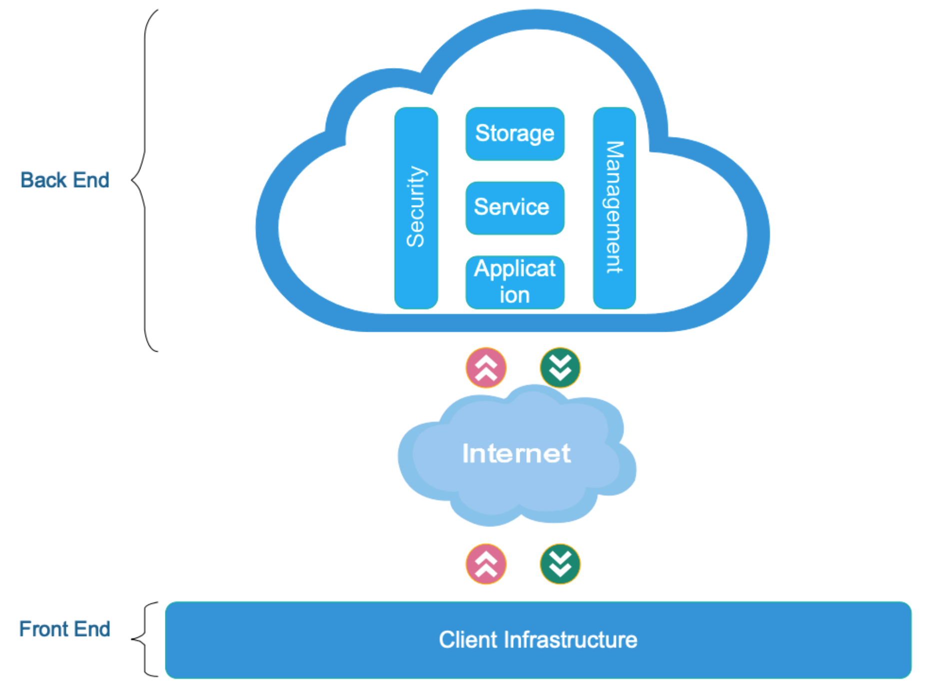

Figure 4.1: Cloud Computing Architecture

The cloud services provider such as Amazon Web Services (AWS) [121] and Google cloud [122] owns and maintains the network-connected hardware required for these application services, while you provision and use what you need via a web application. Due to its simplicity, cost-effectiveness, speed, efficiency, productivity, performance, and security features cloud computing is a popular option for people and businesses. The Figure 4.2 presents the cloud services offered versus on-premises hardware[123].

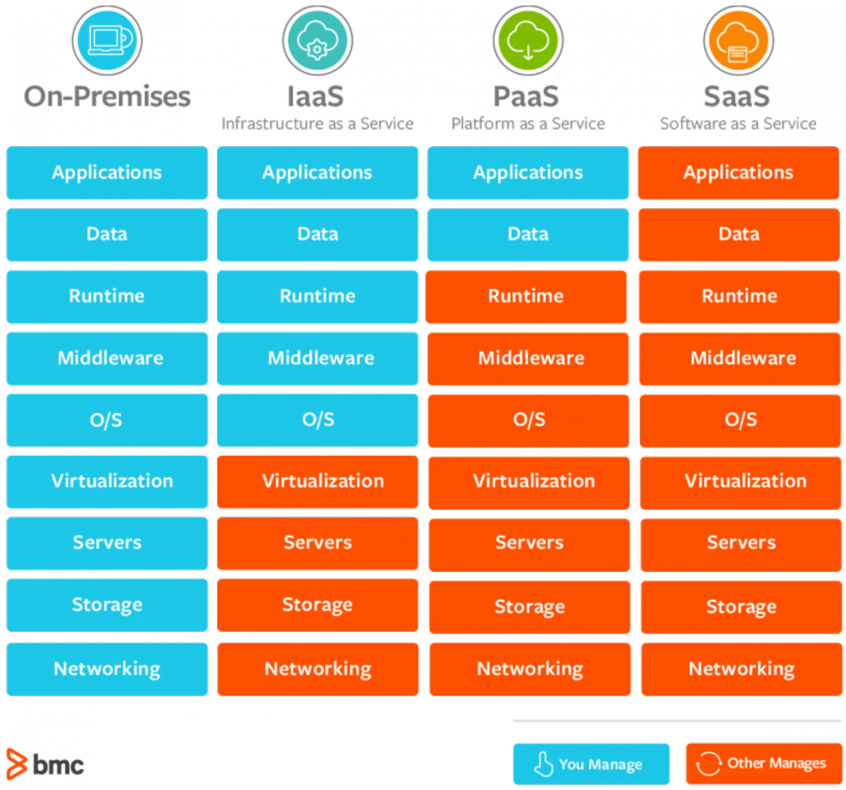

Figure 4.2: Different types of Cloud Services

The cloud services are broadly classified into three categories, i.e.

a) Infrastructure as a Service (IaaS)
b) Platform as a Service (PaaS)
c) Software as a Service (SaaS)

a) Infrastructure as a Service (IaaS)

IaaS, provides raw computing hardware such as storage servers etc.. to the users. The user does not require to maintain the physical hardware and no high upfront cost is required. This is also known as utility computing and examples of IaaS are Amazon EC2[124], Windows Azure[125], Rackspace[126], Google Compute Engine[127] etc.

b) Platform as a Service (PaaS)

PaaS provides both hardware and software platforms to the users for a specific development process. The examples for PaaS are AWS Elastic Beanstalk[128], Heroku[129], Apache Stratos[130], etc.

c) Software as a Service (SaaS)

SaaS provides a specific software to the user, and the provided software runs on a remote machine and the user can use it through the web browser or Linux terminal. The examples for SaaS are Google Apps[131], Microsoft Office 365[132].

In the present research program, the proposed approach for V2I communication has been built upon IaaS service EC2[124] from AWS. This IaaS service provides an optimized network solution, all other required software and its deployment are configured.

4.2.2 Internet of Things (IoT)

The Internet of Things (IoT) is a system of interrelated computing devices with unique identifiers (UIDs), having the ability to communicate and transfer data with each other without requiring human intervention[133]. These computing devices are coupled with mechanical machines, people, objects etc. to provide a connected ecosystem. The IoT is relevant to Vehicular Networks as vehicles become objects and obtain the capability to communicate with their surroundings. IoT integration with VANETs would facilitate safety, security, infotainment and traffic updates. One such example of the integration of IoT with existing cloud services is presented in Figure 4.3, the figure presents the AWS architecture[134] for connected vehicles. This can be observed from the figure that the convergence of many services leads to an overall implementation of V2I based services.

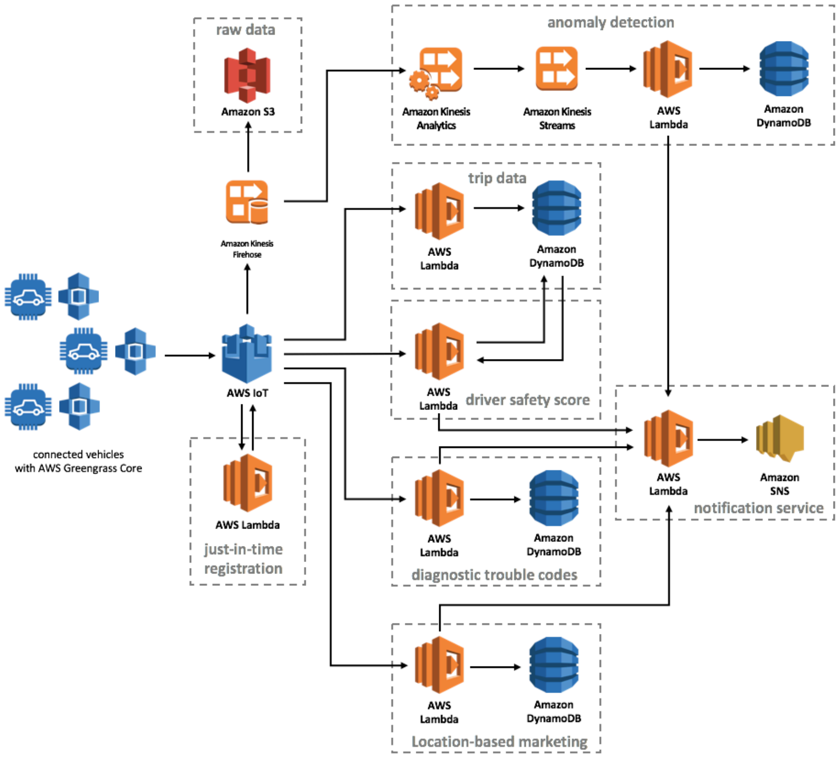

Figure 4.3: AWS architecture for Connected Vehicles in IoT[134]

4.2.3 Message Queue Telemetry Transport (MQTT)

Message Queue Telemetry Transport or MQTT[120] for short is an ISO standard for networking, i.e. ISO/IEC PRF 20922[120], introduced by IBM (1999) and later on standardized by OASIS (2013). The Figure 4.4 presents the MQTT PUB-SUB architecture. MQTT is a lightweight networking protocol based on a publish-subscribe model[135]. It aims to connect applications and networks in a comparatively faster manner as compared to the standard TCP/IP protocol. MQTT is mainly designed to provide faster communication in remote locations with limited bandwidth and a small code footprint [120]. In the middle of the publish-subscribe model sits a message broker. Publishers are mostly lightweight clients submitting information related to some topic or another. Subscribers are the entities interested in the topics. The broker provides communication between the two or more parties involved in communication and is also responsible for classifying messages into topics. MQTT is based on an event-driven architecture where a topic of interest between parties is chosen as a channel for communication.

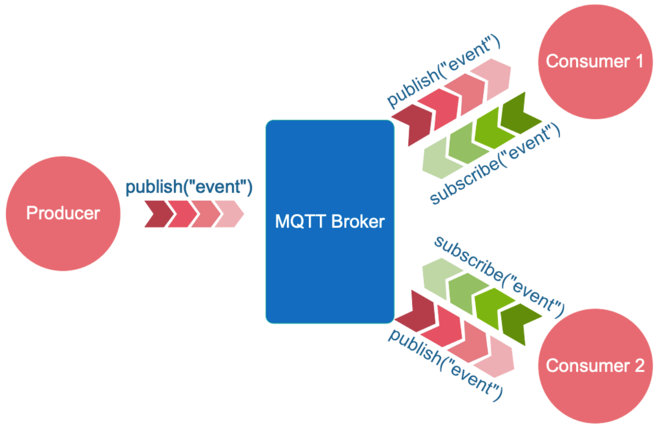

Figure 4.4: MQTT publish subscribe architecture

Publishers publish data concerning a topic and subscribers subscribe to it to receive information. MQTT protocols are proven efficient and scalable and thus work as a solution for servicing Vehicular Ad-hoc Networks. The architecture is such that it enables rapid scalability and the ability to deliver information without getting parties to interact directly. The Figure 4.5 presents the message format of the MQTT protocol.

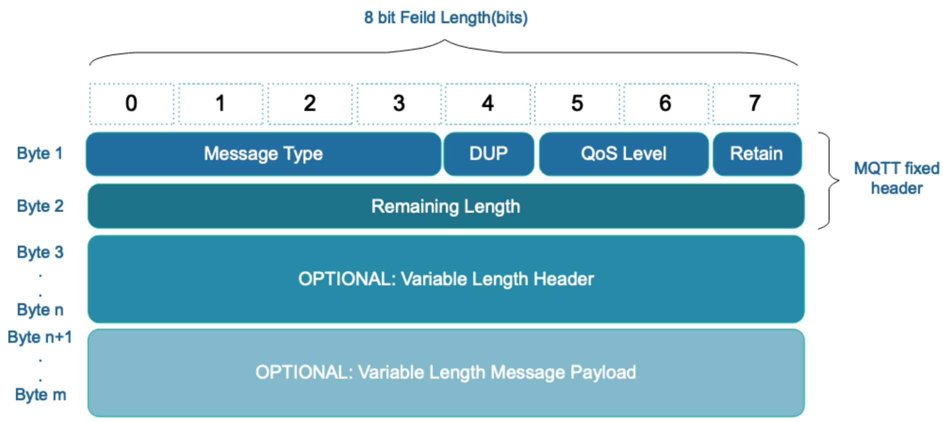

Figure 4.5: MQTT Protocol message format

The MQTT protocols also provide reliability through the QoS settings, the following subsection describes the QoS parameters in the MQTT protocol.

a) Quality of Service (QoS) in MQTT

The MQTT protocol is scalable and efficient but the objective of MQTT protocol is also to ensure the expected delivery of messages. The need of application is to get a reliable delivery even through the unreliable network. However, as the network scales, the number of messages generated and received increases exponentially. This abrupt increase in messages may create server overhead and thereby introduce some latency in the network and thus resulting in the delay of critical information. This reliability and latency can be taken care through the QoS levels provided in the MQTT protocol. The MQTT protocol provides three Quality of Service levels and are used to categorize the messages. The Figure 4.6 presents the various QoS levels and are further explained in detail.

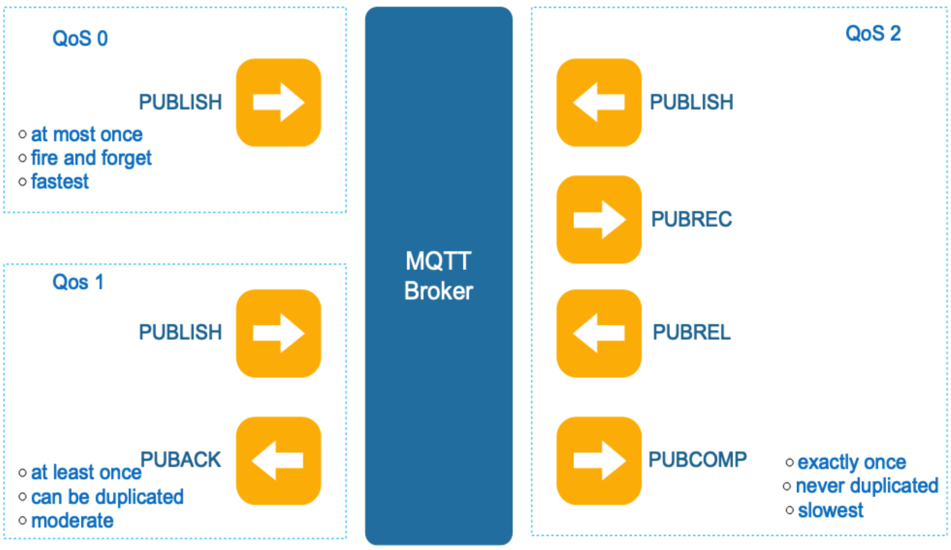

Figure 4.6: QoS level in MQTT protocol

QoS (0): In QoS(0) level, messages will be delivered at most once. QoS(0) is the default mode, and it will not rebroadcast any message. QoS(0) is the fastest mode, however it is the most unreliable way to deliver the information.

QoS (1): This mode ensures that the information is delivered at least once by requesting a PUBACK acknowledgment packet in return. The overhead of the PUBACK exchange introduces a little overhead, and also the same packet can be delivered multiple times to the subscriber.

QoS(2): This mode delivers the message using 4 way message exchange i.e. PUBLISH, PUBREC, PUBREL, and PUBCOMP. The 4 way exchange of message provides reliability with the tradeoff to latency in delivering messages. Hence, in QoS(2) the messages will be delivered exactly one time, and this is the most reliable and slowest mode of QoS mechanisms.

b) The downgrading of QoS

MQTT protocol-based information exchange is a many to many communication mechanisms and both the subscribers and the publishers agree on some QoS to reliably deliver the messages. One of the characteristics of MQTT is that the sender and receiver need not know each other, and they do not directly communicate. This lack of direct communication raises a concern regarding the consensus on the QoS level. This is where the MQTT QoS provides the downgrading mechanism. In the downgrading process, if a publisher publishes some information using the QoS (2) or QoS (1) and the subscriber is not accepting the same QoS, then downgrading of QoS modes takes place until both publishers and subscribers are at the same mode. In this proposed approach QoS level is set to 2. Since the present approach is for class 5 messages. Class 5 messages require reliability with permissible latency. The Figure 4.7 presents the QoS downgrading process.

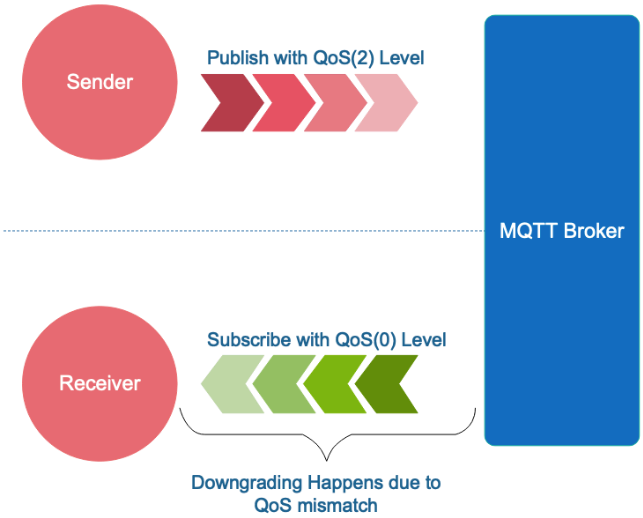

Figure 4.7: QoS Downgrading process

4.3 Proposed approach

This section explains the proposed novel approach to multicast in VANETs. This approach makes use of V2I based communication and has shown significant results in real-world testing. The following section presents the overall working and implementation of the approach.

The proposed approach towards efficient information dissemination in VANETs uses the IaaS cloud services and IoT technology hardware and the MQTT protocol. The MQTT broker server is deployed on the cloud in the application layer and cloud network infrastructure is used to enable communication among various nodes. The Figure 4.8 shows working of MQTT protocol in the V2I scenario. All the vehicles are equipped with the capable hardware to communicate with each other through MQTT protocol, the MQTT broker resides as a central server for the entire network. The information about the event is sensed by some or more vehicles, they publish the information to the broker under the appropriate topic. After publishing the information, the broker forwards it to the subscribers who are subscribed to the topic. The information about the event is sensed by some or more vehicles, they publish the information to the broker under the appropriate topic. After publishing the information, the broker forwards it to the subscribers who are subscribed to the topic.

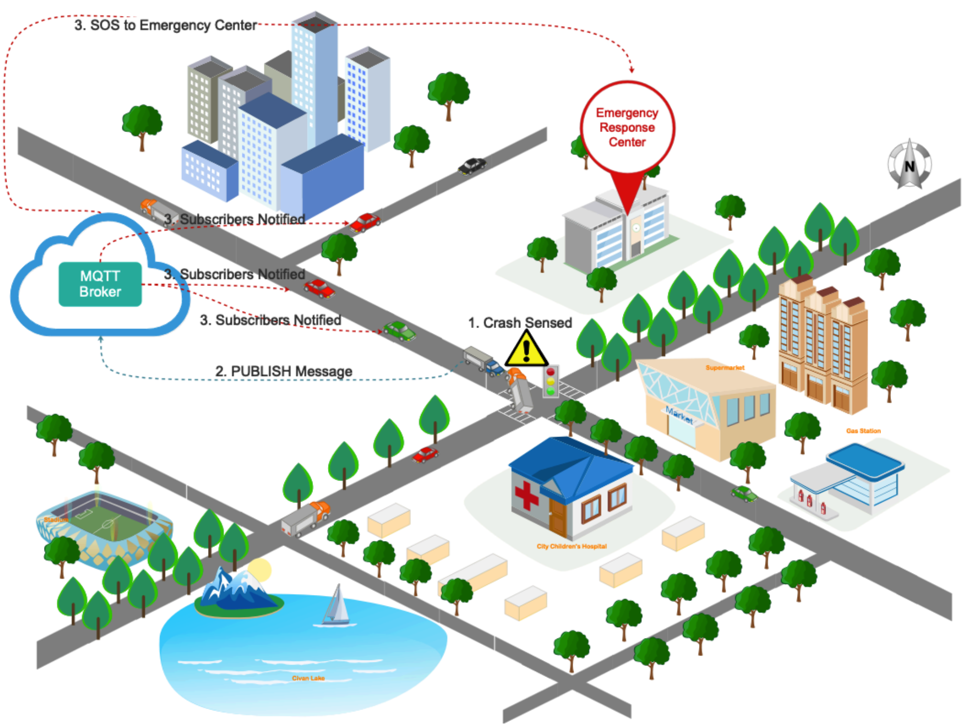

Figure 4.8: Scenario depicting the working of MQTT

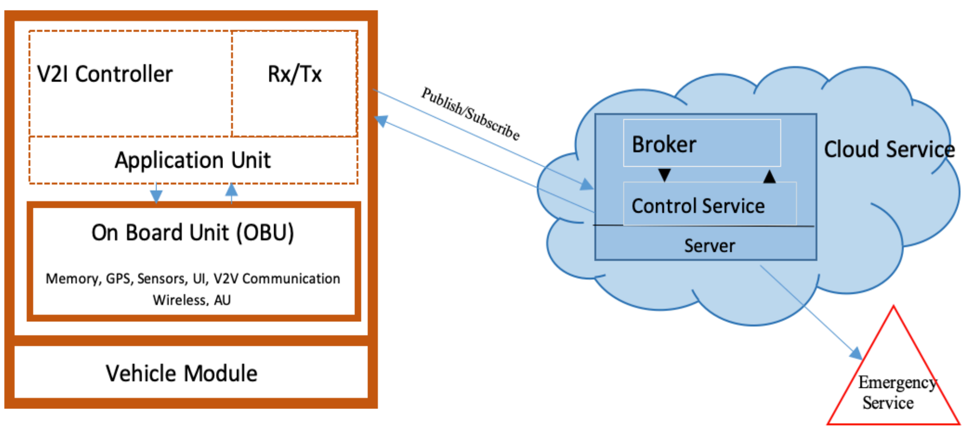

Figure 4.9: Internal structure of each module

The internal structure of each module is presented in the Figure 4.9 . It is assumed that all the vehicles in the network are equipped with an OBU with

Global Positioning System module. OBU is essentially one of the main components of vehicles in VANETs, it is responsible for gathering and processing the information sensed by multiple sensors within the vehicle.

GPS module is used to provide coordinates of the vehicle in real-time. OBU leverages GPS to provide the exact location (latitude and longitude) in the form of a set of coordinates i.e.

$$p \in C \text{ with } C \in \mathbb{R}2 \tag{4.1}$$

where position p belongs to coordinate space *C* and *C* is a two-dimension coordinate space $\mathbb{R}2$. this approach proposes a separate layer on the top of the existing OBU in every vehicle. This layer manages the V2I communication. The transmission and reception of information is handled by this layer. In-vehicle to infrastructure communication, the broker is deployed on the cloud server and enables reliable and efficient information delivery to vehicles. The information is disseminated to vehicles based on topics to which they have subscribed themselves. The working of our model can be better understood by the following three phases:

1) Subscription Phase
2) Information Dissemination Phase
3) Information Reception Phase

4.3.1 Subscription Phase

The subscription phase is the first phase of this approach. This phase begins by requesting the set of coordinates (C) from the OBU of vehicles. The coordinate set comes in the form of latitude and longitudes, these are used to identify the ID of the road on which the vehicle is moving (Road_id). Using this Road_id parameter, common property is established for the vehicles moving on the same road. A Google-based API[136] is used to resolve these coordinates into meaningful information. The API takes a coordinate set of vehicles as input and generates a JSON based output which defines minute details such as route, region, locality, country etc. The Road_id is used as the route name as it is a static and unique string that can be used throughout the working of the model.

This process is repeated at a regular interval to keep vehicle update every time. The Road_id parameter is passed on to the subscribe function of MQTT Server and this further delivers the message to all the vehicles subscribed to the Road_id. The system ensures to unsubscribe to the old Road_id topic as it enters the new Road_id, this avoids the delivery of outdated messages. The Figure 4.10 gives the flow chart depicting the working of the subscription phase.

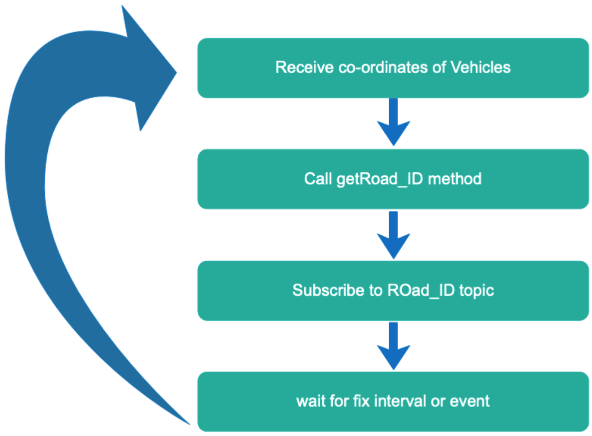

Figure 4.10: Subscription phase

4.3.2 Information Dissemination phase

The Information dissemination phase or the publish phase is called when the network needs to be informed about some event occurred. The vehicles nearby the event will gather data via OBU and send/publish it to the MQTT broker. These vehicles also assign a priority to the messages in the form of QoS. The message is published along with the QoS level and the Road_id as the topic. All the subscribers to that particular Road_id will receive the message broadcasted by the broker. Information dissemination phase flowchart is presented in Figure 4.11.

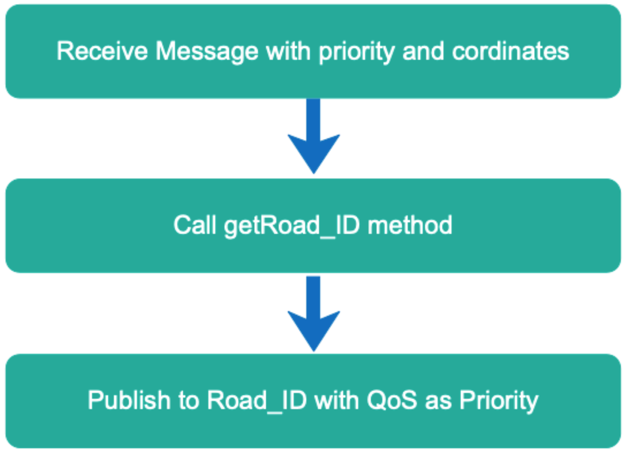

Figure 4.11: Information dissemination phase

4.3.3 Information Reception Phase

The information reception phase is the reception of the published message from the previous phase. In this phase, all the subscribed vehicles receive the message and further action is taken, Figure 4.12 presents the flowchart for this phase.

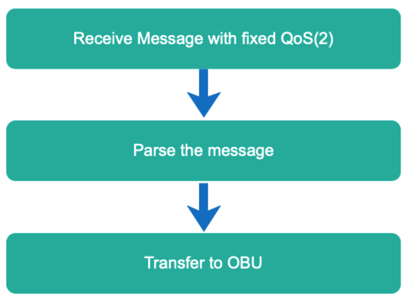

Figure 4.12: Information Reception Phase

4.4 Experimental Scenario

The hardware and software setup used for experiment is detailed in Table 4.1.

Table 4.1: Hardware and Software Configuration

HARDWARE

Sno.	Component	Configuration
1.	NODEMCU V3[137]	Microcontroller: Tensilica 32-bit RISC CPU Xtensa LX106 Operating Voltage: 3.3V Input Voltage: 7-12V Digital I/O Pins (DIO): 16 Analog Input Pins (ADC): 1 UARTs: 1 SPIs: 1 I2Cs: 1 Flash Memory: 4 MB SRAM: 64 KB Clock Speed: 80 MHz Wi-Fi: IEEE 802.11 b/g/n
2.	BREAKOUT BOARD[138]	DC Input voltage: 6V to 24V Onboard 5V / 1A DC-DC step-down converter circuit. Lead out the pins of 5V and 3.3V power supply
3.	UBLOX NEO6MV2 GPS[139], [140]	Receiver Type: 50 Channels, GPS L1 frequency, C/A Code, SBAS: WAAS, EGNOS, MSAS Supply Voltage (V): 2.7~ 6 VDC Main Chip: NEO-6

		Sensitivity: Cold Start (without aiding): -147 dBm, Hot Start: -156 dBm, Reacquisition: -160 dBm Navigation Update Rate: 5Hz Position Accuracy: 2 M and better with multiple good satellite signals Operating Temperature Range: -24ºC ~ 84°C Tracking Sensitivity: -161 dBm Cold Start Time: 27s Warm Start Time: 27s Maximum Speed: 500 M/s
SOFTWARE		
1.	AWS EC2 INSTANCE[124]	ECU: Variable vCPU: 2 Memory: 2 GB Network: up to 5 Gigabit Purchasing option: On-demand Network: vpc-94e966ee EBS-optimized: Yes
2.	MOSQUITTO MQTT BROKER[141]	Protocol: mqtt Port: 1883 Listener: 1884 WebSocket: 8080 Queue_qos0_messages: true

The experiment was carried out on the mosquitto MQTT broker [141], and the broker was deployed on EC2[124] instance of AWS[121]. In the experimental setup, all the vehicles in the network were equipped with ESP826612E microcontroller onboard along with Ublox Neo6mv2 for GPS coordinates. During the experiment, all vehicles subscribed to the topic based on Road_id to which they belonged at that given point of time. The overspeed alert above 50kmph was generated, and it was sensed by the vehicle and then the vehicle published it under the appropriate topic along with its priority over broker. The broker then sent the messages to the subscribers based on the QoS level chosen. The following Figure 4.13 presets image of microcontroller used in experiment.

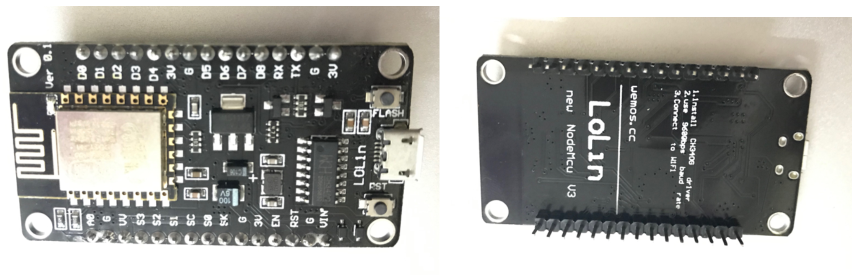

Figure 4.13: NodeMCU with ESP826612E Module

Figure 4.14 presents image of the breakout board for NodeMCU, this board is used to receive 12V power supply from the car battery and power up the microcontroller module.

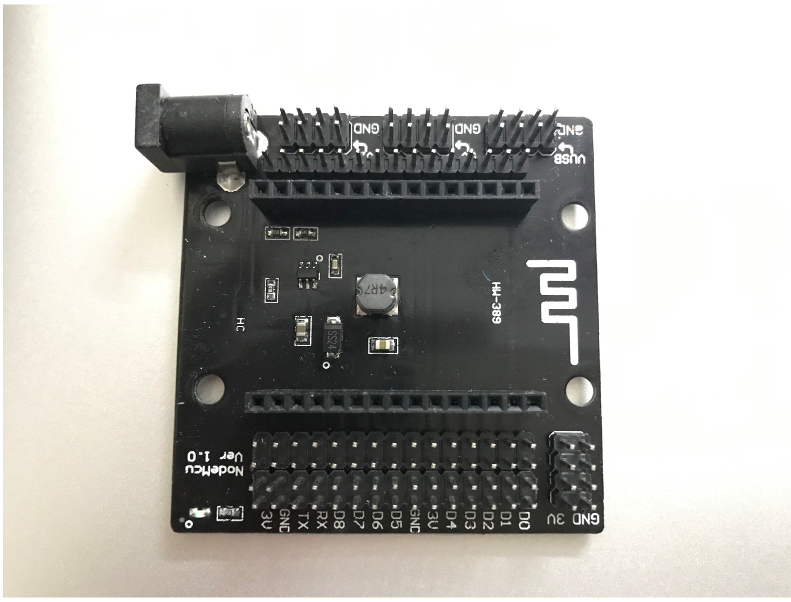

Figure 4.14: Breakout Board for NodeMCU with 12v supply support

Figure 4.15 presents the GPS device used to gather the coordinates of the vehicle at any point in time.

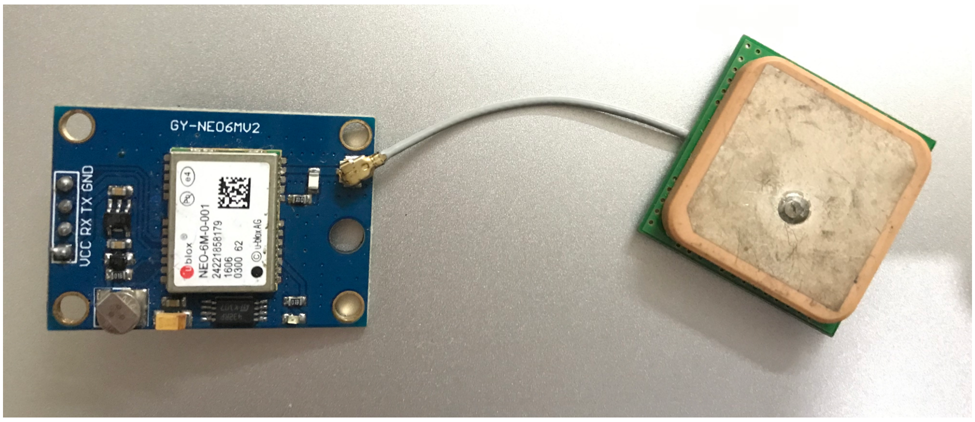

Figure 4.15: Ublox Neo6mv2 GPS device

Figure 4.16 presents the image of fully working hardware integrated in lab.

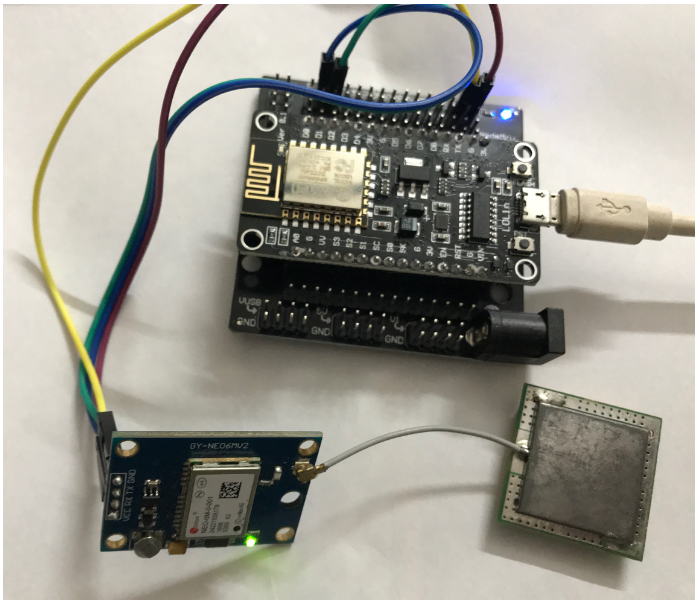

Figure 4.16: Lab View Running Module

Figure 4.17 presents the screenshot displaying the debug console snippet of connecting the microcontroller to the WIFI, MQTT server, sensing the coordinates, setting the topic and finally publishing it.

```
.....
WiFi connected
IP address:
192.168.1.123
Attempting MQTT connection...connected
System Ready, connected to 5 sattelites
Getting Topic.....
found, now setting Topic to Sewla Kalan Majra, Dehradun
****Message arrived****
at SewlaKalanMajraDehradun
{"lat":30.29916,"lon":78.00322,"tst":1572619900}
```

Figure 4.17: Clipped Debug Console

Figure 4.18 presents the final ready hardware, ready to be mounted in the vehicle.

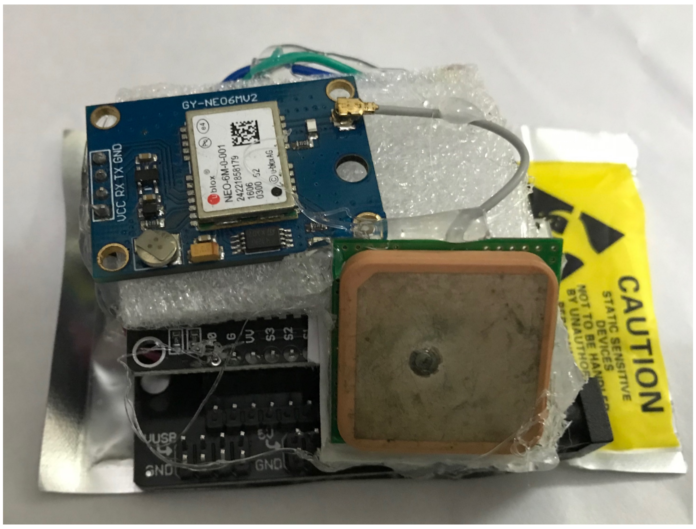

Figure 4.18: Full Prototype Assembled

Figure 4.19 demonstrates the deployed hardware on the car dashboard and updating the real-time location on the cloud server.

Figure 4.19: Mounted in Car Cabin

Figure 4.20 presents the screenshot of the dashboard of running vehicles on the road while sharing their normal running "OK" messages with other vehicles. The dashboard shows, the precise location of the vehicle, number of vehicles on map, latitude, longitude, time and date, topic subscribed, and the last message received.

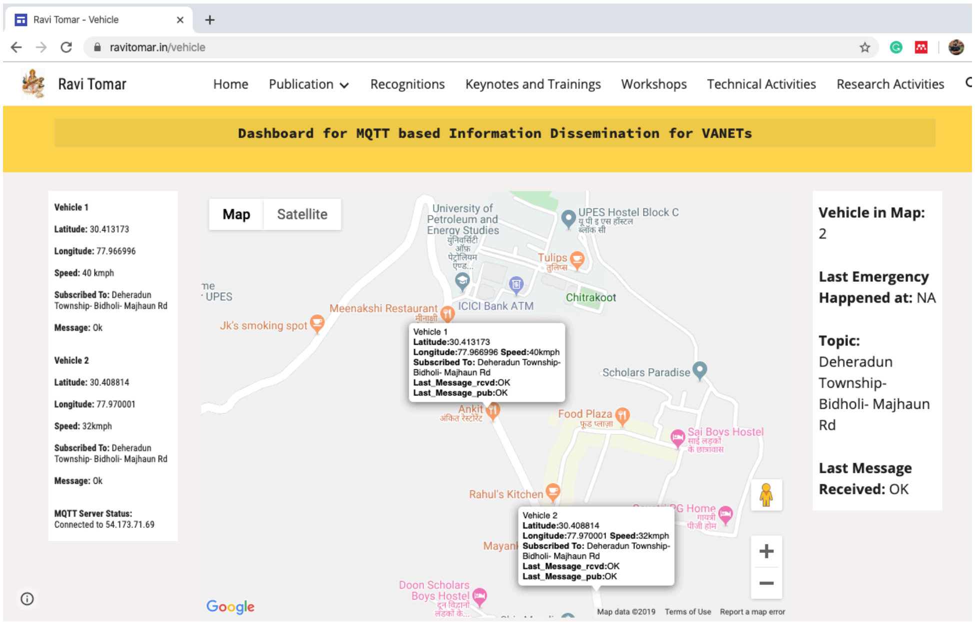

Figure 4.20: Screenshot of dashboard showing running vehicle with no emergency.

The Figure 4.21 presents the screenshot of the dashboard of running vehicles on the road while sharing the alert message of speed above than 50kmph with other vehicles. The dashboard shows, precise location of the vehicle, number of vehicles on map, latitude, longitude, time and date, topic subscribed, and the last message received.

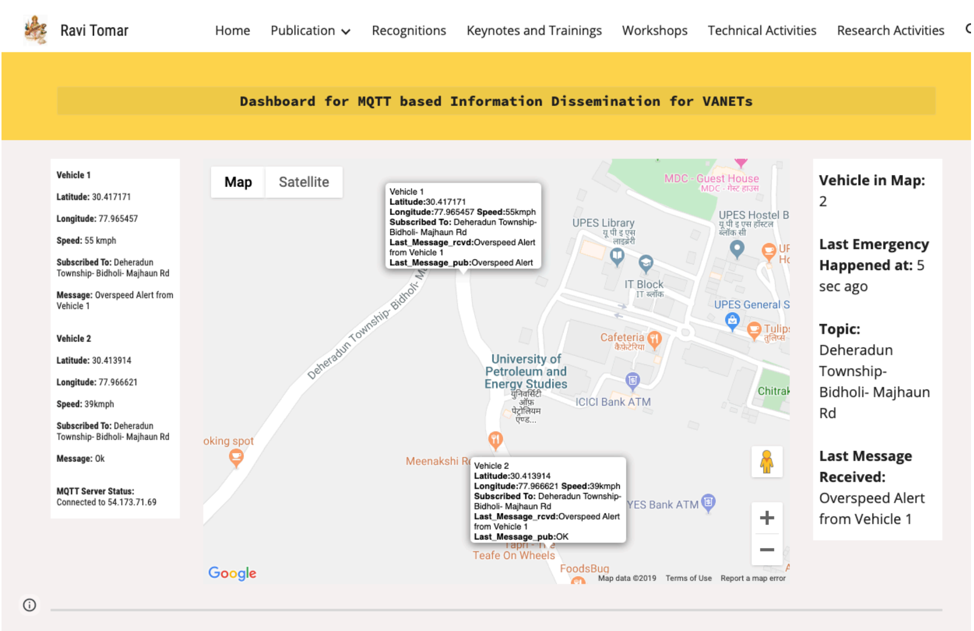

Figure 4.21: Dashboard showing running vehicle with emergency message.

4.5 Chapter Summary

In this chapter, we proposed a novel approach to multicast in a Vehicular network using V2I based communication. The proposed approach handles the class 5 messages. The chapter started with an introduction to V2I and multicast in VANETs and further discussed other relevant technologies required for the proposed work such as cloud computing, IoT and MQTT. Upon identification of the needs and the available technologies, the system model is presented. The working of the approach is explained in detail and the chapter is concluded by presenting the experimental setup with the information about the hardware and software used for developing the working prototype of the approach. In the next chapter, we present a novel protocol to handle the class 1 to class 4 messages, the proposed approach works on V2V domain.

Chapter 5

Priority Based Efficient Information Dissemination Protocol (PBEID)

This chapter describes a novel Priority Based Efficient Information Dissemination protocol for efficient information dissemination over V2V communication. PBEID protocol is the third part of the framework presented in Chapter 3 and is used for the Class 1- 4 message. This protocol is developed to maximize the radio channel utilization and message transmission to maximum nodes in minimum time. Network density and message priority are the significant factors which influence the information dissemination in VANET. PBEID protocol is fully compatible with IEEE 802.11p standards[142]. The following section presents the PBEID protocol architecture and its working model, followed by its experimental and evaluation details.

5.1 Priority Based Efficient Information Dissemination Protocol (PBEID)

The protocol is the part of the proposed framework in Chapter 3, the GENERATEPACKET procedure in the proposed framework is responsible to assign classID to the packets. The packets assigned with classID 1-4 are passed to the PBEID protocol for V2V communication. The proposed PBEID protocol consists of three procedures, i.e. RECEIVEPACKET procedure, REBROADCASTPROCEDURE, and CHECKDIRECTIONPROCEDURE. The PBEID protocol architecture is presented in Figure 5.1, and the subsection presents the detailed explanation.

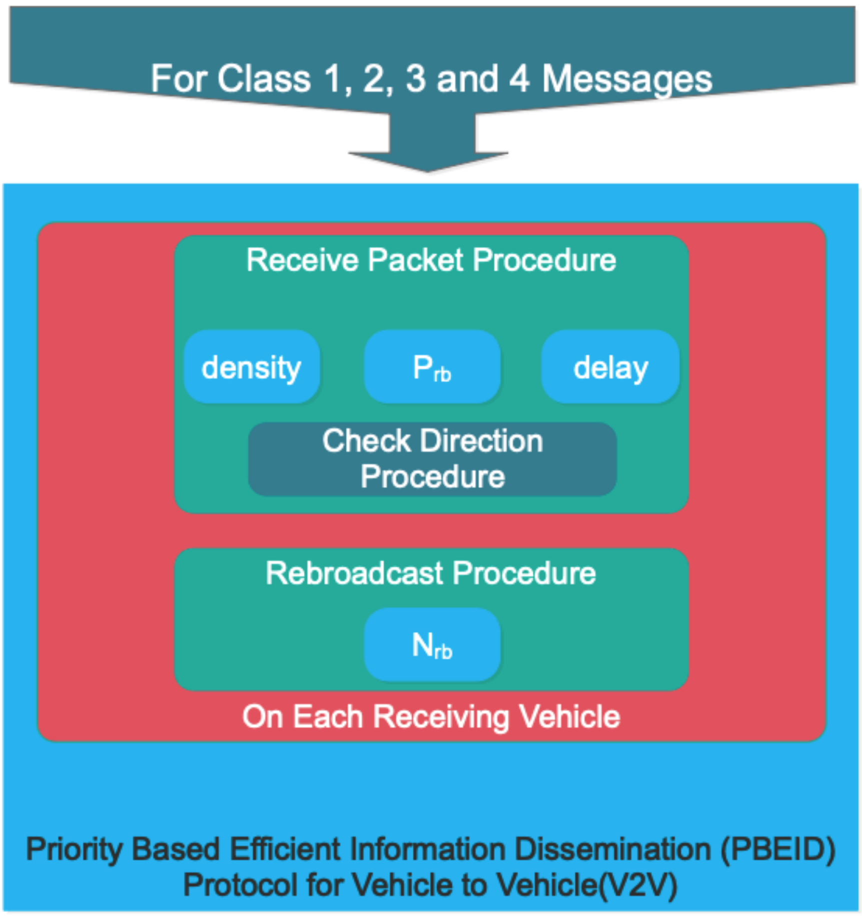

Figure 5.1: Architecture of PBEID protocol

5.1.1 RECEIVEPACKET Procedure

The RECEIVEPACKET procedure consists of three major parameters along with a sub-procedure i.e. density, the probability to rebroadcast P_{rb} and delay between rebroadcast and a CHECKDIRECTION subprocedure. The RECEIVEPACKET procedure executes at the packet receiving node. Based on the three parameters, the proposed RECEIVEPACKET procedure identifies the suitable packets to rebroadcast and pass them to REBROADCASTPROCEDURE along with its delay to rebroadcast. The CHECKDIRECTIONPROCEDURE helps in the selection of the intended vehicle to participate further in message dissemination. The **Algorithm 5** gives pseudocode for the RECEIVEPACKET procedure, and the following subsection presents a detailed explanation of the key parameters and procedures.

a) Novel Network Density Computation Mechanism

Network density plays a vital role in setting up the rebroadcast parameter value. In real-world scenarios, network density is dynamic. In, this, sub-section a novel network density computation function is proposed and employed in the RECEIVEPACKET procedure, this network density computation function is adaptable to the changing network scenarios. The proposed method uses beaconing[143] mechanism, the beaconing mechanism maintains the list of one- hop (h_0) and two-hop (h_1) neighbours information such as speed, distance, and coordinates. The list is pruned based on the distance threshold of the communication range, and the function presented in Eq. (5.1) is composed to compute the density.

$$Density = \frac{\alpha * h_0 + (1 - \alpha) * h_1}{2} \tag{5.1}$$

where h_0 is the one-hop neighbors, h_1 are two-hop neighbors and α is a density parameter and is between $0<\alpha<1$. The α value will be chosen based on h_0 and h_1 values. The Algorithm 3 presents the pseudocode to calculate the α value, and Table 5.1 provides the description for various α values.

Algorithm 3: Procedure for α value computation

procedure α VALUECOMPUTATION(SELF)

```
GET one-hop neighbour in h0
GET one-hop neighbour in h1
if h0 is less than h1
      Calculate α using → h0/h1
else if h0 is greater than h1
      Calculate α using → Average(h0,h1)/h0
Else
```

9: Set $\alpha \rightarrow 0.5$

10: End of Algorithm

Table 5.1: α value description

Value of α	*Deciding factor*	*Indicator*
Towards 0	$h_0 < h_1$	*Sparse network*
Towards 1	$h_0 > h_1$	*Dense network*
No effect	$h_0 = h_1$	*Moderate network*

b) Calculating the Rebroadcasting Probability (P_{rb})

Rebroadcasting probability indicates the rebroadcast probability of a packet. This parameter is used in the RECEIVEPACKET procedure of PBEID protocol to determines the confidence for the received packet to be rebroadcasted in the network. The P_{rb} is calculated using the Eq. (5.2) where Density is calculated from Eq. (5.1), and Nodes are the number of vehicles in the network.

$$P_{rb} = 1 - \frac{Density}{Nodes} \tag{5.2}$$

P_{rb} value nearer to 0 indicates that less rebroadcasting is needed and if P_{rb} value is nearer to 1 then more packets will be rebroadcasted. So, there need to be a mechanism to choose an optimal value based on the requirement of the network.

c) Calculating the Delay between Rebroadcast (D_{rb})

The delay parameter is used in the RECEIVEPACKET procedure to compute the waiting time before rebroadcasting the message. D_{rb} value has to be set such that the farthest node will rebroadcast as early as possible. Delay will be computed using the range of communication medium, distance to the initiator, and Probability to rebroadcast. The D_{rb} is calculated using the equation.

$$Delay(D_{rb}) = \left(\frac{Range-Distance}{Range * Prb}\right)\ milliseconds \tag{5.3}$$

where the range is taken as 250m, distance is calculated through the beacon process data and P_{rb} is calculated from Eq. (5.2).

d) CHECKDIRECTION procedure

The CHECKDIRECTION procedure ensures the vehicle that receives the packet is traveling in the intended direction for message dissemination. This is achieved by checking the calculating the angular direction between the sender and receiver. If the vehicle is not in the intended direction the vehicle needs to refrain itself from participating in the broadcast and hence the procedure returns false in such case. This procedure ensures to limit the generation of unnecessary redundant messages. The pseudocode in **Algorithm 4** presents the algorithm for the CHECKDIRECTION procedure.

Algorithm 4: Check Direction

```
procedure CHECKDIRECTION(P)
    GET Sender position from P
    GET Receiver Position
    Direction ← Calculate angular direction of sender and receiver
    if CID is "1" and Direction is positive
            Return true
    else if CID is "2" and Direction is negative
            Return true
    else if CID is "3" and Direction is positive
            Return true
    else if CID is "4" and Direction is negative
            Return true
    else
```

14: Return false

15: End of Algorithm

5.1.2 Working of RECEIVEPACKET Procedure

The Figure 5.2 presents the flowchart for the RECEIVEPACKET procedure. Initially, this procedure checks that the packet has covered the desired area or not. If the packet has not covered the desired area, then it passes to the CHECKDIRECTION procedure. The CHECKDIRECTION procedure returns true, in case the message is viable for further dissemination otherwise procedure returns false and the RECEIVEPACKET procedure terminates. The RECEIVEPACKET procedure further checks whether the packet has been received previously, if yes then the value of a special parameter N_{rb} is decremented by 1. This parameter is further checked by the REBROADCAST procedure and is used to stop multiple broadcasts of the same packet. Further, the nodes that are flagged to rebroadcast calculates the network density and probability to rebroadcast (P_{rb}) using Eq. (5.1) and Eq. (5.2) respectively. The calculated P_{rb} value is greater than 0.3, then the message will be scheduled to rebroadcast with the calculated delay as mentioned in the pseudocode. To determine the P_{rb} value of a packet, multiple experiments have been carried out and found 0.3 as the threshold value, and the packets with above 0.3 P_{rb} are fit for rebroadcasting. The following figure presents the flow chart of the RECEIVEPACKET procedure followed by the **Algorithm 5** of the RECEIVEPACKET procedure.

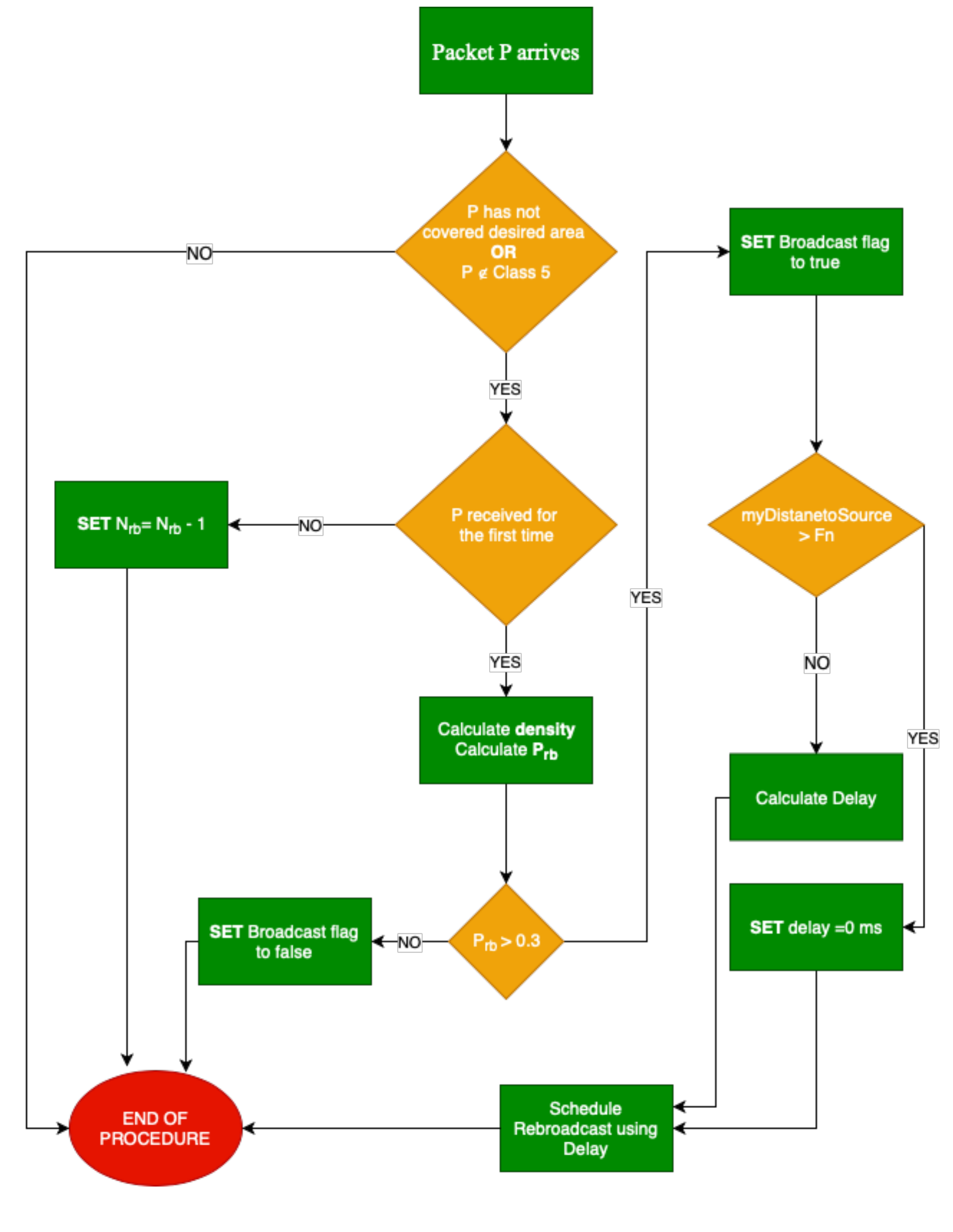

Figure 5.2: Flowchart of RECEIVEPACKET procedure in PBEID

Algorithm 5: Receive Packet

procedure RECEIVEPACKET(P)

if P has not covered the desired area **OR** P do not belong to Class 5 then

If Checkdirection(P)

If P is received for the first time, then

Calculate density using → $Density = \frac{\alpha * h_0 + (1 - \alpha) * h_1}{2}$

Calculate Probability to Rebroadcst → $P_{rb} = 1 - \frac{Density}{Nodes}$

If $P_{rb} > 0.3$ then

RebroadcastFlag ← *true*

If myDistancetoSource > Farthest (Fn)

delay = 0 milliseconds

Calculate Delay using → $Delay(D_{rb}) = \left(\frac{Range - Distance}{Range * Pr}\right)$ *milliseconds*

ScheduletoReBroadcast (delay, P, Rebroadcast)

Else

RebroadcastFlag ← *false*

else

N_{rb} of previously received packet = N_{rb} -1

SchdeuletoReBroadcast (1, P, Rebroadcast)

Else

RebroadcastFlag ← *false*

else

End the Algorithm

5.1.3 REBROADCAST Procedure

REBROADCAST procedure broadcasts the packet scheduled by the RECEIVEPACKET procedure, and the procedure is presented in Algorithm 6. This procedure checks for the rebroadcast flag and value of N_{rb} before rebroadcasting. If the rebroadcast flag is false or Nrb value is zero or negative, it cancels the rebroadcast, otherwise, it checks for class and broadcast the packet on CCH/SCH accordingly. In the case of class 1 and 2, it adapts the store carry forward approach so that the message is disseminated even in the case of hidden node problem.

Algorithm 6: Rebroadcast

```
procedure REBROADCAST(P)
    if RebroadcastFlag is true, then
        If N_rb is not less than or equal to 0
            If P belongs to class 1 OR class 2 then
                Broadcast(P) using CCH
                Store Carry and Rebroadcast after delay
            else if belongs to class 3 OR 4 then
                Broadcast(P) using CCH or SCH
        Else
            cancelRebroadcast
    else
        End the Algorithm
```

5.2 Simulation and Parameters setup

The simulation experiments were carried out in OMNET++ v 5.5.0 [144] and VEINS v2.2 [145] framework and the mobility model generated through SUMO v0.25 [146].

5.2.1 Simulation Setup

The Figure 5.3 presents the overall simulation setup, initially, the map was extracted from the open street map[147], and converted to the SUMO XML format with the help of net convert utility of SUMO[148]. The route was generated manually by plotting the vehicles on a fixed path to include maximum road features such as junctions, turns and curves. The route and map were supplied to the SUMO simulator for mobility modeling and finally, with the help of the TRaCI server, the individual vehicle information from SUMO was sent to the OMNET++ simulator to simulate the network.

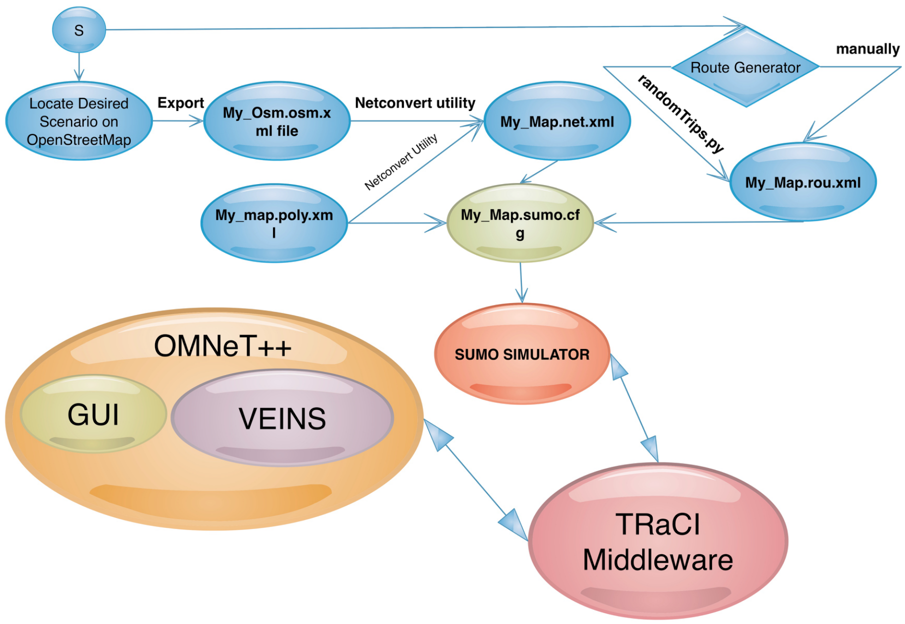

Figure 5.3: Overall Simulation Setup

5.2.2 Simulation Scenario and Parameters

The mobility model was generated for variable vehicles running on a curved road with random speed. The model is realistic due to the random speed. The simple obstacle model was used to depict real-world conditions. An accident message was introduced in the network at a random time during the simulation. The objective was to encompass maximum real-world conditions during the simulation. The simulation was executed for a total of 450 for 30-110 nodes and 475 seconds for 130-150 nodes. The Table 5.2 presents the simulation parameters, and the following subsection presents the screenshot of various stages during the simulation with proper explanation.

Table 5.2 : Simulation Parameters

Parameter	Value
Field	City: 5000m x 5000m,
Simulation Duration	450s/475s
Scheduled Accident	Random time on the mid node of the network
Transmission Range	300m

Beaconing Interval	3s
Mobility	Fixed path
Vehicle Speed	Random with (acceleration = 2.6 m/s,maxSpeed=14 m/s)
Average Speed	13.41 m/s
Number of Nodes	30,50,70,90,110,130,150
Data Packet size	512 byte
MAC protocol	IEEE 802.11p

a) Mobility Modeling

Mobility modeling was carried out in SUMO[148]. The road map was taken from the VEINS framework[145] and the Figure 5.4 presents the city map showing the buildings as blocks and all the connecting roads in the SUMO GUI view. The mobility modeling simulators such as SUMO are not capable to introduce any network capability in the vehicle, the job of mobility simulators is to show the realistic flow of vehicles on the road. Therefore, SUMO provides the TraCI server through which SUMO can be connected to any network simulator using TCP/IP connections. In the present research work, we connect OMNET++ to the SUMO through the TraCI server.

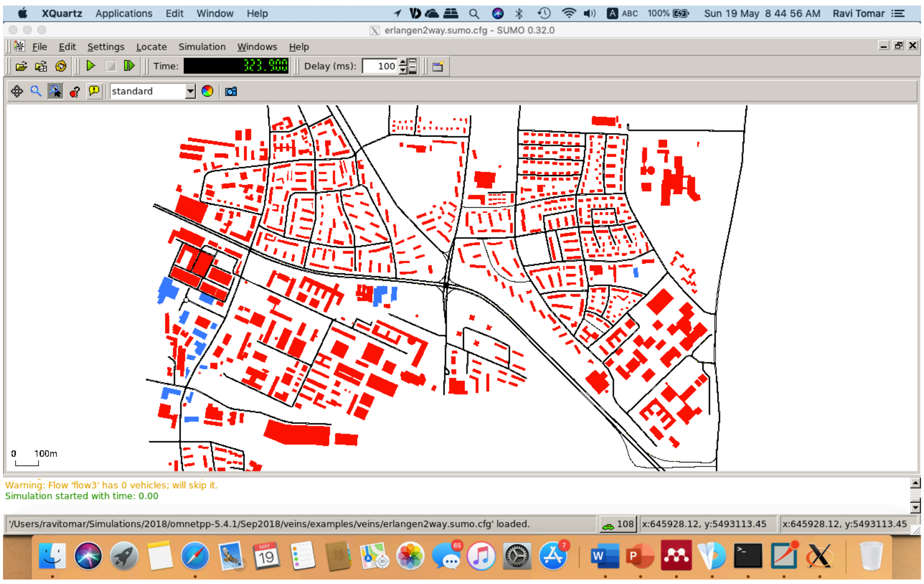

Figure 5.4: Realistic Scenario with vehicles in SUMO

Furthermore, the image in Figure 5.5 presents the zoomed in view of one of the junctions in the city, with yellow triangles denoting the running vehicles.

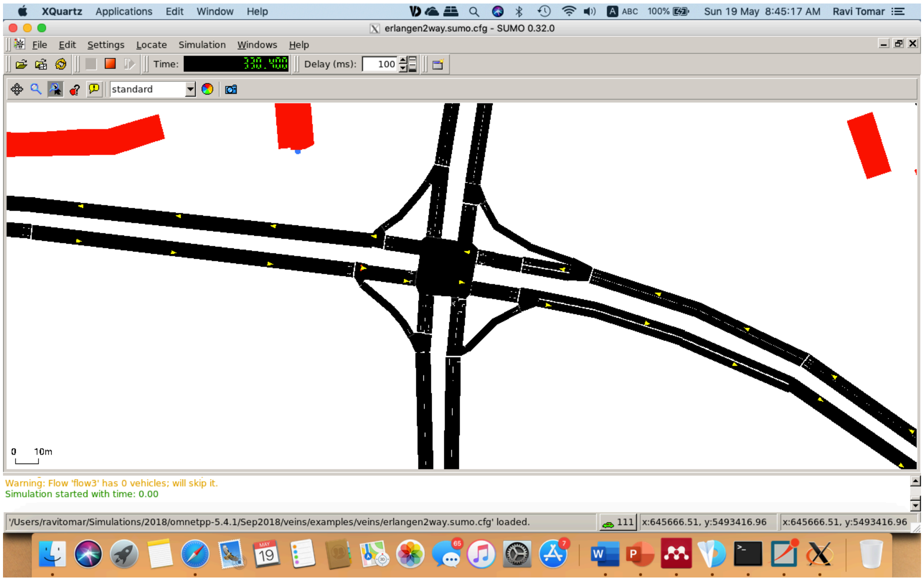

Figure 5.5: Zoomed In view of Moving Vehicles at a junction in SUMO

b) Network Simulator

The network simulator is a software used to simulate the complete networking layer among the nodes and enables communication among them. The present research work used OMNET++ as the network simulator. The image in Figure 5.7 presents the sample snapshot of the carried out simulation.

The Figure 5.6 presents the screenshot of python based TraCI server. The TraCI server acts as a broker between SUMO and OMNET++.

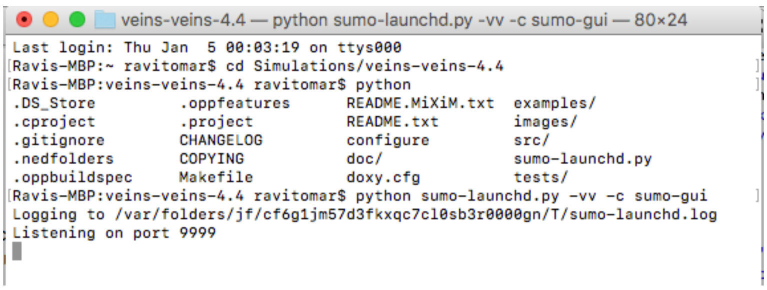

Figure 5.6: TraCI Server started

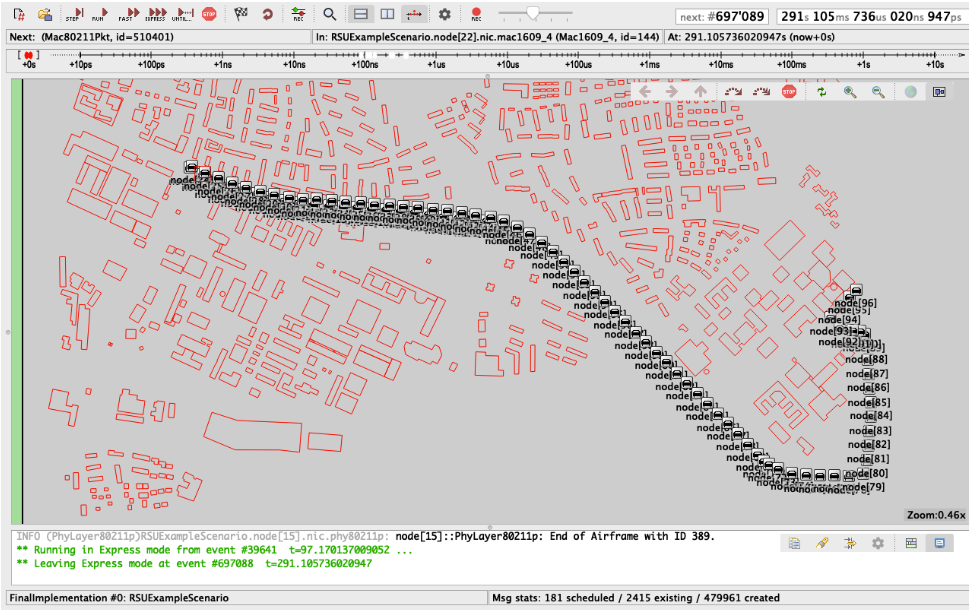

Figure 5.7: Running Vehicles using VEINS on OMNET++

The image in the Figure 5.8 presents the beaconing process among the vehicle in the network. The beaconing is carried out to gather the neighbor's data. The frequency of beaconing is set to 3 seconds in the present work.

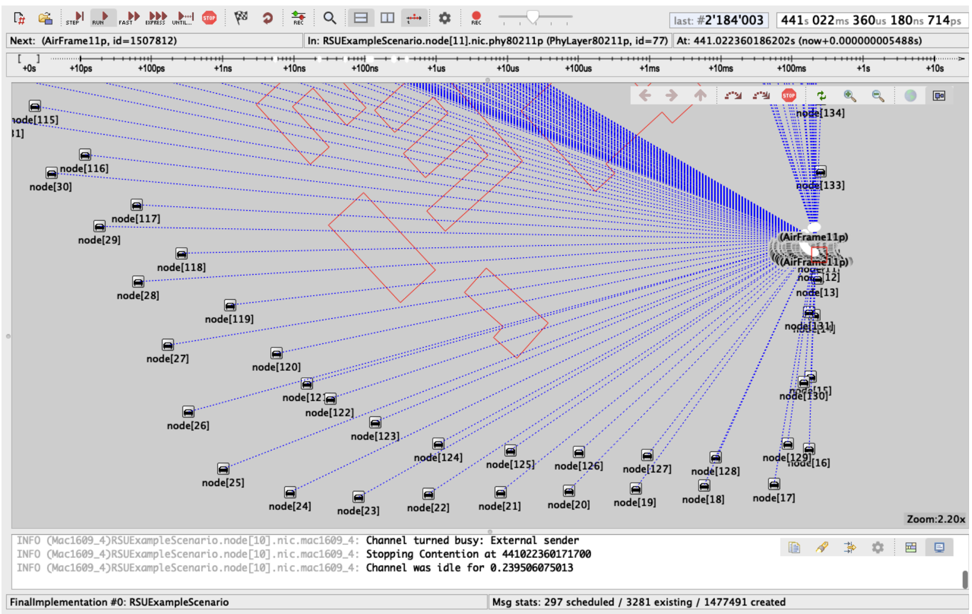

Figure 5.8: Vehicles exchanging Beacons using VEINS in OMNET++

The Figure 5.9 presents the screenshot of flooding mechanism-based information dissemination, in the flooding mechanism setup, every vehicle on the reception of messages instantly rebroadcast the packet and this is repeated indefinitely. This causes the generation of high volume redundant packets and ultimately results in a broadcast storm problem.

The Figure 5.10 presents the screenshot of the probability-based approach, in this approach the vehicles rebroadcast based on a random calculated probability between 0 and 1. This calculated probability decides the further dissemination of the packet. The simulation is carried out and results are interpreted in the next section.

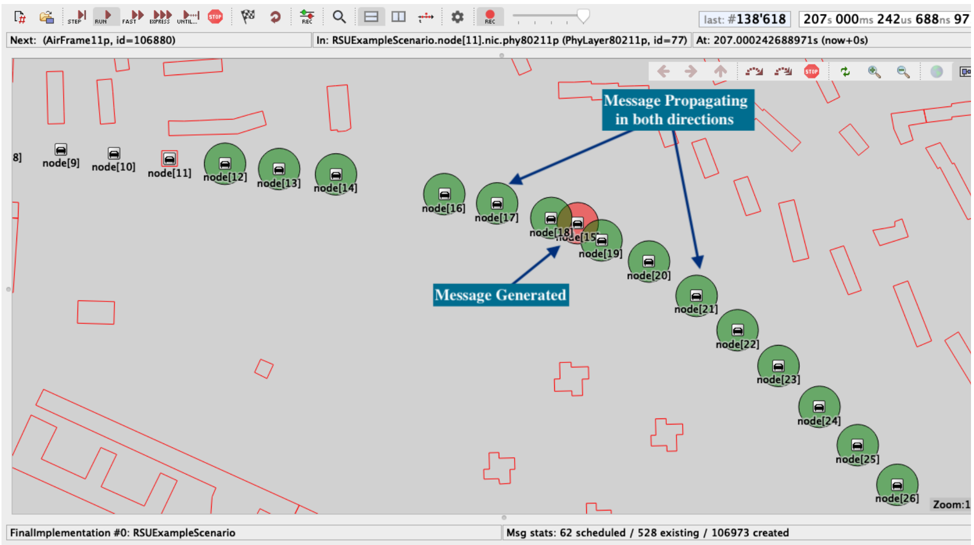

Figure 5.9: Vehicle exchanging Information using Flooding

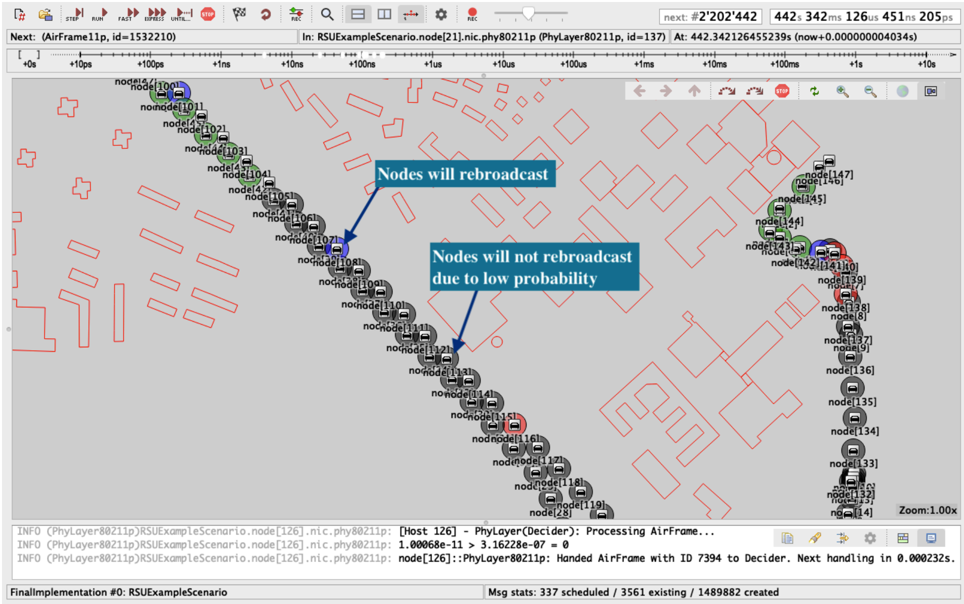

Figure 5.10: Vehicle exchanging Information using Autocast

The Figure 5.11 presents the screenshot of the distance-based approach in information dissemination. The green vehicle indicates the reception of message and grey nodes indicates that these vehicles are not participating in further dissemination due to the distance threshold. Only the vehicles which are farthest from the sender will rebroadcast the message and hence red one indicates the rebroadcasters. In this approach we observed that the number of redundant messages generated was less, the detailed explanation is presented in the next section.

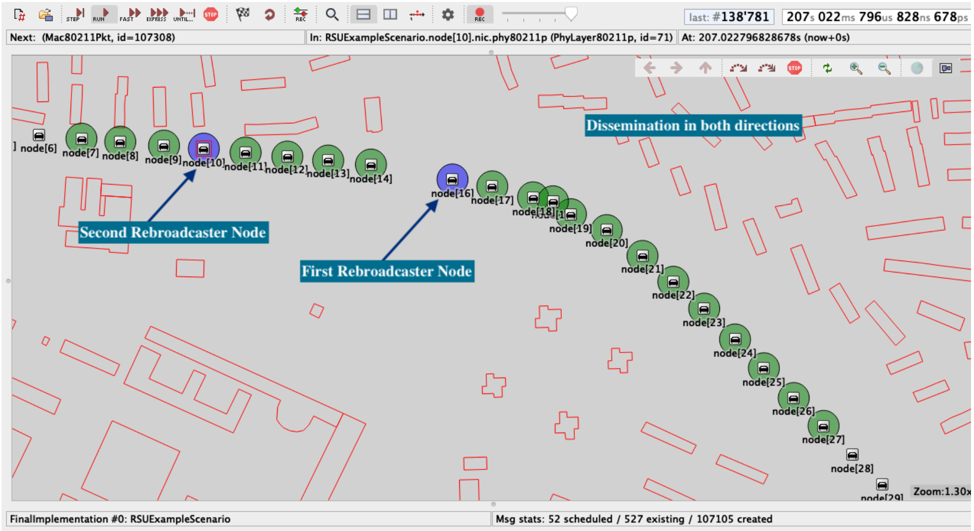

Figure 5.11: Vehicle exchanging Information using Distance based approach

The Figure 5.12 presents the screenshot of the counter-based approach, in this approach the vehicles only rebroadcast the message till it reaches a specified counter value. This restricts the receivers to send infinite redundant messages.

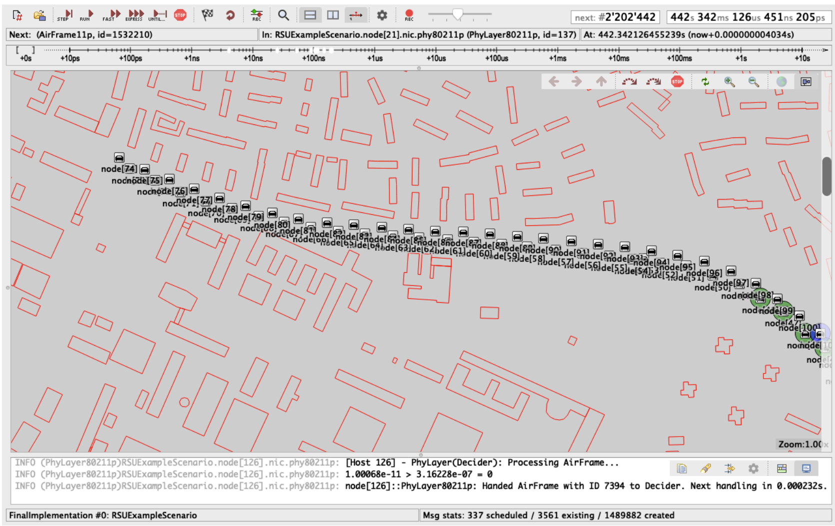

Figure 5.12: Vehicle exchanging Information using Counter Based approach

The Figure 5.13 presents the screenshot of the running novel PBEID protocol for Class 1 message V2V information dissemination in OMNET++. As shown in the image, the red vehicle has met an accident. The vehicle generates the class 1 message, i.e. backward dissemination and High priority, and broadcast the message, upon reception the vehicles indicated in red color opt-out themselves from the rebroadcast process as they are traveling in the opposite direction and they need not participate in the further rebroadcast process. The vehicles indicated in yellow denote the probable rebroadcaster and based on the computations algorithm decides the purple node as the viable rebroadcaster. The results are discussed in the next section.

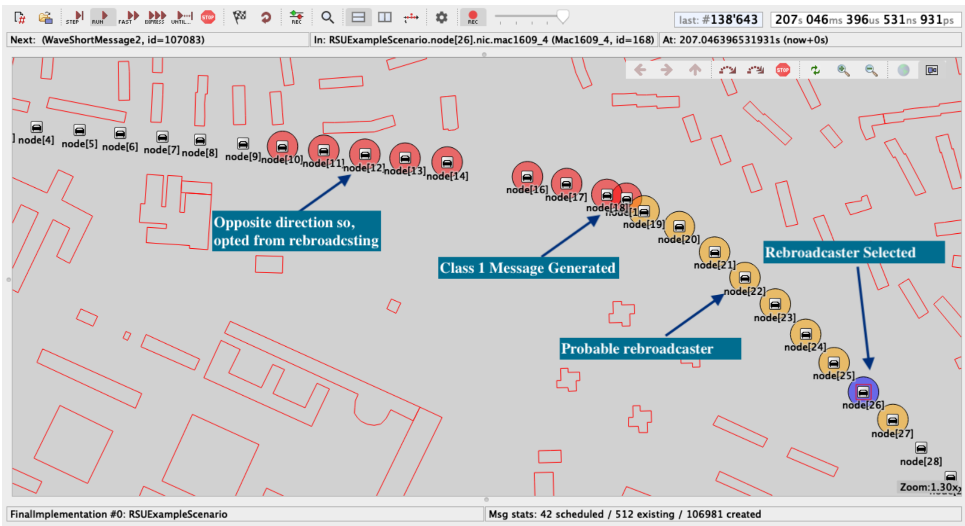

Figure 5.13: Vehicle exchanging Class 1 Message using PBEID Protocol

The Figure 5.14 presents the screenshot of the running novel PBEID protocol for Class 2 message V2V information dissemination in OMNET++. As shown in the image, the red vehicle has met an accident. The vehicle generates the class 2 message, i.e. forward dissemination and High priority, and broadcast the message, upon reception the vehicles indicated in red color opt-out themselves from the rebroadcast process as they are traveling in the opposite direction and they need not participate in the further rebroadcast process. The vehicles indicated in yellow denote the probable rebroadcaster and based on the computation's algorithm decides the purple node as the viable rebroadcaster. The results are discussed in the next section.

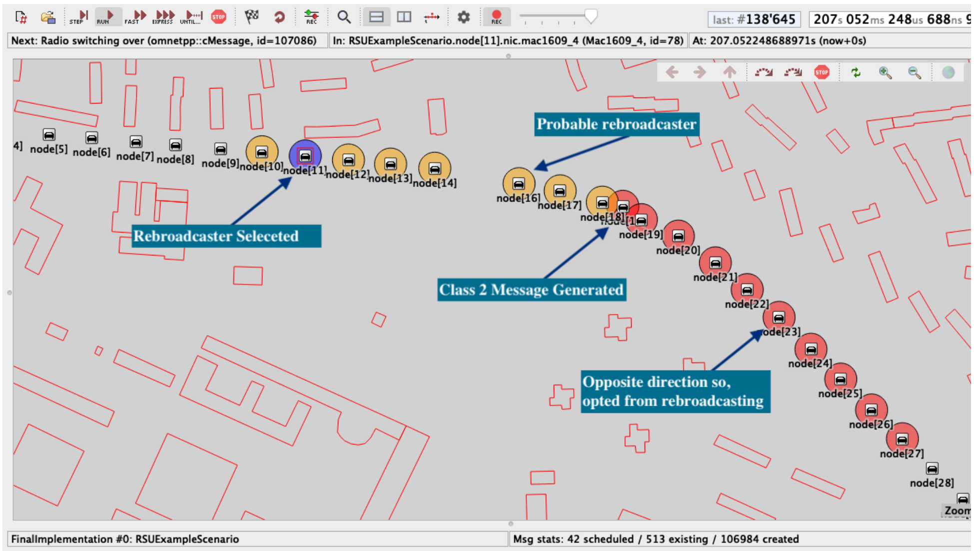

Figure 5.14: Vehicle exchanging Class 2 Message using PBEID Protocol

The image in Figure 5.15 demonstrates the simulation for the scenario in which a vehicle receives the same message from 2 sources, the vehicle then cancels its scheduled rebroadcast and opt-out itself from the rebroadcast process.

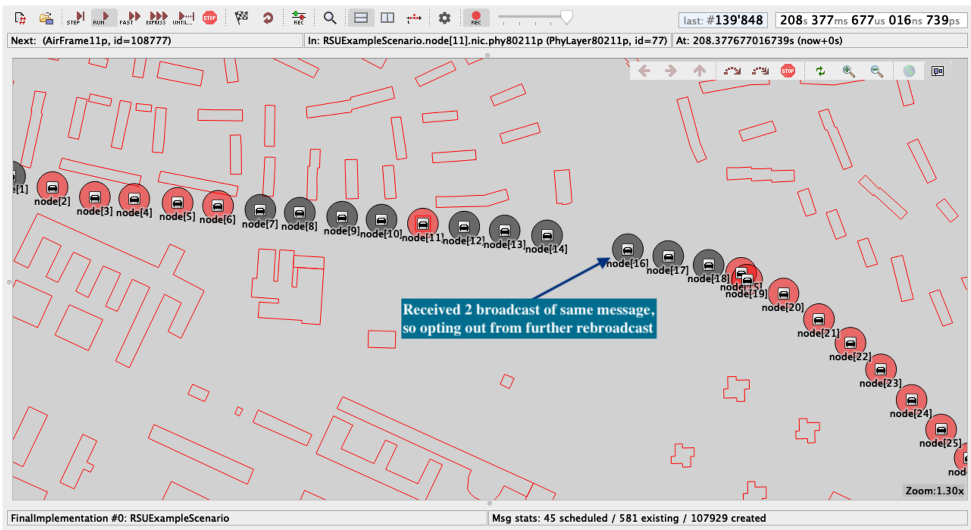

Figure 5.15: Limit Rebroadcast on 2 reception of same message

5.3 Result & Discussion

In this section, we present a performance evaluation of PBEID protocol. The PBEID protocol was compared against the following standard information dissemination techniques and these techniques were also simulated on the same simulation setup.

Flooding: The flooding algorithm is the straight forward algorithm that keeps resending the message to all nodes in the network upon reception[116].

Probability-based: In probability-based protocols, every vehicle which receives an information packet will decide whether to re-broadcast the same packet or not. The decision is taken based on probability-based functions. [149], [150].

Distance-Based: In distance-based protocols, the decision of when to rebroadcast a packet depends upon the distance between the two vehicles. The farthest vehicles rebroadcast early[151].

Counter Based: In this type of broadcasting protocols, the vehicle decides its rebroadcast priority based on a counter which tells the vehicle as in how many times it has received the same packet. [152], [153].

The performance of PBEID is evaluated based on the following metrics [6]

(1) Propagation Time[92], [95], [99], [100], [103], [111].

(2) Reachability Ratio [88], [94], [97], [100]–[102], [104], [105], [111].

(3) Number of Retransmission(Packet Generated) [101], [106], [107], [113] , and

(4) Total packet Loss [91], [93], [97], [99].

The following subsection presents the PBEID simulation results along with its evaluation performance.

5.3.1 Evaluating the Propagation Time

The propagation time is defined as the difference of time between the packet generation at the source node and reception of the first message at the last node. The efficient algorithm aims at minimizing the propagation time. The propagation time is calculated using Eq. (5.4).

$$PT = ReceiveMsgTime - InitTime \tag{5.4}$$

The following subsection presents the simulation data, graphical analysis and statistical analysis for the propagation time of PBEID along with compared protocols.

a) Simulation Data

The Table 5.3 presents the simulation data for calculated propagation time.

Table 5.3: Calculated Propagation Time

Time Taken to Reach all nodes							
Nodes	30	50	70	90	110	130	150
Autocast	0.16335454	0.188492	0.38749816	0.30945716	0.42254208	0.23360201	0.48142893
Counter	2.03984114	3.17096077	3.22017995	4.20799353	6.23368251	8.25656994	9.27413739
Distance	0.090524	0.06740809	0.111197	0.17077356	0.12979437	0.18724773	0.21441028
Flooding	2.03983173	2.06679638	3.10286586	4.1576121	5.19697583	7.26160692	7.40822359
Flooding 2 Sec	4.03741914	4.07368524	6.11024953	8.21866051	10.230658	14.3158911	12.6344948
PBEID Class 1	0.046633	0.0603867	0.1030382	0.100846	0.121835	0.05818122	0.24267966
PBEID Class 2	0.080178	0.100843	0.046132	0.060417	0.049407	0.05161607	0.06211658

b) Graphical Analysis

The propagation time is an important evaluation parameter for critical messages. The Figure 5.16 and Figure 5.17 shows the performance of PBEID protocol with Class 1 and Class 2 message respectively against different techniques in sparse to the dense network environment. We can observe that PBEID protocol is consistently performing well in almost all the scenarios.

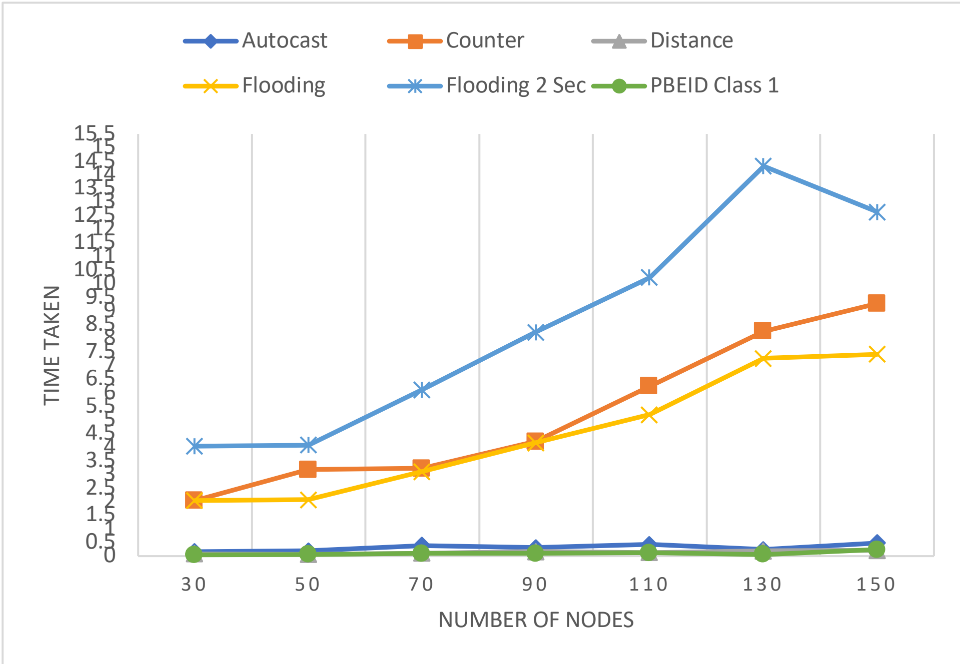

Figure 5.16: Number of Nodes vs Propagation in Time Class 1 Messages

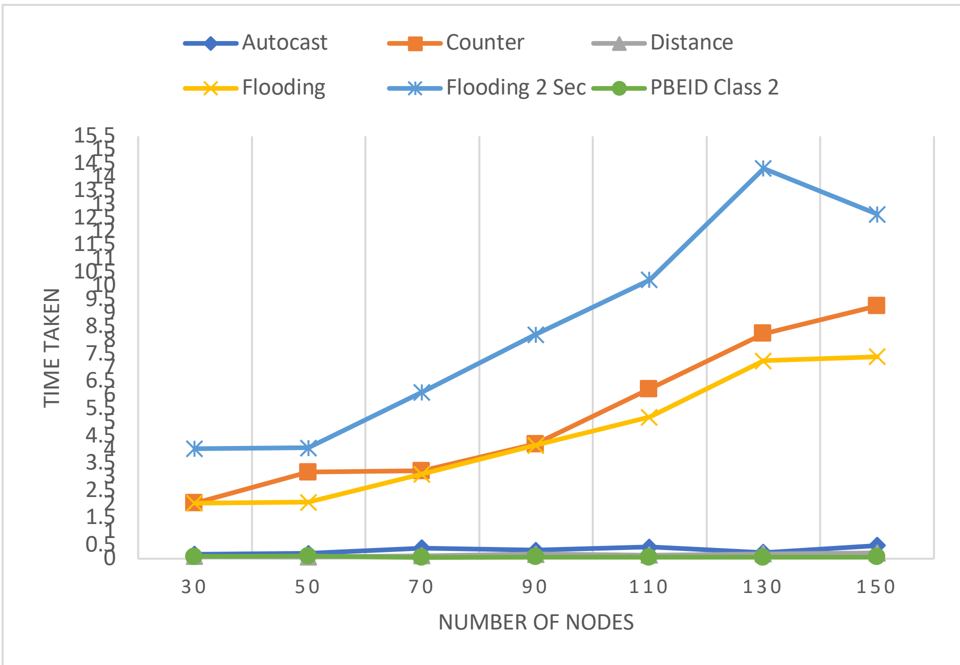

Figure 5.17: Number of Nodes vs Propagation in Time Class 2 Messages

c) Statistical Analysis for Class 1 Messages

The Table 5.4 presents the detailed result and analysis for two independent samples, a lower tailed t-test with a significance level of 5% w.r.t. the propagation time of PBEID class 1 messages along with compared protocols. An optimal algorithm requires minimum propagation time, we tested our results and found PBEID class 1 as significant in comparison with all compared algorithms except the distance-based algorithm.

Table 5.4: Statistical Analysis for Class 1 Messages w.r.t. Propagation Time

Propagation Time						
# Node/Technique	Autocast	Counter	Distance	Flooding 1 Sec	Flooding 2 Sec	PBEID Class 1
30	0.16335454	2.03984114	0.090524	2.03983173	4.03741914	0.046633
50	0.188492	3.17096077	0.06740809	2.06679638	4.07368524	0.0603867
70	0.38749816	3.22017995	0.111197	3.10286586	6.11024953	0.1030382
90	0.30945716	4.20799353	0.17077356	4.1576121	8.21866051	0.100846
110	0.42254208	6.23368251	0.12979437	5.19697583	10.230658	0.121835
130	0.23360201	8.25656994	0.18724773	7.26160692	14.3158911	0.058181225
150	0.48142893	9.27413739	0.21441028	7.40822359	12.6344948	0.242679665

Research Question: **Is PBEID Class 1 (μ1) better than (μ2) concerning Propagation Time ?**

μ1:	mean (Propagation Time of	PBEID Class 1)
μ2:	mean (Propagation Time of	Autocast/Counter/Distance/Flooding 1 Sec/Flooding 2Sec)

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

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

t-test for two independent samples / Lower-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
PBEID C1	7	0	7	4.66E-02	2.43E-01	1.05E-01	6.69E-02
Autocast	7	0	7	1.63E-01	4.81E-01	3.12E-01	1.23E-01
PBEID C1	7	0	7	4.66E-02	2.43E-01	1.05E-01	6.69E-02
Counter	7	0	7	2.04E+00	9.27E+00	5.20E+00	2.77E+00
PBEID C1	7	0	7	4.66E-02	2.43E-01	1.05E-01	6.69E-02
Distance	7	0	7	6.74E-02	2.14E-01	1.39E-01	5.38E-02
PBEID C1	7	0	7	4.66E-02	2.43E-01	1.05E-01	6.69E-02
Flooding 1 Sec	7	0	7	2.04E+00	7.41E+00	4.46E+00	2.26E+00
PBEID C1	7	0	7	4.66E-02	2.43E-01	1.05E-01	6.69E-02
Flooding 2 Sec	7	0	7	4.04E+00	1.43E+01	8.52E+00	4.07E+00

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							
PBEID C1 vs	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
Autocast	-2.08E-01	-3.93E+00	-1.78E+00	12	9.95E-04	H0	**Significantly YES**
Counter	-5.10E+00	-4.87E+00	-1.78E+00	12	1.94E-04	H0	**Significantly YES**
Distance	-3.40E-02	-1.05E+00	-1.78E+00	12	1.58E-01	Ha	**Significantly NO**
Flooding 1 Sec	-4.36E+00	-5.10E+00	-1.78E+00	12	1.30E-04	H0	**Significantly YES**
Flooding 2 Sec	-8.41E+00	-5.47E+00	-1.78E+00	12	< 0.0001	H0	**Significantly YES**

d) Statistical Analysis for Class 2 Messages

The Table 5.5 presents the detailed result and analysis for two independent samples, a lower tailed t-test with a significance level of 5% w.r.t. the propagation time of PBEID class 2 messages along with compared protocols. An optimal algorithm requires minimum propagation time, we tested our results and found PBEID class 2 as significant in all the considered cases.

Table 5.5: Statistical Analysis for Class 2 Messages w.r.t. Propagation Time

Propagation Time						
# Node/Technique	Autocast	Counter	Distance	Flooding 1 Sec	Flooding 2 Sec	PBEID Class 2
30	0.16335454	2.03984114	0.090524	2.03983173	4.03741914	0.080178
50	0.188492	3.17096077	0.06740809	2.06679638	4.07368524	0.100843
70	0.38749816	3.22017995	0.111197	3.10286586	6.11024953	0.046132
90	0.30945716	4.20799353	0.17077356	4.1576121	8.21866051	0.060417
110	0.42254208	6.23368251	0.12979437	5.19697583	10.230658	0.049407
130	0.23360201	8.25656994	0.18724773	7.26160692	14.3158911	0.051616074
150	0.48142893	9.27413739	0.21441028	7.40822359	12.6344948	0.062116581

Research Question:	Is PBEID Class 2 (μ1) better than (μ2) concerning Propagation Time ?

μ1:	mean (Propagation Time of	PBEID Class 2)
μ2:	mean (Propagation Time of	Autocast/Counter/Distance/Flooding 1 Sec/Flooding 2Sec)

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

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

t-test for two independent samples / Lower-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
PBEID C2	7	0	7	4.61E-02	1.01E-01	6.44E-02	1.97E-02
Autocast	7	0	7	1.63E-01	4.81E-01	3.12E-01	1.23E-01
PBEID C2	7	0	7	4.61E-02	1.01E-01	6.44E-02	1.97E-02
Counter	7	0	7	2.04E+00	9.27E+00	5.20E+00	2.77E+00
PBEID C2	7	0	7	4.61E-02	1.01E-01	6.44E-02	1.97E-02
Distance	7	0	7	6.74E-02	2.14E-01	1.39E-01	5.38E-02
PBEID C2	7	0	7	4.61E-02	1.01E-01	6.44E-02	1.97E-02
Flooding 1 Sec	7	0	7	2.04E+00	7.41E+00	4.46E+00	2.26E+00
PBEID C2	7	0	7	4.61E-02	1.01E-01	6.44E-02	1.97E-02
Flooding 2 Sec	7	0	7	4.04E+00	1.43E+01	8.52E+00	4.07E+00

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							
PBEID vs	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
Autocast	-2.48E-01	-5.29E+00	-1.78E+00	12	< 0.0001	H0	**Significantly YES**
Counter	-5.14E+00	-4.91E+00	-1.78E+00	12	1.81E-04	H0	**Significantly YES**
Distance	-7.44E-02	-3.44E+00	-1.78E+00	12	2.46E-03	H0	**Significantly YES**
Flooding 1 Sec	-4.40E+00	-5.15E+00	-1.78E+00	12	1.20E-04	H0	**Significantly YES**
Flooding 2 Sec	-8.45E+00	-5.50E+00	-1.78E+00	12	< 0.0001	H0	**Significantly YES**

5.3.2 Evaluating the Reachability Ratio

The reachability refers to the overall coverage of the message. The Reachability is calculated using Eq. (5.5).

$$\text{Reachability}= \frac{\text{NumberVehicleReceived}}{TotalVehiclesinNetwork} * 100 \tag{5.5}$$

The reachability value calculated using Eq. (5.5) provides the percentage of the intended vehicle receives the message. Furthermore, the ratio between the Reachability in Eq. (5.5) and the PT calculated in Eq. (5.4) provides the Reachability ratio which also considers the reachability in the time taken. The Reachability Ratio is calculated using Eq. (5.6)

$$\text{Reachability Ratio}= \frac{\text{Reachability}}{PT} \tag{5.6}$$

The following subsection presents the simulation data, graphical analysis and statistical analysis for the reachability ratio of PBEID along with compared protocols.

a) Simulation Data

The Table 5.6 presents the simulation data for calculated reachability ratio.

Table 5.6: Calculated Reachability Ratio

Reachablity Ratio							
Nodes	30	50	70	90	110	130	150
Autocast	612.165416	530.526494	258.065742	323.146506	234.511339	428.078508	198.021613
Counter	49.0234254	31.5361833	31.0541652	23.7642951	16.0418821	12.111567	10.1357135
Distance	1104.67942	1483.50146	899.304837	585.570741	763.445357	534.051868	444.630422
Flooding	49.0236516	48.38406	32.2282704	24.0522679	19.2419598	13.7710566	12.6886019
Flooding 2 Sec	24.7682979	24.5477974	16.3659437	12.1674329	9.77454236	6.87777923	7.07059006
PBEID Class 1	2144.40418	1655.99379	970.513848	991.610971	820.782205	1718.76752	412.065841
PBEID Class 2	1247.22492	991.640471	2167.69271	1655.16328	2024.0047	1937.38099	1609.87611

b) Graphical Analysis

The reachability ratio is a prime parameter when it comes to Information dissemination. The reachability is affected by many parameters such as collision, blind node, network contention etc. The Figure 5.18 and Figure 5.19

presents the results of PBEID Class1 and Class 2 messages respectively in comparison to other techniques. We can observe that PBEID is performing better in comparison with all other standard algorithms.

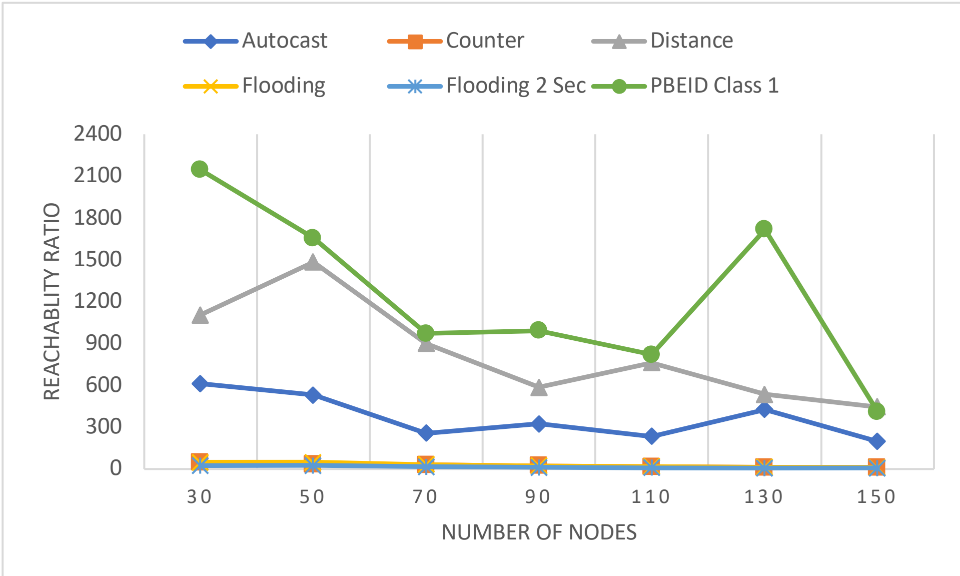

Figure 5.18: Number of Nodes vs Reachability Ratio Class 1 Messages

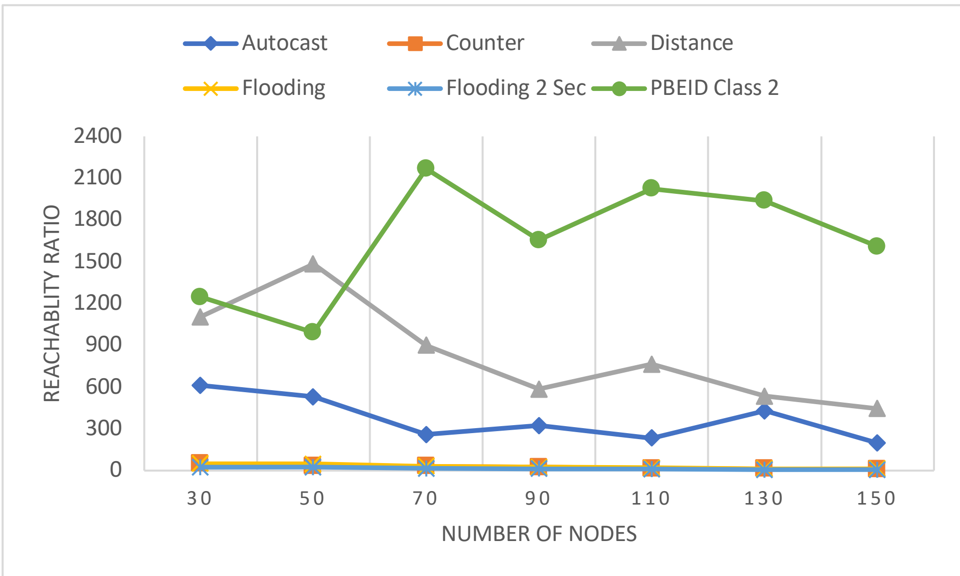

Figure 5.19: Number of Nodes vs Reachability Ratio Class 1 Messages

c) Statistical Analysis for Class 1 Messages

The Table 5.7 presents the detailed result and analysis for two independent samples, upper tailed t-test with a significance level of 5%. w.r.t. reachability ratio of PBEID class 1 message along with compared protocols. An optimal algorithm requires maximum reachability ratio,

we tested our results and found PBEID class 1 as significant in comparison with all compared algorithms except the distance-based algorithm.

Table 5.7: Statistical Analysis for Class 1 Messages w.r.t. Reachability Ratio

Reachability Ratio						
# Node/Technique	Autocast	Counter	Distance	Flooding 1 Sec	Flooding 2 Sec	PBEID Class 1
30	612.1654164	49.02342542	1104.679422	49.02365157	24.7682979	2144.404177
50	530.5264945	31.53618327	1483.501461	48.38405997	24.54779741	1655.993787
70	258.0657415	31.05416516	899.3048374	32.22827042	16.36594373	970.5138483
90	323.146506	23.76429509	585.5707406	24.05226789	12.16743287	991.6109712
110	234.5113393	16.04188212	763.4453566	19.2419598	9.774542361	820.7822054
130	428.0785084	12.111567	534.0518681	13.77105661	6.87777923	1718.767524
150	198.0216131	10.13571355	444.6304223	12.68860191	7.070590059	412.0658405

Research Question:	Is PBEID Class 1 (μ1) better than (μ2) concerning Reachability of nodes?

μ1:	mean (Reachability Ratio of	PBEID Class 1)
μ2:	mean (Reachability Ratio of	Autocast/Counter/Distance/Flooding 1 Sec/Flooding 2Sec)

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 / Lower-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
PBEID C1	7	0	7	4.12E+02	2.14E+03	1.24E+03	6.08E+02
Autocast	7	0	7	1.98E+02	6.12E+02	3.69E+02	1.58E+02
PBEID C1	7	0	7	4.12E+02	2.14E+03	1.24E+03	6.08E+02
Counter	7	0	7	1.01E+01	4.90E+01	2.48E+01	1.37E+01
PBEID C1	7	0	7	4.12E+02	2.14E+03	1.24E+03	6.08E+02
Distance	7	0	7	4.45E+02	1.48E+03	8.31E+02	3.67E+02
PBEID C1	7	0	7	4.12E+02	2.14E+03	1.24E+03	6.08E+02
Flooding 1 Sec	7	0	7	1.27E+01	4.90E+01	2.85E+01	1.53E+01
PBEID C1	7	0	7	4.12E+02	2.14E+03	1.24E+03	6.08E+02
Flooding 2 Sec	7	0	7	6.88E+00	2.48E+01	1.45E+01	7.65E+00

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

Research Conclusion							
PBEID C1 vs	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
Autocast	8.76E+02	3.69E+00	1.78E+00	12	1.55E-03	H0	**Significantly YES**
Counter	1.22E+03	5.31E+00	1.78E+00	12	< 0.0001	H0	**Significantly YES**
Distance	4.14E+02	1.54E+00	1.78E+00	12	7.43E-02	Ha	**Significantly NO**
Flooding 1 Sec	1.22E+03	5.29E+00	1.78E+00	12	< 0.0001	H0	**Significantly YES**
Flooding 2 Sec	1.23E+03	5.36E+00	1.78E+00	12	< 0.0001	H0	**Significantly YES**

d) Statistical Analysis for Class 2 Messages

The Table 5.8 presents the detailed result and analysis for two independent samples, upper tailed t-test with a significance level of 5% w.r.t. reachability ratio of PBEID class 2 messages along with compared protocols. An optimal algorithm requires maximum propagation time, we tested our results and found PBEID class 2 as significant in all cases.

Table 5.8: Statistical Analysis for Class 2 Messages w.r.t. Reachability Ratio

Reachability Ratio						
# Node/Technique	Autocast	Counter	Distance	Flooding 1 Sec	Flooding 2 Sec	PBEID Class 2
30	612.1654164	49.02342542	1104.679422	49.02365157	24.7682979	1247.224925
50	530.5264945	31.53618327	1483.501461	48.38405997	24.54779741	991.6404708
70	258.0657415	31.05416516	899.3048374	32.22827042	16.36594373	2167.692708
90	323.146506	23.76429509	585.5707406	24.05226789	12.16743287	1655.163282
110	234.5113393	16.04188212	763.4453566	19.2419598	9.774542361	2024.004696
130	428.0785084	12.111567	534.0518681	13.77105661	6.87777923	1937.380989
150	198.0216131	10.13571355	444.6304223	12.68860191	7.070590059	1609.876113

Research Question: **Is PBEID Class 2 (μ1) better than (μ2) concerning Reachability of nodes?**

μ1: mean (Reachability Ratio of PBEID Class 2)
μ2: mean (Reachability Ratio of Autocast/Counter/Distance/Flooding 1 Sec/Flooding 2Sec)

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 / Lower-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
PBEID C2	7	0	7	9.92E+02	2.17E+03	1.66E+03	4.26E+02
Autocast	7	0	7	1.98E+02	6.12E+02	3.69E+02	1.58E+02
PBEID C2	7	0	7	9.92E+02	2.17E+03	1.66E+03	4.26E+02
Counter	7	0	7	1.01E+01	4.90E+01	2.48E+01	1.37E+01
PBEID C2	7	0	7	9.92E+02	2.17E+03	1.66E+03	4.26E+02
Distance	7	0	7	4.45E+02	1.48E+03	8.31E+02	3.67E+02
PBEID C2	7	0	7	9.92E+02	2.17E+03	1.66E+03	4.26E+02
Flooding 1 Sec	7	0	7	1.27E+01	4.90E+01	2.85E+01	1.53E+01
PBEID C2	7	0	7	9.92E+02	2.17E+03	1.66E+03	4.26E+02
Flooding 2 Sec	7	0	7	6.88E+00	2.48E+01	1.45E+01	7.65E+00

H0: The difference between the means is lower or equal to 0, i.e. $\mu1 - \mu2 <= 0$.
Ha: The difference between the means is greater than 0, i.e. $\mu1 - \mu2 > 0$
Significance Value 0.05

Research Conclusion							
PBEID C2 vs	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
Autocast	1.29E+03	7.53E+00	1.78E+00	12	< 0.0001	H0	**Significantly YES**
Counter	1.64E+03	1.02E+01	1.78E+00	12	< 0.0001	H0	**Significantly YES**
Distance	8.31E+02	3.91E+00	1.78E+00	12	1.03E-03	H0	**Significantly YES**
Flooding 1 Sec	1.63E+03	1.01E+01	1.78E+00	12	< 0.0001	H0	**Significantly YES**
Flooding 2 Sec	1.65E+03	1.02E+01	1.78E+00	12	< 0.0001	H0	**Significantly YES**

5.3.3 Number of Retransmissions

In the multi-hop dissemination technique, the packet needs to be rebroadcasted upon reception. This rebroadcasting is referred to as retransmission. The *NoOfRetransmission* is calculated as summation of the packet generated on all the nodes in the network. If all the receiving nodes are retransmitting the message, then it may result in network contention and collision. The number of retransmissions is calculated using Eq. (5.7).

$$NoOfRetransmission = \sum_{x=1}^{TotalVehicles} PacketGeneratedat(x) \tag{5.7}$$

The following subsection presents the simulation data, graphical analysis and statistical analysis for packet generated of PBEID along with compared protocols.

a) Simulation Data

The Table 5.9 presents the simulation data for packet generated.

Table 5.9: Simulation data for Packet Generated

Packet Generated							
Nodes	**30**	**50**	**70**	**90**	**110**	**130**	**150**
Autocast	17	26	34	38	57	72	65
Counter	9	12	16	18	20	20	20
Distance	25	45	65	85	104	125	138
Flooding	30	50	70	90	110	130	141
Flooding 2 Sec	30	50	70	90	110	128	118
PBEID Class 1	3	4	5	6	6	10	10
PBEID Class 2	4	5	5	4	4	4	4

b) Graphical Analysis

In the figures Figure 5.20 and Figure 5.21, we can see that flooding and distance-based techniques are gradually increasing packet generation as the number of nodes is increasing. On the other side, we could see that PBEID is performing very well in both Class 1 and Class 2 messages. PBEID is generating a minimum number of packets. We can also observe that due to the adaptive parameters packet generation is decreasing as the number of nodes is increasing.

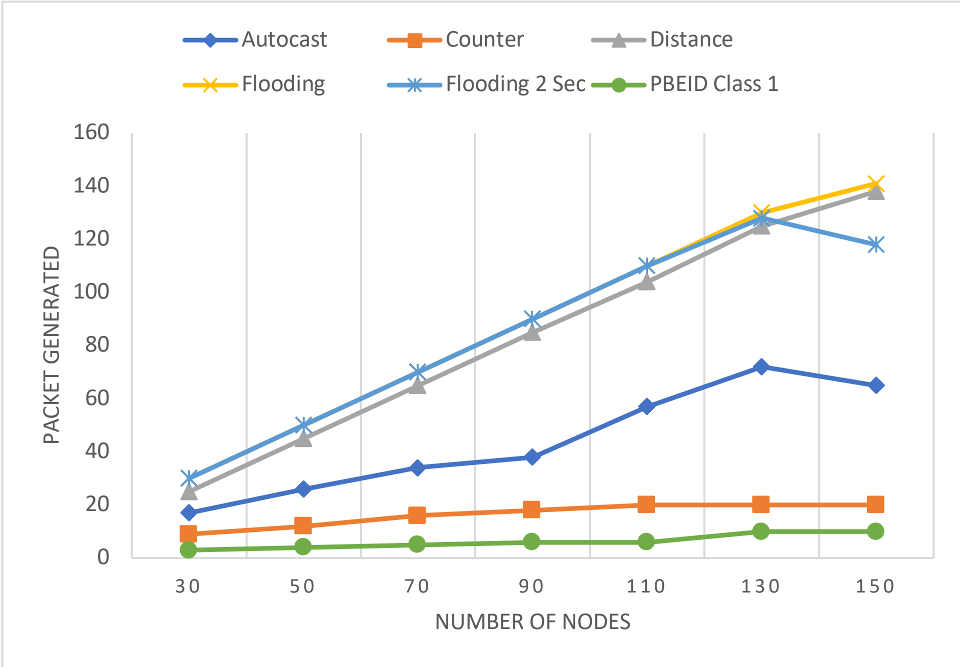

Figure 5.20: Number of Nodes vs Packet Generated in Class 1

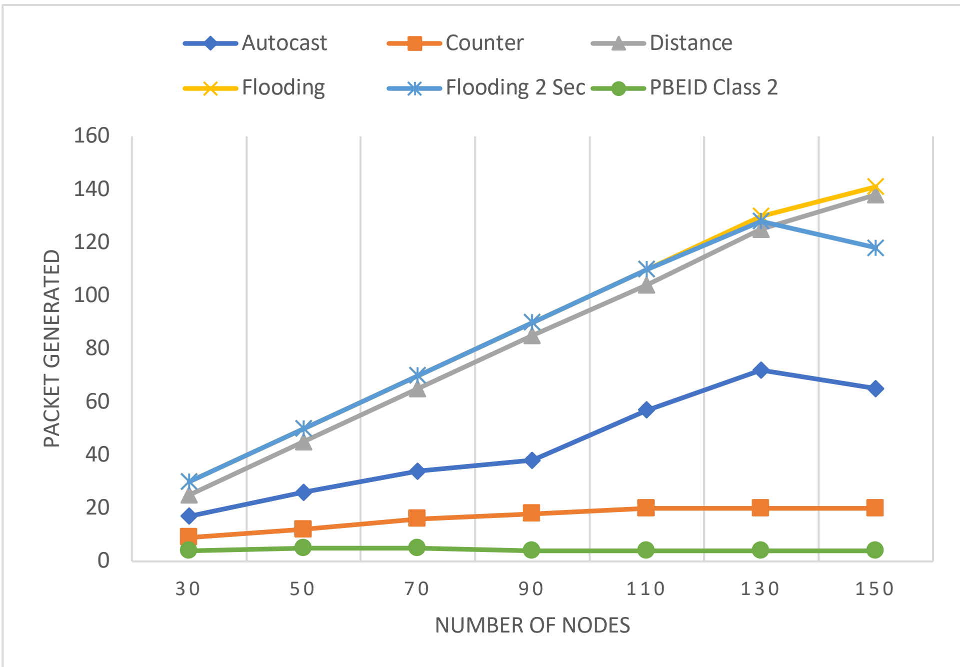

Figure 5.21: Number of Nodes vs Packet Generated in Class 2

c) Statistical Analysis for Class 1 Messages

The Table 5.10 presents the detailed result and analysis for two independent samples, a lower tailed t-test with a significance level of 5% w.r.t. a packet generated of PBEID class 1 message along with compared protocols. An optimal algorithm requires minimum packet generation, we tested our results and found PBEID class 1 as significant in all cases.

Table 5.10: Statistical Analysis for Class 1 Messages w.r.t. Packet Generated

Retransmission of Packet						
# Node/Technique	Autocast	Counter	Distance	Flooding 1 Sec	Flooding 2 Sec	PBEID Class 1
30	17	9	25	30	30	3
50	26	12	45	50	50	4
70	34	16	65	70	70	5
90	38	18	85	90	90	6
110	57	20	104	110	110	6
130	72	20	125	130	128	10
150	65	20	138	141	118	10

Research Question: **Is PBEID Class 1 (µ1) better than (µ2) concerning number of packet Generated in the network ?**

µ1: mean (Packet Generated in PBEID Class 1)
µ2: mean (Packet Generated in Autocast/Counter/Distance/Flooding 1 Sec/Flooding 2Sec)

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

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

t-test for two independent samples / Lower-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
PBEID C1	7	0	7	3.00E+00	1.00E+01	6.29E+00	2.75E+00
Autocast	7	0	7	1.70E+01	7.20E+01	4.41E+01	2.07E+01
PBEID C1	7	0	7	3.00E+00	1.00E+01	6.29E+00	2.75E+00
Counter	7	0	7	9.00E+00	2.00E+01	1.64E+01	4.39E+00
PBEID C1	7	0	7	3.00E+00	1.00E+01	6.29E+00	2.75E+00
Distance	7	0	7	2.50E+01	1.38E+02	8.39E+01	4.16E+01
PBEID C1	7	0	7	3.00E+00	1.00E+01	6.29E+00	2.75E+00
Flooding 1 Sec	7	0	7	3.00E+01	1.41E+02	8.87E+01	4.12E+01
PBEID C1	7	0	7	3.00E+00	1.00E+01	6.29E+00	2.75E+00
Flooding 2 Sec	7	0	7	3.00E+01	1.28E+02	8.51E+01	3.67E+01

H0: The difference between the means is greater or equal to 0, i.e. $\mu1 - \mu2 >= 0$.
Ha: The difference between the means is lower than 0, i.e. $\mu1 - \mu2 < 0$
Significance Value 0.05

Research Conclusion							
PBEID C1 vs	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
Autocast	-3.79E+01	-4.79E+00	-1.78E+00	12	2.22E-04	H0	**Significantly YES**
Counter	-1.01E+01	-5.18E+00	-1.78E+00	12	1.15E-04	H0	**Significantly YES**
Distance	-7.76E+01	-4.93E+00	-1.78E+00	12	1.75E-04	H0	**Significantly YES**
Flooding 1 Sec	-8.24E+01	-5.28E+00	-1.78E+00	12	< 0.0001	H0	**Significantly YES**
Flooding 2 Sec	-7.89E+01	-5.68E+00	-1.78E+00	12	< 0.0001	H0	**Significantly YES**

d) Statistical Analysis for Class 2 Messages

The Table 5.11 presents the detailed result and analysis for two independent samples, a lower tailed t-test with a significance level of 5% w.r.t. a packet generated of PBEID class 2 messages along with compared protocols. An optimal algorithm requires minimum packet generation, we tested our results and found PBEID class 2 as significant in all cases.

Table 5.11: Statistical Analysis for Class 2 Messages w.r.t. Packet Generated

Retransmission of Packet						
# Node/Technique	Autocast	Counter	Distance	Flooding 1 Sec	Flooding 2 Sec	PBEID Class 1
30	17	9	25	30	30	4
50	26	12	45	50	50	5
70	34	16	65	70	70	5
90	38	18	85	90	90	4
110	57	20	104	110	110	4
130	72	20	125	130	128	4
150	65	20	138	141	118	4

Research Question: **Is PBEID Class 2 (µ1) better than (µ2) concerning number of packet Generated in the network ?**

µ1:	mean (Packet Generated in	PBEID Class 2)
µ2:	mean (Packet Generated in	Autocast/Counter/Distance/Flooding 1 Sec/Flooding 2Sec)

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

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

t-test for two independent samples / Lower-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
PBEID C2	7	0	7	4.00E+00	5.00E+00	4.29E+00	4.88E-01
Autocast	7	0	7	1.70E+01	7.20E+01	4.41E+01	2.07E+01
PBEID C2	7	0	7	4.00E+00	5.00E+00	4.29E+00	4.88E-01
Counter	7	0	7	9.00E+00	2.00E+01	1.64E+01	4.39E+00
PBEID C2	7	0	7	4.00E+00	5.00E+00	4.29E+00	4.88E-01
Distance	7	0	7	2.50E+01	1.38E+02	8.39E+01	4.16E+01
PBEID C2	7	0	7	4.00E+00	5.00E+00	4.29E+00	4.88E-01
Flooding 1 Sec	7	0	7	3.00E+01	1.41E+02	8.87E+01	4.12E+01
PBEID C2	7	0	7	4.00E+00	5.00E+00	4.29E+00	4.88E-01
Flooding 2 Sec	7	0	7	3.00E+01	1.28E+02	8.51E+01	3.67E+01

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							
PBEID C2 vs	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
Autocast	-3.99E+01	-5.08E+00	-1.78E+00	12	1.35E-04	H0	**Significantly YES**
Counter	-1.21E+01	-7.27E+00	-1.78E+00	12	< 0.0001	H0	**Significantly YES**
Distance	-7.96E+01	-5.07E+00	-1.78E+00	12	1.39E-04	H0	**Significantly YES**
Flooding 1 Sec	-8.44E+01	-5.42E+00	-1.78E+00	12	< 0.0001	H0	**Significantly YES**
Flooding 2 Sec	-8.09E+01	-5.84E+00	-1.78E+00	12	< 0.0001	H0	**Significantly YES**

5.3.4 Total Packet Loss

The total packet loss refers to the sum of packets in reception loss, transmission loss and Signal-to-interference-plus-noise ratio (SNIR) at all the vehicles participating in the network. The number of collisions is calculated using Eq. (5.8)

$$TotalPacketLoss = \sum_{x=1}^{TotalVehicles} RxLost(x) + TxLost(x) + SNIR_{lostpackets} \tag{5.8}$$

The following subsection presents the simulation data, graphical analysis and statistical analysis for the total loss of PBEID along with compared protocols.

a) Simulation Data

The Table 5.12 presents the simulation data for total packet loss.

Table 5.12: Simulation data for Total Packet Loss

Loss on Nodes							
Nodes	**30**	**50**	**70**	**90**	**110**	**130**	**150**
Autocast	0	38	34	104	120	111	129
Counter	0	63	28	103	120	73	116
Distance	0	40	28	156	154	163	240
Flooding	0	39	28	103	178	71	133
Flooding 2 Sec	0	38	28	104	150	71	104
PBEID Class 1	0	13	14	64	50	17	36
PBEID Class 2	0	26	16	42	64	56	63

b) Graphical Analysis

Total packet loss refers to the number of packets lost in receiving and transmission at the physical layer due to uncontrolled random circumstances like obstacles, buildings, signal fading etc. This also includes the packet collision occurred due to network contention. However, these values are generated due to the random behavior of our simulator every time. In Figure 5.22 and Figure 5.23 we can observe that PBEID is performing well in both Class 1 and Class 2 messages respectively.

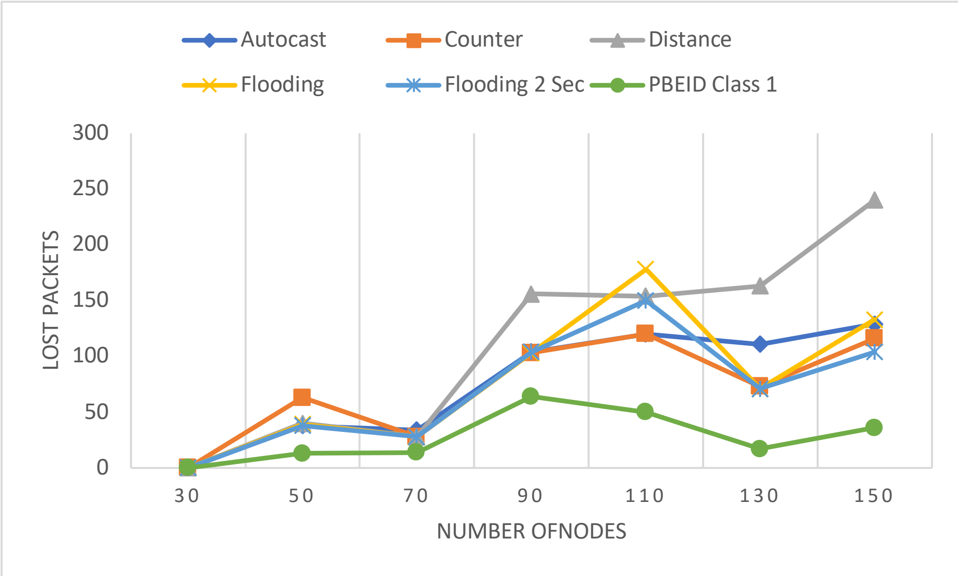

Figure 5.22: Number of Nodes vs Rx Tx Lost Packets Class 1 Messages

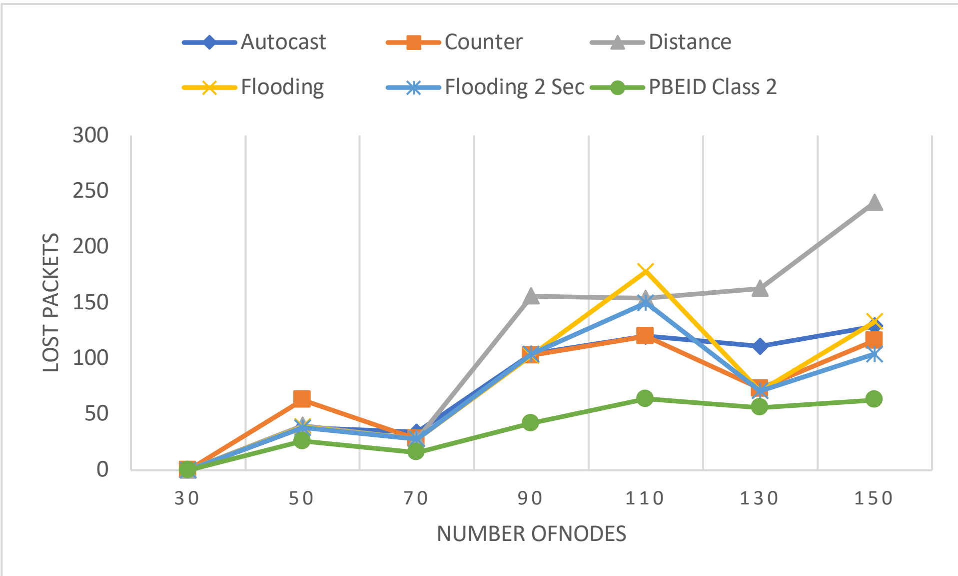

Figure 5.23: Number of Nodes vs Rx Tx Lost Packets Class 2 Messages

c) Statistical Analysis for Class 1 Messages

The Table 5.13 presents the detailed result and analysis for two independent samples, a lower tailed t-test with a significance level of 5% w.r.t. total packet loss of PBEID class 1 message along with compared protocols. An optimal algorithm requires minimum lost packets, we tested our results and found PBEID Class 1 as significant in all cases

Table 5.13: Statistical Analysis for Class 1 Messages w.r.t. Total Packet Loss

Total Packet Loss						
# Node/Technique	Autocast	Counter	Distance	Flooding 1 Sec	Flooding 2 Sec	PBEID Class 1
30	0	0	0	0	0	0
50	38	63	40	39	38	13
70	34	28	28	28	28	14
90	104	103	156	103	104	64
110	120	120	154	178	150	50
130	111	73	163	71	71	17
150	129	116	240	133	104	36

Research Question: **Is PBEID Class 1 (µ1) better than (µ2) concerning the packet loss in network ?**

µ1: mean (Total Packet Loss of PBEID Class 1)
µ2: mean (Total Packet Loss of Autocast/Counter/Distance/Flooding 1 Sec/Flooding 2Sec)

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

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

t-test for two independent samples / Lower-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
PBEID C1	6	0	6	1.30E+01	6.40E+01	3.23E+01	2.13E+01
Autocast	6	0	6	3.40E+01	1.29E+02	8.93E+01	4.22E+01
PBEID C1	6	0	6	1.30E+01	6.40E+01	3.23E+01	2.13E+01
Counter	6	0	6	2.80E+01	1.20E+02	8.38E+01	3.57E+01
PBEID C1	6	0	6	1.30E+01	6.40E+01	3.23E+01	2.13E+01
Distance	6	0	6	2.80E+01	2.40E+02	1.30E+02	8.12E+01
PBEID C1	6	0	6	1.30E+01	6.40E+01	3.23E+01	2.13E+01
Flooding 1 Sec	6	0	6	2.80E+01	1.78E+02	9.20E+01	5.75E+01
PBEID C1	6	0	6	1.30E+01	6.40E+01	3.23E+01	2.13E+01
Flooding 2 Sec	6	0	6	2.80E+01	1.50E+02	8.25E+01	4.60E+01

H0: The difference between the means is greater or equal to 0, i.e. $\mu1 - \mu2 >= 0$.
Ha: The difference between the means is lower than 0, i.e. $\mu1 - \mu2 < 0$
Significance Value 0.05

Research Conclusion							
PBEID C1 vs	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
Autocast	-5.70E+01	-2.95E+00	-1.81E+00	10	7.22E-03	H0	**Significantly YES**
Counter	-5.15E+01	-3.03E+00	-1.81E+00	10	6.31E-03	H0	**Significantly YES**
Distance	-9.78E+01	-2.86E+00	-1.81E+00	10	8.55E-03	H0	**Significantly YES**
Flooding 1 Sec	-5.97E+01	-2.38E+00	-1.81E+00	10	1.92E-02	H0	**Significantly YES**
Flooding 2 Sec	-5.02E+01	-2.43E+00	-1.81E+00	10	1.79E-02	H0	**Significantly YES**

d) Statistical Analysis for Class 2 Messages

The Table 5.14 presents the detailed result and analysis for two independent samples, a lower tailed t-test with a significance level of 5% w.r.t. total packet loss of PBEID class 2 messages along with compared protocols. An optimal algorithm requires minimum packet loss, we tested our results and found PBEID class 2 is significant in all cases.

Table 5.14: Statistical Analysis for Class 2 Messages w.r.t. Total Packet Loss

Total Packet Loss						
# Node/Technique	Autocast	Counter	Distance	Flooding 1 Sec	Flooding 2 Sec	PBEID Class 2
30	0	0	0	0	0	**0**
50	38	63	40	39	38	**26**
70	34	28	28	28	28	**16**
90	104	103	156	103	104	**42**
110	120	120	154	178	150	**64**
130	111	73	163	71	71	**56**
150	129	116	240	133	104	**63**

Research Question: **Is PBEID Class 2 (μ1) better than (μ2) concerning the packet loss in network ?**

μ1:	mean (Total Packet Loss of	PBEID Class 2)
μ2:	mean (Total Packet Loss of	Autocast/Counter/Distance/Flooding 1 Sec/Flooding 2Sec)

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

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

t-test for two independent samples / Lower-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
PBEID C2	6	0	6	1.60E+01	6.40E+01	4.45E+01	2.01E+01
Autocast	6	0	6	3.40E+01	1.29E+02	8.93E+01	4.22E+01
PBEID C2	6	0	6	1.60E+01	6.40E+01	4.45E+01	2.01E+01
Counter	6	0	6	2.80E+01	1.20E+02	8.38E+01	3.57E+01
PBEID C2	6	0	6	1.60E+01	6.40E+01	4.45E+01	2.01E+01
Distance	6	0	6	2.80E+01	2.40E+02	1.30E+02	8.12E+01
PBEID C2	6	0	6	1.60E+01	6.40E+01	4.45E+01	2.01E+01
Flooding 1 Sec	6	0	6	2.80E+01	1.78E+02	9.20E+01	5.75E+01
PBEID C2	6	0	6	1.60E+01	6.40E+01	4.45E+01	2.01E+01
Flooding 2 Sec	6	0	6	2.80E+01	1.50E+02	8.25E+01	4.60E+01

H0:	The difference between the means is greater or equal to 0, i.e. $\mu1 - \mu2 >= 0$.
Ha:	The difference between the means is lower than 0, i.e. $\mu1 - \mu2 < 0$
Significance Value	0.05

Research Conclusion							
PBEID C2 vs	Difference	t (Observed value)	t (Critical value)	DF	p-value (one-tailed)	Rejected Hypothesis	Research Answer
Autocast	-4.48E+01	-2.35E+00	-1.81E+00	10	2.03E-02	H0	**Significantly YES**
Counter	-3.93E+01	-2.35E+00	-1.81E+00	10	2.03E-02	H0	**Significantly YES**
Distance	-8.57E+01	-2.51E+00	-1.81E+00	10	1.55E-02	H0	**Significantly YES**
Flooding 1 Sec	-4.75E+01	-1.91E+00	-1.81E+00	10	4.26E-02	H0	**Significantly YES**
Flooding 2 Sec	-3.80E+01	-1.86E+00	-1.81E+00	10	4.66E-02	H0	**Significantly YES**

5.4 Chapter Summary

In this chapter, we proposed a novel PBEID protocol to disseminate Class 1-4 messages using the V2V approach. The chapter started with a detailed explanation of the proposed protocol. The proposed PBEID protocol simulated from sparse to the dense networks for various classes of messages. The proposed protocol compared against the standard information dissemination protocols on evaluation parameters like propagation time, reachability ratio, the packet generated and total packet loss. Results were graphically presented and to test the confidence of the results a two-tailed, two-sample equal variance (homoscedastic) t-test was also performed. We observed the proposed PBEID protocol is performing better against the standard information dissemination protocols. The next and the final chapter is focused on the findings of this entire research work, and future directions.

Chapter 6

Conclusion and Future Direction

6.1 Summary and Main Contributions

Efficient information dissemination is extremely important in VANETs. Vehicles gather, process and disseminate relevant data to the other vehicles to realize the applications of VANETs. Information dissemination is paramount to support the development of safety applications and other applications of VANETs.

The main focus of this thesis was to study data dissemination solutions for vehicular environments and to provide an efficient information dissemination approach that fulfil the requirements of both safety and other applications of VANETs. The objective of the present research program is to “Design & Implement Efficient Information Dissemination on Vehicular Ad-Hoc Networks using Intelligent Multicasting”

At the beginning of the thesis, we presented a detailed introduction to VANET and the importance of information dissemination in VANETs. Further, that chapter also presented the research objective of the present research program. Chapter 2 is devoted to a detailed literature review of VANETs with a special emphasis on information dissemination techniques. In the survey, we noticed that some techniques have proved better in the sparse network while other in a dense network scenarios. Furthermore, we observed no such technique exists in the literature that utilizes the prioritization of messages and makes use of V2V and V2I approach accordingly. In Chapters 3,4 and 5 we described our contributions towards efficient information dissemination in vehicular networks, and detailed contributions are presented in the following subsection. Finally, present research program concludes by proposing future research directions.

6.2 Contributions

(Contribution 1): Proposed Framework for Efficient Information Dissemination

In chapter 3, we proposed a novel framework for efficient information dissemination that is capable of working with both V2V and V2I approach. In addition, the proposed framework consists of an algorithm that assigns classID to the packets based on its type and priority. Further, based on the priority the message is disseminated using one of the two proposed approaches specifically for V2I and V2V respectively.

(Contribution 2): A Novel Approach to Multicast in VANET (V2I)

In chapter 4, we proposed a novel approach to multicast in a Vehicular network using V2I based communication. This approach is used for the Class 5 messages as explained in contribution 1. The chapter started with an introduction to V2I and multicast in VANETs and further discussed other relevant technologies required for the proposed work such as cloud computing, IoT and MQTT. Upon identification of the needs and the available technologies, the system model is presented. The working of the approach is explained in detail and the chapter concludes by presenting the experimental setup with the information about the hardware and software used for developing the working prototype of the approach.

(Contribution 3): Priority Based Efficient Information Dissemination Protocol (PBEID)

In chapter 5, we proposed a novel PBEID protocol to disseminate Class 1-4 messages using the V2I approach. The chapter started with a detailed explanation of the proposed protocol and followed by the working model of the approach. The PBEID protocol was tested on both sparse and dense network scenarios, and results were compared to the standard information algorithms. The obtained results were graphically presented and statistically analyzed, in most of the cases it was observed that PBEID protocol performed significantly better than the compared standard information dissemination algorithms of VANETs.

6.3 Future Research Directions

Information dissemination is one of the extremely important research areas of VANETs. The present research program can be extended in multiple dimensions for further advancements in this topic. Firstly, research can be extended to the heterogenous networks range with multiples of information exchange among the vehicles in the real time. Machine learning techniques can be applied to fine tune the P_{rb} and α parameters of proposed V2V approach in future research. Designing an exclusive communication protocol for V2I communication for efficient information dissemination is one of the future research works. Further, the research can be extended on the proposed information dissemination mechanism from the perspective of security and privacy aspects of VANETs.

VANETs are still at evolving stage to cater its actual purpose, and a lot of research is in progress. Growth in smart cities and autonomous vehicles has given a lot of scope for research in vehicular communications. In respect to information dissemination over VANETs, semantic web, graph theory and optimization functions are further needs to be explored. Architectures and interoperability in view of Internet of Every Thing have given new scope of further research. Leveraging the benefits of recent developments in artificial intelligence, machine learning and bigdata have open up new research areas in vehicular communications. Further, evolving communication technologies like LiFi and 5G have open the new horizons in vehicular communication research. Efficient routing, security, privacy and QoS will always remain the research areas of VANETs.

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