Republic of Iraq
Ministry of Higher Education and Scientific Research
University of Babylon
College of Information Technology
Information Networks Department

A Developed Technique to Control the Congestion of Wireless Channel in VANET

A Thesis

Submitted to the Council of the College of Information Technology for Postgraduate Studies of University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master in Information Technology-Information Networks

By

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2023 A.D. **1444 A.H.**

بسم الله الرحمن الرحيم

« إِنَّ الَّذِينَ آمَنُوا وَعَمِلُوا الصَّالِحَاتِ إِنَّا لَا نُضِيعُ أَجْرَ مَنْ أَحْسَنَ عَمَلًا»

صَدَقَ اللَّهُ الْعَظِيم

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I certify that the thesis entitled (**A Developed Technique to Control the Congestion of Wireless Channel in VANET**) was prepared under my supervision at the department of Information Networks/ College of Information Technology/ University of Babylon as partial fulfillment of the requirements of the degree of Master in Information Technology- Information Networks.

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Date: / /2023

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In view of the available recommendations, I forward the thesis entitled "**A Developed Technique to Control the Congestion of Wireless Channel in VANET**" for debate by the examination committee.

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Declaration

I hereby declare that this thesis, submitted to the University of Babylon in partial fulfilment of requirement for the degree of Master of Information Technology-Information Networks has not been submitted as an exercise for a similar degree at any other university. I also certify that this work described here is entirely my own except for expert’s and summaries whose sources are appropriately cited in the references.

Signature:

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Date: /   / 2023

Dedication

To those who taught me the meaning of unconditional love, to those who revealed to me the secrets of the human mind, to those who believed in me when I lost faith in myself, to those who chose me in my darkness, to those made me realize the greatness of myself, to those who lit the fire of consciousness in my soul, To those who held my hand when I was torn apart and lonely , to those who made me achieve my dream, to whom words cannot describe my love for them.

To my family

Acknowledgement

In the name of God, Most Gracious, Most Merciful

First and foremost, I thank God Almighty for His innumerable blessings ... My God, to you be praise and thanksgiving until praise reaches its limit ... And your praise and grace have no bounds. Praise Allah for always helping me to achieve my aims.

My great thanks and gratitude to all in the College of Information Technology at the University of Babylon, and especially to the Department of Information Networks, head and members. Thanks and gratitude go to the honorable supervisor for his support in completing this work.

My thanks and high respect to all members of the discussion committee. in particular, to (Dr. Rasim Azeez Kadhim)..

I would like to express my wholehearted thanks to my family for the unlimited support, encouragement, love, and great sacrifice they provided me also for their patience, and help to me during the work.

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Noor Mohammed Abdullah

Abstract

The Vehicular Ad-hoc Networks (VANET) technology is used by the Intelligent Transport Systems (ITSs) to prevent and decrease highway accidents. VANET use of wireless communication technology that includes protocols and applications which offer safety and non-safety features for a safe and convenient driving experience. A major problem is that the vehicles were competing the same network channel of limited bandwidth for sending the safety or beacon messages for awareness, which causes congestion and consequently packet loss, significant transmission delays, and unfair resource utilization. This problem would eventually delay the delivery of the Basic Safety Messages (BSMs) and render the VANET unreliable. Researchers have focusing on numerous approaches for controlling congestion on the network channel such as adapting the rate of BSMs i.e. the number of BSMs that can be sent per second or adjusting the transmission power which is the distance that a message can travel or adjusting the data rate (the bit rate) of the transmitted data.

In this thesis, three techniques for controlling the channel congestion in VANET are proposed. The first technique performs congestion control using the exponential function to decrease the message rate during the congestion. The second technique achieves congestion control by adjusting the transmitted power using an exponential function. In a similar manner, the third strategy adapted the message rate and the transmitted power together for controlling the congestion based on the exponential function.

The proposed techniques are performed by SUMO and the open source OMNET++ software under different number of vehicles (50,100 ,and 150). The simulation results showed that the adaptive approach enhances vehicular network performance by reducing the channel busy time, reducing the number of lost packets in comparison to the normal case without using a congestion control approach. Also, the reduction rate using the exponential function was better with the increasing of the decay factor and the number of vehicles. The ranges of the reduction ratio of average channel busy time about (5.46% to 31.26%), while the reduction ratio of the average total lost packets about (12.39 % to 84.6%) depending on the density of vehicles, adapted parameter, and the exponential decay factor. The results showed that the developed technique enhanced the performance of the VANET which can be adopted in real world applications.

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List of Abbreviations

Abbreviation	Description
API	Arbitration Inter-Frame Spacing
AU	Application Unit
(BACVT)	Balancing Awareness and Congestion with Variable Transmission Power
(BACVT-H)	Balancing Awareness and Congestion with Variable Transmission Power Combination
BER	Beacon Error Rates
BSM	Beacon Safety Message
C2C-CC	Car-to-Car Communication Consortium
CAMs	Cooperative Awareness Messages
CBR	Channel Busy Ratio
CBT	Channel Busy Time
CCH	Control Channel
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
DCC	Decentralized Congestion Control
DENM	Decentralized Environmental Notification Message
DP	Dynamic Programming
DSRC	Dedicated Short Range Communication
E2ED	End-to-End Delay
ECPR	Environment-and Context-Aware Combined Power and Rate
FABRIC	Fair Adaptive Beaconing Rate for Inter-Vehicle Communications
FCC	Federal Communication Commission
GPS	Global Positioning System
I2V	Infrastructure to Vehicular Communications
IPD	Inter Packet Delay
IPG	Inter Packet Gap

ITSs	Intelligent Transportation Systems
JATB	Joint Adaptation of Transmission Power and Bit Rate
LIMERIC	Linear Message Rate Control
MANET	Mobile Ad Hoc Networks
MD-DCC	Message and Data Rate Decentralized Congestion Control
NUM	Network Utility Maximization
OBU	On Board Unit
OMNET++	Objective Modular Network Testbed in C++
OSC	Oscillating
PDA	Personal Digital Assistant
PDR	Packet Delivery Ratio
PLR	Packet Loss Rate
PULSAR	Periodically Updated Load Sensitive Adaptive Rate Control
QoS	Quality of Services
RCP	Resource Command Processor
RSU	Road Side Unit
SBAPC	Speed Based Adaptive Power Control
SCH	Service Channel
SNR	Signal-to-Noise Ratio
SUMO	Simulation of Urban Mobility
TE	Tracking Error
TTC	Time To Collision
Tx	Transmission
UTC	Coordinated Universal Time
V2B	Vehicle-to-Broadband Cloud
V2V	Vehicle to Vehicle
V2I	Vehicle to Infrastructure
VANET	Vehicular Ad Hoc Networks
VEINS	Vehicles in Network Simulation
WAVE	Wireless Access Vehicular Environment Standard

Chapter one

Introduction

1.1 Overview

Intelligent Transportation Systems (ITSs) manage wireless communication in vehicle environments utilizing vehicular ad hoc network (VANET). VANET are intended to offer people a reliable and safe environment by minimizing traffic congestion, accidents on the road, and fuel consumption, and so on [1]. Users of the VANET can be made aware of risky situations by exchanging information about the surrounding environment and communicating via vehicles[1]. VANET are a subset of mobile ad hoc network (MANET)[2]. The main distinction between VANET vehicles and MANET nodes is that VANET vehicles follow predetermined routes and are not constrained by data storage or power issues. It is a wireless transmission network that operates independently and efficiently [2]. Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communication technologies are provided by VANET. VANET has utilized Wireless Access of Vehicular Environment (WAVE) to enable communication between V2V and V2I communication systems. The IEEE 609 and IEEE 802.11p protocols served as the foundation for the development of WAVE at the Physical (PHY) and Medium Access Control (MAC) layers [2]. This makes it possible for the V2V and V2I systems to transmit traffic data over limited communication distances.

There are two main categories of VANET applications firstly safety applications, which send beacon messages and event-driven messages over the Control Channel (CCH), and secondly non-safety applications, which send messages for congested road and parking availability notifications through the Service Channel (SCH). Wireless channel congestion in VANET is viewed as a significant issue because it has an impact on the network's dependability and the transmitted traffic data. Due to the channel's limited bandwidth and small buffer sizes, this issue arises whenever a vehicle sends a significant amount of data across the network or whenever numerous vehicles send multiple packets simultaneously in a crowded environment [4]. This increases transmission overhead and lowers the network's data delivery ratio. As a result, the Quality of Service (QoS), particularly the network throughput, latency, and packet loss, are impacted [4][5][6].

Therefore, a decentralized congestion control method based on an exponential function is suggested to control the wireless channel congestion issue in order to control the broadcasted message rate and transmitted power. This method involves adapting the beacon messages' power transmission, which controls the beacon messages' transmission range, and adapting the message rate, which reduce the number of beacon messages that can be transmitted through the network. The number of lost packets and channel congestion can be decreased by adjusting the message rate and transmit power [3].

1.2 Problem Statement

The ideal vehicular network would have minimal packet loss or error rates, accurate and rapid collision warnings, and timely transmission and reception of packets carrying critical information among nodes. Congestion control in vehicular networks encounters a variety of difficulties as a result of various restrictions, including communication overhead, a high rate of transmission delay, an inefficient use of bandwidth, and an inefficient use of resources that affect the channel used for the transmission of network packets for vehicle awareness. The 5.9 GHz channel, which has 33 dBm power limits and a communication range of 300 m set by the Federal Communications Commission (FCC), is shared by all vehicles in vehicular networks, with competition for resources and channel utilization. Up to 10 beacons per second can be transmitted by each vehicle, placing a significant burden on the channel and leading to packet collisions. Only when a car determines the channel is clear through continuous channel monitoring are packets sent. The IEEE 802.11 channel access mechanisms cannot prevent channel congestion when messages are broadcast because the resource allocation in vehicular network environments is not centrally controlled. In broadcast instances, packets are not recognized because a packet explosion and increased channel traffic would result from every vehicle sending acknowledgement packets to every other vehicle. When channel load is greater than 40% of the potential maximal channel capacity, packet collisions and Medium Access Control (MAC) transmission delay increase exponentially. Safety messages arrive later, there are more packet collisions, and the transmission range is reduced as a consequence of MAC transmission delays. To lessen the congestion without overloading the channels, a congestion management algorithm is needed.

1.3 Aim of Thesis

The main aim of this thesis is the controlling of the channel congestion in VANET. This aim can be obtained through achieving the following objectives:

1- To develop a congestion control technique based on the exponential function for adjusting the message rate or transmitted power, or both in VANET.
2- To simulate the developed technique using SUMO and OMNET++ for different cases.

3- To evaluate the developed technique using the average number of total lost packets, total channel busy time, average throughput, and packet loss ratio.

1.4 Related Works

The Periodically Updated Load Sensitive Adaptive Rate control (PULSAR) was introduced by Tielert et al. The Channel Busy Ratio (CBR) was measured by each vehicle at the ending of a set period of time, and the calculated value was compared to the threshold value. The transmit rate of the vehicle reduced when congestion was discovered and the calculated value exceeded the threshold value (threshold = 0.6). The PULSAR algorithm initially adjusted the transmission range in accordance with the desired target range before adjusting the transmit rate in accordance with CBR measurement[7].

An algorithm for Linear Message Rate Control (LIMERIC) was proposed by Bansal et al. In contrast to the limit cycle behavior shown in PULSAR, By using linear feedback, LIMERIC uses the message rate to regulate the quantity of packets sent each second. Vehicles can modify their message rates using this distributed and adaptive linear control algorithm to make sure that the overall channel load converges to a goal value. Equation 1.1 can be applied to assume the message rate of the jth vehicle:

$$\boldsymbol{R_j(t)} = (\boldsymbol{1} - \boldsymbol{a})\boldsymbol{R_j(t-T)} + \beta\left(\boldsymbol{CBR_T} - \boldsymbol{CBR(t-T)}\right) \qquad (\boldsymbol{1.1})$$

Convergence elements that affect stability, fairness, and state convergence are α and β. The message production rate is Rj(tT), and the measured CBR at t-T is CBR(t-T). (T is the message generation interval and CBRT is the target channel load). Regardless of the quantity of adjacent nodes, LIMERIC offers high throughput [8].

The Fair Adaptive Beaconing Rate for Intervehicular Communications (FABRIC) technique, which is based on a gradient optimization strategy, was first presented by Egea-Lopez et al. In various dynamic and static traffic circumstances, the challenge of beaconing rate control was described as the Network Utility Maximization (NUM) problem. Each vehicle was assigned different rates by selecting a value for the fairness parameter α, which is determined by the available channel load and the needs of the vehicle. In FABRIC, there are two kinds of rate allocation: synchronous and asynchronous. In the synchronous case, FABRIC converges more quickly whereas in the asynchronous case some oscillations occur during rate allocation. The numerical results demonstrate that the FABRIC algorithm mitigates issues with unfairness in contrast to those with LIMERIC and PULSAR [9].

Sharma et al. used a priority model based on the Tabu-search algorithm to adapt the transmission rate in order to decrease network channel congestion. The suggested Decentralized Congestion Control (DCC) method using the CBR measure helps in calculating the channel medium. The results showed an improvement in performance metrics such as End-to-End Delay (E2ED) and Packet Delivery Ratio (PDR) in comparison to those of state-of-the-art approaches [10].

Willis et al. suggested a (OSC) Oscillating algorithm to reduce channel congestion by changing the transmission power value . It is a proactive strategy in which the Basic Safety Messages (BSMs) transmission power oscillates between two levels. One high-power packet is broadcasted after a predetermined number of low-power packets. This cycle remains continuous until a change in the channel circumstances (i.e. channel congestion) is noticed [11].

For adjusting the transmission power of BSMs, Speed Based Adaptive Power Control (SBAPC) based on speed control approach had been suggested. According to its current speed, each vehicle in SBAPC dynamically adjusts the BSM packets' transmitted power. The main principle of SBAPC is that when the vehicle speed increases, the Time To Collision (TTC) for nearby vehicles reduces. Consequently, distant vehicles should be able to receive BSMs in higher speeds and uses a higher transmit power. The result showed that CBR and Inter Packet Delay (IPD) have decreased as opposed to their counterparts in OSC [12].

Navdeti et al. suggested a distributed fair transmit power adaptation based congestion control for the purpose of detecting and alleviating traffic congestion. It makes use of cooperative VANET and transmission node choice for transmission power control in utility function optimization framework. For defining the probability of successful packet receipt between vehicles, they used the nakagami distribution model. They calculated link stability and quality to determine future routing decisions and avoid link breakages. The suggested method works effectively on a crowded network. The suggested solution has a higher average packet delivery ratio and a substantially lower end-to-end packet delivery time in the VANET [13].

Liu et al. introduced a congestion control technique aimed at balancing between the channel congestion and vehicle awareness the primary notion was that awareness of nearby vehicles should take priority over distant vehicles. They firstly introduced Balancing Awareness and Congestion with Variable Transmission Power (BACVT) with various power levels to transmit various BSMs. To further reduce congestion, a hybrid strategy (BACVT-H) has been proposed, combining rate and power regulation to decrease the total number of (BSM). The results showed that the proposed method had the lowest level of CBR while maintaining good awareness performance (IPD).Congestion and awareness are usually important issues in safety communications in VANET [14].

Aygun et al. proposed that Environment-and Context-aware Combined Power and Rate Distributed (ECPR) DCC algorithm can improve cooperative awareness .The transmit power of the messages was modified by ECPR, which also employed an adaptive rate control mechanism to modify the channel load on a regular basis in order to achieve the required awareness ratio. While maintaining the same level of channel load and interference, ECPR could increase awareness by 20%. When allowed by the awareness requirements, ECPR could increase the average message rate by 18% compared with methods that only execute rate adaptation [15].

In order to reduce congestion and meet application requirements, Math et al. suggested a Message and Data Rate Decentralized Congestion Control (MD-DCC) system that offers a fair and effective method of assigning message rate and data rate amongst vehicles. By reducing the message rate, MD-DCC is able to keep the beacon frequency higher than the minimum. The minimum frequency value can be reached although the traffic density continues to increase at some point. As a result, the channel capacity increases due to MD- DCC increased data rate. However, if the vehicles send signals at different data speeds, synchronization between senders and receivers could be challenging. Additionally, larger data rates require higher Signal-to-Noise Ratio (SNR), which becomes increasingly challenging when vehicle densities increase [16].

Wei et al. proposed the Joint Adaptation of Transmission power and Bit rate (JATB) algorithm which modifies the Dynamic Programming (DP) method to find the optimal value between bit rate and transmission power. This algorithm aims to increase the packet rate of success, and decrease each of (CBT),(E2ED).Additionally, JATB employs vehicle density from improve driver awareness of the road environment and adjusts bit rate and transmit power correspondingly. With various beacon rates and simulation scenarios, the adaptability of the JATB algorithm was evaluated. The results display an increase within transmission effectiveness in comparison to the normal VANET algorithm, which uses a constant transmit power (20mw) and a constant bit rate (6Mbps) [17].

Table 1.1 summarizes the congestion control approaches mentioned in the thesis.

Table 1.1: Summary of Congestion Control Approaches

Ref	**Year**	**Algorithm**	**Control Parameters**	**Aim**	**Results**	**Simulator**
[7]	2011	PULSAR	Message rate	Keep BSM-generated channel load below a specified threshold to allocate bandwidth for emergency messages.	The simulation's results demonstrated the suitability of PULSAR for real security applications and the effectiveness of the 2-hop piggybacking technique in reducing both local and global DCC unfairness.	NS2
[8]	2013	LIMERIC	Message rate	For there to be fairness, the message rates of all nodes must converge to the same value.	According to the data, LIMERIC produces less Inter Packet Gap (IPG) and tracking error (TE) than ETSI DCC.	Ns2

[9]	2016	FABRIC	Message rate	To ensure fairness, the NUM theory was used to DCC.	Comparing FABRIC to LIMERIC and PULSAR, the numerical findings show that the new method reduces issues with unfairness.	OMNET++, SUMO
[10]	2022	Tabu-search	Message rate	The goal is to increase transmission rate while maintaining a CBR value below the maximum CBRmax value.	As a result, performance metrics like as PDR and E2ED have improved.	NS 3.26
[11]	2017	OSC	power	The goal is to lower the number of packets received by vehicles traveling at a greater distance and keeping a high level of awareness for surrounding vehicles.	The simulation results show the algorithm's advantages in terms of generally used measures including such Beacon Error Rates (BER), Channel Busy Time (CBT), packet lose, and Inter-Packet Delay (IPD)	OMNET++, SUMO
[12]	2018	SBAPC	Power	The purpose is to determine which other vehicles should get BSM packets from a specific vehicle.	The results of the simulation enhance parameters like packet loss, , channel busy time , ,beacon error rates ,and inter packet delay	OMNET++, SUMO
[13]	2019	Distributed Fair Transmit Power Adaptation	Power	Using optimal node selection for cooperative VANET and transmit power regulation under utility function optimization, detect and reduce channel congestion.	The results of the simulation enhance parameters such as average end-to-end delay and packet delivery ratio.	VANET MobiSim
[14]	2021	BACVT	Power	While keeping a high degree of awareness for nearby vehicles, different transmission power levels are being used to minimize the CBR.	The approach can successfully create a balance between awareness and bandwidth utilization, according to the simulation results.	OMNET++ ,SUMO
[15]	2016	ECPR	Message rate , Power	The transmit power of the messages is modified by ECPR, which also employs an adaptive rate control mechanism to modify the channel load on a regular basis is order to achieve the required awareness ratio.	While maintaining the same level of channel load and interference, ECPR can increase awareness by 20%. When allowed by the awareness requirements, ECPR can increase the average message rate by 18% when compared to systems that only execute rate adaptation.	GEMV2

[16]	2018	MD-DCC	Message rate ,Data rate	Provides fair and efficient method for distributing message and data rates among vehicles in order to reduce congestion and achieve application requirements.	The best data rate and message rate algorithms are combined in MD-DCC, which improves application reliability and significantly raises the maximum supported vehicle density.	NS3,SUMO
[17]	2019	JATB	Power, Bit rate	By combining bit rate and transmission power, it is possible to reduce busy time and end-to-end delay while increasing packet success rates.	The results demonstrate that the normal VANET standard transmission technique, which uses a constant transmit power (20mw) and a constant bit rate (6Mbps) has poor transmission efficiency.	OMNET++, SUMO

1.5 Thesis Layout

This thesis consists of four chapters in addition to this chapter. It involves: chapter 2 which describes the theoretical background of the VANET represented by their structure, applications and the problems related to them. chapter 3 which presents the developed technique for congestion control in VANET, chapter 4 which illustrates the results and evaluates the proposed system performance by using OMNET++ with different densities of vehicles and chapter 5 which concludes the thesis and proposes some future work directions.

Chapter Two

Theoretical Background

2.1 Introduction

VANET aimed at improving efficiency of vehicular environments' traffic and roads safety. These networks consequently provide some significant issues for study in both industrial and academic fields. This chapter which consists of ten sections deals with VANET definitions and fundamental ideas. In section 2.2, components and architecture of VANET are introduced. In section 2.3 communication categories in VANET are discussed. In section 2.4, VANET characteristics are explained. Then, in sections 2.5 to 2.8, VANET standards, applications, challenges, and performance metrics are discussed. In section 2.9 congestion control strategies are explained. In section 2.10 the classification of congestion control strategies based on parameters are presented. Finally, in section 2.11 exponential function are explained and in section 2.12 VANET Simulation are presented.

2.2 Components of VANET

In Intelligent Transportation Systems (ITSs), each vehicle acts as a transmitter, a recipient, and a router that transfers data to a vehicular network or transport agency that uses the data to keep the traffic flow safe and unhindered. The Road Side Unit (RSU), On Board Unit (OBU), and Application Unit (AU) are the three main components of this system[18]. Each vehicle has an OBU and several sensors which allow it to gather data, process it, and then send messages via wireless communication to other vehicles or RSUs. OBU utilizes the services that are provided by an application maintained by RSU. The RSU can also establish a connection to another server or the Internet; enabling AUs from other vehicles to access the Internet [19].

•**On Board Unit (OBU)**: is a device installed on the inside of a vehicle and is used for communicating with RSUs and other OBUs. It includes the Resource Command Processor (RCP), read/write memory for data storage and retrieval, a user interface, a dedicated interface for interacting with other OBUs, a network device that enables short-range wireless communication based on IEEE 802.11p radio communication, and a network device that may also be operated using IEEE 802.11a/b/g/n or other wireless technologies for non-safety applications. The IEEE 802.11p wireless radio channel was utilized by these devices for wireless transmission. The OBU's primary responsibilities include facilitating radio communication, ad hoc and geographical routing, network congestion management, dependable message transfer, information security, and Internet protocol mobility [19] [20].

•**Application Unit (AU)**: The OBU's connection allows the AU, a device mounted inside the vehicle, to access the provider's applications. The AU can perform as either a safety application-specific device or a standard device like a personal digital assistant (PDA). It is possible for the AU and OBU to share one physical unit and to communicate with one another wirelessly or over a wired connection. The only channel of contact between the AU and the networking is the OBU, which manages all network and mobility duties [19] [20].

•Roadside Unit (RSU): is a device of Wireless Access Vehicular Environment standard (WAVE) generally installed next to parking lots, at intersections, or along the side of the road. The RSU is equipped with one network device for a DSRC/WAVE communication on the basis of IEEE 802.11p radio technology, but it is also able to support the installation of other network devices. Principal functions of the RSU include:

- Extending the communication range of the ad-hoc network by sharing the data to other OBUs and RSUs so they can pass it on to other OBUs, as shown in Figure 2.1.

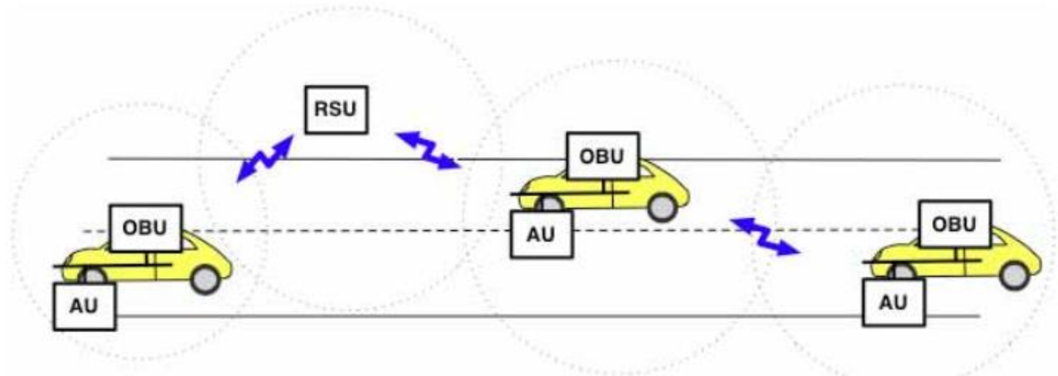


Figure 2.1 RSU Expanding the Communication Range [21].

- Using infrastructure to vehicular communications (I2V) as a source of information to implement safety applications for example a work zone, an accident, or a low bridge warning this is seen in Figure 2.2. Also,

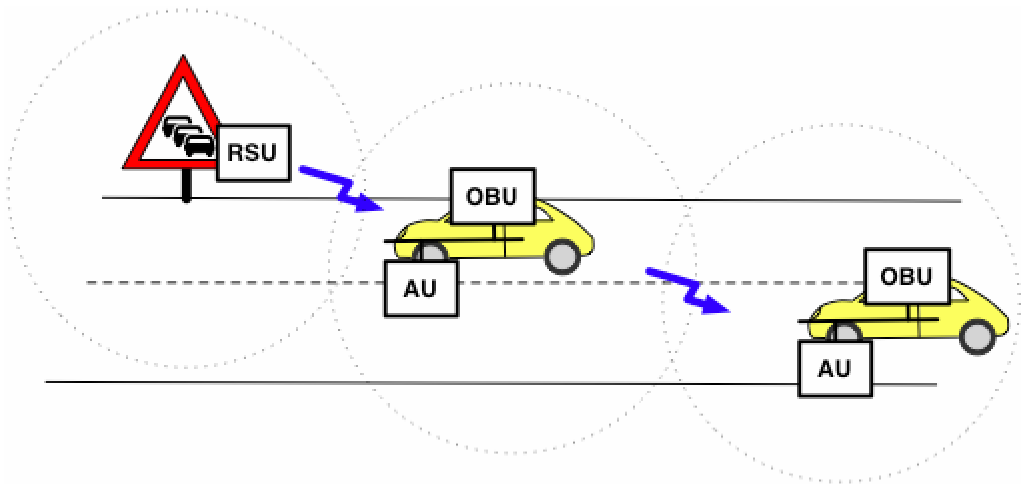


Figure 2.2 RSU Run Safety Applications and Works as Information Source [21].

- Figure 2.3 show the provision of internet connectivity to OBU.

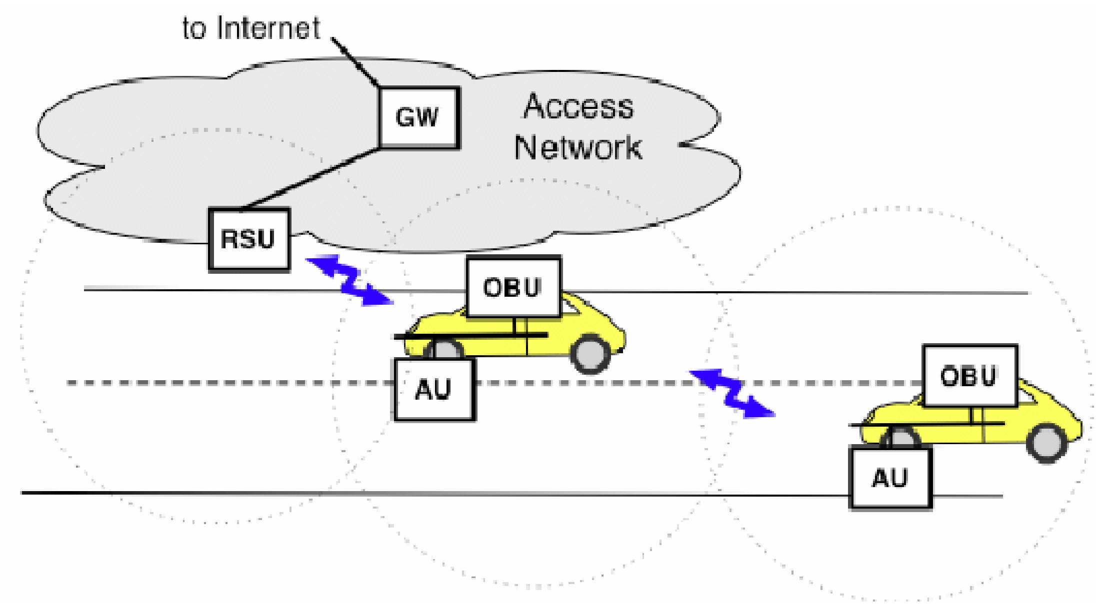


Figure 2.3 RSU Providing Internet Connectivity to OBU [21].

2.3 Communication System and Architecture of VANET

2.3.1 Communication System

- **In-vehicle:** an OBU and one or more AUs that communicate over a wired or wireless link are included in this category. The AU uses the OBU's communication abilities to operate the application that the application provider has provided.
- **Ad hoc domain**: RSUs and vehicles with OBUs make up an ad hoc domain on the VANET. There are two kinds of communications which the ad hoc domain supports [19] [20]:

  – Vehicle to Vehicle (V2V): The vehicles communicate through OBUs in a fully distributed manner with decentralized coordination. Single hop V2V communication occurs where vehicles may communicate with each other directly. If this is not possible, the message is sent from vehicle to vehicle via a particular routing protocol, which is referred to as multi-hop V2V communication until it reaches its target [20]. This thesis focuses on this type of communication VANET

— Vehicle to Infrastructure(V2I): The vehicles communicate with an RSUs to benefit the services and applications it provide or to extend the communication range by sending, receiving, and forwarding the message from and to nodes[20].

— Vehicle-to-Broadband Cloud (V2B): Vehicles use wireless internet technologies like 3G and 4G for communication. Active driving assistance and car tracking will benefit from this type of connectivity because the broadband cloud may include more traffic data, monitoring data, and infotainment.

Figure 2.4 illustrates the main functions of each communication type.

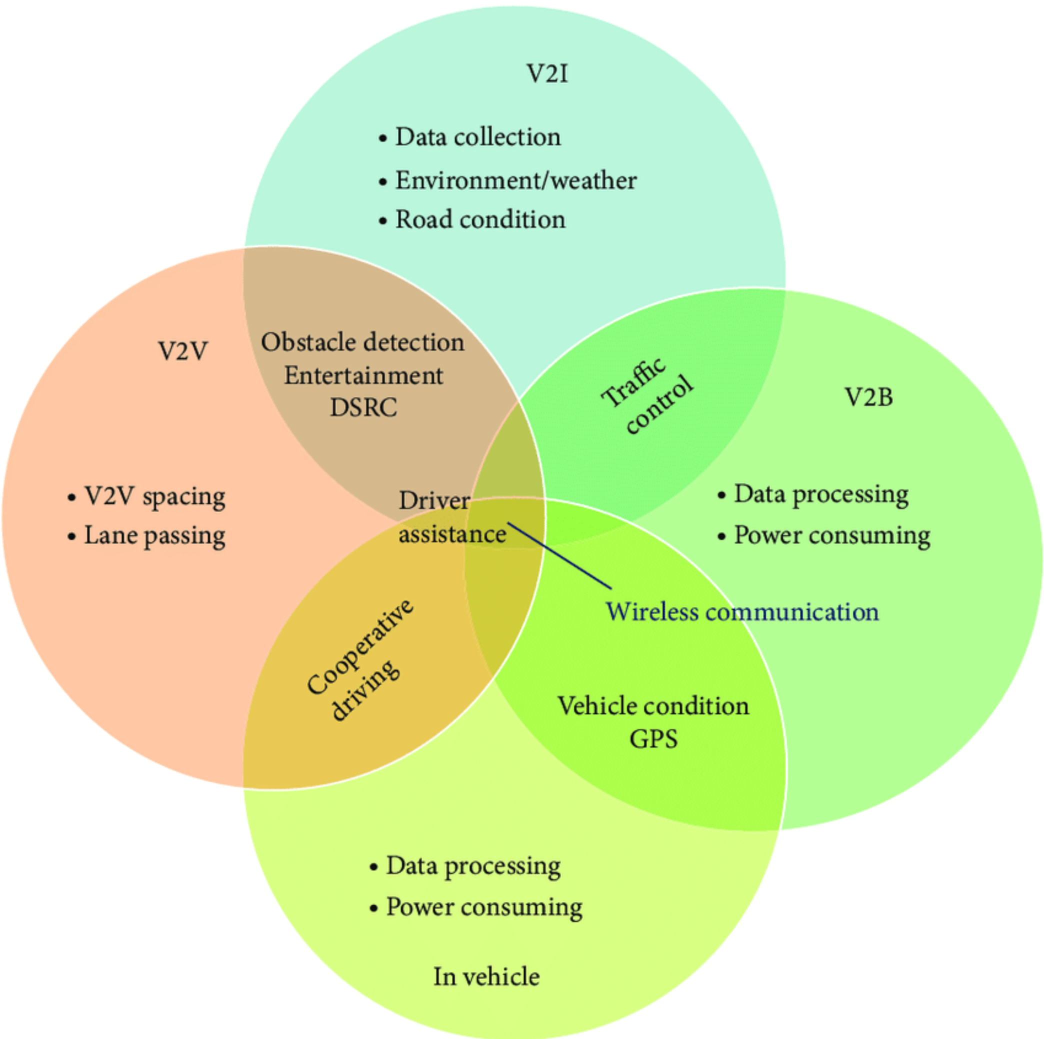


Figure 2.4 Main functions of Each Communication Type [22].

- **Infrastructural Domain:** the RSU with an Internet connection can be used by the OBU to communicate with the infrastructure network. For non-safety applications, OBU also can interact with the other hosts using cellular radio networks (4G, HSDPA ,GPRS, UMTS , GSM and WiMax). Figure 2.5 shows three types of domains for communication between vehicles, RSUs, and infrastructure[23].

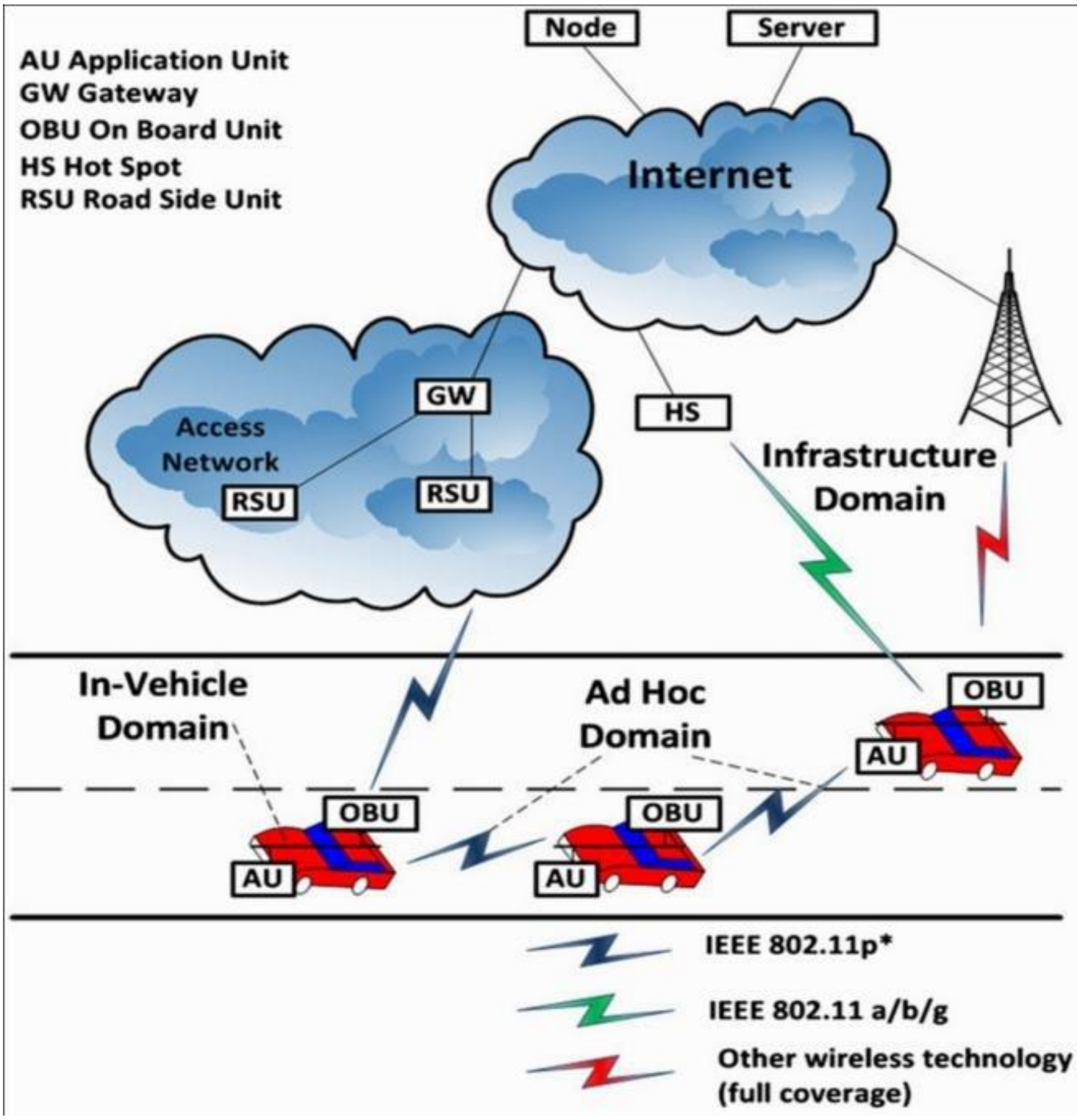


Figure 2.5: Communication Domains in VANET [23].

2.3.2 Dedicated Short Range Communication (DSRC)

The DSRC is somewhat similar to WiFi for use in wireless communications and is used for short-distance networking. However, the most significant distinction between DSRC and WiFi is that LAN networks use WiFi. At the same time, DSRC is a means of connectivity between vehicles and the Infrastructure, ensuring high speed and highly secure wireless communication [6].

The DSRC's core features are:

➢ Too less 0.02-second latency (open and close connection delays).

➢ Very low interference, its short distance, nearly 1000 m DSRC, is very high and effective in front of radio interference.

➢ Condition of weather did not impair its effectiveness.

For sending the different messages produced by safety and non-safety applications, DSRC takes eight channels into consideration. One Control Channel (CCH) is used for safety applications, six Service Channels (SCH) are used for non-safety applications, and one channel is set aside for future use. The control channel is used to send high priority safety messages such as beacon messages and event-driven messages in an emergency. The non-safety communications with low priority are sent across the service channels. The reserved channel has a bandwidth of 5MHz as opposed to 10MHz of the control and service channels [24][25][26]. Figure 2.6 displays the bandwidth based on the DSRC standard assigned to each channel [20].

When changing between the service and control channels there are a sizable delay [27][28]. The creation of an open European standard for V2V and V2I communications is the aim of the C2C-CC research projects for vehicular in Europe. According to C2C-CC, the IEEE 802.11p specification has been altered numerous times to work in European settings. Applications that don't require safety use 802.11a/b/g (GPRS/UMTS) and TCP/UDP levels [25].

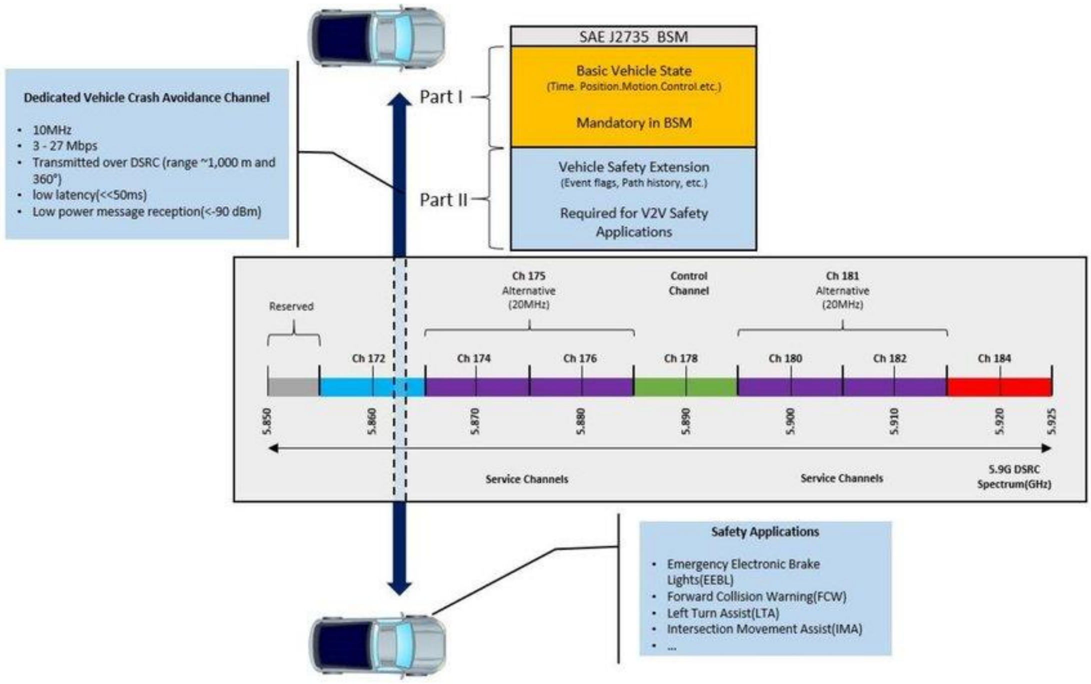


Figure 2.6: DSRC Spectrum Band and Channels[29] .

In V2V communication, there are two main message types that are used to disseminate safety-related messages: periodic messages, and event-driven messages (emergency message). The Basic Safety Messages (BSMs), also known as beacons, and the Cooperative Awareness Messages (CAMs), both defined by SAE J2735 and ETSI TC ITS, respectively, are periodically transmitted to declare the status of the vehicle. When a traffic incident or road hazard is identified, event-driven messages (emergency messages) are sent, such as the Decentralized Environmental Notification Message (DENM) developed by ETSI TC ITS [30].

2.3.3 Architectures of VANET

Vehicles are equipped in cameras, sensors, and/or other devices, as well as application and on-board units. These devices gather data about the road and traffic, including the IDs, types, positions, and distances of other vehicles. To increase vehicle efficiency and safety, these details are then sent to network applications and other vehicles. In more detail, (a) devices on the vehicles gather data, (b) these data are transmitted to other vehicles in accordance with routing algorithms, and (c) transmissions are made through 4G/5G broadband, satellite internet, WiFi, and other means. V2V communications are data transfers between vehicles, and V2I communications are exchanges between vehicles and infrastructure. (d) The security and integrity of the data and the system are protected by network security procedures that surround data transmission. The design of a typical VANET is depicted in Figure 2.7 [31].

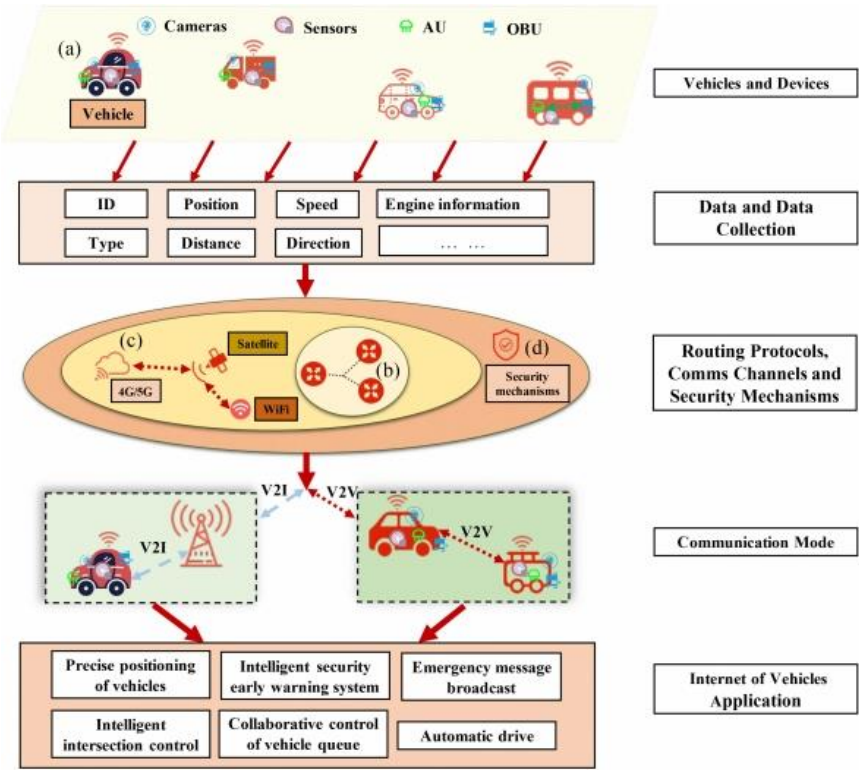


Figure 2.7: Architectures of VANET [31]

2.4 Standards of VANET

Vehicle communications standards are defined by consortia (i.e. the Car-to-Car Communication Consortium (C2C-CC)) and major standardization groups (i.e. ISO, IEEE and IETF). Dedicated Short Range Communication (DSRC) was established by the Federal Communication Commission (FCC) in north America as a new standard for VANET [24]. This standard was licensed a 75MHz spectrum in the (5.9GHz band) ranging from 5.850–5.925 GHz for the purpose (V2V)and(V2I) communications[31][32].

The DSRC specification specifies 10-1000 m and 3-27 Mbps as the maximum transmission distance and rate, respectively. The DSRC standard makes use of (WAVE) to set a benchmark for the efficiency of PHY and MAC layer communications in VANET. WAVE is made up of two IEEE 1609 and IEEE 802.11p protocols that are designed to manage network resources, multi-channel operations, security services, and other things [24].

In order to transmit data in vehicular environments, the IEEE 802.11p protocol specifies the properties of the IEEE 802.11 protocol in the PHY and lower portion of the MAC layers. To distribute data in the VANET, this protocol uses a MAC layer protocol built on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).

IEEE 1609.1 has been defined in the application layers as the standard for managing application activities that produce exchanges between OBUs and other network resources. The WAVE standard-based VANET applications' functioning is standardized by IEEE1609.1. By defining secure communication formats, carrying out secure message processing, and providing message exchange security, IEEE 1609.2 offers the security in WAVE [33].

At the network layer, IEEE1609.3 is defined for message routing and addressing. The IEEE1609.4 is located in the upper portion of the MAC layer, where it handles operations at higher layers without taking into consideration the physical channel parameters of lower layers and enables multi-channel operations in VANET. [25] [26] illustrate the design of the WAVE standard. The WAVE protocols and network levels are depicted in Figure 2.8.

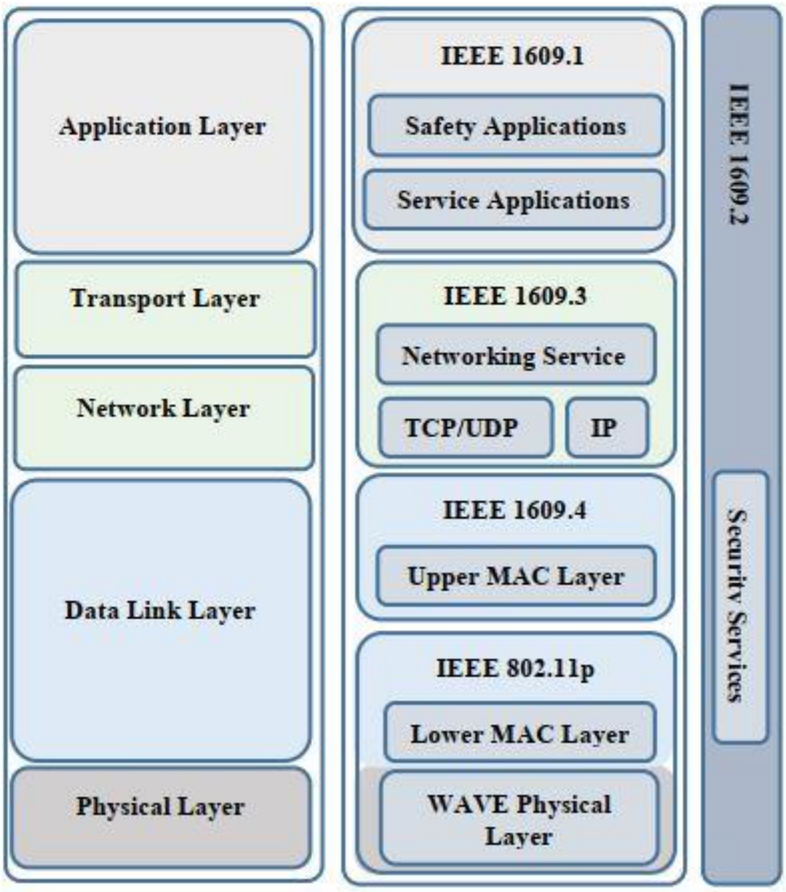


Figure 2.8: WAVE Protocols and Layers of Network [6].

Coordinated Universal Time (UTC) is used to synchronize the vehicles and enable multi-channel single-transceiver operation in VANET. UTC relies on data gathered from GPS or other nearby vehicles to function. Each vehicle's time is changed based on UTC to transition simultaneously between the control and service channels [25], [34].

2.5 Applications of VANET

Applications can be developed using V2V and V2I communications. Applications for VANET are divided into the following categories based on their main usages:

1. **Safety Applications:** These applications are used to safeguard lives and maintain environmental safety increasing the traffic safety and prevent accidents. Applications in this area include emergency warning systems, lane change assistance, intersection coordination, traffic sign/signal violation waning, and road condition warning. The data is used for either displaying the information to activate an actuator in an active safety system or the driver. Hence, direct (V2V) communication is frequently required Because of the strict delay requirements for safety applications, [33].
2. **Comfort/Entertainment Applications:** These are also called non-safety application, and their goals include improving both drivers and passenger's comfort and traffic efficiency. They can provide information on the location and prices of the closest restaurant, petrol station, or motel as well as traffic and weather conditions. While the vehicle is connected to the infrastructure network, passengers can surf the internet, send and receive instant messages, and play online games [19], [35].

2.6 Characteristics of VANET

Even though VANET are a subcategory of MANET, they have properties which distinguish them from MANET. Among these characteristics are [36]:

- **No Power Constraints**: vehicles have long-lasting batteries so they can continuously power the OBU. As a result, power in VANET is not as limited as it is in MANET [23].
- **Predictable Mobility**: VANET have vehicles which are constrained to road topology, traffic restrictions, and communication with other moving vehicles. In contrast to other MANET which include nodes that move randomly, VANET predictable mobility [23][24].
- **Variable Network Density:** in VANET, traffic density determines network size and density; which can be very high in congested areas or very low in suburbia[19].
- **Rapid Changes in Network Topology:** vehicles in VANET move at high speeds, particularly on highways, and drivers' behavior is affected by the need to respond to network data, resulting in fast changes in network architecture. The radio communication range, direction, and vehicle speed all have an impact on the life time of the link between vehicles. As a result, expanding that radio communication range increases a link's life time. When compared to the relationship between vehicles going in the same direction, that link among vehicles moving in opposite directions has an extremely short lifetime. The effective network diameter is small as a result of the quick changes in link

connection since many pathways are shut off before they can be used [20][23].

- **Large Scale Network:** in densely populated locations like highways, city centers, and the boundaries of large cities, the network scale may be substantial [36].

- **High Computational Capacity**: vehicles have the ability to contain a significant number of sensors and computational resources like processors, large memory capacities, advanced antenna technology and Global Positioning System (GPS). These resources improve the node's functionality by providing a dependable wireless connection and precise information about the node's current position, velocity, and direction [21].

2.7 Challenges in VANET

The VANET Challenges can be summarize as the following [37]:

- **Signal Fading:** When there are obstructions between two connecting devices, signals cannot reach their intended location and fade more quickly.
- **Bandwidth Limitations**: Lack of a central coordinator which monitors bandwidth and regulates communication between nodes is a significant problem with VANET [19].
- **Connectivity:** Due to the high mobility and fast topological changes, the network breaks down and loses connectivity. Connectivity is necessary for a transmission power increase [37].
- **Privacy and Security Issue:** One of VANET's main problems is maintaining privacy and security because receiving reliable information from a reliable source can violate the sender's privacy demands [20].

- **Routing Protocol**: The development of an effective protocol that can send a packet in the shortest amount of time is crucial. However, a lot of research has focused on creating routing strategies that are appropriate for environments with high vehicle densities and close spacing between them [37].
- **Effective Protocol:** Improve the reliability and reduce the amount of interference caused by tall buildings To avoid conflicts and deliver packets quickly, particularly in an emergency, scalability must be taken into account [37].

2.8 Performance Metrics

To evaluate congestion control systems, different performance measures are available. Some of the most frequently used ones in V2V communication.

2.8.1 Channel Busy Time (CBT)

The ratio of the amount of time the channel is considered to be busy to the total observation time is known as the "Channel Busy Ratio" (CBR) or "Channel Busy Time" (CBT). (e.g., 100 ms). Based on the quantity of vehicles within its transmission range and each vehicle's individual message generation rates, it is a measurement of the channel load that a vehicle sees. CBR is one of the factors used by different congestion control strategies improve communication [29].

2.8.2 Number of Lost Packets

The network performance can be estimated based on the number of lost packets loss during the total time of simulation [37].

2.8.3 Packets Loss Ratio (PLR)

Different factors, such as collisions, fading, or the expiration of the Control Channel Interval (CCHI), can cause packet loss. PLR calculating the percentage of packets lost due to collisions and/or fading is measured by dividing the number of dropped packets by the overall number of packets generated by the application layer [37].

2.8.4 Average Throughput

The average rate of messages successfully transmitted over communication channels is measured by average throughput [38].

2.9 Congestion Control Strategies in VANET

Two types of strategies namely, proactive and reactive ,are employed to reduce congestion [24].Figure 2.9 shows the congestion management mechanism from the perspective of traditional control theory [38].Based on the safety application requirements, the target is determined (i.e. threshold channel load value). The controller is either open-loop or closed-loop depending on whether it receives feedback from the result or not, whether it comes from the network or from another particular node. Depending on the goals and the traffic condition or scenario, the controller modifies the transmission parameters.

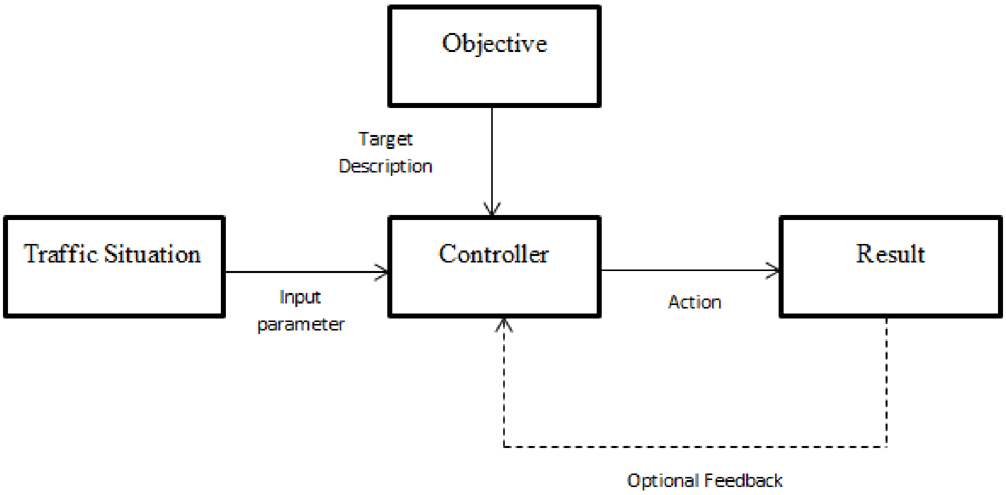


Figure 2.9: Congestion Management Mechanism from the Perspective of Control Theory [38].

Proactive Strategies is to prevent congestion it before occurring. They determine a goal value is typically for a certain channel load metric such as CBR and transmission parameters are adjusted to push the metric to the goal value. A proactive strategy can guarantee that the channel load does not go over a specific limit, but it must calculate and share real-time information about the channel load with its neighboring. The method itself may cause channel congestion if information shared excessively and frequently [38].

Reactive approaches: is to manage congestion after it has already occurred. They react immediately responds to measured channel load. The broadcast behavior can be predefined for any certain channel load value [25].The job between transmission parameters (i.e. transmit rate) and channel load (i.e. CBR) determines the control loop behaves and converges, when either the range of nodes or the rate of their messages varies. They are incredibly adaptable as a result, but they are also difficult to manage and understand. Therefore, due to they work in after to congestion, however certain BSMs may already be lost, which may be dangerous.

2.10 Classification of Congestion Control Strategies based on Parameters

Three types of parameters can be adjusted to control the VANET congestion. They involve rate, power and combination message rate and transmitted power strategies[34].

2.10.1 Message rate Based Strategy

Because transmission rate affects network performance so significantly, rate control-based solutions alter the transmission rate to manage channel load and congestion in networking. For BSM, also called (CAMs), 10 Hz is the standard transmission frequency. When there is a high vehicle density, packet loss and delay occur because the channel load exceeds the channel capacity at this rate [29]. Rate control-based techniques reduce the quantity of safety messages each node transmits in a predetermined period of time if required. The so-called target range, or 100 to 300 meters, is where the safety application-based BSMs typically require a high probability information reception [37].

2.10.2 Power Based Strategy

Transmission power control is adapted to reduce channel congestion. Each node must have an equal chance to communicate with nearby vehicles in order to maintain fairness in VANET. High transmission range is frequently required by safety applications to guarantee their safety messages delivered from as many nodes as possible. To avoid channel collisions, some vehicles should decrease their transmission power when network congestion occurs. As a result, there is a decreased probability of communication with nearby vehicles and consequently the fairness aim in VANET is failed. Additionally, channel collision and saturation are increased due the a high transmission power [29], [39], [40].

2.10.3 Combination of message rate and transmitted power

The Combination strategies for reducing congestion in VANET use two or more parameters. Congestion control primarily aims to raises driver awareness of their vehicles. When attempting to determine what the transmission parameters are, DCC approach doesn’t employ awareness as a measurement. These techniques are designed to jointly modify message rate and power or data rate and power or message rate and data rate in order to attain the appropriate level of awareness for all nearby vehicles [41].

2.11 Exponential Function

An exponential function has an equation called f(x) = ax, where" x "is a variable and "a " is a constant that acts as the base and must be greater than 0. The transcendental integer e, or roughly 2.7182, is the most frequently used exponential function base. Depending on the exponential function, an exponential slope can increase or decrease. Either exponential growth or exponential decay should be present in any quantity that changes by a set percentage over time [42].

A- The Exponential Growth

Quantity grows exponentially when it starts out very slowly and then picks up speed. Change occurs more quickly as time goes on. With passing time, the growth rate increases. "Exponential increase" is the intended term for the quick development. According to [43], the following algorithm describes exponential growth:

$$\boldsymbol{f(x) = Ke^{x}} \qquad (\mathbf{2.1})$$

Where K is constant. Figure 2.10 shows the exponential growth with (K=10)

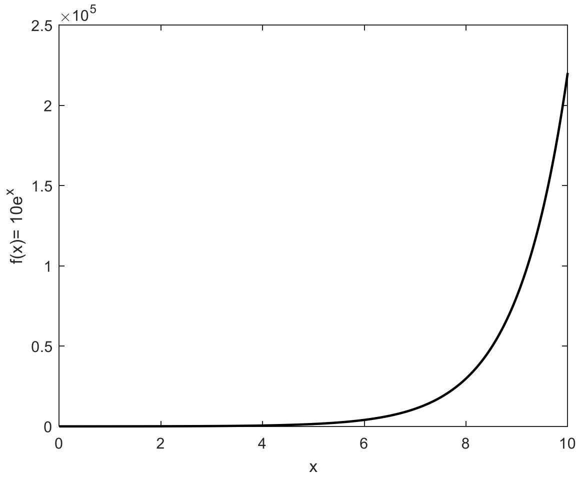


Figure 2.10: The Exponential Growth.

B- The Exponential Decay

Quantity decreases originally very quickly, then gradually. Change happens more slowly over time. As time goes on, change happens at a slower pace. The quick drop was supposed to be a "exponential drop". [42][43] is the algorithm for defining the exponential decay.:

$$\boldsymbol{f(x) = Ke^{-x}} \qquad (\mathbf{2.2})$$

Where K is constant. Figure 2.11 shows the exponential decay with (K=10)

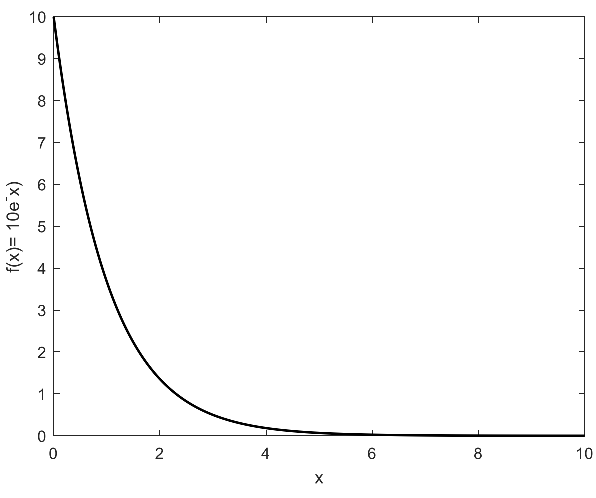


Figure 2.11: The Exponential Decay.

2.12 VANET Simulation

Any network's performance needs to be examined in order to spot any potential issues, and the best way to do this is by using simulations that generate outcomes as close to actual data as is practical. The efficacy of routing protocols in VANET has been evaluated and modelled using a variety of simulation tools, including the Network Simulator Ns-2, Ns-3, MobiSim, glomosim, OMNET++, and Cpp or Java programming languages. Also, an auxiliary software can be used with the above simulator for simulating the real world environments such as Simulation of Urban MObility (SUMO). In this thesis SUMO and OMNET++ will be used for simulating the developed technique[21].

1- SUMO

Since 2001, SUMO has been a free and open traffic modeling tool. SUMO can be used to model intermodal traffic networks, including those incorporating road vehicles, public transportation, and pedestrians. SUMO comes with a variety of auxiliary tools for tasks like route finding, visualization, network import, and emission computation. Custom models can be added to SUMO, and it offers a number of APIs for controlling the simulation from a distance. SUMO has been used in a number of projects, including studies into the influences of autonomous route choice on the entire network as well as the development of novel techniques and assessment of environmentally conscious routing based on pollutant emission. Authorities received traffic predictions from SUMO. SUMO was utilized to allow simulated in-vehicle telephony behavior in order to evaluate the efficacy of GSM-based traffic surveillance. In order to provide precise vehicle traces and assess apps in an online loop with a network simulator, the V2X group heavily utilizes SUMO [44][45].

2- OMNET++

OMNET++, in contrast to ns-2 and ns-3, offers more than just network simulation. Additionally, it can be used to simulate multiprocessor systems and networked hardware. Both Veins (Vehicles In Network Simulation), which combines the network and traffic simulator to simulate vehicle communication, and SUMO (Simulation of Urban MObility), a traffic simulator, are compatible with OMNET++ as a general discrete event, component-based open architecture simulation framework. Veins simultaneously execute OMNET++ for network simulation and SUMO for object modeling(for road traffic simulation). A TCP socket connects the two programs. The Traffic Control Interface protocol has been established for this exchange (TraCI). This enables the simulation of both-way traffic on roadways and in networks. In the SUMO road traffic model, vehicle movement is represented as node movement in an OMNET++ simulation. The current road traffic simulation can then be communicated with by the nodes [21].

Chapter Three

The Developed Congestion Control Techniques

3.1 Introduction

This chapter presents the developed technique for congestion control in VANET. In section 3.2; the general block diagram of the proposed system is present. In section 3.3; which explain the first technique based message rate control. In section 3.4; the second technique adapts transmitted power control .Finally, in section 3.5; the third technique adapts the message rate and transmitted power Control.

3.2 The General Block Diagram

The general block diagram of the proposed system is shown in Figure 3.1. The figure illustrates the main stages of this work starting with the generation of the traffic scenario of the VANET using SUMO. The output of SUMO will feed to the OMNET++ to combine with the initialization parameters and start the simulation. Finally, when the simulation process finished the last stage start to evaluate the achieved results.

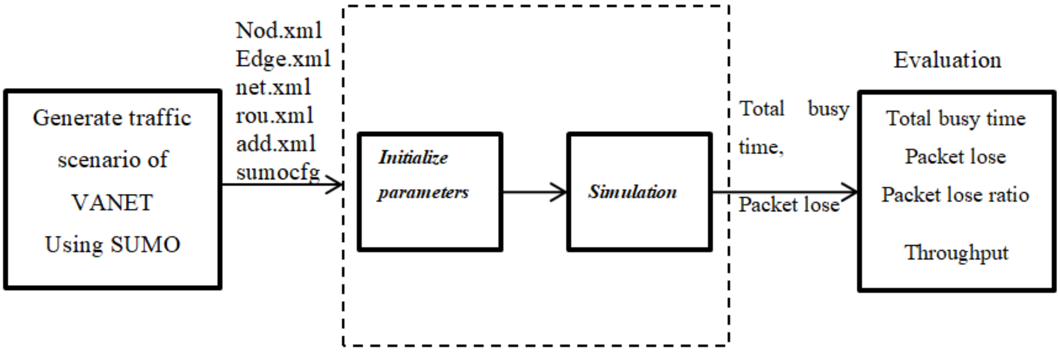


Figure 3.1: The General Block Diagram of the proposed System

There are three directions are adopted in this thesis to control the congestion in the wireless channel according to the parameter that will adapted as discussed in the following sections.

3.3 Message rate Control

The message rate can be adapted to control the congestion in the wireless communication channel of the VANET. In this thesis, the main idea is the investment of the properties of the exponential function value decreases with the increasing the value of the independent variable. The independent variable will be the CBR.

The message rate for BSMs/CAMs is set to 10 Hz by default. When the vehicle density is high, the channel load will exceed channel capacity at this message rate; resulting in packet loss and delay. Congestion control techniques based on rate control adjusts the message rate to decrease the number of safety messages delivered by each node per unit time. The proposed technique employs an exponential function to gradually reduce the message rate. At the end of a specified time interval, each vehicle measures CBR and compares the measured value to the threshold. When the detected value exceeds the threshold (CBR>threshold), the vehicle's message rate is reduced using an exponential function. The adaptation is represented by the following equation:

$$Messagerate = \begin{cases} \text{Messagerate}_{\text{Max}} & CBR < Thr \\ Adapt\ Message\ rate\ =\ Messagerate_{Max} * \exp(-a * CBR) & CBR \geq Thr \end{cases} \quad \textbf{(3.1)}$$

Where $Messagerate_{Max}$ is the maximum value of the message rate, *Thr* is the threshold of CBR, and a is the decay factor of the exponential function.

Figure 3.2 shows the relation between the transmission rate and CBR threshold (Thr) for different values of the decay factor. The steps for implementing, and evaluating the message rate proposed system are detailed in the flowchart as shown in Figure 3.3.

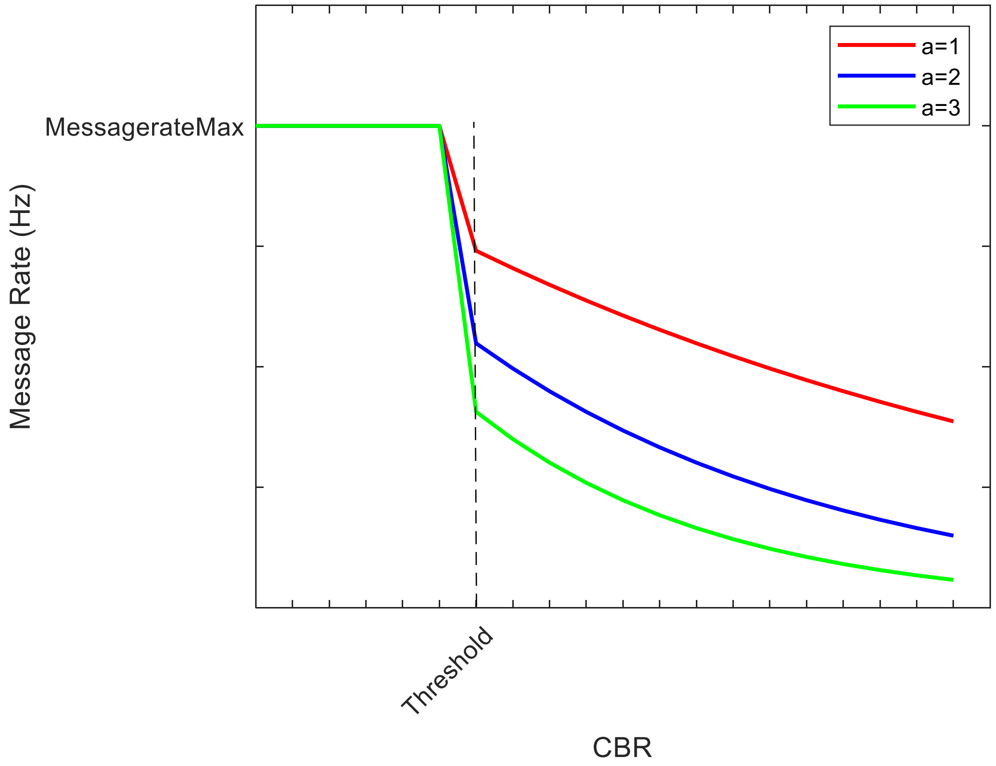


Figure 3.2: The relation between the Message rate and CBR.

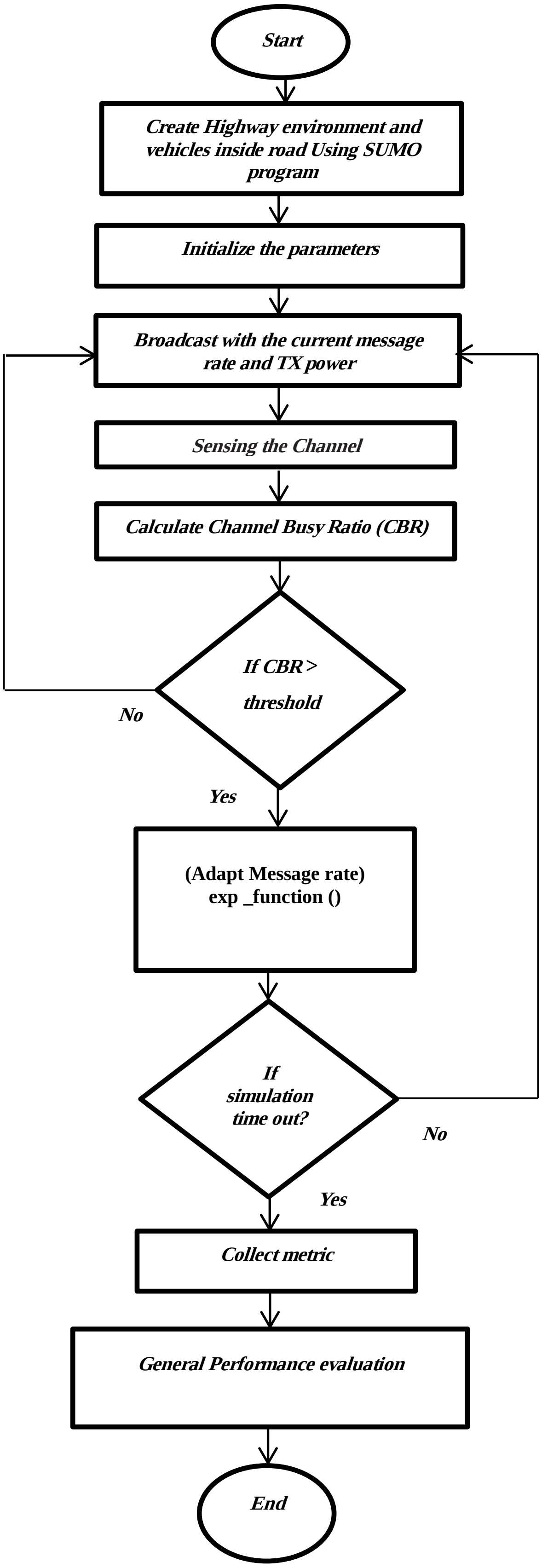


Figure 3.3: The Proposed Message rate adaptation Flowchart.

Also, the pseudo code of the message rate adaptation is illustrated in the following steps:

Algorithm 3.1: **Algorithm of Message Rate Adaptation**

Input: ($Messagerate_{Max}$, $Messagerate_{min}$, a)
Output: (Adapt Message Rate)
Procedure Get CBR
CBR= get CBR ()
If (CBR >threshold) **then**
Adapt Message Rate = $Messagerate_{Max}$*exp (-a *CBR)
If(Adapt Message Rate < $Messagerate_{min}$)
Adapt Message Rate = $Messagerate_{min}$
Else if(Adapt Message Rate > $Messagerate_{Max}$)
Adapt Message Rate = $Messagerate_{Max}$
End if
Else
Adapt Message Rate = $Messagerate_{Max}$
End procedure

3.4 Transmit Power Control

The transmitted power can be adapted to control the congestion in the wireless communication channel of the VANET. The transmit power determines the distance that a message may be sensed and properly received. Transmit power control is really used to adjust the transmit range according to performance metrics. When the transmit power is reduced rather than the message rate, neighboring vehicles will see frequent BSMs. However, remote vehicles will observe no packets from a distant vehicle. As a result, power control sacrifices knowledge of distant vehicles while retaining complete awareness of nearby vehicles. To reach more nodes, safety applications often send their safety messages over long transmission range.

However, if network congestion happens, any vehicle that detects it should decrease its transmission power to avoid channel collision. In this thesis, when the observed value of CBR is above the threshold (CBR>threshold), the vehicle's transmit power is reduced using an exponential function. The adaptation represented by the following equation:

$$Messagerate = \begin{cases} Transmitpower_{Max} & CBR < Thr \\ Adapt\ Transmit\ power = Transmitpower_{Max} * \exp(-a * CBR) & CBR \geq Thr \end{cases} \quad (3.2)$$

Where $Transmitpower_{Max}$ is the maximum value of the power, *Thr* is the threshold of CBR, and a is the decay factor of the exponential function.

The relation between the transmitted power and the CBR is shown in Figure 3.4. Also, the steps for implementing, and evaluating the transmitted power proposed system are detailed in the flowchart as shown in Figure 3.5.

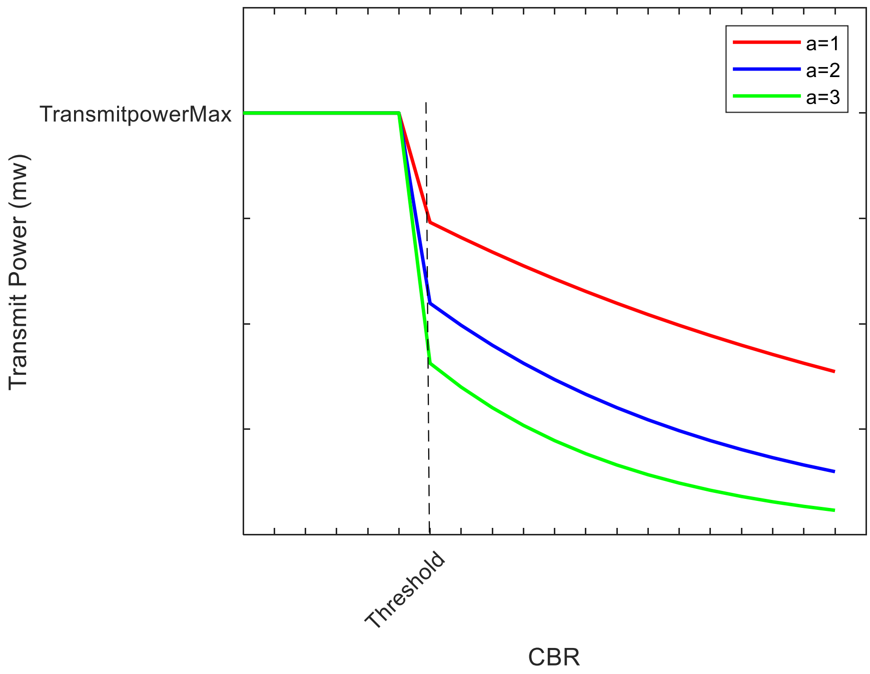


Figure 3.4: The relation of the transmitted power and CBR.

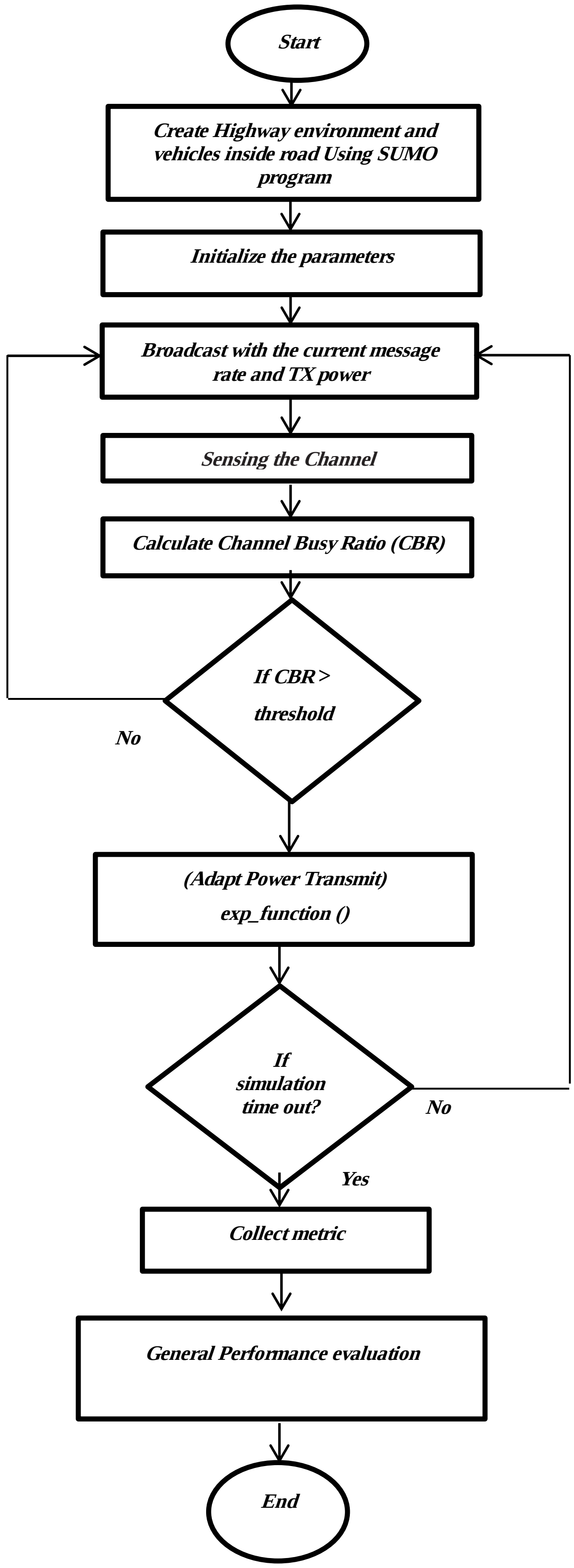


Figure 3.5: The Flowchart of the adaptation of the transmitted power.

Algorithm 3.2: **Algorithm of Transmit Power Adaptation**

Input:
($\boldsymbol{Transmitpower_{Max}}$, $\boldsymbol{Transmitpower_{min}}$,a)
Output:($\boldsymbol{Adapt\ Transmit\ power}$)
Procedure Get CBR
CBR= getCBR ()
if (CBR >threshold) **then**
$\boldsymbol{Adapt\ Transmit\ power}$ = $\boldsymbol{Transmitpower_{Max}}$*exp (-a *CBR)
If ($\boldsymbol{Adapt\ Transmit\ power}$ < $\boldsymbol{Transmitpower_{min}}$)
$\boldsymbol{Adapt\ Transmit\ power}$ = $\boldsymbol{Transmitpower_{min}}$
Else if($\boldsymbol{Adapt\ Transmit\ power}$ > $\boldsymbol{Transmitpower_{Max}}$)
$\boldsymbol{Adapt\ Transmit\ power}$ = $\boldsymbol{Transmitpower_{Max}}$
End if
Else
$\boldsymbol{Adapt\ Transmit\ power = Transmitpower_{Max}}$
End procedure

3.5 Message rate and transmitted power Control

The Combination approach is the third approach where two parameters including (message rate with transmit power, transmit power with data rate, and message rate with data rate) adapted simultaneously. Message rate and transmit power are combined in this thesis to control channel congestion. The steps for implementing, and evaluating the message rate and transmitted power proposed system are detailed in the general flowchart as shown in Figure 3.6.

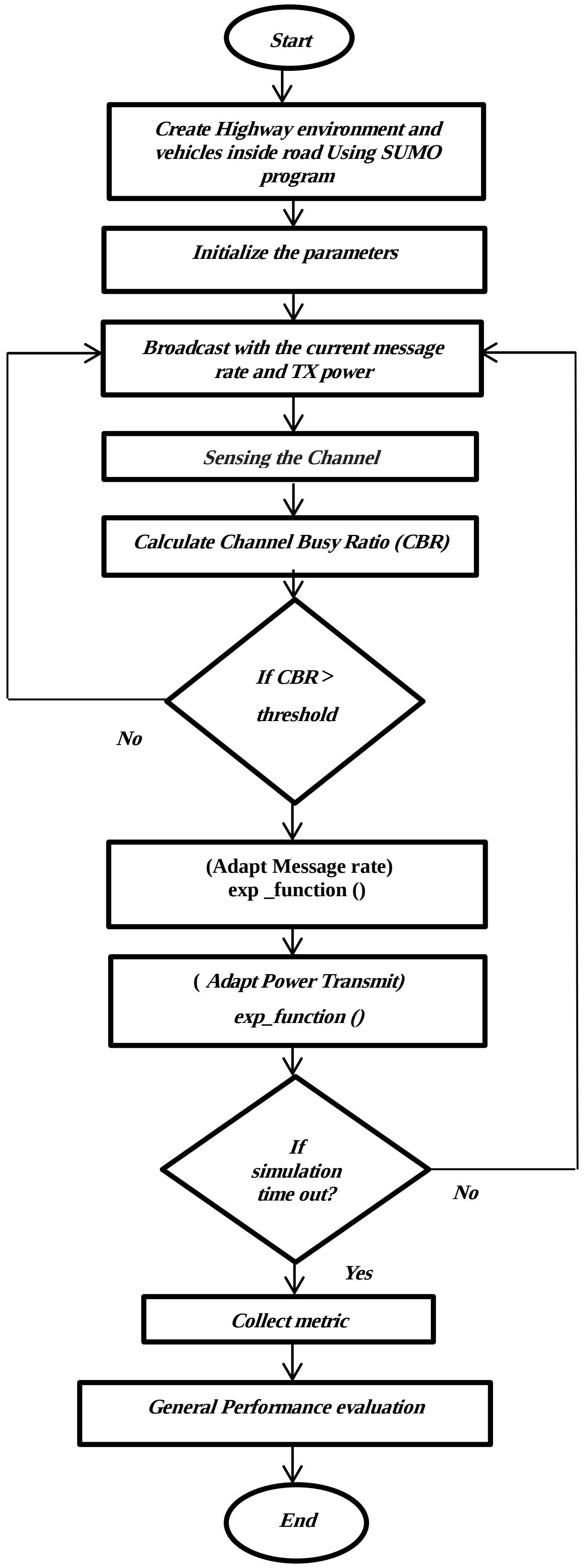


Figure 3.6: Proposed Message Rate and Power Transmit Flowchart.

As in sections 3.2 and 3.3, the Combination control relies on the exponential function to change the message rate and the transmitted power, as shown in the following method. When the detected value exceeds the threshold (CBR>threshold), the vehicle's transmit power and message rate are reduced using an exponential function.

Algorithm 3.3: **Algorithm of Transmit Power and Message Rate Adaptation**

Input:
($\boldsymbol{Messagerate_{Max}}$, $\boldsymbol{Messagerate_{min}}$, $\boldsymbol{Transmitpower_{Max}}$, $\boldsymbol{Transmitpower_{min}}$,a)
Output:
(Adapt Transmit Power, Adapt Message Rate)
Procedure Get CBR
CBR= get CBR ()
if (CBR >threshold) then
Adapt Message Rate= $\boldsymbol{Messagerate_{Max}}$*exp (-a *CBR)
Adapt Transmit Power = $\boldsymbol{Transmitpower_{Max}}$*exp (-a *CBR)
If(Adapt Message Rate < $\boldsymbol{Messagerate_{min}}$)
Adapt Message Rate = $\boldsymbol{Messagerate_{min}}$
Else if(Adapt Message Rate > $\boldsymbol{Messagerate_{Max}}$)
Adapt Message Rate = $\boldsymbol{Messagerate_{Max}}$
End if
Else
Adapt Message Rate = $\boldsymbol{Messagerate_{Max}}$
If ($\boldsymbol{Adapt\ Transmit\ power}$ < $\boldsymbol{Transmitpower_{min}}$)
$\boldsymbol{Adapt\ Transmit\ power}$ = $\boldsymbol{Transmitpower_{min}}$
Else if($\boldsymbol{Adapt\ Transmit\ power}$ > $\boldsymbol{Transmitpower_{Max}}$)
$\boldsymbol{Adapt\ Transmit\ power}$ = $\boldsymbol{Transmitpower_{Max}}$
End if
Else
$\boldsymbol{Adapt\ Transmit\ power = Transmitpower_{Max}}$
End procedure

Chapter Four

The Implementation and Results

4.1 Introduction

The wireless channel congestion in VANET environments can be controlled by several parameters, including the message rate or the transmitted power or simultaneously the message rate and transmitted power. This chapter presents the implementation of the proposed technique using SUMO and OMNET++ software under different cases of vehicles density. Also, the results of this simulation will be illustrated and discussed in this chapter. The end of this chapter contains the comparison results of the proposed technique for different controlling parameters and various cases of vehicles density.

4.2 Implementation of the Developed Technique

VANET experimental studies in real world practical are not possible because they require a lot of time and several required resources to conduct experiments safely and generate accurate results. Therefore, there is the need for simulators to implement experiments that are safe, inexpensive in VANET environment. Two open source software is used to simulate work in this thesis, software to simulate vehicle mobility or traffic scenario and another to simulate the network communication between the mobile nodes.

Simulations of Urban Mobility (SUMO) are used to model road traffic. It is written in C++ and it includes features (clear Microscopic simulator for vehicle simulation, humans, and the public transportation, time schedule generation for traffic signals, and the ability to import real-world maps)[46].

The network is represented using OMNET++ and Vehicles in Network Simulation (VEINS) [47], [48]. OMNET++ is a discrete event simulator, which is a big, modular, a component-based C++ library and a framework for networking, such as wire and wireless channels, queue networks, support for wireless ad-hoc networks, networking protocols, optical networks, and so on.

4.2.1 Simulation setup

All simulation is comprised of its scenario files that determine what it is the simulation behaves. For instance, the frequency of node creation, a behavior, and the roadways used to simulate node activity, and the speed of the nodes. The network simulator OMNET++ specifies simulation parameters using configuration model files (ini, ned). The parameters utilized for simulation runs are shown in Table 4.1.

Table 4.1: Parameters for Simulation.

Parameter	**Representation**
Vehicle Number	50, 100, 150
Simulation duration	Variable
Maximum Vehicles Speed	25 m/s[49][6]
Protocol for Wireless Transmission	IEEE 802.11p
Message Rate Range	1-10HZ[50][6]
Transmit Power Range	1-20mw[17]
Data Rate	6Mbps [3]
Threshould(Thr)	0.3 [50]
Decay Factor (a)	1,3
Road Topology	Highway
Highway Length	1000 m
Sensitivity	-89dBm
Simulator	OMNET++ 5.0, INET 3.4, Veins4.4, SUMO 0.25

Four-lanes highway traveling in one direction were used to test the suggested strategy. Vehicles were added to the simulation environment by SUMO route configuration file. Once a vehicle is created in SUMO, a matching network node on the OMNET++ side to communicate through a network by the sumo-launchd-py, which is a daemon operates in the background and is continually waiting for incoming requests. The highway road was 1000 m and Vehicles are designed with a maximum speed of 25 m/s and they choose a lane at random to enter the simulator and they maintain the route until the end of the highway illustrated in Figure 4.1[49].

If a vehicle reaches the road's end, then the job is complete and it stops broadcasting or contributing to the network, then execution the data collection. The SUMO configuration file contains a specified route for vehicles to follow. All vehicle moves from one road edge to the next according to the route id given in the route file. In the route file includes the parameters that the vehicles will use. The parameters involve the max speed, acceleration, deceleration, the exit lane, vehicle kind, vehicle color, and so on.

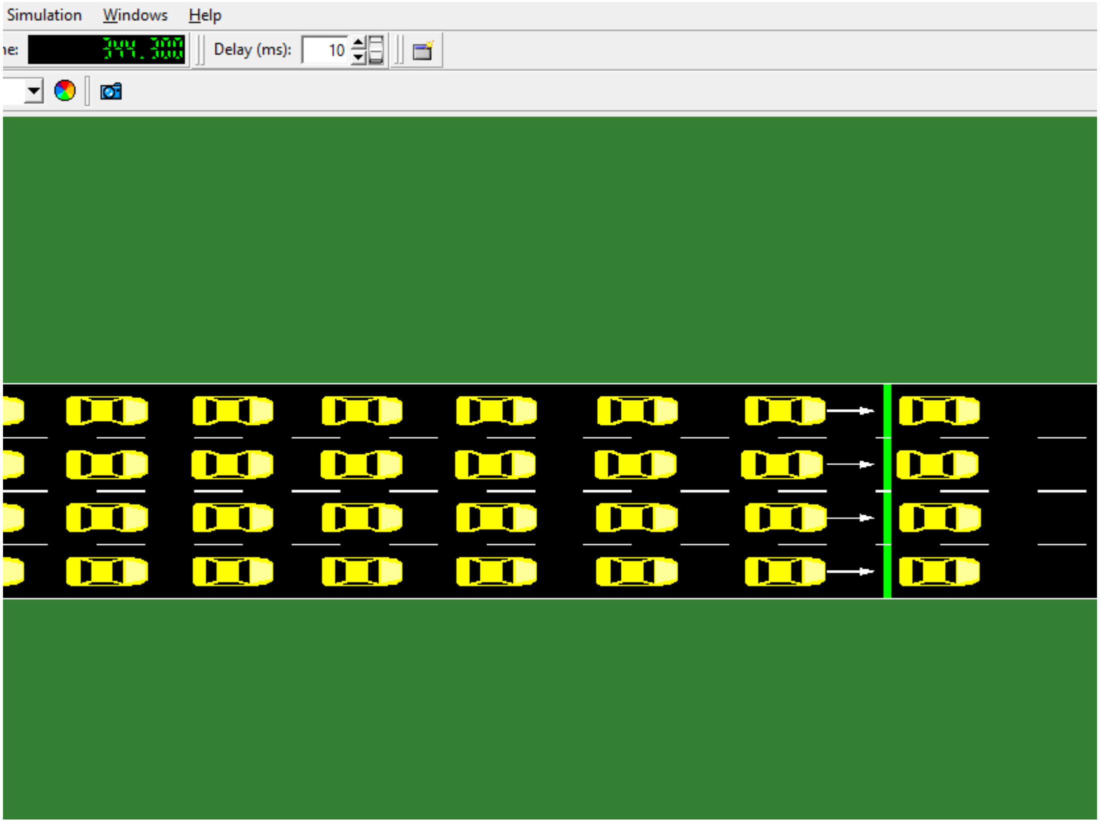


Figure 4.1: Run a Highway Scenario in SUMO.

4.2.2 Simulation Run

The suggested technique is applied in the veins files, which also contain all the required modules to use the DSRC/WAVE protocol module where the message rate and transmit power control and determined the kind of messages can be controlled to be sent . A settings file (ini) which contain of all predetermined parameters for executing the simulation in OMNET++. Only the safety messages were sent during the simulation because they are the most important ones. The BSM packets contain information such as (ID Sender, ID Receiver, Sender Position, and Sender Speed).

In the OMNET++ network environment, the simulation scenarios were run for 200 seconds at a variable transmission rate and a variable transmission power illustrated in Figure 4.2[3]. This network simulation shows the modules that have been used, simulation time and the nodes presently in the simulation broadcasting message. Due to the fact that the simulation involves a V2V network scenario, road side units were not used.

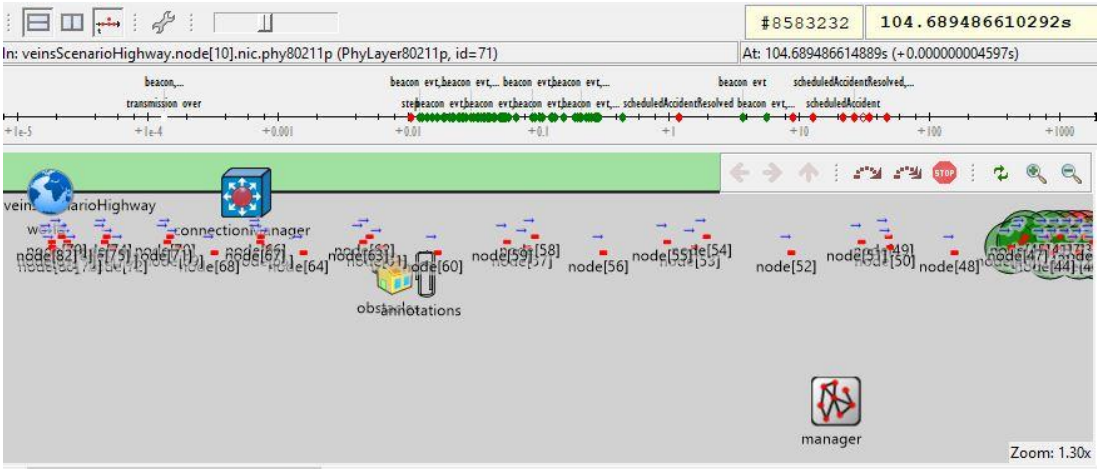


Figure 4.2: Run a Highway Scenario in OMNET++.

Four traffic scenarios are adopted for simulation as follows:

1. The normal VANET standard algorithm, which has a fixed transmission power (20 mw) and message rate (10Hz).
2. The proposed congestion control method which employs an exponential function that adapts the message rate.
3. The proposed congestion control method which employs an exponential function that adapts the transmit power.
4. The proposed congestion control method which employs an exponential function that adapts the message rate and the transmitted power together.

4.3 Results of Simulation

In this section the simulation resulted from the three proposed methods of network congestion in Dedicated Short Range Communication (DSRC) based on the exponential function are discussed and compared with the results of normal VANET method which uses a 10Hz message rate and 20 mw transmit power. The three proposed method involve:

- Implementing message rate control in various scenarios involving vehicle density.
- Implementing transmitted power control in various scenarios involving vehicle density.
- Implementing message rate and transmitted power control in various scenarios involving vehicle density.

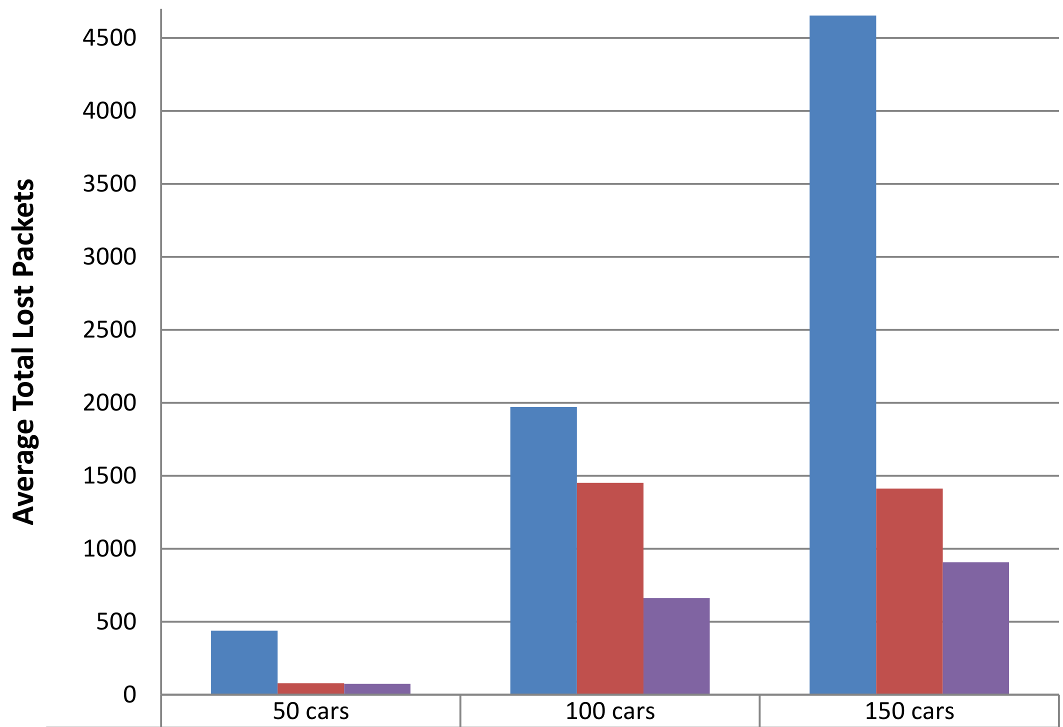
The performance metrics such as (total busy time, total lost packet, average throughput, packet loss ratio) are used to evaluate. The results of performance metrics for each model are compared with those of other models.

4.3.1 Message Rate Control Results

This subsection explains the results in terms of the evaluation metrics represented by the average (total lost packets, total channel busy time, throughput and packet loss ratio (PLR)).

A. Total Lost Packets

The effectiveness of the proposed strategy in the simulation for congestion control can be assessed by looking at the reduction in packet loss. A decrease in the packet loss indicates that network is less congested and that packets are delivered without any issues to the vehicles that require them. Figure 4.3 depicts the average of the total lost packets for (50, 100, and 150) vehicles in the highway scenario tested.



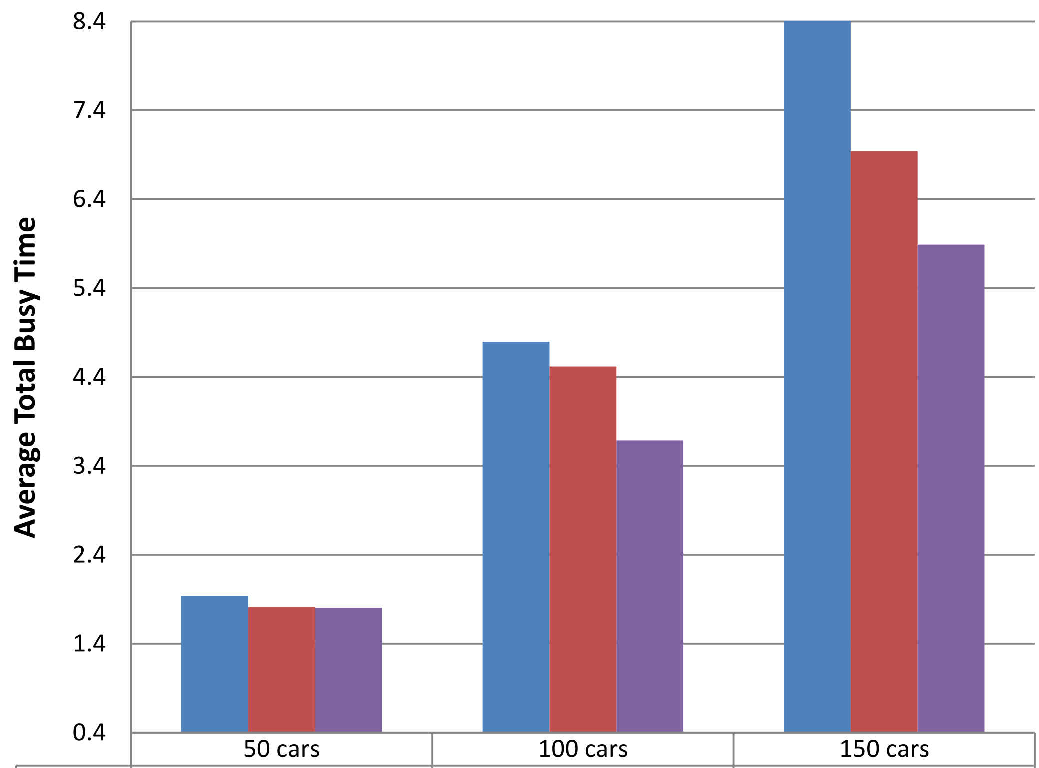
	50 cars	100 cars	150 cars
normal	440.06	1972.39	4653.973333
a=1	79.1	1452.39	1413.88
a=3	74.26	662.18	907.5133333

Figure 4.3: Average Total Lost Packets Based on Message Rate Control Strategy.

This figure shows that the average number of the total lost packets increases with the number of vehicles across the simulation period. The scenarios show that is there a high loss of packets even by 10Hz message rate when the congestion control approach is not applied on the four-lane highway road because of the dense state of traffic jam and so no form of congestion control, leading to lost packets as well as packets not getting received in the network which probably resulted in network congestion and the network performance decreases. The suggested exponential function-based congestion control strategy has a lower average number of the total lost packets. This is because an adapted message rate which improves communication and lessens competition among nodes to improve performance and safety in the network. Also, this figure illustrates that the decay factor (a) has an important effect as he increase in this factor decreased the loss of packets.

B. Total Channel Busy Time

Figure 4.4 displays the average of total channel busy time for a highway scenario with various numbers of vehicles being used. The figure makes it abundantly evident that the busy time results of the channel correlated with the number of messages transmitted. The channel busy time decreases by decreasing number of packets transmit over the network .However, the channel busy time increased with the increasing number of vehicles over the simulated period.



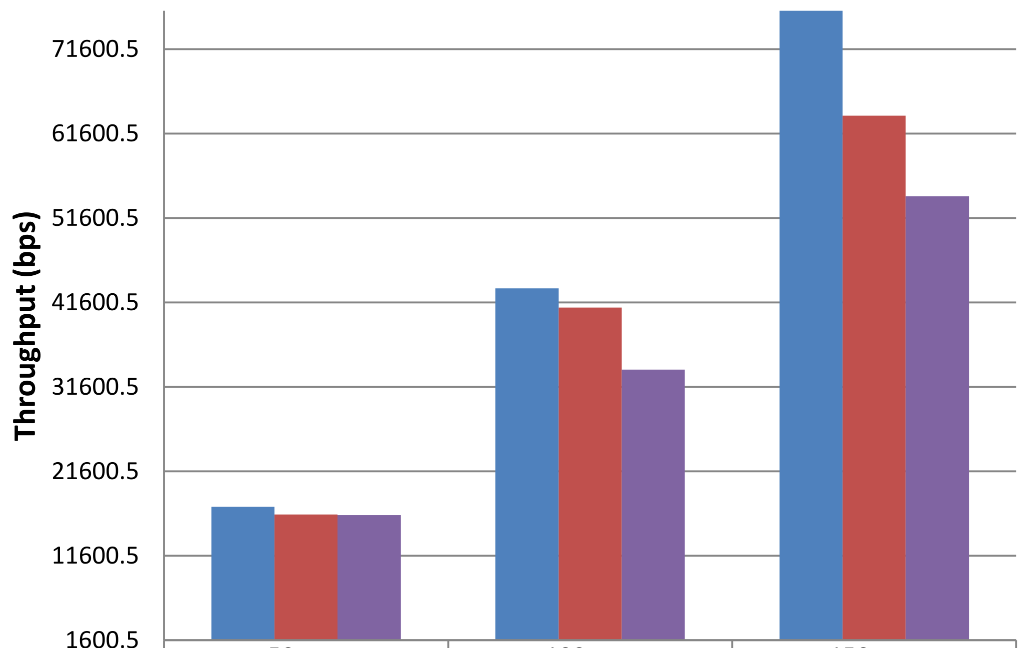
	50 cars	100 cars	150 cars
normal	1.93424914	4.79485202	8.443237647
a=1	1.8148226	4.51648797	6.941240733
a=3	1.8038473	3.68556248	5.89065482

Figure 4.4: Average Total Channel Busy time Based on Message Rate Control Strategy.

It is clear that the performance of the suggested technique in terms of average channel busy time aims to reduce this number. It would be busier without utilizing a congestion control strategy. Also, the decay factor of the exponential function has an important effect on the channel busy time.

C. Average Throughput

The average throughput in the simulations shows the rate of successfully received data in all time of simulation for each vehicle. Figure 4.5 shows the Average throughput values obtained using the highway scenario for different 50, 100 and 150 vehicles. The Adaptive message rate based exponential function had a lower average throughput than that of the (10Hz, 20mw) approach because it reduces the number of transmitted messages which leads to the decrease the number of received messages.

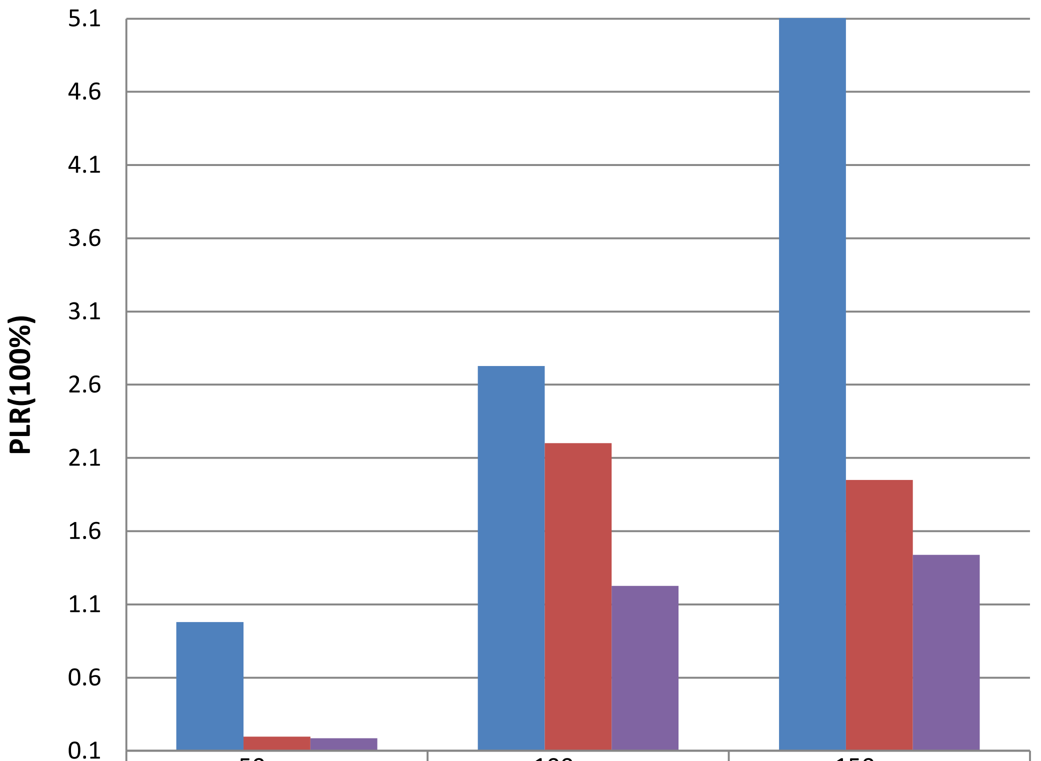


	50 cars	100 cars	150 cars
normal	17393.6384	43252.8768	76163.11467
a=1	16503.9104	40979.8784	63728.54613
a=3	16403.9168	33666.2272	54170.09493

Figure 4.5Average Throughput Based on Message Rate Control Strategy.

D. Packet Loss Ratio

The values of Packet loss Ratio determined for the various vehicles using the highway scenario is shown in Figure 4.6 where it can be noticed that the increase in the decay factor (a) decrease the packet lose ratio. It is clear that the Adaptive message rate approach based exponential function has a better performance than that of the10 Hz and 20 mw approach.



	50 cars	100 cars	150 cars
normal	0.980482153	2.728506915	5.133398534
a=1	0.196864111	2.200924382	1.949318921
a=3	0.185780046	1.225873336	1.438746499

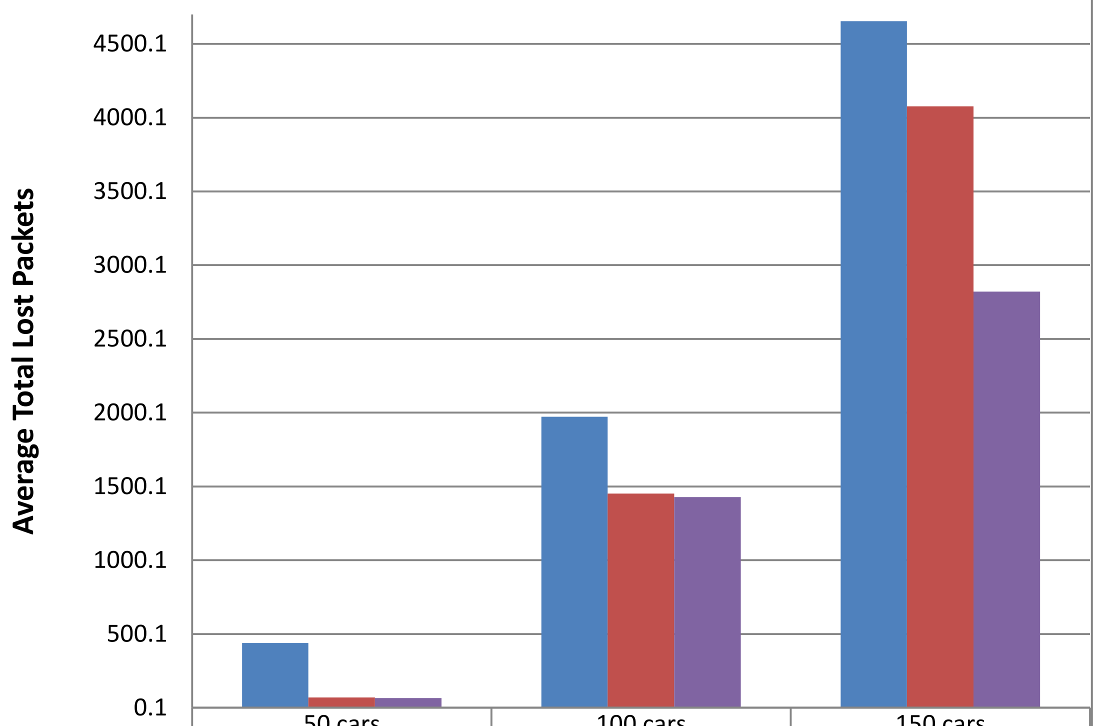
Figure 4.6: Packet Loss Ratio Based on Message Rate Control Strategy.

4.3.2 Transmit Power Control Results

The suggested network congestion control method adjusts transmission power in accordance with the present density of nodes (i.e., vehicles) on the roadways in order to lessen congestion on the network.

A. Total Lost Packets

Figure 4.7 shows the average of total lost packets for vehicles in the highway scenario examined for (50, 100 and 150) vehicles, respectively. The proposed congestion control approach based exponential function has a decreased average of lost packets. This is because the network used the adaptive transmitting power which improves communication while reducing competition between nodes to increase network performance and safety. These statistics also show that the decay factor (a) has a significant impact on the number of lost packets which are inversely proportioned to this factor.

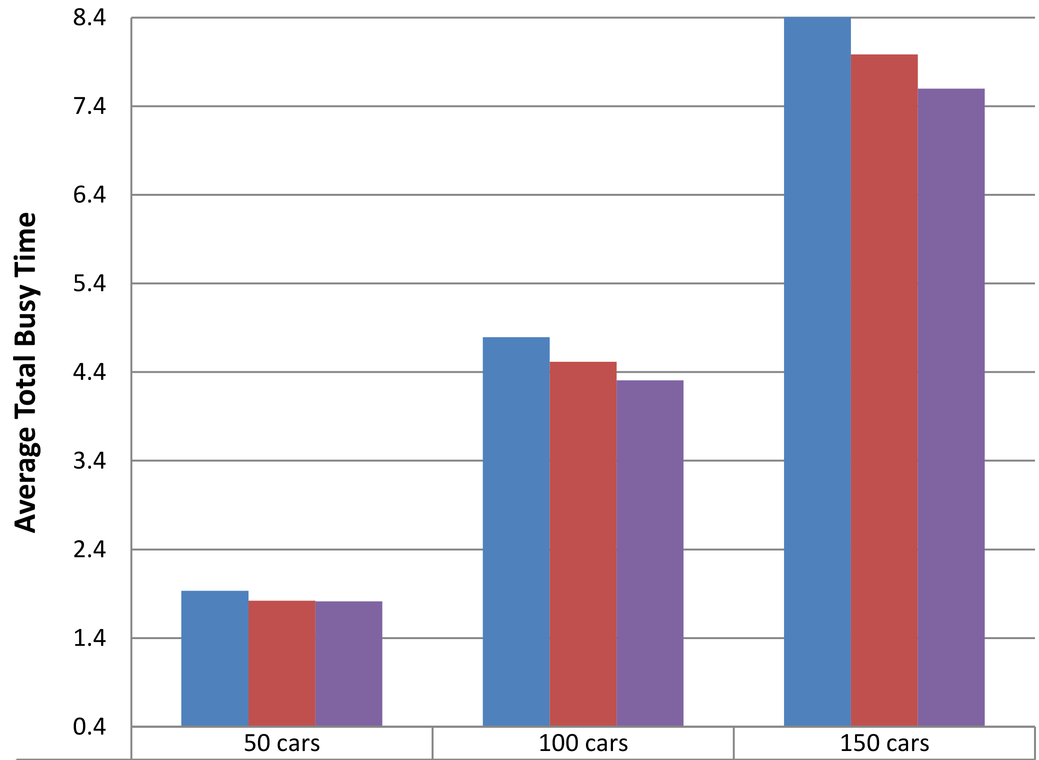


	50 cars	100 cars	150 cars
normal	440.06	1972.39	4653.973333
a=1	71.1	1452.39	4077.24
a=3	67.18	1428.53	2820.44

Figure 4.7: Average Total Lost Packets Based on Power Control Strategy.

B. Total Channel Busy Time

Figure 4.8 displays the changes in the average total channel busy time for different number of vehicles in the highway scenario. The results of the CBT are directly correlated with the number of messages transmitted and it can be seen that fewer packets are delivered through the network, when the CBT is increased. The figure also demonstrates how over the simulation time, the channel busy time increases as the number of vehicles increases.



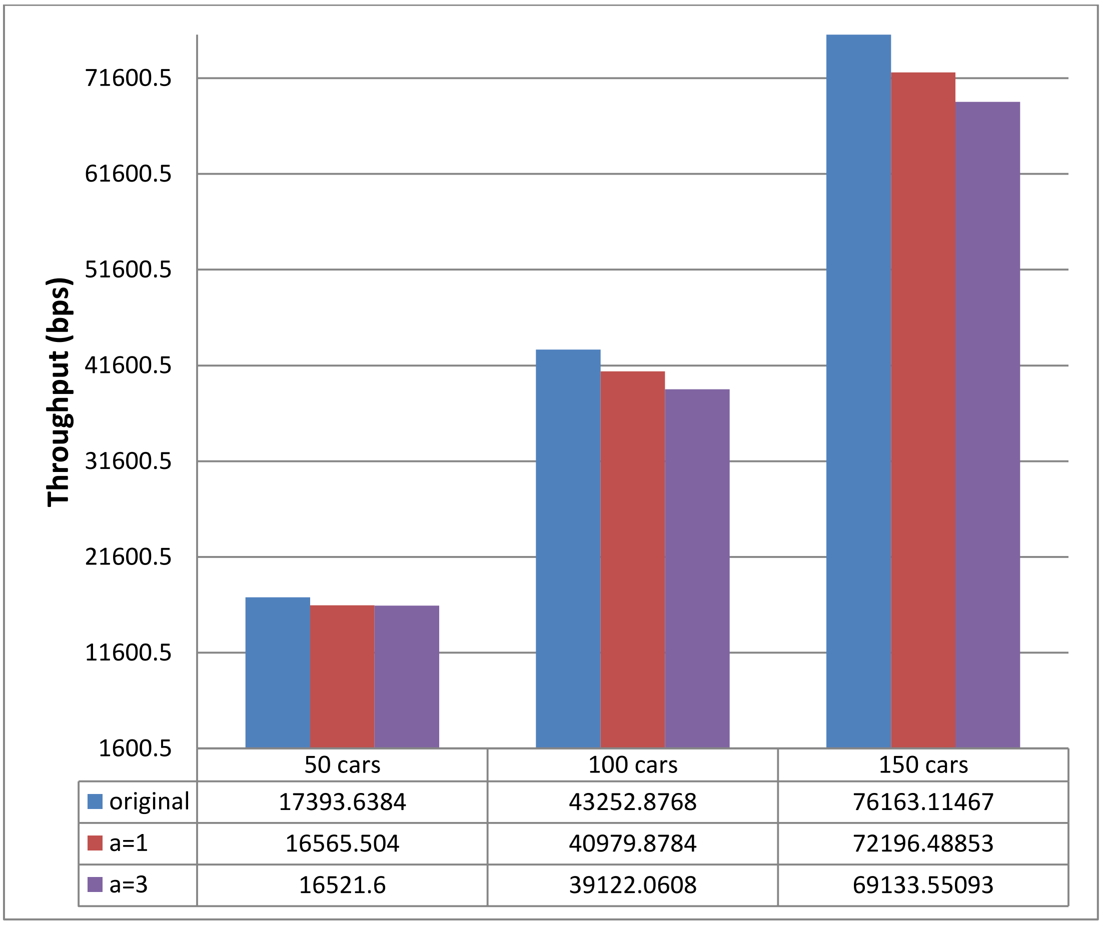
	50 cars	100 cars	150 cars
normal	1.93424914	4.79485202	8.443237647
a=1	1.82130794	4.51648797	7.981923773
a=3	1.81601962	4.30727559	7.59626472

Figure 4.8: Average Total Channel Busy Time Based on Power Control Strategy.

It is obvious that the proposed congestion control technique which is based on an exponential function in terms of channel busy time performs better than without congestion control strategy. This is due to the usage of adaptive power transmission which improves communication and reduces node competition to enhance network performance. Moreover, the increasing of the decay factor gave lowers the channel busy time.

C. Average Throughput

Figure 4.9 shows the relation between the average throughput and the number of vehicles of both the normal state and the proposed technique of congestion control. It is obvious that the adaptive power transmit exponential function based had a lower throughput performance than that of the normal state (i.e., without congestion control) (10Hz, 20mw) approach.

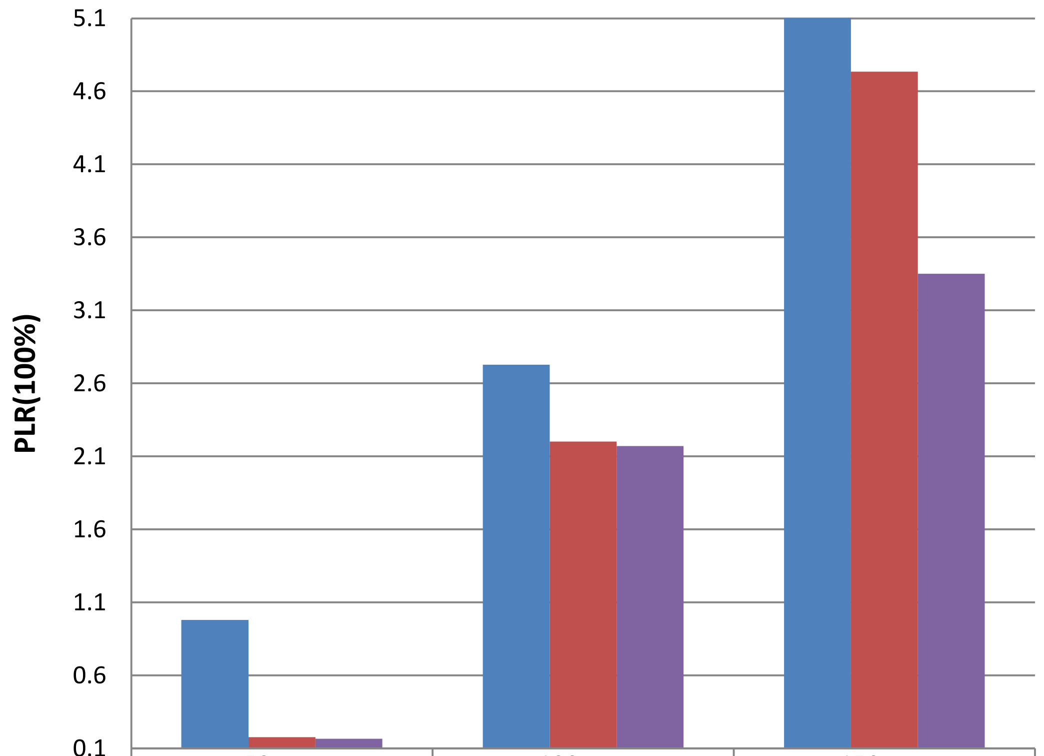


	50 cars	100 cars	150 cars
original	17393.6384	43252.8768	76163.11467
a=1	16565.504	40979.8784	72196.48853
a=3	16521.6	39122.0608	69133.55093

Figure 4.9: Average Throughput Based on Power control strategy.

D. Packet Loss Ratio

Figure 4.10 shows the average Packet loss Ratio for various numbers of vehicles. The adapted transmit power based on exponential function scenario has less packet loss ratio as compared with that of the (10Hz, 20mw) scenario. This means that, in highway conditions, an exponential function based adaptive transmit power can send more packets and reduce channel congestion on highway roads which improve the network performance.



	50 cars	100 cars	150 cars
normal	0.980482153	2.728506915	5.133398534
a=1	0.17618198	2.200924382	4.733894251
a=3	0.166468431	2.17082029	3.350911654

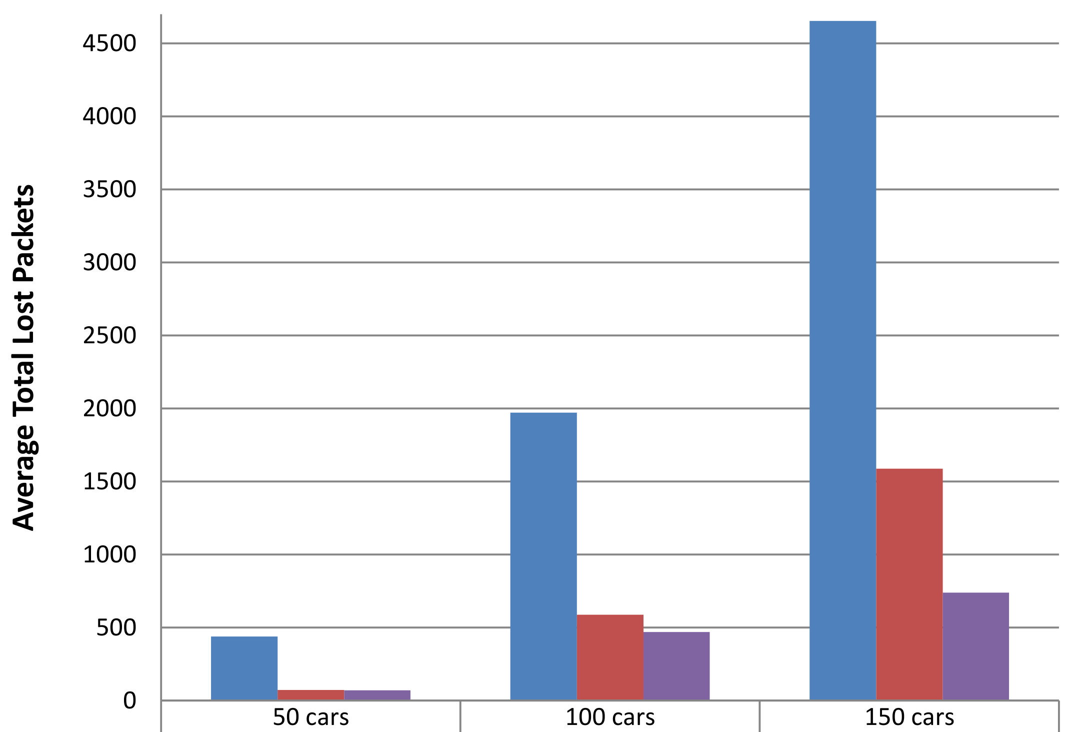
Figure 4.10: Packet Loss Ratio Based on Power Control Strategy.

4.3.3 Combination Message rate and transmitted power Result

The Combination result indicates that the message rate and transmission power controls are combined to.

A. Total Lost Packets

The relation between the average of total lost packets and the number of vehicles (nodes) with and without congestion control is shown in Figure 4.11. Clearly, the proposed congestion control approach improves the performance in term of the average total lost packets. The proposed technique reduced this parameter in a good manner especially when the decay factor was increased.

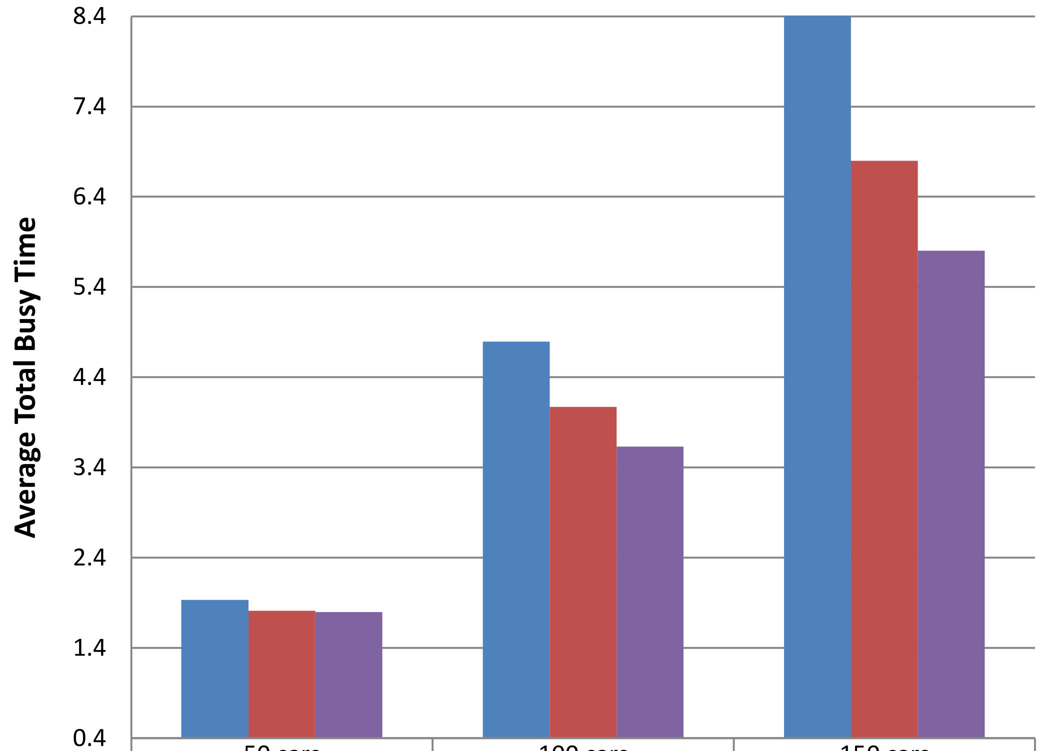


	50 cars	100 cars	150 cars
normal	440.06	1972.39	4653.973333
a=1	71.98	587.68	1588.42
a=3	70.56	470.02	739.6266667

Figure 4.11 Average Total Lost Packets Based on Combination Control Strategy.

B. Total Channel Busy Time

Figure 4.12 displays the average total channel busy time variations of the highway scenario with different number of vehicles. Combining an adaptive message rate and transmit power based on an exponential function affects positively the channel busy time by reducing it to a value lower, than its counterpart in the control approach where the adaption message rate or transmit power are at used.

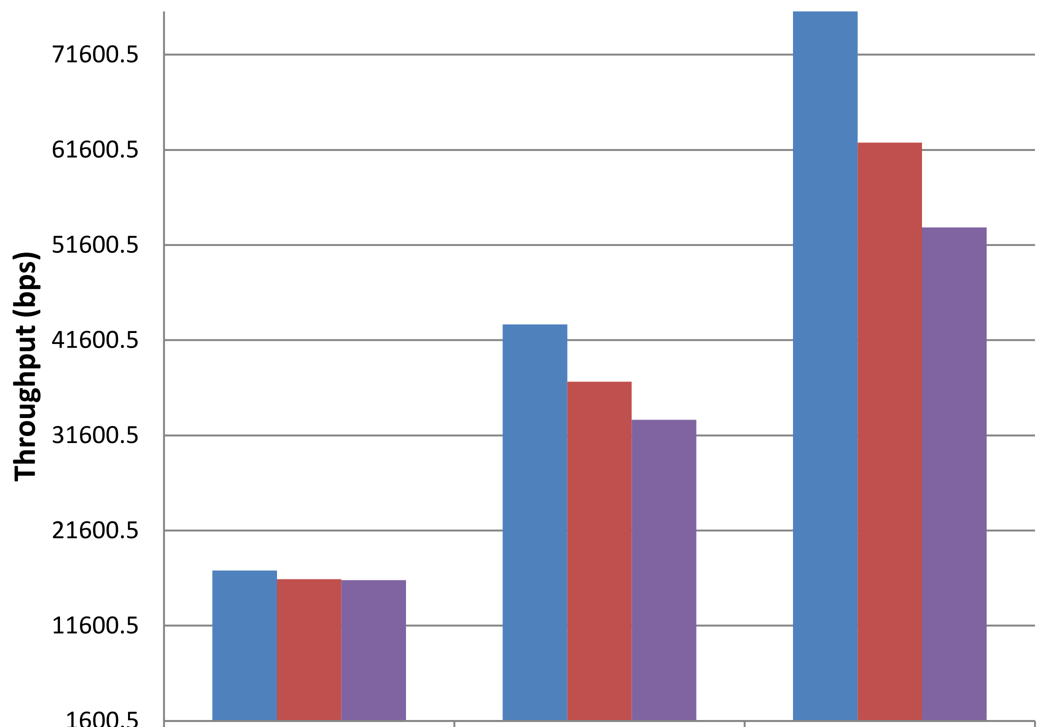


	50 cars	100 cars	150 cars
normal	1.93424914	4.79485202	8.443237647
a=1	1.81259282	4.07148649	6.799462
a=3	1.80005154	3.6322939	5.803436713

Figure 4.12 Average Total Channel Busy Time Based on Combination Control Strategy.

C. Average Throughput

Figure 4.13 illustrates the simulation result of the average throughput in relation with the number of vehicles in highway scenario for different states of congestion control. The Adaptive Combination congestion control based exponential function had a lower average throughput than that of one without congestion control (10Hz, 20mw) approach because the reduction in message rate and transmission power reduce the number of the delivered packets which reduce the throughput of the network.

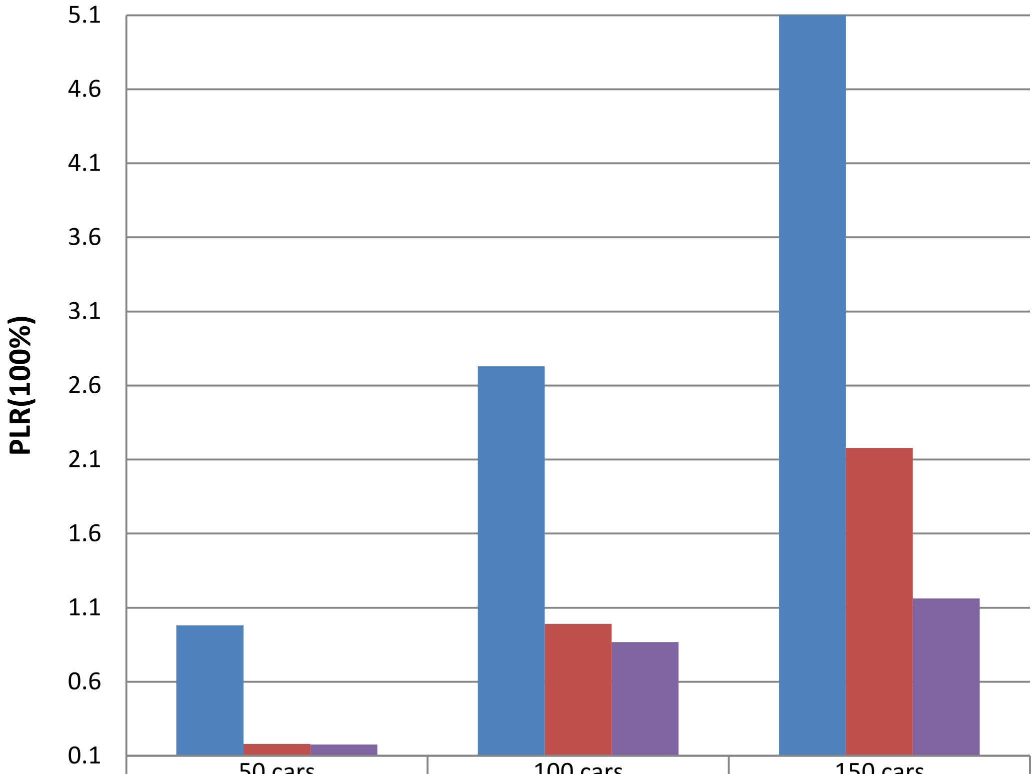


	50 cars	100 cars	150 cars
original	17393.6384	43252.8768	76163.11467
a=1	16484.8896	37252.7616	62361.7792
a=3	16373.7856	33246.016	53430.3232

Figure 4.13: Average Throughput *Based on Combination Control Strategy*.

D. Packet Loss Ratio

The packet loss ratio values for various numbers of vehicles in the highway scenario are shown in Figure 4.14..It means that the exponential function can transmit more successful packets in highway environments, improve the packet delivery rate and collision probability, which reduces channel congestion on highway roads.



	50 cars	100 cars	150 cars
normal	0.980482153	2.728506915	5.133398534
a=1	0.179063635	0.991145666	2.176832277
a=3	0.176523566	0.867964249	1.162435431

Figure 4.14: Packet Loss Ratio Based on Combination Control Strategy.

4.4 Comparison Results

The Comparison results are presented in this section for all the three (50, 100, and 150) vehicles scenarios. The results of 50 vehicles scenario are shown in table 4.2 while the results of 100 and 150 vehicles scenarios are illustrated in tables 4.3 and 4.4, respectively. These tables show the averages of each scenario's total channel busy time and total packet loss for all vehicles. These tables show the calculated values with fixed message rate and transmitted power (i.e. normal), and with adaptive message rate or transmitted power separately or both (i.e. proposed). By reducing the busy time and the lost packets for all the three scenarios, the suggested clearly enhances the system performance in terms of channel busy time and lost packets. Also, the proposed technique achieves more reduction when the Combination case and the number of vehicles are high. In addition to that, the decay factor of the exponential function provides a very good reduction. It can be seen from these tables that the minimum reduction ratio of the average of total busy time around 5.8% is achieved by the transmitted power adaptation technique, while the maximum value of 31% was achieved by the technique of combination of the message rate and power transmission. The same thing occurs with the ratio of the average total lost packets.

Table 4.2: The Case of 50 Vehicles

Parameter	Technique		Average of Total Busy Time (sec)	(Normal-Proposed)/ Normal *100%	Average of Total Lost Packets	(Normal-Proposed)/ Normal *100%
Message Rate	Normal		1.934		440.06	
	Proposed	a=1	1.814	6.17%	79.1	82.02%
		a=3	1.803	6.74%	74.26	83.125
Power Transmit	Normal		1.934		440.06	
	Proposed	a=1	1.821	5.80%	71.1	83.84%
		a=3	1.816	6.11%	67.81	84.73%
Message Rate and Power Transmit	Normal		1.934		440.06	
	Proposed	a=1	1.812	6.28%	71.98	83.64%
		a=3	1.800	6.93%	70.56	83.96%

Table 4.3: The Case of 100 Vehicles

Parameter	Technique		Average of Total Busy Time (sec)	(Normal-Proposed)/ Normal *100%	Average of Total Lost Packets	(Normal - Proposed)/ Normal *100%
Message Rate	Normal		4.794		1972.39	
	Proposed	a=1	4.516	5.80%	1452.39	26.36%
		a=3	3.685	23.13%	662.18	66.42%
Power Transmit	Normal		4.794		1972.39	
	Proposed	a=1	4.516	5.80%	1452.39	26.36%
		a=3	4.307	10.16%	1428.53	27.57%
Message Rate and Power Transmit	Normal		4.794		1972.39	
	Proposed	a=1	4.071	15.08%	587.68	70.20%
		a=3	3.632	24.24%	470.02	76.17%

Table 4.4: The Case of 150 Vehicles

Parameter	Technique		Average of Total Busy Time (sec)	(Normal-Proposed) / Normal *100%	Average of Total Lost Packets	(Normal-Proposed)/ Normal *100%
Message Rate	Normal		8.443		4653.97	
	Proposed	a=1	6.941	17.78%	1413.88	69.61%
		a=3	5.890	30.23%	907.513	80.50%
Power Transmit	Normal		8.443		4653.97	
	Proposed	a=1	7.981	5.46%	4077.24	12.39%
		a=3	7.596	10.03%	2820.44	39.39%
Message Rate and Power Transmit	Normal		8.443		4653.97	
	Proposed	a=1	6.799	19.46%	1588.42	65.86%
		a=3	5.803	31.26%	739.626	84.1%

Chapter Five

Conclusions and Suggestions for Future Works

5.1 Conclusions

V2V safety communication helps drivers to be more aware of other vehicles; which improves road safety. Different methods of handling channel loading must be considered in DSRC. Focusing on the channel congestion problem, this thesis comes up with the following conclusions:

1- A congestion control technique based on the exponential function had been proposed for VANET by adjusting the message rate, transmitted power, and simultaneously both of them.

2- The VANET system had been simulated based on the proposed technique using SUMO and OMNET++ for three different cases of vehicle densities in highway scenario.

3- The proposed technique was evaluated by the simulation in terms of the total lost packets, total channel busy time, and throughput.

4- The proposed technique showed good results, based on the evaluation metrics, in terms of reducing the total lost packets, and the total channel busy time, and increasing the packet delivery ratio.

5- The results showed that the application of the developed technique in adaptation the message rate is more efficient than the adaptation the transmitted power.

6- Also, the congestion control based on the combination of the message rate and transmitted power adaptation is better than the adaptation of the message rate or the transmitted power separately.

7- In the last, the simulation results illustrate that the developed techniques success in controlling the channel congestion in terms of the CBT and PLR about 84% in comparison to the normal case where no congestion control was adopted.

5.2 Suggestions for Future Works

In this thesis, the developed technique was simulated and evaluated in highway environments, so it can be simulated and evaluated in a urban environment with high traffic jam and traffic lights. Also, it can be use the developed technique in centralized strategy where the algorithm apply in the central unit represented by the RSU or in the higher level. In addition, this technique can be used to adapt the data rate with the transmitted power or the message rate.

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الخلاصة

تُستخدم تقنية الشبكات المخصصة للمركبات (VANET) بواسطة أنظمة النقل الذكية (ITS) لمنع وتقليل حوادث الطرق السريعة. حيث تستخدم VANET تقنية الاتصالات اللاسلكية التي تتضمن بروتوكولات وتطبيقات توفر ميزات السلامة وتطبيقات توفر الرفاهية لتجربة قيادة آمنة ومريحة. تتمثل المشكلة الرئيسية في أن المركبات تتنافس على نفس قناة الشبكة ذات النطاق الترددي المحدود لإرسال رسائل الأمان أو المنارة للتوعية، مما يتسبب في حدوث ازدحام وبالتالي فقدان الحزمة، وتأخير إرسال كبير ، واستخدام غير عادل للموارد. ستؤدي هذه المشكلة في النهاية إلى تأخير تسليم رسائل السلامة الأساسية (BSMs) وتجعل VANET غير موثوقة. ركز الباحثون على العديد من الأساليب للتحكم في الازدحام على قناة الشبكة مثل تكييف معدل BSM ، أي عدد وحدات BSM التي يمكن إرسالها في الثانية الواحدة أو تعديل قوة الإرسال وهي المسافة التي يمكن أن تقطعها الرسالة أو تعديل معدل البيانات (معدل بت) للبيانات المرسلة. في هذه الرسالة ، تم اقتراح ثلاث تقنيات للتحكم في ازدحام القناة في VANET. تقوم التقنية الأولى بالتحكم في الازدحام باستخدام الدالة الأسية لتقليل معدل الرسائل أثناء الازدحام. تحقق التقنية الثانية التحكم في الازدحام عن طريق ضبط القدرة المرسلة باستخدام الدالة ألاسية. بطريقة مماثلة ، قامت التقنية الثالثة بتكييف معدل الرسالة والقدرة المرسلة معًا للتحكم في الازدحام بناءً على الدالة الأسية. تم تنفيذ التقنيات المقترحة بواسطة SUMO وبرنامج OMNET ++ مفتوح المصدر لحالات مختلفة من اعداد المركبات (٥٠و١٠٠و١٥٠). أظهرت نتائج المحاكاة أن النهج التكيفي يعزز أداء شبكة المركبات عن طريق تقليل وقت انشغال القناة ، وتقليل عدد الحزم المفقودة مقارنة بالحالة العادية دون استخدام نهج التحكم في الازدحام. أيضًا ، كان معدل التخفيض باستخدام الدالة الأسية أفضل مع زيادة عامل الاضمحلال والعدد الكبير من المركبات. تتراوح نطاقات معامل الاختزال لمتوسط زمن انشغال القناة حوالي (٥,٤٦ ٪ إلى ٣١,٢٦٪) ، بينما يبلغ عامل التخفيض لمتوسط إجمالي الحزم المفقودة حوالي (١٢,٣٩٪ إلى٨٤,٦ ٪) اعتمادًا على كثافة المركبات ، والعامل المعدل ، و عامل الاضمحلال للدالة الأسية. في الختام ، عززت التقنية المطورة أداء VANET والتي يمكن اعتمادها في تطبيقات العالم الحقيقي.

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بابل / كلية تكنولوجيا المعلومات
قسم شبكات المعلومات

تقنية مطورة للتحكم في ازدحام

القناة اللاسلكية في VANET

رسالة مقدمة

إلى مجلس كلية تكنولوجيا المعلومات في جامعة بابل كجزء من متطلبات

الحصول على درجة الماجستير في تكنولوجيا المعلومات / شبكات المعلومات

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1444 هـ 2023 م

الخلاصة