Congestion Control Mechanism based on Power and Rate Adjustments in VANETs

Meseret Asrat Demise

A Thesis Submitted to

The department of Computer science and Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfilment of the Requirement for the Degree of Master's in Computer Science and Engineering

Office of Graduate Studies

Adama Science and Technology University

February, 2023

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Declaration

I hereby declare that this Master Thesis entitled "congestion controlling mechanism based on power and rate adjustment in VANETs" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Congestion controlling mechanism based on power and rate adjustment in VANETs " prepared under my guidance by Meseret Asrat submitted in partial fulfilment of the requirements for the degree of Mater's of Science in Computer Science and Engineering.

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Major Advisor	Signature	Date
Co-advisor	Signature	Date

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I/we, the advisors of the thesis entitled "Congestion Control Mechanism based on power and rate adjustments in VANETs" and developed by Meseret Asrat, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Meseret Asrat have read and evaluated the thesis entitled "Congestion Control Mechanism based on power and rate adjustments in VANETs" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Computer Science and Engineering.

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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LIST OF ACRONYMS AND ABBREVIATIONS

ACK	Acknowledgment
AIFS	Arbitration Inter Frame Spacing
API	Application programming interface
ASTM	American Society for Testing and Materials
AU	Application Unit
BER	Beacon Error Rate
BRR	Beacon Reception Rate
BSM	Basic Safety Messages
CBT	Channel Busy Time
CCH	Control Channel
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CTS	Clear to Send
CTS	Request to Send
DCC	Decentralized Congestion Control
Dens	Density
Dist	Distance
Draw.io	Draw input output
DSRC	Dedicated Short Range Communication
EDCA	Enhanced Distributed Channel access
EV	Ego Vehicle
FCC	Federal Communications Commission
GB	Gigabit
HPP	High Powered Packet

HPPC	High Powered Packet
HPPI	High Powered packet Interval
hr	hour
I2I	Infrastructure-to-Infrastructure
IEEE	International Electrical and Electronics Engineers
ITS	Intelligent Transportation System
KM	Kilometer
LLC	Logical Link Control
LOS	Line-of-Sight
LPP	Low Powered Packet
M	meter
MAC	Medium Access Control
MANET	Mobile Ad hoc Network
Mbps	Megabits per second
MHZ	Mega Hertz
mW	milliWatt
NED	Network Definition
OBU	On-Board Unit
OFDM	Orthogonal Frequency Division Multiplexing
OMNET++	Objective Modular Network Test bed in C++
PDA	Personal Digital Assistance
PHY	Physical
QOS	Quality of Service

RAM	Random Access Memory
Rd	Rate dispersed
RFID	Radio Frequency Identification
Rp	Rate Populated
RSU	Road Side Unit
RTS	Request to Send
RV	Remote Vehicle
SCH	Service Channel
SUMO	Simulation of Urban Mobility
TCP	Transmission Control Protocol
TracI	Traffic Control Interface
Txc	Current transmission
UDP	User Datagram Protocol
US-FCC	United State-Federal Communication Commission
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VANET	Vehicular Ad hoc Network
VEINS	Vehicular Network Simulator
WAVE	Wireless Access in a vehicular Environment
WIMAX	World Wide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WSMP	Wave Short Message Protocol
WSN	Wireless Sensor Network

ABSTRACT

Vehicular manufacturers and researchers have invested efforts to reduce road accidents through the Vehicle to Vehicle wireless communication using Vehicular Ad Hoc Networks. Up-to-date information on the location, speed and other important parameters for each vehicle is shared with neighbouring vehicles through the periodic exchange of BSM. With a high vehicular density, network congestion can quickly arise in the 5.9GHz spectrum, rendering the system as unreliable because safety messages are not delivered and received on time. To solve this problem, there has been considerable research, in recent years, on congestion controlling mechanisms for VANETs. Most of them are generally based on rate or power control of the transmitted packets. In this paper, we propose to combine rate controlling and power altering mechanisms together to reduce packet congestion in VANETs based on the density and speed of vehicles in a standard transmission diameter. Instead of requiring all vehicles to use the same power and rate, our approach allows each vehicle to dynamically adjust the transmit power and data rate of BSM packets, depending on the density and speed of vehicles. Our simulation results demonstrate, packet losing is minimized with 25%, beacon reception rate and channel busy time can be managed up to 50% and beacon error rate is reduced with 30% when using our system, this shows the importance of our algorithm to solve congestion problem that occurred in VANET.

CHAPTER ONE

Introduction

1.1. Background

Vehicular ad hoc network is produced to provide vehicles with a good and cost efficient data communication. It can be used to manage and minimize road accidents, traffic congestion, traveling time, fuel consumption and so on [1] [2]. Vehicular communications allow the road users to get information about critical and dangerous situations, which may happen in their surrounding environment. Therefore, VANETS can play a crucial role to ensure safer urban environments for road users [3].

VANETs are a type of Mobile Ad hoc networks used for communication between vehicles and vehicles as well as roadside equipment [4]. In addition to challenging characteristics in MANETs (such as lack of established infrastructure, wireless links, multi- hop broadcast communications), VANET brings new problems to realize safe communication architecture within such an environment. Within VANET networks nodes are known for their high dynamism and mobility, as well as the rate of topology changes and density variability [5].

VANET is implemented by Intelligent Transportation Systems for Vehicle –to-Infrastructure and Vehicle-to- Vehicle communications [3]. Communications in VANETs pass on standards and protocols defined in Dedicated Short Range Communication and Wireless Access in a Vehicular Environment [4]. IEEE created a full protocol stack of 1609 protocol family WAVE. There are six standards under 1609 family, which named IEEE 1609.1, 1609.2, 1609.3, 1609.4, 1609.5, 1609.6 each one handles different issues at different layers [15].

In permitting the communication in VANET, IEEE 802.11p was produced which combines physical (PHY) and MAC layer [15].

IEEE 802.11p PHY layer is a modified class of the 802.11a. It adopts orthogonal frequency –division multiplexing with 10 MHZ channel and uses data rates varying from 3Mbps- 27Mbps.

MAC layer applies the enhanced distributed channel access which makes its base on the Carrier Sense Multiple Access with Collision Avoidance protocol and prioritization [6].

The applications developed for VANETS can be grouped in to three these are: safety applications, convenience applications, commercial applications [8].These generate two types of messages for communications with in VANETS which includes safety and non-safety messages. The safety messages contain beacon and emergency messages, which are transferred within the control channel. The non-safety messages containing the messages generated by convenience and commercial applications are transferred in service channels [7] [9].

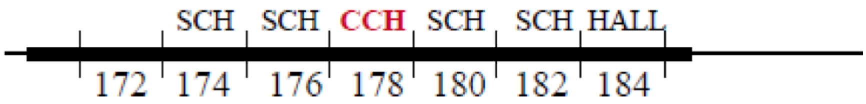

FIGURE 1 DEDICATED SHORT RANGE COMMUNICATION CHANNEL

Data congestion is one of the main problematic issues in VANETS. Starting from now on we will refer to it just as congestion. Congestion occurs in networks when the channels are overloaded in high dense network conditions, ultimately resulting in increased packet loss , delay, and reduced the quality of the network, because of this vehicles wait for extra time and accidents on the road also increased [10]-[13].

Therefore, a good congestion controlling mechanism must be conducted to support QOS and to ensure the safety and reliability condition in vehicular environments and to reduce accidents on the road.

Basically, in VANETS four congestion control strategies are known these are: rate-based, power-based, CSMA /CA-based, prioritizing and scheduling-based. In rate-based strategies, transmission rate is decreased when the channels are congested. In power-based strategies, transmission power or range is dynamically adjusted to decrease the channel's loads. In CSMA/CA –based strategies, congestion is controlled by modifying the CSMA/CA protocol and adjusting the contention window size and /or Arbitration Inter Frame Spacing (AIFS) to decrease the channel access [15]. The prioritizing and scheduling-based methodology define a priority for each message and schedule them in control and service channels such that the emergency and safety messages get higher priorities to transfer with less time[14].

There are various challenges for efficient data transmission and information receiving in VANETS. As the velocity of vehicles is high there is constant change in topology of network. Similarly, the density and velocity of vehicles vary with time and region. The consequence is difficulty in the application of a unified solution for VANETS. There are conditions where the vehicles are sparsely distributed and it is leading to poor connectivity of the network. This situation also results in performance degradation and difficulty to meet quality of services (QOS) standards.

1.2. Motivation

Vehicles need to communicate in order to interchange different information like: collision warning, left turn assistance, emergency electronic brake light, traffic signal violation warning, curve speed warning, pre-crash sending, lane changing warning, stop sign movement assistance and others. But since there are too many data transferred, congestion happen in the vehicles network channel and results data collision, packet loss as well as a beacon error.

The above raised problems create hazard and crash on the road, these results human life cost and critical material damage. So that we need to control congestion in VANET, a common technique to avoid congestion is CSMA/CA where wireless medium is tested to be idle or busy before transmission. But due to dynamic topology and variable speed of vehicles things are difficult to control congestion using CSMA/CA that is what motivated us to create more efficient congestion controlling mechanism in VANET.

1.3. Statement of the problem

Congestion is very serious problem in VANET, if it is not occurred every BSM sent would be correctly and exactly received by the intended recipient with a timely manner and efficient information to perform whatever task required by the safety application be accomplished. However because of congestion VANET encounter several communication problems such as message overhead, inefficiencies in bandwidth and resource usage, and others which can affect the performance of a network and applications that rely on it.

The transmit rate of the BSM packets to be 10HZ within a transmit radius of 300m as defined by the IEEE 1609 standard. [47].With in this standard it is estimated that at 200 vehicles the channel to transfer BSM 100% utilized [23].When channel load is reached above 40% of the theoretical capacity, MAC transmission delays and packet loss increase exponentially [23].In such networks, transmitting vehicles must constantly test the broadcasting medium for activity, and only transmit their own messages when no activity is sensed on the channel, that is when the channel being sensed as idle. This can cause a significant amount of overlap, delay, and packet collisions resulting congestion which cause loss of awareness in the network and the suffering of safety applications.

Researchers provide many works to solve congestion problem using different strategies like transmission power adjustment, transmission rate adjustment, considering packet priority and scheduling, modifying CSMA/CA protocol and others; but still the situation is existed and needs more research to be solved. Our aim is to alleviate this problem by combining power and rate adjustment together when vehicles communicate and interchange safety messages between each other based on the density and speed of vehicles.

Research Questions

Based on the above problem, this study answered the following questions:

- How transmission power can be adjusted?
- How data rate can be controlled?
- How power and data rate controlling combined and reduce congestion?
- How the solution for VANET congestion can be designed?
- How can the new algorithm performance be tested?

1.4. Objectives

General Objective

To design a congestion controlling mechanism based on power and rate adjustment in VANETs, which can improve the process of communication between vehicles.

Specific Objectives

- To review different literatures written about VANET
- To examine related works provided to solve congestion problem in VANET
- To study how power and rate adjustment solve congestion occurred in VANET.
- To design an energy efficient mechanism (algorithm) that can solve a congestion problem.
- To simulate the designed algorithm using simulation software.
- To evaluate performance of the proposed algorithm with the existing ones.

1.5. Significance of the Study

In this work we have tried to understand the idea of past research and gain many outputs from them. We will try to add some new concepts and prepare efficient congestion controlling mechanism in VANET. We think two parts use this paper. Firstly a transport sector can use this work to implement more good and efficient traffic condition, because of that every and each passenger benefited from our work directly or indirectly .Secondly researchers who want to refer it and make detail study about controlling congestion in VANET can use our work.

1.6. Expected outcome

After this congestion controlling mechanism will be developed, it shows how congestion can be managed. This work plays a major role in creating good communication setup between vehicles because of this car accident can be highly eradicated, also it is expected that vehicles are not waiting for extra unnecessary time because of congestion; this shows our work plays some role in reducing fuel consumption, as a consequence minimizing air pollution which is a burning issue on the world now a days.

1.7. Delimitation and Limitation of the Study

1.7.1. Delimitation

From the IEEE created six protocol stack of 1609 protocol family WAVE ,we are focusing only on 1609.4 which works on MAC layer with 802.11P.we don`t touch other five standards since they are not responsible for communication between Vehicles.

1.7.2. Limitation

This work does not consider real field experiments since it is not easy to afford the material and cost to do so. Because of this we make our base of work on VANET simulation software.

1.8. Thesis Organization

Generally, the thesis is organized in to five chapters. The first chapter is talking about the introduction or clue about congestion in VANET, the objective, problem statement, research questions, significance of the study, expected outcome, delimitation and limitation are included there. The remaining chapters are arranged as follows; Chapter 2 presents a literature about ADHOC network from which VANET is outsourced and the related works, Chapter 3 is about a material and methods used to make the study and it shows a research method ,how past papers used in the research, the way to design a solution, performance metrics used to compare and contrast a designed solution with previous algorithms , Chapter 4 presents the detail design of the proposed solution, Chapter 5 provides simulation of the designed solution ,results and evaluation of the proposed solution.

CHAPTER TWO

Literature Review

This chapter is divided into two sections; the first section detailed about vehicular ad hoc networks. The second section is related works.

2.1. Vehicular ad hoc Network

VANET is considered a subclass of Mobile Ad hoc Network. Vehicles are used as the wireless node and can be connected in the wireless range between 100 and 300m. Vehicles are connected together to make a mobile wireless network [21]. The IEEE 802.11p Wireless Access in Vehicular Environments is a standard on which the IEEE is working with, in order to afford Dedicated Short-Range Communication (DSRC) for future Vehicle-to-Vehicle (V2V) communication.

VANET has unique and special features different from MANET including [22]:

1. High mobility

High mobility is the most important feature of Vehicular Ad hoc Networks, which makes the mobility model one of the most important parameters. It should be suspiciously selected when evaluating any protocol [23].

2. Rapidly changing network topology

The high speed of the vehicles and the presence of many available roads lead to the rapid change in network topology [24].

2.2. VANET Type of communications

VANET has three types of communications, which are:

- Vehicle-to-Vehicle Communication.
- Vehicle-to-Infrastructure Communication.
- Infrastructure-to-Infrastructure Communication.

2.2.1. Vehicle-to-Vehicle Communication

Vehicle-to-Vehicle Communications is the dynamic wireless exchange of data between neighboring vehicles that offers information about a vehicle such as speed and position. V2V communication enables active safety systems that assist drivers in preventing 76 percent of the crashes on the roadway, thereby reducing the total of fatalities and injuries that occur each year [25].

2.2.2. Vehicle-to-Infrastructure Communication

Vehicle-to-Infrastructure communications is the dynamic wireless exchange of data between vehicles and highway infrastructure. In V2I, The infrastructure gathers information about the environment state and exchanges this information with a vehicle moving on the road [25].

2.2.3. Infrastructure-to-Infrastructure Communication

Infrastructure-to-Infrastructure communication is the wireless exchange of data between the two base stations. The base station collects data from vehicles and processing will be done [25].

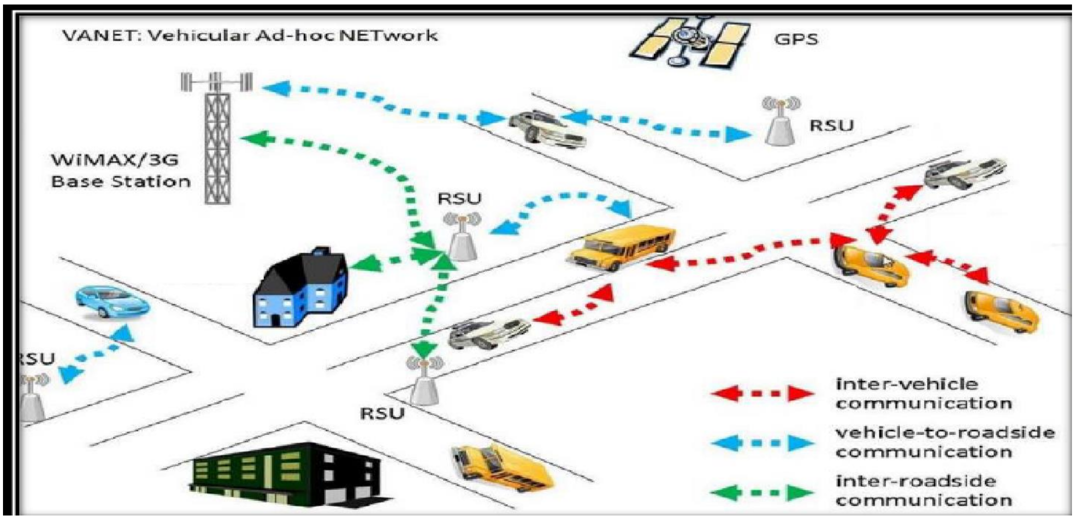

FIGURE 2 DIFFERENT TYPES OF COMMUNICATION

2.3. Components of VANET

There are mainly three components of VANET [26]:

1. On-Board Unit.

2. Road Side Unit.

3. Application Unit.

2.3.1. On-Board Unit (OBU)

An On-Board Unit (OBU) implements the communication protocol stack and provides V2X communication services to application units (AU). OBUs are equipped with at least one network device for short-range wireless communication based on IEEE 802.11p, and may be equipped with more network devices from different technologies. Its main uses and procedures comprise wireless radio access, geographical ad-hoc routing, network congestion control, IP mobility support, and others. On-Board Unit is a physical device located in a vehicle and responsible for V2V and V2I communication.

2.3.2 Road Side Unit (RSU)

Road-Side Units (RSUs) are fixed nodes placed along roads or highways, or at dedicated locations such as traffic signs, parking places or gas stations. RSU has the same communication capabilities of OBUs. It is equipped with at least one device for short-range wireless communications based on IEEE 802.11p, and may be equipped with other network technologies in order to allow communications with an infrastructure network.

RSUs may extend the communication range of the Ad-hoc domain, may provide Internet connectivity or may cooperate with other RSUs in forwarding information [26].

2.3.3. Application Unit (AU)

Application unit is a dedicated entity that runs applications and uses the OBUs communication capabilities. The AU is embedded in a vehicle and be permanently connected to an OBU, or can be dynamically plugged into the in-vehicle network by drivers or passengers. It can also be a portable device such as laptop or PDA; multiple AUs are allowed to be interconnected to a single OBU. AU and OBU communicate inside through Ethernet. Examples of Application Units are [26]:

- A dedicated device for safety applications like hazard- warning
- A navigation system with communication capabilities.

- A hand-held device like a PDA that runs Internet applications

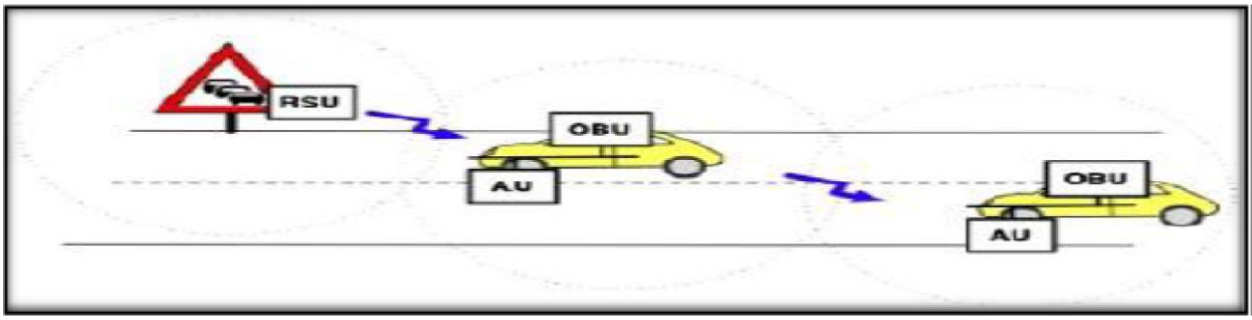

FIGURE 3 COMPONENTS OF VANET

Both OBU and RSU use 802.11p to communicate. 802.11p is from 802.11a, and they are based on OFDM. The major difference between 802.11a and 802.11p is that the 802.11p is proposed to use 10MHZ frequency bandwidth (half of bandwidth of 802.11a) in order to make the signal stronger against fading and increase the tolerance for multipath propagation effects of signals in a vehicular environment. OBU located on vehicles acts as IEEE 802.11 station, while a RSU deployed on a road is serves as IEEE 802.11 access point [27].

As we have seen vehicles and road side units equipped with short-range wireless communication devices based on IEEE 802.11p to communicate with each other in self-organized networks called VANETs. V2X communications combined with vehicular on-board and road-side sensors may support road safety by two means: broadcasting periodic safety messages and disseminating event-driven safety messages [28] [29]. These safety messages typically have to be delivered within a geographical area with certain reliability and delay limits. The periodic messages, also called beacons, carry vehicles' status information such as positions and speeds (Fig. 4).

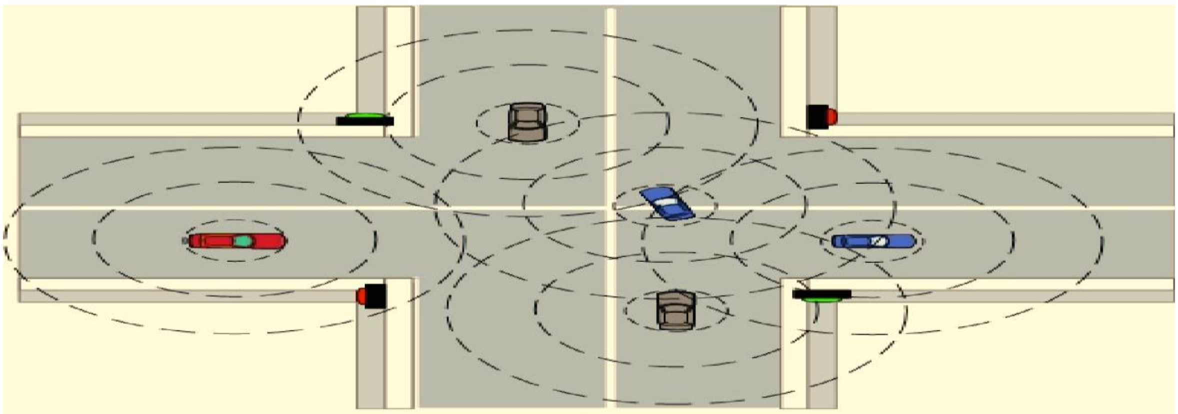

FIGURE 4 PERIODIC BEACONS SENT AT CERTAIN FREQUENCY

Event-driven safety messages are generated when an abnormal situation or an imminent danger is perceived, and disseminated within a certain area with high priority (Fig. 5). Critical event-driven messages usually have strong reliability and delay requirements.

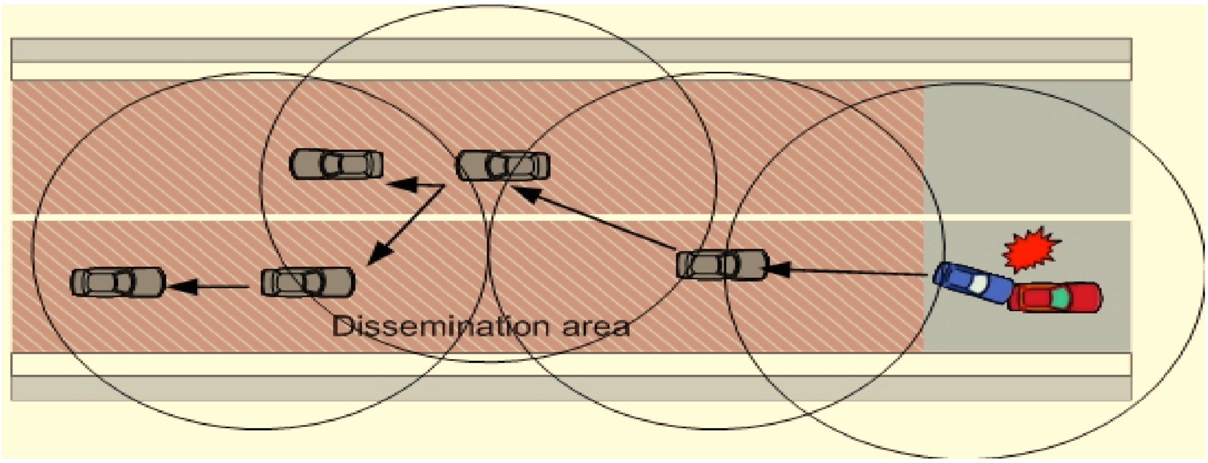

FIGURE 5 EVENT -DRIVEN MESSAGE DISSEMINATION

In high traffic, a large number of vehicles broadcast beacon safety messages at a high frequency or event driven safety messages are broadcast multiple times; the CCH channel will easily congest. This condition will decrease throughput while delay is increasing significantly. On the other side, the easiest method of broadcasting beacon safety messages to all nodes is by using blind flooding. Every node that receives the packets will rebroadcast this packet and will lead the broadcast storm. In VANETs, it's based on the Carrier Sense Multiple Access with Collision Avoidance scheme [30]. In CSMA/CA, when a node receives a packet that is to be transmitting, it senses to be sure the channel is clear (no other node is transmitting at the time).

If the channel is unused, subsequently the packet is sent. When channel is busy, the node must defer its access and in high utilization periods this could lead to unbounded delays, it will affect the safety applications [30]. Furthermore, blindly broadcasting the packet may cause frequent contention and collisions in transmission among neighboring nodes. In addition, a node can under taking very long channel access delays due to the risk of the channel being busy during its listening period of messages [30].

2.4. The IEEE 1609 WAVE Standards

IEEE 1609 WAVE is family of standards for vehicular communication encompassing, vehicle-to-vehicle as well as vehicle-to-infrastructure communications.

- IEEE 1609.1 specifies the services and interfaces of the WAVE Resource Manager application.
- IEEE 1609.2 defines secure message formats and processing.
- IEEE 1609.3 presents transport and network layer protocols, including addressing and routing, in support of secure WAVE data exchange.
- IEEE 1609.4 specifies MAC and PHY layers, which are based on IEEE 802.11.
- IEEE 1609.5 managing layers
- IEEE 1609.6 coordinating facilities

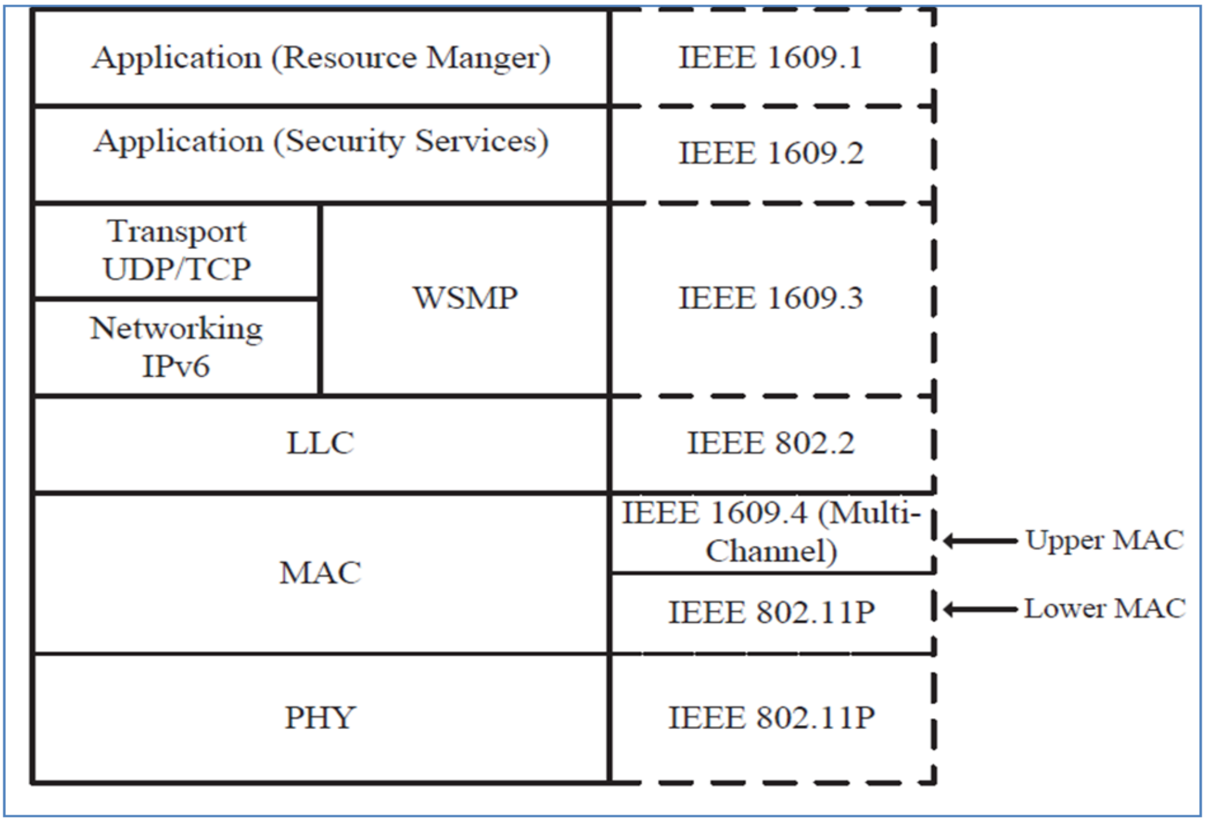

FIGURE 6 THE WAVE PROTOCOL STACKS

2.4.1. DSRC MAC and PHY layers

The veins framework handles the WAVE stack as per the standards IEEE 802.11p and IEEE 1609.4 and WSMP. A bandwidth is allocated as 75 MHz in the 5.9GHz frequency band (5.850 GHz - 5.925 GHz). The bandwidth is divided into seven channels of 10MHz each and a 5MHz guard band to reduce Inter-symbol interference. The channel (ch178) is u Control Channel (CCH) and is used for sending safety messages; the other 6 channels are used as Service Channels (SCH) and used for sending service messages [33]. The DSRC MAC consists of two parts. IEEE802.11p creates the Lower layer and IEEE 1609.4 perform as the Upper MAC layer or also called the MAC extension of 802.11p [33]. Just no ACK mechanism in DSRC as the packets is broadcasted. CSMA/CA not utilizes the RTS/CTS (Request to Send/Clear to Send) mechanism by default. For this reason hidden terminal problems do exist in VANETs. A collision is believed to happen when more than two nodes initiate packet transmission in identical time slot. IEEE 1609.4 creates the EDCA mechanism for giving QoS enhancement and channel switching mechanism [33].

The number of vehicles that have increased on road recently has increased the possibilities of potential threats and road accidents. The operation of the vehicles with the communicating on board unit has become a necessity so that the vehicles may communicate with each other and prevent the potential threats up to a certain level even if there are many problems including hidden terminals which can result in congestion [18].

VANETs (Vehicular AD-HOC Networks) are the most important and one of the major popularity gaining sectors in ADHOC networks because it has the significant potential to enable vast applications associated with safety, efficiency and many more applications of traffic. In these networks MAC (Medium Access Control) protocols are responsible for coordinating the access from the active nodes [18].

This paper aims to develop an efficient congestion controlling mechanism for VANET focused on MAC layer, in order to minimize road hazards, vehicle crash and other problems created because of congestion and harms human beings life as a whole.

2.5. Related Works

To control congestion different works have been done before, most of them propose decentralized congestion control (DCC) mechanisms for VANET. A DCC approach is not based on external RSUs or central processing hubs, allows for less overhead and delay and is self-contained on a traffic way.

There are two main methodologies in DCC techniques: transmission power adjustment and transmission rate adjustment .Algorithms based on a power adjustment adjust the power of transmission which affect the range of vehicles each packet transmission can reach. Algorithms based on rate control adjust how many packets are sent over a given time.

Also there are other methodologies like packet priority and scheduling and CSMA/CA modifying technique. The following table shows some papers with different techniques to solve Congestion.

TABLE 1 RELATED WORKS

Solution	Strength	Limitation
control congestion based on node throughput ;for each node have fixed throughput calculate the difference b/n expected & actual throughput if it is zero no issue, if it is negative node is underutilized, if it is positive node is congested, after detection cutting the traffic or packet rate to control congestion[48].	Minimize congestion through congestion detection.	It sacrifices awareness when cutting packets or traffic rate after congestion is detected.
change transmission power range based on the transmission distance ;for near distance low power for far use high power transmission in order to control congestion[49].	improve congestion problem by interchanging the two power ranges	Lost most packets with data collision.

Solution	Strength	Limitation
Proposed an algorithm which adapts vehicles transmission power according to its own speed, The idea here is that the faster a vehicle is traveling, the less dense the network is (as vehicles need to leave more space at higher speeds) with more space b/n vehicles, higher transmission powers can be used, while a low speed traffic network may suffer from heavy congestion at the same power. Thus, the lower speed vehicles reduce their transmission power[17].	improvement of Congestion in a VANET based on a speed-approximation of density.	If vehicles with the same speed appeared on the road at the same time the solution may not control congestion well.

Solution	Strength	Limitation
Uses channel Busy ratio as criteria for the channel occupation level and when channel is busy apply Control transmit time rate [50].	Controlling congestion based on channel busy time.	Scarifying awareness of vehicles when controlling transmit time rate.
Implemented a multi-state active DCC protocol which can adapt data rate of the system according to available channel load. The channel load is calculated in terms of channel busy ratio. Since the vehicular communication channel uses broadcasting, they use data rates only in range of 3 to 12mbps to avoid flooding(3 to 27mbps supported by the standard) [51].	Reduce congestion in minimizing data rate transmitted when a channel is busy.	Sacrifice awareness by minimizing data rate, because it reduce data rate if congestion happen

Solution	Strength	Limitation
Based on each vehicle's own speed adjusted its transmission power. When a vehicle traveling faster, it uses higher transmission power, while maintaining a constant transmission rate of 10 hz. This was done in three speed windows: Low, medium, and high [52].	It was found effective than using no congestion control.	If vehicles with the same speed appeared on the road at the same time the solution may not control congestion well.
A power adjustment algorithm that involves each vehicle oscillating between two prearranged power transmission situations [53].	This algorithm reduced congestion with the two different power adjustments.	Increasing IPD in further distances
Proposed a new, iterative method in transmission power adaptation [54].	Minimize channel load as well as transmission delays	Data collision may be happen when high amount of data rate sent with high power in a near distance.

Researchers work much based on different congestion controlling methodologies like: prioritizing messages, oscillating transmission power, and adjusting transmission power with vehicles own speed even if they tried to solve congestion problem most of them sacrifices awareness of vehicles and increase inter packet delay as well as seems affected by data collision due to different traffic conditions.

The gap that we have identified from the referred papers and which makes them to not achieve the intended target is, the way they use a single technique as a solution to solve congestion problem in their research and the single method is not enough to solve congestion problem due to different and dynamic topology as well as characteristics of VANET, we want to fill this gap by combining the two techniques that are used as a single in different papers power and data rate adjustment together.

We propose to manage each vehicle transmission rate and transmission power based on the density and speed of vehicles with in 300m area if the traffic condition is congested and the vehicle become slow in speed, use less power with high rate of data, if traffic condition is sparsely dispersed and vehicle use high speed use high transmission power with less data rate, in order to control congestion.

CHAPTER THREE

Materials and Methodology

3.1. Method

In this chapter the method of the research is discussed based on the research objectives and questions stated in the introduction chapter. When collecting, processing and analyzing the gathered information it can be either in qualitative or quantitative research method.

Qualitative research method is where we collect data in the form of text, images, sounds we get from observations, interviews and document evidence, and analyze it using different qualitative data analysis method [41].

Quantitative research method is where we collect numerical data and analyze it using statistical methods; observation, software simulation, direct field measurements and secondary data were the main sources of quantitative data [41].

Qualitative methods tend to be more appropriate in the early stages of research and for theory building .Quantitative methods tend to be more appropriate when theory is well developed and for purposes of theory testing and refinement[41].

In practice, no research method is entirely qualitative or quantitative. For example, a survey may collect qualitative as well as quantitative data using open-ended questions; an experiment may include observation of participant behavior as well as measures of response time and accuracy; a case study may incorporate quantitative data (example, system usage statistics) as well as qualitative data (example, interviews with users [41].

This research try to understand congestion problems in VANET, analyzing problems, reviewing the previous work and come up with problem solving mechanism, which the final result is designing efficient congestion controlling mechanism then test the algorithm with a simulation software and finally check its performance by comparing and contrasting it with the previous selected Congestion Controlling mechanisms using quantitative research method. The whole procedures we follow to conduct this research are going to be discussed below in detail.

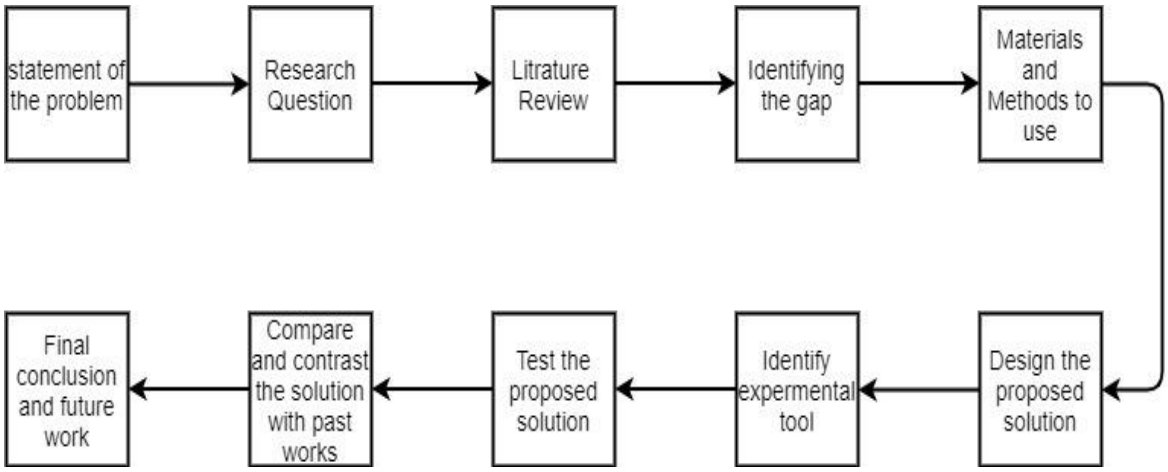

FIGURE 7 RESEARCH STUDY PROCEDURE

The first and most important step of a research is formulation of research problems. It is like the foundation of a building to be constructed. To solve a problem someone has to know about the problem. The "problem" is stated in the opening passages of a study and, in effect, provides a reader the rationale for why the study is important and why it is necessary to read [43].

After determining the research problem and deciding the research approach to use, it is time to begin writing about the "problem" in a statement of the problem section that introduces research study. A problem is defined as "a statement about an area of concern, a condition to be improved upon, a difficulty to be eliminated, or a troubling question that exists in theory or in practice those points to the need for meaningful understanding and deliberate investigation."

A problem statement concisely overviews the issues or problems existing in the concerned area selected for the research. It explains the issues predominant in a particular area which drives the researcher to do in-depth study and analysis in order to understand the issues and/or solve the problem. In our research since our topic is focused on congestion reducing in VANET we tried to understand the topic well first then investigate different situations available in the field and then formulate statement of the problem and as it is mentioned in chapter one when vehicles are densely populated with in a standard DSRC, channel load created which create message drop, delay, and degraded quality of service; those problems create congestion in VANET and we are going to create congestion controlling mechanism for VANET to make communication safe[43].

After identification of the problem statement the next thing is putting a research questions which are going to be answered by the research specifically. A research question should be as specific as possible. Specifying the research question is one of the first methodological steps the investigator has to take when undertaking research [44].

In our research after formulating a problem statement based on it we have generated four questions: how transmission power can be adjusted in VANET? How data transmission rate can be controlled in VANET? How transmission power and data rate controlling can be combined? How will the mechanism to control congestion in VANET be designed? How can the new algorithm be tested? These are questions going to be answered in this paper.

A literature review provides the basis for building a new conceptual model or theory, and it can be valuable when aiming to map the development of a particular research field over time. However, it is important to note that depending on the goal of the literature review, the method that should be used will vary [44].

Numerous papers (research, survey, journal articles…etc) specifically from Google Scholar, Google itself and ASTU previous students work; were referred in this research to know about Ad hoc network how it is implemented in VANET with DSRC and how congestion make influence on vehicles communication setup , and gather different relevant concepts and information to achieve the research objectives.

Quantitative method with a software experiment is used in this research; it is where relationships among variables are manipulated and measured. It simply enables us to improve the conditions under which we observes and thus to arrive at a more precise results. It enables us to relate a given consequent to a specific antecedent rather than to a vague conglomeration of antecedents.

It is a scientific method; give more precise, accurate and reliable results. It is just like an observation under controlled conditions. It acts on the law of single variable and causing factors. It studies cause and effect relationship. It is a systematic and logical method for answering the questions. In this the researcher seeks to evaluate something new. It leads to contribution to the already acquired fund of knowledge. The three essential elements in an experiment are; control, manipulation and observation. In this, experimenter has to imagine that research conditions are entirely new; they did not exist previously and recently. It is a method in which we study the effect of dependent variable on independent variable [42].

In this research we are going to design a new congestion controlling mechanism for VANET to do these we have referred many papers as it is mentioned in chapter two, and we got different knowledge on congestion, now we are going to design a new congestion controlling mechanism than designed and implemented before. In order to do this we focus on density of vehicles with in a standard diameter of DSRC 300m where 200 vehicles appeared at the same time the channel become fully congested.

When number of vehicles become 40% of the fully congested situation, congestion become started to be occurred, to solve this problem we provide as a solution a transmission power and a data rate adjustment based on the density and speed of vehicles, that is using high transmission power and low transmission data rate when there is no congestion, and use low transmission power and high data rate where there is congestion and where full update of information is intended to solve congestion problems in VANET.

3.2. Materials

Different materials and tools used to conduct this research and it is illustrated in the following table:

TABLE 2 TOOLS TO SIMULATE THE PROPOSED SOLUTION

Software	Operating System	Microsoft Windows 10 Pro Microsoft Windows 8.1
	Simulation tool	OMNET++ 4.6 SUMO 1.9.2 VEINS 5.1
	Programming Language	C++ & NED language
	Architecture & diagram draw tool	Draw.io 13.9.9 Microsoft Word Microsoft paint
	Some Charts	Microsoft Excel
Hardware	RAM	Installed memory (RAM) 4GB
	System Type	X64 based processor
	Hard Disk	300GB

In this research we used quantitative experimental method, which means we make a simulation using VEINS and based on the numeric result we got from the experiment we are going to check the performance of the designed solution and then reach to the final conclusion.

VEINS used in this research for simulation. It is an open source software package to held vehicles network simulation. It contains OMNET++ and SUMO together, the simulator instantiates an OMNET ++ node vehicle present in the simulation and then pairs node movements with movements of vehicles in the road traffic simulator which is SUMO. Veins can run on Windows, Linux and Mac OS [47].

Mobility simulator software is used in VANET mainly to generate the movement of vehicles pattern under a certain trace. They can help to show the road topology, car movement constraints speed limit, number of lanes, crossing rules and others SUMO is one of such mobility software that is available in VEINS and used in this research [47].

The OMNET++ package includes an Integrated Development Environment which contains a graphical editor using NED as its native file format; moreover, the editor can work with arbitrary, even hand-written NED code [45].

Allowing arbitrary programming constructs would make it practically infeasible to write two-way graphical editors which could work directly with both generated and hand-made NED files.

The OMNeT++ provides a rich object library for simple module implementers. There are several distinguishing factors between this library and other general-purpose or simulation libraries. The OMNeT++ class library provides reflection functionality which makes it possible to implement high-level debugging and tracing capability, as well as automatic animation on top of it (as exemplified by the Tkenv user interface, see later). Memory leaks, pointer aliasing and other memory allocation problems are common in C++ programs not written by specialists; OMNeT++ alleviates this problem by tracking object ownership and detecting bugs caused by aliased pointers and misuse of shared objects. The requirements for ease of use, modularity, open data interfaces and support of embedding also heavily influenced the design of the class library. The consistent use of object-oriented techniques makes the simulation kernel compact and slim. This makes it relatively easy to understand its internals, which is a useful property for both debugging and educational use [45].

3.3. Performance Evaluation

The proposed energy efficient congestion controlling algorithm can be compared with the existing ones by using different parameters such as: Beacon reception rate, Beacon error rate, and Channel busy ratio or Channel busy time.

Beacon reception rate- is a performance metric which measures the total number of packets received correctly by all vehicles in the network divided by the total number of all packets sent by all vehicles in the network over a predetermined period of time.

Beacon Error Rate- this is a performance value which measures the total number of lost packets from all vehicles divided by the total number of packets sent by all vehicles. This gives a clue as to how bad the congestion in the network is as more lost packets means more packet collisions, which indicates more overlap and congestion.

CBR/CBT- is the total amount of time each vehicle takes in sensing the channel as busy (another message is being transmitted). Once the channel is sensed to be idle, messages can be transmitted. This can be represented as a scalar value (with CBT represented as total seconds each node spent in a waiting state) or a ratio (divided the total CBT by the total simulation time).

CHAPTER FOUR

Design of the Proposed Congestion Controlling Algorithm

In order to provide acceptable awareness to surrounding vehicles, it is reasonable to manage vehicles communication based on their density and speed they use to travel in the standard range. Densely populated and slow speed vehicles are more likely to interact sooner than those sparsely dispersed, and therefore require updated information as they are closer together. In order to achieve this behaviour, we exploit the relationship between the transmit power of a packet and the data rate that can be received based on the density and speed of vehicles in 300m radius. A packet transmitted with a higher power can be received farther away than one sent with less power. With this algorithm we are able to maintain two separate transmit rates such that vehicles at close range see all packets at their full rate with less power to avoid collision of data and those farther away see only those packets sent at a higher transmission power to avoid data fading and others.

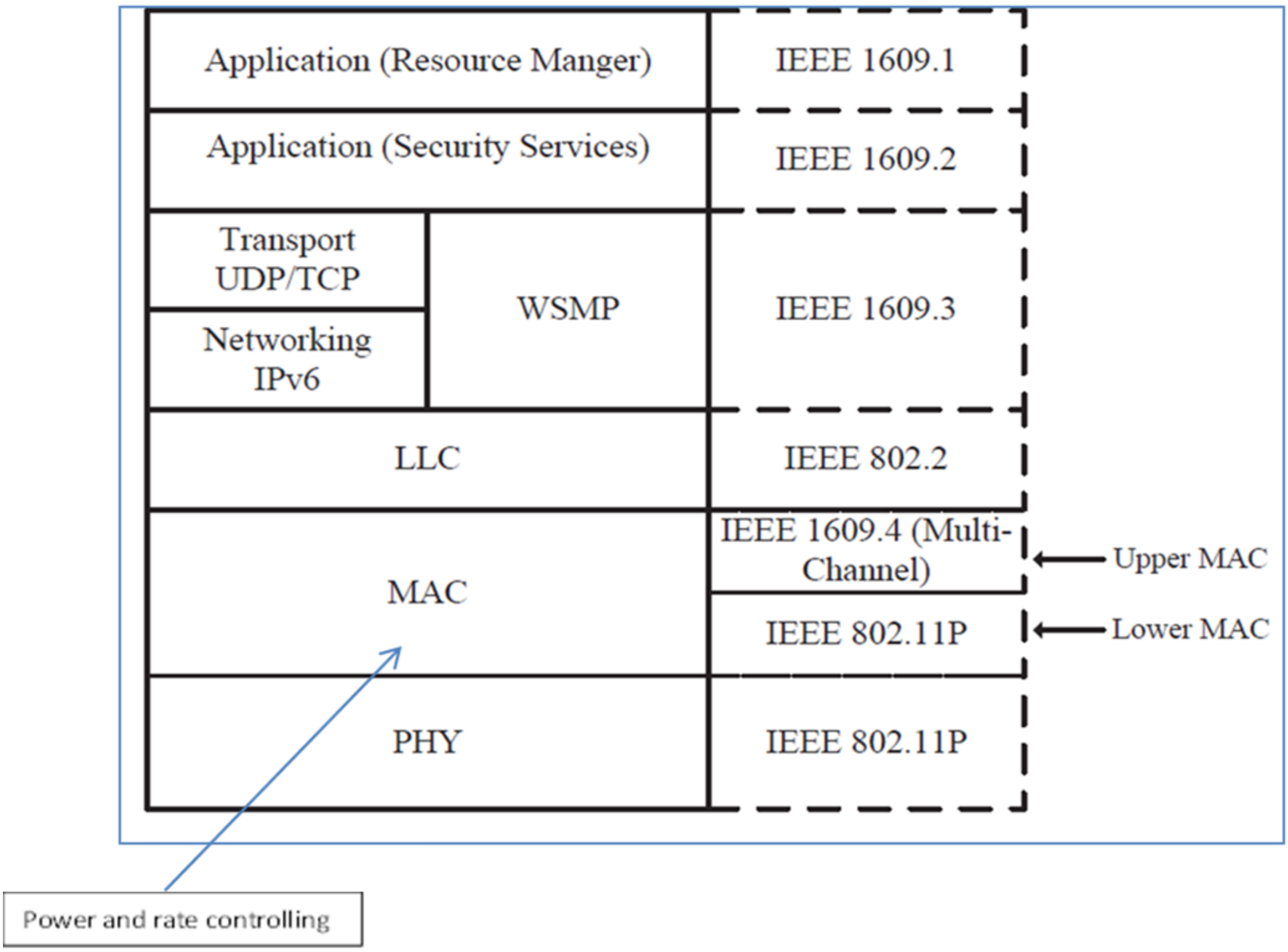

FIGURE 8 THE DESIRED CHANGE ON THE WAVE ARCHITECTURE STACK

The proposed solution involves alternating the power level of outgoing packets in different ways. Using a static ratio between high and low powered packets, we will attempt to send fewer rates of data to sparsely dispersed vehicles. The intended behavior is that the sparsely dispersed vehicles, which do not need updates frequently, will receive fewer data while maintaining high awareness levels in the immediate area where vehicles are highly populated or congested.

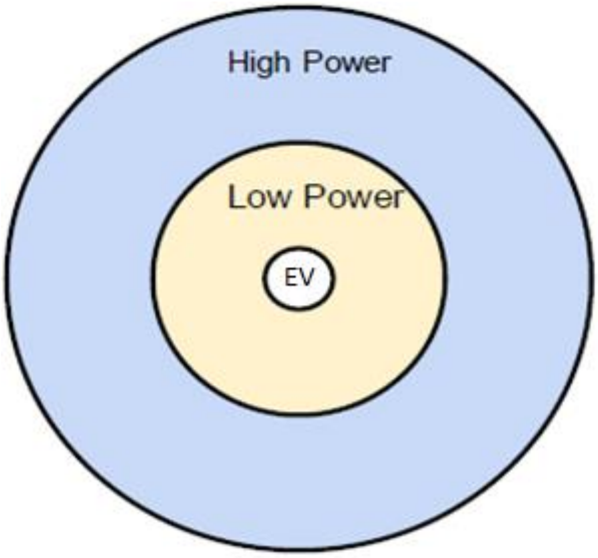

FIGURE 9 POWER ADJUSTMENT

1. Initially set maximum and minimum transmission power for vehicles
   Maximum power=tpMax
   Minimum power=tpMin
   a. set the distance approximation b/n vehicles(example 3 seconds of distance)d
   b. set the number of vehicles approximately you wish to reach,r based on the distance-approximation
2. For each BSM the ego vehicle (EV) sends,do:
   a. Let vehicleSpeed be EV`s current speed in m/s
   b. Calculate desired transmission range t.
      $\mathrm{t} = \mathrm{r} * ((\mathrm{d} * \mathrm{vehicleSpeed}) + 2)/1000$ (here we add 2 for the length of the vehicle and divide by 1000 to convert to kilometers)
   c. Calculate the transmission power newPower based on the desired transmission range t.
      (using the free-space path loss formula).
   d. If (newPower<tpMin)
      Set EV transmission power to tpMin
      Else if (newPower>tpMax)
      Set EVtransmission power to tpMax
      Else
      Set EV transmission power to new power

Power adjustment algorithm

Our algorithm starts in setting initial parameters:

Step1. Contain 4 parameters:

-Maximum transmission power

-Minimum transmission power

-Speed-density approximation

-Target range

The maximum transmission power, which represented by tpMAX is the upper limit of the transmission range.

The minimum transmission power, which represented by tpMIN is the lower limit of the transmission range.

Max and min are decided in order to check for the situations where cars could be travelling too fast and sparsely populated so using high transmission power, or too slow and highly populated or congested and have too small of a transmission power. The speed density approximation is approximate how many seconds of distance exist in between each vehicle during their driving time. Whereas the target range considers the number of vehicles ahead we hope for each transmission to reach with in density approximation of s.

In step 2 under (a) we look at the current speed of vehicle. Then the algorithm is running around all vehicles with in the network. Using EV`s speed we can calculate their target transmission range which is represented by t.

Under (b) we are going to calculate t as: t=r*((d*vehicleSpeed)+2)/1000

Because the speed is calculated in meters per second, we are dividing the result by 1000 to convert it and know the target range in kilometers. We add 2 amount of space in assuming length of cars themselves which is settled in the simulation parameters.

Under (c) The new transmission power needed for transmitting a message with in a target range t is calculated. Here we use an ideal scenario which only affected by pathloss transmission reception range.

Pathloss is a formula used in a transmission power measurement it is a transmission power(tx) minus receiver sensitivity (rx).In our simulation the receiver sensitivity is the default value which is -89dBm.

The free path loss formula to calculate the required transmission power is:

Since pathloss = tx – rx and our transmission frequency is 5890MHz according to DSRC standards, we can substitute these known values and isolate for tx:

$$(dBm) = 20log10(t) + 20log10(5890) - 56.56$$

Because the software API receives the transmission power update in milliwatts (mW) we have to convert our result to this unit using the following formula:

$$power\ (mW) = 10power(dBm)/10$$

Under (d) we determine whether the newly calculated power newPower is less than tpMin, greater than tpMax, or in between them and then set the transmission to tpMin, tpMax or newPower respectively. This finalizes the algorithm and is repeated every time the EV sends a new packet (as described in step (2)) which occurs 10 times per second.

The second thing is that remote vehicles (RV), vehicles that are sparsely dispersed and travelling with high speed are able to observe high distance messages at a low rate. This reduces the channel congestion. As the Vehicles get closer and densely populated or congested and travel with slow speed, they able to see all packets from the surrounding vehicles to restoring full awareness at a high rate. This is an acceptable loss of accuracy given that the vehicles further away are less important than closer ones [29].

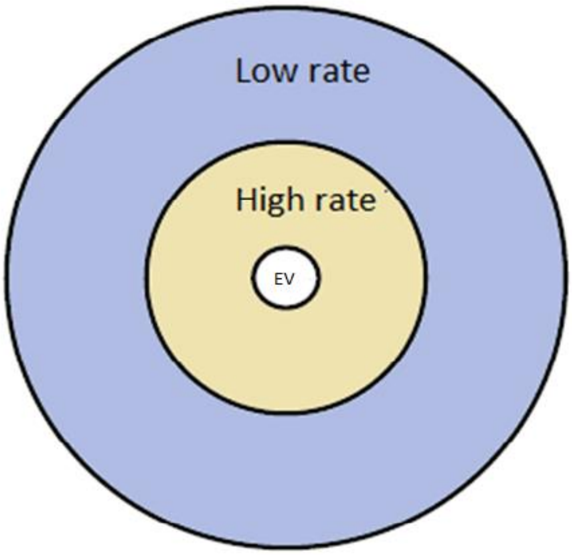

FIGURE 10 RATE ADJUSTMENT

Algorithm 2 Data Rate Control Algorithm

Input: bitrate values are to be listed (Br), index indicating which bitrate in Br is currently being used (level), high (cbrhigh) and low (cbrlow) CBR threshold values, and current CBR (cbr)

Output: Updated bitrate values and currentlevel

$if\ cbr < cbrlow\ then$

newlevel = level

bitrate = Br[currentlevel]

for i (0, level) do

if cbr * (Br[level]/Br [i]) < 0.95 * cbrhigh then

currentlevel = i

bitrate = Br [i]

break

end if

end for

end if

if cbr > cbrhigh then

newlevel = maxlevel

bitrate = Br[currentlevel]

for i (level + 1, maxlevel) do

if cbr * (Br[level]/Br [i]) < 0.95 * cbrhigh then

newlevel = i

bitrate = Br [i]

19:break

20:end if

21:end for

22:end if

23:if cbrlow = cbr = cbrhigh then

24:currentlevel = level

25:bitrate = B[level]

26:end if

The algorithm receives as input the lower and the upper threshold levels for the desired range of cbr values .The main aim of this algorithm is to control the measured CBR with in the specified range.

Another thing is the algorithm also receives as input list of bitrates allowed in Mbps as well as the bit rate used by the vehicle in the previous basic safety message transmission. Based on the DSRC standard the known bitrates are 3Mbps, 6Mbps, 9Mbps, 12Mbps, 24Mbps and 27Mbps.Here we use Br=[3,6,9,12,18,24,27].These bitrate is specified using the parameter level ,which is used as an index for the list of Br, to determine bitrate being used. Example, if level=2 then the corresponding bitrate is Br[2]=9.The maximum level corresponds to the highest possible index value for the list Br and is given by maxlevel=len(Br)-1.

Steps 2 to 11 are executed when the current CBR (cbr) goes below the low CBR threshold (cbrlow). Step 1 checks if the current CBR (cbr) is below the threshold (cbrlow). If the condition is satisfied, then steps 2-11 are used to determine if a lower bitrate can be used. Steps 2 and 3 are used to assign the previous BSM bitrate as the new value. This will be used only if a lower bitrate cannot be found. Steps 4-10 are used to iterate through each potential bitrate value from bitrate from Br[0] to Br[level] to see if it can be used, i.e. the condition in step 5 is satisfied. Step 5 checks whether the expected CBR, when using the new bitrate B[i] falls below 95% of the high CBR threshold (highcbr).

If so, the corresponding value of i is used to determine the bitrate to use (step 7), the loop is terminated (step 8) and these updated values of newlevel and bitrate (steps 6 and 7) are returned. This means that the lowest possible bitrate that satisfies the condition in step 5 is selected as the new bitrate.

Steps 13 to 22 are executed when the current CBR (cbr) is higher than the threshold (cbrhigh). This means that the channel is getting congested and a higher bitrate must be used. Step 12 checks if the current CBR (cbr) is below the threshold (cbrhigh). If the condition is satisfied, then steps 13-22 are used to determine if a suitable higher bitrate for BSM transmission.

Steps 13 and 14 are used to assign the highest possible bitrate as the new value. This will be used only if even the highest bit rate does not satisfy the condition in step 16. Steps 15-21 are used to iterate through each potential bitrate value from bitrate from next higher bitrate B [level + 1] to the highest bitrate Br[maxlevel] to see if it can be used, i.e. the condition in step 16 is satisfied. Step 16 is similar to step 5 and checks whether the expected CBR, when using the new bitrate Br [i] falls below 95% of the high CBR threshold (highcbr). If so, the corresponding value of i is used to determine the bitrate to use (step 18), the loop is terminated (step 19) and these updated values of newlevel and bitrate (steps17 and 18) are returned. This means that the lowest possible bitrate that satisfies the condition in step 16 is selected as the new bitrate.

Steps 24 to 26 are executed when the CBR (cbr) falls between high (cbrhigh) and low CBR (cbrlow) thresholds, i.e. the condition in step 23 is satisfied. This means that the CBR is within the proper range and no bitrate variation is required since the channel load is already balanced. So, the level which is already in use will be assigned as the newlevel by step 24. Step 25 assigns the newlevel as the next bitrate for the packet transmission.

As we have seen data rate control algorithm checks for channel busy ratio and decide the amount of bit rate level to be transferred lonely. But when we combine the two algorithms together the data rate control not need to be measure a channel busy ratio it can depend on a power controlling algorithm since the power controlling algorithm measure all tasks data rate can be adjusted based on the transmission power of data. So this is the advantage of our algorithm than others combining the two mechanisms together.

1. Set maximum and minimum transmission power for vehicles as well as data rate level [3,6,9,12,18,24,27].

Maximum power=tpMax

Minimum power=tpMin

Minimum rate=minlevel

Maximum rate=maxlevel

a.set the distance approximation b/n vehicles(example 3 seconds of distance)d

b.set the number of vehicles approximately you wish to reach,r based on the distance-approximation

2.For each BSM the ego vehicle (EV) sends,do:

a.Let vehicleSpeed be EV`s current speed in m/s

b.Calculate desired transmission range t.

$\mathrm{t} = \mathrm{r} * ((\mathrm{d} * \mathrm{vehicleSpeed}) + 2)/1000$ (here we add 2 for the length of the vehicle and divide by 1000 to convert to kilometers)

c.Calculate the transmission power newPower based on the desired transmission range t.

(using the free-space path loss formula).

d.If (newPower<tpMin)

Set EV transmission power to tpMin and data transmission rate to maxlevel

Else if (newPower>tpMax)

Set EVtransmission power to tpMax and data transmission rate to minlevel

Else

Set EV transmission power to newPower and data transmission rate to newlevel b/n min and max level

The proposed algorithm

```
Initalize
Set
tpMax tpMax is maximum transmission power
tpMin  tpMin is minimum transmission power
ntp = tpMin < ntp < tpMax ntp is new transmission power
Set
Br = [3,6,9,12,18,24,27] Br is bit rate
uL = len(Br) − 1 uL is upper level
lL = Br[0]  lL is low level
nL = Br[0] < nl < len(Br) − 1 nL is new level
Set
d = dbv   d is distance between vehicles
r = nv      r is number of vehicles
s = sv    s is speed of vehicles
t = r ∗ ((d ∗ s + 2)/1000 t is  transmission range
tx(dbm) = 20log10(t) + 20log10(5890) − 56.56  tx is transmission power
tx = Br
If (tx ≤ tpMin)
Br = uL
elseif ( tx ≥ tpMax)
Br = lL
else
Br = nL
endif
end
```

Pseudo code of the proposed algorithm

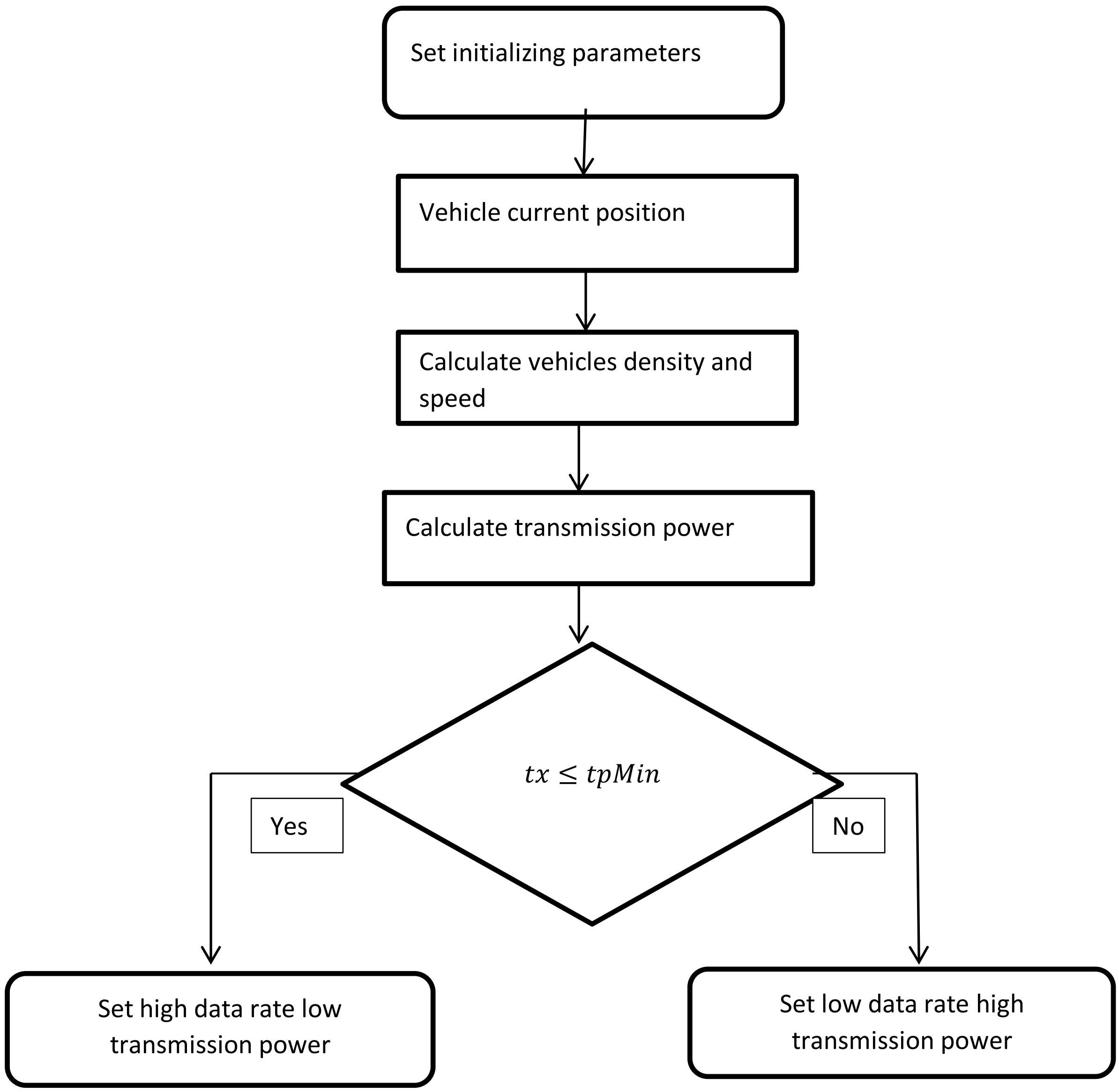

FIGURE 11 FLOWCHART OF THE PROPOSED ALGORITHM

CHAPTER FIVE

Results and Discussions

5.1. Simulation

It is difficult to execute experiments to test the effectiveness of congestion controlling mechanisms in a real-world scenario due to the expense, equipment and resources needed and safety concerns. Therefore, we use simulation software to execute such experiments on a digital scale. This is a much cheaper and safer method of testing the algorithms and analyzing the results. For our experiments, we used the three known software together. They consist of a network simulator, a traffic simulator, and communication software for interaction between the two. The traffic simulator used was Simulation of Urban Mobility SUMO. SUMO is a free and open source microscopic simulation software implemented in C++ which uses portable API libraries and can be used to simulate vehicles, pedestrians, public transport, etc.

The network simulator used was OMNET++ which is a modular component-based C++ simulation library and framework. Tying these two software packages together is VEINS which is a framework that includes models for making traffic simulations realistic and providing communication between SUMO and OMNET++ by means of the Traffic Control Interface. Veins provide commination between SUMO and OMNET++ by means of a TCP socket connection.

5.1.1. Simulation Setup

There were two traffic scenarios used to test the performance of the proposed algorithm.

• A six-lane highway composed of three lanes in either direction, with a speed limit of 80km/hr. This simulation was run for 15 seconds.

• A twelve-lane highway composed of six lanes in either direction, with a speed limit of 50km/hr. This simulation was run for 15seconds.

The road in each scenario consisted of a 300m long horizontal stretch of road. Traffic was split evenly between east-bound traffic and west-bound traffic. The following parameters were used to test the designed mechanism of congestion controlling:

TABLE 3 PARAMETERS OF THE SIMULATION

Parameter	6-lane highway high speed	12-lane highway slow speed
Simulation duration	15 seconds	15 seconds
Bitrate	9Mbps	27Mbps
Transmission power	6mW	2mW
Transmission rate	10HZ(10 packets per second)	10HZ(10 packets per second)
Receiver sensitivity	-89dBm	-89dBm
Road length	300m	300m
Lanes	6(3 in each direction)	12(6 in each direction)
Vehicle speed	80km/hr	50km/hr
Total number of generated vehicles	49	105

Each traffic scenario was run by omitting and using power and rate adjustment as needed:

• No CC, not using any congestion controlling mechanism.

• The Oscillating transmission power algorithm labelled as "OSC" in result graphs (based on transmission power mainly).

•Limeric (based on rate controlling to avoid congestion).

• Our congestion controlling mechanism which is labelled as "NDCC".

Throughout all runs of each simulation, vehicles only transmitted BSMs as messages consistently and continuously throughout the duration of the simulation. Each BSM contained important information such as:

• Sender ID

• Sender Speed

• Sender Position

The information contained in each BSM such as position, was used to calculate results (such as distance from sender).

Each vehicle drove in a straight line from the beginning to the end of the road (respective of where they started). Vehicles were consistently generated every 0.1 seconds in any lane with space availability.

5.2. Simulation Results

Each simulation gathered result data for the analysis and examination of the performance of each algorithm. Such data included total packets sent, total packets received, total packets lost, CBT. The details of each result are discussed below.

5.2.1. Packets Sent

Figures 12 and 13 shows, the total number of packets sent by all vehicles, in the 6-lane and 12-lane. We notice that the fewest packets were sent in the 6-lane simulation, and the most packets were sent in the 12-lane simulation.

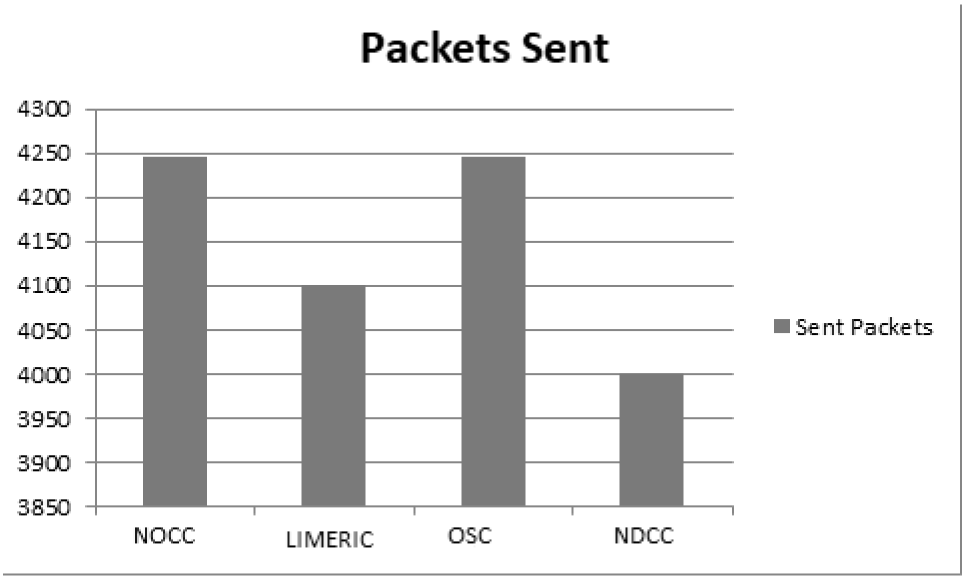

FIGURE 12 PACKETS SENT IN 6-LANE HIGHWAY SIMULATION

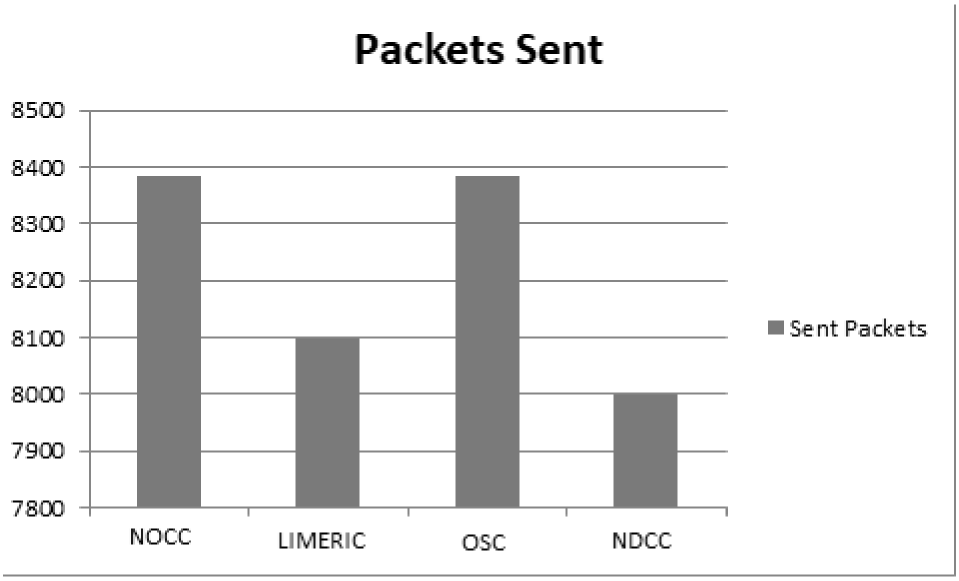

FIGURE 13 PACKETS SENT IN 12-LANE HIGHWAY SIMULATION

5.2.2. Packets Received

The amount of received packets gives a general idea of how much awareness is in the algorithm. This is the sum of all packets received by all vehicles for the duration of the simulation. We can see that using not using any congestion controlling result in the highest amount of received packets, while the congestion controlling algorithms all performed relatively similar in this area. However, this does not mean that not using congestion controlling mechanism is better than using congestion controlling mechanisms. Receiving more packets does not necessarily translate to better performance of safety applications. It simply means that each beacon was transmitted further, and therefore received by more distant vehicles than the congestion controlling vehicles, which were limiting the transmission range based on various factors. In figures 14 and 15, we can see that all DCC algorithms received fewer packets than the general approach, due to limiting the transmission power and controlling transmission rate of messages. The DCC algorithms performed relatively similarly.

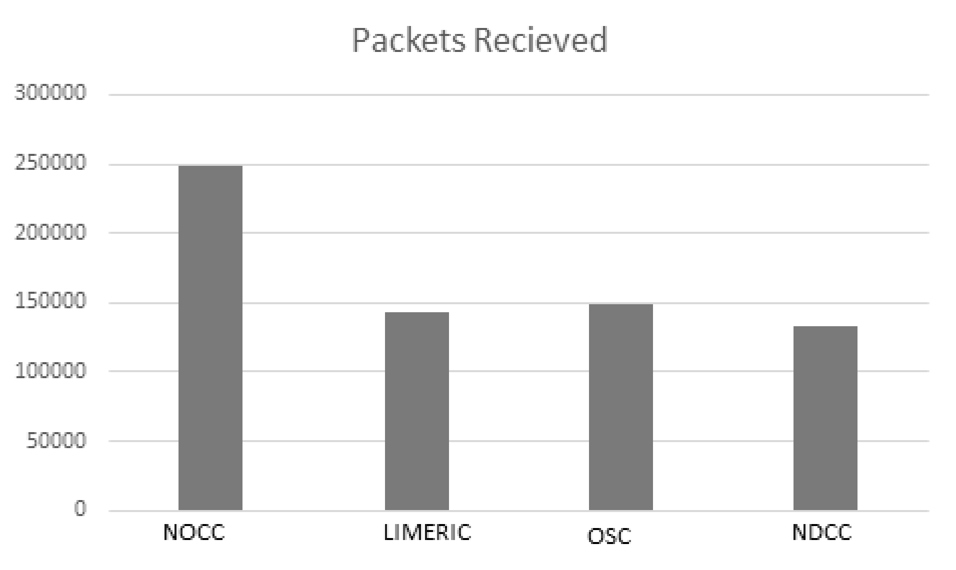

FIGURE 14 PACKETS RECEIVED IN 6-LANE HIGHWAY SIMULATION

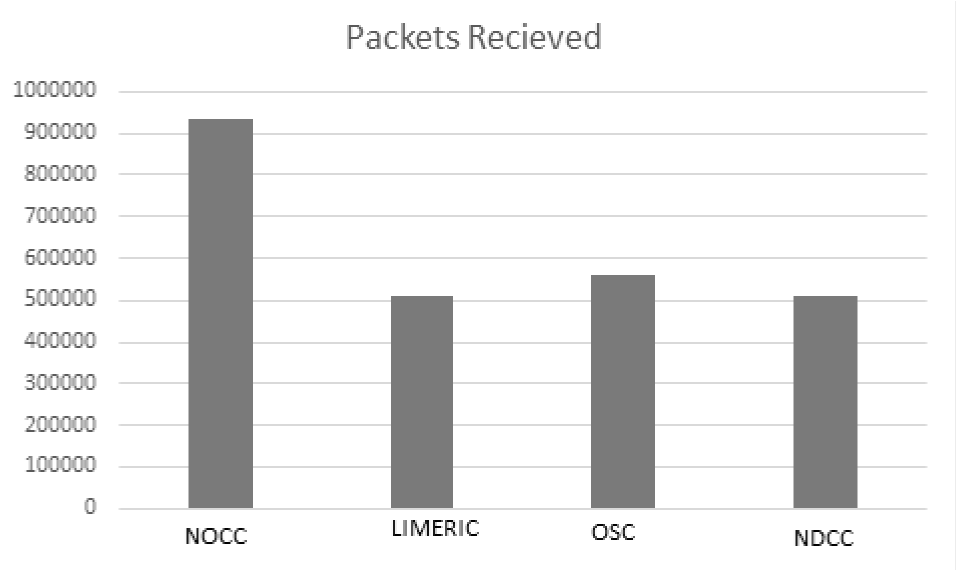

FIGURE15 PACKETS RECEIVED IN 12-LANE HIGHWAY SIMULATION

5.2.3. Packets Lost

Measuring packet loss gives us a general idea of how congested the network is. As mentioned earlier, packet loss occurs with packet collisions, which happens more often in a congested network than a non-congested network. A high amount of packet loss can affect performance of safety applications. Observing figure 16, we see that using no DCC results in the highest amount of packet loss, while DCC algorithms can reduce the amount of packet loss significantly. We observe that the lowest amount of packet loss occurs in OSC, followed by LIMERIC. However, in figure 17 we can see that the proposed algorithm begins to perform better, as the stress of the network increases. The 95% confidence values show a sizable difference between, no DCC approach and the rest of the DCC algorithms, meaning no DCC suffer from more volatile individual values among the vehicles.

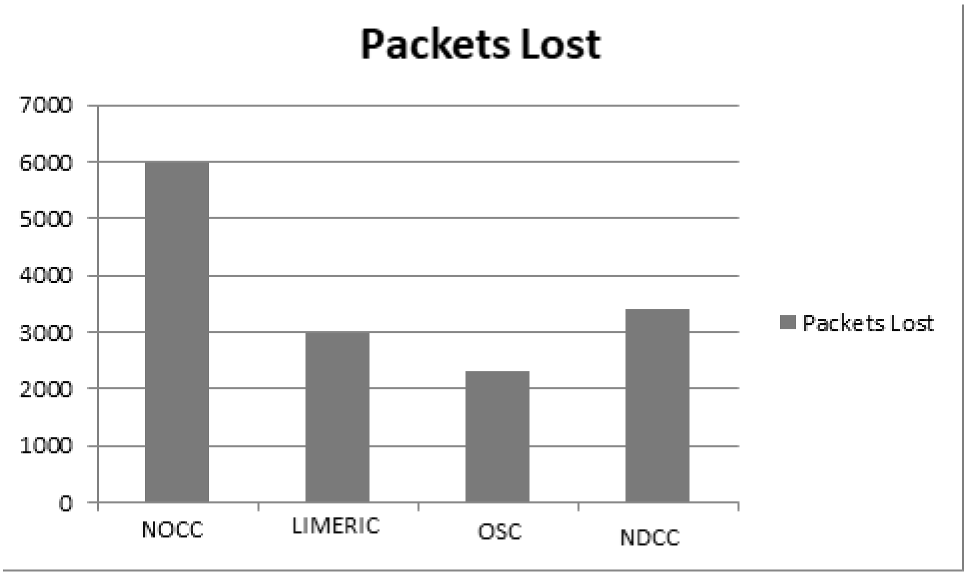

FIGURE 16 PACKETS LOST IN 6-LANE HIGHWAY SIMULATION

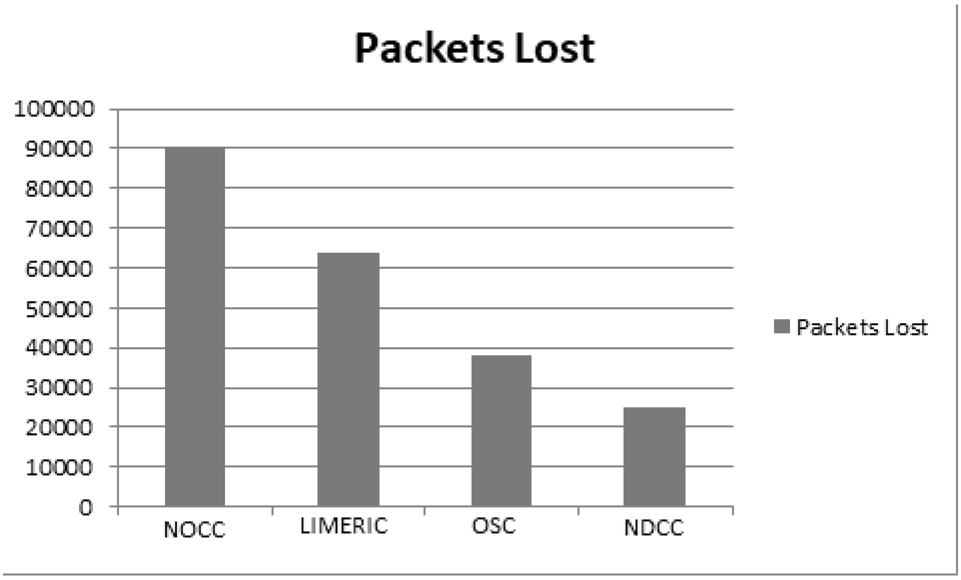

FIGURE 17 PACKETS LOST IN 12-LANE HIGHWAY SIMULATION

5.2.4 Beacon Reception Rate

BRR is the ratio of packets received to packets sent in the network. Without question, a high amount of received packets in the network directly translates to a high BRR. As we can see in figures 18 and 19, using no DCC has the highest BRR. As mentioned earlier, this does not necessarily translate to a higher performing safety application, since it usually also means a higher BER as well, as we will see in the next section. BRR is a secondary performance measure we look at after all other things are considered. Among DCC approaches, there is a smaller BRR, the two DCC algorithms have similar performance, and the proposed algorithm has better performance it is with less BRR.

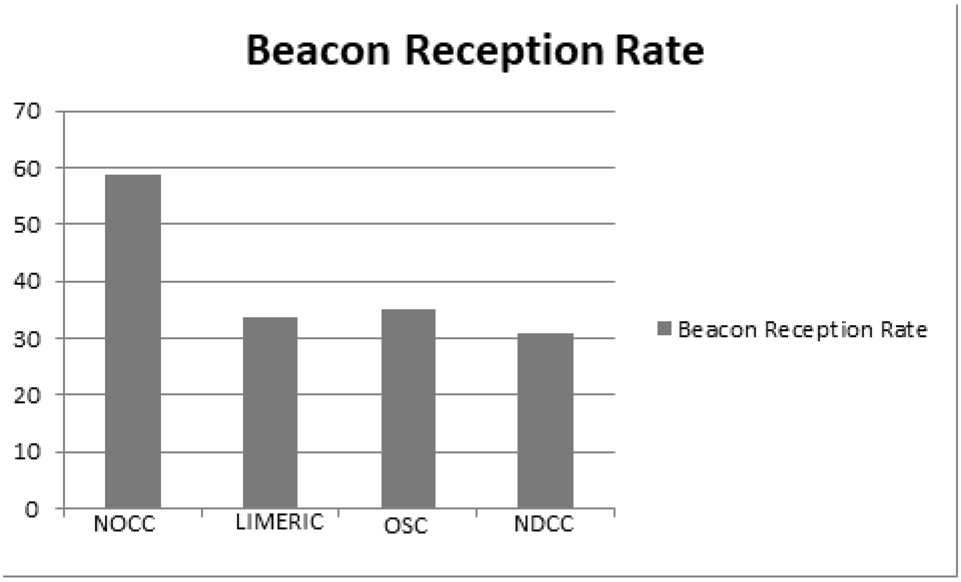

FIGURE 18 BEACON RECEPTION RATE IN 6-LANE HIGHWAY SIMULATION

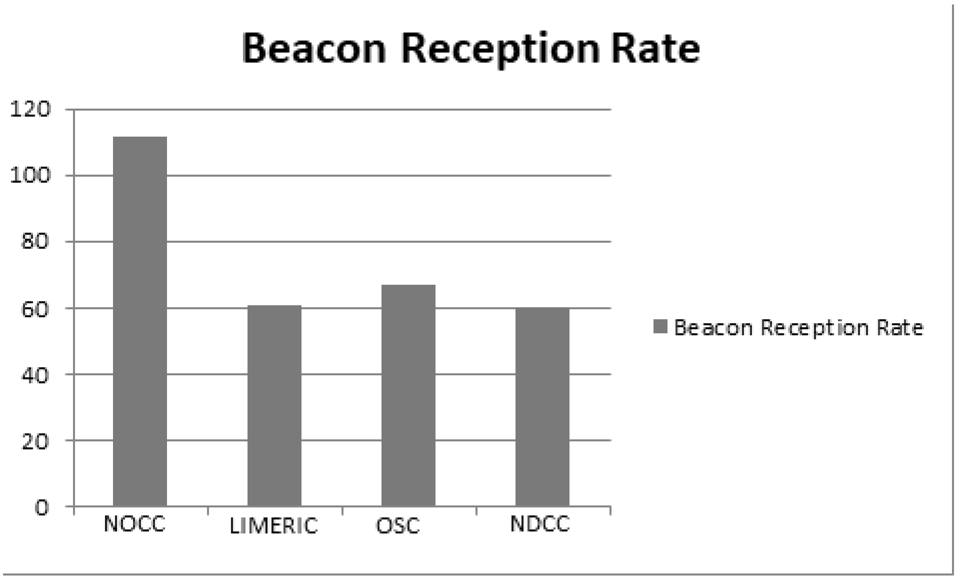

FIGURE 19 BEACON RECEPTION RATE IN 12-LANE HIGHWAY SIMULATION

5.2.5 Beacon Error Rate

The BER is the ratio of lost packets to received packets. In figure 20, we see that there is not a significant difference between no DCC, and the DCC approaches. However, when considering figure 21 we can see that an increased load in the network exposes the packet loss rate in the no DCC and the LIMERIC. With a high BER, we cannot reliably say that important BSMs will be received at the appropriate times (such as when a vehicle collision is imminent) and therefore translates to less reliable performance in safety applications.

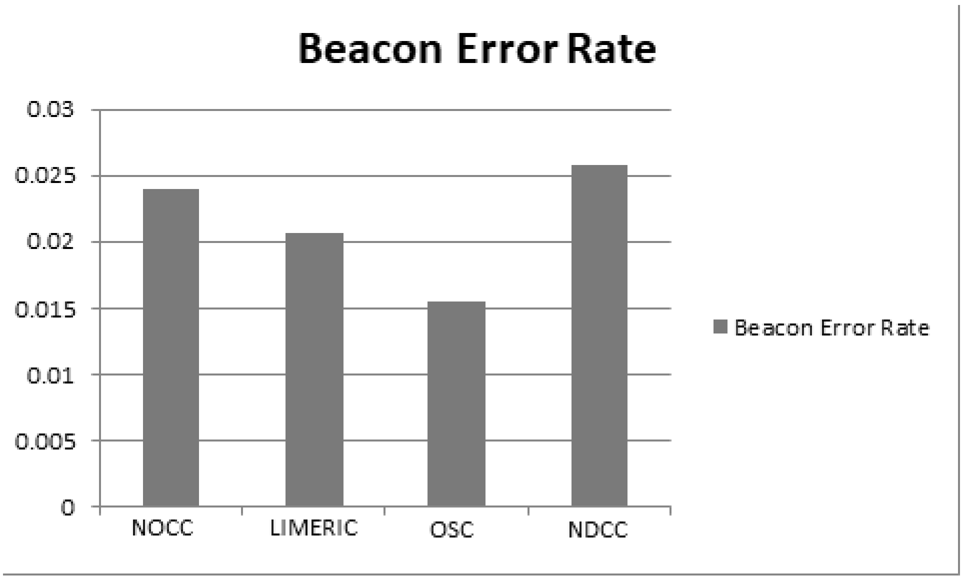

FIGURE 20 BEACON ERROR RATE IN 6-LANE HIGHWAY SIMULATION

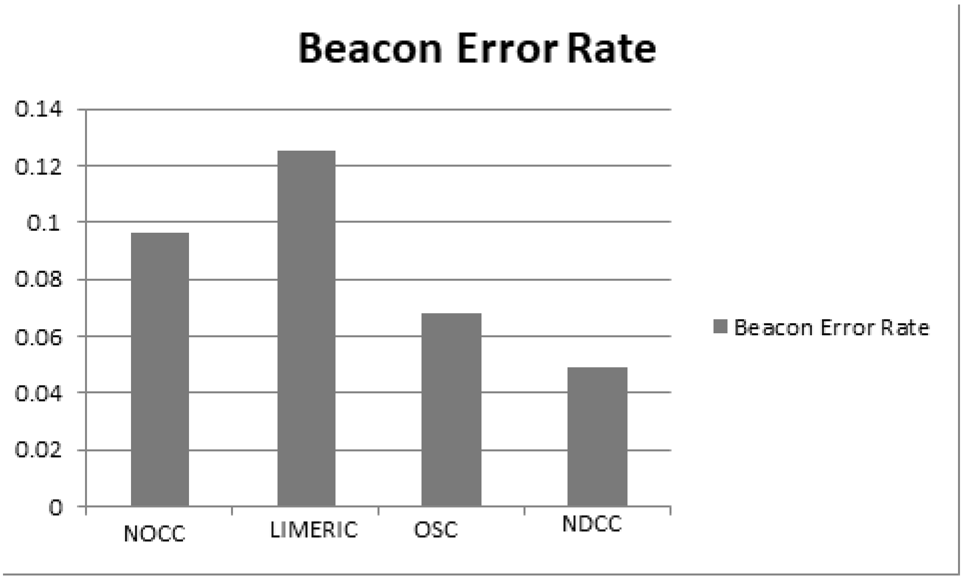

FIGURE 21 BEACON ERROR RATE IN 12-LANE HIGHWAY SIMULATION

5.2.6 Channel Busy Time

CBT is another way to approximate the amount of congestion in a network. Before transmitting a message, the transmitting vehicle must first listen and check if the channel is clear. If there aren't currently any messages propagating through the network (that the transmitter is capable of hearing) then it proceeds with its broadcast. However, if nearby broadcasts are heard, the transmitter must wait an amount of time before testing the channel again, and assure the channel is clear for transmitting. The total amount of time spent waiting in this manner is the CBT, which can be different for each vehicle. To measure this value, we take the average total amount of CBT of each vehicle in the simulation. A high average translates to more congestion in the network, and vice versa. In figures 22 and 23 we can see that the general approach of using no DCC results in much higher CBT than when using DCC. As the network load increases, we can see this effect increase. All DCC algorithms perform similarly in this area, with the algorithm having a slightly higher CBT than the rest. The error bars representing the 95% confidence intervals show us that the variability between individual data is similar among all algorithms; there is high CBT with no DCC.

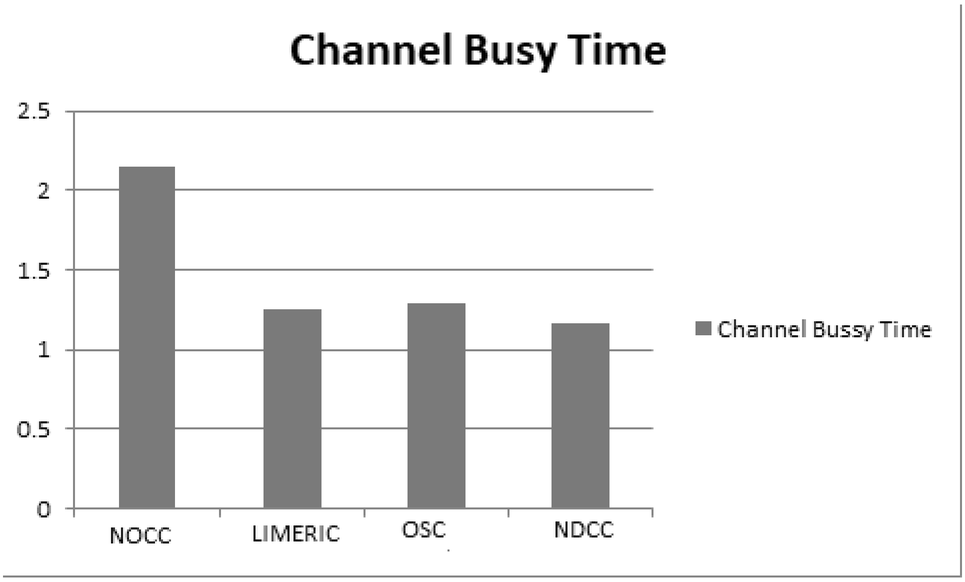

FIGURE 22 CHANNEL BUSY TIME IN 6-LANE HIGHWAY SIMULATION

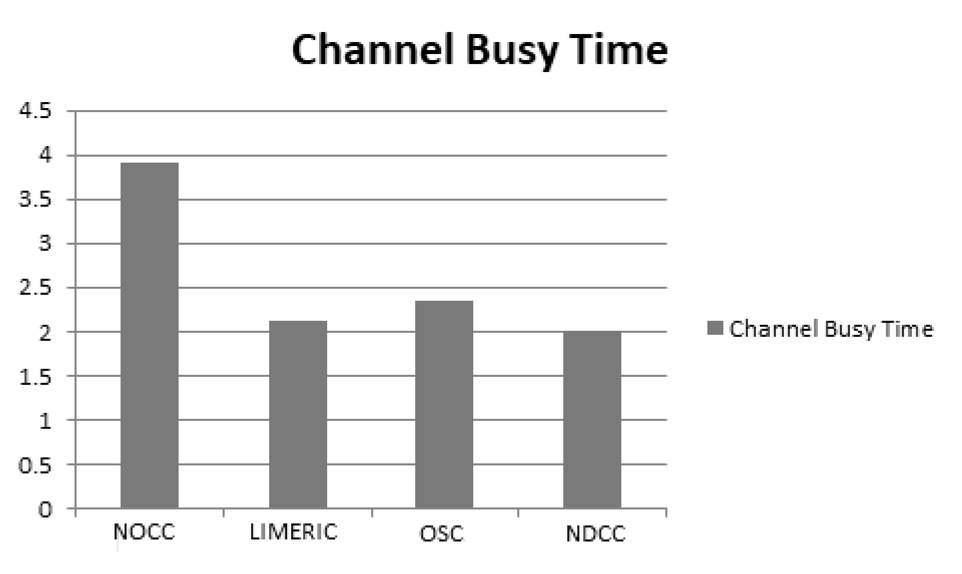

FIGURE 23 CHANNEL BUSY TIME IN 12-LANE HIGHWAY SIMULATION

CHAPTER SIX

Conclusions and Future work

6.1. Conclusions

Sending and receiving high number of messages means, the occurrence of congestion is very high, our proposed algorithm does the opposite of this; it can manage the data to send and received and amount of power to be used based on the density of vehicles available on the road.

In no DCC, there is much loss of packets since unwanted messages go far and near distance messages can be bumped together because of high power that can be used to send a message; when number of vehicles are sparsely populated, other DCC algorithms perform better than the proposed algorithm but as the number of vehicles increase on the road or congestion occurred, the proposed algorithm is better and can reduce lost packets.

Where vehicles are sparsely dispersed beacon error rate is high in the proposed system, since rate and power are controlled without enough reason. As the number of vehicles increase on the road and congestion of vehicles occurred the proposed system highly reduce beacon error rate and it is preferable than the others contrasted DCC algorithms with it. When vehicles are sparsely dispersed and highly populated or congested, channel busy time is reduced in a well manner in the proposed DCC algorithm than others.

In all performance metrics our proposed algorithm is best, it can manage congestion when vehicles are highly populated on the road and it is very useful for the intended reason it is proposed for.

6.2. Future work

Future work can be focus on a real field than based only on a simulation software if cost is affordable, in order to get more actual data to solve the congestion problem in VANET.

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APPENDIX-A : NED file

```
simpleveh
{
parameters:
@display("i=block/routing");
gates:
inout gate[];
}

network Vehicles
{
types:
channelChannelextendsned.DatarateChannel {
delay=100ms;
doubletxPower@unit(mW);
        }

submodules:
veh[149]: veh;
connections:
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[1].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[2].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[3].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[4].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[5].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[6].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[7].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[8].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[9].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[10].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[11].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[1].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[2].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[3].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[4].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[5].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[6].gate++;
```

```
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[7].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[8].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[9].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[10].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[11].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[1].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[2].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[3].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[4].gate++;
veh[0].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[5].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[6].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[7].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[8].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[9].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[10].gate++;
veh[5].gate++ <--> Channel{datarate = 27Mbps;txPower=2mW;}<-->veh[11].gate++;
}
```

Appendix - B: Sample of the simulation


```
object="simulation"
label="Vehicles"
simtime="14.9"
network="Vehicles"
>
<object class="cSimulation" fullpath="simulation">
<info></info>
<object class="cModule" fullpath="Vehicles">
<info>id=1</info>
<object class="veh" fullpath="Vehicles.veh[0]">
<info>id=2</info>
<object class="cGate" fullpath="Vehicles.veh[0].gate$i[0]">
<info>&lt;-- veh[1].gate$o[0], (Vehicles.Channel)channel disabled=false
delay=0.1 datarate=2.7e+007 ber=0 per=0 </info>
</object>

<object class="cGate" fullpath="Vehicles.veh[0].gate$i[1]">
<info>&lt;-- veh[2].gate$o[0], (Vehicles.Channel)channel disabled=false
delay=0.1 datarate=2.7e+007 ber=0 per=0 </info>
</object>

<object class="cGate" fullpath="Vehicles.veh[0].gate$i[2]">
<info>&lt;-- veh[3].gate$o[0], (Vehicles.Channel)channel disabled=false
delay=0.1 datarate=2.7e+007 ber=0 per=0 </info>
</object>

<object class="cGate" fullpath="Vehicles.veh[0].gate$i[3]">
<info>&lt;-- veh[4].gate$o[0], (Vehicles.Channel)channel disabled=false
delay=0.1 datarate=2.7e+007 ber=0 per=0 </info>
</object>

<object class="cGate" fullpath="Vehicles.veh[0].gate$i[4]">
<info>&lt;-- veh[5].gate$o[0], (Vehicles.Channel)channel disabled=false
delay=0.1 datarate=2.7e+007 ber=0 per=0 </info>
</object>

<object class="cGate" fullpath="Vehicles.veh[0].gate$i[5]">
```

```
<info>&lt;-- veh[6].gate$o[0], (Vehicles.Channel)channel disabled=false
delay=0.1 datarate=2.7e+007 ber=0 per=0 </info>
</object>

<object class="cGate" fullpath="Vehicles.veh[0].gate$o[0]">
<info>--&gt; veh[1].gate$i[0], (Vehicles.Channel)channel disabled=false
delay=0.1 datarate=2.7e+007 ber=0 per=0 </info>
<object class="cDatarateChannel" fullpath="Vehicles.veh[0].gate$o[0].channel">
<info>disabled=false delay=0.1 datarate=2.7e+007 ber=0 per=0 </info>
</object>

</object>

<object class="cGate" fullpath="Vehicles.veh[0].gate$o[1]">
```