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A NOVEL CONGESTION CONTROL ALGORITHM FOR VANETs

A DISSERTATION SUBMITTED BY

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1. **Nahar, K., Sharma, S., Chahal, M. and Harit, S., 2019. A Review on Congestion Control in Vehicular Ad Hoc Network at MAC Layer.** ***Available at SSRN 3356206*** **(Published).**

2. **Nahar, K., Sharma, S., Chahal, M. and Harit, S., Congestion Control in VANET at MAC Layer: A Review submitted at Recent Patents on Engineering, Bentham Science Special Issue On: Implementation of Vehicular Cloud Networks Using Wireless Sensor. Reference#: BMS-ENG-2019-HT4-408-7 (Accepted).**

Abstract

Vehicle ad-hoc network has been designed to improve traffic safety application by enabling vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) or vehicle-to-everything (V2X) communication. In VANET, each and every vehicle exchanges the information among them, therefore, a high density of vehicles leads to the problem of congestion. It results in end-to-end delay and packet loss during communication. Towards the solution of these critical challenges, decentralized congestion control (DCC) mechanism has been designed by the European Telecommunication Standard Institute (ETSI).

Medium Access Control (MAC) protocols have been designed to improve the real-time communication between vehicles and roadside components with minimal transmission collision.
DCC is a cross-layer function located at each layer of ETSI Intelligent Transport System (ITS) protocols. DCC algorithms are intended to adapt parameters such as message-rate, data-rate, etc to enhance the congestion. Our objective is to design, an improved and reliable schemes which reduce the congestion between V2V and V2I environments.

We compare decentralized congestion control (DCC) with over proposed algorithm as representative of the three transmission principles, we analysed the Packet delivery ratio (PDR), delay, and throughput in numbers of vehicles. We observed that the proposed algorithm has higher performance in terms of DCC when the number of vehicles increased. In general, the results showed decreasing in, when the number of vehicles is increased. The delay is high when the density becomes lower.

Chapter 1
Introduction

According to the World Health Organization (WHO), a period of ten years of road traffic accidents (injuries) is seen as one of the major public health/safety issues. The road accidents will rise to become the 5th leading/prime/major cause of death in 2030 by the prediction of the WHO. To control this issue, the WHO motivates governments and countries to sincerely increase road safety.

In 2009, through traffic accidents, 35,0000 people died and over 1.7 million were injured in the European Union (EU). Therefore, a novel EU road safety guidelines aim to control European road deaths by 50% by 2020.

To enhance the traffic/road safety and capability through combining communication technologies into transport infrastructure and vehicles to create a detailed real-time transport management system in a wide area. Vehicular Ad-hoc Network (VANET), when both types of communication co-exist (such as vehicle t-to-vehicle and vehicle-to-infrastructure) are key/major components in ITS framework to maintain/control road safety and efficiency.

1.1 Problem Statement

To improve the safety and the efficiency of transportation, On-board unit V2V communication system aims for vehicles to exchange their basic information with the next vehicle or neighbour vehicles. Due to the high density of vehicle the communication channel gets crowded/busier in the network, which may cause of the congestion in the channel. It's results higher probability of packet loss, packet collision and quality of services degradation, etc.

To mitigate the problem various congestion control schemes have been designed by tuning the transmission behaviour according to the channel load. Usually, congestion control schemes can be centralized or decentralized. A centralized congestion control scheme, in this a central unit will determine the operational parameters of all the vehicles in a particular area. A big disadvantage of the centralized congestion control scheme is, it requires the large computation on the central unit which makes it unfeasible to be implemented in a real-time traffic network.

A decentralized congestion control schemes, each vehicle independently performs congestion control algorithm in the network. To control the high mobility and unpredictability of each particular vehicle, decentralized approaches are proposed for congestion control. Thus, we only discuss the decentralized congestion control in this thesis.

A typical representation of message-rate DCC algorithm is named as Linear Message Rate Integrated Control (LIMERIC), proposed by authors **(ETSI, I. (2015)**. When the communication channel gets situate, each vehicle increases its data-rate in the network so that packets are transmitted in shorter air time. Furthermore, control the channel utilization under the threshold. DCCs may also reduce the reliability of safety applications. Safety applications have different communication requirement in terms of the communication range and the message-rate.

The periodic message packets require 1Hz to 10 Hz message rate range which event-driven packet usually requires a higher message-rate. Simultaneously, most safety application has a required range for communication between 50 meters and 300 meters. The curve speed warning application requires a message-rate of only 1 Hz and the maximum communication range of 200 meters.

1.2 Thesis Structure

The rest of this thesis is structured as follows: In Chapter 2, we present the background of the VANET. A detailed description of the DCC algorithm is explained in Chapter 3. We discuss the proposed algorithm, simulation tools and setup in chapter 4. The simulation results and analysis are discussed in Chapter 5. In Chapter 6, we conclude our study and give suggestions on further research topics.

Chapter 2
Background

2.1 Intelligent Transportation System

Road safety is a global issue increase in death ratio. According to the World Health Organization (WHO), in 2013 nearly 1.5 million people died due to road accidents. In 2015, according to the National Safety Council in US 38,300 people were killed as well as 4.4 million people were suffered from injured because of traffic accidents.

Now a day's Intelligent Transport System (ITS), has grown rapidly as the purpose of improving traffic efficiency and management. ITS provides Vehicular Ad-hoc Network (VANET), in order to define routers, transport, reliable transmission efficient channel access mechanism. VANET provides two types of communication that are vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) as shown in Fig.2.1, are major components in ITS framework. Infrastructure is cost-effective; therefore V2V communication is more efficient than V2I. VANET has three types of applications namely safety, infotainment and traffic management. Safety application is very crucial as it saves a life. For VANET, Dedicated Short-Range Communication (DSRC) has been developed in the 1990s.

DSRC is a wireless communication channel, it could be established the communication connection by one-way or two-way. It directly communicates with vehicles automatically from short-range to medium-range. DSRC band operates the IEEE802.11 devices for V2X communication. DSRC spectrum using 5.9GHz bandwidth for reliable communication however partitioned into seven of 10MHz wide channels. Here only one control channels (CCH) i.e. 178 channel (5.885-5.895 GHz), it is mainly used for the safety communications. For the future safety application purpose, two channels are reserved in WAVE. The idle channels are known as a service channel (SCH), which is worked for both safety and non-safety applications. At the PHY level, the IEEE802.11p design to make a fair communication connection with WAVE devices among the fast-moving vehicle in the environment.

To permit the communication in VANET, IEEE 802.11p is released that combines physical (PHY) and MAC layer specification. IEEE 802.11p PHY layer is a modified class of the 802.11a specification. It adopts orthogonal frequency-division multiplexing (OFDM) with 10 MHz channel and uses data rates varying from 3Mbps- 27Mbps. MAC layer uses the enhanced distributed channel access (EDCA) which is based on the carrier sense multiple access with collision avoidance (CSMA/CA) protocol and prioritization. For reliable communication define the protocol stack with the IEEE 1609 WAVE family.

For the multi-channel environment, the MAC layer is correctly modified. These EDCA functions help to handle the queues for packets dissemination to the vehicular environment. WAVE support the IPv6 protocol stack as well as handle the WAVE-mode short message protocol (WSMP), carry the high-priority message for the sensitive safety. WAVE is further discussed in section 2.2.4.

VANET applications can be divided into three sub-categories that are safety application, non-safety application, and Traffic management. Safety applications are lane change warning, post-crash warning, navigation, Low Bridge warning, etc. Non-safety applications are weather information, internet access, toll tax, and, etc. Traffic management applications are Collision avoidance, Blind spot warning and Traffic optimized, etc. Safety application can help to reduce the number of accidents. 60% of accidents can be avoided if a driver receives a warning message, at least one-half second before the accident. Safety messages include the two types for communication beacon message and event-driven message. Beacon message used for the status of

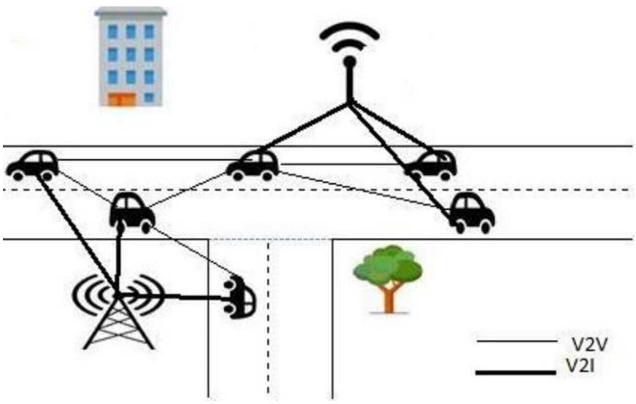

Fig. 2.1: Architecture of VANET

a vehicle, for example; location, speed, etc. The event-driven message used for warning messages, for example; crash warning, children warning, etc.

In VANET as the vehicle density increases, it results in congestion due to an increase in the number of beacons. However, the MAC layer plays a vital role in controlling congestion. Though MAC protocols are difficult to deploy, that is the pivot on a centralized controller, for example; Time-division multiple.

2.2 Communication in VANET

VANETs assist various safety applications for dissimilar safety cases. Due to the range of communication ITS divides the range between two types such as long-range; depends on the infrastructure that is a cellular network and short-range; they adhere the IEEE 802.11 family standard, no requirement of infrastructure.

Due to the long connection setup delay, VANET applications (safety and non-safety) are failed to support reliable communications. Therefore, Dedicated Short Range Communication (DSRC) a wireless technology was designed. It directly communicates with vehicles automatically from short-range to medium-range. Mobile Ad-hoc Network (MANET) is an example of VANET.

VANET offers direct communication between vehicles or infrastructure by using wireless communication. For better communication, it works in two modes; vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I). Also, VANET uses three components for communications such as On-Board unit (OBU), Roadside Unit (RSU), and Authenticated unit (AU).

2.2.1 Types of communication in VANET

VANET focus on communication among vehicles and between vehicles and fixed roadside types of equipment.

- **Vehicle-to-Vehicle**: V2V is an ad-hoc communication network between vehicles, also known as Car-to-Car (C2C) communication. Usually, vehicular applications are interactive or cooperative. They can share or exchange information with other vehicles or among the vehicles to understand the particular area of their environment. This cooperative message exchange is known as over-the-horizon Awareness, helps to minimize the traffic jams.

- **Infrastructure-to-Infrastructure**: This kind of communication is done between the infrastructure objects such as OBU, RU, and AU. The main idea of I2I is done by measures of wired and wireless communication such as variable message signs, traffic light control, and data collection. In data collection, a wireless sensor network is used for adaptive traffic light control. For traffic management and maximize the traffic flow is using the ITS assists traffic operators.
- **Vehicle-to-Infrastructure**: This kind of communication takes place between vehicle to infrastructure or vice-versa in the ad-hoc network. Here each and every vehicle is fully facilitated with devices, known as OBU, which fulfill the algorithm and protocol for

communication. The infrastructure domain/network access the different network, so it is not bounded to only ad-hoc communication between RSU and OBU, also called as Vehicle-to-Roadside (V2R) communication.

2.2.2 Architecture of VANET

The principal integrals of VANET architecture as follow: Roadside unit (RSU), Trusted Authority (TA), On-Board unit (OBU) and Application unit (AU) according to **(Rasheed at el. 2017)**. Each integral are simplify below.

- **OnBoard unit (OBU):** An OBU is typically organized and initiates a vehicle for better exchanging the information among the vehicles or RSU. Which mean that each vehicle communicates with other vehicle or RSU and receiving messages from OBU, it is fully equipped with an Event data recorder, Trusted component, and GPS, etc.

  It also consists of a Resource Command Processor (RCP), it may include a memory for reading/write. A special interface is connecting with other OBUs, and with network devices with short-range communication, which is based on IEEE 802.11P wireless standard. The purpose of OBU includes geographical routing, wireless ratio access, mechanisms to control the congested network, data security, and reliable message transfer, etc., OBU also including a network device for non-safety applications.

- **Roadside unit (RSU):** RSU are gateways, it allows a vehicle to establish a connection with the internet, it is fixed part for the network. RSU facilitate with only one network device for a DSRC, based on IEEE 802.11.

  We discussed the main function of RSU as follows:

  1. Increasing the network area of the vehicular network and thereby allowing the exchange of information among OBUs and RSUs.

  2. RSUs behave as the hub of information.

  3. RSU is also responsible for connecting the OBU to the internet.

  4. RSU helps to broadcast the safety messages periodically.

- **Trusted Authority (TA):** TA is enabling security for the network. For two or more vehicles in an ad-hoc network to communicate security, each of them has a copy of other's credentials in the form of a certificate. The universally- trusted Certificate Authority (CA), provides vehicles with signed or original certificates, must revoke the certificates i.e. previously signed **(Baldessari at el. 2010)**.

CA includes the identification of the revoked certificate from the Certificate Revocation List (CRL). Now CA publishes the updated CRL to all vehicles, and inform/tell them not to trust any revoked certificate.

The main function of TA as follows:

1. Build keys for encrypting the messages/packet and send the key over the secure channel.

2. To manage the list of participating vehicles/nodes.

3. Pursue/detecting the origin of messages that are responsible for creating the problems in the network.

4. Finds the attacks if any occur.

- **Application unit (AU):** AU is a device, which is initialized inside the vehicle in the ad-hoc network. This device can be enlarging the safety applications and to allow the OBU to connect to the internet/network.

2.2.3 VANET Applications

VANET's applications play a vital role in communication among vehicles for controlling safety. Mainly, there are three types of applications such as safety-related, non-safety and traffic management. These are explained in a detailed manner.

2.2.3.1 Safety-related application: These applications give warning message for public safety.

- **Intersection collision warning**: Collect information about road intersection.
- **Left turn assistant**: Inform the vehicle to left turn.
- **Emergency vehicle warning**: Provides the alert message for the vehicle which may be stuck in road jam.
- **Post-crash warning**: Prevent potential accident before occurrence.
- **Curve speed warning**: This indicates the dissemination of message for the high speed approaching vehicles towards the curves to prevent accidents.
- **Work zone warning**: Alert message for a driver to a specific work zone.
- **Low bridge warning**: It indicates an alert message for the driver to know about the height and width of the bridge.

2.2.3.2 Non-Safety related application: These applications provide the services to the user. We discuss the following service to the user apart from a safety view.

- **Peer to peer application**: These applications are helpful to pair or connect with the other nodes in the network for file sharing, example music, and movie, file sharing, etc.
- **Internet connection**: It maintains an internet connection with vehicles all the time.
- **Other services**: VANET has other several applications for a user such as toll taxes, parking place, fuel station, restaurants, etc.

2.2.3.3 Traffic management: These applications provide road safety.

- **Collision avoidance**: Driver must receive the message before the occurrence of a collision.
- **Traffic optimized**: Traffic can be optimized by the use of sending signals to avoid jam, accidents, etc. Among the vehicles, it results vehicles chose their alternate path at the same time.
- **Blind spot Warning**: Send a message about the blind spot.
- **Emergency electronic brake lights**: Warn other vehicles for sudden hard braking.
- **Cooperative adaptive cruise control**: Maintain the vehicle's speed at the road.
- **Just-in-time repair notification**: To alert about fault resolution.

2.2.4 Protocol Stack

The protocol stack used by the USA (WAVE) and Europe (DSRC) is described in detail.

A) Wireless Access in a Vehicular Environment (WAVE)

WAVE is a promising technology for VANETS, which is designed by the Institute of Electrical and Electronics Engineers (IEEE) standards, in 2006 as shown in Fig. 2.1. WAVE main objective is, it supports making a safe connection between vehicles/node for reliable communication in the ad-hoc network.

A lot of research conducted around the world to help define the standard for the vehicles ad-hoc networks that fairly work on routing algorithms, frequency allocation, security issues, PHY and link layer standard, and some new application. VANET used WAVE for communication. WAVE consist the IEEE 1609.x family.

These family members are:

- **IEEE 1609.1**: WAVE Resource Manager Application, define service for vehicle
- **IEEE 1609.2**: Wave Security Application, defines a secure message
- **IEEE 1609.3**: WAVE data Exchange, using routing the message between the network layer and transport layer
- **IEEE 1609.4**: WAVE Multi-hops operation, based on IEEE 802.11 that specify PHY and MAC layer

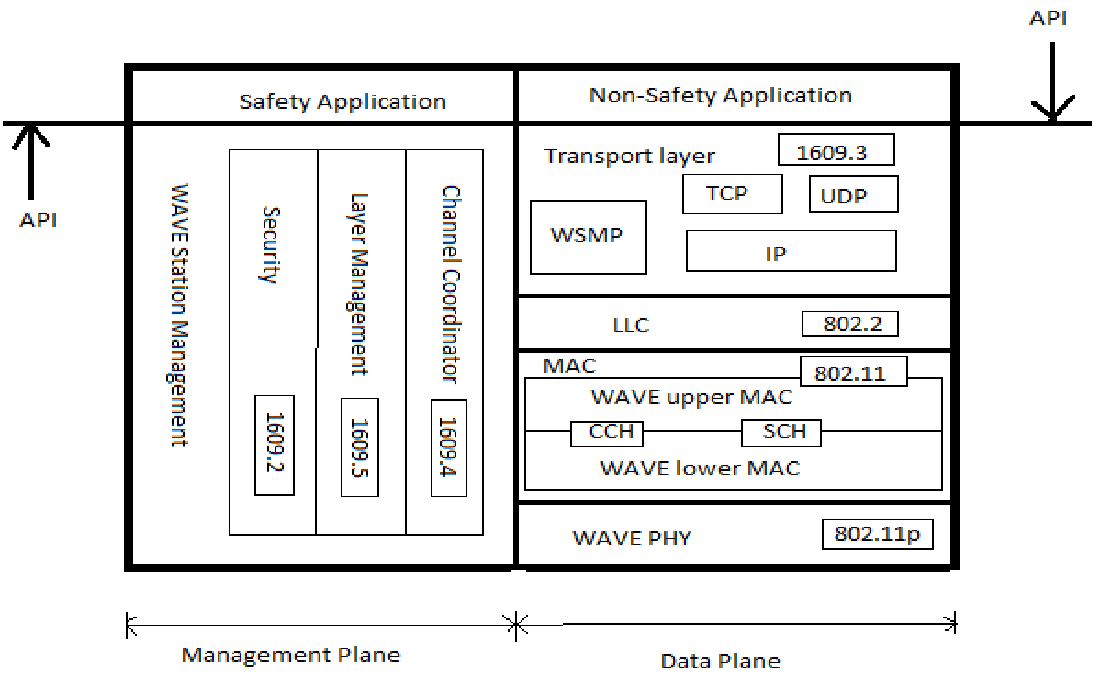

Fig. 2.2: WAVE Protocol Stack.

WAVE Application: WAVE disseminates the safety messages into two categories such as Basic Safety Message (BSM) also known as Beacon messages and Decentralized Environment Notification Messages (DENMs). The Beacon message is time-triggered message periodically other hand DENMs has broadcast the messages when an emergency event occurs.

B) Dedicated Short Range Communication (DSRC)

DSRC is a wireless communication channel, it could be established the communication connection by one-way or two-way. It directly communicates with vehicles automatically from short-range to medium-range.

DSRC communication has been allocated a frequency range from 5.850-5.925 GHz. IEEE designed wireless access for vehicle communication is known as a wireless environment in vehicular environments (WAVE) standard. For VANET communication multiple channel system is designed by DSRC. The DSRC spectrum is divided into seven different channels one is control channel (CCH) and the other six are service channels (SCH), each channel has been used 10 MHz bandwidth. For the safety messages CCH (channel 178) is used and on the other hand, SCH is adopted for the non-safety messages.

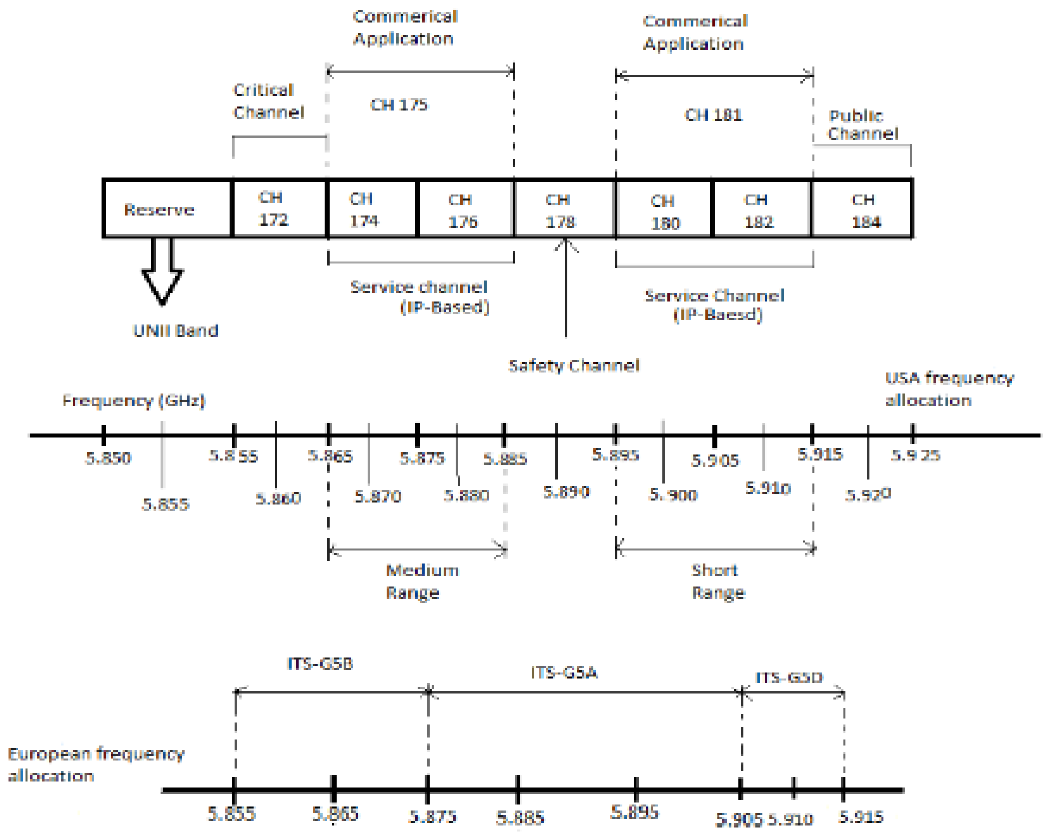

Fig. 2.3: DSRC Spectrum

In 2008, the European transport standard Institute (ETSI) allocates the frequency band at 5.875-5.905 MHz as shown in Fig. 2.3. ETSI aims to improve traffic safety applications. Therefore they introduced a set of protocol for packet dissemination among V2X system and smart infrastructure. For the primary safety, ITS-G5A is used, named as a control channel (CCH). ITS-G5B having two service channels, per channel is 10 MHz, which is used for a non-safety application. ITS-G5C is used in Wi-Fi device and has been work on 10 or 20 MHz channels. For better understanding, we follow table 2.1.

Table 2.1 Difference between WAVE and ETSI protocols

Parameters	**WAVE**	**ETSI**
Spectrum Bandwidth	75MHz	50 MHz
Frequency Range	5.855 - 5.925 GHz	5.855 - 5.925GHz
Control Channel Frequency	5.89 GHz	5.9 GHz
Number of Service Channels	6	4
PHY/MAC Layer	IEEE 802.11p	Multiple Access Technologies
Main Safety Messages	BSM	CAM, DENM
Higher Layer	Application, Transport, IEEE 1609.3, IEEE 1609.4, LLC	Application, Facilities, Network, Transport

2.3 Congestion

Congestion is an important issue at MAC layer in VANET. Congestion occurs when the packets are increased over the capacity of the network and it results in packets loss, quality of services degradation, etc.

Originate of congestion:

- **Congestion occurs when it sends data faster against the router capacity**
  - Slow hosts
  - Limited bandwidth
  - Data arriving from multiple lines at the same time
- **The system is not balanced**
  - Correcting the problem at one router will probably just move the bottleneck to another router
- **Incoming messages placed in queues**
  - long queue delay will cause a packet to be resent
  - an overflowing queue will cause the packet to be dropped

Therefore, congestion control schemes are designed to enhance the reliability, scalability, and throughput of the congested network. IEEE 802.11p based congestion control approaches aim to overcome the channel load and provide fair communication between vehicles. In general, to prevent the congestion occurrence we categorized the congestion control mechanism based on time-turning the transmission of parameters is called proactive, reactive and hybrid congestion control.

2.4 Survey on Congestion

Congestion Control Classification

Congestion is a big problem in the data network, and control congestion is more challenging because of the high-density environment and frequent changes in network topologies. Congestion control schemes are focused to provide the fair and reliable channel access. However, it uses the different transmission parameters with a predefined threshold value, to reduce the channel load.

This section describes the various congestion control classes available in literature along with the finding of research gaps

2.4.1 Reactive Based:

Reactive congestion control is a first-class, which is direct works on the channel load to overcome the congestion in a vehicular network. This approach takes action after the congestion occurs. Also helps to improve the congestion situation to normal conditions. However, it reveals safety application to the hazard of not being able to attain their desired objectives, also distribute their facility without any delay. Packet generation and fairness both are the major characteristics of reducing the congestion in a vehicular network. The main disadvantage of the approach is latency, which means it can't maintain the fast changes in a vehicular network.

Authors of **Subramanian et al. (2012)** showed that a guard is around transmitters, therefore responsible for low performance of IEEE802.11p MAC at high density. Poor packet reception rate depends upon the ALOHA behaviour. To reduce the channel load European telecommunication standard (ETSI) developed the decentralized congestion control (DCC). DCC is an asynchronous algorithm; however, it uses different parameters for transmission. At various congestion conditions, parameters of transmission don't modify easily. Thus the author aims to solve this problem by using transmit power control (TPC) algorithm. TPC allows the dissimilar to transmit power values at different channel load

Due to the high network flow, congestion is disturbed by the vehicular network. As in result packet is a loss, decrease the throughput and also energy was wasted. To improve the packet delay ratio and quality of service, authors of **Wang et al. (2006)** proposed the node priority-based congestion control protocol PCCP). To calculate the degree of the collision, they measure the packet inter-arrival time along with the time of packet service. Also, maintain the degree of congestion by using hop-by-hop control as the priority of node index. A PCCP scheme reduced the collision every efficiently and faster, instead of other energy efficiency techniques.

Authors of **Bansal et al. (2013)** designed an error model based on adaptive rate control (EMBARC) to control the saturated condition in a vehicular network. EMBARC is an extension of LIMERIC. To trace the error in a congested network, EMBARC uses the adaptive rate control. Here pre-emptive scheduling is using in tracking techniques. This protocol aims to reduce the channel load for the high-density vehicle. Hence EMBARC mechanism is best tracking accuracy between the wide ranges of vehicle densities.

In **Smai and Thorelli (1998)** authors uses timeout mechanism to find the congestion in the network, and also use the handshaking in a router, therefore help to inform the congestion area. This mechanism uses the specific area of the network interface and the processing elements. Performance is evaluated by the network stability. Therefore it tries delaying in worst-case and providing the bounds on average delay, it might be possible by to choosing the right timeout.

For a high-speed network, authors of **Kenney et al. (2011)** purposed a novel congestion control mechanism called TCP- Illinois. To control and manage the congestion, TCP-New Reno, SACK TCP, and TCP-Reno are the traditional version of TCP congestion control schemes. This mechanism is truly based on the window size (increased or decreased). This algorithm using the information about packet loss to diagnose the size of the window should be increased or decreased and also use the knowledge about queuing delay to decide the load of increment or decrement. Hence TCP-Illinois helps to attain maximum throughput, assign the network resource fairly. TCP-Illinois also have another quality to improve the robustness against sudden variation in delay measurements, busty packet arrival process, etc.

In **Mondal and Mitra (2014)** authors present the work to control the congestion dynamically along with the reducing transmission rate. The transmit rate to control the messages among the vehicles, only the authorized vehicles can utilize the resources in the vehicular network. To protect the vehicular network from the unwanted message, at the root level certifying authority (CA) have been used, at a middle level the base stations are used, and at leaf level vehicles are used. Hence each and every vehicle it controls the triggering of the unsafe message in VANET.

Congestion in the vehicular network is a big issue. To label this issue, authors of **Benatia et al. (2013)** designed a novel Markov chain model. However, this model has followed the four tread: congestion detection phase, beacon transmission rate, buffer monitoring and priority assignment to simplify the emergency packets dissemination. In vehicular network, the beacon consuming the large amount the bandwidth, therefore it results event-driven warning message is not properly transmitted in a vehicular network.

Observation:

Reactive congestion control comes approaches come under the closed-loop. Therefore it means that these protocols are used to remove the congestion after it occurs. Transmission of rate and power based congestion control adjusts either the packet generation rate or transmission of power measured based on channel busy time ratio. TCP-Illinois aims to achieve a better average throughput than standard TCP for any size of butter router. However, it helps to maximize its rate to full and faster utilization. Moreover to achieve the maximum fairness, vehicles exchanges their local measurements with immediate neighbour's vehicle and also allowing maximize of the power and rate transmission, if only the current used value is under the average rate or power by the neighbour's vehicle.

2.4.2 Proactive Based:

Proactive congestion control is the second class of congestion control mechanism. Proactive protocols based on the table-driven model. The number of nodes in the area and packet generation, to estimate which transmit parameter will not come under in congestion. This protocol using the system model to evaluate the channel load under the given transmission parameters and optimization algorithms also determine maximum transmit power and/or rate.

In a vehicular environment, for safety applications ratio of communications is primarily used, radio performance might be critically threatened by congestion control. A big advantage of this approach is lower message latency (router are immediately available). While the communication model and accurately estimate is a drawback in a vehicular environment.

Authors of **Yang et al. (2004)** proposed the vehicle-to-vehicle communication protocol mechanism for cooperative collision warning (VCCW). VCCW prevent congestion during the packet generation rate and also achieve delivery of emergency messages at low-latency. VCCW works as an open-loop controller. However, when a vehicle comes at an abnormal state, the vehicle controller monitors the vehicle dynamically and activates the collision warning automatically. Performance is predicted by only the packet generation rate. To achieve network stability channel feedback plays a role. To use of primary feedback, transmission rate might be adjusted easily, also is helping to make a decision at emergency.

In **Wischhof and Rohling, (2005**) authors designed a hop-by-hop proactive congestion control mechanism for the vehicular network. This congestion control mechanism truly based on packet forwarding and utility function. This mechanism uses highly specific utility function and encrypts the related information in a data packet, however, is transmitted data in a transparent way. A decentralized scheme helps to calculate the "average utility value" of each node according to the utility of its data packets. Thus the part of accepting data rate will be share to its relative priority. For calculating the performance of a network, purposed decentralized utility-based packet forwarding and congestion control (UBPFCC) is implemented at topmost of the IEEE802.11 MAC protocol. UBPFCC is more efficient, and fairness of data dissemination in the vehicular network. This mechanism need to context exchange among the neighbour nodes, however, it increased the overhead in the communication channel. To evaluating the message priority, depends on packet size and utility, therefore reducing the performance of dissemination of packet for the event-driven safety message.

Authors of **Torrent-Moreno et al. (2004)** designed broadcast reception rates and effects of priority access (BRA-ERA) algorithm. BRA-EPA works on transmitting power control, which is the main factor to reduce congestion. The main idea to control transmit power for low priority messages, and also maintaining the transmit power for the high-density traffic. Transmission of power control aims to maintain the point-to-point connectivity for communication and also making the limited channel usage to control the congestion. Therefore, also used for dynamically reserving an area of accessible bandwidth for the safety application.

According to **Tielert et al. (2011)** reduces the congestion the rate adaption based protocol is using the periodically updated load sensitive adaptive rate control (PULSAR). There are three main parts of PULSAR to control the congestion that is as follows: Channel load assessment is detected by channel busy ratio (CBR) and also congestion detect by the threshold. Rate adaption is calculated by the new CBR value from the end of channel monitoring and decision interval. By using PULSAR, compare the new value of CBR with the target value. Also, the binary decision helps to take a decision for the transmission rate: If CBR(new) less then to Target T(value) called as transmission rate is decreased or if CBR (new) greater then T(value) called as transmission rate is increased. Information sharing occurs when all nodes want to participate in congestion control at a specific range, known as channel state (CS) range.

Authors of **Torrent-Moreno et al. (2006)** designed distrusted fair power adjustment for vehicle networks (D-FPV), is distributed and localized algorithm. To control the congestion, fairness, and prioritization transmits power control of vehicle play n important role. D-FPV balances the availability between the beacon and event-driven messages. Moreover, D-FPAV used to achieve a goal using "water-filling approach." The author defined the fixed max beaconing load (MBL) threshold that helps to obtain first and second goals.

According to **Sepulcre(b), et al. (2010)** the congestion control scheme was designed for vehicular network. In this policy, according to their single utilization, the communication parameters in each and every vehicle are adapted. These mechanisms fulfil the target performance of every single vehicle and also help in reducing the channel load for better communication. Every algorithm needs different requirement and is closely run by the same vehicle; hence this approach not satisfied all requirement of different application.

In the field of proactive congestion, authors of **Viriyasitavat et al. (2011)** designed an urban vehicle broadCAST (UV-CAST) algorithm. UV-CAST is very helpful in reducing the broadcast storm problem. As well as UV-CAST was designed to solve the disconnect problem in an urban area. UV-CAST mainly focused on safety applications/messages. By adaptation of the propagation model, UV-CAST increased the number of the informed vehicle in a specific region. Performance is calculated by the network, reaches ability, network overhead and received distance. Hence UV-CAST is a purely distributed broadcast protocol. However, each vehicle has been local information and operates independently itself. On the other hand, this approach work only low density might be less than 50 vehicles/km^2.

In **Hsu at el. (2011)** author designed a novel MAC channel congestion control (MAC-CC) algorithm. To reduce the collision situations, MAC-CC and adaptive offset slot (AOS) is used. To calculate the number of co-vehicle in the network, Hello message broadcasting is used broadcasting is done at both ends that are safety-related and non-safety applications. However, to minimize the number of conflicts depends upon the number of vehicles expected offset slots at the network.

Authors of **Sepulcre(a) at et. (2010)** designed Contextual communication congestion control (contextual C-CC) protocol to minimizing the channel load in a vehicular network. Contextual C-CC provides fairly and reliable communication among the vehicle and infrastructure. Lane change assistance application was useful for case study to better understand.

Observation:

Proactive congestion control schemes are very helpful to immediately evaluate the minimum-maximum r[ate of transmission. For the traffic safety cooperative collision warning (VCCW) is used. These approaches perform on the rate of packet generation to prohibit congestion. Further, typically approaches are an open-loop controller that means protocols are tried to exclude congestion before it occurs. As long as multiplicative rate reducing schemes that are used to adapt the rate of packet generation based on estimated performance of communication channel. In particular, these algorithms typically implement a system model to calculate the load of the channel and construct the optimal algorithm to control the maximum transmission power or rate.

2.4.3 Hybrid Based:

The third type of congestion control mechanism is hybrid congestion control. This approach depicts the virtue of reactive and proactive mechanisms. Example; adaption of the rate of messages is reactive and transmit power is proactive. Earlier solutions can be categorized with reference to the means between which congestion is controlled. However, it obtained by controlling packet generation rate, transmit power, the carrier sense threshold or a combined of a subset of the transmission parameter. Some time it suffers from both hurdles (bandwidth overhead and latency), at the same time which degrades its performance.

Due to the high density of traffic periodic beacons uses the entire bandwidth of medium, it results in congestion. However, the channel is not properly disseminated the packet of messages. By the time researchers have designed many mechanisms, to solve the saturated condition. Hence, authors of **Mughal et al. (2010)** see that many mechanisms are relying on the concept of limitation of beacon bandwidth chunk for high priority even-driven message. To reducing the channel load, transmission rate and transmission power schemes are used.

In **Zhang et al. (2007)** authors proposed a new approach to reduce the congestion called "concepts and framework congestion control" (CC-CF). CC-CF is a distributed in nature, whereas each node utilized both algorithm that is proactive and reactive. Instated of blind broadcasting, they use the intelligent and efficient rebroadcast in a vehicular network. Event-driven and beacon message is control by reducing and a specific number of redundant packets.

Authors of **Guan et al. (2012)** designed the two-level adaptive message rate control (AMRC) algorithm. AMRC allowed the high availability channel for safety application. To find the favourable values of the messages rate, channel interval, quality of services and back-off exponent (BE) for the limited number of vehicles, an off-line procedure to be calculated at the first level. At the second level, roadside units (RSU) or access points are helpful to broadcast the acquired information to the vehicles. AMRC is performed like as centralized behaviour. The main motive of the AMRC scheme is trying to make the bandwidth free for non-safety and beacon messages.

In **Fallah et al. (2010)** authors designed a novel channel occupancy-based congestion control (CO-CC) protocol. CO-CC focused to provide the congestion control in safety application at specific feedback from the vehicular network. It is results, making fast decisions on packet traffic condition CBT is using the metric in the channel. The main advantage of this approach is using the propagation model, transmission rate and vehicle density in a network.

Both authors **Djahel and Ghamri-Doudane (2012)** introduced another congestion control scheme based on power and rate control (P&PC). In this algorithm, have been three main key conditions that are priority assignment, beacon load adjustment, and congestion detection. Also, congestion detection is using the three metrics; collision rate (CR), average waiting for time (AWT) and beacon reception rate (BRR). The transmit power and beacon generation rate is helpful to adjust the beacon load at fine-tuning.

According to **Le et al. (2011)** for increasing road safety and traffic effectiveness, the intelligent transportation system (ITS) applications use the two types of messages: Beacon and event-driven warning messages. Here author evaluates three beacon congestion control algorithms whereas handling the beacon load under the predefined threshold by adapting the transmission power or transmission rate for the beacon messages. The distance between the receiver and the sender increases, the reception rates for both warning and beacon messages drop.

According to **Huang et al. (2010)** adaptive inter-vehicle communication control (AICC) another hybrid congestion control mechanism. Here beacon changes both in a proactive way (generation rate) and in a reactive way (transmission power), to maintaining the channel load. For tuning the beacon generation rate and power two different congestion control approaches are applied for improving the vehicle's ability. Beacon generation rate is adjusted on the forecast (guess) tracking error of own position. Moreover, transmission power control is involved the observed the status of the channel, on the behalf of channel load. Hence both the beacons transmit power and generation rate uses the direction to control the parameters of transmission among the vehicles.

In **Baldessari et al. (2010)** authors are tried controlling the channel load. They designed novel schemes for the combination of message interval and power control into a one algorithm loop. The designed algorithm is based on the framework, which consists of three stages: load change estimation, channel monitoring, and action. Whenever the channel usage is under the saturated level, the channel access time and reliability of the packet delivery reduce as the load increases.

Observation:

A hybrid congestion control aims to integrate the objectives of both reactive and proactive protocols; however, it combined the transmission rate and power for congestion control. Their results involve an enhanced rate control, enhanced power control and also joined rate and power control scheme. Channel load is calculated to obtain the number of immediate vehicles in the nearby area. To directly obtain the packet rate, evaluate the number of vehicles and predefined channel busy time threshold in a specific area. However, no congestion control algorithm is appealed for the huge intersection, the transmit rates of both warning and beacon messages are lower-grade than those acquired with the congestion control protocols.

Table 2.2 shows the congestion control classification with various congestion control approaches using different scenario. Also, we are discussing transmission parameters with various characteristics of vehicular networks.

Table 2.2 Congestion control approaches and their different characteristics for vehicular networks:

Congestion Control class	Approaches	Access priority	Simulator	Transmit power Control	Transmit data-rate control	Performance Metric	Traffic Density	CBT	Scenario
Proactive	VCWC (Yang et al., 2004)	-	Ns-2	-	✓	Maximum delay(see), number of messages, delay	High Low	-	Highway
	UBPFCC (Wischhof and Rohling 2005)	-	Ns-2	-	✓	Drop-rate (bit/s)	High	-	Highway
	BRR-EPA (Torrent-Moreno et al., 2004)	✓	-	-	✓	-	High	-	Highway
	PULSAR (Tielert at et., 2011)	-	-	-	✓	Rate adaption	High	-	Highway
	D-FPAV (Torrent-Moreno et al., 2006)	✓	Ns-2	✓	-	Probability of message reception, Channel busy time rate	High	✓	Highway
	Application-based congestion control (CC) (Sepulcre(b) et al., 2010)	-	Ns-2	✓	-	Packet received/s, Transmission power (dBm)	Low	✓	Highway
	UV-CAST (Viriyasitavat at et., 2011)	✓	SUMO	-	✓	Average received distance (pkts), number of messages	High Low	-	Highway Urban

	MAC-CC (Hua at et., 2013)	-	MATLAB	-	✓	Throughput (Mbps), packet-loss probability	Low	-	Urban
	Contextual C-CC (Sepulcre(a), 2010)	✓	Ns-2	-	✓	Transmission power(dBm), CBT(%)	Low	✓	Highway
	DCC (Subramanian at et., 2012)	-	Ns-2	✓	-	Average of number	High	✓	Highway
	EMBARC (Bansal et al., 2013)	-	SUM0 Ns-2	✓	✓	Tracking error(m), packet error ratio, mean IPG (sec.)	High	-	Highway
	PCCP (Wang et al., 2006)	✓	-	-	✓	Normalized node throughput	Low	✓	Highway
Reactive	Timeout Mechanism (Smai and Thorelli 1998)	-	Time-driven	-	✓	Worst-case delay, number of a missed deadline, latency (clock cycles), delivery throughput	Low	-	Urban
	TCP-Illinois (Liu at el., 2008)	-	Ns-2	-	✓	throughput The ratio between measured throughput and computed average throughput	Low	-	Highway

	Combined-CC (Mondal and Mitra 2014)	✓	PML, PSMR	-	✓	Delay-Rev (in sec)	Low	-	Highway
	Markov chain (Benatia at el., 2013)	✓	Ns-2	-	✓	Loss rate (%)	Low	-	Highway
Hybrid	Power & rate combined CC (Mughal at el., 2010)	✓	-	✓	✓	-	Low	-	Highway
	CC-CF (Zhang at el., 2008)	-	-	✓	✓	-	High	-	
	AMRC (Guan et al., 2012)	✓	Discrete event-driven	-	✓	Average packet delay, the utility value of Θ, message success probability	Low	-	Urban
	CO-CC (Fallah et al., 2010)	-	OPNET, SHIFT	✓	-	Channel occupancy, IDR(packet nodes/sec.)	High	✓	Highway
	P & RC (Djahel and Ghamri-Doudance 2012)	✓	OPNET	-	✓	Beacon delivery ration, total delay (ms), emergency message reception ratio	Low	✓	Highway
	Beacon congestion control (Le et al., 2011)	✓	Ns-2	✓	✓	Reception rate (%), CBT (%)	High	✓	Urban

	AICC (Huang at el., 2010)	-	OPNET	✓	✓	The population of tracking error, the percentage among all packet losses, adaptive transmission probability, adaptive transmission power (w)	High	-	Highway
	Power or rate integrated schemes (Baldessari et al., 2010)	-	Ns-2.31	✓	✓	CBT (%)	High	✓	Highway

2.5 Research objectives:

Following objectives have been formulated:

1. To study the existing DCC protocols and identify their limitations in vehicular networks.
2. To propose an algorithm for congestion control of safety message (beacon) in V2V and V2I environments.
3. To compare and analyze the performance of the proposed algorithm with other existing algorithms of VANETs.

Chapter-3

Decentralized Congestion Control (DCC)

3.1 Introduction to DCC

ITS was designed by European Telecommunications Standards Institute (ETSI). When density increases MAC layer suffer from congestion. This situation decreases the transmission of safety application on time. Through the control channel, a safety message is transmitted among vehicles. To reduce channel load ETSI design the DCC mechanism that adapts various transmission parameters such as power control, data rate control, etc. DCC follow the cross-layer mechanism which deployed on a reference measure (rate) in the MAC layer.

To the reduce channel load ETSI design the DCC mechanism that adapt various transmission parameters. For DCC mechanism, compulsory to go through the ITS-G5 stations as shown in Fig. 3.1.

The ITS-G5 stations are mentioned below:

- **DCC Access**: to control congestion by act on transmission parameters (Transmit power control (TPC), Transmit rate control (TRC), Transmit data rate control (TDC), DCC Sensitivity control (DSC), Transmit access control (TAC).
- **DCC Net**: mapping the traffic with Cooperative Awareness Message (CAM) to DCC profile.
- **DCC facilities**: provide service according to Decentralized Environment Notification Message (DENM) and CAM profiles.
- **DCC Management**: inter-operation between the different layer-specific DCC entities.

DCC used at every station to control network stability, fair resource allocation, and throughput Efficiency, therefore, working at ITA-G5A (safety-related application in frequency range 5.875 GHz to 5.905 GHz) and ITS-G5B (non-safety related application in frequency range 5.855 GHz to 5.875 GHz).

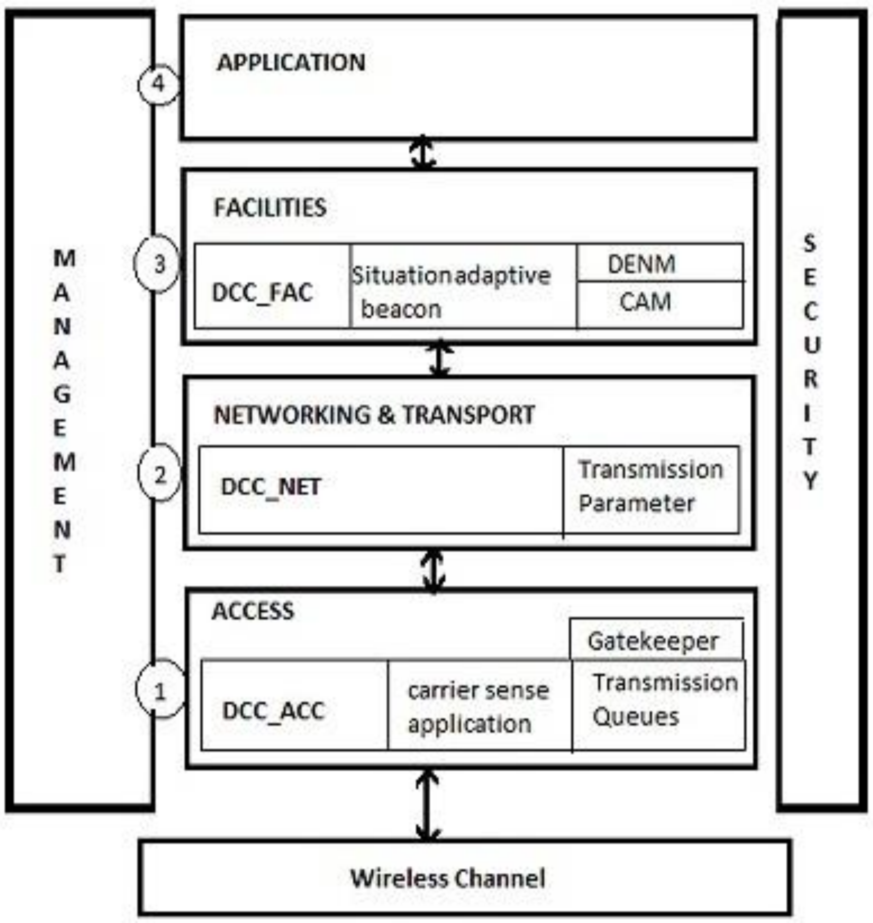

Fig.3.1: DCC Protocol.

The key DCC functionalities are mentioned below:

1. Within the particular area of communication, it provides the same resources allocation channel access probability to all ITS stations.
2. Through the specific thresholds, it maintains the amount of data in the channel under.
3. For high priority communication, some resources are safe such as car accidents, police vehicles, etc.
4. A high variable environment also adopts such as the opposite fast or radio channel might change from free to busy.
5. To control the oscillations in the manage loops within the limits
6. Also helpful to fulfil the necessary requirements coming from the upper layer that is reliability etc.

The modification's in DCC

These previous functionalities are not directly communicated to the physical layer but also coming from the upper layer. It is the only reason DCC situated inside all the ETSI protocol architecture, expect application and security layer, rather than situated only access layer.

DCC Application: ETSI has been defined two types of messages that are CAM and DENM. CAM provides information of a vehicle presence, position, and basic status to one-hop neighbour within 1to 10 Hz range of frequency. DENM simulated to event-driven message. The message is triggered when ITS station detects any kind of hazard event, it broadcasting the DENM message to the specific geographical area repeatedly, till the event is over.

A) **Cooperative Awareness Message (CAM):** CAMs messages aim to permit the live information of ITS station to the neighbour or immediate ITS stations that is available in one single hop. Due to the constant mobility, only one single hop is allowed in a network. Due to the aim of continuously notify the nearby station, the CAM messages must be sent frequently, within a second, a maximize and a minimized number of CAM can be sent (as shown in Fig. 3.2). Example; i.e. a minimize of 1 CAM sent per second a maximize of 10 CAM sent per second. CAM generation and ITS stations are controlled by depending on the channel congestion and needs of each ITS stations.

The inner structure of CAM are given below:

CAM messages are arranged in containers, Data Frames (DF) and Data Elements (DE).

Container: the container is a table/block of information that carries a sequence of Dfs or Des. A container may also include sub-container, have more certain information about the ITS station.

Data Elements: A particular data held in a data type.

Data Frame: It contained the more than on DE which is following the predefined data type.

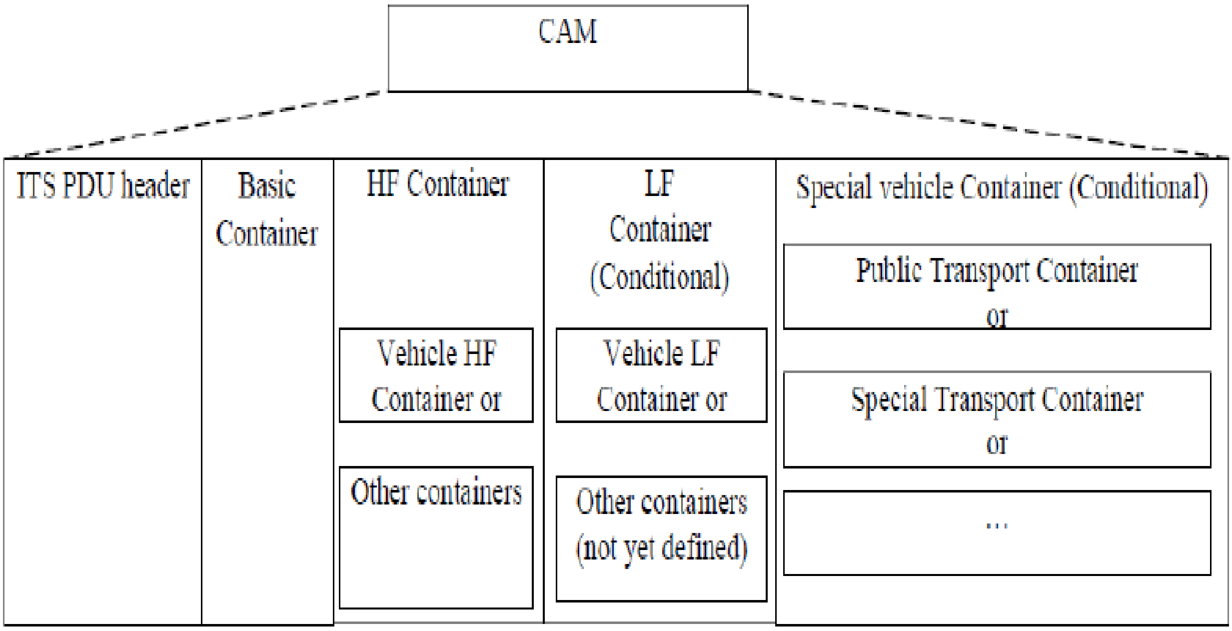

Fig. 3.2: CAM general structure

This layout allows different/various options rely on the ITS station which generates CAM and send it over the network. All CAMs have included the ITS PDU header and basic container. Depending on spread information and type of ITS station, more fields (container) might be involved. However, the major five fields are:

1. **ITS PDU Header:** It holds the protocol version, type of message and also ID of ITS station of the sender
2. **Basic Container:** It holds basic information which belongs to ITS sender
3. **High Frequency:** It holds vital information which belongs to ITS sender such as speed, longitude, direction, etc. Basic vehicle HF container is an example of sub-container
4. **Low-Frequency Container:** It holds static information belonging to ITS sender such as vehicle size, colour, brand, etc. Basic vehicle LF container is an example of sub-container,
5. **Special Vehicle Container:** It holds the particular information which is belonging to ITS sender that describing the role of the vehicle such as ambulance, police care, etc.
6. Public transport container, road work container, dangerous good container are the example of sub-container.

B) Decentralized environment notification message (DENM): DENM is alike to the CAM, is used to broadcast the information about than traffic on the road as shown in Fig. 3.3. While CAM passes the current mobility information to ITS station, DENM passes the live information about the traffic event (such as traffic jams, car accidents) to the nearby ITS station, in order to apply a solution as soon as possible.

Due to the traffic events, DENM is dissemination a short or long period of time to ITS stations, ITS-stations are also responsible to forward and resend the DENM message to nearby ITS-stations. Once the event is resolved, a lost DENM will disseminate to ITS stations, which inform about end of events.

According to event duration time, it consists of four different types of DENM messages:

1. **New DENM:** It sent when an event is found/detected by an originating ITS station, for every event an "action ID" is generated and also sent with the event characteristics (type, position, etc).
2. **Update DENM:** it sent by the originating ITS station of the new DENM that holds updated information about the event.
3. **Cancellation DENM:** It used to inform about the end of the event, it also sent by the originating ITS station of the new DENM.
4. **Negation DENM:** It used to inform about the end of the event by different ITS stations, which did not generate the new DENM.

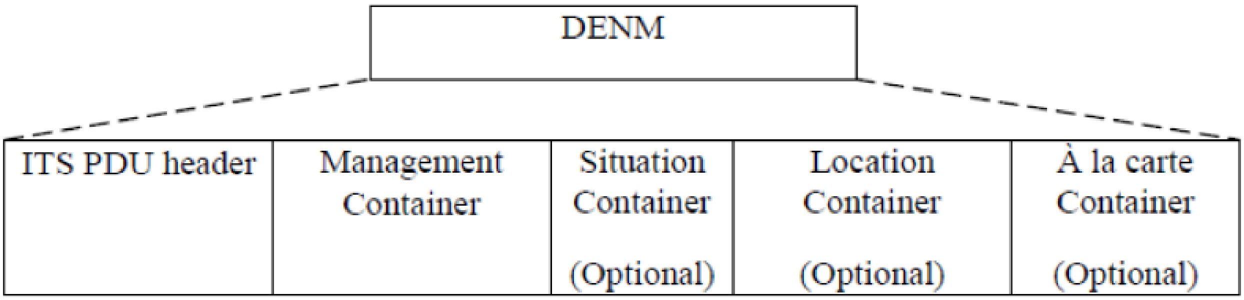

Fig. 3.3: DENM general structure

The basic layout of DENM messages has at least two fields, and also three other optional fields/containers.

1. **ITS PDU Header:** It holds the protocol version, the station identifier of the originating ITS station, the message type identifier.

2. **Management Container:** It contains information related to the DENM protocol and the DENM management
3. **Situation Container:** It holds information belonging to the types of the detected event.
4. **Location Container:** It holds information belonging to the event location and the location reference.
5. **‘A la carte container**: container-specific/particular information about an event in case it is required to transmit additional information not included in the three previous containers.

To uses of these two services (CAM and DENM) together, vehicles should be able to recognize the status of the traffic and is also increasing traffic safety and efficiency.

3.2 LIMERIC:

LIMRIC stands for Linear Message Rate Integrated Control; it supports to Message-rate decentralized congestion control algorithms. This scheme uses the CBR (Channel Busy Ratio) as input to modify or improve the message-rate and enhanced the utilization of channel to an appropriate target level. To maintain an appropriate utilization of the desired channel, LIMERIC also establishes a fair message rate between vehicles.

There are two prime inputs for LIMERIC, CBR_T is the target channel load where the system desires to reach and $CBR_K(t)$, computed by total vehicle k at time t is the overall medium busy ratio created by vehicles within a specific area. The message-rate of vehicle k as $R_K(t)$ maintains every interval θ seconds as follows:

$$\mathbf{R_k(t) = (1-\alpha) \times R_k(t-P) + \beta \times (CRR_T - CBR_k(t-P))} \quad \text{…………………………..} \textbf{ Eq. 3.1}$$

Where P is the CBR measurement of a time period (in this thesis P is set to 200 ms), where a convergence of speed is determined by α and β support stability and convergence steady state. In **Math (b), (2017),** the author gives detail about the impact of α and β on LIMERIC. Moreover, β plays an important role in the capability of ensuring convergent behaviour of α, is more related to the speed and the equilibrium of convergence.

LIMRIC enhance to converge CBR to CBR_v while promising a fair message-rate for all vehicles k as proven as follows:

$$CBR_V = \frac{i \times \beta}{\alpha + i \times \beta} \times CBR_T \quad \text{......Eq. 3.2}$$

Where i denotes the total numbers of cars in a communication network.

Chapter-4

Proposed Work and Simulation Setup

Proposed Work

In this project we discuss the dissemination of packet with high transmission rate therefore, we using the high priority of beacon messages. All messages are dividing into two queues. The first queue is safety messages (sft_msg), and others are all other messages (oth_msg). Here only safety queue is selected because of the higher priority which is set for beacon messages, other queue is discarding. Now the loop is running, where the condition is met. Apply LIMERIC on high priority message.

Besides, the system generates beacon messages immediately and transmits it with higher priority whenever a critical event occurs or the vehicle dynamics condition is met.

4.1 Proposed Algorithm

Input two queues, first for safety messages (sft_msg), second all other messages (oth_msg)
Output: Message dissemination with a high transmission rate

1: Group all the received messages in their respective queues (sft_msg, oth_msg) according to the priority.
2: queue sft_msg _ GetLocalNodemsg (M,N)
3: queue oth_msg _ GetLocalNodemsg (M,N)
4: Select queue safety and discard queue othermsg
5: Set the priority of Beacon messages
6: while queue sft_msg = NULL do
        high priority message = Max (priority queue safety, N)
        Apply LIMERIC scheme on high proritymsg
    end while
7: Maximize the transmission rate of high priority message in order to minimize the congestion

Simulation setup

In this project, we use the artery simulator to calculate the performance of DCC protocols for enhancing safety applications. In this chapter, we discuss the project's simulator which we used also parameters setting of traffic simulation, network simulation.

4.2 The Simulator Used

On this thesis, we choose Artery simulator. This simulator gives full support to ETSI ITS-G5 protocol stack for communication and also fulfills the following requirements:

1. IEEE 802.11p protocol implementation with multi-channel.
2. ETSI ITS-G5 protocol implementation as the main one.
3. IPv6 protocol support (together with 802.11p or in a different module).
4. 4G/LTE support for future researches and other technologies comparison.
5. Realistic traffic support to have more accurate results respect the real world.
6. Real maps support to simulate real scenario cases.

The selected simulator to fulfill the previous requirements is a combination of multiple software components, which are:

1. Omnet++: The basic software is not a simulator itself but its platform functionality allows it to join multiple modules and it can be seen as a network simulator.

2. Simulation of Urban MObility (SUMO): Open-source traffic simulator that allows defining traffic (number of vehicles, routes, speeds, etc.) along multiple roads. It allows defining the characteristics of each vehicle route individually (different speeds, destinations, paths, etc.).

3. Veins: Open-source software containing the 802.11p and IEEE 1609.4 DSRC/WAVE (including multichannel) and able to reconfigure the vehicles and their routes respect the packets exchange. It allows importing real-world scenarios (buildings, speed limits, etc) from OpenStreetMap and takes into account the shadowing created by buildings and vehicles.

4. Artery: Veins framework extension that contains the ETSI ITS-G5 standard including GeoNetworking, BTP and DCC protocols by using Vanetza. Based on this standard, it is able to simulate V2X communications.

As Fig 4.1 Shows, Omnet++ is the basic framework that manages all the other components within it. Omnet++ is responsible for controlling and designing any simulation and it allows to configure parameters like sensibility, data rate, transmission power, etc. of each ITS stations (OBU or RSU). Omnet++ is also responsible for controlling the channel and therefore it can collect the statistics generated data in other modules within the simulator.

Within Omnet++, the first module to be found is Veins, this module manages the first layer of the ETSI ITS protocol stack and the other important point as it is to simulate vehicles mobility. To do this, Veins module uses the SUMO module (they work together in parallel) which is the module responsible for constantly generating the traffic flow by changing the vehicles speed (and so, their position), advancing or stopping other vehicles, etc. SUMO module is also responsible for the scenarios by creating them or by using real maps; it is also responsible for generating all vehicles behaviour by allowing to define different vehicle types (cars, ambulances, pedestrians, etc.) in general or individually among other possible situations.

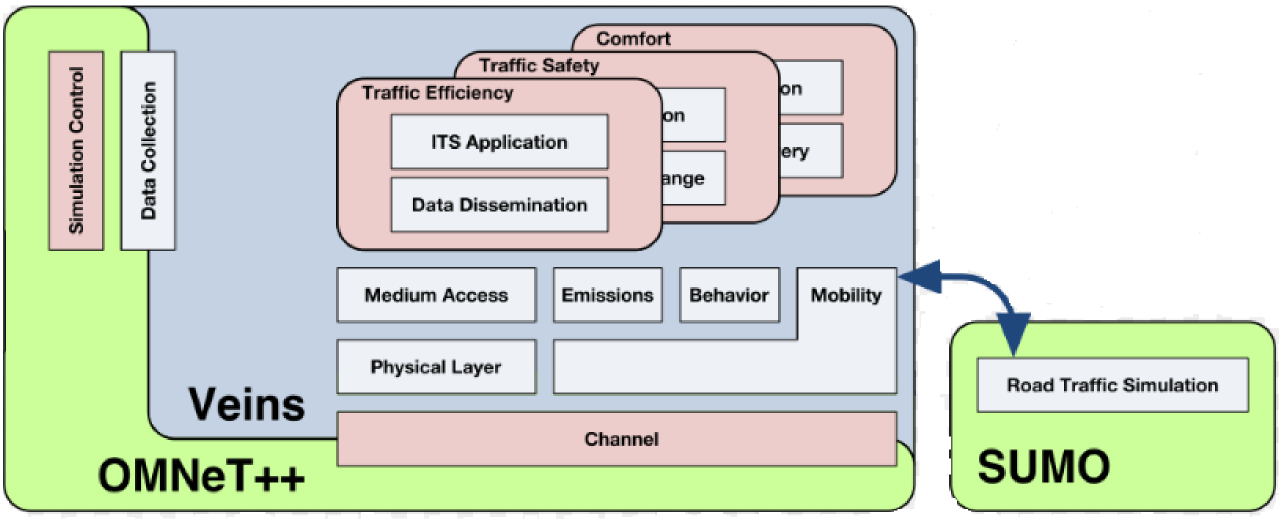

Fig. 4.1: Simulator architecture

Within Veins module, there is the Artery module managing all information related to the Applications level (simulating a vehicle application) and the two upper layers of the ETSI ITS protocol stack (Facilities, Transport, and Networking). At this module, all statistics are collected to be sent to Omnet++ and save them for later analysis.

While the Physical layer management and control is shared by Omnet++ and Veins module, the Networking layer management and control is shared by Artery and Vanetza. Vanetza is the last module used in our simulation framework and is responsible for having a good Transport layer functionality.

To understand better all the relationships within this framework, it is better to follow all the transmission and reception process through within the Artery module, there is an application simulating the Cooperative Awareness Basic Service (2.5.1). Every 0,1 seconds in order to generate a CAM is sent from the Applications module to the Facilities module. Once a CAM is created, the Facilities module passes it to the Transport module (belonging to Vanetza) and this encapsulates the CAM into a BTP packet (2.4.1.3). The BTP packet follows the same process by being sent to the Networking module and encapsulated into a GeoNetworking (2.4.1.3) message. Finally, this message is sent to the Medium Access and Physical modules to be encapsulated into a MAC (2.4.1.4) frame and sent.

Once the MAC frame is received by each available ITS station, the frame follows an opposite process to extract all the information layer by layer from the Access layer up to the facilities layer which will present the information to the user through the right user application.

4.3 Traffic Simulation Setup

As stated earlier we use the Artery simulator together with SUMO to benchmark the performance of LIMERIC algorithm. We created a realistic 3-lane highway scenario using the SUMO traffic simulator.

Each lane is 3.5 m in width and 3 kilometers in length. In this highway scenario, vehicles are running in loops means that when a vehicle reaches the road's end it enters the opposite direction of the road. The density of traffic might have an impact on DCCs performance. We built up the three different scenarios which support the various vehicular densities (Medium, dense, extreme).

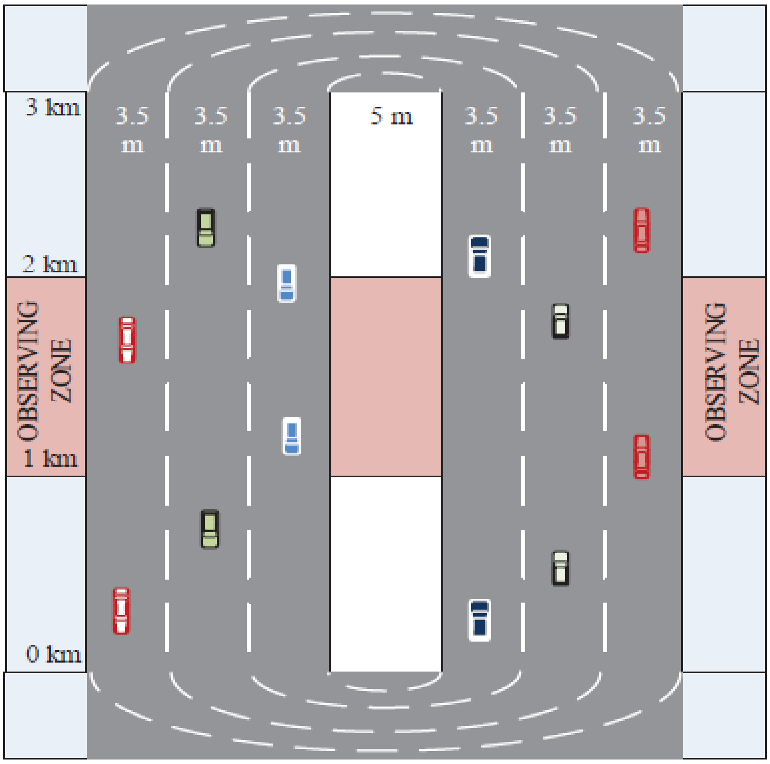

Fig. 4.2: Traffic Scenario

The vehicular mobility simulated in SUMO is generated as a TraCI and it can be used in Artery network simulator as the mobility model. For the analysis of simulation results, we only considered the vehicles in the observing zone within the range of 1 km as the highlighted region is shown in Fig. 4.2.

4.4 Network Simulation Configuration

The artery is an extension of Veins simulator which supports IEEE 802.11p PHY/MAC layer and IEEE 1609.4 DSRC/WAVE network layer for vehicular communication. We only use the CCH since it is used for the periodical transmission of control information. The carrier frequency in the PHY layer is 5.89 GHz. The selected data-rates for LIMERIC are 6 Mbps (default data-rate), 12 Mbps and 24 Mbps.

For LIMERIC $\alpha = 0.1$ and $\beta = 0.33$, are selected such that the algorithm is stable for different densities and data-rates. A summary of traffic simulation parameters as shown in Table 4.1.

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Table 4.1: Simulation parameters

Vehicle density	Medium, dense, extreme
Carrier sensing threshold	LIMERIC: -85dBm
Transmission rate	LIMERIC: 6Mbs
Transmission power	LIMERIC: -82dBm
Message rate	LIMERIC: varies
Payload size	300 bytes
Simulation area	3000 m $\times$ **25** m
Simulation period	30 s
Mobility	SUMO

Chapter 5
Simulation Results and Analysis

In this chapter, the results of simulations in the artery will be presented and discussed.

5.1 Simulation Metrics

The two major parameters for the dissemination of packet with a high transmission rate is PDR and packet delay.

5.1.1 PDR:

The first evaluation was done and measured in term of packet delivery ratio (PDR). This value is calculated by dividing the overall number of message arrived at the destination node by the overall message sent from source nodes according to the following equation:

$$PDR = \frac{Total\ packet\ received\ by\ all\ nodes\ in\ the\ distination}{Total\ packet\ sends\ by\ all\ source\ node} \text{.......................................Eq. 5.1}$$

5.1.2 Delay:

The delay represents the time period that needs to route a packet from the source to the desired destination which depends on PDR value in the system and can be calculated as the following equation:

$$Delay = \frac{Number\ of\ sending\ bits\ in\ packet}{throughput} \text{..Eq. 5.2}$$

5.1.3 Throughput:

The last performance is evaluated in term of packet throughput. Throughput refers to the average number of successfully delivered data packets on a communication network or network node. Throughput indicates the total number of packet reception at the destination out of the total number of packet transmission. It is calculated in bytes/sec or data packets per second according to the following equation:

$$\textbf{Throughputs} = \frac{\text{Total packets received at destination}}{\textit{total packets sent at destination}} \quad \text{...} \textbf{Eq. 5.3}$$

5.2 *Simulation results discussion*

In this section, we discuss the metrics used to evaluate PDR, delay for the packet transmission to control the congestion in a channel.

5.2.1 PDR:

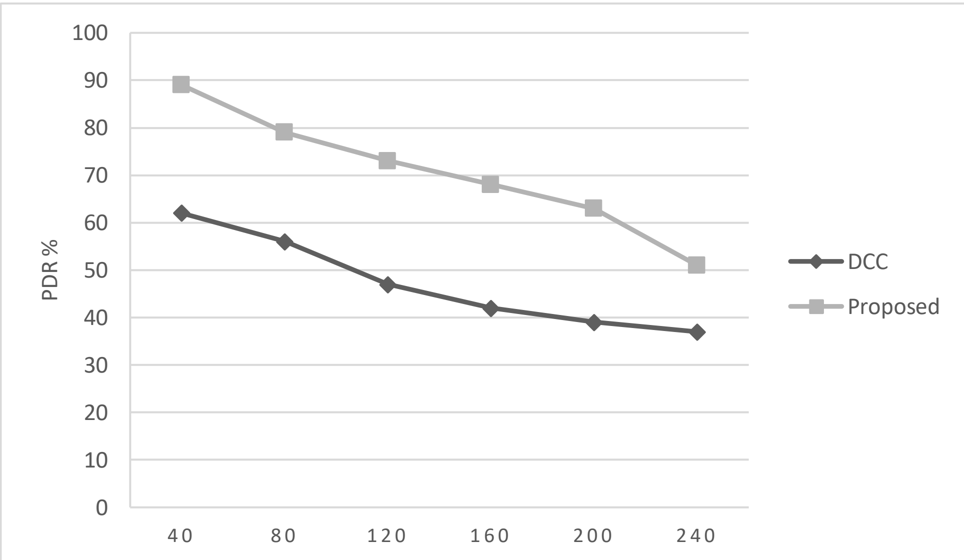

Fig. 5.1: Numbers of vehicle and PDR

Fig. 5.1 shows the effect of increasing the number of vehicles on PDR for VANET system. The results represented comparing the view of the PDR system with DCC. Here in this graph, the PDR versus several vehicles is plotted. As can be seen from the graph, by increasing the number of vehicle nodes the PDR in general for these DCC protocols will be decreased. Example of this, by using DCC protocol, PDR is increased suddenly from 62.64% to be 89.46% and then 79 for numbers of nodes become 40 and 80 respectively. This happened in the same manner for the other DCC protocols due to fewer numbers of collisions in this simulated traffic. However, the result shows the poor effect of the DCC protocol when the number of vehicles is increased. Thus, DCC is not a good choice when the number of vehicles becomes higher. Besides, the graph presents the maximum value of PDR is obtained by using the proposed algorithm which equals to 89.46%.

5.2.2 Delay:

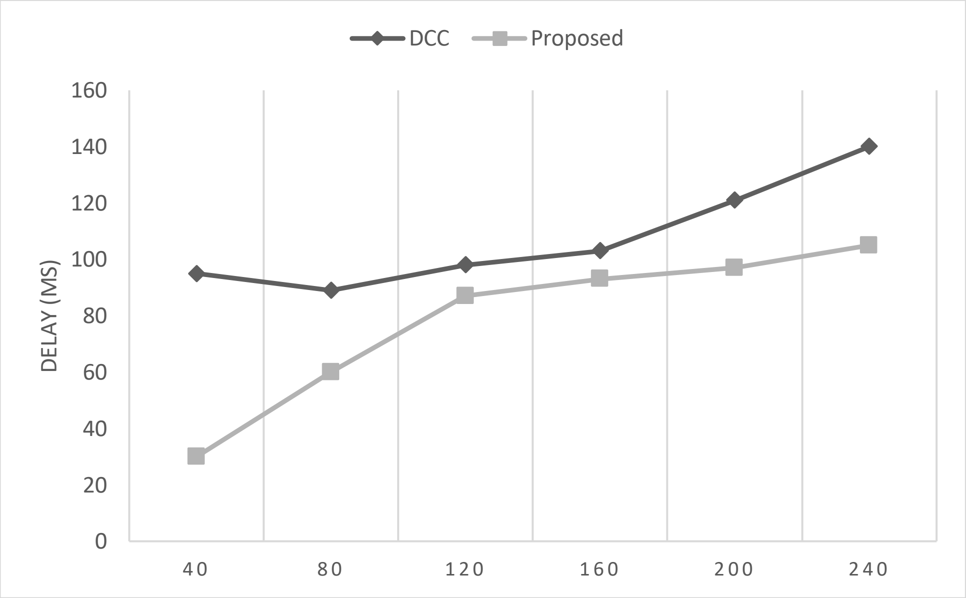

Fig. 5.2: Numbers of vehicle and Delay

Fig. 5.2 which shows delay metric to analyze the system performance, the poor effect is obtained from using DCC protocol. It can be realized that the maximum delay happened by using the DCC protocol. Minimum values of delay were 30.33ms for proposed algorithm and 95.81ms for DCC and then 60.21ms to 89ms when nodes equal to 40 and 80 respectively. Therefore, the proposed algorithm improves the system performance in terms of delay when the number of vehicles is increased.

5.2.3 Throughput:

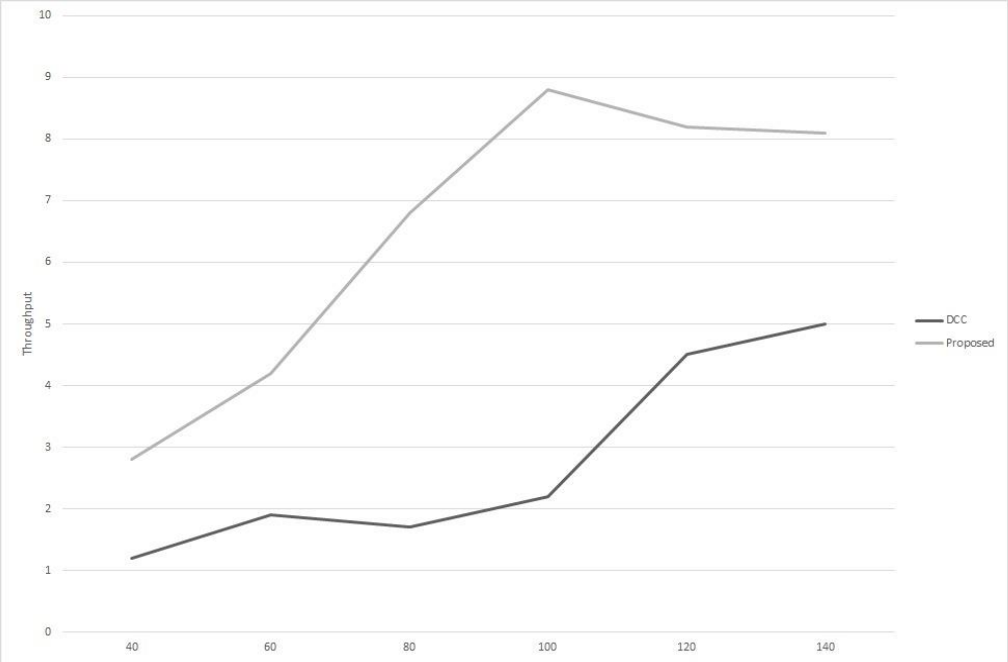

Fig. 5.3: Numbers of vehicle and Throughput

Fig. 5.3 depicts the achievable throughput as the number of vehicles increases. As shown in the fig, the proposed scheme outperforms the legacy protocol by a ratio of 5–15%. Here we analyze the system performance, the poor effect is obtained from using the DCC protocol. The maximum throughput happened by using the proposed scheme over the DCC. Throughput is increased from 1.33sec to be 2.8sec and then 2.9sec to be 4sec when nodes become 40 and 80 respectively. Therefore, the proposed algorithm improves the system performance in terms of throughput when the number of vehicles is increased.

It reveals that the proposed scheme could reduce the packet collision probability and average packet access delay without sacrificing the overall system performance. Based on the above simulation results, it is confirmed that the proposed scheme achieves high packet delivery ratio, low delay in transmission of safety messages, and high achievable channel throughput for high priority packets by employing a dynamic initial contention window size. A good communication protocol design can achieve highly reliable, highly scalable, high performance, and create secure vehicular ad hoc networks.

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Chapter 6
Conclusion and Future Work

6.1 Conclusion

VANET is a challenging network due to the high speed of vehicles, dynamic changing topology, and different quality of services requirement. For improving safety applications in VANET, we require reliable and effective MAC protocols. Due to beacon load results in congestion under high vehicle density.

Using artery simulator, we compared the DCC technique for the system better performance with the proposed algorithm. For better communication, we choose to transmit rate control. We discussed the three key performance criteria such as PDR, delay, and throughput on medium. We compared the message-rate based LIMERIC for different data-rates.

The proposed algorithm has higher performance in terms of DCC when the number of vehicles increased. In general, the results showed as the number of vehicles increases. The delay and throughput both are high when the density becomes lower.

We found that the proposed algorithm is more efficient utilization of the channel load at dense traffic densities. We try to improve the dissemination of packet transmission at a high rate using the proposed algorithm. The simulation result indicates a significant gain in the PDR, delay, and throughput which can add a huge advantage for safety applications.

6.2 Future Work

Research is needed to see how the proposed algorithm along with adapting other parameters such as message-rate, data-rate, power, etc. can be used to further improve reliability. Although the current results are based on the highway scenario, we believe that our conclusions also apply to other scenarios such as rural and urban. Future work should confirm this.

The fairness of the proposed algorithm has not been evaluated. Therefore, future work of investing in the fairness of different nodes in VANET should be conducted.

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