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Adaptive Transmission Power with Vehicle Density for Congestion Control

By

Oluwaseyi Akinlade

A Thesis
Submitted to the Faculty of Graduate Studies
through the School of Computer Science
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2018

Adaptive Transmission Power with Vehicle Density for Congestion Control

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ABSTRACT

The Intelligent Transport Systems (ITS) employs the Vehicular Ad-hoc Networks (VANET) technology to prevent and reduce accidents on highways. VANET uses wireless communication technology that includes protocols and applications that provides safety and non-safety features for a safe and comfortable driving experience. A major problem with VANET is that the network channel utilized for the transmission of network packets for awareness becomes congested due to vehicles competing to use the channel leading to packet loss, high transmission delay and unfair resource usage. These problems would eventually lead to the periodic exchange of Basic Safety Messages not being delivered on time, thereby making VANET unreliable. Researchers have focused on numerous approaches for controlling congestion on the network channel such as adapting the rate of transmission of packets i.e. the number of packets that can be sent per second or adjusting the transmission power which is the distance a packet can travel. An approach is proposed in this thesis to adapt the transmission power, based on the vehicle density state of the network, with the aim of reducing congestion on the network channel and improving the performance of VANET. Results indicate that this can lead to improved performance in terms of reduced packet loss and inter-packet delay.

DEDICATION

I dedicate this thesis to my Parents Mr & Mrs Akinlade, for their prayers, blessings and motivating words always kept me going. I was told to always do my best despite all odds and give all thanks to God Almighty. Thank you for everything you have done in my Life.

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Firstly, I would like to give thanks to God Almighty for giving me the grace, favour and will to complete my program.

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ABBREVIATIONS

BER	Beacon Error Rate
BRR	Beacon Reception Rate
BSM	Basic Safety Message
CBR	Channel Busy Ratio
CSMA	Carrier Sense Multiple Access
DCC	Decentralized Congestion Control
DSRC	Dedicated Short Range Communication
FCC	Federal Communications Commission
IEEE	Institute of Electrical and Electronic Engineers
IPD	Inter-Packet Delay
ITS	Intelligent Transport Systems
MAC	Medium Access Control
MANET	Mobile Ad-hoc Network
NS2	Network Simulator 2
OSC	Oscillating Power Control
RESCU	Road Emergency Services Communication Unit
RSU	Road Side Unit
SUMO	Simulation in Urban Mobility
VANET	Vehicular Ad-hoc Network
VEINS	Vehicle in Network Simulation
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to Anything
WAVE	Wireless Access in Vehicular Environment

CHAPTER 1

INTRODUCTION

1.1 Vehicular Ad-Hoc Network

Traffic collisions often occur due to factors such as nature of the road and vehicle, driving under the influence, skill level of driver, over-speeding which may lead to loss of life and property. There is clearly a need to make driving experience on roads safe and comfortable for both drivers of vehicles and pedestrians alike.

The Intelligent Transport System (ITS) [49] makes use of Vehicular Ad-Hoc Networks (VANET) technology [1], a subset of Mobile Ad-Hoc Networks (MANET) [50] to improve road and vehicle safety by using wireless communication to transmit data between nodes (vehicles) [1]. The communication between nodes can be described as *Vehicle to Vehicle* communication (V2V), which allows vehicles to communicate directly with other vehicles [2]. *Vehicle to Infrastructure* (V2I), allows communication between static structures such as Traffic lights and buildings [1]. (V2X), allows communication between mobile aspects of the traffic system. VANETs are typically composed of high speed mobile communication nodes i.e. vehicles moving at high velocities, possess high density of nodes on the network, constant change in topology, no energy restrictions [1][2].

1.1.1 VANET Applications

VANET applications are categorized into safety and service applications [3]. Safety Applications include Curve speed warning, Forward Collision warning, Pre-crash awareness, Left turn assist, Lane change warning, Emergency brake lights

Service Applications include traffic optimization and route guidance, infotainment applications such as Internet access, media and connectivity, and payment services such as parking and E-toll collection

1.2 Motivation

The aim of VANET is generally to increase the safety and comfort of mobile vehicle drivers and all road users on the roads. This is ensured by the nodes (vehicles) constantly sending and receiving messages or packets with other nodes and infrastructure in a vehicular network environment. The types of messages transmitted are Periodic messages, safety or event driven messages and data messages. The messages are transmitted through the channels allocated in the DSRC/WAVE system [6], with the aid of On Board units (OBU), located in the vehicles, and Road Side Units (RSU). This helps to avoid vehicle collisions thereby increasing safety and providing services necessary for a comfortable driving experience.

Congestion occurs in channels when there is saturation of the channels by nodes competing to acquire channel access [5]. Congestion control is a challenging issue in any vehicular environment. The channels on the network necessary for the transmission of these important messages may become congested due to factors such as high density of nodes, rapid topology change etc. The messages especially the Basic Safety Message

(BSM), which is under the SAE J2735 [10] protocol that contains vital information such as vehicle speed, GPS data, acceleration and many others might fail to properly reach the destination, leading to accidents and potentially loss of life and property. It is important to develop congestion control algorithms [31] to ensure congestion in network channels are reduced to ensure proper delivery of messages.

1.3 Problem Statement

An ideal vehicular network should consist of a network where packets containing vital information are sent and received between nodes in a timely manner as scheduled with minimum drop in packets or error rate resulting in accurate and timely collision warnings. In Vehicular networks congestion control encounters different challenges, due to various obstacles such as communication overhead, high rate of transmission delay, inefficient utilization of bandwidth, inefficient use of resources which affect the channel utilized for the transmission of network packets for awareness in vehicles [31].

In vehicular networks the 5.9 GHz channel with power limits of 33 dBm [11] using a communication range of 300m prescribed by Federal Communications Commission (FCC) used for safety messages and service announcements is being shared with all vehicles competing for resources and usage. Each vehicle can transmit at a rate of up to 10 beacons per second, which causes a heavy load on the channel and consequent packet collisions. Packets are only sent when a vehicle senses the channel is clear by constant monitoring of the channel [12]. The resource allocation in the vehicular network environments are not managed centrally making the channel access mechanisms of IEEE 802.11 [31] unable to prevent channel congestion when messages are broadcasted. In broadcast situations packets are not acknowledged because every vehicle sending out acknowledgement packets to every other vehicle will cause a packet explosion and extra traffic on the channel. Packet collisions and Medium Access Control (MAC) transmission delay grow exponentially when channel load is above 40% of the theoretical maximum channel capacity [13]. MAC transmission delays result in late arrival of safety messages, high packet collision rate and reduction in transmission range. A Congestion control algorithm is required to reduce the congestion without overloading the channels.

1.4 Solution Outline

Constantly transmitting packets at a fixed high transmission power without taking into consideration the dynamic topology of VANET is highly inefficient and will lead to high number of packet collisions on the channels, a large number of packets lost, high beacon error rate, degradation of the performance of VANET and congestion on the channels. The above-mentioned flaws will cause for packets to not get delivered to the vehicles that need them hence safety of vehicles on the network is at risk. An approach is proposed in this paper to control congestion by adapting the transmission power according to the vehicle density state of the road. Vehicles will broadcast packets at suitable transmission powers based on the density of the vehicles on the roads. The approach aims to reduce packets lost, Inter-Packet Delay, beacon error rate, channel busy time thereby increasing the performance of VANET. The outcome of this approach and results will be discussed in chapter 4 of this thesis.

1.5 Thesis Organization

The remaining parts of this thesis will be organized as follows. Chapter 2 will discuss and review background knowledge in this research area. Chapter 3 will discuss the approach used for congestion control and Chapter 4 will contain the analysis of the results. Chapter 5 will explain the results and relevance to future research in the VANET field.

CHAPTER 2

BACKGROUND

2.1 TERMINOLOGY

This section defines some of the important terminology used in the rest of the thesis.

- **Intelligent Transportation Systems (ITS):** A broad range of intelligent technologies which consider vehicles, infrastructure, and driver's all interacting with each other dynamically for safety, security and improving efficiency of transportation. The Road Emergency Services Communications Unit (RESCU) [16] employed by the city of Toronto is an example of the ITS system. Collision avoidance systems that use Radar, sonar and different sensors to detect potential hazards and alert drivers is also an example. The city of Minneapolis uses a Lane departure Warning system for the bus fleet to allow transit buses to safely drive on the shoulder lane of the interstate [53].
- **Vehicle to Vehicle Communication**: This is simply communication between two vehicles by using wireless technology.
- **Vehicle to Infrastructure**: Wireless communication between a vehicle and road side units (RSU).
- **Dedicated Short Range Communication**: Defined by the United States District of Transportations as a two-way short to medium-range wireless communications technology [17] capable of high data transmissions in safety-based applications for vehicular networks.

- **Wireless Access in Vehicular Environments**: Wave technology is the next generation Dedicated Short Range Communication technology capable of high-speed V2V and V2I wireless communication with significant applications in ITS which operates on 5.850-5.925 GHz band with data rates of 6-27 Mbs/s [18].
- **Congestion:** Congestion occurs in channels when there is saturation of the channels by nodes competing to acquire channel access [5] leading to packet delay, packet errors, inefficient channel utilization etc.
- **Congestion Control Algorithms**: These are the protocols or strategies designed to prevent and control congestion in the channels [5]. These are designed to improve VANETs.
- **Decentralized Congestion Control**: DCC is a specification in the European Telecommunications Standards Institute (ETSI) in which the strategy is to avoid degradations such as packet transmission delays, packet losses, reduction in communication range by limiting the load of each vehicle on the channel and not exceeding a certain threshold [11].
- **Basic Safety Message**: Messages required by V2V safety applications for low latency and localized broadcast [19] in VANETs containing vehicle information such as Vehicle size, speed, position, acceleration etc.
- **Medium Access Control**: In a vehicular environment Mac layer enables a decentralized behavior in which vehicle nodes can communicate without joining the network. It eliminates the need for a central manager controlling the channel access [20]. The MAC mechanism is based on the IEEE 802.11 Distributed Coordination Function (DCF), It is a contention-based mechanism which relies on

the Carrier Sense Multiple Access plus collision avoidance (CSMA/CA) to arbitrate channel access [26]

- **Cooperative Awareness Messages**: These are messages sent between vehicles that show current awareness of all surrounding vehicles and their status used for safety applications. Vehicles with safety applications store a relational table consisting of vehicles stored in a neighbors table and vehicles that should be stored [21].

2.2 Dedicated Short Range Communications/ Wireless Access in Vehicular Environments (DSRC/WAVE)

Dedicated Short Range Communication [4] is a standard for VANET employed in North America by the Federal Communication Commission, which allocates 75 MHz of Spectrum in 5.9 GHz bandwidth [5] for Vehicle to Vehicle communication and Vehicle to Infrastructure communication. The transmission ranges are between 10-1000m and 3-27 Mbps for rate.

Wireless Access in Vehicular Environments (WAVE) belongs to the IEEE 1609 and IEEE 802.11p family of standards, which provide services and interfaces that enable secure vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication, multi-channel operations, management of network services, enhanced navigation and many other applications [1][6]. The WAVE architecture components are the On-Board Units (OBU) found in vehicles, Road Side Units (RSU) such as traffic lights, and finally WAVE technology [7].

2.2.1 DSRC/WAVE Standards

The wave protocol stack comprises of the Society of Automotive Engineers SAE J2735 [8], IEEE 1609 [9] and IEEE802.11p family protocol of stacks.

- IEEE1609.0 Draft Standard for WAVE: Architecture necessary for Multi-channel DSRC/WAVE devices to communicate in a mobile vehicular environment.
- IEEE 1609.1 Trial Use Standard for WAVE: Resource Manager that describes the data and management services offered by the WAVE architecture for safety and service applications.
- IEEE 1609.2 (Trial Use Standard for WAVE: Security Services for Applications and Management Messages.
- IEEE 1609.3 Trial Use Standard for WAVE: Networking Services
- IEEE 1609.4 Trial Use Standard for WAVE: Multi-Channel Operations
- IEEE P1609.11 Over the Air Data Exchange Protocol for Intelligent Transportation Systems (ITS)
- IEEE802.11P Part 11 Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications

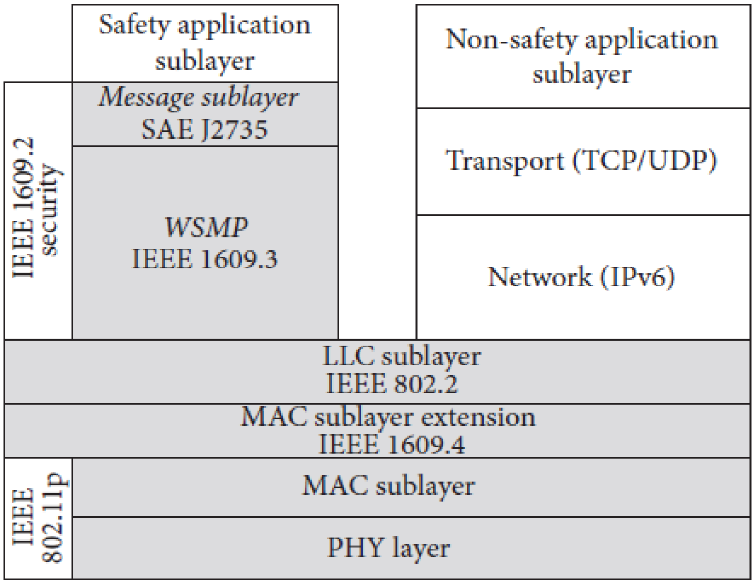


Figure 1: DSRC/Wave Architecture

2.3 Basic Safety Messages

Vehicle networks periodically exchange single-hop status information broadcasts otherwise known as beacons [14] or *basic safety messages* (BSM). The basic safety messages are the most important message type for awareness on vehicular networks because it is constantly being exchanged with nearby vehicles or roadside units. BSM's utilize the DSRC protocol stacks to deliver these messages, from the lower layers by the IEEE 802.11p to the upper layer protocols covered by the IEEE 1609.x series of standards. The BSM transmit rate is set to 10Hz by the North America Safety Pilot Model [15] and can also be reduced if channel load is high. The contents of basic safety messages include:

PART 1 DATA ELEMENT: A Mandatory representation of Vehicle State [15]

- DSRC message ID
- Message count

- Latitude/Longitude
- Current Time
- Position Accuracy
- Transmission and Vehicle Speed
- Steering Wheel Angle
- Acceleration
- Braking State, Status
- Vehicle Size
- Path history
- Front and Rear Wiper Status
- Steering Wheel Angle
- Lights Status (headlights, turn signals, hazard light)
- Differential GPS corrections

PART 2 DATA ELEMENT: Optional Information

- Vehicle, Bumper heights
- Throttle position
- Vehicle mass
- Vehicle type
- Vehicle identification number (VIN)
- Tire conditions
- Cargo weight
- Daily solar radiation

- GPS status and quality

2.4 Fundamental Concepts of Congestion Control

The goal of congestion control is to enhance the performance of VANETs by controlling congestion on the channels, reduce packet loss and delay, increase throughput and providing a safe and reliable environment for VANET users.

Congestion control utilizes different approaches to adjust and determine the transmission parameters. The classes include:

Reactive Congestion Control: It takes actions to reduce channel load after congestion on a channel is detected [22]. This system basically gathers information about the status of channel congestion and decides what actions are to be taken.

Proactive Congestion Control: Proactive systems estimate channel load under given sets of parameters, uses optimization algorithms to then determine the maximum Power or Rate setting that are needed to limit the maximum congestion level [23]. It uses number of surrounding nodes and data generation patterns to estimate the transmission parameters [22].

Hybrid Congestion Control: Hybrid approaches combine Reactive and Proactive systems for congestion control. Tielert et al in [51] used joint power and rate to control congestion. Javed et al [52] used a combined transmission range and packet generation rate control algorithm that considers safety of the vehicles and maximizes channel utilization.

2.5 Performance Criteria

The performance criteria also known as performance metrics are the basis to examine performance of congestion control schemes. Some common performance metrics for congestion control algorithms are outlined below.

Fairness: Fairness is a performance metric to determine quality of a DCC scheme. It is the ratio between maximum and minimum of the number of channel access opportunities of each vehicle on a vehicular network [13]. In some cases, it represents the performance of a network instead of individual vehicles. In [24] Batsuuri describes an ideal "fair" case in his example saying each vehicle has a Successful Packet Reception (SPR) rate of 80%. An unfair situation includes one in which some vehicles have an SPR of 100% and some will have as low as 10%.

Transmit Rate: This is the number of transmission opportunities within a given time interval in a vehicle [13].

Beacon Reception Rate (BRR): This is the most common metric used to evaluate the performance of a network, a good measure for awareness. It is the number of packets or beacons received from a vehicle with an interval of 1s [13]. Safety applications depend on the successful receptions of the messages sent. An increase in the beacon reception rate relates to an increase in awareness for neighboring vehicles.

Beacon Error rate (BER): Frequent broadcast of Basic Safety Messages at high rates such as 10Hz to increase awareness [25] especially in dense environments increases packet collisions. The collisions result in reduction in quality of the beacons sent. The information carried by the beacons will contain errors and useful data missing. Errors in the packets will lead to the packet not being used and eventual wastage in network resources. Awareness and fairness is reduced due to this rate of high packet collisions and errors.

Efficiency of Cooperative Awareness: It is measured by the packet success rate which is dividing the Number of decoded packets by the number of received strong signals [27].

Channel Busy Ratio (CBR): The channel busy ratio is a good measure for channel load. It is the overall observation time and the time a channel is sensed to be busy. The total observation time is usually set to 100ms [13]. The CBR is dependent on the congestion control scheme utilized. It is also an input for congestion control. CBR represents the fraction of time a channel is busy.

Inter-Packet Delay (IPD) or Update Delay: This is the delay time between subsequent packets received from the same sender [37] [38].

2.6 Current Research Problems and Solutions

Unrealistic Simulation of Traffic Scenarios

In this field of research majority of the VANET traffic scenarios are performed with simulators due to the high cost of operating in real world scenarios. The current simulators being used have come a long way from previous simulators which assumed unrealistic models. An example is the mobility model, the scale of the map, distance and speed used in simulators doesn’t always translate to real world. These factors might affect how vehicles frequently receive messages subsequently affecting how congestion in the channels are controlled.

Specific Improvement of Performance Metrics

Majority of congestion control schemes only focus on specific performance metrics such as CBR, Throughput, Reception rate etc. only and not schemes that collectively improve the network performance with minimum trade-off [28].

Lack of transmission of non-safety beacons

In dense traffic situations, priority is given to the transmission of safety messages over non-safety messages which is an open issue. A scheme should be developed to utilize the control channel properly so both messages can be delivered at the same time.

Generation of Extra Packets

Congestion control schemes might on some occasions generate extra packets during the transmissions of messages creating awareness of the current congestion situation, the additional packets sent increase channel load therefore creating communication overhead and a packets storm leading to further congestion on the network [29].

Beacon Rate Reduction

An increase in transmission rate allows safety applications to function better due to frequent updates in safety messages received. In high vehicle density scenarios, transmitting beacons at a high rate the control channel might become overloaded and eventually congested. Reducing the beacon transmit rate results in safety applications having a failure or delay in messages received [31].

Transmission Power Increase

Congestion control schemes that are based on adjusting the transmit power only have a problem when safety messages are transmitted at high power, so packets can be received by vehicles at a greater distance. The number of vehicles receiving messages greatly increases leading to packet collisions on the channels and congestion on the network from all vehicles competing for channel access. Jordan [31] in his paper developed a scheme to oscillate between high power and low power transmissions so vehicles that are near receive more packets and vehicles that are far also receive packets but fewer.

2.7 Literature Review

This section discusses the important research papers related to congestion control on Vehicle to Vehicle networks. The ideas, algorithms, parameters, performance criteria's, limitations and comparison with other schemes will be observed.

An algorithm that deals with power adaptation in an interesting manner is the Decentralized Congestion Control Algorithm for Vehicle to Vehicle Networks Using Oscillating Transmission Power [31]. The author proposes a novel method for adapting the transmission power in an Oscillating manner which alternates between high and low powered transmissions. The algorithm attempts to solve the problem of reducing the number of packets received by vehicles at greater distances while increasing the packets received by vehicles nearby thereby, increasing awareness to nearby vehicles who need the packets for frequent updates. Two drastically different powers and rates are selected for the algorithm, the rates are then combined to select a Low Powered Packet Interval (LPPI) which is the number of low powered packets that should be sent between high powered packets [31]. The author also modified the

OSC algorithm to include a rate control algorithm called LIMERIC [35] to further control congestion according to the CBR. The performance metrics considered were Beacon Error Rate, Beacon Reception Rate, Channel Utilization, Channel Busy Time, Inter-Packet delay.

The simulations were carried out using the Vehicle in Network Simulation framework (Veins) [32] to connect the OMNET++ Discrete event network simulator [33] and Simulation of Urban Mobility (Sumo) [34], in parallel. The results of the simulation proved that the OSC method was able to reduce the number of packets sent to distant vehicles while packets were sent to nearby vehicles at a high rate. The channel utilization also showed a decrease in congestion compared to a 10 Hz control with no congestion control algorithm used. High channel utilization might lead to increase in PER is a limitation observed.

The Linear Message Rate Integrated Control (LIMERIC) [35] is a linear adaptive control algorithm which adapts message rate so the CBR does not go beyond a specific limit [13] and executed by each vehicle on a network unlike other similar approaches which used a binary control. LIMERIC results show a provable convergence to fair and effective channel utilization [13]. LIMERIC also avoids fairness problems observed in algorithms that use binary control. LIMERIC is shown to quickly adapt to changing network conditions. LIMERIC was compared with other DCC schemes [36] which included a 10 Hz control + DCC, CAM + DCC then lastly a 10 Hz control. SUMO and NS2 were used to perform the simulations. Numerical results showed that the CAM + DCC control had the highest packet error rate, 10Hz and LIMERIC had similar PER, 10 Hz recorded lower Inter-Packet Delay compared to LIMERIC, LIMERIC shows lower reception intervals and tracking error than DCC schemes used. LIMERIC's ability ensures max throughput and awareness irrespective of vehicle density [36].

Integration of Congestion Control and Awareness control (INTERN) [39] was described as a scheme that integrates congestion and awareness control processes. INTERN proposes a scheme that dynamically adjusts the transmission rate and power of the beacons of each vehicle, so application requirements are satisfied at the same time controlling channel load [39]. The objectives are to have vehicles use minimum transmission settings which satisfy individual vehicles application requirements under dense traffic scenarios and enable the increase of transmission settings under low traffic scenarios so desired CBR is achieved. Performance of INTERN was evaluated using MATLAB in different scenarios and compared against schemes such as Minimum Packet Transmission Frequency (MINT) [40] an awareness control protocol and a congestion control scheme combining LIMERIC and PULSAR [38].

Results show that INTERN can maintain the CBR below CBR_{max} in scenarios with low and medium traffic scenarios. Maintenance of stable levels of the channel load and application effectiveness is also observed in the literature.

The Centralized and Localized Data Congestion Control Strategy for Vehicular Networks Using a Machine Learning Clustering Algorithm [41] deals with congestion control in Urban Areas. The literature discusses that intersections are very critical locations where accidents, injuries and fatal loss of life and property occur. In the paper a centralized and localized data congestion scheme is proposed to control data congestion using Road Side Units (RSUs) at traffic intersections. It uses three methods to detect congestion, clustering of messages and finally controlling congestion on the channels. The channel usage level is the performance criteria for detecting congestion in the channels. K-means clustering algorithm is used for clustering the gathered and filtered messages based on factors such as size of messages, validity of messages and type of messages. The clustered messages are then passed through the data congestion unit which assigns proper values to parameters such as transmission rate, range, Contention Window Size (CW) and Arbitration Interframe spacing (AIFS) for each cluster of messages. The RSUs situated at the intersections transmit the appropriate information to vehicles that are stopped at red traffic signals to help reduce packet collisions thereby reducing congestion on the channels. The aim of the literature is to improve on throughput, delay and packet loss ratio compared to other congestion control strategies. The author mentioned that intersections are highly critical places with the most likelihood for the occurrence of traffic collisions and reported the death of 800 road users and 7250 seriously injured at intersection traffic collisions [42]. The reason for congestion occurring on the channels at intersections is due to the high rate of vehicle density at red lights and it affects the Quality of Service (QoS) of VANET systems [43]. A congestion area is formed before the traffic lights due to the large amount of communication between vehicles resulting in high packet loss and increase in packet delay in the immediate area. The centralized strategy operates in each RSU located at the intersections. The Congestion Detection Unit works by measuring the channel usage level unlike other strategies that sense the channels periodically to measure parameters such as messages in the queue and channel occupancy time [44].

Congestion is assumed to occur when the channel usage level exceeds a predefined threshold. The Data control unit utilizes Unsupervised Machine Learning algorithms [45] which are used for unlabeled data and do not need to employ a training data set. The proposed K-Means Unsupervised Algorithm used for the clustering works by firstly selecting initial centroids for K clusters, Secondly Computing the squared Euclidean distance of each data of the centroids, thirdly computing the new centroids cluster to find closest centroids then the second and third steps are repeated until a change in cluster members no longer exist [46] [47].

The Congestion Control Unit discussed in the literature adjust communication parameters for the individual clusters set by the data control unit. The strategy selects values of the parameters according to the range of values defined by the DSRC standard [1], the data rates are in the range of 3-27 Mbps and 10-1000m for the transmission range. The proposed strategy adjusts the parameters by using the formulas estimated in [48] [34] to calculate the delay for the centroid of each cluster and by considering all possible combinations of the communication parameter values. The values corresponding to the lowest delay are selected as the communication parameters of each cluster. The RSUs then send the parameters to the vehicles located before the red lights at the congestion area and the vehicles based on this information for congestion control.

The Simulations were carried out using SUMO, NS2 and Mobility model generator for Vehicular networks (MOVE). An Urban scenario was simulated using the Manhattan road pattern with eight intersections, Nakagami model for a propagation delay model and Poisson distribution for data generation. Performance metrics considered were Average delay, Average Throughput, Number of Packets Lost, Packet Loss Ratio, Collision Probability and Packet Delivery Ratio.

The scheme was compared against CSMA/CA, D-FPAV, CABS and NC-CC Strategies and results showed that the proposed strategy in the literature outperformed the other strategies. It improved the performance of VANETs by reducing the packet loss ratio, average delay, increased throughput and packet delivery. The limitation discovered is the computation time due to the Machine Learning Algorithm conducting large calculations.

CHAPTER 3

PROPOSED VEHICLE DENSITY BASED POWER CONTROL ALGORITHM

3.1 Introduction

The topology of VANET is extremely dynamic as vehicles go in and out of the transmission range rapidly, which has an effective max distance for packet delivery at 1000m. The purpose of the network congestion control algorithm proposed in this thesis is to reduce congestion on the network by adjusting the transmission power according to the current density of nodes (i.e. vehicles) on the roads. The number of vehicles includes both parked and moving within the transmission range of the ego vehicle. The goals of the proposed algorithm are:

- reduce Inter-Packet Delay (IPD),
- reduce the rate of lost packets,
- reduce channel busy time, and
- reduce Beacon Error Rate

This will lead to increased throughput of the network, lower delay in communication and generally improve the safety of vehicles on the road.

3.1.1 How It Differs from Existing Approaches

The proposed algorithm differs from other algorithms in this field by:

- Adjusting Transmission power based on vehicular density.
- Using the Traffic command Interface of the simulator to determine the traffic conditions or node density as opposed to using Local density estimates [54].

The approaches discussed in chapter 2 all made use of various methods ranging from acting upon specific parameters to maintain a certain threshold to reduce congestion and combining multiple factors for congestion control. In [31] the author of the paper used an oscillating power control to adjust transmission power to alternate between high power and low power transmissions by intentionally sending a number of low powered packets to reach vehicles that are nearby followed by sending fewer high power packets to reach vehicles that are distant, prioritizing awareness for vehicles that are nearby. Awareness is sacrificed and there is an increase in IPD for distant vehicles. Compared to the oscillating power approach [31], the proposed approach can effectively reduce the IPD, by considering node densities leading to an improved awareness for the vehicles.

3.2 High Level Outline

The proposed approach is based on how a single vehicle i.e. ego vehicle should adapt its transmission power according to the current vehicle density condition on the road and broadcast packets to other surrounding vehicles on the road accordingly. There is need for the transmission power to be controlled in the Medium Access Layer (MAC) to address situations such as:

1. A single high transmission power at a high vehicle density will lead to packet congestion, leading to packet collisions and lost packets, which will cause reduction in VANET performance.
2. A single low transmission power at low vehicle densities will most likely result in awareness problems since distant vehicles will be unable to receive the packet.
3. Using the same transmission power at various vehicle densities will lead to wastage of resources and/or poor performance of the network.

The above-mentioned situations are addressed in the proposed approach. The algorithm is split into two parts, the first is for acquiring the current number of vehicles either in a parked state or driven state presently on the road. The second is for allocating the transmission power to be used.

```
1. Select maximum transmission range, calculate the required transmission power based on the transmission range.
2. For each packet a vehicle sends, repeat steps 4-5
3. Procedure SetVehicleDensity
      a. VehicleCount = getVehicleCount()
      b. if (VehicleCount ≥ 100) then VehicleDensity← Dense
      c. else if (50 < VehicleCount && VehicleCount < 100) then VehicleDensity ←Moderate
      d. else if (VehicleCount ≤ 50) then VehicleDensity←Sparse
      e. end if
      f. end procedure
4. Procedure AllocateTransmissionPowerLevel
      a. if  VehicleDensity= High  then setTxPower (LowTxPower)
      b. if  VehicleDensity= Moderate then setTxPower (MediumTxPower)
      c. if  VehicleDensity = Sparse then setTxPower (HighTxPower)
      d. end if
      e. end procedure
```

Figure 3.1: Proposed Algorithm

In the simulation environment to be used an initialization method is called at the beginning of the simulation to load the necessary modules when a vehicle is created in the simulation. A maximum transmission range is selected, which is the maximum distance a packet can travel in the network. In our simulations, this is set to 1000m and corresponds to the highest transmission power level. The maximum packet transmission rate is also selected at a constant rate of 10Hz i.e. 10 packets are sent every second to neighboring vehicles. A reduction in the transmission rate will cause delay in significant or critical safety messages that are needed to be delivered in a specific time period [55]. The first part of the pseudocode in Figure 3.1 (step 4. a-f) counts the numbers of vehicles presently on the road and determines if the vehicle density state is *Dense*, *Moderate* or

Sparse as vehicles enter and exit the network. A flowchart for these steps is shown in Figure 3.2

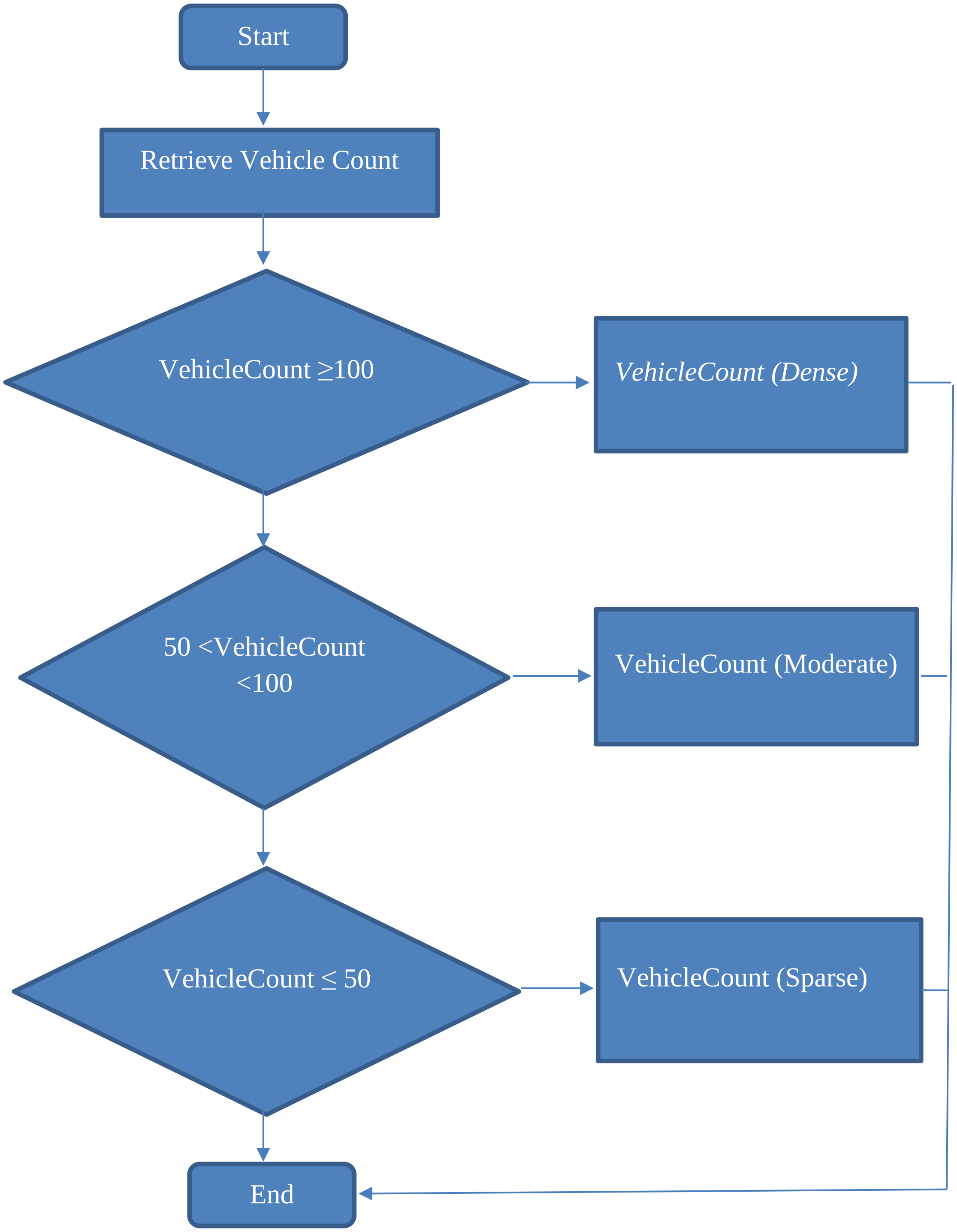


Figure 3.2: Flow chart showing vehicle density state

A *dense* density state is when there are more than 100 vehicles present on the road. This can be due to various reasons such as accidents, traffic lights, poor driving abilities, and rush hour times. Traffic speeds are usually low, and vehicles are closer to each other. A *Moderate* density state is when there are 50 to 100 vehicles presently on the road. This is usually free flowing traffic. A *Sparse* state is one in which there are less than 50 vehicles presently on the road. The vehicles are thinly spread apart or faraway from each other, with high vehicle speeds, and traffic is free flowing. A pictorial representation of the three density levels are shown in Fig. 3.3 - Fig. 3.5.

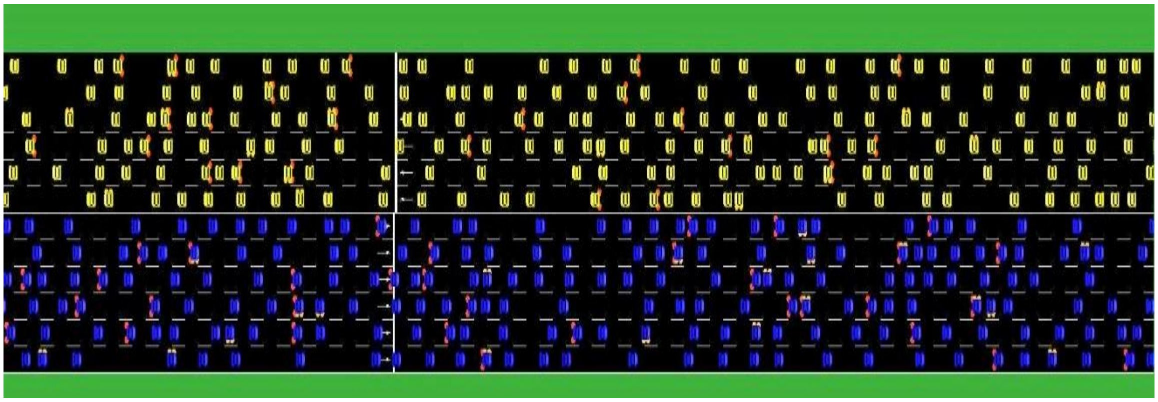


Figure 3.3: A Dense vehicle state

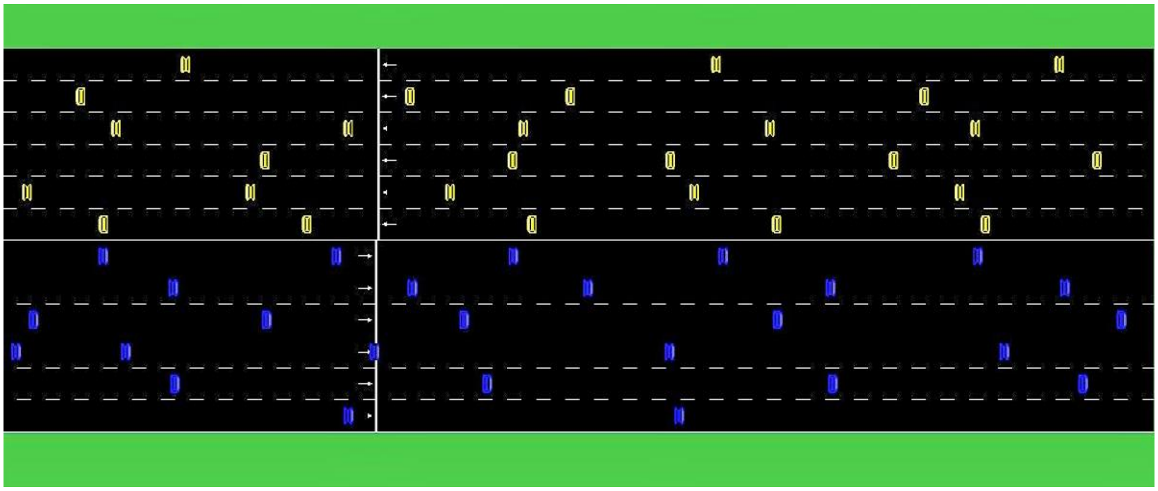


Figure 3.4: A Moderate vehicle density state

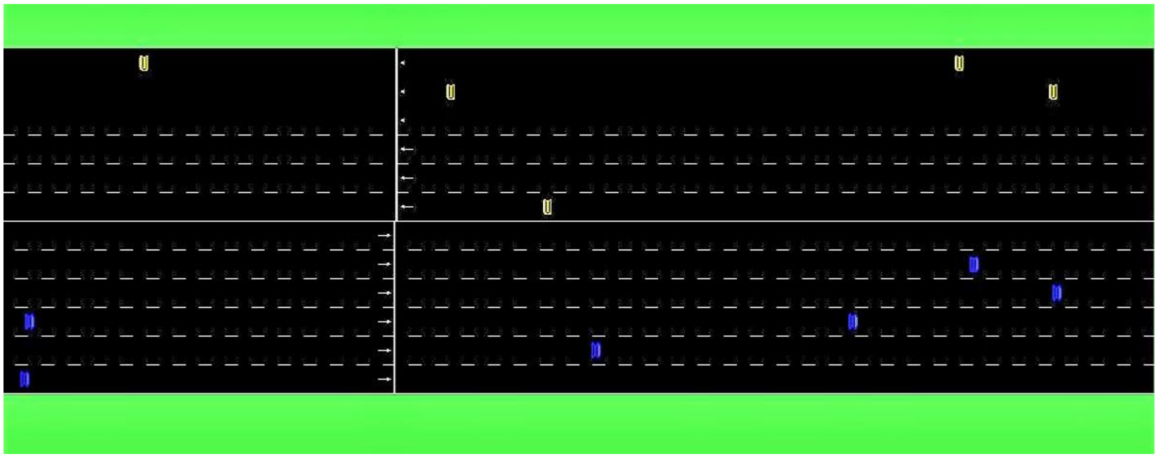


Figure 3.5: Sparse vehicle density state

The second procedure involves the allocation of the transmission power for the various vehicle density state mentioned. The *Dense* traffic density state is assigned a low transmission power. This is reasonable because of the proximity of the vehicles, so that the low power packets can reach the neighboring vehicles. A high transmission power in a dense environment may cause a high number of packet collisions and congestion which will reduce performance of VANET.

The *Moderate* state is assigned a medium power, a power that is not too low that packets will not get delivered to vehicles faraway and just high enough to accommodate vehicles that are afar. The *Sparse* state is assigned a high transmission power to make provision for vehicles that are far away from each other due to the low number of vehicles on the road and relatively high speeds. A flowchart for these steps is shown in Fig. 3.6

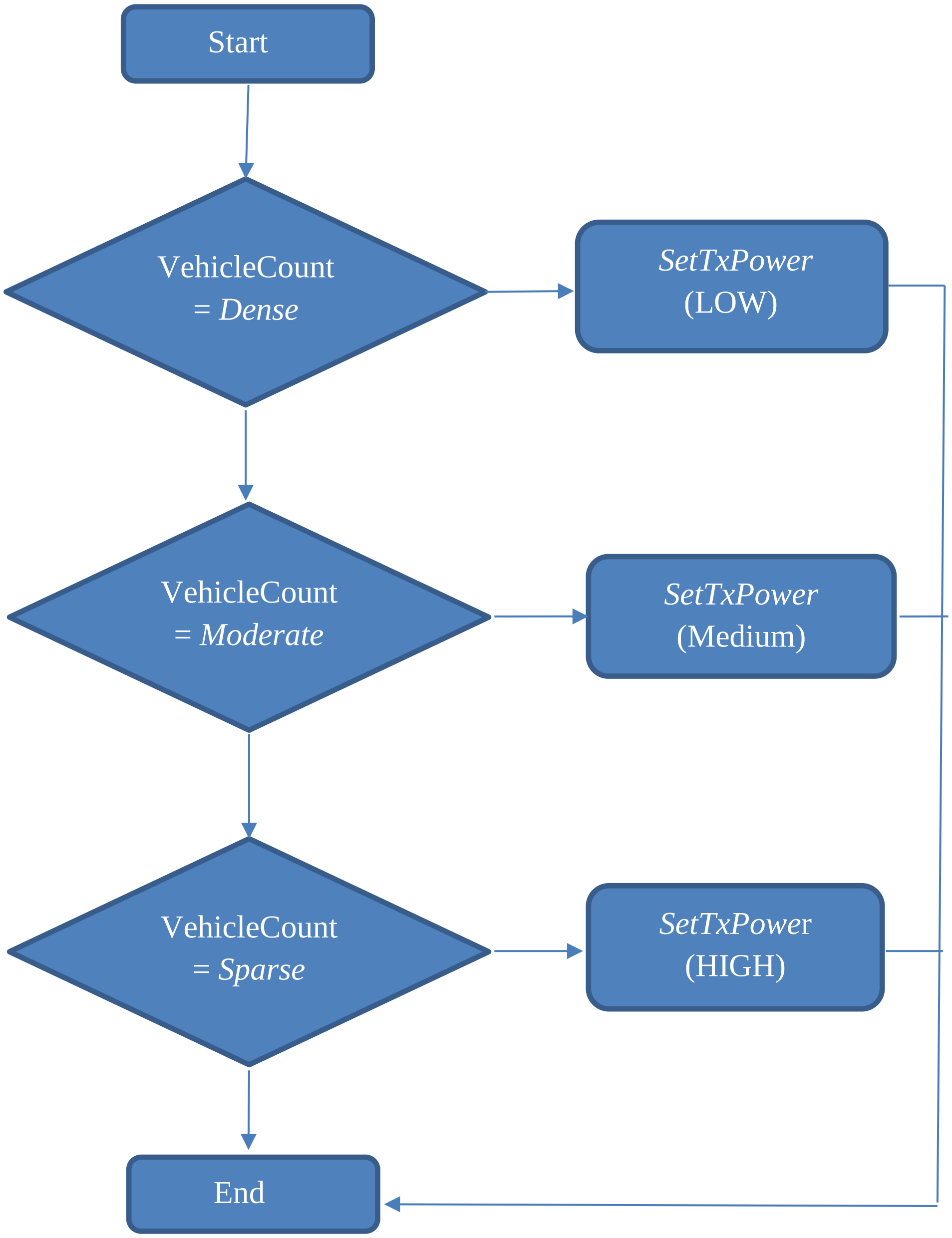


Figure 3.6: Procedure for assigning transmission power

CHAPTER 4

SIMULATIONS AND RESULTS

4.1 Simulation

Real world practical experiments of VANET are not feasible due to the time-consuming nature and large amount of resources that are required to conduct the experiments safely and for significant results to be obtained, hence the need for simulators to carry out the experiments which are safe, cheap and can replicate the VANET scenarios. A collection of open source software is used to simulate our work which would consist of a software to simulate vehicle mobility or traffic scenario and another to simulate the network communication between the high speed mobile nodes. The Simulation of Urban Mobility (SUMO) [34] tool which is widely used in this research field was used for the simulation of road traffic. It is implemented in C++ and includes features such as explicit Microscopic simulation for simulating vehicles, pedestrians and public transport, generation of time schedules for traffic lights and supports the import of real world maps. The simulations are deterministic by default, but parameters are set in place to introduce randomness. The network is modeled using OMNET++ [33] and Vehicles in Network Simulation (VEINS) [32]. OMNET++ is a Discrete Event Simulator which is an extensive, modular, component-based C++ library and framework for building networks such as wired and wireless communication networks, queuing networks etc. and support of wireless ad-hoc networks, internet protocols, photonic networks etc. Figure 4.2 shows the simulation environment in OMNET++ with nodes. VEINS contain detailed models of the IEEE 802.11P and IEEE 1609.4 DSRC/WAVE network layers and is the tool that connects the traffic scenario (SUMO) with the network simulator (OMNETT++) to simulate VANET scenarios and protocols. VEINS was modified to include the proposed algorithm and collection of the results and statistics.

4.1.1 Simulation Setup

Parameter	VALUE
Simulation Duration	50s
Max Transmission Range	1000m
Bitrate	6Mbps
Sensitivity	-89dBm
Thermal Noise	-110dBm
Transmission Rate	10Hz
BSM size	250 Bytes

Table 4.1: Simulation Parameters

The proposed approach was tested using three scenarios which are:

- A Six-lane highway consisting of three lanes in both directions
- A Twelve-lane highway consisting of six lanes in both directions
- A Twelve-lane highway consisting of six lanes in both directions and a slow-moving traffic to stress the network

The length of roadway was 900m with vehicles having a max speed of 80km/hr for the six and twelve lane roads then 50km/hr for the twelve-lane road built to stress the network. SUMO utilizes a route configuration file for the vehicle and traffic route parameters. The parameters include acceleration, deceleration, vehicle type, color, min-gap between vehicles, impatience of the drivers, max speed, emission class, depart lane and so on. Vehicles enter and exit the traffic simulation depending on the set route as shown in Figure 4.1. Vehicles were added into the simulation at a constant rate of 0.1s in any random lane with space availability.

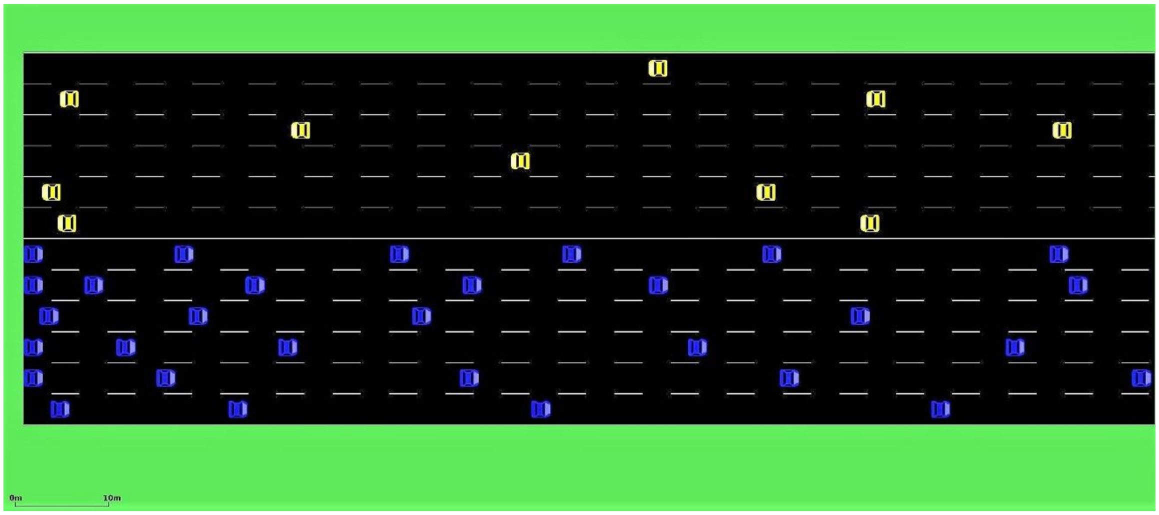


Figure 4.1: Vehicles created in SUMO entering and exiting the road network

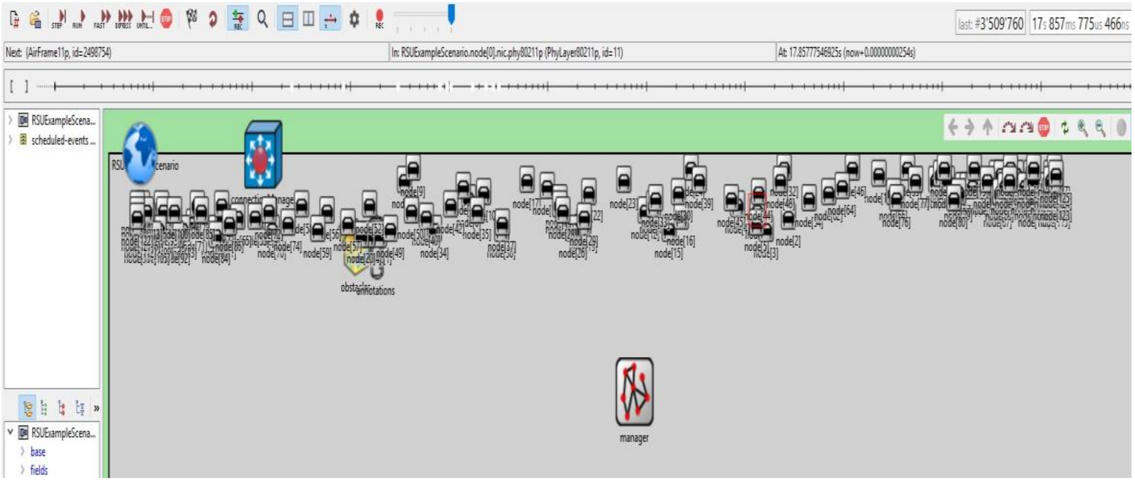
The proposed approached is implemented in the veins source files which consist of the various modules necessary for the use of the DSRC/WAVE protocol such as the MAC module where the transmission power can be controlled, messages module for creating and controlling the type of messages to be sent, a settings file that consist of all predefined parameters for running the simulation in OMNET++ and so on. Only Basic Safety Messages were broadcasted in the simulation because they are the most important messages when it comes to safety. Some of the information contained in the BSM packets are:

- Sender ID
- Receiver ID
- Sender Speed
- Sender Position

4.1.2 Simulation Runs

The scenarios for the simulations were all run in the OMNET++ network environment for 50 seconds at a transmission rate of 10Hz and a maximum transmission range of 1000m. The network simulation environment shows the modules used, nodes presently in the simulation broadcasting messages, time of simulation. Road side Units were not used in the simulation because it is a V2V network scenario. Three simulations were run for each traffic scenario which are:

1. The 10Hz transmission rate without the use of a congestion control algorithm
2. The Oscillating Power algorithm
3. The proposed Adaptive power with vehicle density algorithm



last: #3'509'760

17s 857ms 775us 466ns

Next: (AirFrame11p, id=2498754)

In: RSUExampleScenario.node[0].nic.phy80211p (PhyLayer80211p, id=11)

At: 17.85777546925s (now+0.00000000254s)

Figure 4.2: OMNET++ Environment showing a network simulation in progress

4.2 Simulation Results

The results collected in the simulations are discussed in this section. At the end of the simulations scalar values were collected from each vehicle and calculated to obtain the results below:

- Packets Sent
- Packets Received
- Packets Lost
- Beacon Reception Rate
- Beacon Error Rate
- Channel Activity
- Inter-Packet Delay

The total number of vehicles generated during the simulations varied for the different road traffic scenarios used due to factors such as number of lanes and space availability but did not change for the different approaches meaning the simulation generated the same number of vehicles when the different approaches were used on a specific road.

Scenario	Number of Vehicles
6 Lanes	137
12 Lanes	272
12 Lanes (Slow)	280

Table 4.2: Total number of vehicles generated

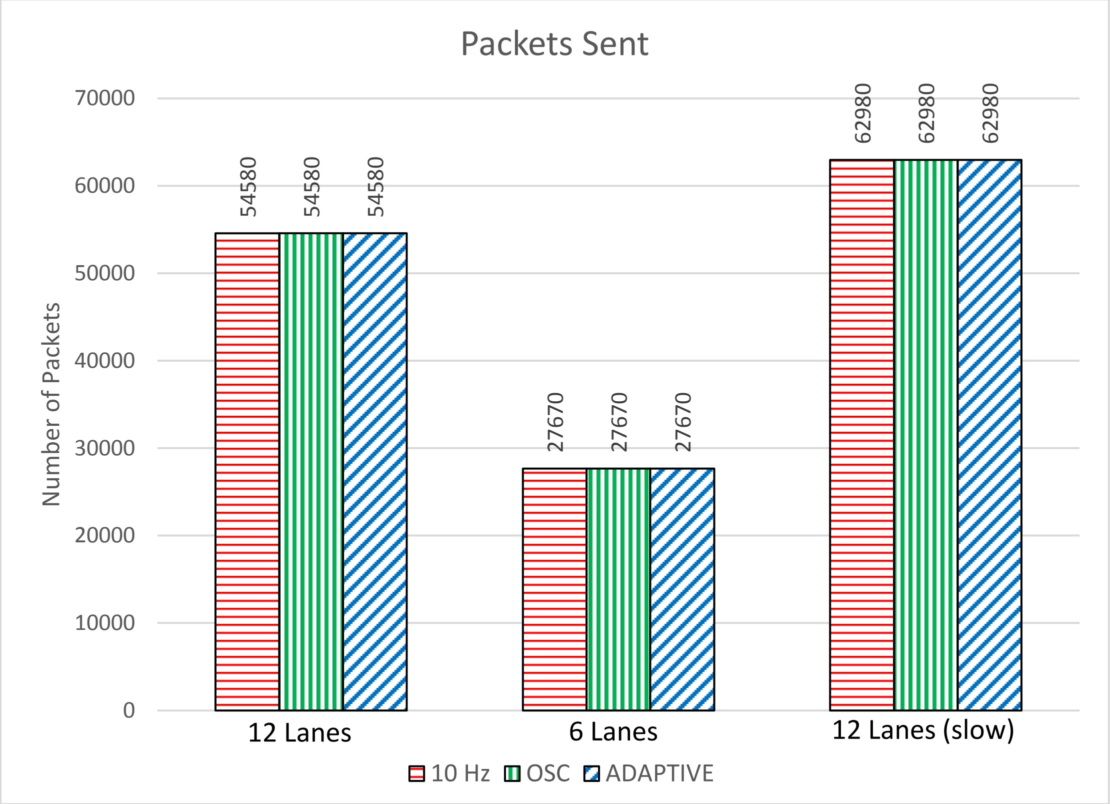


Figure 4.3: Total Packets Sent

4.2.1 Packets Sent

Figure 4.3 shows the total number of packets sent by all the vehicles by the congestion control approaches used in the three road scenarios. The three approaches investigated all sent the same number of packets to the surrounding vehicles in the network which is expected due to the deterministic nature of the road traffic simulator (SUMO) and the fixed transmission rate of ten packets per second utilized. The twelve lanes with 50 km/hr sent the most packets because it had slower moving traffic and slightly more vehicles generated than the 12 Lanes with 80 km/hr traffic.

4.2.2 Packets Received

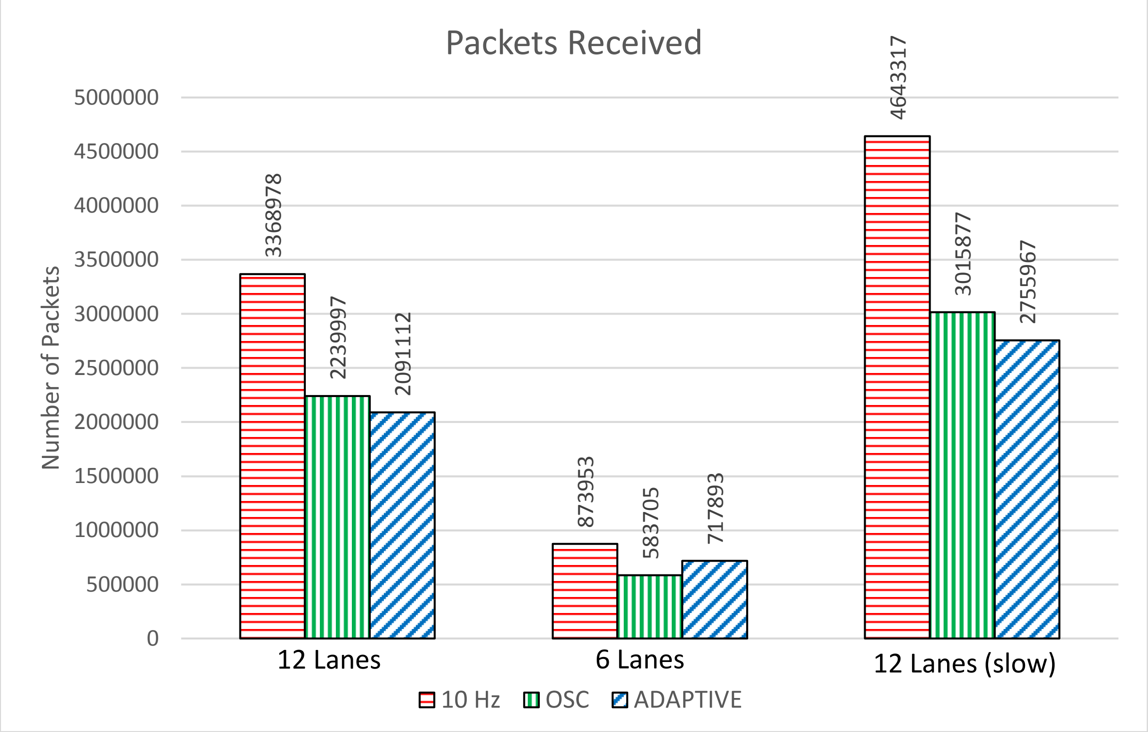


Figure 4.4: Total Packets Received

The total number of packets received by the vehicles in the scenarios vary by the congestion control algorithm used. It is shown in figure 4.4 that the 10Hz with no congestion control algorithm used receives significantly more packets compared to OSC power control and the adaptive method that adjust transmission power with vehicle density. This occurs due to the fixed high power used by the 10Hz approach and the broadcasting of packets to all vehicles in the simulation regardless of how great the distance of the vehicles which will lead to congestion in the network. The congestion control algorithms all receive less packets which is expected because of the control methods used regarding the transmission power. An approach receiving more packets compared to the other does not necessarily mean it outperforms the other approaches in terms of reducing congestion in the network.

4.2.3 Lost Packets

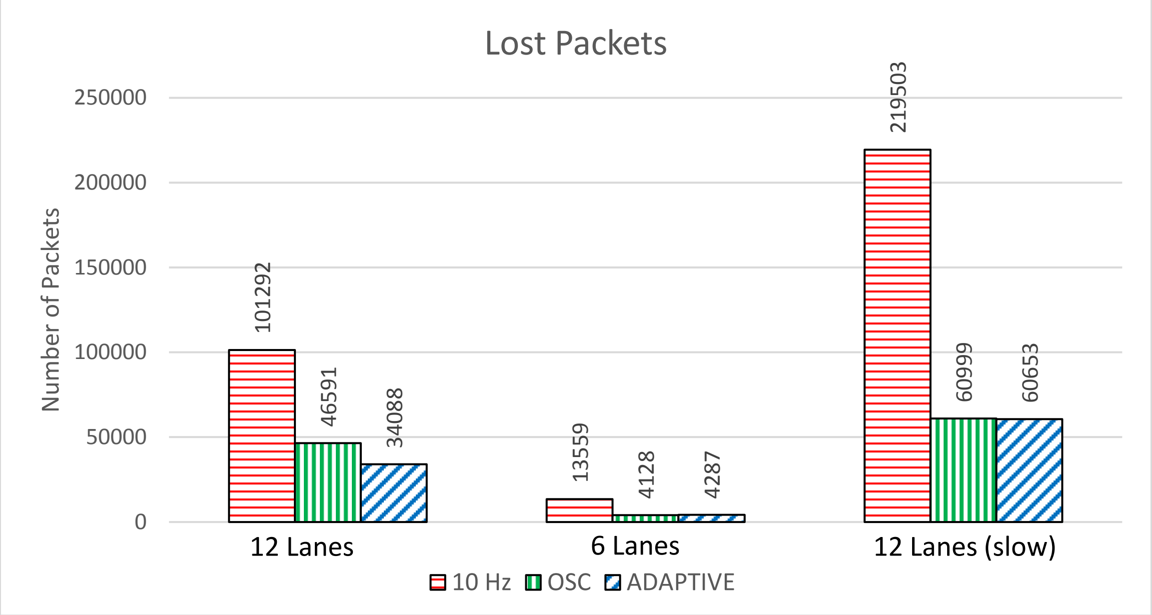


Figure 4.5: Total Lost Packets

A reduction in packet loss is a good measure to determine how effective our approach is in the simulations for congestion control. A reduction in packet loss would mean that the network is less congested, and packets are transmitted to the vehicles that need them without any problems. The scenarios in Figure 4.5 show that there is an increased loss of packets by the 10Hz approach on the twelve lanes road due to the Dense state of vehicle traffic and no form of congestion control leading to packet collisions and packets not getting delivered in the network which eventually results in a congested state of the network. This reduces the performance of safety in the network. The Adaptive and OSC approaches both have an almost similar reduction in the total number of lost packets in the scenarios.

4.2.4 Beacon Reception Rate

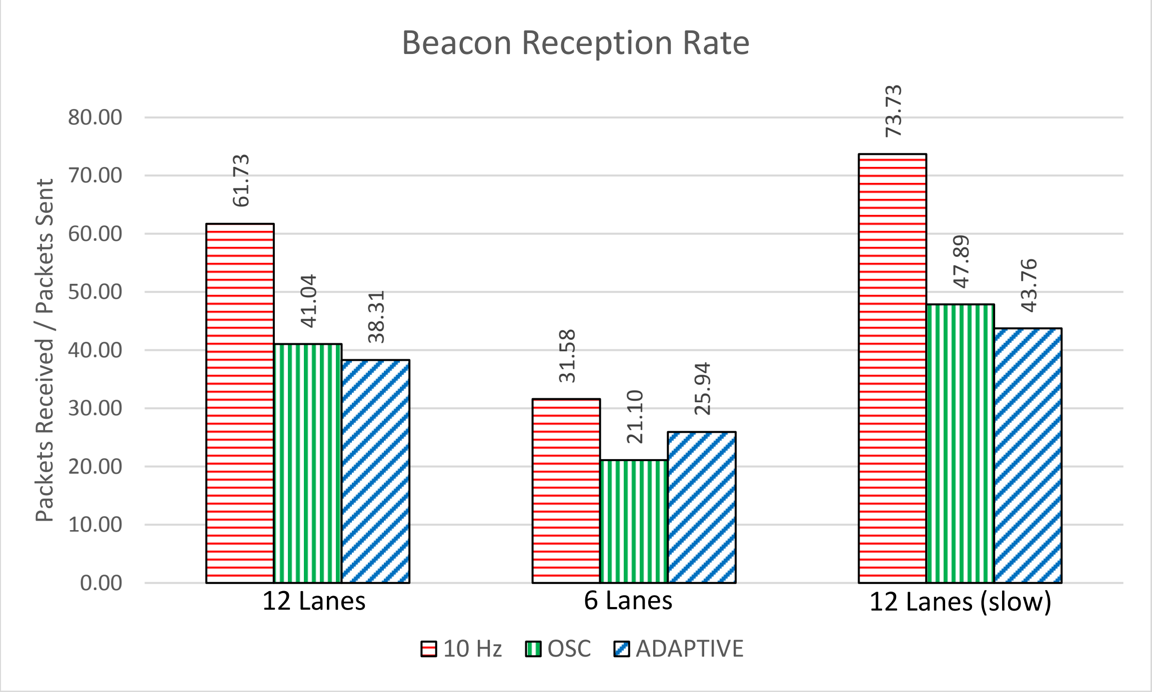


Figure 4.6: Beacon Reception Rate

Beacon Reception Rate is the comparison of the ratio of the total number of packets received and packets sent in the simulations. The 10 Hz with no congestion control approach shows a higher Beacon Reception Rate due to packets being able to travel a far distance throughout the duration of the simulation compared to the other approaches with congestion control methods used. This would lead to an increased Beacon error rate and eventually contribute to the degradation and increase in congestion of the network. The adaptive approach recorded less beacon reception rate because of the change in density states in the simulation and reduction of transmission power at high density states which would affect the distance a packet would travel just for reducing congestion.

4.2.5 Beacon Error Rate

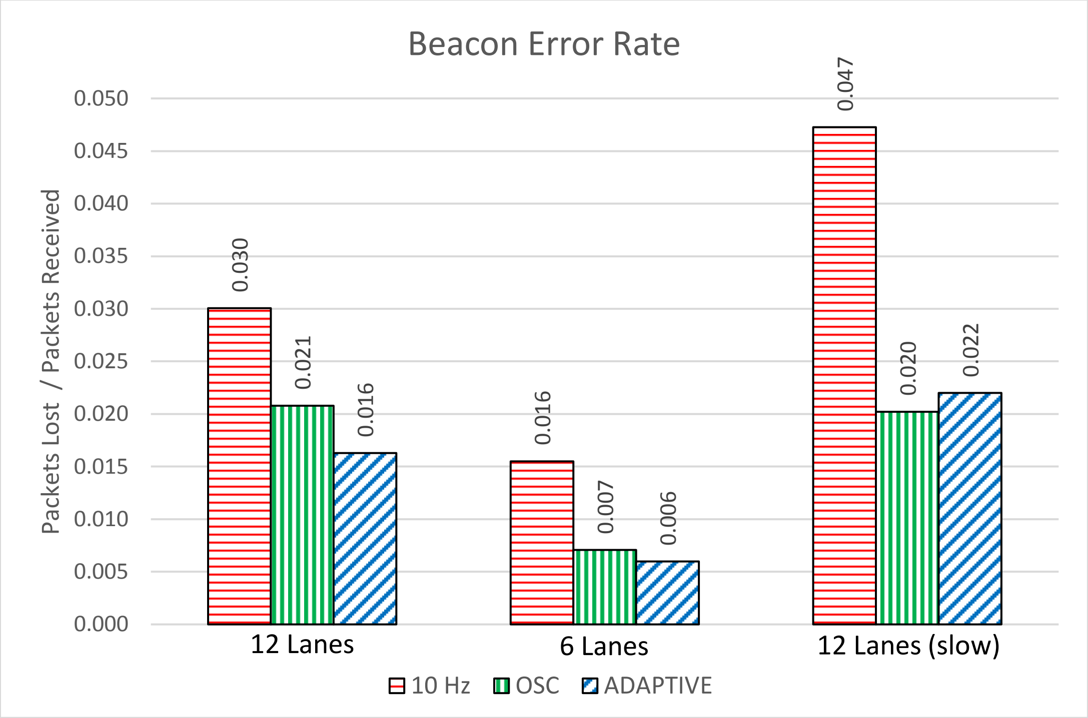


Figure 4.7: Beacon Error Rate

The beacon error rate shows the ratio of packets lost over the packets received in the simulations. According to figure 4.7 the OSC and Adaptive approaches had slightly similar beacon error rates. The Adaptive approach had a slightly better performance than the OSC approach and significant improvement compared to the 10Hz only approach. This improvement was possible due to the adaptive approach seeking to accommodate the appropriate transmission power needs of the various traffic densities and limiting the wastage of resources in the process. The 10Hz only approach without a congestion control algorithm performed poorly compared to the others due to the high beacon reception rate mentioned earlier.

4.2.6 Channel Activity

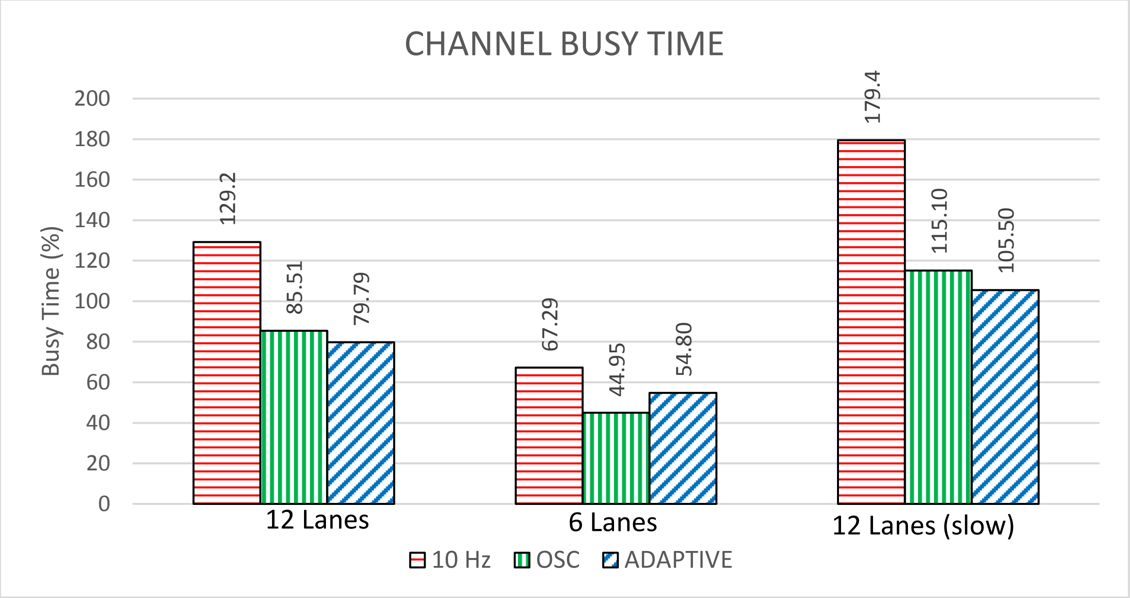


Figure 4.8: Channel Activity

Figure 4.8 is an indication of congestion level on the network. The channel busy time recorded in the simulation by the MAC layer is the percentage of time the channels are treated as busy. The Total Busy time of the individual vehicles are divided by the total simulation time which tells us the amount of time the MAC layer is busy. A vehicle needs to wait for the channel to be clear before a packet can be transmitted in the network. Percentages above 100% indicate heavy overlapping transmissions, resulting in the channel being highly congested and harming the performance of the network. The adaptive algorithm shown in figure 4.8 performed better than the other approaches in the twelve-lane 50km/hr scenario that was dedicated for stressing the network. In the scenarios where no congestion control method was used a high level of congestion is discovered which is harmful to the performance of VANET.

4.2.7 Inter-Packet Delay

The Adaptive control that adjust transmission power according to change in vehicle density states aims to perform better than the OSC power algorithm that records a rapid increase in IPD which would be harmful to the use of Safety Applications. The delay time between packets sent needs to be reduced or kept at a gradual increase. The IPD is calculated by finding the average IPD for each second an Ego vehicle transmits to a receiving vehicle and the average transmission distance in that instant. The transmission distances are grouped into 20-meter intervals.

The results from the scenarios collected in Figures 4.9, 4.10 and 4.11 all indicate a gradual increase of IPD in the OSC control method. The OSC shows a reduction in IPD only for distances that are less that 150m in all scenarios. The 10Hz with no congestion control performed better than the OSC in all scenarios because of the steady fixed transmission power and rate utilized. An almost consistent state of IPD was discovered in the simulations. The Adaptive control records an increase of IPD in figure 4:10 and 4:11 which would be because of a vehicle density state change. A reduction in IPD is also noticed at greater distances for the adaptive control which is due to the transmission power being low and gradually fading in the dense vehicle density state. This result by the Adaptive control indicates that it performs significantly better than the OSC algorithm which records a significant gradual increase of IPD in all scenarios.

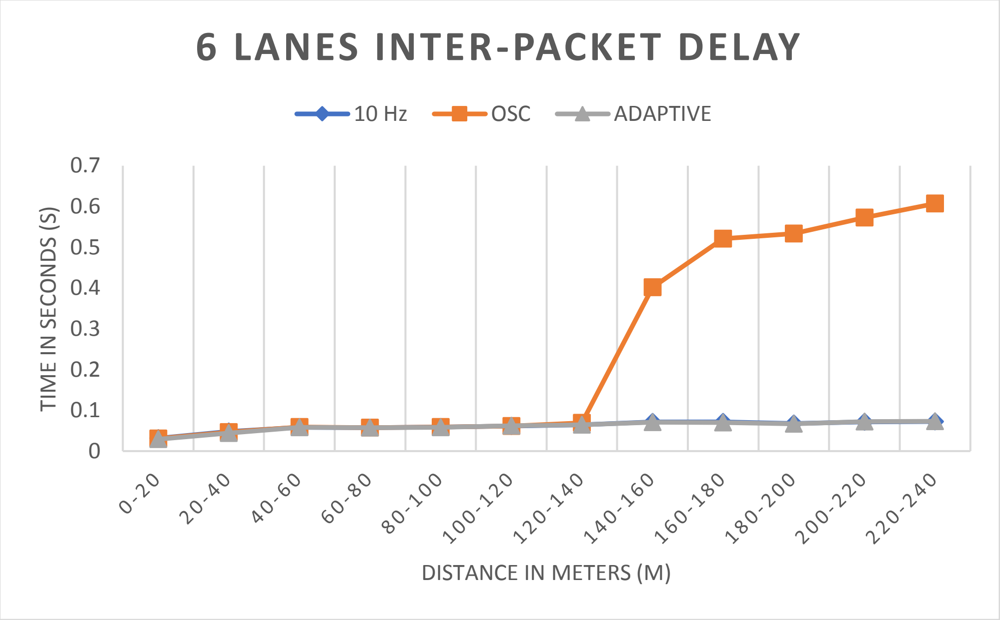


Figure 4.9: 6 Lanes IPD

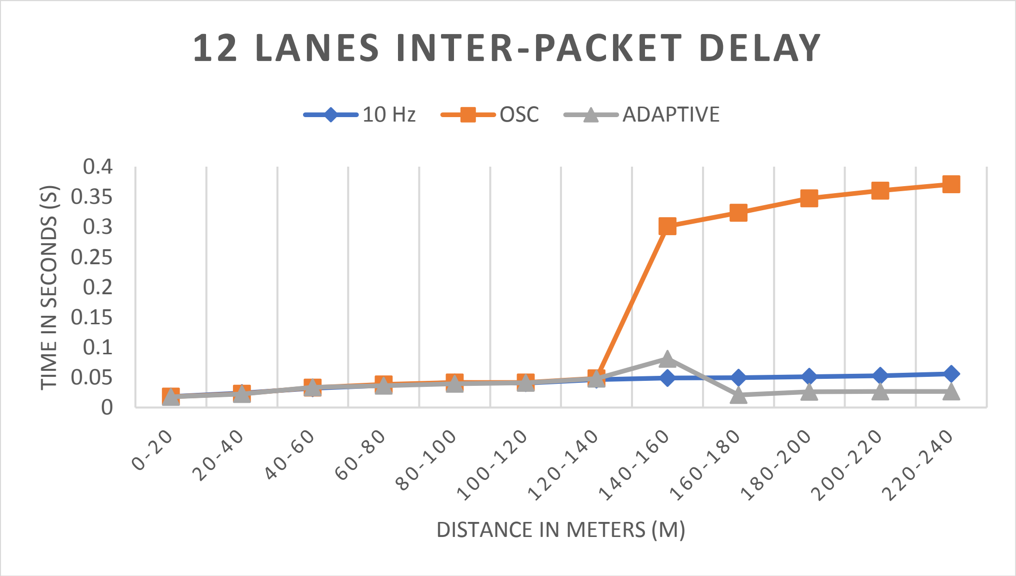


Figure 4.10: 12 Lanes IPD

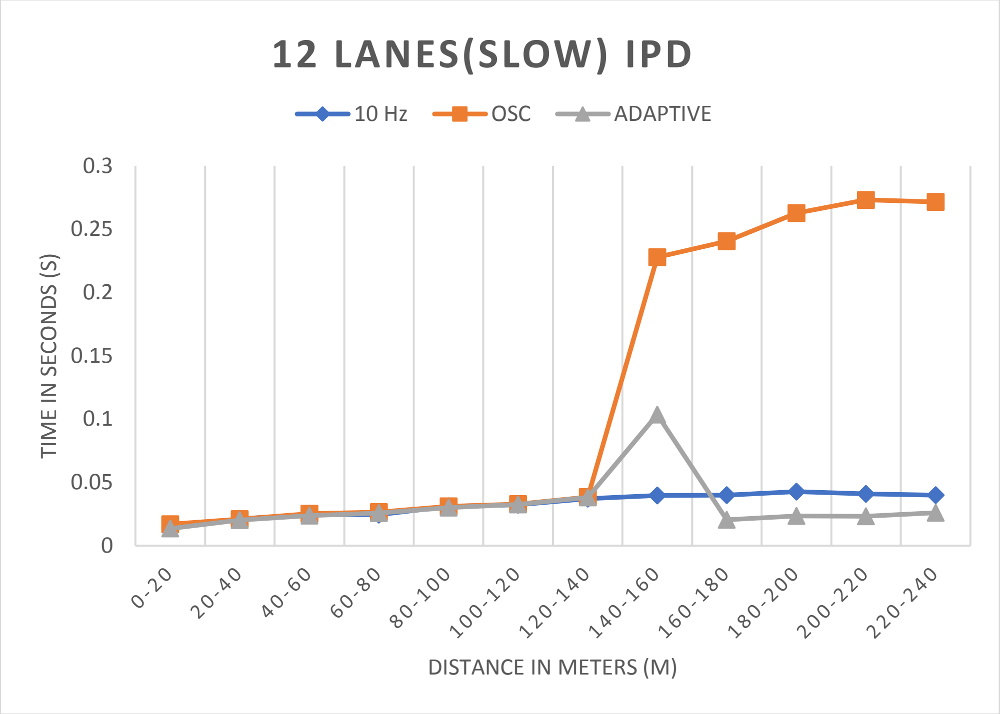


Figure 4.11: 12 Lanes (slow) IPD

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

In this thesis, we have proposed and analyzed an approach to adapt transmission power according to vehicle density with the aim of controlling and reducing channel congestion on VANET. The approach was able to use different transmission powers to control channel congestion at Dense, Moderate and Sparse vehicle density states. The adaptive approach has shown to have improvement in reducing the channel busy time, reducing the number of lost packets, less beacon error rate recorded for the packets and a reduction in IPD as opposed to not using a congestion control approach and the OSC approach.

5.2 Future Work

There is plenty of room for the improvement of the adaptive transmission power with vehicle density approach. Combination of the adaptive approach with other approaches in the research field to make it Hybrid will further improve the performance of VANET and reduce congestion on the network. Introduction of a Rate control algorithm to the proposed approach which uses a single fixed transmission rate to control the number of packets sent will help with congestion control. Combining the OSC with the proposed approach in the dense vehicle density state will boost awareness in the network by sending some packets to vehicles at greater distances but this will need to be tested and improved upon because of the gradual increase of IPD caused by the OSC algorithm.

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APPENDIX A

Scalar Results

	6 Lanes	12 Lanes	12 Lanes (Slow)
Sent Packets	27670	54580	62980
Received Packets	873953	3368978	4643317
Lost Packets	13559	101292	219503
Channel Activity (%)	67.29	129.2	179.4
Beacon Reception Rate	31.58	61.73	73.73
Beacon Error Rate	0.016	0.030	0.047

Table 1: 10 Hz Scalar Results

	6 Lanes	12 Lanes	12 Lanes (Slow)
Sent Packets	27670	54580	62980
Received Packets	583705	2239997	3015877
Lost Packets	4128	46591	60999
Channel Activity (%)	44.95	85.51	115.10
Beacon Reception Rate	21.10	41.04	47.89
Beacon Error Rate	0.007	0.021	0.020

Table 2: OSC Scalar Results

	6 Lanes	12 Lanes	12 Lanes (Slow)
Sent Packets	54580	27670	62980
Received Packets	717893	2091112	2755967
Lost Packets	4287	34088	60653
Channel Activity (%)	54.80	79.79	105.50
Beacon Reception Rate	25.94	38.31	43.76
Beacon Error Rate	0.006	0.016	0.022

Table 3: Adaptive Scalar Results

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