Performance Enhancement in VANET with Admission Control and Contention Window Adjustment

by

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B.Tech, National Institute of Technology-Durgapur, 2009

A Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF APPLIED SCIENCE

in the Department of Electrical and Computer Engineering

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ABSTRACT

Vehicular Ad Hoc Networks (VANET), a derivative of mobile networks, has the capability to increase the safety, efficiency and comfort of transportation systems, and provide users on-the-road Internet connectivity. Because of its impetus and significance in practical scenarios, it becomes a sought after topic in both industry and academia. In this thesis, we focus on the vehicle-to-infrastructure (V2I) drive-thru Internet services in a highway scenario. The road side unit (RSU) along a highway can provide network services for vehicles within the coverage. To enhance the network performance, we propose two strategies. First, to ensure a high network throughput, the RSU uses an admission control strategy to limit the competition among vehicles, and avoid the waste of channel time to the low-data-rate users. Second, based on the vehicle density, we also propose a contention window (CW) adjustment strategy which can reduce the collision probability when the network is congested, and reduce the idle time otherwise. Extensive simulations using network simulator (NS-2) are given, which demonstrate the effectiveness of the proposed solutions.

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ACKNOWLEDGEMENTS

The last two years at the University of Victoria have been an intensely rewarding and educating experience for me. I feel I have made a lot of progress in my chosen line and I am thankful to my supervisor Dr. Lin Cai for giving me this wonderful opportunity and for opening a window to the world of Networks, which fascinates me. No words can express sufficiently, the gratitude I feel for the countless hours of patient tutoring and constant direction, without which this thesis would not have been a reality today.

During the course of my studies, I worked as a co-op student at Broadcom. It was only possible by the constant support from Dr Cai. I sincererly thank her for giving me this opportunity to gain industrial experience and broaden my horizon to look into engineering aspects with out of box thinking.

I am also thankful to my friends, especially my lab mates , Zhe Yang, Yaunqian Luo, Siyuan Xiang and Bojiang Ma, and my well wishers who have been a consistent source of support and encouragement. Without you, I may not have been able to accomplish the journey I undertook. Thank you for tiding me over my darkest phases and gently egging me on to achieve my goal.

Last but definitely not the least, I would like to thank my parents and my siblings, Priti and Rachna, for their constant support and motivation, without which nothing would have been possible.Thank you for always being my guiding light. I am blessed to have received your love, your care and your time.

DEDICATION

To my Family.

Chapter 1

Introduction

1.1 Vehicular to Infrastructure Communication

The study of Vehicular Ad-Hoc Network (VANET) has attracted attentions recently. By definition, VANET is a form of mobile ad-hoc network(MANET), to provide communication among nearby vehicles and between vehicles and nearby fixed infrastructure. Vehicles may be equipped with on board devices, which can provide them Wireless Local Area Network (WLAN) connectivity through an access point (AP) installed in a road side unit (RSU). With advancement in technology sector, vehicular network is anticipated to be on a high rise and its usage is going to increase manifold on a scale similar to the huge scalable network of world wide web. We need to come up with robust techniques to make VANET reliable and at the same time seamless in nature. Ott et al [20] were among the first one who reported the real-world measurements between a moving car with an external antenna and roadside wireless LAN Access Point, namely drive-thru Internet. The authors showed that by using IEEE 802.11b hardware, a vehicle could maintain a connection to a roadside access point (AP) for around 500m and transfer several megabytes of data at a speed of 80 km/h. Many of the automobile companies are working in this area to provide better connectivity for vehicles with the AP and to exchange as much information as possible within the time span where a vehicle is in the range of an AP.

1.2 Challenges

Reliability is a key requirement for any kind of vehicular communication since one of their main applications is safety in road traffic. Regarding communication, VANET is one specific scenario of Mobile Ad hoc Network (MANET). This means VANET also has some characteristics of MANET such as, self-organizing capability, topology change due to node mobility [3] etc. The protocols for both the networks are similar. Beside some common characteristics with MANET, the VANET also has its own characteristics such as high node mobility, very frequently changing network topology, challenging aspect of end-to-end connectivity and usually more than one hop relay transmissions. For the above reasons, VANET is much more complicated than traditional wireless networks [15]. Various factors that are considered vital for VANET are listed below:

- Velocity of the vehicles: IEEE802.11 physical (PHY) and medium access (MAC) protocols were designed for fixed/nomadic stations. In VANET, high velocity causes a large and fast variation of the channel conditions which may lead to performance degradation if necessary measures are not taken beforehand. In order to design any model we need to take account of the density of vehicles which in turn is affected by velocity.

- Vehicle density: In a zone which can be pivotal when the problem of interference and congestion control arises, vehicle density can have significant impact. It can influence factors such as capacity, routing efficiency, delay, and robustness. Traffic jams, caused by constraints in the transportations network, traffic controls, or driving fluctuations, cause the networks density to vary from one location to another, thus disturbing the homogenous distribution of nodes

- Mobility pattern: Since the nature of network is dynamic, it is challenging to define the pattern in a deterministic way. Earlier models used in general MANETs, such as the random waypoint, are unsuitable for the VANET application, where the nodes no longer move freely in the open area. In VANET the nodes are bound to follow the road patterns, and constrained by many parameters such as route intersections, stop and trafc light signals, the presence of other vehicles in front the vehicle, and etc.

- Distance: IEEE 802.11p is for short range communication with upto a few hundred meters. With this limitation, we need to have several APs/Road Side

Units (RSUs) to cover the road or to manage the existing RSU work in such a way that its interaction with the vehicles in the range are properly polled.

The above factors along with supporting critical, time sensitive applications, are the major challenges faced by researchers [30].

1.3 Salient Features

While VANET uses the same protocol as IEEE 802.11 Distributed Coordination Function (DCF) there are certain features where it is different and hence IEEE 802.11p protocol has been developed for “Wireless Access in Vehicular Environment” (WAVE). Though the difference lies in the channel allocation, frequency and bandwidth, the operational aspect remains the same as that of DCF. The major advantages of DCF are twofold:

- It is completely distributed, which is imperative in vehicular communications. As frequent hand offs and topology changes are made due to high node mobility, the distributed behaviour of DCF makes the system robust.
- Its binary exponential back-off strategy is scalable and applicable for different traffic and road environments, e.g., urban and rural regions. It gives fair opportunity to all the stations/nodes to get access to the channel based on their individual back off counter.

The MAC protocol for VANET is based on the Carriers Sense Multiple Access/Collision Avoidance (CSMA/CA). The WAVE protocol provides enhancements PHY and MAC layers of the existing 802.11 wireless standards. These improvements are required to support the Intelligent Transportation Systems (ITS) and for various commercial usages such as infotainment, web browsing etc. The different types or modes of communication in VANET are vehicle-to-infrastructure (V2I) and vehicle-to-vehicle communication (V2V). As the name suggests, for V2I communication, vehicles communicate with the APs or the RSUs to establish connection and for V2V, the method of establishing connection and exchanging messages remain the same except that no AP is involved. In our work, we discuss the V2I communication.

Considering an established communication in the network using either V2V or V2I type, different stations or vehicles have different contention window (CW) parameters to deal with the channel errors. In IEEE 802.11 wireless local area network or 802.11p network, the nodes or in our case vehicles, that experience collision of data packet should back-off for a random time before retransmission according to the CW. The CW is dynamic in its nature and is controlled by an exponential back-off algorithm, which will be discussed in detail in the following chapters. This binary exponential back-off scheme, tries to minimize the collisions between the packets. But its performance becomes unsatisfactory when the traffic becomes larger and denser. Small CW can cause collisions and interference if vehicles contend for the same slot in order to transmit packets to the RSU. This limitation of the basic IEEE 802.11 DCF mechanism urges us to have a look into various aspects when dealt with the CW. Since minor changes in CW can have a larger impact on the throughput of the network, we improve the throughput when the binary multiplicative factor can be adjusted according to the congestion level of the network. Along with CW adjustment we introduced the concept of admission control where we made the transmission power of the AP adaptive based on the presence of vehicles in certain zone. For our approach, we considered a highway scenario with varying density of vehicles and one AP for our network which can be extended by installing multiple RSUs as illustrated in Figure 1.1:

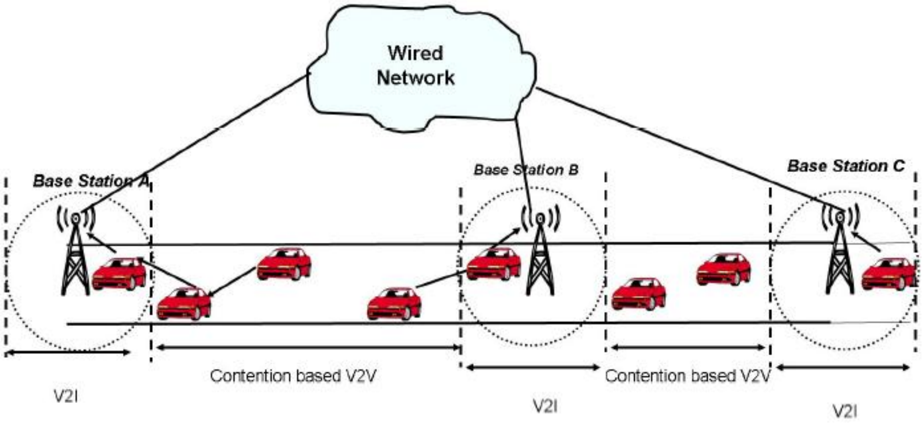


Figure 1.1: Vehicular to Infrastructure Communications

1.4 Contributions of this Thesis

Our strategy in increasing the performance of VANET and strengthening the communication links in VANET is to incorporate the mechanism of admission control and CW adjustment based on density of vehicles. The transmission range of the AP is made adaptive in nature. Whenever the AP senses the presence of any vehicles in the nearest zone, it will reduce its transmission range. However, in the absence of vehicles in that zone, the AP will increase its transmission range. It follows that dynamic adaptation of transmission range combined with transmission power with respect to changing traffic density is a critical requirement in VANET. Along with this change, we propose to change the CW back-off parameter to consider the density of vehicles in certain zone.

In this thesis we thoroughly discuss the impact of Contention Window and the Transmission Range of the AP in V2I mode of communication. The main contributions are listed as follows:

- We proposed and reviewed the modified DCF system which is implemented and compared it with the widely deployed IEEE 802.11 DCF protocol
- We analyzed the impact of multiplicative factor in back-off, and with the help of simulation, made an approximate relation between the contention window and density of vehicles to ensure that the factor to be used with contention window provides us better network performance.
- We proposed new algorithms to fine tune transmission range of AP and the contention window of the vehicles, based on the density of vehicles, which can improve the network performance.
- We also did extensive simulation to endorse our proposed solutions and to compare with the standard DCF protocol.

1.5 Thesis Outline

In the next chapter, we will discuss related work which were substantial in the improvement of VANET. In Chapter 3, we will discuss the general system model and Chapter 4 will cover the main idea and design in detail. Chapter 5 will present the simulation results and the Chapter 6 will have the concluding remarks and some future work which can be done in this field to add some more improvements in the existing network.

Chapter 2

Background and Related Work

In this chapter, we first discuss about the background knowledge regarding VANET with respect to its spectrum, architecture and the functionalities of Medium Access Control (MAC) and Physical (PHY) layer. Then, we explain the existing work in this area concerning CW and transmission range adaptation in VANET.

2.1 Background Knowledge

There are active research undergoing in VANET, to make the system more reliable, scalable, secured and congestion free for the users. With more and more Internet users becoming mobile, it is imperative to make the network more robust and efficient.

One of the most important usage of VANET is to enhance road safety. VANET offers several benefits to organizations of any size. While such a network does pose certain safety concerns for example, one cannot safely type an email while driving, but this does not limit VANETs potential as a productivity tool. GPS and navigation systems can benefit, as they can be integrated with traffic reports to provide the fastest route to work. A commuter can turn a traffic jam into a productive work time by having his email downloaded and read to him by the on-board computer, or if traffic slows to a halt, read it himself.

With VANET many applications can be integrated to facilitate the message dissemination in the network to provide fast and seamless connectivity, although for a small sojourn time. We can imagine the power and future of VANET.

So far there has been extensive work done on the improvement in VANET that ranges from routing, Quality Service (QoS), broadcasting, security attacks and threats, network capacity, collision and interference, power control algorithms, congestion control to service discovery etc. These areas have been pursued actively by researchers.

2.1.1 Spectrum and Architecture

The IEEE 802.11p/WAVE stack uses CSMA/CA as the basic medium access scheme for link sharing and uses one control channel to set up transmissions, and data transmission should be conducted in several data channels. At the PHY layer, 802.11p is expected to work in the 5.850 - 5.925 GHz DSRC spectrum in North America, which is a licensed ITS Radio Services Band in the United States. Using the Orthogonal Frequency Division Multiplexing (OFDM) technology, both V2V and V2I wireless communications have a transmission range upto 1 km, which may vary according to the environment such as, high absolute or relative velocities, fast multipath fading and different surroundings (rural, highway, and city). Operating in 10 MHz channels, it should allow data communication throughput of 3 Mb/s to almost 27 Mb/s. It can achieve the throughput of 54Mb/s if it uses the optional 20Mhz channel. As the overall DSRC communication stack between the link and application layers is being standardized by the IEEE 1609 Working Group, the overall DSRC communication architecture in the draft IEEE 1609 standard contains two parallel stacks: one for TCP/IP based communications and the other for safety messaging as shown in Figure 2.1. The WAVE standard specifies the architecture, communication model, management structure, synchronization methodology, security manner and physical access features for vehicular communications. The specification of WAVE is called P1609 series standards. IEEE P1609 series standards were composed of six different specifications that define various topics in different areas, i.e. 1609.0 - 1609.5 [12]

- 1609.0 defines the architecture. This standard describes the Wireless Access in Vehicular Environments (WAVE/DSRC) architecture and services necessary for multichannel DSRC/WAVE devices to communicate in a mobile vehicular environment. The purpose of this standard is to describe the architecture of the DSRC/WAVE operations currently represented by the family of IEEE 1609 standards and IEEE P802.11p.

- 1609.1 is used as resource manager and it specifies the key components of the WAVE system architecture and defines data flows and resources as well as command message formats and data storage formats.

- 1609.2 is used for security services for applications and management messages. This specification deals with security services for applications and management messages.

- 1609.3 provides the networking services corresponding to WAVE. WAVE networking services provide services to WAVE devices and systems. It represents roughly layers 3 and 4 of the OSI model and the Internet Protocl (IP), User Datagram Protocl (UDP), and Transmission Control Protocol (TCP) elements of the Internet model. The services include management and data services between WAVE devices. A new transport/network protocol - WAVE Short Message Protocol (WSMP) is defined and provides an alternative transmission methodology directly controlled by applications.

- 1609.4 and 1609.5 protocols are still under development. The 1609.4 standard is responsible for managing communication. It defines communication management services in support of wireless connectivity among vehicle-based devices, and between fixed roadside devices and vehicle-based devices for wireless access in VANET.

- 1609.5 is used for different facilities. A combination of the layers nominally referred to as Session, Presentation, and Application. It is commonly refered as WAVE communications manager.

2.1.2 MAC and PHY in VANET

The DCF of the IEEE 802.11 standard provides distributed, contention-based access to the wireless medium. There are two access modes defined in the DCF, the basic access mode and the optional RTS/CTS (Request To Send/Clear To Send) access mode. In the basic access mode, before starting a frame transmission, each station checks the medium status by carrier sensing. If the medium is idle for longer than DIFS (DCF Inter Frame Space), the transmission may proceed immediately; if the medium is sensed busy, the station defers its transmission until the medium is determined to be idle for DIFS and the binary exponential back-off procedure is invoked. While the medium stays idle, the back-off timer is decreased by one slot time for each back-off slot as shown in Figure 2.2.

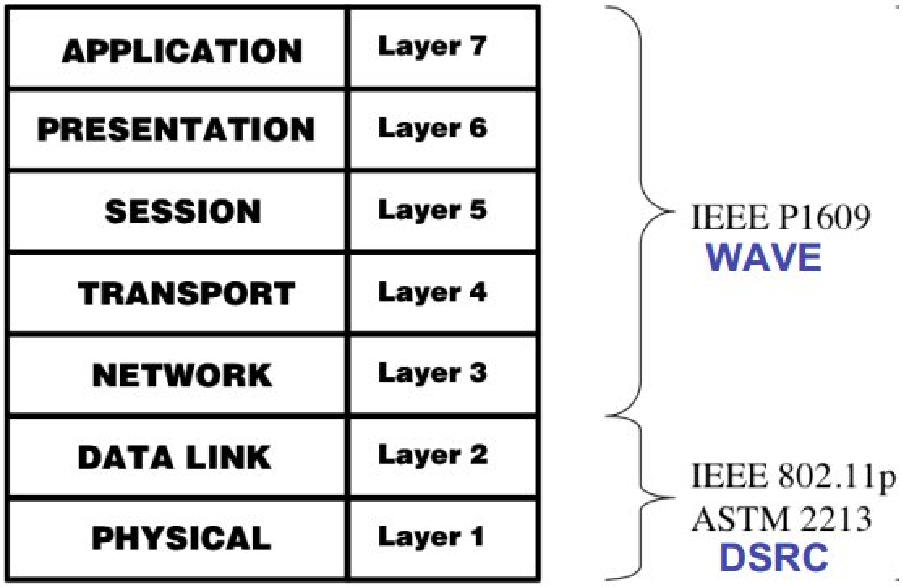


Figure 2.1: IEEE 1609 Standard for WAVE [43]

Back-off is incorporated to resolve the contention between different stations willing to access the medium. The method is such that each station sets a timer by randomly selecting a counter between 0 and the given number, namely the contention window, CW and then it waits till this timer expires before accessing the medium. Exponential back-off means that whenever a collides, the station will increase the CW exponentially. The frame is transmitted when the timer reaches zero. During the busy period, the timer is frozen and then is resumed after the channel is idle for Distributed Inter Framce Space (DIFS) time period. In binary exponential back-off (BEB), the random back-off timer is set as follows:

$$Backoff\ Timer = Random() \times aSlotTime$$

where $Random()$ is a pseudo-random integer drawn from a uniform distribution over the interval of [0,CW], where $CW = 2^m.CW_{min}$ for m-th retransmission of the packet, where $CW \in [CW_{Min}, CW_{Max}]$, where CW_{Min} and CW_{Max} are the minimum and maximum values of the Contention Window. The BEB procedure for CW adjustment is summarized below:

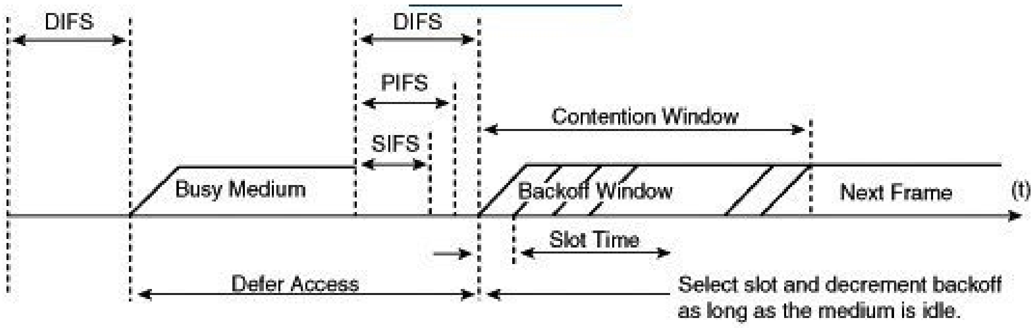


Figure 2.2: IEEE 802.11 DCF Protocol Mechanism [14]

- Intially, all stations have $CW = CW_{Min}$
- On transmission success, exceeding the retry limit:
  $CW = CW_{Min}$
- On collision:
  $CW = min(2 \times CW, CW_{Max})$

In a long run, the DCF algorithm ensures an equal access to the shared medium among all the contending stations. Although equal access probability does not guarantee the same throughput among all the hosts. For example a station moving away from the AP may result in the degradation of its link data rate due to the reduced signal strength. This aspect is quite predominant in VANET where the vehicles are constantly changing their locations and as a result their bit rates also change. In this case, the vehicle near the AP will always have the highest signal strength which results in the highest raw data rate. Vehicles far away from AP takes longer time to transmit a packet thus affects the total network throughput. We will propose a solution which will address this concern.

The Physical layer is significant in the reception of packets in all the 802.11 networks. Path loss and shadowing are two aspects which attributes to variation in received signal power over distance. Path loss, is caused by loss of the power radiated by the transmitter as well the effects of the propagation channel [2]. On the other hand, shadowing is caused by obstacles between the transmitter and the receiver that attenuate signal strength by reflection, scattering and refraction. Variations due to path loss occurs over long distances while shadowing occurs over distances proportional to the obstructing length. Since both are relatively long distances they are considered as large-scale propagation effects. Sometimes we also have losses due to multipath. This phenomenon is due to the receiving of multiple components of the signal. These components may be attenuated, delayed, shifted in phase and/or frequency from the LOS (Line of Sight) signal path at the receiver. Various deterministic propagation model which are used to model the system are generally Friis Free Space propagation model, Two Ray Ground propagation model and Probabilistc model such as Log Normal Shadowing, Rayleigh and Nakagami fading models [38]. We will discuss about it in further detail in the next chapter.

2.2 Literature Survey

There is immense work done so far in the field of VANET since its inception to enhance and improve the system [22]. As discussed, the MAC protocol for VANET is IEEE 802.11p [33], [18], [44], which has almost the same features as that of the basic IEEE 802.11 [14]. Most of the previous work incorporated new features in 802.11b and assumed it to be working for 802.11p. There is no denial of the fact that the basic functionality of the protocol remains the same, but the dynamics of the environment needs to be taken care of to check the feasibility with 802.11p, while incorporating the features in VANET. In this section we discuss the related work done in VANET with regard to performance improvement in VANET in general and with transmission range change and CW adaptation in 802.11 networks.

In the literature there are excellent discussions on the issues concerning IEEE 802.11p [13] [15] protocol and its performance analysis. The paper by Stephan,E. et al. [34] provided a performance evaluation of the WAVE standard, considering collision probability, throughput and delay. This paper shows that WAVE can transmit prioritized messages (based on arbitrary inter frame space). Besides, in dense and high load scenarios the throughput decreases while the delay increases significantly. Cali et al. [7] proposed a new mechanism which uses the IEEE 802.11 protocol by p-persistent CSMA where each station transmits with a certain probability after collision rather than choosing a back-off window uniformly from [0, CW]. They showed convincingly that in order to reach the theoretical throughput limit of IEEE 802.11, the transmitting probability needs to be adaptive to the channel condition such that the time between two consecutive transmissions is minimized. In [16] the authors estimate the duration of the collisions on the channel during transmission of data. In this paper, the authors proposed a mechanism which makes the performance better by collision alleviation scheme to alleviate intensive collisions between highest priority access categories which usually used to schedule emergency message. As the applications of VANET are immense, as a subset of the applications, there are related work which tries to enhance user experience for video streaming in VANET. Although the authors [41] came up with novel idea of implementing adaptive video streaming by dividing the highway into several zones. However they mentioned that contentions should be considered to achieve realistic and practical results.

2.2.1 CW Adaptation

The CW also plays a significant role in performance of the network [45] [14]. So far there are numerous papers and research being done on the adaptation of CW for 802.11 family of network. Most of these changes are made for either static network or random ad hoc network. For instance, the CW dynamic tuning to gain performance improvement over Binary Exponential Back-off has been discussed exhaustively in [26], [19], [39].

Since the CW reset scheme of Binary Exponential Back-off (BEB) may lead to unnecessary collisions and retransmissions when the contention level has not dropped, in [5], MILD (multiplicative increase linear decrease), CW adjustment scheme was introduced to solve this problem: a node increases its CW by multiplying it by 1.5, and decreases it by 1 upon a success, that is:

$CW = min(1.5 \times CW, CW_{Max})$ - On collision of packets
$CW = max(CW - 1, CW_{Min})$ - On success

It also included a CW copy mechanism to address the fairness issue. By smoothening the CW decrease, this scheme performs well when the network load is heavy. However, when the number of active stations changes sharply from high to low, MILD [39] cannot adapt fast enough because of linear decrease. There are other algorithms which were proposed after MILD, including EIED [26], LMILD [19] etc. All these schemes aimed at making the CW oscillate around the optimal value without complicated runtime estimation; they only differ in linear/multiplicative increase/decrease factors. In [10], the authors developed a p-persistent IEEE 802.11 protocol which closely approximates the standard protocol. Based on this, an analytic model was derived to study the theoretical capacity limit of the p-persistent protocol and computed the optimal 'p' that maximizes the capacity.

In the paper by Wang [21], the CW of a vehicle is adapted according to the neighbourhood density of a stationary unit (RSU). Thus, the adaptation algorithm is centred on the RSU. Also in order to improve the message dissemination by improving the quality of service, Adler et al. [6] proposed a system to prioritize messages based on context and content. On this basis, a function of relevance is calculated for each message, and each message will have different CWs.

The problem of dynamically adapting the CW size for reliable broadcast in VANET was discussed by Balon and Guo [5]. However, the authors of [5] only considered the channel access time depending on the urgency of messages and their delay requirements, without considering the adaptation of transmission power, or the prioritization of messages according to their urgency, or the adaptation of the CW size for transmission opportunity, which can enhance system throughput while reducing end-to-end message delay. Also [42], is novel in terms of a novel mechanism where in the CW parameter is made adaptive to the changes in the data rate.

Razvan Stanica et al [32], addressed the performance issue of VANET by making amendments in CW. Their work in terms of CW adaptation is appreciated and they have shown that their mechanism helps in achieving better results than previously existing approaches.

2.2.2 Transmission Range and Rate Adaptation

Shankar et al [28] showed that the frequent changes in the connections and the rapid mobility of vehicles cause the under-utilization of network resources when the default network settings are static. The authors proposed a scheme for adapting the transmission rate to better utilize network capacity. For this adaptation, the mechanism evaluates some information from GPS (Global Positioning System) and some metrics of network performance. However the authors did not consider density as a context parameter. Artimy et al [25] considered density as an important parameter in their work. The rapid change in topology, due to traffic jams, disturbs the homogeneous distribution of vehicles on the road. Dynamic transmission power has been proposed as a manner to maintain network connectivity and minimize the adverse effects of unregulated power. The topology of the VANET changes frequently because of the high mobility of vehicles. Due to the frequent topology changes, the time that a communication link exists between vehicles and the AP, is brief. The reason why the link in a VANET is short lived is because vehicles travel at high speeds. One solution is to increase the sojourn time of the vehicles which is accomplished by increasing the transmission range of the AP. The problem associated with increasing a AP's transmission range in order to maintain a communication link is that it also decreases the throughput in the network because of large number of vehicle contention and severe interference. The work by M. Torrent et al. [37] proposed the distributed fair power adjustment for vehicular networks algorithm that dynamically adjusts each vehicles transmission power to prevent packet collisions. The concept focuses on fairness of each vehicle to receive and send safety information rather than network capacity, connectivity or coverage. The idea propsed and work done by these authors are novel and highly appreciated by research fraternity.

One of the earliest work in this area was proposed by Suthaputchakun et.al [35] where they incorporated a priority based algorithm for vehicular communications. However, while incorporating Enhanced Distribution Channel Access mechanism (802.11e) in VANET, they did not address the problem of adapting transmission power according to local traffic conditions or density of vehicles in certain range/zone which is imperative in such a dynamic environment. The issue regarding adapting transmission power in VANET based on vehicle density was addressed by Artimy [25]. The proposed mechanism is new of its kind but can be a bottleneck in a heterogeneous network. The transmission range is decided based on the density of vehicles as shown in the equation below:

$$T_r = min\left(M_r \times (1-K), \sqrt{\frac{M_r ln(M_r)}{K}} + \alpha \times M_r\right)$$

where

T_r = Transmission Range of the AP,
M_r = Maximum Transmission range/ Lenth of the Zone in question,
K = Density of Vehicles in that Zone,
and α = Traffic Flow theory constant (considered to be 0.25).

Along with a limitation regarding the heterogenity of the network, the solution does not solve the contention among the vehicles rather the contention always remains the same unless the density varies significantly.

As discussed in this section, researchers have proposed practical changes which can improve the network significantly without un-necessary overload. Similarly our proposed mechanism is based on the adaptability of various parameters and considers the dynamics of the environment.

Chapter 3

System Model

In VANET, each vehicle will carry an On Board Unit (OBU) that can facilitate wireless communication with other vehicles and APs [4]. Vehicles must also be equipped with hardware that permits detailed position information such as Global Positioning System (GPS) receiver. Fixed APs, which are connected to the backbone internet, must be in place to facilitate communication. The V2I communication configuration represents a single hop communication link. The AP sends a beacon messages to all OBUs equipped in the vehicles in the vicinity periodically. We consider single AP establishing communication with different vehicles in the AP range. In our work on the contention window analysis we consider the medium access part of 802.11p. The topology is a simple model with n vehicles connected to an AP. The coverage range of AP is based on the changing number of vehicles, n. [14].

3.1 Structure

There are various sets of constraints to the development of applications in VANET. The message dissmeniation is characterized by these constraints, which make VANETs a very distinct category of ad hoc networks. In this section, we categorize these characteristics for the development of the VANET.

The regular VANET V2I scenario is similar to what is seen in Figure 3.1 [8].

The AP, stationed as shown in Figure 3.1, is considered the main controlling station in the VANET scenario for V2I communication. The vehicles are considered to be moving along the highway unidirectionally. The AP broadcasts beacon messages periodically. The vehicles in the range of the beacon message, send association request

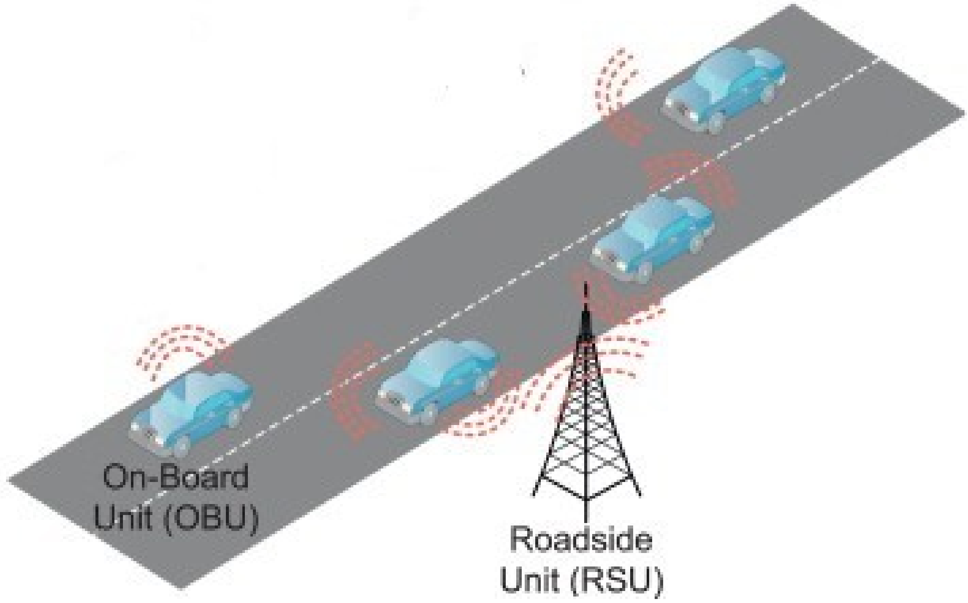


Figure 3.1: V2I Communication

to the AP. The AP, once receives the association request, replies back to the vehicles with an association reply and after a few exchange of authentication messages, the connection between the vehicle and the AP is established. The reply messages by vehicles are used by the AP to estimate the density of the VANET network and can be utilized to re-model the system, cluster the vehicles and perform admission control to improve the network performance.

3.2 Mobility Model

Mobility in vehicles is the main aspect for the system model as it describes the dynamics of the VANET. We designed the model in such a way that takes into account various parameters such as intervehicular distance, velocity and the number of vehicles. The intervehicular distance can either be deterministic i.e. a constant value throughout the simulation or an exponential random variable. Since the movement of vehicles are always changing it is more practical to consider different intervehicular distances. The velocity is considered to be constant for the entire simulation time. Vehicles do not move around arbitrarily, but use predefined roads, usually in two directions. Unpredictable changes in the direction of vehicles usually only occur at intersections of roads. We investigate a single dimensional highway model where vehicles are travelling unidirectionally. For different runs, the velocity can be changed to study different scenarios. We investigated the performance for different velocities of vehicles on the highway ranging from 50km/hr to 120km/hr. In our system model, the vehicle speed is independent of the observation time, and it is equal for all the vehicles in the same road segment. This is an important property for our simulation and analysis because it implies that:

- The sojourn time of each vehicle under the APs coverage area is fixed, as the velocity of the vehicles are pre-defined and
- The inter-vehicular distances is maintained throughout the traffic flow and is considerd to be constant or exponentially distributed [11].

The duration of a session for a tagged vehicle is determined by its speed and the AP's transmission range. This leads to interesting and important interplays between vehicular traffic parameters, wireless network settings and individual vehicles communication/data download performance within a drive-thru Internet system. The mobility of vehicles in highway traffic is a complex dynamic scenario, and its modelling has drawn huge interest in the research community [24], [29]. Usually with fewer vehicles on the roadway (i.e. at low vehicle densities), cars move with an average free flow velocity, which depends only on factors such as maximum speed limit. As density is increased the velocity decreases as a function of average density. At higher densities, when the traffic comes to a halt, i.e., at jam density, the average velocity drops to zero. With this situation the vehicles can barely move as seen in Figure 3.2.

3.3 Application

Integrating a network interface, GPS receiver, different sensors and on-board computer gives an opportunity to build a powerful car-safety system, capable of gathering, processing and distributing information. Numerous applications can be deployed in a network established with such equipped vehicles and proper infrastructure. With our

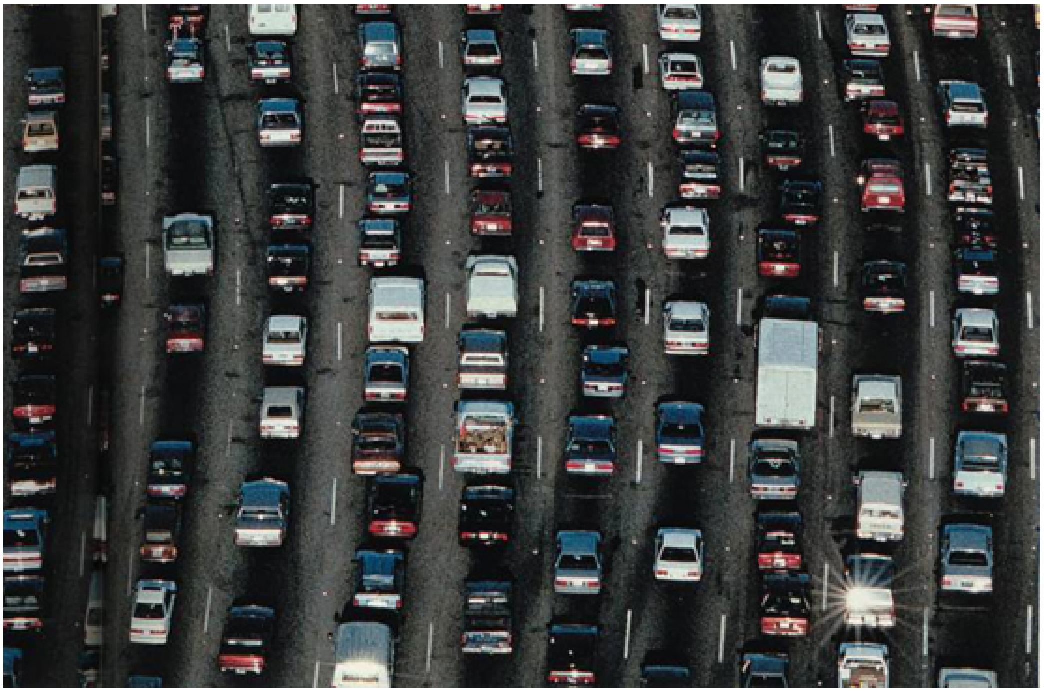


Figure 3.2: Snapshot of a Traffic Jam

system model, we intend to address the macroscopic model of VANET by making the channel more user friendly and accesible to vehicles. Our model considers a single AP and the network is considered to be saturated, i.e. all vehicles requesting the drive-thru Internet service have sufficient data to transmit to the AP. We also focus on uplink transmission which is a more challenging problem than the downlink one due to the random contention among the vehicles (vehicles to AP message dissemination). Uploading sensed data or video are some of the widely used applications.

To effectively facilitate these applications in V2I scenarios, a fast and efficient network configuration of vehicles with AP is needed to minimize the time spent in control overhead and to ensure continuous connectivity and fast delivery for real-time and other time sensitive applications. We try to address this issue by reducing the congestion in the wireless network.

3.4 Propagation Model

The propagation model used in a VANET simulation has a large influence on the results. It impacts which nodes are able to communicate and the probability of correct reception and also is used to judge the effects of propagation of electro-magnetic waves through the medium and usually this medium is air. As a result, it can influence the speed at which messages propagate through the network, directly influencing the performance metrics of the network.

There are different propagation models which can be considered for a wireless network. We described in Chapter 2 regarding the PHY layer in VANET, the consequences of path loss in such networks and their cause. Since the model considers a highway drive-thru Internet type of scenario where the interaction is V2I based communication, considering Friis space model [38] as propagation model is justified. The receiver in this case is in the Line of Sight (LOS) and free of obstacles.

For our model we will use Friis Free Space Model [38] that considers a perfectly reception of the signal over one path at distance d. The receptor is on Line of Sight (LOS) and free of obstacles. The equation for Friis Free Space Model [38] is as follows:

$$P_r = \frac{P_t \times G_t \times G_r \times \lambda^2}{(4 \times \pi)^2 \times d^2 \times L} ,$$

where we have:

P_r - Receiving Power,
P_t - Transmitting Power,
G_r - Receiving Antenna Gain,
G_t - Transmitting Antenna Gain,
λ - Signal Wavelength,
L - System Loss,
d - Distance between transmitter and receiver.

The Physical layer parameters are significant for simulations and designing the model and we have chosen our parameters based on [46] with minor modifications.

Due to dynamics of the network, for different zones in a highway, as explained in the next chapter, the data rate is different based on the distance from the AP. This multi-rate feature is standardized in almost all 802.11 versions (b/g/n). As varying distance has a direct impact on channel quality and thus on data rate, hence there is a tradeoff among communication range and link data rate for instance whenever the vehicles are in Zone 1, the transmission rate is 11Mbps and the rate will decrease with the increase in distance, i.e. 5.5Mbps, 2Mbps and then 1Mbps for Zone 2, 3 and 4 from the AP respectively.

3.5 MAC Protocol

According to the IEEE 802.11p standard, transmission of messages often suffers from the consecutive collisions in bursty networks or congested scenarios since it selects a small initial back-off parameter for CW size, by a primitive assumption of a low level of congestion in the system, and thus results in transmission packet delays. This strategy might allocate an initial size of contention window, which can be insufficient when the load is high. The size of contention window must then be enlarged after each collision. Furthermore, after a successful transmission, the size of contention window is reset again to the minimum value without considering the current channel status. This problem, if solved, can open several scopes for enhancement in VANET. Our focus is to adjust the CW parameter with respect to the density of vehicles in the zones divided based on their distance from AP. The packet access delay and loss can be greatly reduced to deliver messages without degradation of the throughput by a proper choice of the contention window size.

Chapter 4

Enhanced Admission Control and Contention Window Design

4.1 Motivation

As stated in the previous chapters, improving the network performance of VANET poses many challenges because of its structure. High mobility in the network makes the system more intriguing. With ever increasing traffic, the motivation to achieve better performance of VANET is inevitable. In V2I based communication, the network can harness the fixed infrastructure for improved performance and functionality. VANETs are distinguished from other kinds of ad hoc networks by their hybrid network architectures, vehicle movement characteristics and new application scenarios thereby face many unique networking challenges such as high mobility, scalability, connectivity etc.

In VANET, with a highly changing topology, it is challenging to sustain the connections for extended period of time. Broadcasting messages is so far most scalable solution but they can have unwanted repurcusions if not well regulated. Related work in this field such as in [23] [17] discussed the disadvantages of flooding of messages, which results in huge number of collisions in the network and hence degrading the performance. The alternative is to disseminate data using intelligent techniques like clustering [9]. Clustering is one solution for the scalability problem and is vital for efficient resource consumption and load balancing in large scale VANETs. In this work, we focus on the V2I scenarios where a APs provide Internet services for vehicles within its coverage. Our objective is to improve the network performance by reducing the contention, minimizing the communication overhead and at the same time making it scalable and backward compatible with the regular 802.11p (WAVE) protocol. We discuss our proposed design in the following sections.

4.2 Admission Control

In a wireless network, there are several ways to improve the overall efficiency of the network with respect to transmission range. The efficiency is improved by controlling the admission range. Usually as the transmission range increases, the transmission rate decreases to improve the resiliency of the packet flow. Although the channel time consumption increase, but it does help in improving the overall network performance. The greatest chance of increasing the throughput of the network is to make it adaptive based on the requirement of the network. The AP in our system model will do the admission control by changing its admission range periodically based on the association request accepted from the vehicles in the vicinity. It is clear that once the AP receives association request by any vehicle, it is an indication that there are vehicles present in the concerned zone on the highway and if not, the AP will increase its admission range. The objective of this proposed mechanism is to reduce the number of contending vehicles by clustering them based on different zones for channel access and increase the network throughput.

The vehicles in VANET are continuously moving in and out of the coverage of the AP. The amount of data that a passing vehicle can send or download from AP is dependent upon two main factors [24]:

- the period for which the vehicle is within the APs coverage range, and
- the number of other vehicles competing for the wireless resources during its connected time with AP

In our model, we consider a highway drive-thru Internet scenario, wherein vehicles are moving at a constant velocity. This can be attributed to the fact that we consider a steady traffic flow in one direction. Although the intervehicular distance is a parameter which can be changed to make the system more realistic. Hence for our system we considered both constant and exponential randomized intervehicular distance. This assumption captures the essential traffic regime in a non-congested highway condition. These vehicles establish connections to AP along the road. Once an AP receives a connection request packets from the vehicles, it counts the vehicles in the concerned zone. The highway under AP's transmission range is divided into several zones based on the distance from the AP and the as shown in Figure 4.1:

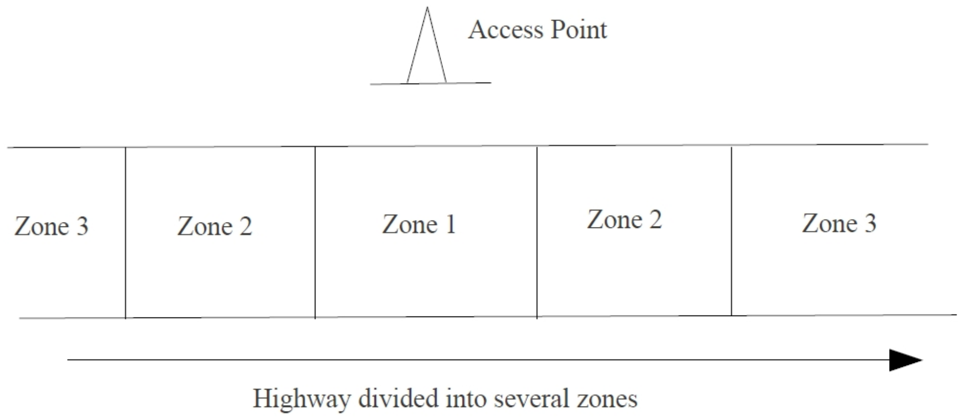


Figure 4.1: Highway Zoning and AP

In each zone the transmission rate between the AP and the vehicles is assumed the same wherein Zone1 has the highest rate. We consider the network to be saturated, i.e. all the vehicles on the highway have packets to send to the AP based on 802.11 DCF MAC. Initially the AP has the transmission range which is just enough to receive messages from the closest zone. Therefore as shown in Figure 4.2, initially the AP will be communicating with only from those vehicles in Zone 1. However, we need to consider two cases:

- Vehicles present in Zone 1 (closest zone to AP).
- No Vehicles in Zone 1.

For the first case, once the AP receives information from the vehicles, the AP will allow the channel access only to vehicles belonging to Zone 1. The vehicles in other zones are not allowed to contend for the channel access. We attain this feature of admission control by making changes to the admission range of the AP. The AP will keep its transmission range and its accessibility such that vehicles in Zone 1 will be allowed to send messages, since vehicles belonging to that Zone will always have the highest priority of transmitting. Once the connection is established among the vehicles and AP, the mechanism of CW adjustment will take place among vehicles contending for the channel access, as discussed shortly.

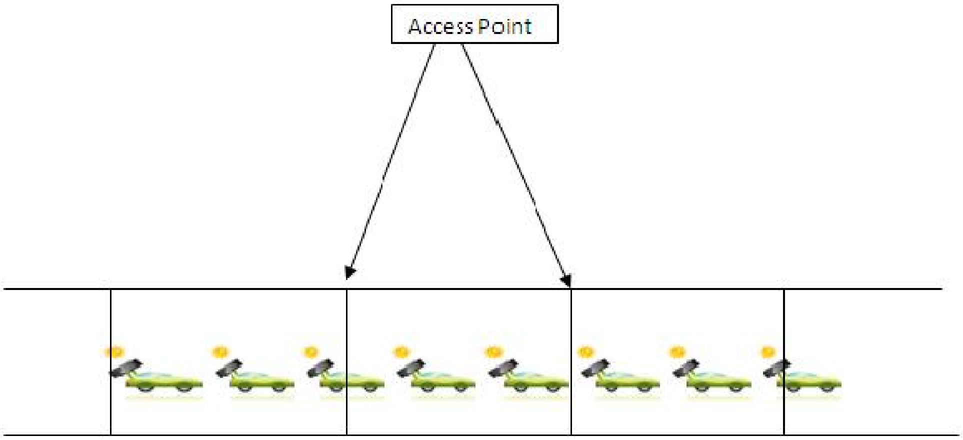


Figure 4.2: Transmission Range for Vehicles in Zone 1

As seen in Figure 4.2, the admission range is such that the AP is capable of serving vehicles in Zone 1 only, without giving access to communication channel to vehicles in Zone 2. This method reduces the contention by a large amount. Since all vehicles will eventually enter Zone 1, this method is also fair.

Whenever there is no vehicle in the Zone 1, the AP will extend its admission region to serve vehicles in Zone 2 respectively. This indirectly includes Zone 1. Recall that vehicle's movement is deterministic, any vehicle in Zone 2 is bound to enter Zone 1. In order to take account of this fact, the AP will broadcast beacon messages periodically. Whenver it serves the vehicles in Zone 1, it will reduce the admission region to Zone 1 only.

The lookout for vehicles in the respective zone will take place periodically for each beacon intervals. Based on the requests received and the location of the vehicles, the AP will adjust its beacon transmission range. Since the probability and priority of transmitting a packet successfully is highest for the vehicles in the Zone 1 (nearest to the AP), the AP will try to converge its admission range within that zone, as soon as it discovers vehicle's presence in Zone 1. Once admission range is established, we match it to an actual beacon transmission power value required to maintain the

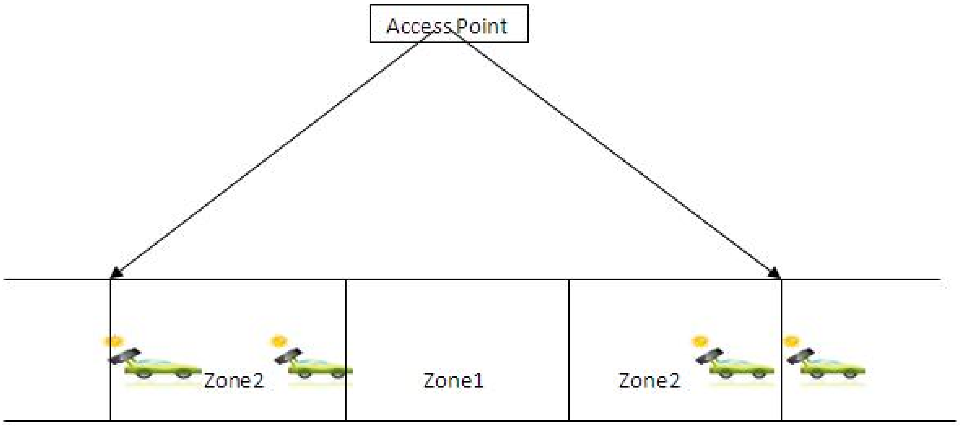


Figure 4.3: Transmission Range for Vehicles in Zone 2 and Zone 1

specified range. To do so, we match the transmission power values corresponding to different transmission ranges. In our study we use the Friss free space model propagation model in order to generalize the problem of changing node densities. Also by using Friis equation, we assume the lowest possible path loss, resulting in higher radio range than expected in the real world. Through some basic simulations of propagation model we obtained the relation between the admission range and the power required to match upto the required range. The reason to do so is fast computation for simulations.

Table 4.1: Range vs Power

Admission Range(m)	Beacon Transmission Power (dB)
10→50	-13
50→150	-4
150→250	5
250→400	12
400→500	14
500→650	18
700→900	26

In order to establish a connection with the AP, the vehicle keeps actively scanning for beacons from AP. Once the beacon from AP is detected, the vehicle sends an association request frame and AP replies back with an association response which contains the association id. The vehicles upon receiving the ID, sends an ACK to the AP and hence the final connection between the vehice and AP is established.

Pseudo code for admission control can be seen below:

Algorithm 1 Adjusting $T_x range$ by AP based on received messages

```
INPUT: Message IDs; Set of Beacon Tranmsission Power ; $CW_{min}$, $CW_{max}$.

OUTPUT: Beacon Coverage based on vehicles and their locations (Message IDs).

if messages from Zone 1 then
  Estimate density of Vehicles in the Zone 1 using messages counter == $\frac{K_{jam} \times No,of Vehicles}{18}$;

  Beacon Transmit Power = -8.5 dB
else
  if messages from Zone 2 then
    Estimate density of the vehicles in the increased Zone==$\frac{K_{jam} \times No,of Vehicles}{54}$;

    Beacon Transmit Power = 13 dB
  else
    if messages from Zone 3 then
      density == $\frac{K_{jam} \times No,of vehicles}{102}$;

      Beacon Transmit Power = 24 dB
    else
      Beacon Transmit Power = Max-Power
    end if
  end if
end if
```

As seen, if AP receives any message from Zone 1, it will transmit data for only the vehicles within that Zone. This is achieved by changing the transmission power of the AP. The values are used from the look up table as seen in Table 4.1.

As shown in the Algorithm 1, we consider the K_{jam} (maximum number of vehicles which can be accommodated in certain zone) for different zones to be different i.e 18 vehicles for Zone1, 54 vehicles for Zone2, 102 vehicles for Zone 3 and so on [25]. In order to cover different zonal range, AP needs to transmit the packets at different transmission power which is -8.5dB for Zone1, 13dB for Zone2 and 24 dB for Zone3 as derived by simulation and seen in Table 4.1.

4.3 *CW* Adjustment

CW is one of the main parameters of IEEE 802.11 DCF MAC protocol. [31]. Back-off after collision is an important mechanism to ensure the stability of the network. For our purpose we use the basic access mechanism as shown in Figure 4.4. In our case we consider the basic access model i.e. IEEE 802.11 DCF MAC with the absence of request to send/ clear to send (RTS/CTS) messages. One of the main reason to consider this model, is that RTS/CTS approach was designed for multi-hop and stable environment, e.g. positions of the nodes (or vehicles in this case) and a stable communiction link. Although the probability of collisions may be dropped using the RTS/CTS mechanism, according to the IEEE 802.11 standard, RTS/CTS is not preferred in a single hop environment.

Access.jpg

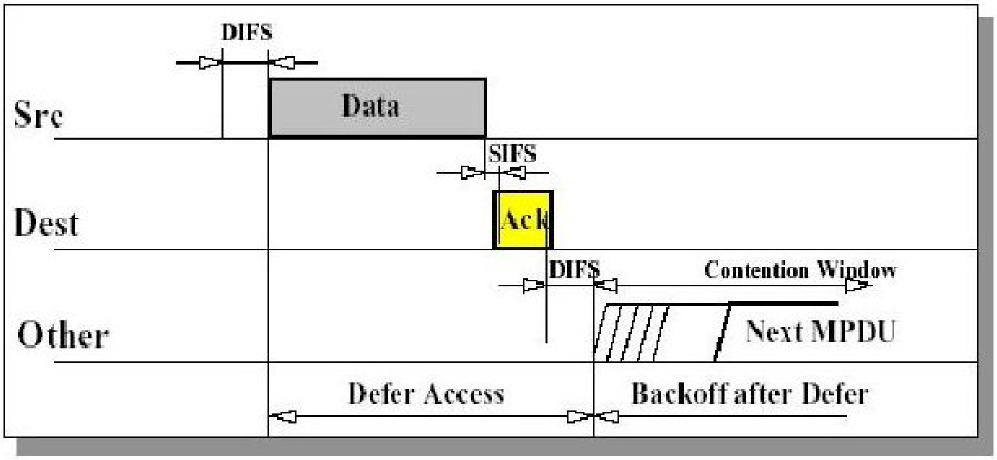


Figure 4.4: Basic Channel Access without RTS/CTS

The AP in a VANET is able to detect network congestion by simply analyzing the sequence numbers of packets it has recently received. Based on the number of successfully received packets in the last few seconds, the AP determines the current local conditions of the network and roughly estimate the number of vehicles in its communication range. Therefore, a node is able to dynamically adjust the PHY and MAC parameters, such as contention window size, transmission rate, and transmission power, to improve the delivery rate of broadcast messages.

Along with the admission control, we propose to modify the regular DCF protocol which allows the stations to contend for channel access. Based on the vehicle density, the AP will send the information about the CW back off parameter, in its broadcasted beacon message, so that in the case of low load, i.e. less number of vehicles, the back off parameter should be such that it resets back to the minimum in order to allow packet transmission in the shortest possible time and to avoid the wastage of a large amount of waiting time to access the channel. On the other hand, if the density of vehicles is high, having a small backoff parameter may result in more consumption and eventually wasting bandwidth and time due to frequent collisions of transmitted packets. Hence, the back-off parameter is calculated such that that for the entire network throughput during that time can be higher than the regular IEEE 802.11 DCF protocol.

As mentioned, if the channel is busy, the station monitors the channel until it is measured idle for a DIFS time period. After this, the station generates a random back off counter to minimize the probability of collision with packets, sent by other stations. If the channel is idle, the back-off counter is reduced by one. If the channel is busy, the counter freezes till the channel is idle again. The IEEE 802.11 DCF employs an exponential back off scheme. The back off counter is uniformly chosen in the range [0, CW-1], at each packet transmission, where CW is the contention window and is dynamic in nature. Its value depends on the number of collisions suffered by the packets. At the first transmission the CW value is set to a value CW_{min}, i.e. the minimum Contention Window. After each failed transmission, CW is doubled up to the maximum value, CW_{max}, which is equal to $(2^m \times CW_{min})$. The value of m is equivalent to the maximum number of retransmission attempted by the station for the erroneous packets. In basic IEEE 802.11DCF protocol, m is set to 7. The back-off timer is decremented as long as channel is sensed idle. It is frozen when the channel is busy, and reactivated when the channel is sensed idle again for more than one DIFS. The station transmits the packet when the back-off timer reaches zero.

Within the communication range of APs, packet transmissions are coordinated by the DCF scheme. The main aspect of concern is that DCF was originally designed for bursty traffic in indoor networks. When used for the dynamic vehicular communications, the performance of DCF highly depends on the mobility of nodes and the traffic pattern. Hence the CW parameter needs to be maneuvered. The transmission of packets by a contending vehicles/node is probabilistic in nature and is very well defined through transition state probabilities by [14]. An important property of a Markov process is that it is 'memoryless' i.e. a process satisfies the Markov property if one can make predictions for the future of the process based solely on its present state. We first briefly analyze the relation between the collision probability with repsect to the CW and the contending vehicles in the zone.

For this model, there are several assumptions similar to [14]:

- The zone within the transmission range of the AP, consists of 'n' contending vehicles.
- Each vehicle has always a packet available for transmission, i.e. the node is saturated.
- Conditional collision probability 'p' of a transmitted packet is constant and independent of retransmissions this packet has suffered in the past.

Once p is supposed to be a constant value the two-dimensional model (back-off time counter for a given station and back off stage (0,....,m) of a station at time t) is designed as a Markov chain as illustrated in Figure 4.5 [14]:

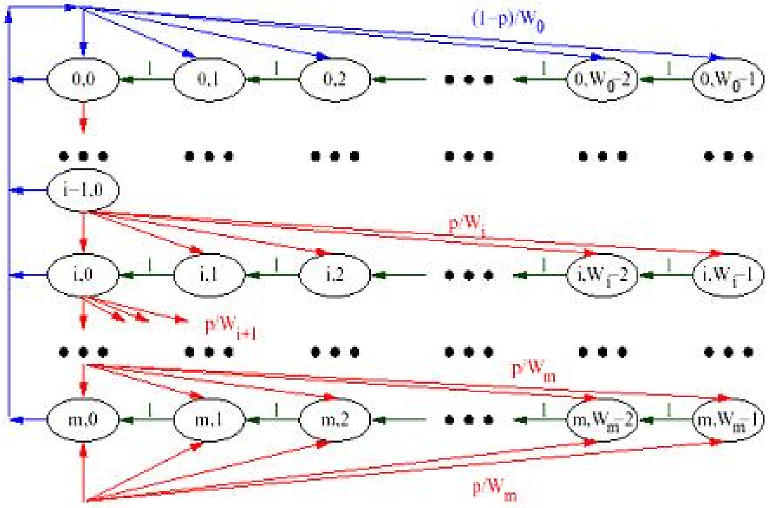


Figure 4.5: 2-dimensional Markov Chain [14]

With the above assumptions, and the Markov model following one step state transition probabilities obtained in [14].

$$P\{i,k|i,k+1\} = 1, k \in (0, W_i - 2), i \in (0, m), \tag{4.1}$$

$$P\{0,k|i,0\} = \frac{1-p}{W_0}, k \in (0, W_0 - 1), i \in (0, m), \tag{4.2}$$

$$P\{i,k|i-1,0\} = \frac{p}{W_i}, k \in (0, W_i - 1), i \in (1, m), \tag{4.3}$$

$$P\{m,k|m,0\} = \frac{p}{W_m}, k \in (0, W_m - 1), \tag{4.4}$$

where
m = Maximum back-off stage,
$W_0 = CW_{min}$ at first transmission attempt,
$W_i = 2^i * CW$ where i $\in (0, m)$ is called back-off stage.

Equation (4.1) summarizes the fact that, for each idle slot time, the backoff counter is decremented. Equation (4.2) tells us that a new packet following a successful packet transmission starts with backoff stage zero, and thus the backoff is initially uniformly chosen in the range (0, W_0-1). Equation (4.3) implies that when an unsuccessful transmission occurs at backoff stage (i-1), the backoff stage increases, and the new initial backoff value is uniformly chosen in the range (0, W_0). Equation (4.4) implies the fact that once the backoff stage reaches the value m, it is not increased in subsequent packet transmissions.

Using the Markov chain model, the probability, τ, that a station transmits a packet in a randomly chosen slot time is equal to

$$\tau = \frac{2 \times (1 - 2 \times p)}{(1 - 2 \times p) \times (CW + 1) + (p \times CW)(1 - (2 \times p)^m)}, \tag{4.5}$$

and the probability p_c that a transmitted packet encounters collision is given by:

$$p_c = 1 - (1 - \tau)^n \tag{4.6}$$

The above two non-linear equations can be solved by numerical methods in order to find out the values of p and τ. Based on [14], the probability P_s that a transmission is successful, given there are n active stations is given as:

$$P_s = \frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n} \tag{4.7}$$

Based on (4.6) and (4.7), the objective is to increase P_s or decrease p_c in the network in order to achieve higher throughput. This can be obtained if the value of $(1-\tau)^n$ increases which implies that τ needs to be small. As seen in (4.5), if we increase the value of CW, we can obtain smaller τ. From simulation as shown in Figure 4.6, as the number of active stations increases, the high value of CW helps to achieve higher network throughput.

Since VANET is a dynamic environment, it is imperative that the vehicle remains active during the sojourn time and exchanges beacon message with the AP to obtain information about its own back-off factor. The vehicles based on the density measured by AP changes its back off parameter in case of collision.

As shown in (4.6), the probability of a collision decreases when CW increases and this effect is more pre dominant for higher values of n. Hence based on the zone and the mobility of vehicles, CW size is determined. Since we are investigating the impact of adapting settings for CW based on the traffic density in order to increase the efficiency of the 802.11p (WAVE) protocol, it is suggested to have intial CW size equal to 16 [40] [1] [27]. The rest of the parameters are shown in Table 4.2.

Table 4.2: Zonal Parameter

Zones	Zonal Lenth(m)	Rate(Mbps)
1	150	11
2	450	5.5
3	850	2
4	1050	1

Since CW is a sensitive factor, a minor modification can result in a large impact on the throughput of the network. If the system is designed in such a way that the contending stations do not wait for a long period of time for re-transmitting lost packets, or in other words the stations should have a smaller idle time, the throughput of the network can be improved to a large extent. We intend to draw a relation between the density and the back-off parameter, which will curb down the wait time and as a result will contribute to enhance the network throughput.

The operation of our algorithm can be described as:

$$CW \leftarrow min(x \times CW, CW_{max}) \qquad - OnCollision \tag{4.8}$$

$$CW \leftarrow CW_{min} \qquad - OnSuccess \tag{4.9}$$

Here x is the multiplicative factor which will be used to change the CW after a collision. The approach is quite similar to EIED back off adjustment but the major difference lies in the fact that we intend to design the multiplicative factor x in such a way that it is based on the density of vehicles. As previosuly stated "probability of a collision decreases when CW increases and this effect is more important for higher values of n" we want to have a quick back off strategy for fewer number of stations and vice versa. Quick back off strategy will help to reduce the idle time and hence will improve the network throughput. In order to figure out the value of x, we simulated the network with different densities to check out different values of x which can fetch us significant throughput with respect to other chosen factors.

In the standard DCF protocol, the backoff is binary exponential as described previously. Taking account of the constant changing environment and dynamics of the network we change the value x based on the density of vehicles. We simulated the network consisting of 70 nodes in a network with different values of back-off multiplicative factor ranging from values greater than 1 to less than 4 and found out the relation between density and back off parameter as shown in Figure 4.6.

Figure 4.6 shows the comparison in normalized throughput with the number of active nodes. The range considered for the simulation is Zone3 which is sufficient enough to accommodate 70 vehicles in the network. In other words we can say that the length of the highway for the simulation is considered to be around 850 m. The factor in exponential back off was varied from 1 to 4 in four different schemes. The factor x can be a non integer value as seen in Figure 4.6.

The result showed significant changes in throughput of the network. When the factor x was decreased from 2 such that $1 < x < 2$, precisely 1.5 in this case, there is a sharp increase in the throughput when the nodes less than 10, but as soon as the number of active nodes increases the throughput drops faster than the other two curves. This can be attributed to the fact that when there is a collision the contention

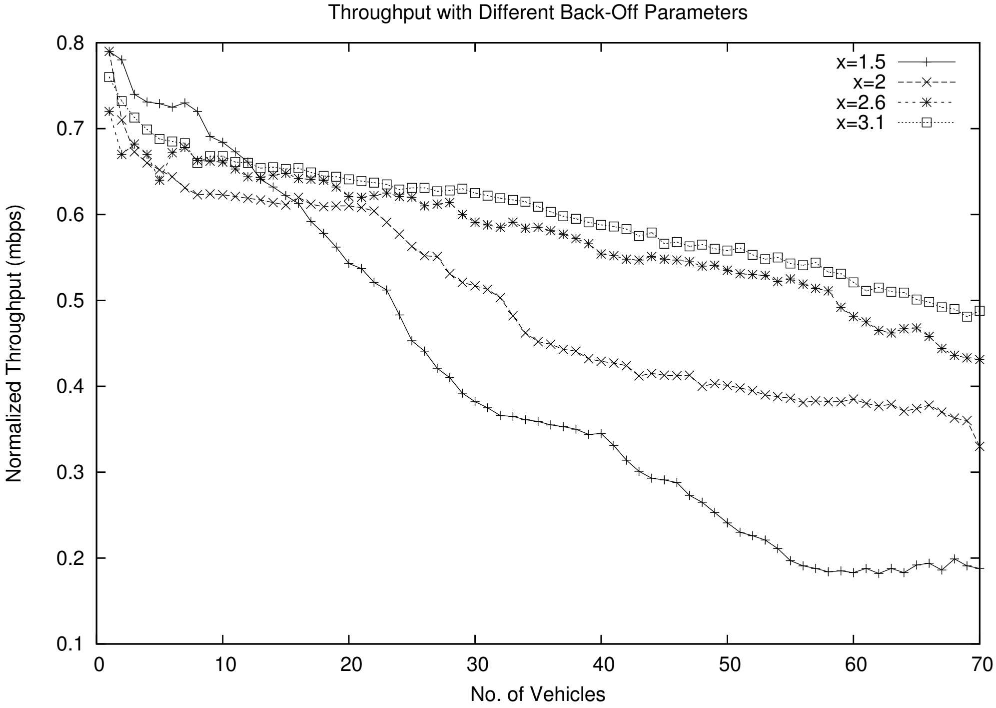


Figure 4.6: Throughput with Different Backoff Parameter Settings

window increases to a value which is less than its doubled value. Since the value of the back-off multiplicative factor is small, the station takes less time to decrement the counter back to CW_{min}, for contending to transmit the packet in the channel successfully. Hence there is a sharp increase in the throughput value initially.

As soon as the number of active nodes increases in the network, due to slowness in adapting the CW to the congestion level, collision will increase, and the throughput will decrease quickly. The situation will be slightly better for the binary exponential back-off which is the standard IEEE 802.11 DCF protocol. When the factor x is such that, $2 < x <= 4$, i.e. $x = 2.6$ and 3.1 the result is different and improved for more densed scenario with respect to the previous two mechanisms. Since these factors are larger than the standard mechanism, they will take extra time to countdown to 0 for each retransmission. The maximum throughput achieved in this mechanism is not as high as the previous two schemes, when the number of nodes is less than 15. As the number of active nodes increases in the network than 15, they provide higher throughput than the other two mechanisms with lower collision probability. Since the station takes time to win the contention to transmit the packet, other contending stations get ample time to get access to the idle channel. This scheme can be favourable when the number of vehicles is large in a certain zone to have sufficient large network throughput.

Based on the results we obtained (through extensive simulations) we draw a one on one relation for density and the backoff parameter as shown in Table 4.3.

Table 4.3: Density and Back off Parameter

Density	Back Off Parameter (x)
$0.1K_{jam}$	1.2
$0.2K_{jam}$	1.3
$0.3K_{jam}$	1.5
$0.4K_{jam}$	2.0
$0.5K_{jam}$	2.5
$0.6K_{jam}$	3.1
$0.7K_{jam}$	3.7

As previously stated, it is recommended to adjust the contention window size based on the number of active stations in the network. In case of fewer vehicles, one must go with an exponential scheme which results in smaller CW on average, to gain access to the channel as soon as possible to decrease the unwanted idle period of the network. When the number of active vehicles is large, we should go with a higher value of x to avoid excessive collisions.

In Table 4.3, K_{jam}, as previously stated, is the maximum number of vehicles which can be accommodated in the respective zones. Since the AP knows about the density of the vehicles for the concerned zone, in the beacon message it will inform about their back-off paramters and all the vehicles follows the suit by AP to achieve a better performance.

The algorithm for the above mentioned admission control can be described as below:

In the next chapter we will discuss about our simulation results.

Algorithm 2 Adjusting CW by vehicles based on received beacons

INPUT: Beacon message with information about density of vehicles in the Zone

OUTPUT: Contention based on density of vehicles in the Zone within transmission range.

```
if density = N × $K_{jam}$ where $0 < N < 1$ then
    Back off parameter $x$, for equated density using lookup table 4.3;
    Successful transmission $CW = CW_{min}$
    Collision of data packets, $CW = min(x \times CW, CW_{max})$
end if
```

Chapter 5

Simulation Results

To evaluate the performance of the proposed mechanism we have conducted simulations using NS-2.34, since it supports the 802.11p model. Simulation of VANET is a long process and requires careful study of simulation settings and parameteres. Since the required technology is currently under development, the cost to perform real world experiments is unaffordable and simulation is the preferred experimental validation technique. In this chapter we show the results to endorse the fact that our proposed solution is well suited for a dynamic environment along with better network performance.

We used a combination of the latest network simulation tool NS-2.34 version, C++, TCL and AWK to simulate a WAVE environment of vehicles comprising of different values, with varying inter-vehicular distances to change the densities and the vehicle velocity. We ran several iteration ($\tilde{5}$) to obtain the average values for all the results obtained in our analysis,which we have discussed in the section below.

5.1 Simulation Settings

The network is simulated for a highway scenario where the road segment is divided into 5 Zones (2 Zone 3 , 2 Zone 2 and 1 Zone 1) based on the distance from AP. The stretch is considered to be 1Km long and the distance from the AP to the edge of the zones are 150m, 450m, 850m and 1km, for Zone 1, 2, 3 respectively. The zone smallest in length and apparently the nearest to the AP is the one for which AP tries its transmission range to keep covered. Vehicles velocity varies from 50 km/hr to 120 km/hr to test the impact of the speed in the network performance. The maximum transmission range of the AP is set to be upto 1000m which is the standard for DSRC communication. The beacon message is sent by the AP periodically and based on the identity of vehicles (their location and based on sequence number), the AP updates its count of vehicles.

Simulation in VANET comprises of two important components:

- Traffic simulator
- Network simulator

The traffic simulator addresses the movement pattern of the vehicles in the network and generates a trace file which provides us an insight into realistic vehicular movements. This trace file is fed into the network simulator which defines the vehicular movement and position of each vehicle in the network realistically. A traffic simulator is used for the vehicle movement on the highway. The movement file of the vehicles contains the initial (x, y) coordinate of each node at ground level, or z = 0. The file also provides node movement instructions that specify the target destination (x, y) of each node and the speed at which the node moves toward that destination, in m/s, as shown in Figure 5.2.

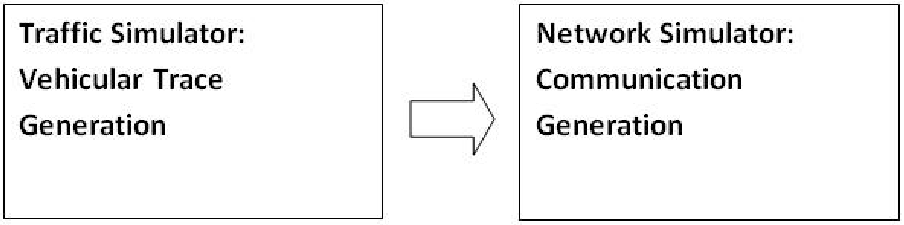
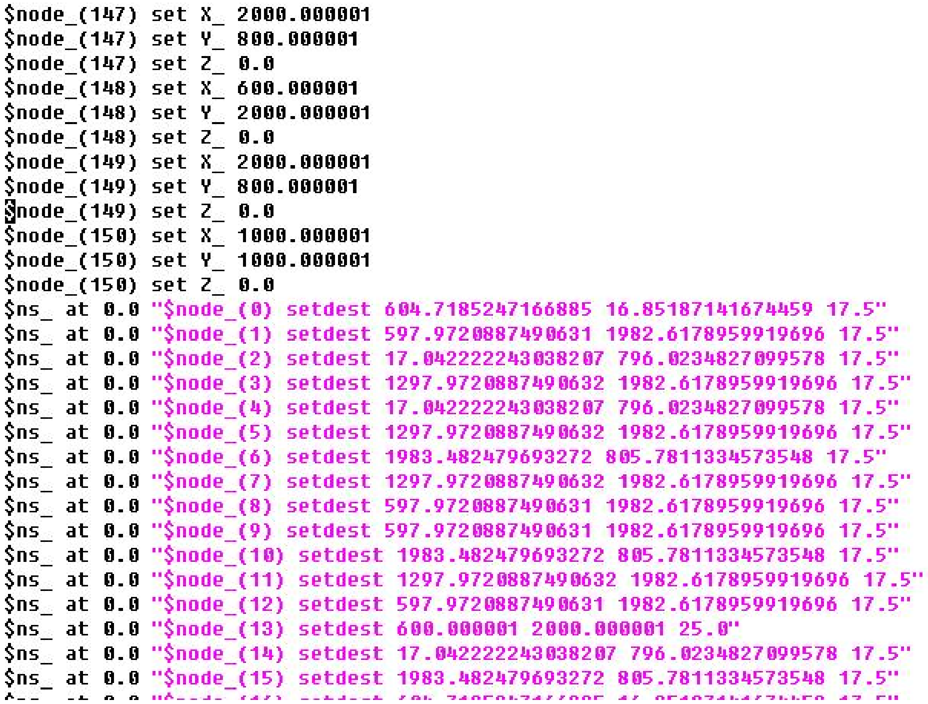


Figure 5.1: Relation between Traffic and Network simulation

The network simulator implements the 802.11p or VANET protocols to generate and prepare a trace file which contains the information about the events taking place during the simulation. Information contained in the trace file is eventually analyzed to retrive the results of the network condition. As stated we designed a traffic simulator for the vehicle movement on the highway.

The setting for different MAC and traffic parameters are listed in Table 5.1.



```
$node_(147) set X_ 2000.000001
$node_(147) set Y_ 800.000001
$node_(147) set Z_ 0.0
$node_(148) set X_ 600.000001
$node_(148) set Y_ 2000.000001
$node_(148) set Z_ 0.0
$node_(149) set X_ 2000.000001
$node_(149) set Y_ 800.000001
$node_(149) set Z_ 0.0
$node_(150) set X_ 1000.000001
$node_(150) set Y_ 1000.000001
$node_(150) set Z_ 0.0
$ns_ at 0.0 "$node_(0) setdest 604.7185247166885 16.85187141674459 17.5"
$ns_ at 0.0 "$node_(1) setdest 597.9720887490631 1982.6178959919696 17.5"
$ns_ at 0.0 "$node_(2) setdest 17.042222243038207 796.0234827099578 17.5"
$ns_ at 0.0 "$node_(3) setdest 1297.9720887490632 1982.6178959919696 17.5"
$ns_ at 0.0 "$node_(4) setdest 17.042222243038207 796.0234827099578 17.5"
$ns_ at 0.0 "$node_(5) setdest 1297.9720887490632 1982.6178959919696 17.5"
$ns_ at 0.0 "$node_(6) setdest 1983.482479693272 805.7811334573548 17.5"
$ns_ at 0.0 "$node_(7) setdest 1297.9720887490632 1982.6178959919696 17.5"
$ns_ at 0.0 "$node_(8) setdest 597.9720887490631 1982.6178959919696 17.5"
$ns_ at 0.0 "$node_(9) setdest 597.9720887490631 1982.6178959919696 17.5"
$ns_ at 0.0 "$node_(10) setdest 1983.482479693272 805.7811334573548 17.5"
$ns_ at 0.0 "$node_(11) setdest 1297.9720887490632 1982.6178959919696 17.5"
$ns_ at 0.0 "$node_(12) setdest 597.9720887490631 1982.6178959919696 17.5"
$ns_ at 0.0 "$node_(13) setdest 600.000001 2000.000001 25.0"
$ns_ at 0.0 "$node_(14) setdest 17.042222243038207 796.0234827099578 17.5"
$ns_ at 0.0 "$node_(15) setdest 1983.482479693272 805.7811334573548 17.5"
```

Figure 5.2: Snapshot of the Movement and Position (coordinates) of different Vehicles

Table 5.1: MAC and Traffic Parameters

Notation	Values
δ (Slot time)	30μs
T_{SIFS}	40μs
T_{DIFS}	70μs
T_{Data}	2000μs
T_{Ack}	200μs
K_{jam}	102 vehicles(Zone3), 54 vehicles(Zone2), 18 vehicles(Zone1)
CW_{min}	16
CW_{max}	1024

In NS-2,the network simulator, gives us the the option of implementing three radio propagation models, which are embedded in the simulator:

- Free Space
- Two ray ground reflection
- Shadowing

For simplicity in our work, we used the Friis Free Space propagation model [38]. Since the scenario is highway drive-thru, this propagation model is quite justified as there is less likely to have buildings and other road side obstacles to attentuate the signal. We assume that there is no packet loss due to fading. Packet losses are mainly due to collisions and interference in the model.

5.2 Simulation Results

In this section we show the readers our simulation results for our propsoed solution compared to the standard 802.11p protocol.

5.2.1 Successful Transmissions of Data Packets

We considered the ratio of successful transmission with total transmission to compare our proposed solution with the regular IEEE 802.11p mechanism. In order to do so we considered two different densities, i.e. 0.3 K_{jam} and 0.7 K_{jam}. To avoid any anomaly, we considered the same zone for our findings. The objective of doing this simulation was to gauge the performace of back-off parameter based on density in our mechanism. For density equivalent to 0.3 K_{jam}, the back-off parameter is set to be 1.5 rather than 2 as in binary exponential back-off scheme. For 0.7 K_{jam} we considered the back-off is set to be 3.7. With a large number of vehicles, there will be more contention and having a comparatively large back-off parameter will provide ample time for each vehicle to adjust to the network condition. The vehicular speed is considered to be 60 km/hr and the zonal range is confined to Zone 1 which stretches upto 150 m.

As seen from the result in Figure 5.3, when the number of vehicles are not large the ratio between successful to total transmission in both the cases remain the same. The improvement becomes significant as soon as simulation time increases after 10s. As the vehicles are continuosly entering into the zone, their number keeps increasing. Due to the large contention, it is justified that the ratio will suffer a decline compared to when there are few vehicles for contention. However, as the number of vehicles increases, the back-off parameter makes quite significant difference in performance. As our proposed mechanism adapts quickly based on the density we see significant improvement in the performance compared to the standard 802.11p protocol. For 0.3 K_{jam}, the ratio doesn't drop down beyond 60% and the average remains around 64% $\backsim$ 65%, compared to the regular binary mechanism where the performace ratio drops down to around 50%, a 20% decrease than the adaptive scheme. There is a performance drop when the density increases to 0.7 K_{jam} in both cases. We observe that for adaptive scheme, the average lies within 43%, compared to binary exponential where the performance is around 30% only.

The objective of the new proposed algorithm is to improve the overall throughput of the network. In this regard we intend to find out the results of average network

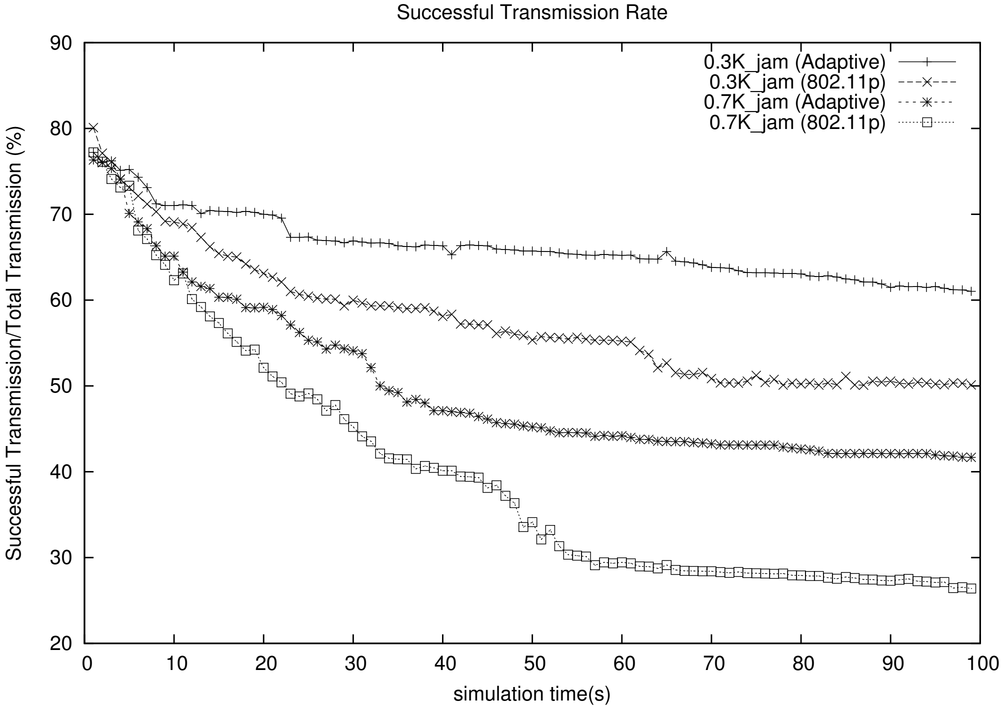


Figure 5.3: Successful Transmission Rate

delay, packet loss and aggregated normalized throughput.

5.2.2 Average End to End Delay

The delay considered in our case is the time required by the packet to reach the receiver (AP) successfully after its inception at the source i.e. the vehicles. Here in this result we demonstrated the performance of adaptive scheme with admission control, adaptive CW and combining both the schemes repectively, with respect to 802.11p protocol.

5.2.2.1 Admission Control

The queue length is an important parameter when considering end to end delay, because a data packet, once generated at the source spends some time in the queue, before it is finally transmitted by the vehicle. In order to do so we ran the simulation with 2 different queue lenghts i.e. 3 and 10 for both the adaptive and the regular 802.11p scheme. Since the simulation considers only the admission control strategy, we considered the same density for both the adaptive and 802.11p scheme i.e. $0.4K_{jam}$, so that the exponential factor remains the same i.e. 2.

We see from Figure 5.4 that the average delay for adaptive scheme is better than the regular 802.11p protocol. Here in this simulation experiments, we kept the back-off multiplicative factor to be the same, i.e. 2, for both the schemes since the density of the vehicles in the zone is kept constant, but the variable is the admission range of the AP. The end to end delay is the duration when a packet enters a queue of a beginning node which is the vehicle, until it arrives at the ending node which happens to be the AP. Since different packets have different UID, they can be easily differentiated for any packet specific information. However as illustrated Figure 5.4, having a delay of 12ms is quite optimistic, even though the adaptive scheme performs better than the regular 802.11p protocol. This can be attributed to the fact that the packet loses some time in the queue, before it is finally transmitted by the vehicles towards the AP. The delay in 802.11p is around 12.18ms compared to the adaptive scheme where the delay is around 12.12ms. In order to gauge the effect of queue lenght on the end to end delay, we did the same simulation, with queue length 10 compared with the previous simulation where the queue length was equal to 3.

We see in Figure 5.5, that the Average delay (end to end) has increased from 12ms to around 50ms. Though the increase in delay is seen for both the schemes, the

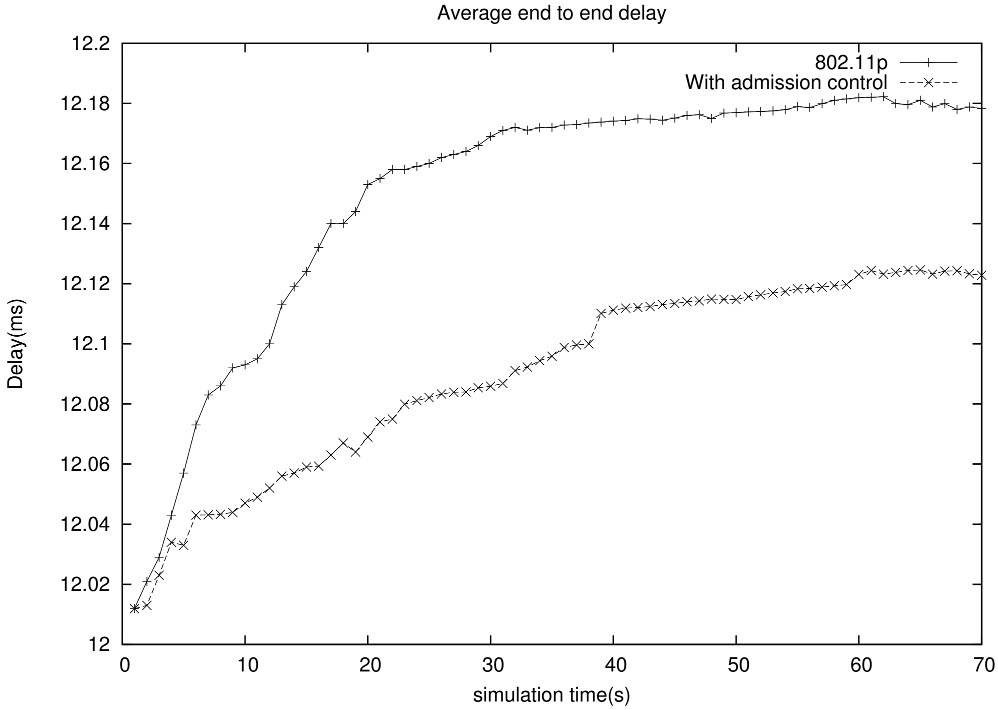


Figure 5.4: Average End to End Delay with Queue length 3

adaptive protocol performs better than the standard 802.11p protocol. The increase can be attributed to the fact that a packet after its inception, spends some time in the queue before it is transmitted to its destination which is the AP. Although our prime intention was to compare the delay in both cases with the same parameters and gauge the performance with respect to the access delay and we see that the adaptive scheme has better performance compared to 802.11p.

5.2.2.2 Adaptive CW

In this section we implemented the proposed solution with adaptive CW keeping the admission range constant for Zone 1, for both the scenarios. The interarrival time between the vehicles are exponential random distibution to vary the density during our simulation. The density of the vehicles varies from $0.4K_{jam}$ to $0.6K_{jam}$ with velocity, 80km/hr. The density is varied in order to gauge the performance of the adaptive scheme vs 802.11p scheme with change in density of vehicles. The queue length is kept the same as the previous result i.e. 10. Here we observe, how the selection of the back-off multiplicative factor based on density outperforms the

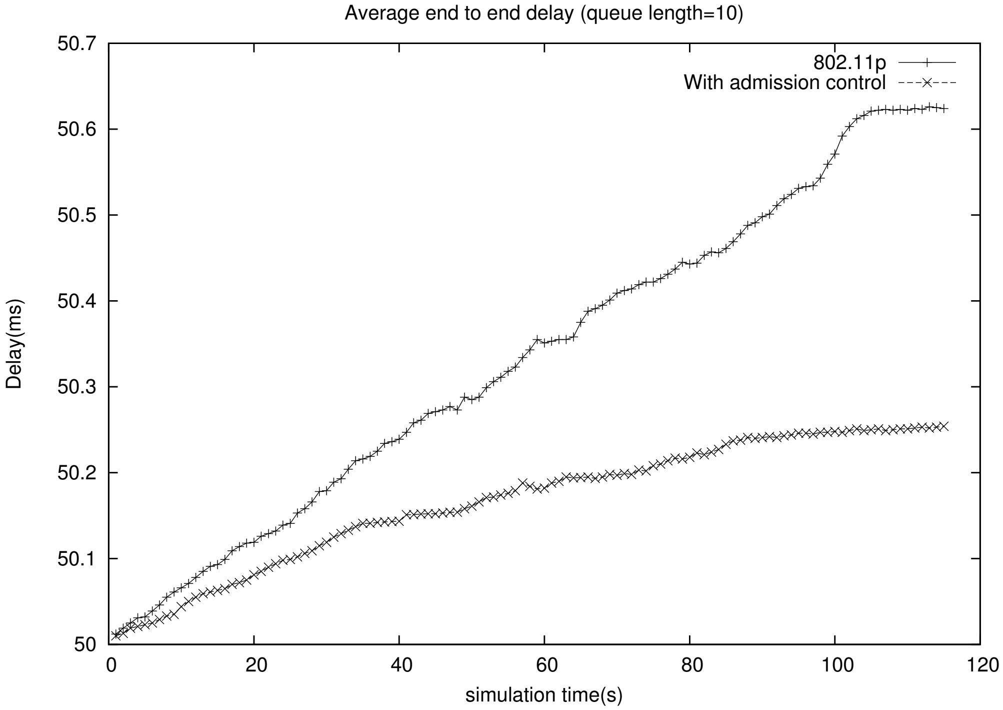


Figure 5.5: Average End to End Delay with Queue length 10 (Admission Control)

standard 802.11p protocol.

As seen in Figure 5.6, the adaptive CW copes well with any change in density with respect to the binary exponential back-off scheme where it always doubles the CW, irrespective of number of active nodes in the network. The delay starts from 48ms and slowly climbs upto 52ms. This can be attributed to the fact, that with increase in density, no matter how you design the MAC, you can't completely get rid of the latency due to increase in the number of contentions. Although, the performance does improve, but that may cost the performance of other metrics. With increase in the density, the adaptive CW has better statistics when compared with 802.11p. The improvement seen is around 5-7%.

5.2.2.3 Adaptive CW and Admission Control

In this result section we incorporated both admission control and adaptive CW to measure the impact of the joint mechanism with respect to the standard 802.11p. The settings are kept the same as when the simulation were run for adaptive CW i.e. the density varies from $0.4K_{jam}$ to $0.6K_{jam}$ and the admission range of AP is kept

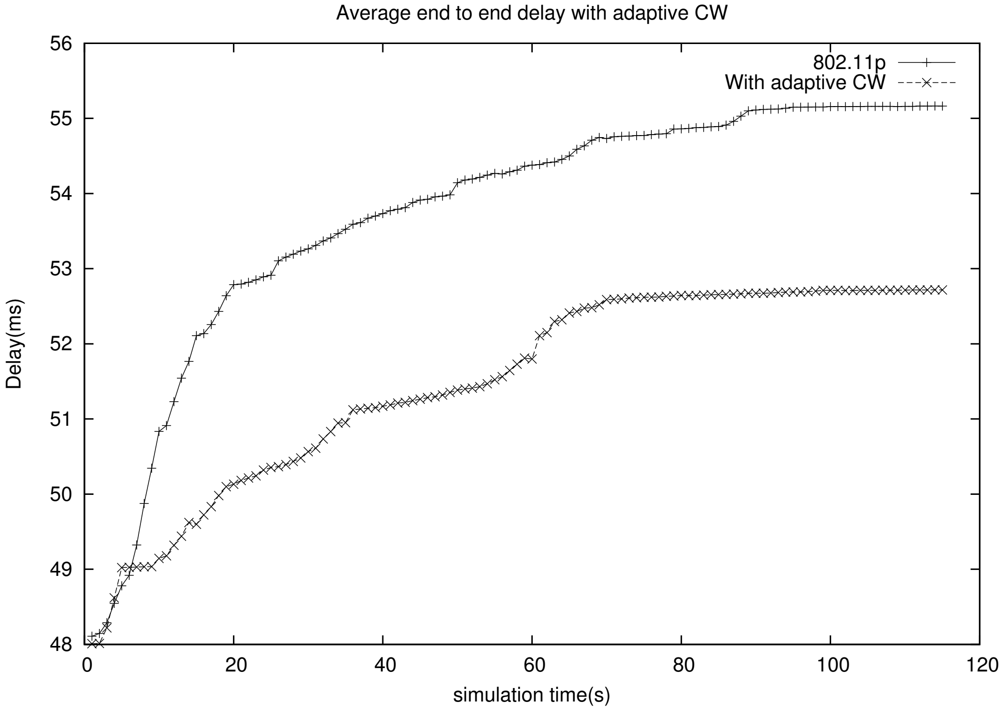


Figure 5.6: Average End to End Delay with Queue length 10 (Adaptive CW)

such that it covers the maximum range possible i.e. 900m. The range changes, as soon as the vehicles are discovered in Zone 2 and then Zone 1.

We see that the improvements is even better than considering adaptive CW and admission control separately. The maximum delay in this scheme reaches to upto 50ms which is better than the only adaptive CW scheme which in turn is even better than standard 802.11p protocol. During the entire simulation the the delay varies from 48ms to 50ms. The conjunction of adaptive CW and admission range does help in reducing the delay and improve the network performance.

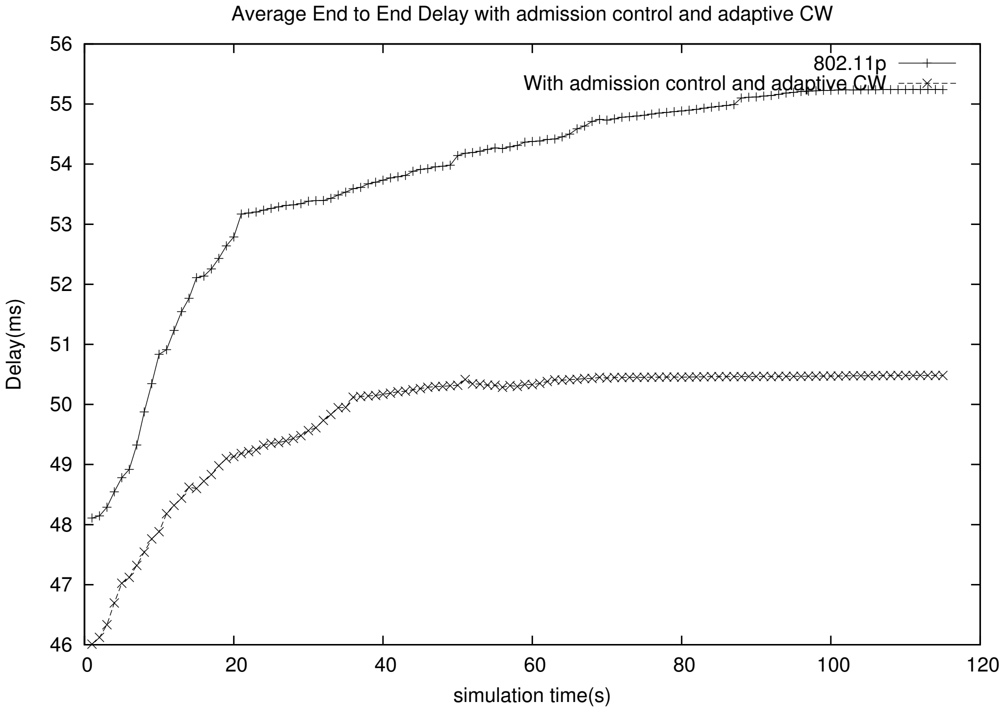


Figure 5.7: Average End to End Delay with Queue length 10 (Adaptive CW and Admission control)

5.2.3 Packet Loss

We obtained the results for packet loss in the given network with different velocities (50km/hr, 70km/hr, 90km/hr and 120km/hr). The vehicles are moving with the above mentioned speed with an intervehicular distance of 10 m for speed 50km/hr and 70km/hr and 15 mt for 90km/hr and 120km/hr respectively. Since the vehicles are uniformly moving on the highway, the transmission range of the AP is confined to zone 1. The results are plotted for loss (%) with the simulation time (x-axis).

5.2.3.1 Adaptive CW

The MAC layer will follow a best-effort strategy to reduce the congestion or lest collisions by prioritizing the packets. However in high-load situations a significant number of packet collisions may occur. The reasons for packet loss can be due to several reasons. While assuming equal transmit power, the packet of the vehicle that is farthest away is lost when competing with other vehicles which are near to the AP. Also regardless of the distance between two transmitting vehicles, a packet collision can occur if at least two stations have the currently lowest back-off slot. Hence, they start the transmission at the same time. This also allows for two colliding transmissions within receiving range of each other which is in contrast to the classic hidden station problem. In this scenario we consider that the density of the vehicles vary from $0.3K_{jam}$ to $0.6K_{jam}$ and the multiplicative factor is varied from 1.5 to 3.1. The admission range of the AP is kept constant i.e. the zonal area for simulation is considered to be Zone 2 i.e. 450 m in length. Although for the best effort strategy in adaptive scheme, the range is such that the AP tries to mimimize its admission range to Zone 1, in this simulation our motive is to estimate the performance variation with different multiplicative factor with respect to different density. Considering larger zone gives sufficient sojourn time for vehicles and AP communcation and helps us to gauge the change is parameter with respect to density more precisely.

We observe that once the vehicles start entering the zone, the loss(%) of packets start increasing slowly. It remains around 2% in the beginning for the adaptive scheme as compared to 4% packet loss with the regular 802.11p protocol. The actual effect of the adaptive scheme is seen about 13 sec into the simulation, once the system becomes stable and the vehicles in the admission range gets populated. On an average it is evident that the packet loss for 802.11p throughout the rest of the simulation time remains around 12-13 % compared to 6-7% with the adaptive scheme.

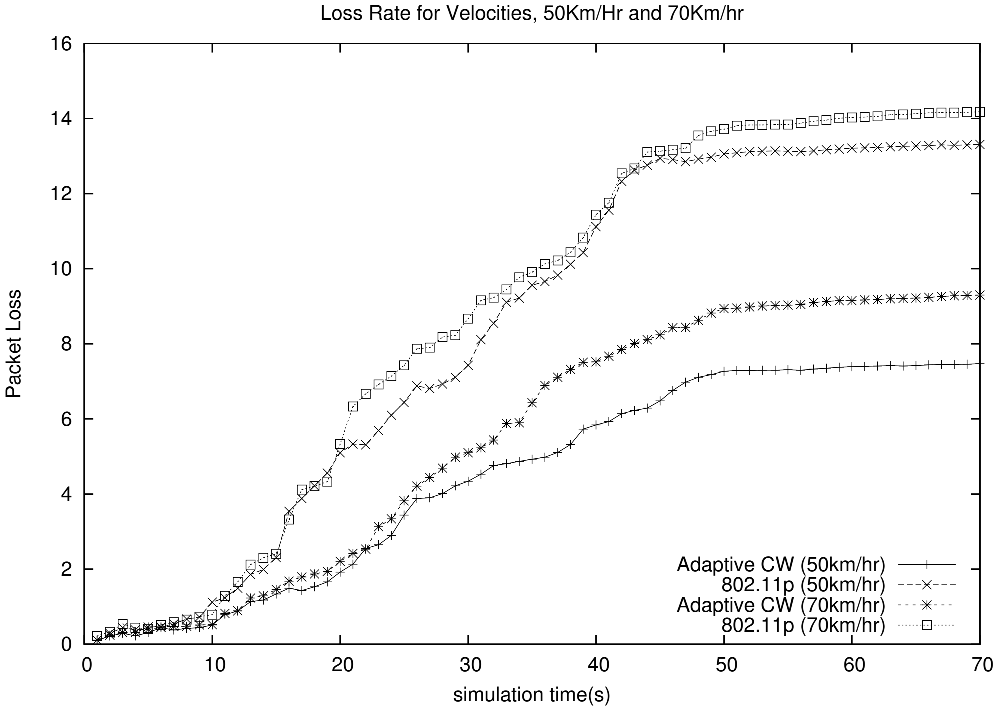


Figure 5.8: Loss Rate with Simulation time

We tried the same set of simulation with higher velocity. Change in velocity does not seem to have large impact on the packet loss. Also the same fact has been endorsed in [36]. It is observed that the loss observed for 90-120km/hr is around 13-16% for the 802.11p protocol and around 9-12% . Although the sojorun time is less for speedy vehicles, there is no change in the architectural aspect of communication.

5.2.3.2 Admission Control

Since the previous results included only Zone 1 statistics, we showed the performace of our propsed mechanism with adaptive CW. There was no admission control in the previous case. We simulated the network to consider the admission control strategy and to measure the loss(%)of packets while transmission. Initially the admission range of the AP is set to cover the entire stretch of the highway (in simulation), which is nearly 900m long. In the standard 802.11p, the admission range never changes, irrespective of any vehicles in any zones. On the contrary the adaptive scheme, converges its range to Zone 1 as soon as it discovers the availability of vehicles in that zone. The velocity of the vehicles are considered to be around 70km/hr and

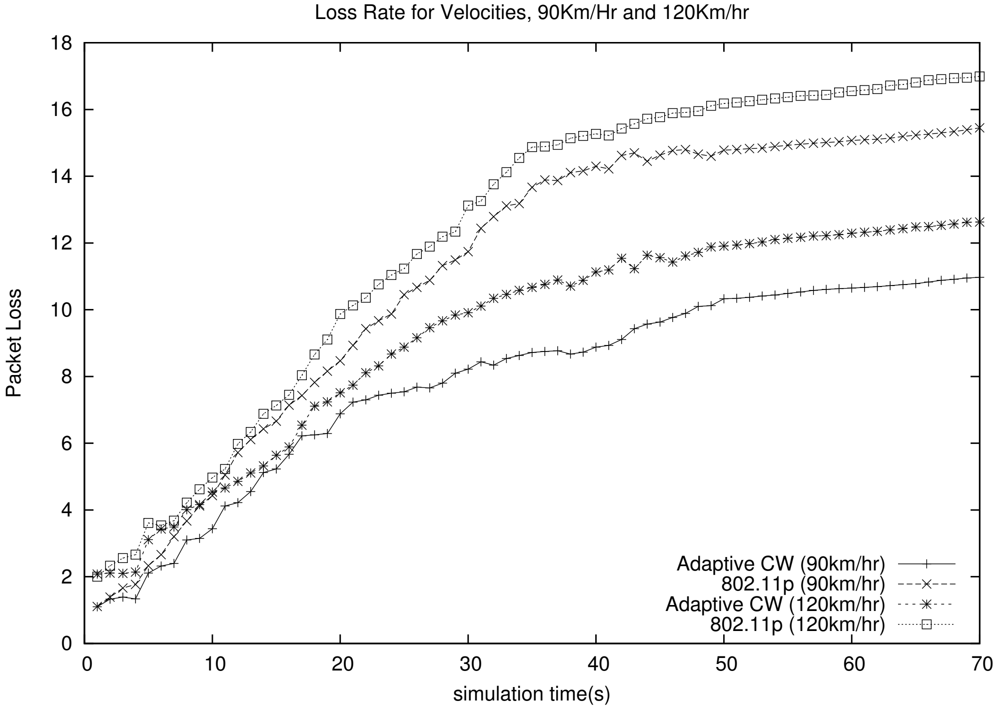


Figure 5.9: Loss Rate with Simulation time

intervehicular distance of 10m. The results are averaged over 3 runs.

We see that for the first few seconds into the simulation(7sec), the loss remains the same for both the scheme. As soon as the vehicles start entering other Zones i.e. Zone 2 and then Zone 1 eventually, the admission control proves to be a better mechanism than the standard 802.11p. Since clustering of vehicles, reduces the contention and hence lessens the lost packets, with time adaptive scheme outperforms 802.11p protocol. The improvement in this scheme is around 20-25% throughout the simulation.

5.2.3.3 Adaptive CW and Admission Control

As seen in the previous two results, the adaptive CW and admission control outperforms 802.11p quite convincingly. Although in this section we show the result by combining both the adaptive CW and admission control. The parameters for simulation, are kept same as the previous two results to maintain the generality i.e. the density varies from $0.3K_{jam}$ to $0.6K_{jam}$ and the admission range varies from Zone 3 to Zone 1 for adaptive scheme with velocity equivalent to 70km/hr. The admission

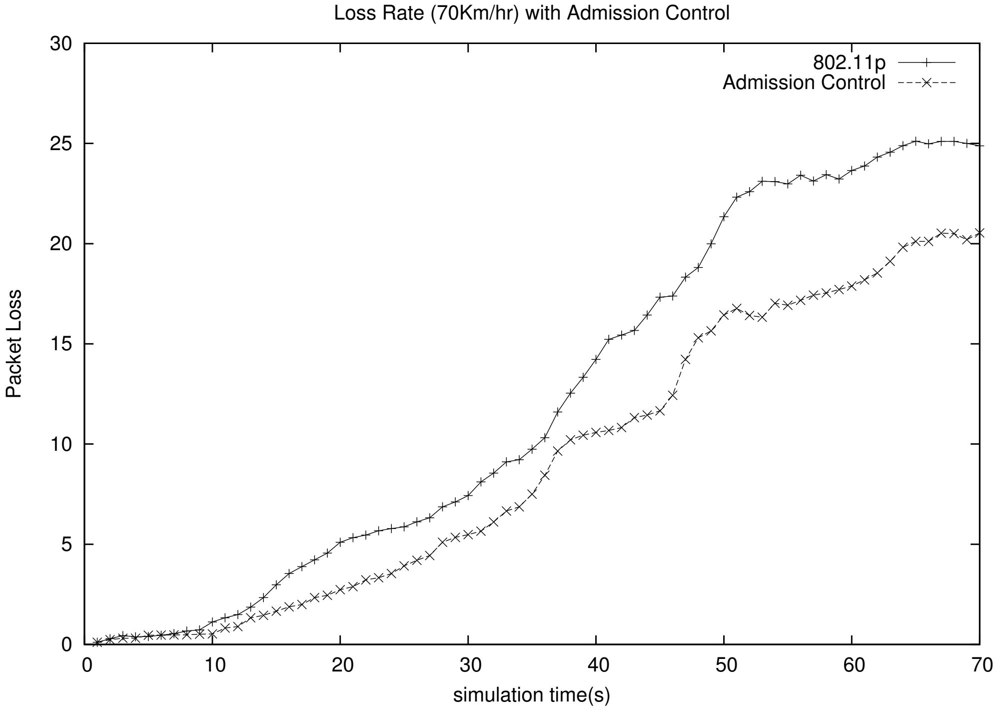


Figure 5.10: Loss Rate with Admission Control vs Simulation time

range for 802.11p scheme is considered to be Zone 3 as no clustering is involved in the standard protocol.

The results are convincing and the improvements are significantly better than the standard 802.11p as seen in Figure 5.11. There is increase in packet loss after around 40seconds in the simulations, where the standard 802.11p goes from 10% to 25% in packet loss. On the contrary due to clustering mechanism by admission control and adjusting the CW based on the density of vehicles, the adaptive scheme goes upto 15% throughout the simulation time. This kind of scheme will be much beneficial whenever the scenario is quite dense. Although, we simulated our model with highway drive through internet scenario, we believe that with urban scenarios, this solution will fetch far better results than the standard 802.11p.

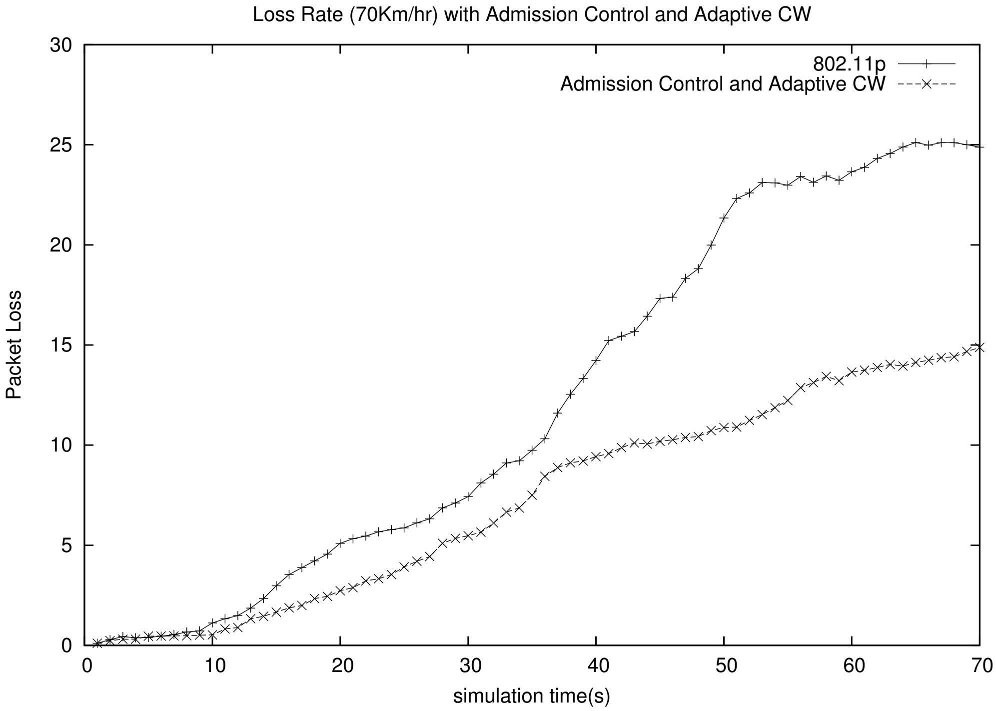


Figure 5.11: Loss Rate with Admission Control and Adaptive CW vs Simulation time

5.2.4 Normalized Throughput

With the adjustments made in the protocol, we have seen that the performance of the adaptive scheme outperforms 802.11p in packet loss and average end to end delay in performance. In addition to the above results we found out the normalized throughput of the entire network during the simulation. This entity can be defined as the ratio between the goodput to the data rate provided i.e. amount of data sent without re-transmission. In order to do so we found out the number of received data packets without duplication.

5.2.4.1 Adaptive CW

The performance is evaluated with vehicular speed equivalent to 70Km/hr with two different densities, $0.4K_{jam}$ and $0.7K_{jam}$, respectively. Using the relation between the back-off parameters and zonal density as shown in Table 3.3, we use 1.8 and 3.7 as back-off parameters respectively.The region selected for the evaluation is Zone 1.

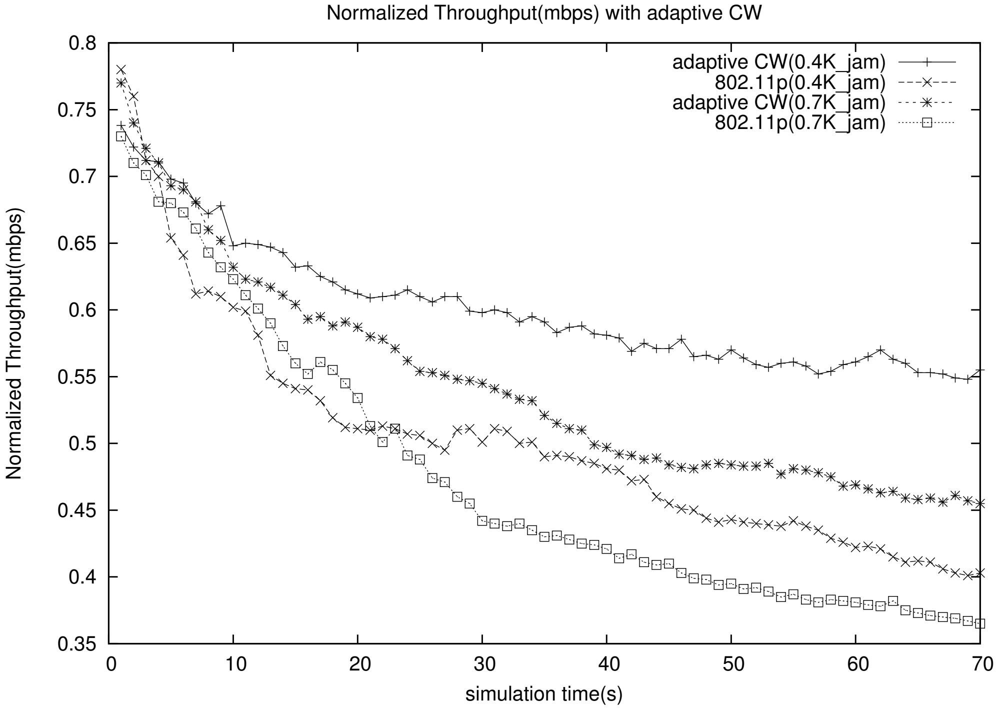


Figure 5.12: Normalized Throughput with CW Adaptation

We included only successfully bytes received by the AP, in the MAC layer in our aggregated normalized throughput. An event of type r and a trace level of MAC identified such events in the NS-2 trace file. We notice that, in the beginning, the throughput remains almost the same for both the adaptive scheme and regular 802.11p protocol. This can be attributed to the fact that the network may take some time to stabilise. Also once the time elapses the vehicles in the range of AP gets populated, which does provide us better results and insights. After few seconds into the simulation, the AP has some primitive information about the density of the vehicles in the zone through exchange of messages. After exchanging first few messages (sending beacons and receiving acknowledgement), it sets it admission range. Though the system is such that, the admission range of the AP will be confined to Zone 1. Its only after data exchange and discovering that no vehicle is in the Zone 1 it increases its admission range. In this case the simulation zone is considered to be the one nearest to the AP i.e. Zone 1. The estimation of density is a periodic process which takes place by the AP after every 100ms. As seen in the figure which represents the result for normalized throughput,it can be seen that the adaptive scheme has a better throughput for different densities of vehicles, i.e. $0.4K_{jam}$ and $0.7K_{jam}$. For adaptive scheme the average normalized throughput varies from 0.78Mbps to 0.56Mbps throughout the simulation time for density equivalent to $0.4K_{jam}$. The drop in throughput can be considered to the fact that as vehicles are entering the zone continuosuly, there will be contention for channel access irrespective of how you design MAC protocol.With increase in contention, the packets collide more often, which results in thoughput decline. Although its almost impossible to get rid of collisions entirely, reducing the number of collisions is achievable. That is what the adaptive scheme does to its best. It reduces the collision to a significant extent compared to the regular 802.11p by making its back-off adaptive to the density of vehicles. With $0.4K_{jam}$ density, the performance gain of the adaptive scheme is almost 10%. With a higher density $0.7K_{jam}$, the collisions of data packets will be more and hence the overall throughput will be on lower side compared to when the density is lower. The average value in this case varies from 0.73Mbps to 0.48Mbps as compared to regular protocol, which varies from 0.72Mbps to 0.39Mbps. The improvement in this case is seen to be around 22% $\backsim$ 25%.

5.2.4.2 Admission Control

We also ran several iterations to gauge the performance of the adaptive scheme with only admission control. Although we can have both the adaptive CW and admission control together or each of them separately, we simulated to chcek the improvements in all the combination possible. The admission range of the AP is made to cover the entire range, at the beginning of simulation, in both cases. Although 802.11p protocol does not change the range in due course of time with respect to the admission control scheme. The velocity of vehicles is 70km/hr with 10m of intervehicular distance. The result is averaged over 3 runs.

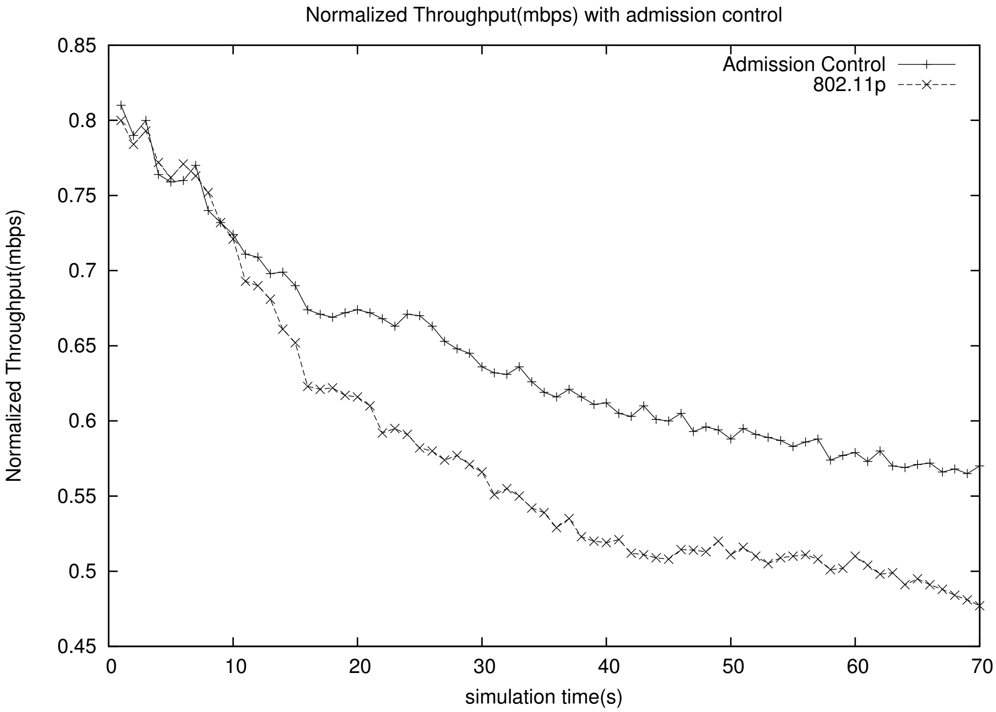


Figure 5.13: Normalized Throughput with Admission Control

As seen in the figure, the admission control does help to achieve more network throughput than standard 802.11p. The increase is around 15-20%.

5.2.4.3 Adaptive CW and Admission Control

This time we measured the normalized throughput with both the scheme in place i.e. adaptive scheme with both CW adjustment and admission control with respect to standard 802.11p.

In this simulation the interarrival time is considered to be a poisson distribution which generates randomness in the inter-arrival times among the vehicles. The interval is considered to be, 4-13 secs. Velocity of the vehicles is 80km/hr on the highway.

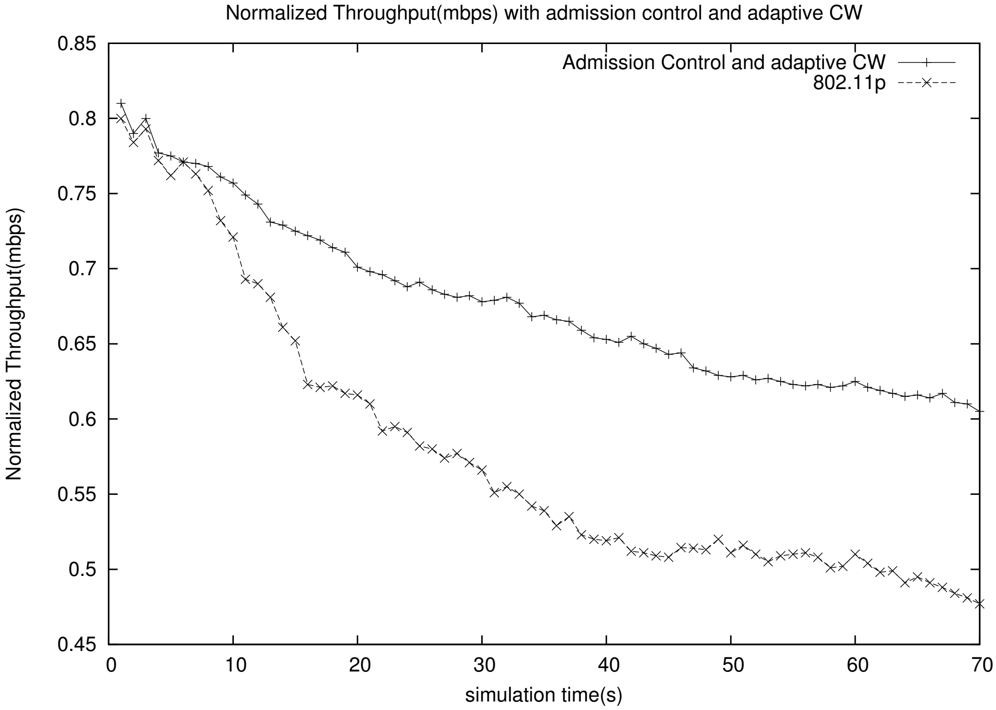


Figure 5.14: Normalized Throughput with Admission Control and CW Adaptation

The results seen in Figure 5.15, is promising. The adaptive scheme with both the CW adjustment and admission control outperforms standard 802.11p convincingly. The normalized throughput for adaptive scheme remains at around 0.65mbps contrary to 0.5mbps in the 802.11p protocol, which is nearly 30% improvement in the entire network throughput.

5.3 Summary

As seen from the results, we simulated the scenario considering entire network as a whole. Although for different vehicles in the network, there can be disparity in their individual performances due to the dynamics of the environment and other traffic and network constraints. The readers should note that as our prime objective was to improve network throughput with reduction in collisions, idle time and other performance metrics, which we were able to achieve successfully compared to the standard 802.11p scheme.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

The main goal of this thesis is to improve the performance of VANET in a drive-thru Internet, highway scenario. In this thesis, we have introduced and implemented two mechanism of admission control and CW adaptation for improving the performance of VANET with emphasizing on V2I communication. We have shown that our approach can outperform the regular 802.11p (WAVE) protocol considereing different performance metrics.

In the literature so far, there were a few work which addressed the Contention Window convergence mechanism to improve the performance but they did not address the concept of limiting the number of vehicles for the contention. We limit the number of vehicles by dividing the highway into several zones based on its distance from the AP. The vicinity of the vehicles are determined by the GPS which we assume to be known by the AP. Based on these parameters, collectively the transmission range is made to change to restrict the number of vehicles and give more priority to the vehicles near the AP.

We have seen that vehicle density is a significant factor for all of the performance metrics. On increasing density, the back-off parameter needs to be adjusted to avoid severe network congestion and collisions.

The simulation based study using NS-2 have been conducted to investigate the performance of the proposed solution. One of the reasons for selction of NS-2 was to make the model more realistic. A simulator model of a real-world system is necessarily a simplification of the real-world system itself. Especially for VANET simulations one has to be very liberal, because there are huge number of parameters which are too sensitive to emulate the behavior as in VANET.

6.2 Future Work

In order to simulate our system model we considered a few assumptions underlying the entire toplogical aspects of VANET in a highway scenario. As the future work, incorporating fast fading in the system model can make the system more realistic, e.g, Nakagami fading channel compared to Friis Free space propagation model. Although in a highway drive through scenario, VANET does not come across much road side obstacles, it will be a good idea to extrapolate the work in urban scnearios. Doing so will be challenging because the traffic in urban areas are more complex, given the fact that the velocity and speed of vehicle keeps on changing dynamically and there will be more road side obstacles to consider in the system model. In such cases a mobility generator like VanetSim or SUMO will be handful,which gives an option of designing urban scenarios with Manhatten grid mobility model. Also an insight over deployment of APs (in terms of quantity) to provide seamless connectivity is an interesting topic to ponder and work on.

Also the model can be developed further by considering more dense QoS provision schemes for supporting multimedia applications.

We considered single hop approach in our design where the vehicles are establishing communication directly with the AP. As a future work, multihop system can be considered, which is more challenging given the velocity, density of vehicles, intervehicular distance keeps on changing frequently. Nonethless our work provides the basis for many such explorations given the fact that improvements are done on the MAC/PHY level.

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Appendix

AP : Access Point
ACK : Acknowledgement
BEB : Binary Exponential Back-Off
CSMA/CA : Carrier Sense Multiple Access/Collision Avoidance
CW : Contention Window
CW_{Min} : Minimim CW
CW_{Max} : Maximum CW
dB : Decibel
DCF : Distributed Co-ordination Function
DIFS : DCF Inter Frame Space
DSRC : Dedicated Short Range Communication
EIED : Exponential Increase Exponential Decrease
K_{jam} : Maximum number of vehicles accommodated in a zone/ Density of Vehicles
LAN : Local Area Network
LOS : Line of Sight
GPS : Global Positioning System
MANET : Mobile Ad Hoc Network
MAC : Media Access Control
PHY : Physical
RTS/CTS : Request to Send/Clear to Send
RSU : Road Side Unit
SIFS : Short Inter Frame Space
TCP : Transmission Control Protocol
T_x : Transmission
UDP : User Datagram Protocol
UID : Unique ID
VANET : Vehicular Ad Hoc Network
V2V : Vehicle to Vehicle
V2I : Vehicle to Infrastructure
WAVE : Wireless Access in Vehicular Environment