Study of Reliability Issues for Communication Protocols in Vehicular Ad-hoc Networks

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Certificate

This is to certify that the thesis entitled Study of Reliability Issues for Communication Protocols in Vehicular Ad-hoc Networks has been prepared by Mrs. Vaishali D. Khairnar under my supervision and guidance. The thesis is her original work completed after careful research and investigation. The work of the thesis is of the standard expected of a candidate for Ph.D. Programme in Computer Science and Engineering and I recommend that it be sent for evaluation.

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Abstract

The increase in number of vehicles on Indian Highways and the immense number of fatal accidents have driven research and development of new generation technology to help drivers travel more safely. One major cause of traffic accidents is that drivers cannot appropriately respond to the changing road conditions consistently. In fact, most of the accidents could be avoided if drivers could use traffic related relevant information on Mumbai-Pune Express Highway, India using wireless communications technology.

Recently, the IEEE adopted the IEEE 802.11p standard as the main technology for Vehicular Ad-hoc Networks. To test the feasibility of this technology, most researchers use simulations, to evaluate protocols for new applications and prohibit the cost of implementing real time Vehicular Ad-hoc Network setup on Mumbai-Pune Express Highway. Different simulators like Openstreet, eWorld, SUMO, NS2, NS3 etc. as well as routing protocols like AODV, DSDV, DSR, GPSR for vehicular ad-hoc networks were looked upon for this study.

Wireless channel for Vehicular Ad-hoc Networks was analyzed, using simulation techniques to find out the most appropriate propagation model with minimum hidden terminal problems for reliable communication. Broadcast communication protocol is proposed for Vehicular Ad-hoc Networks using clustering formation algorithm and CDS connectivity with efficient routing algorithm for V2V communication on Mumbai-Pune Express Highway. It is based on exchange of information with neighboring vehicles, which will reduce the channel contention and message travel time leading to reliable and efficient data dissemination. Our goal is to find a connected dominating set (CDS), then calculate CDS for multi-hop, then construct clusters using the cluster-head selection code and extend this approach to multi-level clusters for communication on Mumbai-Pune Express Highway.

The reliability of the IEEE 802.11p in Vehicular Ad-hoc Networks, safety and warning applications scope after taking into consideration many factors, is analyzed. Further, it is authenticated through extensive simulations that the specifications of Direct Dedicated Short Range Communication (DSRC) protocol may lead to undesirable performance under harsh vehicular environments. An adaptive algorithm is proposed to alleviate the impact of the hidden terminal problem, and increase the network capacity and reliability. Reliability in the context of VANETs broadcast services is defined as the networks ability, for all intended mobile nodes, to receive the broadcast messages within specified duration of operation.

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Declaration

I, Mrs. Vaishali D. Khairnar, registered as Research Scholar, bearing Registration Number 09EXTPHDE21 for Doctoral Programme under the Faculty of Technology and Engineering of Nirma University do hereby declare that I have completed the course work, pre-synopsis and my research work as prescribed under R. Ph. D. 3.5.

I do hereby declare that the thesis submitted is original and is the outcome of the independent investigations / research carried out by me and contains no plagiarism. The research is leading to the discovery of new techniques already known. This work has not been submitted by any other University or Body in quest of a degree, diploma or any other kind of academic award.

I do hereby further declare that the text, diagrams or any other material taken from other sources (including but not limited to books, journals and web) have been acknowledged, referred and cited to the best of my knowledge and understanding.

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Khairnar

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List of Abbreviations

AC .... Access Class

AIFS .... Arbitration Inter Frame Space

AIFSN .... Arbitration Inter Frame Space Number

AMA .... Adaptive and Mobility Algorithm

AODV .... Ad-hoc On Demand Distance Vector Routing Protocol

CCI .... Control Channel Interval

CDMA .... Code Division Multiple Access

CDS .... Connected Dominating Set

CCH .... Control Channel

CCA .... Cooperative Collision Avoidance

CH .... Cluster Head

CODEB .... CODEing-Based

CSMA .... Carrier Sensing Multiple Access

CSMA/CA .... Carrier Sensing Multiple Access with Collision Avoidance

CTS .... Clear-To-Send

CW .... Contention Window

DCF .... Distributed Coordinated Function

DCTS .... Directional Clear-To-Send

DDCDS .... Dynamic Directional Connected Dominating Set

DIFS .... Distributed Coordinated Function Inter-frame Spacing

DMAC .... Directional Medium Access Control

DoS .... Denial-of-Service

DRTS .... Directional Request-To-Send

DSDV .... Destination-Sequenced and Distance-Vector

DS-NES .... Dominating Set and Neighbor Elimination Scheme

DSR .... Dynamic Source Routing

DSRC .... Dedicated Short Range Communication

DSSS .... Direct Sequence Spread Spectrum

DV-CAST .... Distributed Vehicular Broadcast

EBCD ..... Efficient Broadcasting Using Network Coding and Directional Antennas

FDMA .... Frequency Division Multiple Access

FIS .... Fuzzy-Logic Inference System

GI .... Guard Interval

GPS .... Global Positioning System

ISI .... Inter Symbol Interference

MAC .... Medium Access Control

MANET .... Mobile Ad-hoc Network

NAV .... Network Allocation Vector

NLOS .... Non-line-of-sight

OCTS .... Omni-directional Clear-To-Send

OBU .... On Board Unit

OFDM .... Orthogonal Frequency Division Multiplexing

OFDMA .... Orthogonal Frequency Division Multiple Access

ORTS .... Omni-directional Request-To-Send

PBSM .... Parameterless Broadcast in Static to highly Mobile

PDR . . . Packet Delivery Ratio

QoS . . . Quality of Service

RREQ . . . Route Request

RTS . . . Request-To-Send

RSU . . . Road Side Unit

RSS . . . Received Signal Strength

SCI . . . Service Channel Interval

SCH . . . Service Channel

SDMA . . . Space Division Multiple Access

SI . . . Synchronization Interval

SIFS . . . Short Inter-frame Spacing

SINR . . . Signal to Interference and Noise Ratio

SNR . . . Signal-to-Noise Ratio

TDMA . . . Time Division Multiple Access

UDG . . . Unit Disk Graph

UMB . . . Urban Multi-hop Broadcast

VANET .... Vehicular Ad-hoc Network

VCS .... Virtual Carrier Sensing

WAVE .... Wireless Access in Vehicular Environment

WLAN .... Wireless Local Area Network

Chapter 1

Introduction

Exponential growth of vehicles on highways during recent years in India, and the immense number of fatal accidents have allowed the researchers for the development of new generation technologies to help the drivers travel more safely on highways. One major cause of traffic accidents is that drivers cannot consistently and appropriately respond to the changing Mumbai-Pune Express Highway Road conditions. In fact, most of the accidents can be avoided if drivers could obtain relevant information of traffic that which is beyond their vision, using vehicular communication technology.

Rapid increase and advancement of wireless technologies create new avenues to utilize these technologies in support of vehicular safety applications. The new Dedicated Short Range Communication (DSRC) or IEEE 802.11p protocol, enables a newer class of vehicular safety applications which will increase the overall safety on Mumbai-Pune Express Highway Road, reliability, and efficiency of current transportation system. Vehicular Ad-hoc Networks (VANET), which is a part of Intelligent Transportation Systems (ITS), will provide a wide spectrum of applications to avoid highway accident.

1.1 Overview

Vehicular Ad-hoc Networks (VANET), a part of Intelligent Transportation Systems (ITS) (S) is referred to as the integrated applications of the advanced technologies in Information Technology, communications logic controls and sensor networks provide travelers and authorities important information they need to make the transportation system more safe, efficient, effective and reliable. Since the advent of Vehicular Ad-hoc Networks, lots of research work for real-time transportation system management, has been conducted. Recent advances in wireless and sensor technologies rapidly promote the seamless integration of various types of information from transportation networks, to benefit drivers and provide a wide array of transportation-oriented services. Vehicle-to-Vehicle and Vehicle-to-Infrastructure communications will be important practically in the near future resulting in an operational Internet on the highways called vehicular ad-hoc networks (VANET) that will revolutionize our concept of travelling.

As reported in Times of India (TOI) (Times) (WHO) Jan-2014 newspaper, more than 81.5% people died on Mumbai-Pune expressway accidents accounted due to human error. In a highway scenario due to speed, drivers slow reaction time can often lead to catastrophic multi-vehicle pile ups. Most of the traffic accidents can be preventable if an vehicular ad-hoc networks (VANET) system is installed to inform the driver instantly about the obstacles ahead.

Accidents, delays and traffic congestion causes significant loss of lives, waste of energy, increased carbon dioxide gas emissions and loss in productivity. Solving these issues by building wider highway and flyovers is costly, time consuming and impossible in some congested areas. Therefore, applying the latest wireless technologies to the current infrastructure will help in improving its safety, reliability, efficiency and security.

The Vehicular Ad-hoc Networks System is composed of the following major parts:

a. Vehicles: Automobile industry is giving more attention to the safety of their vehicles by equipping them with complex sensor arrays to continuously gather information. They, pay attention to many aspects as air bags, tyre pressure, mechanical and electronic parts, speed, breaking condition, steering condition, distance detection and collision events. This gathered information will help the driver and the vehicle to avoid serious accidents by taking the appropriate action or by initiating built in control system to bring the vehicle to a safe mode. It is crucial to forward this information to neighboring vehicles to quickly respond in time.

b. Infrastructure: Many highway in India are equipped with signs, with messages to alert the drivers on road conditions. Based on the advertised messages, the drivers may take actions like slowing the speed or changing lanes. Sensors or cameras installed on roads, measure the traffic movement and the number of vehicles passing from one point. Thus, help in making plans for better traffic flow.

c. Control Systems: Systems are deployed to take appropriate action automatically, when an error, such as forgetting to turn on the headlight at night, that is potentially dangerous on highway. The actions taken by the system may ranging from turning on the headlight, to activating the braking system.

d. Communication System: This is the most important aspect of VANET system, since without communicating essential information with proper recipients, the VANET system will not achieve its goal, of providing safety and comfort to passengers. Highway safety has attracted more attention, such as active accident warning, icy patch alarm, and others. Whether a successive collision can be effectively avoided mainly depends on transmitting warning information reliably and efficiently on multi-paths. Vehicles can form a mobile ad-hoc network on the highway to pass this essential information to each other. If the driver becomes aware of the emergency braking of the preceding vehicle, in time, he can slow down enough to avoid an accident.

The vehicular communication system is classified as follows:

(1) Intra-Vehicle Communication System: This system is adapted inside the vehicle itself. It can be a wired or wireless communication system like Bluetooth (IEEE 802.15.1)(Gla), Ultra Wide-band (UWB) (IEEE 802.15.3) (Three) or ZigBee (IEEE 802.15.4) (Four). To reduce the amount of wiring complexity usually used in vehicles and to offer more mobility.

(2) Vehicle-to-Vehicle Communication System (V2V): It is a major part of the VANET architecture, since it enables the drivers to communicate with other drivers or vehicles even if they are out of range of Line Of Sight (LOS). Ad-hoc mode is the most appropriate model that suits (V2V) (where vehicles communicate with each other without a centralized ser-

vice), due to high mobility of vehicles and the changing relative speeds between vehicles. This will add more challenges to the wireless communication system compared to the indoor Wireless Local Area Networks (WLAN) or Mobile Ad-hoc Networks (MANETs).

(3) Vehicle-to-Infrastructure Communication System (V2I) : This type of communication is between roadside unit and vehicles to provide services to drivers and passengers, like high-speed Internet or traffic information. These units are placed along the highway road to maintain the high data rates and facilitate the hand-off from one zone to another.

The VANET system will enable new mobile services and applications for the traveling public. The integration of sensor networks and computers inside the vehicle itself with the Global Positioning Systems (GPS), digital road maps and the wireless communication technologies will open the door widely to many safety and non safety applications. The Vehicle Safety Communication (VSC) project (Transportation) determined 34 possible safety applications for VANET.

These applications can be categorized as follows:

- Safety applications: Protect lives and properties by warning drivers of related traffic hazards, as shown in Figure 1.1, traffic jams, halted vehicle, lane closure and rail crossings. These applications can also include left-turn and stop sign movement assistance, blind spot warning, traffic signal violation warning, curve speed warning, emergency break light warning and lane change warning.

- Traffic management applications: Authorities help in managing the traffic such as control signals to reduce traffic jam, fleet management and cargo tracking systems.

- Infotainment applications: Enhance the drivers by providing Internet connection and instant messaging system between vehicles. They also include vehicle rental help, drive through and petrol/LPG payment, toll collection and enhance route guidance.

Several projects were initiated to address VANET's challenges around the world. Fleet-Net is one of the pioneer European projects (B) to standardize VANET so-

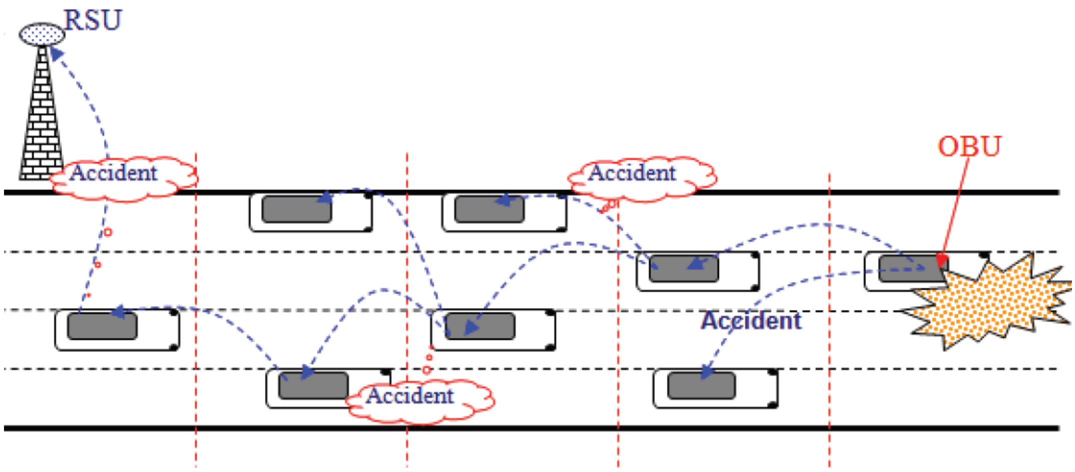

Figure 1.1: Hidden node and Exposed node

lutions and develop a platform for Vehicle-to-Vehicle communication. Network on Wheels (NoW) (S.) and CarTALK2000 (Morsink and Schulz) are other European projects for the development of vehicular communication and co-operative driver assistance systems. Car-to-Car Communication Consortium (C2C-CC) (Car) is an organizational umbrella for VANET research activities in Europe. It includes many automobile industry members like Daimler, BMW, Audi, Fiat, Renault and some German Universities. The overall objective of C2C-CC is to initiate, develop and oversee vehicle-to-vehicle communication standards, business models and regulatory matters in the European Union.

In US, the Vehicle Infrastructure Integration (VII) Initiative (VII) is a cooperative effort between US government and automobile manufacturers. Its goal is to let vehicles communicate between them and with road side units, in order to increase the safety, efficiency, and convenience of the transportation system. Their solutions based on the IEEE 802.11p, rely on a business model to satisfy the interest of all participating parties. Its safety solutions rely on radar, vision systems to reduce rear-end collisions by tracking obstructions in front or behind the vehicle and apply brakes automatically when needed.

The development of Vehicle-to-Vehicle and Vehicle-to-Infrastructure mobile mesh and ad-hoc networks, is one of the most challenging and critical issues for the VANET research and automobile industry. The characteristics of VANET are different from those of Mobile Ad-hoc Networks (MANETs). Vehicles move with high speed, highly changing topology. This results in shorter communication links between vehicles and unpredictable node density. Since VANET's effective network diameter is small, their redundancy is limited. So, it is unrealistic for a node to maintain a complete global network topology. This adds more challenge to apply the existing routing and MAC algorithms in MANETs, to VANET. Due to high mobility of vehicles, it is difficult to maintain any form of group membership or establish an accurate list of neighboring vehicles. Hence, it is difficult to implement protocols that rely on group membership such as clustering or flat routing. Another challenge in VANET is its security. Driver's anonymity and privacy must be preserved; hence vehicle movement is not recorded and VANET messages are not tampered. Tampering of safety messages could result in traffic accidents, which VANET are designed to prevent. Contrary to MANETs, VANET do not move in random directions and have no constraints on storage capacity, battery and processing power. A good characteristic of VANET that help in building a new stable protocol, is the future movement of a vehicle is predictable, since it is constrained by the highway road.

1.2 Problem Statement

The main objective of this research work is to design a new Broadcasting protocol for Vehicular Ad-hoc Networks (VANET). The challenges and limitations of the existing protocols in vehicular environments must be explored first in order to achieve this objective. Secondly, issues towards the design of the new broadcasting protocol must be identified by using theoretical foundations and algorithmic methodologies.

The key contributions of this dissertation are summarized as follows:

- To develop a simulation and analysis setup for IEEE 802.11p protocol using test bench development is a difficult and costly proposition. Therefore, simulations are used to study and analyze VANET.
  - Study of different mobility and network simulators is performed to select an appropriate simulator, in order to solve the real-time vehicle-to-vehicle communication on highway road.
  - Wireless channel in VANET and its different radio propagation models are analysed to find the most appropriate model that best characterises in

vehicular environment.

  - Analysis of physical wireless channel and the best propagation model will derive a formula for the probability density function (pdf) of the communication range that will be used in our subsequent analysis.
  - The different routing protocols in VANET are studied and their performance on highway is analysed.
  - A new mobility model is developed that takes into account the vehicles that follow the safety rules. This will accurately capture the relationship between the vehicle's speed and network density.

- A new Broadcast Protocol for vehicular ad-hoc networks is developed for the vehicle-to-vehicle communication on highways.
  - A new broadcast algorithm to alleviate the impact of broadcast storm problem in VANET is introduced, taking into consideration the network topology and traffic parameters. This will also reduce the effect of the hidden terminal problem.

- An analytical model is developed to evaluate the performance of the IEEE 802.11p PHY and MAC protocol in single-hop (broadcast mode) and multi-hop scenarios.
  - An analytical framework is proposed that models the reliability of the Dedicated Short Range Communication (DSRC) control channel to handle VANET safety applications.
  - Using analytical model, an adaptive algorithm is presented in order to increase the DSRC systems reliability in terms of the probability of packets for successful reception and time delay of emergency messages, in a harsh vehicular environment.

The performance of the proposed protocol is evaluated through extensive simulations using the SUMO and Network Simulator (NS2 version 2.34) (DNS). Some of the existing MAC protocols are developed for the sake of comparison. Hence, the evaluation result shows that the proposed protocol and algorithms can support traffic safety and increase VANET efficiency and reliability.

1.3 Dissertation Outline

Dissertation is organized as follows:

- Chapter 2, presents the literature study.
- Chapter 3, investigates the physical wireless channel of the DSRC.
- Chapter 4, the performance of different routing protocols on highways/roadsis analysed.
- Chapter 5, a new mobility model is proposed.
- Chapter 6, a new broadcast protocol is proposed to alleviate the broadcast storm problem and hidden terminal problem in VANET.
- Chapter 7, performance of V2V Communication is evaluated using IEEE 802.11p and STDMA.
- Chapter 8, performance of IEEE 802.11p is analysed.
- Chapter 9, Conclusion and future scope of research work.

Chapter 2

Literature Review

The chapter explores the initial developments that were carried out in creating a broadcast protocol. During the last few years, a lot of broadcasting protocols for VANETs have been reported in literature. They can be generally classified into two main categories according to the spreading of information packets in the network. These categories are (Li and Wang Willke, Tientrakool, and Maxemchuk Panichpapiboon and Pattara-atikom Festag, Papadimitratos, and Tielert Hall Junhai et al. Badarneh and Kadoch Sebastian et al. Lua et al. Zhou et al. Shevade et al. Guo, Ammar, and Zegura Chu and Huang) as follows:

- Single-hop Broadcasting: In Single-hop Broadcasting, information packets are not flooded by vehicles. Instead, when a message is received by a vehicle, information is kept in the vehicle's On-Board database. Periodically, every vehicle selects some of the records stored in its database to broadcast. Hence, in Single-hop Broadcasting, each vehicle carries the traffic information with in itself as it travels, and this information is transferred to all other vehicles in its one-hop neighborhood in the next broadcast cycles. Ultimately, vehicle's mobility is involved in spreading the information in Single-hop Broadcasting protocol.

- Multi-hop Broadcasting: In Multi-hop Broadcasting strategy, a message is spread in a network through flooding. In general, when a sender vehicle broadcasts an information message, a number of vehicles within the vicinity of the sender will become the next relay vehicles, by rebroadcasting the message further in the network. Similarly, after a relay vehicle (node) rebroadcasts the message, some of the vehicles in its vicinity will become the next relay nodes and perform the task of forwarding the packets further. As a result, the information message is able to propagate from one sender to the other distant vehicles.

2.1 Single-hop Broadcasting Protocols

In Single-hop Broadcasting, vehicle periodically disseminates some of the information in its database to the other vehicles in the network. Broadcast interval and information are the two choices that need to be considered while designing the broadcast protocol for VANETs. To keep the most up-to-date information without redundancy, the broadcast interval must be set appropriately. It should neither be too long nor too short. Apart from this, important and relevant information should only be selected to broadcast. Single-hop Broadcasting protocols can be further divided into following two categories:

a. Fixed Interval Based Single-hop Broadcasting Protocols

b. Adaptive Interval Based Single-hop Broadcasting Protocols

2.1.1 Fixed Interval Based Single-hop Broadcasting Protocols

Fixed broadcast interval protocols focuses only on the selection and aggregation of information. TrafficInfo (Zhong, Xu, and Wolfson) is an example of fixed broadcast interval protocol in which every vehicle is equipped with a Global Positioning System (GPS) and digital road map and periodically broadcasts the traffic information stored in its database. A particular type of traffic information reported during the travel times on the road segments. During broadcasting process, each vehicle stores its own travel time and time taken by other vehicles during travelling into the database. Although Single-hop Broadcasting scheme is inefficient in broadcasting all the records from database, TrafficInfo uses the bandwidth efficiently and broadcasts only the most relevant information from the database. The relevance of the information is determined by a ranking algorithm, which is based on the current location of the vehicle and the current time.

TrafficView is another single-hop fixed interval broadcasting scheme (Nadeem et al.) designed for enabling an exchange of traffic information among vehicles. Speed and position are two information types that are exchanged among vehicles. In this scheme, when a vehicle receives a broad-casted message, it first stores the information in its database. The information is then rebroadcasts in the next broadcast cycle. However, instead of broadcasting all stored record from the database, only a single record is broad-casted after aggregating the multiple records. Ratio-based and the cost-based are the two algorithms that are used for aggregation. In the ratio-based algorithm, a road is divided into smaller regions, and an aggregation ratio is assigned to each region according to the importance of the region and the level of accuracy required for that region. In cost-based algorithm, cost can be regarded as the loss of accuracy incurred from combining the records. Simulation shows that although the cost-based algorithm yields better accuracy, the ratio-based algorithm gives more flexibility.

2.1.2 Adaptive Interval Based Single-hop Broadcasting Protocols

In adaptive broadcast interval protocols, an adjustment of broadcast intervals is also taken into consideration. Collision Ratio Control Protocol (CRCP) (Fujiki et al.) uses adaptive broadcast interval in which each vehicle disseminates the traffic information periodically. The traffic information in this case is the location, speed and road ID. This information is measured every second. This protocol employs a mechanism for dynamically changing the broadcast interval based on the number of message collisions. Basically, the protocol aims at keeping the collision ratio at a targeted level regardless of the vehicle density. Intuitively, the number of message collisions increases with an increase in network density. Apart from adaptive broadcast interval mechanism, three methods Random Selection (RS), Vicinity Priority Selection (VPS), and Vicinity Priority Selection with Queries (VPSQ) are proposed for selecting the data to be disseminated.

Abiding Geo-cast protocol (Yu and Heijenk) is another example of adaptive broadcast interval protocol which was designed to disseminate safety messages within a useful area where these messages are still relevant. In this scheme, a vehicle which detects an emergency situation first starts broadcasting a warning message. Message specifies the area where the warning is still relevant. When another vehicle receives the warning message, it will act as a relay node and keep broadcasting the warning message as long as it is still traveling in the concerned area. Each vehicle adjusts its rebroadcast interval dynamically in order to reduce the number of redundant warning packets. The rebroadcast interval is decided by the transmission range, speed and the relative distance between the emergency site and the vehicle.

Segment-oriented Data Abstraction and Dissemination (SODAD) protocol (Wischhof, Ebner, and Rohling) also uses adaptive broadcast interval in which roads are divided into segments of predefined length. Each vehicle collects the data by sensing the information itself and from the reports of other vehicles. Each vehicle adaptively adjusts its broadcast interval to reduce the redundancy.

Information received from other vehicles is characterized in two ways:

- Provocation
- Mollification

A provocation event, is an event that reduces the time until next broadcast, whereas a mollification event, is defined as an event that increases the time until next broadcast. When a vehicle receives a message, it determines whether it is a provocation or a mollification event by assigning a weight, to the received message. Weight is calculated from the discrepancy between the received data and data available in vehicles knowledge database. The weight will be high if the received information is newer than the stored information. Based on the message weight, node determines whether a provocation or mollification event has occurred by comparing it with a threshold. The time for next rebroadcast is increased or decreased depending on the weight.

2.2 Multi-hop Broadcasting Protocols

In Multi-hop Broadcasting (Korkmaz, Ekici, and Uner Fasolo, Zanella, and Zorzi Li et al., "A Distance-Based Directional Broadcast Protocol for Urban Vehicular ad-hoc Network" Wisitpongphan et al. Taha and Hasan Schwartz et al.), flooding is used for message propagation in the network. However, a pure flooding is inefficient because, it lacks scalability and message collision. Redundancy increases as the network becomes denser and reduces throughput, thereby reducing network scalability. In addition, message collision is another critical problem because multiple vehicles in the same region may rebroadcast the message at the same time. This is called broadcast storm problem (Ni et al.). Multi-hop broadcasting can further be divided into the following three categories (Bilal, Chan, and Pillai Alshaer and it Wegener et al., "AutoCast: An Adaptive Data Dissemination Protocol for Traffic Information Systems" Katti et al. Li et al., "Network Coding-based Broadcast in Mobile ad-hoc Networks" Yang and Wu Kadi and Agha Qayyum, Viennot, and Laouiti).

a. Delay Based Multi-hop Broadcasting Protocols

b. Probability Based Multi-hop Broadcasting Protocols

c. Network Coding Based Multi-hop Broadcasting Protocols

2.2.1 Delay Based Multi-hop Broadcasting Protocols

In a Delay Based Multi-hop Broadcasting scheme, different waiting time before rebroadcasting the message is assigned to each receiving vehicle. Fundamentally, the vehicle having the shortest waiting time gets the highest priority to rebroadcast the message. In addition, redundancy is avoided by other vehicles by aborting their waiting process once they know that the message has already been rebroadcasted. While different delays are assigned to each vehicle in delay-based broadcasting protocols, a different rebroadcast probability is assigned to each vehicle in a probabilistic protocol.

Urban Multi-hop Broadcast (UMB) protocol (Korkmaz, Ekici, and Uner) is a delay based multi-hop broadcasting protocol designed to solve the broadcast storm, the hidden terminal, and the reliability problems in multi-hop broadcasting. UMB divides a road within the transmission range of a transmitter vehicle into smaller segments, and it gives the rebroadcast priority to the vehicles that belong to the farthest segment.

UMB uses two types of message forwarding:

a. Directional Broadcast

b. Intersection Broadcast

UMB is inefficient because, next rebroadcast vehicle has to wait for the longest time before being able to transmit the Clear-To-Broadcast (CTB) message. This is due to the longest black-burst duration is assigned to the next rebroadcast vehicle.

Smart Broadcast (SB) (Fasolo, Zanella, and Zorzi) was proposed to improve the shortcomings of UMB protocol. In SB, when a source vehicle has a message to send, it transmits a Request-To-Broadcast (RTB) message containing its location and other information such as message propagation direction and contention window size. Also, all vehicles in the range of the source that receive the RTB message determine the sector in which they belong to, by comparing their locations with that of the source vehicle. Next, all vehicles that receive the RTB message choose a contention delay based on the sector that it resides.

Efficient Directional Broadcast (EDB) protocol (Li et al., "A Distance-Based Directional Broadcast Protocol for Urban Vehicular ad-hoc Network") is another delay-based multi-hop broadcast protocol that works somewhat similar to UMB and SB protocols. However, it does not use RTB and CTB control packets. EDB also exploits the use of directional antennas. In particular, it is proposed that each vehicle is equipped with two directional antennas, each with 30-degree beam width. Similar to UMB protocol, EDB also uses two types of message forwarding, namely directional broadcast on the road segment and directional broadcast at the intersection.

Slotted 1-Persistence Broadcasting protocol (Wisitpongphan et al.) is a message forwarding approach, similar to those of the other delay-based multi-hop broadcasting protocols, in which the vehicles that are farther away from the transmitter will get the rebroadcast priority. In this protocol, when a vehicle receives a message, it rebroadcasts the message according to an assigned time slot, where the time slot is a function of distance between the vehicle and the transmitter. In particular, each vehicle computes the time slot in which it will rebroadcast the message based on the following equation 2.1:

$$T_{S_{ij}} = S_{ij} * \tau \qquad (2.1)$$

where τ is an estimated one-hop propagation and medium access delay, and S_{ij} is the assigned slot number.

Reliable Broadcasting of Life Safety Messages (RBLSM) (Taha and Hasan) is also a class of delay based multi-hop broadcasting, in which, as soon as a node receives a message from source, it determines the waiting time for rebroadcasting the message. In RBLSM, the priority is given to the vehicle nearest to the transmitter. The reason behind choosing the nearest vehicle as the next rebroadcast vehicle is that, it is considered to be more reliable than the other vehicles that are far away or at a distance from the transmitter. It is assumed that the nearer vehicle has better received signal strength. This protocol also uses the concept of RTB and CTB control packets. Performance evaluation is done via simulation with only single hop latency. Link-based Distributed Multi-hop Broadcast, (LDMB) is a similar protocol which assigns the waiting delay based on the link quality as proposed in (Schwartz et al.).

Fastest-Vehicle (Bilal, Chan, and Pillai), is another multi-hop routing protocol. It uses speed information of each vehicle for message transfer and distance of the selected vehicle from the destination vehicle. On the basis of speed v of the vehicles and distance s of the vehicles from the destination, the time t for each vehicle within the transmission range is calculated. The vehicle with the least time is selected as the next hop for data dissemination.

2.2.2 Probability Based Multi-hop Broadcasting Protocols

In probabilistic broadcasting approach, each vehicle rebroadcasts a message according to the assigned probability. Since, only few vehicles will rebroadcast the message, redundancy and message collisions are reduced. The third category of multi-hop broadcasting is network coding, which has caught attention in the field of ad-hoc wireless communications.

Weighted p-Persistence protocol (Wisitpongphan et al.) is a probability based broadcasting scheme, in which, a vehicle that receives a message for the first time computes its own rebroadcasting probability based on its distance from the transmitter. The distance can be computed by comparing its current position with the position of the transmitter specified in the message. In particular, the rebroadcast probability is computed from the following equation 2.2:

$$P_{ij} = \frac{D_{ij}}{R} \tag{2.2}$$

where P_{ij} represents the probability between transmitter i and vehicle j, D_{ij} represents the distance between transmitter i and vehicle j, and R is the transmission range of transmitter i. On the basis of above equation, vehicles that are far away from the transmitter will get higher rebroadcast probabilities. However, vehicle density is not taken into consideration in this probability assignment function. Hence, in the dense network, the number of rebroadcast packets can still be large.

There is another protocol named, Optimized Adaptive Probabilistic Broadcast (OAPB) protocol (Alshaer and it), in which number of neighbors i.e. local vehicle density is also taken into consideration while determining the forwarding probability. Each vehicle exchanges HELLO packets periodically to select an appropriate forwarding probability. In particular, when a vehicle receives a message, it computes its own forwarding probability based on the following equation 2.3:

$$\bar{\phi} = \frac{P_1 + P_2 + P_3}{3} \tag{2.3}$$

where P_1, P_2,and P_3 are functions of the number of one-hop neighbors, the number of two-hop neighbors, and a set of two hop neighbors that can only be reached through a particular one hop neighbor (Alshaer and it).

Auto-Cast protocol (Wegener et al., "AutoCast: An Adaptive Data Dissemination Protocol for Traffic Information Systems") is similar to OAPB in which the rebroadcast probability is determined from the number of neighbors around the vehicle. However, it uses a different probability function to obtain rebroadcast probability equation 2.4:

$$p = \frac{2}{N_h * 0.4} \tag{2.4}$$

where N_h is the number of one-hop neighbors. According to the above probability assignment function, the rebroadcast probability decreases as the number of neighbors increases. Evidently, this function can only work when the number of neighbors, $N_h \geq 5$. However, it is not clearly specified in [58] how the probability is assigned in the cases where $N_h < 5$.

2.2.3 Network Coding Based Multi-hop Broadcasting Protocols

Network coding is a new way of information dissemination which can be applied to a deterministic broadcast approaches, resulting in significant reductions in the number of transmissions in the network and hence yields a much higher throughput than the traditional way of transmission.

COPE introduced in (Katti et al.) is based on the principle of network coding. Although COPE is a uni-cast routing protocol, it is a foundation for many multi-hop routing protocols. The COPE was intended to realize the benefits of network coding beyond the simple duplex flows.

The COPE was based on three key techniques:

a. Opportunistic listening,

b. Opportunistic coding, and

c. Neighbor state learning.

Opportunistic listening allows nodes to take the advantage of wireless broadcast medium by snooping all data packets. Each overheard message will be stored in the nodes buffer for a limited time period. These packets will later be used for network coding when the opportunity presents. Opportunistic coding, defines some basic rules for a node to encode and transmit a message. Basically, a node should ensure that its next hop neighbor has enough information to decode the encoded message that has been transmitted. Usually, a node will be able to correctly decode a message i from an encoded message created from packets p_1,p)2,...,p_n if it has $n-1$ of these packets. Thus, learning what packets its neighbors are having is crucial, and this is achieved with a periodic broadcast of reception reports. Hence, every node periodically announces packets that are stored in its reception buffer to all its neighbors.

CODEB is another network coding-based broadcasting protocol introduced in (Li et al., "Network Coding-based Broadcast in Mobile ad-hoc Networks"). It extends the concepts and techniques proposed in COPE to cover broadcasting scenarios in wireless ad-hoc networks. It uses opportunistic listening, where every node snoops all packets overheard by it. In addition, each node periodically broadcasts the list of its one-hop neighbors. This allows all nodes to build a list of its two-hop neighbors, which will further be used to construct a broadcasting backbone. Moreover, CODEB relies on opportunistic coding, in which coding opportunities to transmit coded packets is determined. CODEB also pointed out that opportunistic coding for broadcast is somewhat different from coding for unicast. In broadcasting, all the neighbors of the node must receive the message where as in unicasting, only the intended next hop node receives a given message. Hence, broadcasting increases the level of complexity as all nodes that receive message must be able to decode.

Efficient Broadcasting Using Network Coding and Directional Antennas (EBCD) is a network coding-based broadcasting protocol which gains the benefit of both network coding and directional antennas (Yang and Wu). EBCD similar to CODEB, determines a subset of neighboring nodes that can perform forwarding task deterministically. Although, Dynamic Directional Connected Dominating Set (DDCDS) algorithm is used by EBCD. As a result, a directional virtual network backbone is constructed by DDCDS, where each node determines both its forwarding status as well as the outgoing edges (antenna sectors) in which the packets can be transmitted. In EBCD, network coding is applied in each sector of the directional antennas around the node, whereas in CODEB, network coding applied is Omni-directional. EBCD shows significant improvement with directional antennas and network coding in terms of number of transmissions, compared to other schemes.

DifCode is also a network coding-based broadcasting protocol. Its goal was to reduce the number of transmissions required to flood packets in wireless ad-hoc network (Kadi and Agha). Similar to CODEB, DifCode also chooses the next forwarding nodes deterministically. However, DifCode uses a selection algorithm based on multipoint relay (MPR) (Qayyum, Viennot, and Laouiti). MPR of a node is the list of its one-hop neighbors that cover its two-hop neighborhood. In DifCode, nodes can encode and broadcast only those packets that are received from those nodes that select it as their MPR. DifCode and CODEB also differ by their opportunistic coding techniques. In CODEB, all neighbors of a transmitter decode the received packets immediately and hence limit coding opportunities. On the other hand DifCode relaxed this constraint by allowing nodes to buffer packets that are not immediately decodable. Specifically, all nodes maintain buffers for keeping three different types of packets:

a. Successfully decoded packets,

b. Not immediately decodable packets, and

c. Packets that need to be encoded and broad-casted further.

Simulation results show that DifCode results in lower redundancy rate than the probabilistic broadcasting protocols.

2.3 CDS-Based Broadcasting

The problem of designing efficient broadcast protocols for ad-hoc networks has been investigated for several years. Probably, the most common technique to reduce redundant transmissions in a broadcasting task is the use of connected dominating sets. Let G(V,E) be the graph induced by the network topology, so that V is the set of nodes in the network and E represents the connectivity between them. Then, a subset $V_D \subseteq V$ is said to be dominating, if each node in V either belongs to V_D or has at least one neighbor which belongs to V_D. V_D is Connected Dominating Set (CDS), if it is connected. In CDS-based broadcasting, only those nodes belonging to the Connected Dominating Set (CDS) are required to retransmit the broadcast message, and it will indeed reach the whole network. Therefore, fewer the number of nodes in the CDS, less redundant the broadcast protocol will be.

Unfortunately, the problem of finding the minimum CDS was shown to be NP-hard (Clark, Colbourn, and Johnson), and many heuristics have been proposed since then. (Wu and Li) described several lightweight backbone construction schemes. A modified definition from (Stojmenovic, Seddigh, and Zunic) and (Stojmenovic) of the basic concept in (Wu and Li), because of its reduced message overhead.

Assume that each node x is identified by a unique key, key(x). Then, a node is said to be an intermediate node if it has two unconnected neighbors (Wu and Li). A node u is covered by neighboring node v if each neighbor of u is also a neighbor of v, and key(u) <key(v). A node u is covered by two connected neighboring nodes v and w if each neighbor of u is also a neighbor of either v or w (or both), key(u) < key(v), and key(u) < key(w). An intermediate node not covered by any neighbor becomes an inter-gateway node. An inter-gateway node not covered by any pair of connected neighboring nodes becomes a gateway node. A set of gateway nodes form a CDS.

(Wu and Li) concepts require either one-hop knowledge of neighbors with their position, or two-hop neighbor topology information. Such information is obtained by exchange of periodic 'hello' (beacon) message exchange. Experimental data from several sources confirm that (Wu and Li) concepts provide small size CDS on average. Each node makes a decision about CDS membership without communication between the nodes, beyond the message exchange, node use decision to discover each other and establish neighborhood information.

A framework and general algorithm in (Stojmenovic, Seddigh, and Zunic) and (Stojmenovic) is based on two concepts:

- CDS as a particular type of backbone that provides reliability,
- Neighbor elimination scheme.

In NES (Stojmenovic, Seddigh, and Zunic), (Stojmenovic), (Peng and Lu), a node does not need to rebroadcast a message if, all its neighbors are believed to be covered by previous transmissions. After each received copy of the same message, a node eliminates, the neighbors that are assumed to have received the same message (based on local knowledge) from its rebroadcast list. If the list becomes empty before the node decides to rebroadcast, the retransmission is cancelled.

The general Dominating Set and Neighbor Elimination Scheme (DS-NES) (Stojmenovic, Seddigh, and Zunic), (Stojmenovic) for intelligent flooding proceeds as follows: the source node transmits the message. Nodes not in the CDS do not retransmit the message. Upon receiving the first copy of the message, a node in the CDS will select a time-out period to wait. It will also eliminate (originally containing all one-hop neighbors) all neighbors that received the same copy of the message from its forwarding list. While waiting, more copies of the message could be received. For each of them, all neighbors receiving it are eliminated from the forwarding list. When the time-out expires, the node will retransmit if its forwarding list is not empty, otherwise it will cancel retransmission. This framework was applied in (Stojmenovic, Seddigh, and Zunic) and (Stojmenovic) using clustering-based and (Wu and Li) concept-based backbones.

The Parameter-less Broadcast in Static to highly Mobile (PBSM) ad-hoc networks protocol (Korkmaz et al.), makes use of the DS-NES framework to develop an adaptive algorithm which does not depend on any parameter or threshold value. Due to of its flexibility and good performance, it is used as the basis of Broadcast protocol for vehicular ad-hoc networks. In PBSM, each vehicle maintains two lists of neighboring vehicles with respect to the message being disseminated and local one-hop knowledge: R and N, containing neighbors that already received (did not receive, respectively) the message. After a delay time-out, s retransmits the message if the list N is nonempty. Both the list R and N are updated with every copy of message and beacon exchange message received, which may trigger further retransmissions, if N becomes nonempty again. Nodes in the CDS set shorter waiting time-outs than nodes that are not part of it.

2.4 VANET-Specific Broadcasting

limit review to protocols designed primarily for non-safety applications (and therefore not emphasizing minimal delay as the main objective). Vehicles tend to travel forming groups in highly disconnected networks. Vehicular density can be extremely high in a traffic jam, while surrounding streets or lanes could have low traffic density. This uneven node (and speed) distribution is characteristic of vehicular settings. Therefore, several broadcast protocols specifically designed for such networks have been proposed so far.

A few simple geo-casting algorithms are offered in (Lee et al.). Each node periodically broadcasts its query to neighboring nodes. Query is dispersed via mobility and only to one-hop neighbors. It is then extended toward m-hop retransmission similarly (with decreasing hop counter until reaching 0). Next, each receiving vehicle will retransmit with certain fixed probability. Further scheme is random walk to spread the query to k proxy vehicles, and then these vehicles periodically inform their one-hop neighbors. In neighbor split scheme, originator splits k proxy advertisers equally among its neighboring nodes. This continues recursively and then one-hop neighbors are informed periodically. These schemes do not meet satisfactory reliability objective.

In (Sun et al.), two solutions which consider vehicles located in multiple lanes on a highway, all driving in the same direction, are presented. In proposal (sender oriented), the vehicle transmitting the message decides the next forwarder by including the identifier of its farthest neighbor (in the direction of the broadcast propagation) within the message. This approach is not reliable because the intended neighbor might not be reachable when the transmission takes place, since the connectivity was established at a previous beacon message exchange. Such situation would stop the flooding process prematurely. In the second solution, the next forwarder selection is performed at the receiver. The transmitting vehicle appends its own location to the broadcast message. Receivers defer the retransmission for a 'back-off' time which is inversely proportional to their distance from the previous forwarder. In a one-lane highway scenario, the next forwarder is normally the farthest car from the previous forwarder, among those that received the retransmission. This protocol is not intended to guarantee delivery to all nodes. It only discusses progress between two intersections, which is more precisely a small-scale routing task, and not how to retransmit and provide message to nodes between two forwarders. It also is 1D, and messages may 'jump' over intersections. A variant of this scheme has been proposed to implement Cooperative Collision Avoidance (CCA) (Biswas, Tatchikou, and Dion). A 1D broadcasting algorithm to disseminate the same message to all vehicles on a road segment, is described in (Li, Lou, and Zeng). As in (Sun et al.), the farthest node from the sender retransmits the message for fast progress. The extension is that, the node closest to the middle, between two senders retransmits for increased reliability. It is not clear how many such iterations are needed, and how this can be extended to 2D scenarios.

Other variants, rely on the MAC layer to improve the broadcasting task in vehicular networks. The Urban Multi-hop Broadcast (UMB) protocol (Korkmaz et al.) is an 802.11-based solution targeted at reducing the broadcast storm and Hidden node problems, while maximizing the reliability. The broadcast storm is minimized by only allowing the farthest vehicle which receives a message to forward it. For this, after successfully receiving a message, vehicles issue a black-burst jamming signal, whose duration is directly proportional to the distance between the transmitter and the receiver. When the signal transmission ends, the vehicle listens to the medium to check if other neighbors are still transmitting a black burst. If not, that vehicle is the farthest one, from the transmitter and forwards the message. The hidden node problem is addressed by adding a Request-To-Broadcast (RTB)/Clear-To-Broadcast (CTB) exchange, similar to the case of uni-cast messages. In addition, reliability is expected to be improved via acknowledgment messages (ACKs, also like unicast). The protocol is designed for dense urban scenarios, with intersections and streets in several directions. Along each street, directional broadcasts take place in the direction of the message propagation. UMB assumes that a repeater is deployed at each intersection, thus initiating directional broadcasts along each of the converging streets. There is also a version of the protocol which substitutes repeaters for regular vehicles which are crossing the intersection (Korkmaz, Ekici, and Uner), therefore eliminating the need of infrastructure.

A highway probabilistic flooding algorithm, is proposed in (Nekovee). Front and back counters are updated for received message copies. Before possible retransmission, there is a waiting time that includes the urgency of the message. Probabilistic retransmission decision favors large difference in counters. Upon retransmission, a node sets another waiting time. Cluster merging, balances counters and reduces retransmission probability. The protocol assumes uni-directional traffic only, is probabilistic, and has slow merging, when one counter is already large.

Three probabilistic and timer-based broadcasting suppression techniques for well-connected vehicular networks were proposed in (Wisitpongphan et al.). Their objective was to minimize the well-known broadcast storm problem. In the weighted p-persistence scheme, upon receiving a message, node j waits for a constant time W to receive other potential copies of the message. Let i be the closest neighbor from which the message has been received. Then, j rebroadcasts the message with probability $p_{ij} = D_{ij}/R$ if it receives the message for the first time, and discards it otherwise, where D_{ij} is the distance between i and j and R is the transmission radius. In case j decides to not retransmit, it waits for an additional time δ (accounts for transmission and propagation delays) to overhear the same message again from any neighbor. If this is not the case, j rebroadcasts with probability 1. In the slotted 1-persistence scheme, j selects time slot , $S_{ij} = N_s(1 - [D_{ij}/R])$, where N_s is the maximum number of slots. It rebroadcast (with probability 1) at the assigned slot, if it receives the message for first time, does not hear any duplicate before the assigned slot; otherwise, the message is discarded. Finally, in the slotted p-persistence scheme, rebroadcasting is done with predetermined probability p instead of probability 1, and retransmission with probability 1 is scheduled if no duplicate was heard within certain time limit. Versions of the algorithms using the Received Signal Strength (RSS), instead of position information, are also described.

The solutions described so far are designed for highway (Sun et al.), (Biswas, Tatchikou, and Dion), (Wisitpongphan et al.) scenarios. None of them address the issue of temporary disconnections in VANET, which is one of its most salient properties. The Distributed Vehicular Broadcast (DV-CAST) protocol (Tonguz et al.) is the only solution found in the literature, that explicitly addresses the various connectivity conditions, which are present in vehicular networks, although, it can only be applied to rectilinear streets with several lanes (like highways). Vehicle behavior is decided by its status. It is in well-connected status if it has at least one neighbor of the same cluster in the message forwarding direction. In such case, the well-connected vehicle runs one of the broadcast suppression techniques described in (Wisitpongphan et al.). A vehicle is operating in sparsely connected regime if it is the last one in the cluster of vehicles. In addition, it is said to be in a sparsely connected neighborhood if it has at least one neighbor in the opposite direction. Otherwise, the vehicle is in a totally disconnected neighborhood. Upon receiving a message, the sparsely connected vehicle immediately rebroadcasts it. If it moves in the same direction as the original message source, the message is then discarded. Otherwise, the message is carried until it expires or can be retransmitted back to the original message forwarding direction. Message is carried until an implicit acknowledgment is received (from another vehicle with greater hop count), and is being retransmitted, if new neighbors are identified. Vehicle in totally disconnected mode carries the message until a new neighbor is identified, retransmits it with probability 1 immediately, and discards it afterwards.

There are a few drawbacks in the DV-CAST protocol. The notions of neighbor in 'message forwarding' and in 'opposite direction' may often be unclear, e.g., for highway scenarios with several roads joining at an intersection. Therefore, DV-CAST will not work in such scenarios. Further, the algorithm also depends on whether or not a sparsely connected vehicle moves in the same direction as the original message source. However, there are scenarios where the message source is static. Next, after a node rebroadcasts the message in totally disconnected mode, it deletes, therefore the next coming neighbors will not receive this message in a scenario where all vehicles on the road are totally disconnected. Finally, after each transmission, neighboring vehicle is assumed to have received it, and there are no attempts to guarantee delivery to all vehicles in the area.

2.5 MAC Protocols for VANETs

MAC layer protocols are responsible for managing and maintaining the wireless channel use. Their main job is to decide which of the nodes should get the channel access and which should wait. There are two managing techniques:

- Contention free, like TDMA, FDMA, STDMA and CDMA, where the need for a central entity is crucial for the fair distribution of the channel resources among the nodes.
- Contention based, or random access protocol, such as the Carrier Sense Multiple Access (CSMA/CA) of IEEE 802.11.

MAC protocols such as TDMA, FDMA, STDMA or CDMA are difficult to implement for vehicular ad-hoc networks (VANETs) since time slots, channels, or codes have to be dynamically allocated. This requires synchronization which is difficult to achieve in high dynamic networks such as vehicular ad-hoc networks (VANETs) (Xu et al.).

To have a reliable and efficient medium access control (MAC) protocol, that suits the high mobility of vehicles, the proposed MAC protocol should avoid transmission collisions between vehicles, hence emergency messages will be forwarded in a real time manner. Moreover the medium (wireless channel) has to be shared efficiently and fairly between vehicles. The transmitted information is usually small, but it has to be propagated to the intended distance in a very short time, usually less than 0.5 seconds as studied by (IntelliDrive). Therefore, the MAC protocol in vehicular ad-hoc networks (VANETs) has to pay more attention to the medium access delay and less attention to the power constraints because vehicles have no power constraints and

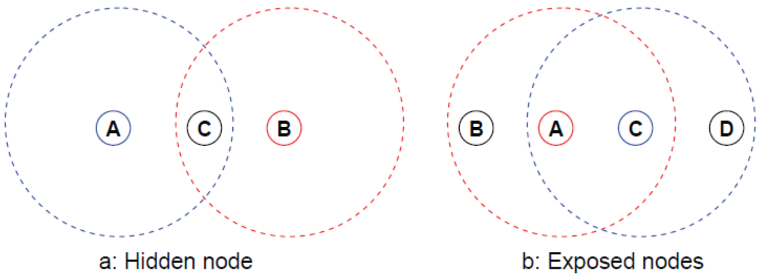

Figure 2.1: Hidden node and Exposed node

can use global positioning system (GPS) for positioning and time synchronization. Moreover, the proposed MAC protocol should pay attention to the Hidden terminal, Exposed node and capture problems.

The Hidden terminal problem happens when a node is in the range of the receiver but out of the range of the sender. This node cannot hear the transmission from the sender to the receiver. Hence, it may start sending to the receiver at the same time causing collisions as shown in Figure 2.1a. If node A is transmitting to node C, node B is a Hidden Terminal since, it cannot hear the ongoing transmission. Therefore, it may start using the channel, causing a collision at node B. The exposed node problem happens when the node is in the range of the sender but out of the range of the receiver. This node will hear the transmission of the sender to the receiver, therefore it will not use the medium during that transmission while it can transmit to other nodes in its range but out of the range of both the sender and the receiver as shown in Figure 2.1b. If node C is transmitting to node D, node A cannot use the channel although it can transmit to node B without any interference with node D. The capture problem, occurs when two nodes send data at the same time to another node. One node is closer to the receiver, hence the receiver will decode its data without errors. This will lead to unfairness problem.

Code Division Multiple Access (CDMA) is used between nodes to share a common medium where each node has an orthogonal code to encrypt messages before sending them. Multi-Code MAC (MCMAC) (Jin and Cho) protocol uses one common code for control packets and other codes for data transmission. When the sender wants to initiate a transmission, it sends first RTS message to the receiver encrypted by a common control code, this message includes the data encryption code. Upon receiving the RTS message, the receiver checks if there is any code conflict with another transmission and replies by CTS message; otherwise it will send the sender its usable codes to select one of them and start the RTS message again. When the sender receives CTS, it starts transmitting the data.

The authors in (Borgonovo et al.) introduce a new MAC architecture called AD-HOC MAC to solve the problems associated with mobile ad-hoc networks and guarantee a relatively good QoS in VANETs. This protocol is developed for the CarTalk2000 project (Morsink and Schulz). This architecture is based on a technique called Reliable Reserved ALOHA (RR-ALOHA) to dynamically assign a single broadcast channel called, Basic Channel (BCH) to every node in the network using slotted or framed structure. The AD-HOC MAC protocol works by grouping the nodes into groups where all nodes are interconnected by broadcast radio communication called One Hop cluster (OH). The main drawbacks of this protocol are that the number of vehicles within the one hop range is restricted to the number of frame time slots and the high overhead ($\geq 25\%$) of dedicating a single control channel for each node in the one hop cluster.

The Dedicated Omni-Purpose Vehicle-to-Vehicle Communication Linkage Protocol for Highway Automation (DOLPHIN) system in (Tokuda, Akiyama, and Fujii) is one of the first V2V Communication protocols and was adopted by the Japanese V2V Communication system to deal with a group of vehicles driving in a platoon. All vehicles in the platoon communicate with each other and send periodic information like speed, direction, and emergency braking of a vehicle to other vehicles in their line of sight (LOS) or route it to the NLOS conditions on vehicles. The platoon in DOLPHIN does not require any fixed infrastructure, since it uses CSMA/CA as the basis for its MAC protocol. The emergency information is allocated the shortest time slot, while other types of information are allocated the larger transmission time slots. This allows the vehicle with critical information to capture the channel before other nodes that have normal information.

Most MAC protocols designs based on IEEE 802.11 standard, use Omni-directional antennas, while using directional antennas will allow VANETs to efficiently use the channel resources. As vehicles are moving in directional roads, directional antennas may help in reducing transmission collisions. The space around each vehicle is divided into N transmission angles of ($\theta = 2\pi N$) and a separate antenna is responsible for each direction. In (Bazan and Jaseemuddin) and (Michael and Nakagawa), it has been proved that using sector antennas will increase the throughput and only a small increase in received packets is achieved when using more than two antennas. In (Young-Bae, Shankarkumar, and Vaidya) the authors proposed a Directional MAC (DMAC) protocol, assuming each node knows its position and the position of its neighbors using GPS. Based on the receivers location, the sender will use one of its directional antennas to send packets to the receiver. The DMAC scheme is based on RTS, CTS and ACK as in IEEE 802.11, except that the ACK is sent using directional antenna instead of Omni-directional antenna. The neighboring nodes that are not participating in the current transmission and upon receiving RTS or CTS by one of its directional antennas will block that antenna during the transmission period specified in RTS or CTS packets.

In Figure 2.2, if node A has a message to transmit to node B, first, it will send a Directional RTS (DRTS). Upon receiving the DRTS, node B will send an Omni-directional CTS (OCTS). A neighbor such as Node C will block its directional antenna that receive the maximum power for duration specified in OCTS. When node A receives OCTS, it will start sending the data. Node B will send an ACK to node A when the transmission is complete.

Most wireless communication standards use Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) in IEEE 802.11 to overcome collisions and the hidden terminal problem. The sender will send Request-to-Send (RTS) to the receiver to inform neighbors of the transmission process. The receiver will reply if ready by a Clear-to-Send (CTS) message to the sender. The neighbors upon hearing the CTS, will be aware of the upcoming transmission and will avoid using the channel. After that the sender will start sending the message without any risk of collisions. In the following subsection, the MAC protocol of IEEE 802.11 will be briefly introduced followed by the IEEE 802.11p, which is adopted by the IEEE community as a main technology for VANETs.

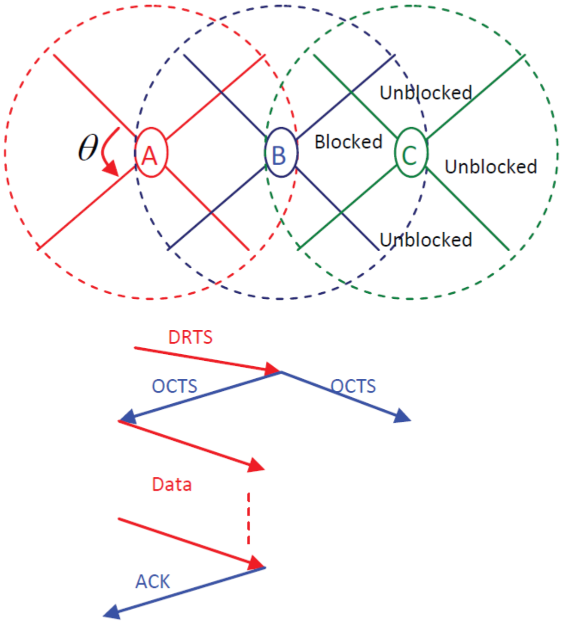

Figure 2.2: Directional MAC process

2.5.1 IEEE 802.11 MAC Layer

The IEEE 802.11, was introduced in 1990 with the interest to develop a wireless LAN operating in the Industrial, Scientific and Medical (ISM) band. Till date the IEEE 802.11 group has issued many standards. The IEEE 802.11a was introduced in 1999 to work in the 5GHz band and using Orthogonal Frequency Division Multiplexing (OFDM) to reach the rates from 6-54Mbps. The IEEE 802.11b is the most accepted standard, introduced in 1999 which uses the ISM 2.4GHz band and Direct Sequence Spread Spectrum (DSSS) to reach rates from 5.5-11Mbps. The IEEE 802.11g uses the same physical layer as IEEE 802.11b but can reach rates more than 20 Mbps up to 54Mbps. The use of the ISM 2.4 GHz unlicensed band increases the interference from other wireless devices like cordless phones, wireless IP cameras and other devices using the same band.

The IEEE 802.11 can work either in a centralized or decentralized mode. An Access Point (AP) is mandatory for the wireless nodes to communicate in the centralized mode, while in the decentralized mode it is not needed (AD-HOC mode).

The availability and the low cost of IEEE 802.11 devices attracted Engineers to implement this technology in the Vehicle-to-Vehicle Communication. The IEEE 802.11

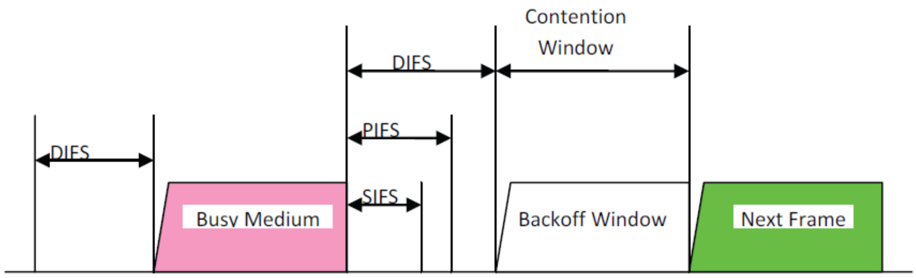

Figure 2.3: IEEE 802.11a Inter-Frame Spacing

MAC layer covers three functional areas: reliable data delivery, MAC access control and security.

Reliability in the context of VANETs broadcast services is defined as the networks ability for all intended mobile nodes to receive the broadcast messages within specified operation duration. The IEEE 802.11 uses RTS, CTS and ACK to ensure reliability and uses three Inter Frame Spaces (IFS) to control medium access and minimize frame collisions. The Short IFS (SIFS) is the shortest IFS and used by immediate responses like ACK, CTS and Poll response. The Point coordination Function IFS (PIFS), which is the medium length IFS, is used by the centralized controller. The Distributed Coordination Function IFS (DIFS), which is the longest IFS, is used as a minimum delay by all asynchronous frames contending for medium access. The three inter frame spacing intervals are shown in Figure 2.3.

The IEEE 802.11 uses CSMA/CA as follows:

a. First, a node that has data to send will sense the channel. If it is idle, the node waits for a period of DIFS. If the medium is still idle it will send RTS message including its ID and the duration of the whole transmission. Upon receiving the RTS message the receivers neighbors will set their NAV (Network Allocation Vector) to the time indicated in the RTS message and will not use the medium during that time.

b. Upon receiving the RTS message, if receiver is ready, it waits for the time duration called SIFS. If the medium is still idle it will send a CTS message including the transmission duration time. All neighbors receiving this CTS message will set their NAV to the time indicated in the CTS message (the medium is busy).

c. Upon receiving the CTS message, the transmitter waits for SIFS time before starting the data transmission.

d. When the receiver successfully receives the data, it will wait for another SIFS and sends an ACK only to the sender. All neighbors receiving the ACK message will set their NAV to zero, indicating that the channel is free.

e. If the sender senses the medium as busy, it will wait for a duration of DIFS. If the medium is still busy it will back off a random amount of time before sensing it again. If the medium becomes busy during the back off time then the back-off timer is halted and resumes when the medium becomes free.

f. If the sender did not receive an ACK, it will assume a failed transmission and try to retransmit again.

g. The back-off mechanism used is a binary exponential back-off, that is after every collision, the sender will wait for double the last delay up to a maximum value. Therefore the repeated collisions result in longer waiting times.

In 2007, the IEEE community, published a set of improvements to the MAC layer in IEEE 802.11 standard to enhance the Quality of Service (QoS) for wireless LAN applications. Those improvements enhance the DCF and PCF in the standard 802.11 MAC by introducing a new Hybrid Coordination Function (HCF) which has two methods to access the channel: HCF Controlled Channel Access (HCCA) and Enhanced Distributed Channel Access (EDCA). The IEEE 802.11e (for Information technology) defines Traffic Classes (TCs) in both HCCA and EDCA, hence, the traffic with the high priority wins the contention and waits less time before it is transmitted.

2.5.2 Wireless Access in Vehicular Environments (WAVE)

The IEEE society, has developed a Wireless Access in Vehicular Environments (WAVE) (International) architecture to provide wireless access for vehicular ad-hoc networks. This subsection gives an overview of this architecture following the layered ordering of the open systems interconnection (OSI) model.

In 1997, the Federal Communications Commission (FCC) allocated a bandwidth of 75 MHz in the 5.9 GHz band (5.85-5.925 GHz range) to support the dedicated short-range communications (DSRC) for ITS. In 2004, an IEEE task group (known as IEEE 802.11p (IEEE, "IEEE P802.11p/D5.0 Draft Amendments for Wireless Access in Vehicular Environments (WAVE)")) started developing an amendment to the 802.11 standard for the use of VANETs. Another IEEE group (working group 1609), took the role to develop other OSI layers specifications. There are four documents in the IEEE 1609 standards set: IEEE 1609.1 (P1609.1), IEEE 1609.2 (P1609.2), IEEE 1609.3 (for Information technology), and IEEE 1609.4 (P1609.4). Figure 2.4 shows the WAVE architecture and Table 2.1 lists the services requirements of the IEEE 1609 standards (Jiang and Delgrossi, "IEEE 802.11p: Towards an international standard for wireless access in vehicular environments"). The IEEE 802.11p and IEEE 1609 standards together are called wireless access in vehicular environments (WAVE) since their main goal is to facilitate the provision of wireless access in vehicular environments. Therefore, in the remaining of this thesis, use IEEE 8021.11p, DSRC and WAVE interchangeably.

The WAVE system consists of two units:

a. Roadside units (RSUs), which are installed along the side roads

b. On-board units (OBUs) which are mounted on vehicles.

The standard is intended to allow Vehicle-to-Vehicle (V2V) and Vehicle-to-Roadside (V2R) communications. In this technology, vehicles communicate with each other and the RSUs to form VANETs on the road. VANETs will allow vehicles to send their status and safety messages amongst one another to indicate the presence of accidents and other hazards. In order for these safety applications to run effectively, it is necessary to have a highly reliable Medium Access Control (MAC) layer, such that vital safety messages can be delivered in a timely manner.

The WAVE PHY and MAC layers are based and intended to enhance the IEEE 802.11a, to support the Vehicular Ad-hoc Networks (VANETs) applications. The IEEE group is working on Physical and MAC amendments to the IEEE 802.11, to make it more suitable for the high mobility and fast changing topology of VANETs, where reliability and low latency are crucial. WAVE uses the licensed ITS 5.9 GHz

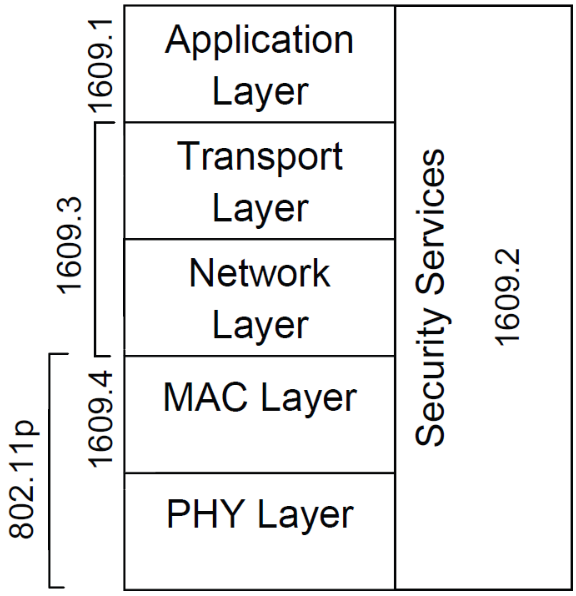

Figure 2.4: Wireless Access in Vehicular Environments (WAVE) Architecture

(5.850-5.925 GHz) band in North America (75 MHz spectrum) and uses Orthogonal Frequency Division Multiplexing (OFDM) scheme to provide for both the Vehicle-to-Vehicle Communication and Vehicle-to-Infrastructure communications a wireless connection up to 1000m.

The physical layer of the IEEE 802.11p is a variation of the IEEE 802.11a standard as shown in Table 2.2. Figure 2.5 shows the message structure of the IEEE 802.11p. It employs 64 OFDM sub-carriers where 52 of them are used in actual data transmission. The short and long training symbols located at the beginning of every message are used for signal detection, time synchronization and channel estimation while the guard intervals (GI) are used to eliminate the inter symbol interference (ISI) from the multi-path propagation channel.

The IEEE 802.11p defines up to four EIRP (Effective Isotropic Radiated Power). The maximum power (30W) is reserved for emergency vehicles so that they can reach longer distances to allow drivers to yield the way. The typical safety status messages use the 33 dBm EIRP.

The 75MHz spectrum is divided into seven channels and a 5 MHz guard band. Each channel uses 10MHz frequency bandwidth in contrast to IEEE 802.11a which uses 20MHz to increase its tolerance to the multi-path propagation and Doppler spread

Table 2.1: Operations of WAVE functional entities

Entity	Operation
1609.1	Specifies the services and interfaces of the WAVE Resource Manager application
1609.2	Defines secure message formats and processing
1609.3	Defines network and transport layer services including addressing and routing support of secure WAVE data exchange
1609.4	Enables operation of upper layers across multiple channels, without requiring knowledge of PHY parameters
802.11p	Define the WAVE signaling technique and interface functions that are controlled by the IEEE 802.11 MAC

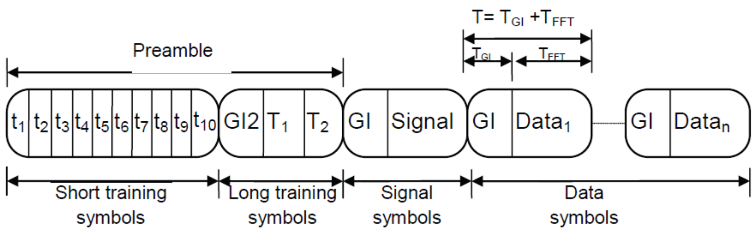

Figure 2.5: Message structure in IEEE 802.11p

effects in vehicular networks. Using 10MHz channels results in data rates from 3 to 27 Mbps. Figure 2.6 shows the channel allocations in IEEE 802.11p. Channel 178, called the control channel, will be used for safety applications while channels 174, 176, 180 and 182 are service channels and will be used for non safety applications. Two service channels can be combined to form one large channel for certain applications that need large bandwidth. Channels 172 and 184 are dedicated for public safety applications.

Each vehicle will alter between the control channel (CCH 178) and one of the service channels. The control channel of each vehicle will send periodic status messages (beacons), which include its position and status information like speed, acceleration

Table 2.2: Parameters of the DSRC IEEE802.11p and the IEEE802.11a

Parameter	IEEE802.11p	IEEE802.11a
Data rate (Mbps)	3, 4.5, 6, 9, 12, 18, 24, 27	6, 9, 12, 18, 24, 36, 48, 54
Modulation	BPSK, QPSK, 16-QAM, 64-QAM	BPSK, QPSK, 16-QAM, 64-QAM
No. of sub-carriers	52 (48 data & 4 pilot)	52 (48 data & 4 pilot)
OFDM symbol duration (μ s)	8	4
Guard time (μ s)	1.6	0.8
FET period (μ s)	6.4	3.2
Preamble duration (μ s)	32	16
Subcarrier freq. spacing	156.25 KHz	312.5 KHz

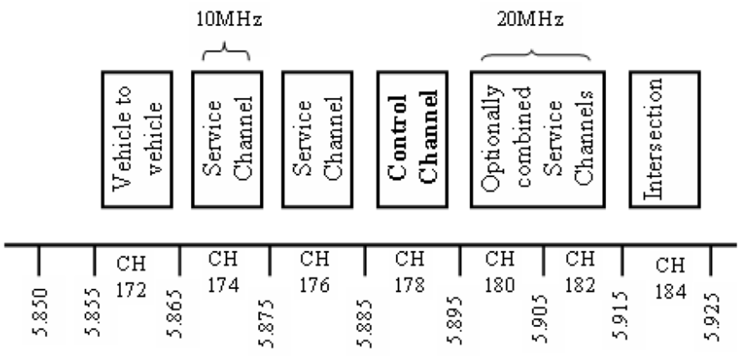

Figure 2.6: Channel allocation in IEEE 802.11p

Table 2.3: Contention parameters for IEEE802.11p CCH

AC No.	Access Class	CW_{min}	CW_{max}	AIFSN
0	Background Traffic (BK)	15	1023	9
1	Best Effort (BE)	7	15	6
2	Voice (VO)	3	7	3
3	Video (VI)	3	7	2

and direction to the neighboring vehicles. Upon receiving these messages, vehicles will process this information. If any dangerous situation is detected, the vehicle can send a warning message with high priority access class to all other vehicles in the direction of interest for a certain distance to alert drivers to take appropriate and timely action.

WAVE will use CSMA/CA as in IEEE 802.11a and the Enhanced Distributed Channel Access (EDCA) as in the IEEE 802.11e standard as its basic MAC protocol. In this standard, messages are categorized into four different Access Classes:

a. Background

b. Best Effort

c. Voice

d. Video

The contention parameters for the four classes are shown in Table 2.3. Each AC has a separate queue and all four queues will contend internally and the winner message will contend externally with other nodes in the network for accessing the wireless channel.

Each node (vehicle) in IEEE 802.11p network contains these four queues and each queue has different Arbitration Inter-Frame Space (AIFS) which equals to $SIFS + AIFSN\varrho$ where ϱ is the time slot. The queue with the highest priority has the shortest AIFS and will wait the shortest time before its transmission can start. For the first transmission the node will randomly select a value between $([0 - CWmin])$, where CW_{min} is the minimum contention window for this access class. This contention window (CW_{min}) will be doubled as $(2(CW_{min} + 1) - 1)$ each time a collision occurs until the CW_{max} or the maximum number of retransmissions reached. In case of a collision, the message will be retransmitted after a back-off time. This back-off time is shorter for the high priority traffic. Therefore, the queue with the highest priority will always win the contention of accessing the channel, while other, low priority traffic must back-off and try to retransmit after its back-off time expires.

Chapter 3

Analysis of the IEEE 802.11p Physical Wireless Channel

There are many parameters that affect the performance of vehicular ad-hoc networks (VANETs), applications and protocols. To test the new applications and protocols on a real time setup is very difficult and expensive. Most researchers use simulation tools to study and analyze vehicular ad-hoc networks (VANETs). The simulators usually use simple radio propagation models that did not take into account all the obstacles in the environment. Therefore, different radio propagation models are analyzed in the context of VANETs safety applications. Through simulations using network simulator Network Simulator (NS-2.4) and Matlab, the radio propagation model is found that best characterize the vehicular environment.

3.1 Overview

In the near future, vehicles will be equipped with Dedicated Short Range Communication (DSRC) devices (IEEE 802.11p) (IEEE, “IEEE P802.11p/D5.0 Draft Amendments for Wireless Access in Vehicular Environments (WAVE)”) to form vehicular ad-hoc networks on the road. There are many applications and routing protocols that have been developed or are under development for VANETs to help drivers to travel more safely and to reduce the number of fatalities due to road accidents. For example, if one vehicle meets with an accident, it has to send a warning message to all vehicles behind it in order to avoid a chain collision. The safety information has to be propagated in a short time (usually less than 0.5 sec) (IntelliDrive).

The research and application development in VANETs are driven by the IEEE802.11p technology (IEEE, "IEEE P802.11p/D5.0 Draft Amendments for Wireless Access in Vehicular Environments (WAVE)") which is intended to enhance the IEEE 802.11 to support the Intelligent Transportation System (ITS) applications, where reliability and low latency are crucial. The IEEE 802.11p technology is aimed to support upto 1000 meters communication range between vehicles, or vehicles and infrastructure. A realistic study conducted by (Gallagher, Akatsuka, and Suzuki) shows that this technology can reach up-to 800 m in a highway scenario for the line of sight (LOS) and 58 to 230 meters in the non line of sight (NLOS). It seems that this technology did not take into account all the mobility effects and the characteristics of VANET's radio environment. The nodes (vehicles) are in high mobility either in the same or in opposite direction which results in Doppler shift causing frequency dispersion. The radio wave in vehicular environment faces many challenges such as:

- Absorption
- Reflection
- Refraction
- Diffraction
- Scattering

due to obstacles on the road. The vehicular environment is very large and to test the new applications and protocols designed for this environment on a real setup is very difficult and expensive. This is the reason why most researchers use simulation tools to study and analyze VANETs. The simulators use, simple propagation models that did not take into account all the obstacles in the environment.

3.2 Radio Propagation Models

In this section present the most common radio wave propagation models which are implemented in the network simulator (NS-2.34). They are either large scale propagation models to predict the mean signal strength for large transmitter-receiver distance or small scale propagation models to predict the short-time fluctuations over small distances.

a. Free Space Propagation Model: It is a large scale propagation model that assumes only the existence of the LOS path between the transmitter and the receiver. The received power P_r at distance d from the transmitter is given by the Friis Equation (Rappaport) as

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{4\pi^2 d^2 L} \tag{3.1}$$

where P_t is the transmitted power, G_t and G_r are the transmitter and receiver antenna gains, L is the system loss and λ is the wave length in meters.

b. Two-Ray model: It is also a large scale model in which the received signal is the sum of the LOS signal and the one reflected from the ground. This model is more accurate than the free space model in predicting the received signal strength for large distances. The received power is given by (Rappaport) as

$$P_r(d) = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4} \tag{3.2}$$

where h_t, h_r are the transmitter and receiver antennas heights.

c. Rayleigh Fading Model: This model assumes that the magnitude of the received signal r varies randomly according to a Rayleigh distribution which is a sum of two uncorrelated Gaussian random variables $r(t) = \sqrt{I(t)^2 + Q(t)^2}$ (in-phase and quadrature components). It has a probability density function (pdf) as

$$p(r) = \frac{r}{\sigma^2} \exp(\frac{-r^2}{2\sigma^2}), for r \geq 0, \tag{3.3}$$

where σ^2 is the time average power of the received signal (the variance of I(t) and Q(t)). This model is suitable for wireless channels that have no LOS component but multi-path components that vary in amplitude and phase. The received components will have zero mean and uniformly distributed phase between [0, 2π].

d. Ricean Fading Model: In this model the random multi-path components will be added to the LOS which can be seen as a DC component to the random multi-path in Rayleigh distribution. If the in-phase and quadrature components I(t) and Q(t) have a jointly Gaussian pdf, then the pdf of the received signal is found to be Ricean distribution as

$$p(r) = \frac{r}{\sigma^2} \exp(-\frac{r^2 + A^2}{2\sigma^2}) I_0(\frac{Ar}{\sigma^2}), A \geq 0, r \geq 0, \tag{3.4}$$

Where I_0 is the modified first kind and zero-order Bessel function. When A (the LOS component) tends to zero, the Ricean distribution corresponds to a Rayleigh distribution and when A tends to infinity, the Ricean converges to Gaussian distribution.

e. Shadowing model: This model has two parts. The first part is the path loss component which is used to predict the received power at distance d from a known reference power at distance d_o. The second part is the log-normal shadowing which reflects the variations of the received power at certain distance d from the transmitter. It is a log-normal distribution or Gaussian distribution if measured in dB. Therefore the overall shadowing model is represented as:

$$\frac{\overline{P_r d_0}}{P_r(d)} = (\frac{d}{d_0})^n + X_\sigma, \tag{3.5}$$

where n is the path loss exponent, X_σ N(0, σdB), and σdB has a value from 4 to 12 dB in an outdoor environment.

f. Nakagami-m distribution: This model is frequently used to characterize the statistics of signals transmitted over multi-path fading channel and its pdf describes the distribution of the envelop r of the received signal and is given by

$$P_r(r) = \frac{2}{\Gamma(m)}\frac{m}{\Omega}r^{2m-1}e^{\frac{-mr^2}{\Omega}}, forr \geq 0, \tag{3.6}$$

where Γ(o) is the gama function, $\Omega = E(R^2)$ is the average received power and the parameter $m = \frac{\Omega^2}{E[(R^2-\Omega)^2]}$ is the ratio of moments and is called the fading factor. If m = 1 then the Nakagami distribution will reduce to a Rayleigh distribution.

The Free Space and Two-Ray models are deterministic radio propagation models. They assume a successful reception of the signal, if the received signal strength (RSS) is greater than a threshold. This means that their communication range is an ideal circle and they always determine the same RSS for the same distance. While in reality, the RSS is a random variable due to the multi-path propagation effect. This makes the successful detection of the signal uncertain. The shadowing, Rayleigh, Ricean and Nakagami are probabilistic propagation models and their successful reception of the signal is a decreasing function of the distance.

3.3 VANET Wireless Channel Analysis

The vehicular ad-hoc networks have many moving and stationary objects that can reflect, scatter, diffract or even block the signals. Therefore, the received signal by any vehicle is composed of many reflected versions of the original signal, that have different time and angle of arrival which cause them to have, randomly distributed amplitudes and phases. Each of the multi-path signals will have either a constructive or a destructive effect on the total received signal depending on its phase and amplitude (fading). Also, due to their high speed, vehicles could pass through many fades in a very short time or could reach a point where the received signal is highly distorted. This is a serious issue for vehicular time critical safety applications such as accident warning system.

To analyze the wireless channel in VANETs, an accident scenario model is built. In this model, the vehicle that is involved in an accident sends a warning message to all vehicles behind it. This vehicle could manage to send the warning message only once, before it is broken. The vehicles behind should receive this message correctly and in a very short time; so they can take action to prevent a chain or a secondary accident. At the time of accident, assume that the broken vehicle has almost zero speed, while the behind vehicles are at full speed 33 m/s. Assume also that the communication range is R meters and there are many vehicles in between the transmitter and the receiver as shown in Figure 3.1

In this model, there are two paths for the transmitted signal to propagate to the receiver:

- The direct path in which the signal could follow the free space propagation model, if the distance between the transmitter and the receiver is less than 100 m
- The Two-Ray model.

If there are vehicles, in the way, from the transmitter to the receiver, the received signal through the direct path could lose some or most of its strength, depending on the heights and locations of the vehicles in between. The in-between vehicles block, at least half of the first Frensel zone (Rappaport). Therefore the received signal strength

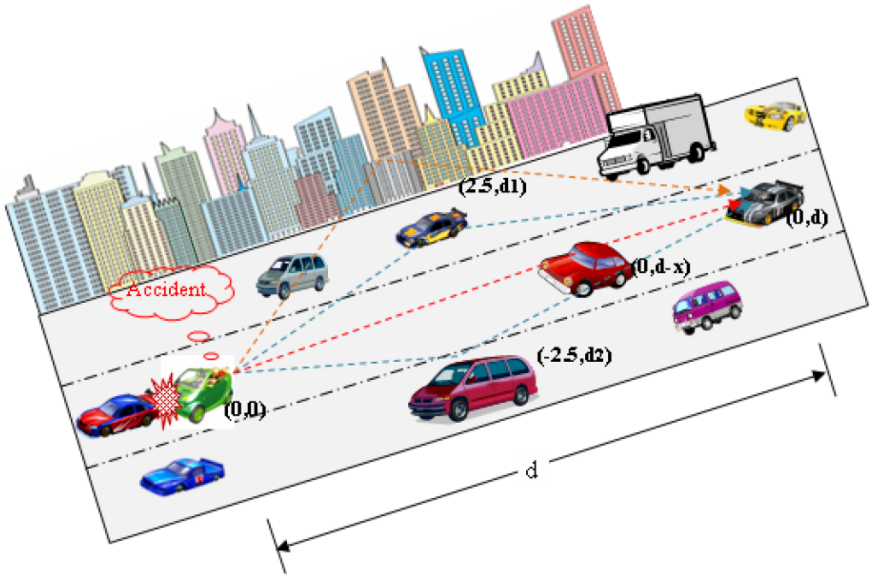

Figure 3.1: Accident scenario in VANET

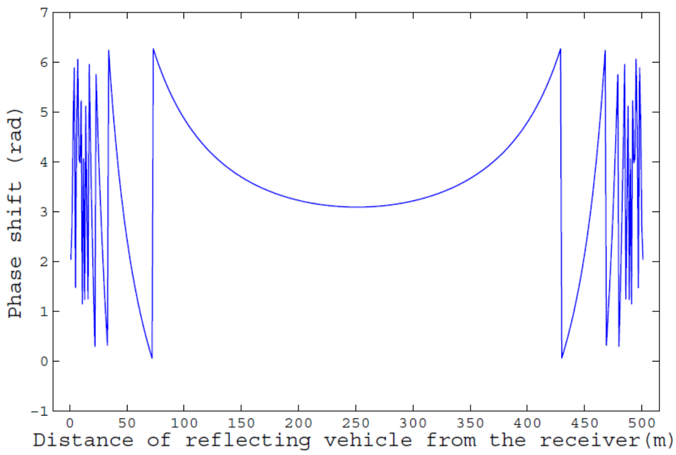

Figure 3.2: The Phase shift vs the position of the reflecting vehicle from the receiver

will lose at least 6 dB on top of the Free-Space, or Two-Ray attenuation. The second way is the reflected path from each side of the lane where the accident happens. The signal could be reflected from the adjacent vehicles, or the buildings along the highway. Moreover, due to the movement of the receiver, towards the transmitter, the received components will arrive in different frequencies higher than the original frequency due to different Doppler shifts. Figure 3.2, which is a Mat-lab simulation, shows that the phase of the reflected signal is in high degree of fluctuation when the in-between vehicles are concentrated around either the transmitter or the receiver.

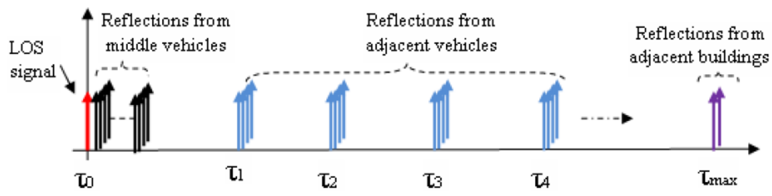

Figure 3.3: The impulse response of the modeled channel

In general, the received signal can be expressed as in (Rappaport) by

$$r(t) = \sum_{i=0}^{N-1} a_i e^{-j\Theta_i(t)}, \tag{3.7}$$

where N is the number of received signals, $\Theta_i(t) = 2\pi(f_c + f_d)t + \Phi_{\Delta i}$, f_c and f_d are the carrier and the Doppler frequencies and $\Phi_{\Delta i}$ is the phase shift. The first component in Equation (3.7), which is the direct signal, is attenuated by the knife-edge diffraction model. This attenuation depends on the height and distance of the in between vehicles. The multi-path components, which are reflected from vehicles within 100 m, will have different, arrival times. At each time, there will be up to four signals that have the same phase. While the components reflected from vehicles located in the middle will have almost the same arrival time as the direct one but with different phase. Figure 3.3 shows the impulse response of the modeled channel from which can derive the power delay profile of the channel, by averaging the squares of the magnitudes as $\tau = \frac{a_k^2}{\sum_k a_k^2}$. From the power delay profile, the mean excess delay, is the first moment of the power delay profile, can be defined as

$$\overline{\tau} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} \tag{3.8}$$

From (3.8), the maximum excess delay can be defined as excess delay of the last component, it has a magnitude that exceeds a certain threshold. The root mean square value (rms) delay spread, which is a measure of the variation of the delays, about its mean, can be derived as

$$\sigma_\tau = \sqrt{\overline{\tau^2} - \overline{\tau}^2} \tag{3.9}$$

The IEEE 802.11p is set to use the OFDM modulation technique with 64 sub-carriers that are orthogonal to each other. Therefore, the Guard Interval (GI) that precedes each symbol as shown in Figure 2.5 (Chapter 2), has to be longer than the time delay profile, which is longer than the maximum excess delay, to alleviate the impact of the Inter Symbol Interference (ISI) and maintain the symbols orthogonality. At the same time increasing the GI more than needed will reduce the channel throughput. From the IEEE 802.11p specifications listed in Table 2.2 (Chapter 2), it can be seen that the Guard Interval is 1.6 μs and the maximum excess delay in the highway scenario is 1.4 μs as measured by (Cheng et al.). Although the Guard Interval is enough to eliminate the Inter Symbol Interference (ISI) in the highway scenario, it could be not enough for rural areas that exhibits longer maximum excess delay due to far reflecting objects.

To test for fading in vehicular ad-hoc networks, define first the channel coherence bandwidth B_c, which is the reciprocal of the power delay profile, as a measure of a range of frequencies over which the channel is considered to be flat. If the frequency correlation function of the spectrum envelope is above 0.9, the coherence bandwidth is estimated as $B_c = \frac{1}{50\sigma_\tau}$(Rappaport) and if it is above 0.5 then $B_c = \frac{1}{5\sigma_\tau}$. If the bandwidth of the signal B_s is less than the coherence bandwidth B_c of the channel, the channel will be considered as a flat fading channel where signal amplitude may vary (fade) but may not be distorted. On the other hand, if $B_s \gg B_c$ then the signal will go under frequency selective fading, where its amplitude may not vary, but will be distorted.

Since IEEE 802.11p uses OFDM signals, the frequency spacing between the sub-carriers should be less than the coherence bandwidth of the channel to ensure flat fading as

$$B_s = \frac{10MHz}{64subcarriers} = 156.25KHz \gg B_c \tag{3.10}$$

Moreover the spacing between adjacent carrier's frequencies must be much larger than the Doppler spread B_D to ensure that the multi-path signals do not interfere with adjacent carriers such as

$$B_s \gg B_D = 2\frac{\upsilon}{\lambda} \tag{3.11}$$

where υ is the relative speed between vehicles and λ is the wave length. Therefore, the following condition has to be assured to avoid fading

$$B_c \gg B_s \gg B_D \tag{3.12}$$

The rms delay spread σ_τ is reported in (Yin et al.) as 400 ns for the NLOS scenario, hence the 0.9 coherence bandwidth can be calculated as 50 KHz which is less than the symbol frequency $B_s = 156.25KHz$. This means that the received signal may suffer from frequency selective fading.

In vehicular environment, the propagation channel is considered to be a time-varying channel due to the motion of the transmitter, the receiver and other reflecting objects on the road. The coherence time $T_c \approx \frac{1}{f_m}$ of the channel is a statistical measure over which the channel can be considered invariant, where $f_m = \frac{v}{\lambda}$ is the maximum Doppler shift. In most cases they calculate the coherence time as $T_c \approx \frac{0.423}{f_m}$ (Rappaport). Need to make sure that the symbol duration in OFDM, which is $T_s = 8ms$, is much less than the coherence time T_c to ensure slow fading channel. The training sequence sent before each message is used to estimate the channel and detect its coherence time and this estimation will be used for the whole message. Therefore, the message duration has to be less than the coherence time to reduce the message error probability.

If the maximum vehicle speed, is assumed to be 125 Km/h, then the maximum relative speed between two vehicles moving in opposite directions is 250 Km/h. Therefore, the maximum Doppler shift is $f_m = 1.366$KHz and the coherence time is

$$T_c = \frac{0.423}{1.366KHz} = 310\mu s, \tag{3.13}$$

which is the maximum message length duration without distortion during transmission. Moreover the preamble duration, which is set to ($32\mu s$) as listed in Table 2.2 (Chapter 2), is much less than the coherence time of the channel and may not be enough to estimate the channel for long message transmissions.

3.4 Simulation

To find the propagation model that best characterizes vehicular ad-hoc networks channel, two kinds of simulations are conducted, one by using MATLAB and the other by using Network simulator NS-2.34.

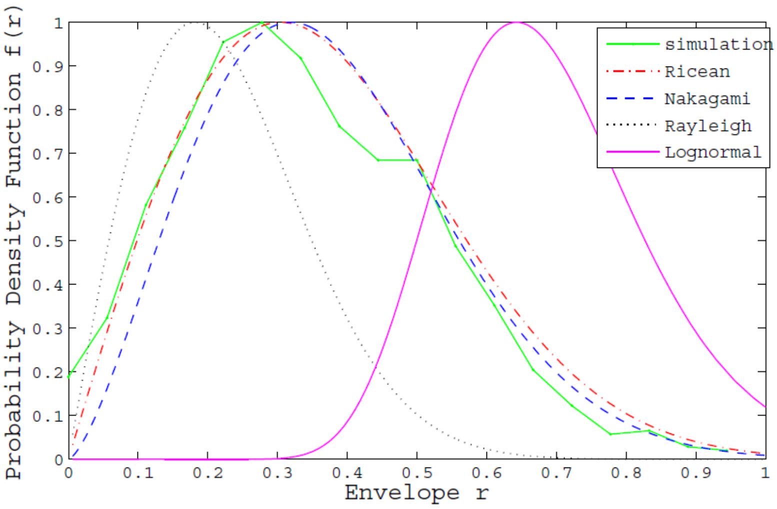

Figure 3.4: The pdfs of the received signal and propagation models

3.4.1 MATLAB simulations

Model Equation 3.7 using MATLAB and calculate the probability density function (pdf) of the received signal envelop. To test this pdf against the pdfs of the probabilistic propagation models mentioned in section 3.2, calculate the parameters of the Rayleigh, Ricean, Shadowing and Nakagami propagation models from the received signal itself. Figure 3.4 shows the pdfs of the simulated signal and the aforementioned propagation models. can see that the received signal is more close to the Ricean and Nakagami distributions, since there is a diffracted LOS component. Figure 3.5 shows the outage probability, which is the probability that the received signal power is below a certain threshold. It is also clear that the simulated outage probability is more close to the Ricean distribution. From Figures 3.4 and 3.5 , it can be concluded that Ricean and Nakagami models are more appropriate to describe the received signal in a highway scenario.

3.4.2 NS-2 simulations

The network simulator NS-2.34 is used, which is a well known simulator in both academic and industrial fields for simulating and analyzing VANET environment. The simulator has been extended to model VANETs by utilizing the IEEE 802.11p technology. The simulated network is mapped as circular bidirectional highway with a diameter of 2000 m (6283 m length), with 4 lanes in each direction. There are 600

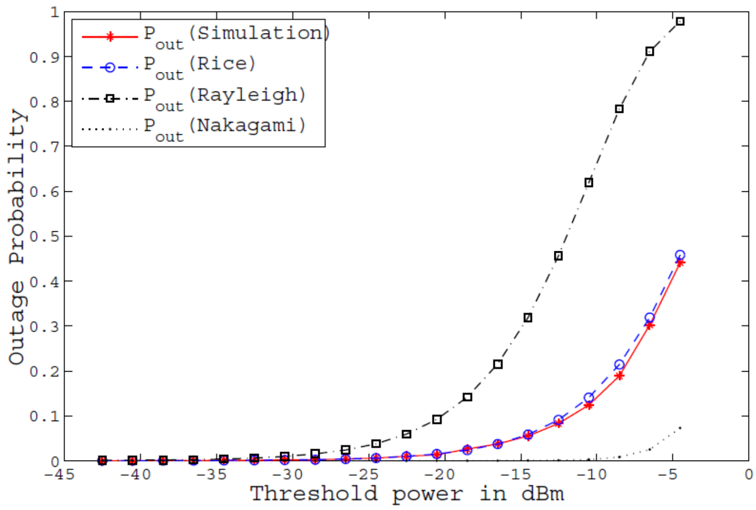

Figure 3.5: The simulated and analytical outage probability

vehicles on this highway segment and all of them equipped with DSRC and GPS technologies. The vehicles speeds range from 70 to 120 Km/h and their movements follow a microscopic mobility model where the instantaneous speed is influenced by front vehicle's speed and has to change lane if it decides to bypass another vehicle. Each vehicle is configured to broadcast a status message of size 250 bytes periodically and all vehicles within its range are possible recipients. All configuration parameters are listed in Table 3.1. At the end compare and analyze the different propagation models based on the message delivery ratio and the time delay in receiving an emergency message.

In the first simulation scenario, only one vehicle is broadcasting its status message; all other vehicles are potential recipients. Interested in the successful ratio of the received messages at different distances from the transmitter.

For the Shadowing propagation model, use 2.8 as the path loss exponent and 4 as a standard deviation as specified in NS-2.34 for the highway scenario. For the Nakagami propagation model, used the parameters specified by (Torrent-Moreno et al., "IEEE 802.11-based one-hop broadcast communications: understanding transmission success and failure under different radio propagation environments"). Figure 3.6 shows the message successful reception rate versus distance. It is obvious that different propagation models give very different results for the same setup. This means that choosing the propagation model in any simulation setup is a main factor to judge

Table 3.1: Value of parameters used in simulation

Parameter	Value
Data rate of IEEE802.11p	6 Mbps
Message size	250 Bytes
Vehicles speed	$70 - 120$ km/h
Vehicles density	12 vehicles/km/lane
Transmission power (P_t)	0.001
Received power threshold (RxThreshold)	$3.162e - 12$
Carrier sense threshold (CSThreshold)	$3.162e - 12$
Noise power threshold (Noise-floor)	$1.26e - 13$
Height of the T_x and R_x antennas	1.5 m
Gain of the T_x and T_r antennas ($G_t = G_r$)	4 dB

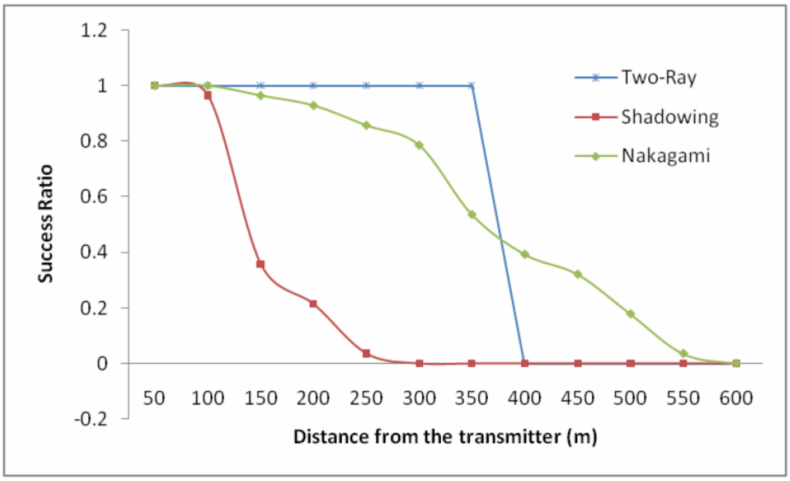

Figure 3.6: The Success Ratio vs Distance

on the validity of the results. Therefore, conducting the simulations and analysis of vehicular ad-hoc networks, based on a simple model such as the Free Space and Two-Ray models is not correct as prov-en by the MAT-LAB simulations.

In the second simulation scenario, use the same parameters as in the first scenario except for two: the transmission power is increased to 0.002 W and all vehicles are transmitting their status messages periodically. One vehicle is configured to send an emergency safety message to all vehicles behind. Interested in the time till the warning message reaches a distance of 2000 m. Figure 3.7 shows the time delay until the emergency message reaches the intended distance versus the status messages sending rate (traffic load). It is obvious that the Two-Ray model suffers from high delay in a high traffic situation, since all nodes within the range are competing to use the channel. In the probabilistic models, (Shadowing and Nakagami) not all nodes receive the signal successfully. So the number of nodes competing for the channel is less. It can be seen also that different propagation models give different results for the same scenario. This is a very serious issue in vehicular ad-hoc networks, especially in an accident situation where safety messages have to be propagated to all vehicles behind the accident in a short time. Using a simple model, which assumes that all vehicles in the range receive the message successfully, while in reality they are not, may result in fatal consequences.

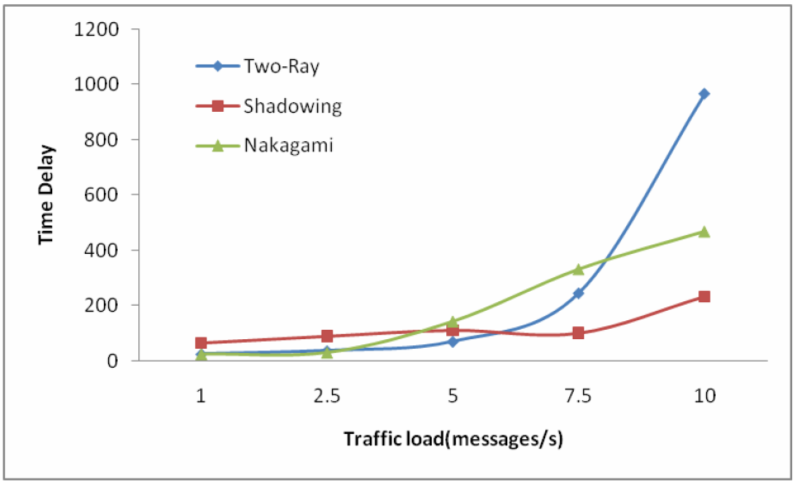

Figure 3.7: Time delay vs Traffic load

3.5 Summary

In summary, the radio channel in VANETs is very complex and has many parameters that affect the amplitude and phase of the received signal. Using simple models like the Free-Space and Two-Ray models is not accurate in all scenarios. simulations using NS-2.34 show very different results for different propagation models. Therefore, choosing the optimal model in each scenario, is the challenge that is faced by researchers. The best way to model the radio channel is, by conducting real experiments on the road. MATLAB simulations show that Ricean and Nakagami distributions are the appropriate models to describe the received signal in a highway scenario. results show that the simulated results agree with the analytical results.

Chapter 4

Vehicular Ad-hoc Networks Routing Protocols

VANET is autonomous and self-organizing wireless ad-hoc communication network. In this network, vehicles are called nodes which involve themselves in peer-to-peer for communication. Many research projects related to VANET are COMCAR (Ericsoun), DRIVE, FleetNet (W.Franz, Hartenstein, and Eds) and NoW (Festag), CarTALK 2000 (D. et al.), CarNet (R. et al.). Many different VANET applications such as Vehicle Collision Warning, Security Distance Warning, Driver Assistance, Co-operative Cruise Control, Dissemination of Road Information, Internet Access, Map Location, Automatic Parking and Driver-less Vehicles. This research, has analysed the performance of AODV, DSR and GPSR routing protocol on CBR connection pattern with different pause time, speed time, also different network parameters and different measured performance metrics such as Packet Delivery Ratio, Packet Loss, Throughput and End-to-End Delay, of these, three routing protocols are compared for their performance analysis.

4.1 Vehicular Ad-hoc Routing Protocols

An ad-hoc routing protocol is a standard (Rahman, Anwar, and Abedin), that controls how vehicle nodes decide in which way to route the packets between computing device in vehicular ad-hoc network. There are different types of routing protocols in VANET, such as proactive routing protocol, reactive routing protocol, hybrid routing protocol, topology based routing protocols and position based routing protocols. Existing uni-cast routing protocols of VANET, is in capable of meeting every traffic on highways/roads scenarios. They also have some advantages and disadvantages. have selected two reactive routing protocols i.e. AODV and DSR and one position-based routing protocol i.e. GPSR for simulation purpose and analysis.

4.1.1 Ad-hoc On Demand Distance Vector Routing Protocol (AODV)

It is purely On-Demand route acquisition routing protocol.It is better protocol than Destination-Sequenced and Distance-Vector (DSDV) network as the size of network may increase depending on the number of vehicle nodes (Ullah, Amin, and ul Ghaffar Tuteja, Gujrl, and Thalia Usop, Abdullah, and Abidin).

Path Discovery Process

In order to discover the path between source and destination, a route request message (RREQ) is broad-casted to all the neighbors, who again continue to send the same to their neighbors, until the destination is reached. Every node maintains two counters: sequence number and broadcast-id in order to maintain loop-free and most recent route information. The broadcast-id is incremented for every RREQ the source node initiates. If an intermediate node receives the same copy of request, it discards it without routing it further. When a node forwards the RREQ message, it records the address of the neighbor from which it received the first copy of the broadcast packet, in order to maintain a reverse path to the source node. The RREQ packet contains:

- The source sequence number and
- The last destination sequence number known to the source.

The source sequence number is used to maintain information about reverse route and destination sequence number tells about the actual distance to the final node.

Route Maintenance

A moving source node sends a new RREQ request packet to find a new route to the destination. But, if an intermediate node moves from its place, its upstream neighbor notices the move and sends a link failure notification message to each of its active

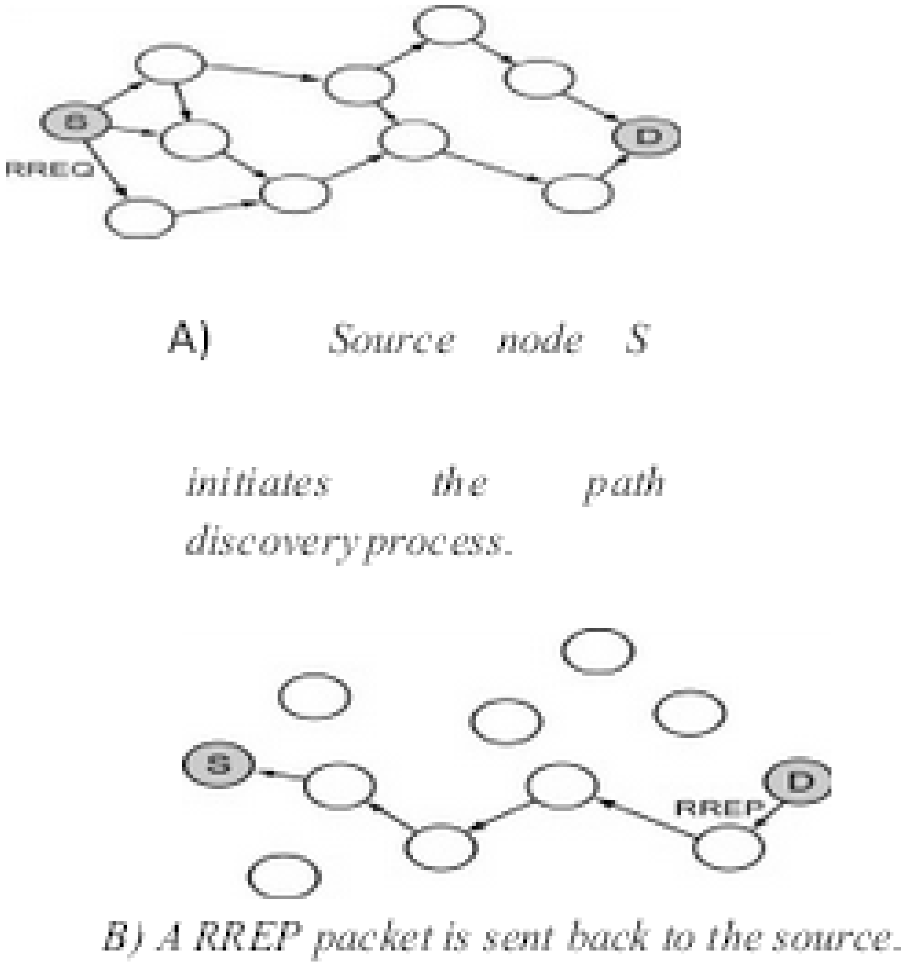

Figure 4.1: AODV Path Discovery Process

upstream neighbors to inform them about the move until the source node is reached. After that, the discovery process is again initiated.

4.1.2 Dynamic Source Routing Protocol (DSR)

It is an On-Demand routing protocol in which the sequence of nodes through which a packet needs to travel is calculated and maintained as an information in packet header. Every mobile node in the network needs to maintain a route cache where it caches source routes that it has learned. When a packet is sent, the route-cache inside the node is compared with the actual route needs to be covered. If the result is positive, the packet is forwarded otherwise route discovery process is initiated again.

Route Discovery

The source node broadcasts request-packets to all the neighbors in the network containing the address of the destination node, and a reply is sent back to the source node with the list of network-nodes through which it should propagate in the process. Sender initiates the route record as a list with a single element containing itself followed by the linking of its neighbor in that route. A request packet also contains an identification number called request-ID, which is counter increased only when a new route request packet is being sent by the source node. To make sure that no loops occur during broadcast, the request is processed in the given order.

- If the pair, source node address, request-ID is found in the list of recent route requests, the packet is discarded.
- If the hosts address is already listed in the requests route record, then also the packet is discarded ensuring the removal of later copies of the same request that arrive by using the loop.
- When a destination address, in the route request, matches the hosts address, a route reply packet is sent back to the source node containing a copy of this route.
- Otherwise, add this hosts address to the route record field of the route request packet and rebroadcast the packet.

A route reply is obtained in DSR by two ways: Symmetric-links (bidirectional), in which the backward route is followed again to catch the source node. Asymmetric-links (unidirectional) needs to discover the route up to the source node, in the same manner as the forward route is discovered.

Route Maintenance

It can be accomplished by two ways:

a. Hop-by-Hop acknowledgement at the data link layer.

b. End-to-End acknowledgements.

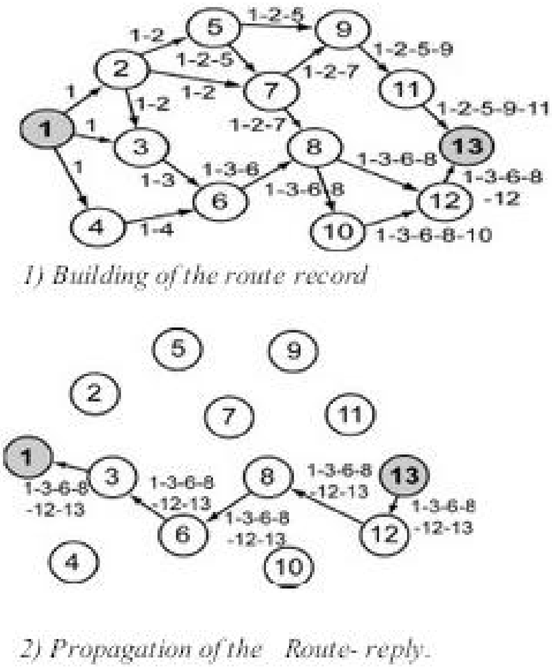

Figure 4.2: DSR Route Discovery Process

The first method allows the early detection and retransmission of lost or corrupt packets in the data-link layer. If a transmission error occurs, a route error packet containing the address of the node detecting the error and the host address, is sent back to the sender. Whenever a node receives a route error packet, the hop in error is removed from the route cache and all routes containing this hop are truncated at that point. When the wireless transmission between two nodes does not work equally well in both directions, then end-to-end replies on the application or transport layer may be used to indicate the status of the route from one host to the other.

4.1.3 Greedy Perimeter Stateless Routing Protocol (GPSR)

Greedy Perimeter Stateless Routing (GPSR) (B., Kung, and T) is one of the best examples of position based routing. GPSR uses closest neighbors information of destination in order to forward packet. This method is also known as greedy forwarding. In GPSR each node has knowledge of its current physical position and also the neighboring nodes. The knowledge about node positions provides better routing and also provides knowledge about the destination. On the other hand neighboring nodes also assist to make forwarding decisions more correctly without the interference of topology information. All information about nodes position is gathered through GPS devices.

GPSR protocol is normally devised in to two groups:

- **Greedy forwarding**: This is used to send data to the closest nodes to destination.
- **Perimeter forwarding**: This is used in such regions where there is no closer node to destination.

In other words can say it is used where greedy forwarding fails. Further will see in detail how these forwarding strategy works and what are issues in them.

Greedy Forwarding

In this forwarding strategy, data packets know the physical position of their destination. As the originator knows the position of its destination node, the greedy regions/hops are selected, to forward the packets to the nodes that are closer to destination. This process repeats until the packet is successfully delivered to the desired destination. Nearest neighbors physical position is gathered by utilizing beaconing algorithms or simple beacons. When a neighboring node forwards a packet to the closer region to destination, the forwarding node receive a beacon message that contains IP address and position information. Then it updates its information in the location table. If forwarding node does not receive beacon from its neighboring node within a specific time period, it assumes that either the neighbor fails to forward packet to region closer to destination or neighbor is not in its radio range. So it removes its entry from location table (B., Kung, and T). The major advantage of greedy forwarding is that it holds current physical position of forwarding node. Thus by using this strategy total distance to destination becomes less and packets can be transmitted in short time period. Besides its advantages there are few drawbacks of this strategy too i.e. there are some topologies used in it, that limits the packet to move to a specific range or distance from the destination. Furthermore, this strategy fails when there are no closer neighbors available to destination.

Perimeter Forwarding

Perimeter forwarding is used where greedy forwarding fails. It means, when there is no next hop or closest neighbor to the destination available, then perimeter forwarding is used. Perimeter forwarding uses nodes in the void region to forward packets towards destination. The perimeter forwarding uses the right hand rule. In right hand rule, the void regions are exploited by traversing the path in counter clockwise direction in order to reach a specific destination. When a packet is forwarded by a source node, it is forwarded in counter clockwise direction including destination node, until it again reaches the source node. According to this rule each node is involved to forward the packet around the void region and each edge that is traversed are called perimeter. Edges may cross when right hand rule finds perimeter that are enclosed in the void by utilizing heuristic approach (B., Kung, and T). Heuristic has some drawbacks but it provides maximum reach ability to destination. The drawback is that it removes without consideration of those edges which are repeated and this may cause the network partitions. To avoid this drawback another strategy is adopted that is described below.

Planarized Graph

When two or more edges cross each other in a single graph it is called planar graph. Relative Neighborhood Graph (RNG) and Gabriel Graph (GG) (B., Kung, and T) are two types of planar graphs used to remove the crossing edges. Relative neighborhood graph (RNG) is defined as, when two edges intersect with radio range of each other and share the same area. For example, x and y are the two edges that share the area of two vertices's x and y. The edge x, y are removed by using RNG because another edge from x towards v is already available Figure-4.3. Gabriel Graph (GG) is used to remove only those crossing edges which are between the shared area of two nodes having the same diameter as the other nodes have. Figure-4.4 depicts GG: shows that the midpoint diameter is less than the diameter of node x or node y. Thus the edge from x, y cannot be removed. So there is less network, disconnection in the GG as compared to RNG.

4.1.4 Features of GPSR

GPSR combines the greedy forwarding with the perimeter forwarding, to provide better routing decision on both full and Planarized network graph, by maintaining neighbor's information in the location table. For the forwarding decisions in perimeter mode, GPSR packet header include the following distinct characteristics (B., Kung,

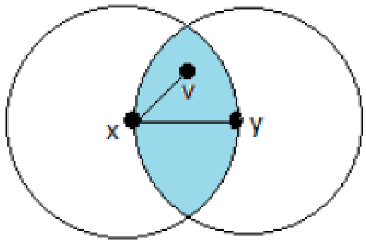

Figure 4.3: Example of RNG

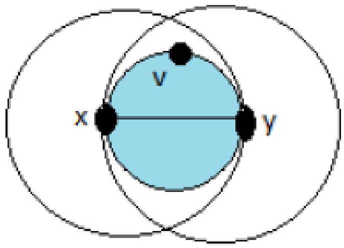

Figure 4.4: Example of GG

and T).

- GPSR packet header has the flag identity that is used to identify whether packet is in greedy forwarding or in perimeter forwarding.
- It contains destination nodes physical address.
- GPSR packet header also contains location of packet in the perimeter mode and the location of the new face, to take a decision whether to hold the packet in the perimeter mode or to return it to the greedy mode.
- GPSR also has the record of sender and receivers address of the packet, when the edges cross in the new face.

GPSR also has several distinct characteristics, that are, if the packet is in perimeter mode then its location address is compared to forwarded node address and if distance between location and destination node is less then packet, it switches to greedy mode to forward packet towards destination. GPSR discards those packets that are repeatedly forwarded as destination, for such packets are not in range. The packets in perimeter mode never send twice, through the same link, if destination is in range. Overall GPSR is an efficient example of the position based routing that uses the geographic location of nodes and reduced usage of routing state on each node. Furthermore, it provides maximum robustness in highly dynamic, wireless ad-hoc networks.

4.1.5 Issue in GPSR

Besides GPSR certain characteristics, it suffers from several drawbacks. Greedy forwarding, is measured as unsuitable for the vehicular networks, where the nodes are highly mobile and the node may not be able to maintain its next hop neighbors information as the other node may have gone out of range, due to high mobility. This can lead to data packet's loss. The second problem may occur during beaconing mechanism that beacons may lose due to channel destruction or bad signal. This problem can lead to removal of neighbor information from location table (Lochert et al., "Geographic routing in city scenarios"). GPSR uses Planarized graphs, as its repair strategy where greedy forwarding fails. But these graphs perform well in the highway scenario, due to their distributed algorithms (Lochert et al., "A routing strategy for vehicular ad-hoc networks in city environments" Kaushikl and P.R.Deshmukh). These graphs do not perform well, in such environment of vehicular communication, where a lot of radio obstacles are involve, in addition to this, their distributed nature may lead to certain partition of network and may lead to packet delivery impossible. Hence there is need of such position based routing protocols, which merge position information with the road's topological structure in order to make possible, vehicular communication in presence of radio obstacles.

4.2 Performance Metrics

4.2.1 Packet Delivery Ratio

Packet delivery ratio is a very important factor to measure the performance of routing protocol in any network. The performance of the protocol depends on various parameters chosen for simulation. The major parameters are packet size, number of nodes, transmission range and the structure of the network. The packet delivery ratio, can be obtained from the total number of data packets arrived at destinations divided by the total data packets sent from sources. In other words Packet delivery ratio is the ratio of number of packets received at the destination to the number of packets sent from the source. The performance is better, when packet delivery ratio is high. Mathematically it can be shown as equation 4.1.

$$PDR = \frac{(\text{Total packets received by all destination node})}{(\text{Total packets send by all source node})} \tag{4.1}$$

4.2.2 Average End-to-End Delay

Average End-to-end delay is the time taken by a packet to route through the network from a source to its destination. The average end-to-end delay can be obtained computing the mean of end-to-end delay of all successfully delivered messages. Therefore, endto-end delay partially depends on the packet delivery ratio. As the distance between source and destination increases, the probability of packet drop increases. The average end-to-end delay includes all possible delays in the network i.e. buffering route discovery, latency, retransmission delays at the MAC, and propagation and transmission delay. Mathematically it can be shown as equation 4.2.

$$D = \frac{1}{n}\sum_{i-1}^{n}(T_{r_i} - T_{s_i}) * 1000 \tag{4.2}$$

4.2.3 Packet Loss Ratio

Packet Loss Ratio, is the ratio of, the number of packets that never reached the destination, to the number of packets originated by the source. Mathematically it can be shown as equation 4.3.

$$PLR = \frac{nSentPackets - nReceivedPackets}{nSentPackets} * 100 \tag{4.3}$$

4.2.4 Packet Loss

Packet Loss, is the ratio of, the number of packets that never reached the destination to the number of packets originated by the source. Mathematically it can be shown as equation 4.4.

$$PL = \frac{(nSentPackets - nReceivedPackets)}{nSentPackets} \tag{4.4}$$

4.2.5 Average Throughput

It is the average of the total throughput. It is also measured in packets per unit TIL. TIL is Time Interval Length. Mathematically it can be shown as equation 4.5.

$$AverageThroughput = (\frac{recvdSize}{(stopTime - startTime)}) * (\frac{8}{1000}) \tag{4.5}$$

Table 4.1: Various parameters used while varying number of connections

Parameter	Value
Protocols	AODV, DSR, GPSR
Number of Nodes	30, 50, 150, 300
Simulation Time	600s
Traffic Type	CBR
Routing protocol	AODV, DSR, GPSR
Transmission Range	250m
Mobility Model	Random Way-point
Simulation area	500 m $\times$ 500 m
Node Speed	20m/s
Pause Time	00s
Interface Type	Queue
MAC Protocol	802.11Ext
Packet Size	512MB
Queue length	50
Radio Propagation Model	Two Ray Ground

Table 4.2: Performance Evaluation for various number of connection using AODV Routing Protocol

Traffic(#nds)	PL(#pkt)	Av.E2E(ms)	PDR(%)	Av.Thput(b/s)	PLR(%)
30	248	120.442	93.6028	240.9	2.890
50	644	131.145	97.5757	278.97	4.908
150	799	130.306	98.1747	240.58	5.999
300	1285	129.825	92.3664	266.87	6.789

Table 4.3: Performance Evaluation for various number of connection using DSR Routing Protocol

Traffic(#nds)	PL(#pkt)	Av.E2E(ms)	PDR(%)	Av.Thput(b/s)	PLR(%)
30	246	127.754	72.8348	218.56	1.590
50	173	74.7002	45.1786	248.55	1.678
150	383	193.11	11.4177	190.18	1.909
300	313	142.524	1.2919	198.33	1.909

4.3 Simulation Setup and Results Analysis

Two On-Demand (Reactive) routing protocols, namely Ad-hoc On-Demand Distance Vector Routing (AODV) and Dynamic Source Routing (DSR) and one Geographical (Position-Based) routing protocols namely Greedy Perimeter Stateless Routing (GPSR) protocol is used. The mobility model used is, Random way-point mobility model, because it models the random movement of the vehicle mobile nodes.

Scenario 1: In this scenario, number of nodes connected in a network, at a particular time is varied and thus the number of connections also varies, through the

Table 4.4: Performance Evaluation for various number of connection using GPSR Routing Protocol

Traffic(#nds)	PL(#pkt)	Av.E2E(ms)	PDR(%)	Av.Thput(b/s)	PLR(%)
30	235	110.750	70.8090	210.56	1.050
50	160	70.7008	40.4567	214.55	1.150
150	280	110.90	10.990	150.90	1.190
300	280	90.00	1.989	140.89	1.190

comparison graph.

Scenario 2: In the second scenario, the total number of vehicle nodes in the network, at a time, remains fixed and pause time of the nodes is varied. Results are as shown in Table 4.5, Table 4.6, Table 4.7 and Table 4.8.

Scenario 3: In the third scenario, the total number of vehicle nodes in the network, at a time, remains fixed and thus speed of the node with which they are moving in the area of 500 m $\times$ 500 m network. Results are as shown in Table 4.9, Table 4.10, Table 4.11 and Table 4.12.

4.4 Result Analysis

The thesis shows, the realistic comparisons of protocols, which are both reactive and position based routing protocol and the simulation results agree based on theoretical analysis. The different scenarios were made in the SUMO and NS-2.34. Run the simulations for 600 s and generate the trace file, from which save the graphs for analysis and calculation as shown above. These graphs are found to be very helpful in the statistical analysis of these routing protocols performance. The required graphs were saved as the bitmap image for statistical analysis.

Scenario1: Number of Nodes Varied: In this scenario, the vehicle nodes were simulated using Ad-hoc On Demand Distance Vector (AODV), Dynamic Source Routing Protocol (DSR) and GPSR routing protocol using CBR traffic application which were

Table 4.5: Various parameters used while different pause time in the network

Parameter	Value
Protocols	AODV, DSR, GPSR
Number of Nodes	200 with 100 connections
Simulation Time	600s
Traffic Type	CBR
Routing protocol	AODV, DSR, GPSR
Transmission Range	250m
Mobility Model	Random Way-point
Simulation area	500m × 500 m
Node Speed	10m/s
Pause Time	50s,100s, 150s, 200s, 250s, 300s
Interface Type	Queue
Mac Protocol	802.11Ext
Packet Size	512MB
Queue length	64
Radio Propagation Model	Two Ray Ground

Table 4.6: Performance Evaluation for different pause time using AODV Routing Protocol

Time(s)	PL(#pkt)	Av.E2E(ms)	PDR(%)	Av.Thput(b/s)	PLR(%)
50	1157	163.395	87.1369	204.97	2.890
100	995	104.604	92.892	452.67	2.345
150	1372	204.393	88.6116	248.94	2.134
200	1037	72.9835	92.1389	415.84	1.567
250	1355	101.22	95.859	608.61	1.456

Table 4.7: Performance Evaluation for different pause time using DSR Routing Protocol

Time(s)	PL(#pkt)	Av.E2E(ms)	PDR(%)	Av.Thput(b/s)	PLR(%)
50	541	140.519	2.96298	87.66	2.1890
100	754	227.774	6.31215	156	2.0981
150	1350	179.826	10.4053	117.3	1.8909
200	525	145.887	13.7914	221.97	1.7898
250	1434	208.651	35.0666	356.86	1.5678

Table 4.8: Performance Evaluation for different pause time using GPSR Routing Protocol

Time(s)	PL(#pkt)	Av.E2E(ms)	PDR(%)	Av.Thput(b/s)	PLR(%)
50	450	130.908	2.45689	78.99	2.1345
100	680	234.900	2.56756	123	1.23474
150	590	139.080	8.76543	112.77	1.4568
200	300	123.879	9.78645	123.67	1.2349
250	560	178.094	15.6754	234.56	1.1230

checked by different parameters such as E2E Delay, Packet Delivery Ratio, Packet Loss Ratio, Throughput etc. Graph show the Packet Delivery Ratio(%). The x-axis denotes the number of nodes and y-axis is PDR(%).

- **E2E Delay**: Performance of DSR increases and then decreases with increasing number of vehicle nodes, but the delay decreases with increasing number of vehicle nodes for GPSR network. For AODV, it varied with increasing number of vehicle nodes.

- **Packet Loss**: With increasing number of vehicle nodes, AODV show worst-performance, It remains same for all less number of vehicle nodes, but with increasing vehicle nodes AODV show maximum packet loss.

- **Packet Delivery Ratio**: Performance of AODV remains constant for increasing number of vehicle nodes, whereas performance of GPSR is better than DSR.

- **Throughput**: The performance of AODV, DSR and GPSR remains almost constant for increasing number of vehicle nodes but GPSR and DSR shows better than AODV.

- **Packet Loss Ratio**: With the increasing vehicle nodes AODV show maximum packet loss.

Table 4.9: Various parameters used while varying mobility of the vehicle nodes i.e. speed of the nodes in the network

Parameter	Value
Protocols	AODV, DSR, GPSR
Number of Nodes	200 with 100 connections
Simulation Time	600s
Traffic Type	CBR
Routing protocol	AODV, DSR, GPSR
Transmission Range	250m
Mobility Model	Random Way-point
Simulation area	500m × 500m
Node Speed	10m/s, 30m/s, 50m/s, 70m/s, 90m/s
Pause Time	10s
Interface Type	Queue
Mac Protocol	802.11Ext
Packet Size	512MB
Queue length	50
Radio Propagation Model	Two Ray Ground

Table 4.10: Performance Evaluation for different vehicle speed using AODV Routing Protocol

Speed(Km/h)	PL(#pkt)	Av.E2E(ms)	PDR(%)	Av.Thput(b/s)	PLR(%)
10	1157	163.395	87.1639	204.87	42.5789
30	908	176.577	90.6245	249.17	10.678
50	954	323.638	88.1336	182.41	2.3456
70	1225	118.265	91.5398	327.57	2.4567
90	993	142.934	88.6138	217.87	1.5678

Table 4.11: Performance Evaluation for different vehicle speed using DSR Routing Protocol

Speed(Km/h)	PL(#pkt)	Av.E2E(ms)	PDR(%)	Av.Thput(b/s)	PLR(%)
10	541	140.519	2.95298	86.66	2.4567
30	127	159.535	0.18956	75.78	10.903
50	331	56.067	0.15583	52.18	1.2456
70	207	108.879	0.25082	53.29	2.3456
90	124	107.668	0.03373	11.02	2.5567

Table 4.12: Performance Evaluation for different vehicle speed using GPSR Routing Protocol

Speed(Km/h)	PL(#pkt)	Av.E2E(ms)	PDR(%)	Av.Thput(b/s)	PLR(%)
10	528	135.900	1.8900	87.00	2.900
30	110	167.900	0.7829	72.00	11.780
50	135	78.900	0.6790	45.89	1.8902
70	178	108.890	0.1890	42.90	2.1900
90	109	107.099	0.1900	10.90	1.2899

Scenario 2: Pause Time Varied:

- **E2E Delay**: AODV serves the best among all the protocols.
- **Packet Loss**: GPSR outperforms all other protocols under all conditions.
- **Packet Delivery Ratio**: GPSR performance is better than AODV and DSR routing protocol.
- **Throughput**: GPSR outperforms the other two protocols but AODV shows better performance than DSR routing protocol.
- **Packet Loss Ratio**: GPSR outperforms all other protocols under all conditions.

Scenario 3: Mobility of nodes is varied:

- **E2E Delay**: AODV performs constantly when speed of node changes whereas GPSR performs better than DSR.
- **Packet Loss**: GPSR and DSR performance, better than AODV.
- **Packet Delivery Ratio**: DSR performs constantly under all conditions whereas AODV performs better than both GPSR and DSR.

- **Throughput**: DSR performance well under all conditions but GPSR performs better than AODV.

- **Packet Loss Ratio**: GPSR and DSR performance, better than AODV.

4.5 Summary

AODV shows the best performance with its ability to maintain connection by periodic exchange of information required for TCP network. AODV performs best in case of packet delivery ratio and GPSR outperform others in case of throughput. Varying pause time, GPSR outperform others in case of packet loss and throughput, but overall AODV outperforms GPSR and DSR as in high mobility, environment topology change rapidly and AODV can adapt to the changes, but after taking everything into account GPSR is better than others. At higher node mobility, AODV is worst in case of packet loss and throughput but performs best for packet delivery ratio, GPSR performs better than AODV for higher node mobility, in case of end-to-end and throughput, but DSR performs best in case of packet loss. Hence, for real time traffic GPSR is preferred over DSR and AODV. Finally, from the above research work performance of AODV is considered best for Real-time and TCP network.

Chapter 5

Vehicular Ad-hoc Networks Mobility Model

To get accurate results from the simulations of the designed applications and protocols, the analytical analysis and simulation setup should be built on a realistic mobility model that involve all constraints and facilities related to vehicular movement on Mumbai-Pune Express Highway Road. Therefore, in this chapter we discuss related to analysis and simulation results in Chapter 4 the communication range in vehicular environment is studied. Moreover, a new mobility model will be built, that takes into account the vehicles follow-on safety rule on Mumbai-Pune Express Highway India, too accurately derive the relationship between vehicle's speeds, position and network density. Researcher also derives the distribution of vehicles on Mumbai-Pune Express Highways Road which affects the link availability and duration of connection between vehicles in cluster network formation. It also determines the size of vehicles present within the cluster for communication and the number of vehicles in the two interfering (hidden terminal) cluster areas.

5.1 Introduction and Related Work

The mobility model is a crucial part in analyzing and testing VANET. Modeling vehicle's mobility is quite challenging since the movement of each vehicle is constrained by many factors such as the road topology, neighbor vehicle's movements, the information advertised on the messaging signs along the road, and the drivers' reactions to these factors. In (Wegener et al., "TraCI: An interface for coupling road traffic and network simulators"), a set of movement changes is introduced such as changing lanes, slowing down or even change routes, to allow a micro-mobility behavior control. Other models, such as (Choffnes and Bustamante), studied driver reactions based on the movement of the neighboring vehicles.

In the literature, there are many studies on network connectivity, for example (Jin and Recker)-(Yousefi et al.).Most of these studies are based on the assumption that nodes have stationary distribution. In (Jin and Recker), the authors present an analytical model for multi-hop connectivity assuming that vehicles positions are known either by simulations or observations. They assume the propagation of information is instantaneous with respect to vehicle movement. In (Khabazian and Ali), the authors derived a mobility model for VANETs considering the arrival of vehicles to a service area as a Poisson distribution without including the follow-on safety rule. In (Ghasemi and Nader-Esfahani) and (Desai and Manjunath), the authors derived the probability of connectivity assuming a uniform stationary distribution of nodes in the network. While in (Saoud, Al-Zubaidy, and Mahmoud), an upper bound of the connectivity probability, for a triangular lattice topology is derived, the authors in (Yousefi et al.) studied the connectivity of VANETs considering only the free-flow state in a low density network. They used the common homogeneous Poisson model in vehicular traffic theory, in which the inter arrival times between vehicles are exponentially distributed, without deriving the relationship between network density and vehicle's average speed. They assume that vehicle speed does not change over time, which is referred to as the constant speed model.

Many surveys of VANETs mobility models have been conducted, such as in (Harri, Filali, and Bonnet) and (Martinez et al.). They all agreed, that mobility models have to be adaptable to all factors mentioned above to realistically characterize vehicle movements on the road. In (Sommer and Dressler), the authors argued that, coupling more than one simulator is an important step towards a realistic vehicular ad-hoc network mobility model. In (Sommer, German, and Dressler), the authors discussed, the need for bidirectional coupling of network simulation and road traffic micro simulation for evaluating Vehicle-to-Vehicle Communication protocols. They developed the hybrid simulation framework Veins (Vehicles in Network Simulation), which is composed of the network simulator OMNeT++ (OMNeT++) and the road traffic simulator SUMO. Therefore, coupling the MOVE (Karnadi, Mo, and Lan) mobility model, with the micro-traffic simulator SUMO (Krajzewicz et al.), that produces, realistic vehicle movement traces for the network simulator NS-2.34, could exhibit the real vehicle movement on the road.

5.2 Communication Range

Since vehicular ad-hoc networks have many moving and stationary objects that can reflect, scatter, diffract or even block the signal, the received signal by any vehicle is composed of many reflected signals with randomly distributed amplitudes and phases. Recently, many researches have paid more attention to the vehicle-to-vehicle (V2V) channel propagation models. In (Hafeez et al., "The optimal radio propagation model in VANET"), researches showed that VANETs fading channel could be characterized by a Rician distribution for short distances and tends toward Rayleigh distribution for large distances. Therefore, the Nakagami fading distribution, whose parameters can be adjusted to fit a variety of empirical measurements and can model Rayleigh and Rician distributions is used. The Nakagami model has a probability density function (*pdf*) of the received signal power (x) (Proakis and Salehi) as

$$P_{z^2}(x) = (\frac{m}{P_r})^m \frac{x^{m-1}}{\Gamma(m)} e^{-\frac{mx}{P_r}}, for x > 0, \tag{5.1}$$

where $\Gamma(.)$ is the Gamma function, $P_r = \frac{P_t K}{r^\alpha}$ is the average received power, r is the distance in meters, α is the path loss exponent, $K = G_t G_r (\frac{C}{4\pi f_c})^2$, C is the speed of light, $f_c = 5.9GHz$ is the carrier frequency, G_t and G_r are the transmitters and receiver's antenna gains respectively and m is the fading factor. For $m = 1$, the Nakagami distribution reduces to Rayleigh and for $m = \frac{(k+1)^2}{2k+1}$, it approximates a Rician distribution with parameter k which is the ratio of power in the line-of-sight to the power in the non line-of-sight.

From (7.1), Calculate the CDF of the communication range, following the same approach as in (Miorandi and Altman), when the received power is greater than the threshold P_{th} as

$$\begin{aligned} F_R(r) &= 1 - P(x > P_{th}) \\ &= 1 - \int_{p_{th}}^{\infty} P_{Z^2}(x) dx \end{aligned} \tag{5.2}$$

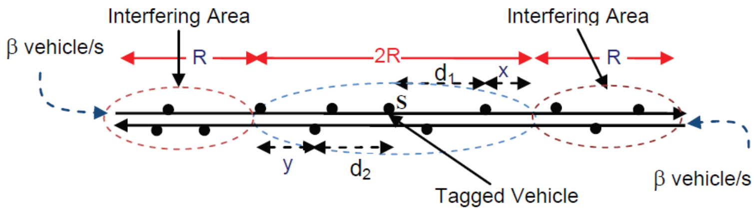

Figure 5.1: Simplified one dimensional highway scenario in each direction of the road.(Hafeez et al., "The optimal radio propagation model in VANET")

Substituting (5.1) in (5.2) and some manipulation, the CDF can be written as

$$F_R(r) = 1 - (\frac{m}{P_r})^m \frac{1}{\Gamma(m)} \int_{P_{th}}^{\infty} x^{m-1} e^{-\frac{mx}{P_r}} dx$$

$$F_R(r) = 1 - \frac{1}{\Gamma(m)} \sum_{i=0}^{m-1} \frac{(m-1)!}{(m-1-i)!} (\frac{mP_{th}}{P_r})^{m-1-i} e^{-\frac{mP_{th}}{P_r}} \tag{5.3}$$

The average value of the communication range $E[R]$ can be derived as

$$E[R] = \int_0^{\infty} (1 - F_R(r)) dr \tag{5.4}$$

Substituting (5.3) in (5.4) and integrating over the limits,

$$E[R] = \overline{R} = \frac{1}{\alpha\Gamma(m)} \sum_{i=0}^{m-1} \frac{(m-1)!}{(m-1-i)!} \Gamma(m-1-i+\frac{1}{\alpha})(\frac{mP_{th}}{P_t K})^{-\frac{1}{\alpha}} \tag{5.5}$$

To derive the average carrier sense range ($E[LCS]$) where nodes can sense the message but can not receive it, the same procedure as in (5.5) is followed except for the received power threshold (PCS), which will be defined as a percentage of the threshold P_{th} as

$$P_{CS} = \rho P_{th} \tag{5.6}$$

where $\rho \in [0, 1]$. Therefore, the expected carrier sense range will be

$$E[L_{CS}] = \frac{ER}{\sqrt[\alpha]{P}} \tag{5.7}$$

In the following, researcher may use interchangeably $\overline{R}$ or R to represent the average communication range, and $E[L_{CS}]$ or L_{CS} to represent the average carrier sense range. It is also assumed that the communication range covers the width of the road.

5.3 Mobility Model

The proposed vehicular ad-hoc network mobility model (Hafeez et al., "Impact of mobility on VANETs safety applications"), is built based on a one way multi-lane highway segment. In vehicular ad-hoc networks, the communication range is much larger than the width of the road, therefore, the network in each direction of the road is simplified as a one dimensional vehicular ad-hoc network as shown in Figure 5.1. Vehicles will follow the direction of the road with a speed uniformly distributed between V_{min} and V_{max} with mean $\mu = \frac{v_{min}+v_{max}}{2}$ and variance $\sigma^2 = \frac{(v_{max}v_{min})^2}{12}$. In this model, researchers are interested in the distribution of vehicles on the road, number of vehicles (N_c) around the transmitter (contention region) and the number of vehicles (N_h) in the hidden terminal areas (interference region).

In this model, an arbitrary starting point of the highway is first defined, and the number of vehicles that cross the starting point in each lane (assume the road has N_l lanes) is modeled as Poisson process, with average rate β_i vehicles/s for the i_{th} lane, such that the total number of vehicles per second that cross that point is

$$\beta = \sum_{i=1}^{N_l} \beta_i \tag{5.8}$$

Empirical studies (Roess, Prassas, and Mcshane) show that the Poisson process is sufficiently accurate assumption for modeling, vehicles arrival process, in a highway scenario. It is assumed that vehicles move independently of each other; hence, the total distance that a vehicle travels during an interval of $(0, t)$ approaches a normal distribution and the inter-distance between two vehicles crossed that point with time difference τ_d also has normal distribution. For more details, this model is published in (Hafeez et al., "Impact of mobility on VANETs safety applications").

To find the probability of having N_c vehicles, within the range of any tagged vehicle, the mobility model in (McDonald and Znati) is extended, to include the minimum safety distance between vehicles in each lane (t_s seconds rule). This means that the following vehicle, which is traveling with speed V_j , has to keep a safe distance (d_{th}) from the vehicle in front, such that $d_{th} > V_{jts}$ to avoid an accident if the vehicle in front stops suddenly. This minimum distance is a random variable and depends on the following vehicle's speed V_j if a fixed t_s is assumed, which is the response time, for a driver to react in a sudden incident. Moreover, the following two cases are considered: low density and high density networks.

5.4 Low Density Network

In this case, assume that the number of vehicles that cross the defined reference point is small, such that the inter arrival time ($\tau_d = \frac{1}{\beta_i}$) between vehicles in the i_{th} lane is larger than t_s. Therefore, in this case, the safety distance does not appear in the analysis, since the distance between vehicles is assumed to be larger than the safety distance.

The movement of each vehicle will follow the direction of the road and consists of a sequence of random length intervals that have an exponential distribution with mean $\frac{1}{\alpha}$. Therefore, the distribution of the number of mobility intervals M(t) is a Poisson process with mean αt. During each interval, each vehicle selects a random constant speed from the interval $[v_{min}, v_{max}]$. Therefore, during an interval m of length Tm, the vehicle n travels a distance $D^n_m = v^n_m \cdot T^n_m$, where v^n_m is the speed of vehicle n in the interval T_m. Considering, vehicles have the same mobility model, therefore, the superscript n can be eliminated. The speed of all vehicles during each interval is modeled by uniform distribution with mean $\mu = \frac{v_{min}+v_{max}}{2}$ and variance $\sigma^2 = \frac{(v_{max} v_{min})^2}{12}$. Assume that vehicles move independently of each other, this means that drivers can choose any speed from $[v_{min}, v_{max}]$ within any interval and always there is a possibility of change of lane.

Since the average number of intervals during the time $[0, t]$ is $\alpha t \gg 1$, the total distance that a vehicle travels during this interval is

$$D(t) = \sum_{m=1}^{M(t)} D_m = \sum_{m=1}^{M(t)} v_m \cdot T_m \tag{5.9}$$

It is clear that $D(t)$ is a compound Poisson process that has mean and variance as in (Kleinrock and Systems).

$$E[D(t)] = \alpha t E[v_m \cdot T_m] = \frac{v_{min} + v_{max}}{2} t = \mu t, \tag{5.10}$$

$$Var[D(t)] = \alpha t E[(v_m \cdot T_m)^2] = \frac{2t}{\alpha}(\sigma^2 + \mu^2) \tag{5.11}$$

As t increases, $D(t)$ approaches a normal distribution with the same mean $E[D(t)]$ and variance $Var[D(t)]$.

To find the neighboring probability, i.e. the probability of having k vehicles within the range of any tagged vehicle, a reference vehicle is defined to arrive at the starting point of the highway at $t = 0$. The arrival event is denoted by $A(0)$. If a vehicle arrives at the same point a period of time τ after the reference vehicle, then the mean and variance of its distance at time t will be

$$E[D(t-\tau)] = \alpha(t-\tau)E[v_m \cdot T_m] = \frac{v_{min} + v_{max}}{2}(t-\tau) = \mu(t-\tau) \tag{5.12}$$

$$Var[D(t-\tau)] = \alpha(t-\tau)E[v_m \cdot T_m)^2] = \frac{2(t-\tau)}{\alpha}(\sigma^2 + \mu^2) \tag{5.13}$$

Hence, their inter-distance $D_d = D(t) - D(t-\tau)$ has also a normal distribution with mean and variance as

$$E[D_d] = \mu_d(\tau) = \mu\tau, \tag{5.14}$$

$$Var[D_d] = \sigma_d^2(\tau) = \frac{2(2t-\tau)}{\alpha}(\sigma^2 + \mu^2) \tag{5.15}$$

If n vehicles arrived in the period of $[0, t]$ and since each arrival time is uniformly distributed over this interval, then the conditional probability $P_{\overline{R}}(t \mid A(0))$ that a vehicle is within the range of the reference vehicle at time t conditioned on that the reference vehicle arrived at $t = 0$ is

$$P_{\overline{R}}(t \mid A(0)) = \frac{1}{t}\int_0^t \int_{-\overline{R}}^{\overline{R}} \frac{1}{\sqrt{2\pi\sigma_d^2}} \exp^{-\frac{(x-\mu_d)^2}{2\sigma_d^2}} dx d\tau. \tag{5.16}$$

Let $N(t)$ denote the number of vehicles at time t within the range $\overline{R}$ of the reference vehicle given that n arrivals, then the conditional probability of having k vehicles within this range in the i_{th} lane at time t can be derived as

$$P_k(t \mid A(0)) = P(N(t) = k)$$

$$P_k(t \mid A(0)) = \sum_{n=k}^{\infty} P[N(t) = k \mid narrivalsin(0,t)] \frac{e^{-\beta_i t}(\beta_i t)^n}{n!} \tag{5.17}$$

Because each vehicle from the n arrivals will be within the range of the reference vehicle at time t according to independently identically distributed Bernoulli trials, then the probability of having k vehicles within the range is

$$P[N(t) = k \mid narrivalsin(0,t)] = (\frac{n}{k})(P\overline{R}(t \mid A(0)))^k (1 - P\overline{R}(t \mid A(0)))^{n-k} \tag{5.18}$$

By substituting (5.18) in (5.17), then

$$P_k(t \mid A(0)) = P(N(t) = k) = \frac{[\beta_i t P_{\overline{R}}(t \mid A(0))]^k}{k!} e^{-\beta_i t P_{\overline{R}}(t)} \tag{5.19}$$

Equation (5.19) shows that the number of vehicles within the reference vehicle's range can be modeled by a Poisson process with parameter ($= \beta_i t P_{\overline{R}}(t)$). Therefore, the average number of vehicles that arrive after the reference vehicle and stay within its range at the steady state is

$$\phi = \beta_i \lim_{t\to\infty} tP_{\overline{R}}(t \mid A(0))$$

$$\phi = \beta_i \lim_{t\to\infty} \int_0^t \int_{-\overline{R}}^{\overline{R}} \frac{1}{\sqrt{2\pi \frac{2(2t-\tau)}{\alpha}(\sigma^2+\mu^2)}} e - \frac{(x-\mu\tau)^2}{2\frac{2(2t-\tau)}{\alpha}(\sigma^2+\mu^2)} dx d\tau \tag{5.20}$$

substituting $y = 2t - \tau$ yields

$$\phi = \beta_i \lim_{t\to\infty} \int_{-\overline{R}}^{\overline{R}} \int_t^{2t} \frac{1}{\sqrt{2\pi \frac{2y}{\alpha}(\sigma^2+\mu^2)}} e - \frac{4\mu^2 y}{2\frac{2}{\alpha}(\sigma^2+\mu^2)} dy dx \tag{5.21}$$

Let $z = \sqrt{\frac{4\mu^2 y}{\frac{2}{\alpha}(\sigma^2+\mu^2)}}$ and take the limit to infinity

$$\phi = \beta_i \frac{1}{\mu} \int_{-\overline{R}}^{\overline{R}} \int_0^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}} dz dx = \frac{\beta_i \overline{R}}{\mu} \tag{5.22}$$

Proposition 1 *For vehicles that arrive before the reference vehicle, the probability that, a vehicle falls within the reference vehicles range is the same as in (5.16) and the probability of having k vehicles from n vehicles that arrive before the reference vehicle to be within its range is the same as in (5.19).*

To prove this, follow the same approach as in the previous case assuming that a vehicle arrives in time τ before the tagged vehicle. Therefore, its distance from the reference vehicle has a mean of $_d = -\tau$ and variance of $\alpha_d^2 = \frac{2(2t+\tau)}{\alpha}(\sigma^2 + \mu^2)$. Since $\tau \in [-\infty, 0]$ in this case and by substituting this mean and variance in (5.16), the result will be the same as (5.19). Since the sum of two independent Poisson processes is a Poisson process with rate equal to the sum of their rates, then the conditional probability of having k vehicles within the range of the reference vehicle and moving in the same direction at the steady state is:

$$P_{2\overline{R}}(k \mid A(0)) = \frac{(\frac{2\beta_i \overline{R}}{\mu})^k}{k!} e^{-\frac{2\beta_i \overline{R}}{\mu}} \tag{5.23}$$

Proposition 2 *Let the probability of having k vehicles within a range of $2\overline{R}$ from one direction at any time be denoted as $P_{2\overline{R}}(k)$, then $P_{2\overline{R}}(k) = P_{2\overline{R}}(k \mid A(0))$.* Due to the memory less property of the Poisson process, $P_{2\overline{R}}(k \mid A(0)) = P'_{2\overline{R}}(k)P(A(0))/P(A(0)) =$

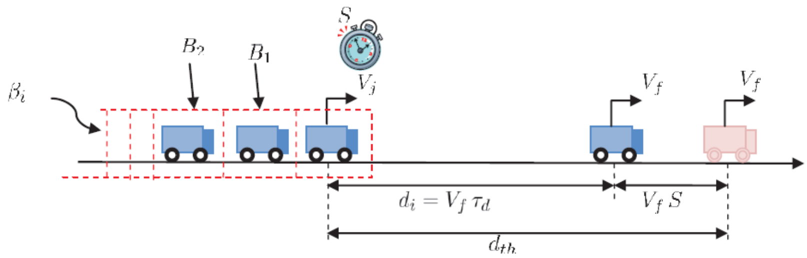

Figure 5.2: Single server queue model.(Hafeez et al., "The optimal radio propagation model in VANET")

$P'_{2\overline{R}}(k)$ Therefore, in this case the probability of having $N_{ci} = k$ vehicles within the communication range of the tagged vehicle (that is within a distance of $2\overline{R}$) in the ith lane is

$$P_{2\overline{R}}(N_{ci} = k) = \frac{(\frac{2\beta_i\overline{R}}{\mu})^k}{k!} e^{\frac{2\beta_i\overline{R}}{\mu}} \tag{5.24}$$

and the average number of vehicles around the tagged vehicle in the ith lane is

$$\overline{N_{ci}} = \frac{2\beta_i\overline{R}}{\mu} \tag{5.25}$$

The probability of having $N_{hi} = k$ vehicles within the carrier sense range of the tagged vehicle is

$$P_{2L_{cs}}(N_{hi} = k) = \frac{(\frac{2\beta_i\overline{R}}{\mu\sqrt[\alpha]{\rho}})}{k!} e^{-\frac{2\beta_i\overline{R}}{\mu\sqrt[\alpha]{\rho}}} \tag{5.26}$$

5.5 High Density Network

In this case, the number of vehicles that cross the reference point is so large that the inter arrival time between two following vehicles is less than the safety time t_s. As a consequence, the inter distance between two neighboring vehicles in one lane is less than the threshold distance as

$$d_i = V_f \tau_d < V_j t_s \tag{5.27}$$

whereV_f andV_j are the speeds of in front and following vehicle, on the i_{th} lane, respectively. In this case, the following vehicle has to reduce its speed in order to avoid an accident. To derive an expression for this reduction in speed, the system is modeled as a single server, Poisson arrival queue as shown in Figure 5.2.

A vehicle is immediately served if the server is empty and its service time(S) will be $(S + \frac{1}{\beta_i}) \times V_f = V_j t_s$ and therefore

$$S = \frac{V_j}{V_f} t_s - \frac{1}{\beta_i} \tag{5.28}$$

On the other hand, if a vehicle finds another one is being served (i.e. reducing its speed to maintain the threshold distance), the new vehicle should wait in the queue for time B_1 until the first one finishes the service (that is, the distance which the vehicle traveled equals d_{th}). If another vehicle arrives during the time (S), it will wait in queue until all vehicles in front of it have been served, that is, the distance between any two neighboring vehicles is at least equal to d_{th}. After that, vehicles would move according to new speed limits which reflects this increase in the inter distances between vehicles. Since the arrival time is Poisson with rate β_i, the number of vehicles ($N(s)$) that will arrive during the time S has Poisson distribution and the server busy time can be modeled as

$$B = S + \sum_{i=1}^{N(S)} B_i \tag{5.29}$$

However, for given S, $\sum_{i=1}^{N(S)} B_i$ is a compound Poisson distribution and its mean $E[B]$ can be derived as

$$E[B] = \frac{E[S]}{1 - \beta_i E[S]}, \tag{5.30}$$

where $E[\cdot]$ is the expected value. To derive $E[S]$, it is seen from (7.28) that S has a ratio distribution and its mean value is

$$E[S] = E[\frac{V_j}{V_f}] t_s - \frac{1}{\beta_i} \tag{5.31}$$

Define a random variable $Z = \frac{V_j}{V_f}$ which has values in the interval $(\frac{V_{min}}{Vmax}, \frac{V_{max}}{V_{min}})$; hence the pdf of Z can be divide as

$$\begin{aligned} f_Z(Z) = \frac{1}{2(V_{max} - Vmin)^2}(V_{max}^2 - \frac{V_{min}^2}{Z^2}), \frac{V_{min}}{V_{max}} < Z \leq 1 \\ \frac{1}{(V_{max} - Vmin)^2}(\frac{V_{max}^2}{Z^2} - V_{min}^2), 1 < Z \leq \frac{V_{max}}{V_{min}} \end{aligned} \tag{5.32}$$

Therefore, $E[Z]$ can be derived as

$$E[Z] = \frac{V_{max} + V_{min}}{2(V_{max} - Vmin)} \ln(\frac{V_{max}}{V_{min}}) \tag{5.33}$$

Substituting (5.33) in (5.31),

$$E[S] = \frac{V_{max} + Vmin}{2(V_{max} - V_{min})} \ln(\frac{V_{max}}{V_{min}})t_s - \frac{1}{\beta_i} \tag{5.34}$$

Substituting (5.34) in (5.30), the average server busy time is

$$E[B] = \frac{\frac{V_{max}+V_{min}}{2(V_{max}-V_{min})} \ln(\frac{V_{max}}{V_{min}})t_s - \frac{1}{\beta_i}}{1 - \beta_i[\frac{V_{max}+V_{min}}{2(V_{max}-V_{min})} \ln(\frac{V_{max}}{V_{min}})t_s - \frac{1}{\beta_i}]} \tag{5.35}$$

Equation (5.35) represents the average time that a vehicle will wait in the queue, such that the inter distance between two following vehicles, in one lane, is greater than or equal to the threshold distance d_{th}. To reflect this waiting time in the real scenario on the road, vehicles in our model will reduce their speed proportionally with $E[B]$ which is normalized by the average number of vehicles within the range $\mu_n = \frac{\beta_i \overline{R}}{\mu}$. The more the waiting time, the more is reduction in the average speed of all the following vehicles until it reaches zero speed, defined as a jam state. In this state vehicles will come to a complete stop or move in a speed close to zero. Therefore, it is assumed that each vehicle occupies a space of 10 *meters* on average and this is the maximum vehicle density a road lane can handle. The new speeds and their mean, as a function of their old values, are given respectively as

$$V_{max_{[new]}} = Vmax_{[old]} e^{-\varepsilon \frac{E[B]}{\mu_n}}, \tag{5.36}$$

$$V_{min_{[new]}} = Vmin_{[old]} e^{-\varepsilon \frac{E[B]}{\mu_n}}, \tag{5.37}$$

$$\mu_{new} = \frac{V_{max_{[new]}} + V_{min_{[new]}}}{2}, \tag{5.38}$$

where $\varepsilon \in (0, 1)$ is the fraction of vehicles that follow, the following distance safety rule. For example, if $\varepsilon = 0.8$, this means that 80% of the drivers on the road will follow this rule. This percentage will vary from country to country and from city to city, even each lane on a road could have a different value.

From the new values of the maximum and minimum vehicle speeds in (5.36) and (5.37), respectively, it is required to calculate a new value of $E[S]$ as $E[S]_{new}$ and substitute it in Equation (5.35) to calculate a new value of $E[B]$ as $E[B]_{new}$. The new distribution of vehicles will be a new Poisson but with different mean $\frac{2\overline{R}\beta_i}{\mu_{new}}$ if the condition $\beta_i E[S]_{new} < 1$ is satisfied. Otherwise, the road reaches the jam state.

Therefore, the average number of vehicles (N_{ci}) within the communication range of any tagged vehicle in the i_{th} lane will be

$$N_{c_i} = \frac{2\overline{R}\beta_i}{\mu}, E[s] = 0$$
$$\frac{2\overline{R}\beta_i}{\mu_{new}}, E[S] \neq 0, \beta_i E[S]_{new} < 1$$
$$\frac{2\overline{R}}{10}, E[S] \neq 0, \beta_i E[S]_{new} > 1 \quad (5.39)$$

The vehicles arriving rate and average speed, could vary from lane to lane. The left most lane could have higher average speed and arriving rate, than the right most lane. To find the total number of vehicles within the communication range of the transmitter, one can use (5.39) to calculate the number of vehicles N_{c_i} in each lane and sum them all such that $N_c = \sum Nl_{i=1} N_{c_i}$. Without loss of generality, assuming that all lanes have the same arriving rate and average speed, then the total number of vehicles that are located within the range of the transmitter is

$$N_c = \frac{2\overline{R}\beta}{\mu}, E[s] = 0$$
$$\frac{2\overline{R}\beta}{\mu_{new}}, E[S] \neq 0, \beta E[S]_{new} < 1$$
$$\frac{2\overline{R}}{10} N_l, E[S] \neq 0, \beta E[S]_{new} \geq 1 \quad (5.40)$$

5.6 Mobility Model Validation

In this section, researcher used the NS-2.34 simulation setup. In this setup, researcher is interested in the number of vehicles within the communication range of the tagged vehicle.

To compare the accuracy of the proposed mobility model, with mobility models based on Poisson distribution, the average number of vehicles within the transmitter range is plotted in Figure 5.3 as a function of the vehicles arriving rate. Note that the Poisson models do not take into account the follow-on safety rule, the increase in vehicles arriving rate, or the maximum road capacity. From the numerical results in Figure 5.3, it is shown that the proposed model, is more accurate in predicting the number of vehicles around the transmitter than other models that use only one Poisson distribution. It can be seen that, as the number of vehicles arriving at

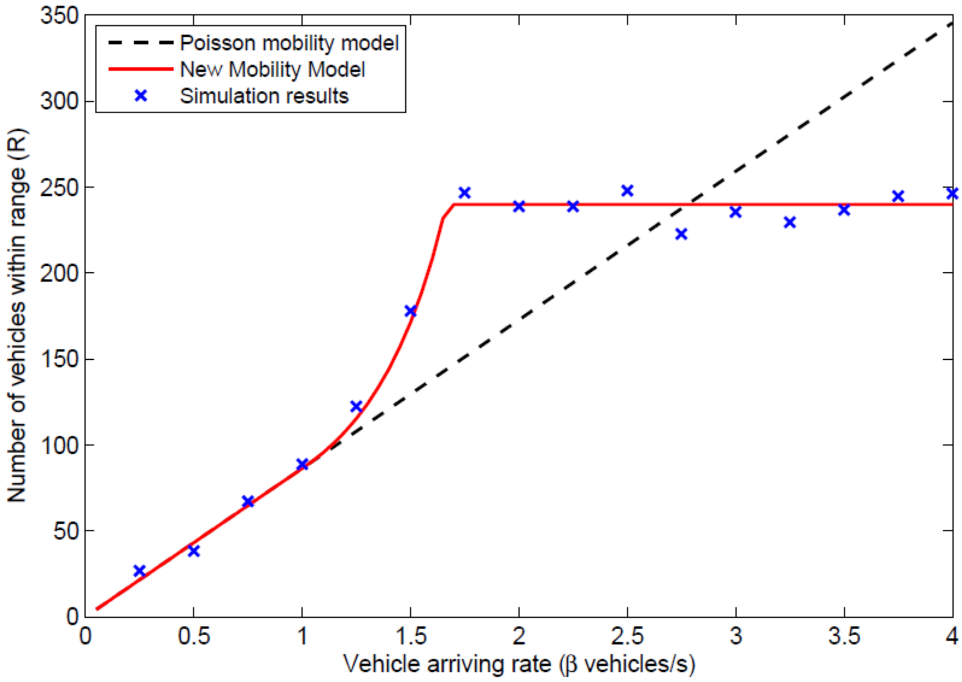

Figure 5.3: Number of vehicles within the communication range of the transmitter.

the reference point increases, the number of vehicles will start to deviate from the conventional model assumption, until it reaches a point where it stays constant. This is the jam scenario case, where vehicles start to backlog on the road, decreasing the inter distance between them, as a result of decreasing their speed. This is also obvious from Figure 5.4 which shows how vehicles average speed and density are affected by the increase of their arrival rate.

5.7 Summary

In this chapter, we derived the communication range and the carrier sense range based on the physical wireless channel analysis and the propagation model that best characterize vehicular ad-hoc networks as conducted in Chapter 3. We also introduced a new mobility model in which the relationship between vehicle density, speed and the follow-on distance rule is derived. The model is accurate in deriving the number of vehicles within the communication range as shown in the simulation results. These results will help in designing and analyzing all proposed algorithms and protocols.

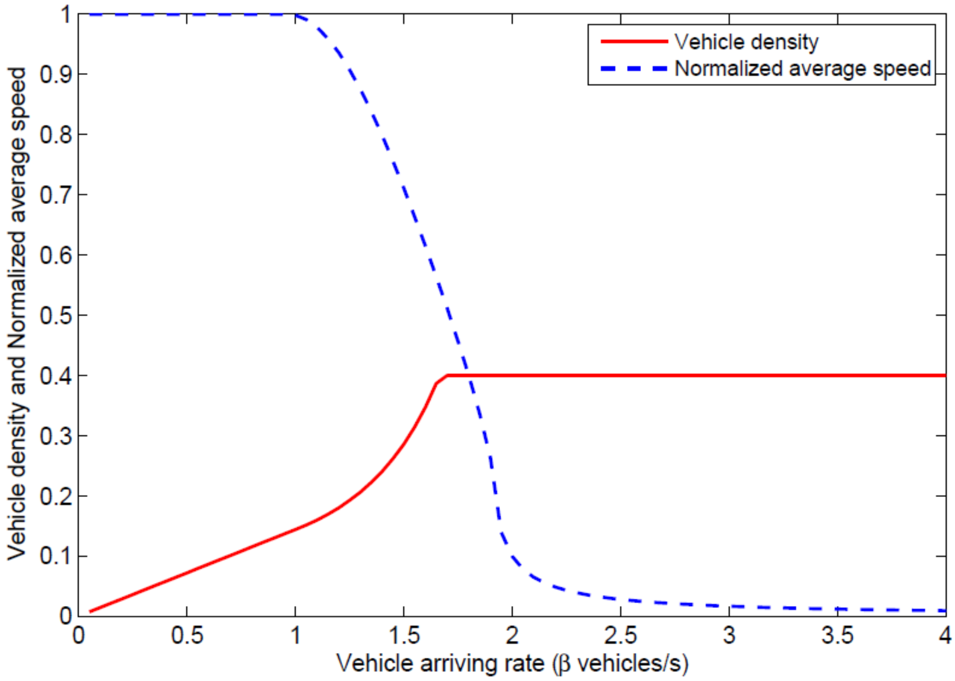

Figure 5.4: Vehicle density and their normalized average speed vs vehicle arriving rate.

Chapter 6

New Broadcast Protocol for Reliable and Efficient Data Dissemination in Vehicular Ad-hoc Networks

In this chapter researcher proposed a new broadcast protocol which is suitable for a wide range of vehicular scenarios used for real time Mumbai-Pune Express Highway India, which not only employs local or status information but also employs warning or emergency information acquired via periodic beacon messages, containing Acknowledgment Messages of the circulated broadcast messages. Each vehicle decides whether it belongs to a connected dominating set (CDS), than it calculates multi-hop CDS which will reduce redundancy of transmitted messages. Vehicles in the CDS use a short waiting period/time before it is possible to retransmit. At time-out expiration, a vehicle retransmits, if it is aware of at least one or two neighbor in need of the message. To address intermittent connectivity and appearance of new neighbors, the evaluation timer, can be restarted. Once the CDS is calculated then cluster is formed for Vehicle nodes in communication range on Mumbai-Pune Express Highway. Cluster Head (CH) is elected which will try to broadcast messages to Cluster Member (CM) in the Cluster of vehicle nodes. The protocol resolves propagation at road intersections without any need to even recognize intersections. It is inherently adaptable to different mobility regimes, without the need to classify network or vehicle speeds. In a thorough simulation-based performance evaluation, the protocol provide higher reliability and message efficiency than existing approaches for non safety applications.

6.1 Introduction

Vehicular Ad-hoc Networks consist of collections of vehicles on Mumbai-Pune Express Highway India. Mumbai-Pune Express Highway is 3-Lane road on each direction equipped with wireless communication capabilities. Vehicles cooperate to deliver different types of messages such as local or status messages and warning or emergency messages through multi-hop CDS connectivity and cluster formation of vehicle on Mumbai-Pune Express Road. To achieve this, V2V communication protocol must cope with the mobility of vehicles on Mumbai-Pune Express Highway Road and the dynamics of wireless signals without Road side Infrastructure. Vehicle movements are restricted by the Mumbai-Pune Express Highway Road layout in bi-directional manner with multi-lane on each side of road. This leads to highly partitioned networks with non uniform distribution of nodes. Further-more, Mumbai-Pune Express Highway scenario need to be addressed, when studying vehicular ad-hoc networks. Technical challenges in this environment are discussed in (Hartenstein and Laberteaux)(Munoz) with these other technical challenges are A central challenge of VANET's is that no central coordination or handshaking protocol can be assumed, and given that many applications will be broadcasting information of interest to many surrounding vehicle on Mumbai-Pune Express Highway Road, the necessity of a single, shared control channel can be derived. The bandwidth of the frequency channels currently assigned or foreseen for VANET applications ranges from 10 to 20 MHz.

With a high vehicular traffic density, those channels easily could suffer from channel congestion. Making use of more than one channel leads to multichannel synchronization problems. Other Challenges are the dynamic network topology based on the mobility of the vehicles and the environmental impact on the radio propagation. The low antenna heights and the attenuation or reflection of all the moving metal vehicle bodies provides for adverse radio channel conditions. All together, VANET's must work properly in a wide range of conditions, including sparse and dense vehicular traffic. There is a strong need for adaptive transmit power and rate control to achieve a reasonable degree of reliable and low latency communication. In addition, there is a challenge in balancing security and privacy needs. On the one hand, the receivers want to make sure that they can trust the source of information. On the other hand, the availability of such trust might contradict the privacy requirements of a sender. Socio-Economic Challenges are as follows: Market introduction of direct communication between vehicles is suffering from the network effect: the added value for one customer depends on the number of customers in total who have equipped their vehicle with VANET technology. A key question, therefore, is how to convince early-adopters to buy VANET equipment for their vehicles.

Broadcasting is the task of sending a messages from a source node, to all other nodes in the vehicular ad-hoc network on Mumbai-Pune Express Highway Road. It is frequently referred to as data dissemination with a communication range of 0.25 km. The design of reliable and efficient broadcast protocol is a key for the successful deployment of vehicle-to-vehicle communication services. Most of the envisioned services rely on the delivery of broadcast messages to the vehicles inside a certain area of interest (Khabazian and Ali). This operation is therefore also known as Geocasting. Vehicle-to-vehicle (V2V) communication system can also be used as a distributed platform for 'opportunistic cooperation' among people with shared interests or goals (Lee et al.).

6.2 Related Work

One of the challenge for VANET's is the dynamic and dense network topology on Highway Road, resulting from the high mobility and high node-density of vehicles. This dynamic topology causes routing difficulties as well as congestion from flooding, and the dense network leads to the hidden terminal problem. A clustered structure can make the network appear smaller and more stable in the view of each node. By clustering the vehicles into groups of similar mobility, the relative mobility between communicating neighbor nodes will be reduced, leading to intra-cluster stability. In addition, the hidden terminal problem can be diminished by clustering.

Another issue generated by the dynamic and dense network, is the Broadcast Storm Problem. The broadcast storm problem describes the congestion resulting from rebroadcasts and flooding in a VANET. The dynamic topology of VANET's demand a high frequency of broadcast messages to keep the surrounding vehicles updated on position and safety information or messages. In addition, many routing algorithms necessitate flooding the network to find routes, which in a dynamic network needs to be done frequently to keep routes updated. All of this flooding leads to severe congestion, which can be alleviated by a clustered topology (Hsiao-Kuang et al.). When the network is clustered, only the cluster-head participates in finding routes, which greatly reduces the number of necessary broadcasts.

An additional challenge for VANET's is Quality-of-Service (QoS) provisioning. In VANET's, many different types of data will need to be transmitted, and messages will be both delay-intolerant and delay-tolerant. For example, safety messages will demand high reliability and low delay, whereas non-vital road and weather information will be tolerant to longer delays. These different data types necessitate QoS provisioning, which can be achieved by a clustered network (Hsiao-Kuang et al.).

Clustering is the process of separating the nodes of a network into organized partitions called clusters. The clusters form sub-networks in the overall network, thus forming then hierarchical topology. Nodes in a cluster must be one of the following types Figure 6.1:

- Cluster head (CH)– An elected node that acts as the local controller for the cluster. The cluster-head's responsibilities may include: routing, relaying of inter- cluster traffic from cluster members, scheduling of intra-cluster traffic, and channel assignment for cluster members.

- Cluster Member (CM)– A normal node belonging to a cluster. Cluster members usually do not participate in routing, and they are not involved in inter-cluster communication.

- Cluster Gateway Node (CG)– This is an optional node, which is used in some clustering schemes. The gateway node belongs to more than one cluster, acting as the bridge between cluster-heads. When present, the gateway nodes participate in both forwarding of inter-cluster traffic and the routing process. The cluster-heads and gate-way nodes form the backbone network.

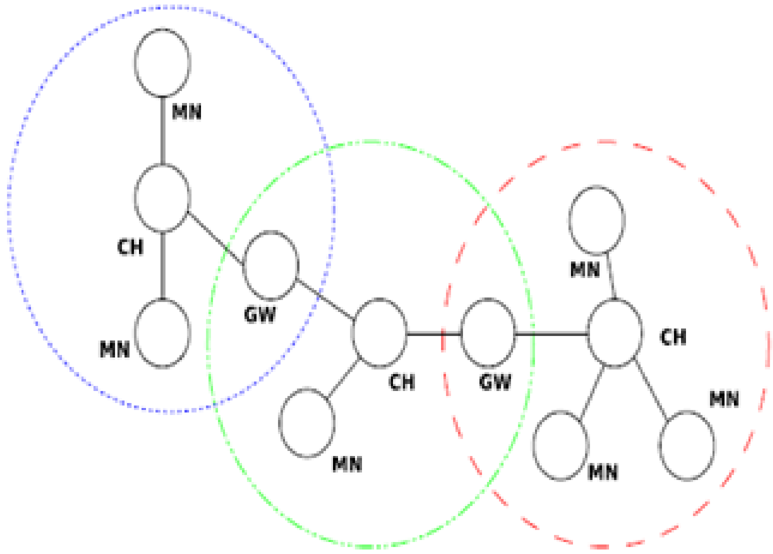

Figure 6.1: Clusters in VANET

The main aim of clustering algorithm is to minimize cluster reconfiguration and cluster-head changes, which are unavoidable due to the dynamic nature of the network. Having a good clustering algorithm requires selecting the cluster-head that will serve most of the vehicles communication on road for the longest possible time. Knowing the traffic flow and the general information of a vehicle, such as speed, direction, location and lane, should lead to better cluster-head selection.

The various cluster-head selection algorithms are as follows:

- Lowest-id clustering algorithm: It has the lowest overhead. In Lowest-ID, each node is assigned a unique ID, and the node with the lowest-ID in its two-hop neighborhood is elected to be the cluster-head (Gerla, M., and Tsai). The algorithm works as follows:
  - Each node periodically broadcasts its unique-ID, along with the ID of its neighbors.
  - If a node has the lowest-ID of all ID's it hears, it becomes a cluster-head.
  - The lowest-ID a node hears its cluster-head, unless that node gives up cluster-head status to another lower ID node. In this case, the node will re evaluate lowest-ID status amongst undetermined nodes.
  - A node that hears from more than one cluster-head is a Cluster Gateway node.

- In an effort to reduce the frequent re-clustering involved in maintaining the lowest-ID status of all cluster-heads, the Least Cluster Change (LCC) algorithm was suggested (Hsiao-Kuang et al.). In LCC, re-clustering is only performed when two cluster-heads come within range of one another. At this point, the cluster-head with the lower ID remains the cluster-head.

- In highest degree based clustering algorithm each node in the network is assigned a degree based on the number of neighbors in the defined range. The node with the highest degree is selected as the cluster head (Gerla, M., and Tsai).

These algorithms do not exhibit cluster stability because they make no attempt to select a stable cluster-head during initial cluster-head election. For highly-mobile networks, mobility must be considered during the clustering process in order to ensure cluster stability.

In this chapter, researcher focus on the problem of broadcasting protocol in Vehicular Ad-hoc Networks without infrastructure support i.e. V2V Communication. Primary goal is to achieve high reliability, while minimizing the total number of retransmissions using CDS and clustering algorithm with Acknowledgment message. In some safety applications, the delivery latency is critical. However, considering all these goals, appears to be a very challenging task on real time scenario of Mumbai-Pune Express Highway India, and concentrate here on non safety applications only. At the same time, vehicle still may not delay retransmission for too long as the reliability would otherwise suffer.

Topology changes due to mobility, cause frequent and temporary disconnections. Message might require to, be buffered and carried by a given vehicle until a new forwarding opportunity emerges. Several broadcasting protocols have been previously proposed. However, they are designed for either rectilinear highways/roads (Sun et al.), (Biswas, Tatchikou, and Dion), (Tonguz et al.). More surprisingly, only one of them (Tonguz et al.)addresses the issue of temporary disconnections in VANET, which is one of its most salient properties.

Researcher have developed the Broadcast Protocol which is fully distributed adaptive protocol suitable for Vehicular Ad-hoc Networks with all mobility scenarios. This protocol automatically adjusts its behavior without keeping track of the degree of mobility sensed by the vehicle on road. Each node independently decides whether or not to forward a received broadcast message. Such decision is solely based on the local or status information, that vehicles acquire from their neighborhood by means of periodic beacon messages. This guarantees ultimate scalability regardless of the size of the VANET. The set of parameters in Broadcast Protocol is minimal and consists only of few natural choices.

6.3 Proposed Protocol

In Broadcast Protocol, a vehicle on Mumbai-Pune Express Highway receives a broadcast message which does not retransmit it immediately. Instead, the vehicle waits and checks if any retransmissions from other neighbors already available which will cover its whole neighborhood, making its transmission then redundant. To acquire multi-hop neighborhood position information, periodic beacons contain the position of the sender. Such information suffices to compute a connected dominating set (CDS). Nodes in the CDS select a shorter waiting time-out than regular nodes. This allows them to retransmit first if their neighborhood has not been covered already. That is, we combine two different techniques, CDS and Cluster algorithm (Stojmenovic, Seddigh, and Zunic), (Stojmenovic). Once CDS is calculated then cluster is formed for Vehicle nodes in communication range on Mumbai-Pune Express Highway. Cluster Head (CH) is elected which will try to broadcast messages to Cluster Member (CM) in the Cluster of vehicle nodes. The protocol resolves propagation at road intersections without any need to even recognize intersections. It is inherently adaptable to different mobility regimes, without the need to classify network or vehicle speeds. Beacons also include, identifiers of the recently received broadcast messages, which serve as acknowledgments of reception. This way, nodes can check whether all their neighbors successfully received a message from Cluster Head to Cluster Member within Cluster and also check successfully messages received from one Cluster Gateway to other Cluster Gateway which will have inter cluster communication. If this is not the case, a retransmission is scheduled. Otherwise, retransmission would be redundant. In both cases, when a new neighbor emerges, nodes restart their evaluation time-out, if the message being disseminated but not acknowledged. If the message identifier is actually included within the beacon, the neighbor already has got the message and no retransmission is scheduled. Hence, the use of acknowledgments using RTS/CTS concept, makes the protocol more robust to transmission failures while, at the same time, saves redundant retransmissions.

Temporary disconnection incurs, delivery delay to any protocol. Although the described protocol inherently uses the store-carry-forward paradigm, Broadcast Protocol does not incur large delivery latencies. Vehicles connected to the Cluster Head will receive the message with small delay, due to propagation via CDS.

In a simulation-based study, we analyze the performance of Broadcast Protocol on Mumbai-Pune Express Highway, India scenario. Vehicles movements are generated with a microscopic road traffic simulation package i.e. eWorld and SUMO 12.0 from Google Maps, in order to mimic, common scenario of real vehicular networks on Mumbai-Pune Express Highway, India is considered. Different mobility conditions are simulated between different intersection points on Mumbai-Pune Express Highway like Kharghar, Panvel, Lonvala etc. Under realistic IEEE 802.11p (P802.11p/D0.21) models and AODV and DSR routing protocols.

6.4 The Broadcast Protocol

6.4.1 Overview

Propose of Adaptive Broadcast Protocol, which is suitable for a wide range of mobility conditions. The main problem that a broadcast protocol faces is its adaptability to the very different vehicular arrangements in real highway road scenarios. It should achieve high coverage of the network, at the expense of, as few transmissions as possible, regardless of whether the network is extremely dense or highly disconnected.

The Broadcast Protocol is localized, and based on applying the CDS and Cluster algorithm concepts on the currently available neighborhood information. In addition, Protocol assumes ideal communication radios to estimate the network connectivity and therefore apply the CDS and cluster algorithm techniques. Since real communication links are far from ideal, the protocol makes use of broadcast acknowledgments to insure the reception of the message or retransmit it. A message is acknowledged during its whole lifetime. At expiration, it is removed from the vehicle's buffer and no more acknowledgments are issued. Given that broadcast messages are acknowledged,

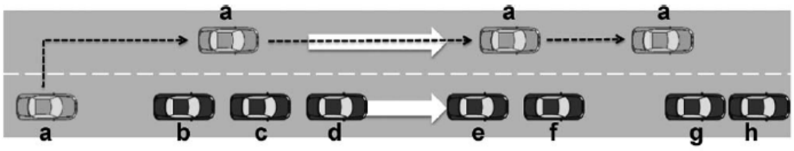

Figure 6.2: Common vehicular scenario. Vehicle a overtakes vehicles b - f.(Munoz)

it is assumed that they can be uniquely identified.

Vehicles are assumed to be equipped with Global Positioning System receivers. Periodic beacon messages are exchanged to update the vehicle's local topology knowledge. The position of the sender is included within the beacons, which suffices to calculate a CDS backbone after each beacon message round. The source node transmits the message. Upon receiving the message for the first time, each vehicle initializes two lists: list R containing all nodes believed to have received the message, and list N containing those neighbors in need of the message. Then, each receiving node sets a time-out waiting period. If a node is not in the CDS, then it selects longer time-out than the nodes from the CDS, so that the latter reacts first. For each further message copy received, and its own message sent, every node updates R, N, and the time-out. At the end of the time-out period, it transmits, if N is nonempty. Both ways, the message is buffered until it expires. For each beacon message received, N and R are updated according to the presence or absence of acknowledgment. Nodes that are no longer one-hop neighbors, are eliminated from these lists. Regardless of previous decisions, all nodes that so far, received the broadcast message check whether N becomes nonempty. If so, they start a fresh time-out. In addition, acknowledgments of received broadcast messages are piggy backed to periodic beacons. Nodes that was included in R because they were believed to have received the message, but did not actually get it, are later removed from R and inserted into N. This algorithm is executed for each different message. Therefore, the beacon size increases linearly, with the number of simultaneous broadcasting tasks.

Illustrates the protocol behavior on one example. Given the scenario depicted in Figure 6.2, vehicle a generates a broadcast message which is first buffered by a, and then received by b, c, d. Receivers set up a waiting time-out which is shorter, if the vehicle belongs to the computed CDS. Let d be in the CDS, thus it retransmits first. Vehicles b and c cancel their retransmission because all their neighbors have been covered by $d's$ forwarding. Vehicles e and f receive the message. However, none of them have uncovered neighbors, so the retransmission does not take place. The Broadcast Protocol saves these redundant transmissions because the beacons contain the acknowledgment of the message, and therefore the newly discovered neighbors are not covered again.

Vehicle a speeds up and overtakes vehicles $b - f$. In the case of PBSM, new transmissions would occur because new neighbors e and f must be covered by a (and vice versa). However, they are redundant because all the vehicles have already received the message. The Broadcast Protocol saves these redundant transmissions because the beacons contain the acknowledgment of the message, therefore, the newly discovered neighbors are not covered again.

6.4.2 CDS Broadcast Protocol Details

Pseudo-code of The Broadcast Protocol is given in Algorithm 1. Upon receiving the broadcast message, vehicle x includes in R the sender and all its known neighbors (and starts *to-ack* timers), because it is likely they have also received the message (lines 5-14). Accordingly, those vehicles are removed from N (7,12). The remaining neighbors of x which are not connected to the sender (their distance is greater than transmission radius r) are inserted into N (15-16). There exists a time-out function *to-ev* which assigns a waiting time to each vehicle before its possible retransmission. *to-ev* is proportional to $1/|N|$, where $|N|$ is the number of elements in N, and depends on whether or not the node is currently in the CDS (shorter waiting time if in the CDS). The rationale is to provide vehicles that have more neighbors in need of the message, priority to retransmit first. If several neighbors have the same status and number of neighbors in need of the message, they will obtain the same *to-ev* value. However, this does not mean an increased number of collisions, since The Broadcast Protocol runs at the network layer and these messages still have to contend to access the medium at the link layer (IEEE 802.11p).

Whenever a new neighbor (except the source of a newly received message) is inserted into R, x (vehicle under consideration) initializes a time-out *to-ack* attached to such neighbor (line no. 14). It is used to wait for the acknowledgment of reception.

Set *to-ack* to approximately the beacon holding time which is the maximum amount of time a node waits without receiving beacons from a neighbor, before deleting it from its neighbor list (line nos 53-60). This allows nodes to still receive acknowledgments after more than one beacon interval, in case the original message was not initially received but later it was received, from other retransmitters. That is, it allows saving some extra retransmissions by just waiting a bit longer for those acknowledgments. If *to-ack* expires and the acknowledgment has not been received, the corresponding neighbor is moved from R to N (Line nos. 49,52), or it is removed from the lists, if its expected beacons were not received. If N was empty and a new element is inserted, *to-ev* is reactivated if it was not already running (line nos 50-51). In case *to-ev* was running, it is updated according to the new value of $|N|$ and the elapsed time since the last schedule (line nos. 50-51). In case N becomes empty ($|N| = 0$), x cancels $to - ev$ and decides not to retransmit (line nos. 21-24). When $to - ev$ expires, if N is not empty, x retransmits the message and moves the content of N to R (causing the activation of time-outs *to-ack*) (line nos. 42-49). For each acknowledged message listed within a beacon from neighbor b, x cancels the associated *to-ack* (29-30) and adds or confirms b in R (removing it from N if it was there) (line no. 31). Note that some acknowledgments can be received, before the message itself, so R may be nonempty already when the message is received for the first time.

6.4.3 Cluster Algorithm for Broadcast Protocol Details

The proposed algorithm is a distributed clustering algorithm. It possesses excellent cluster stability, where stability is defined by long cluster-head duration, long cluster member duration, and low rate of cluster-head change. The relative mobility between vehicle node X and vehicle node Y is then approximated by taking the ratio of time T taken at vehicle node Y for two successive Hello messages to arrive from vehicle node X. The relative mobility metric,

$$(M^{rel}Y(X)) \tag{6.1}$$

, at vehicle node Y with respect to vehicle node X, is as follows:

$$M^{rel}Y(X) = 10 \log 10 \frac{T^{new}X \rightarrow Y}{T^{old}X \rightarrow Y} \tag{6.2}$$

In the above metric, if

$$T^{new} X \to Y \leq T^{old} X \to Y, then M^{rel} Y(X) \leq 0, \tag{6.3}$$

which implies the nodes are moving towards one another.On the other hand, if

$$T^{new} X \to Y \geq T^{old} X \to Y, then M^{rel} Y(X) \geq 0, \tag{6.4}$$

which indicates that the nodes are moving away one another. Therefore, the closer

$$M^{rel} Y(X) is to zero, \tag{6.5}$$

the lower the relative mobility. Vehicle Node Y calculates an aggregate mobility metric by considering the equation 6.1 for each neighbour, Xi. The aggregate mobility metric is found by finding the variance, with respect to zero, for the set of relative mobility values, equation 6.1. This aggregate mobility metric is computed:

$$M^{rel} Y(X) = var\{M^{rel} Y(X)\}_{j=1}^{m} \tag{6.6}$$

Following is the proposed Cluster Algorithm for Vehicular to Vehicular communication on Mumbai-Pune Express Highway India.

- In the first executed tcl file(message.tcl), all the nodes in the cluster will send messages to others. This will help to capture their speed which will be used for finding the cluster-head for that particular cluster.
- From the trace file(messageout.tr) generated, node id and speed of vehicles are obtained and stored in variance.txt as shown in Figure 6.3 using Cluster-Head.awk file.
- The second executed tcl file(chselection.tcl) will calculate the cluster head.

6.4.4 Use Case Diagram for OBU is not Damaged

As shown in figure 6.4. In use case diagram it will check if a vehicle node(an actor) meets with an accident and its OBU is not destroyed then it will send the message to the head of the cluster(an actor).Cluster Head will search for other vehicle OBUs. If found then the message change path will be broadcasted to all nodes(an actor) present in the cluster. cluster head will also unicast the message to the other cluster head.

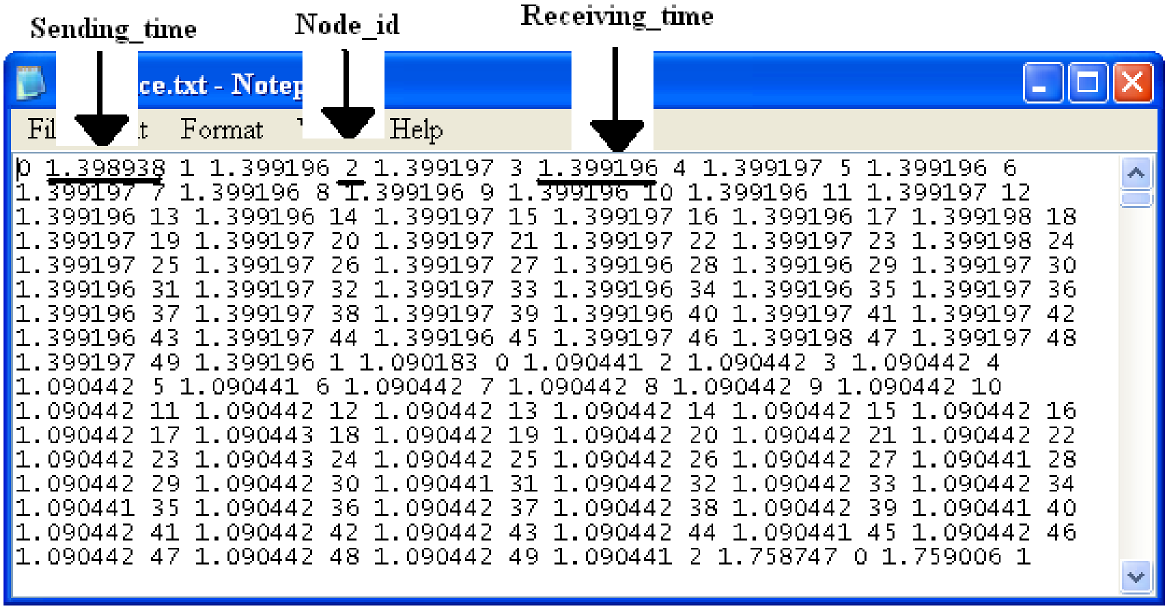

Figure 6.3: Variance.txt Screen shot

As shown in figure 6.5. In class diagram Cluster head, other clusters head, cluster nodes, accidental node are represented by class. They have attributes like id which uniquely identifies them, x cood and y cood which gives their position, acceleration, deceleration, speed which tells about their movement. They have operations like search for OBU, unicast, receive message which helps in searching OBUs, sending and receiving messages.Cluster heads can broadcast the message and hence they have an additional operation named multicast.

As shown in figure 6.6. In sequential diagram it will check if accidental node will send the message to the cluster head. Cluster head will prepare itself for sending the message. It will then send the message to cluster nodes and other cluster heads. other cluster heads will further send it to all nodes present in its cluster. After receiving the message, cluster nodes will change their path.

As shown in figure 6.7. In activity diagram it will check When a node meets with an accident, it will send the message to its clusters head. Cluster head will check for OBUs. If OBUs are present then the head will prepare itself for sending the message. It will then send the message to cluster nodes and other cluster heads. other cluster heads will further send it all nodes present in its cluster. After receiving the message, cluster nodes will change their path.

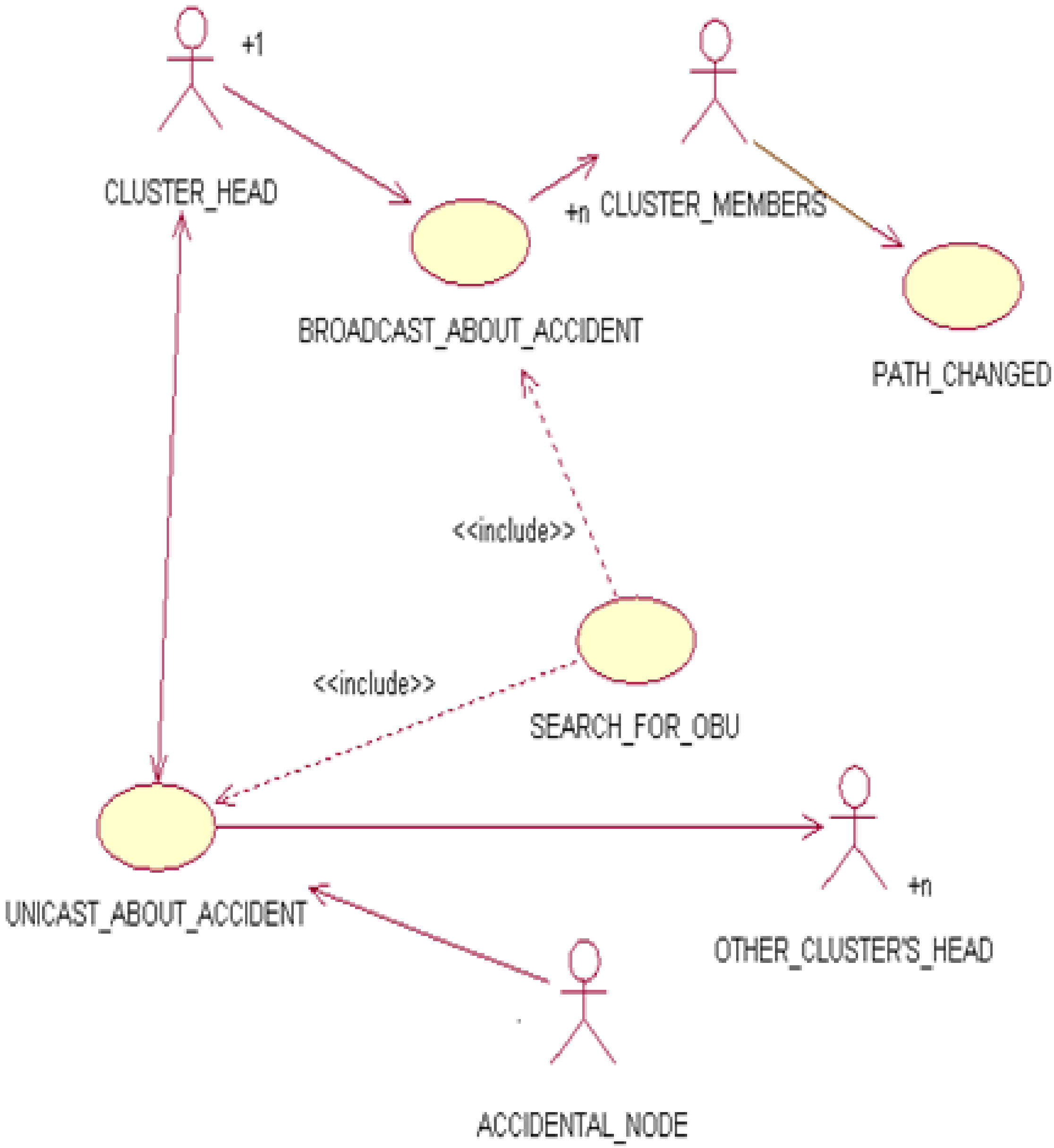

Figure 6.4: Use Case Diagram when OBU is not damaged

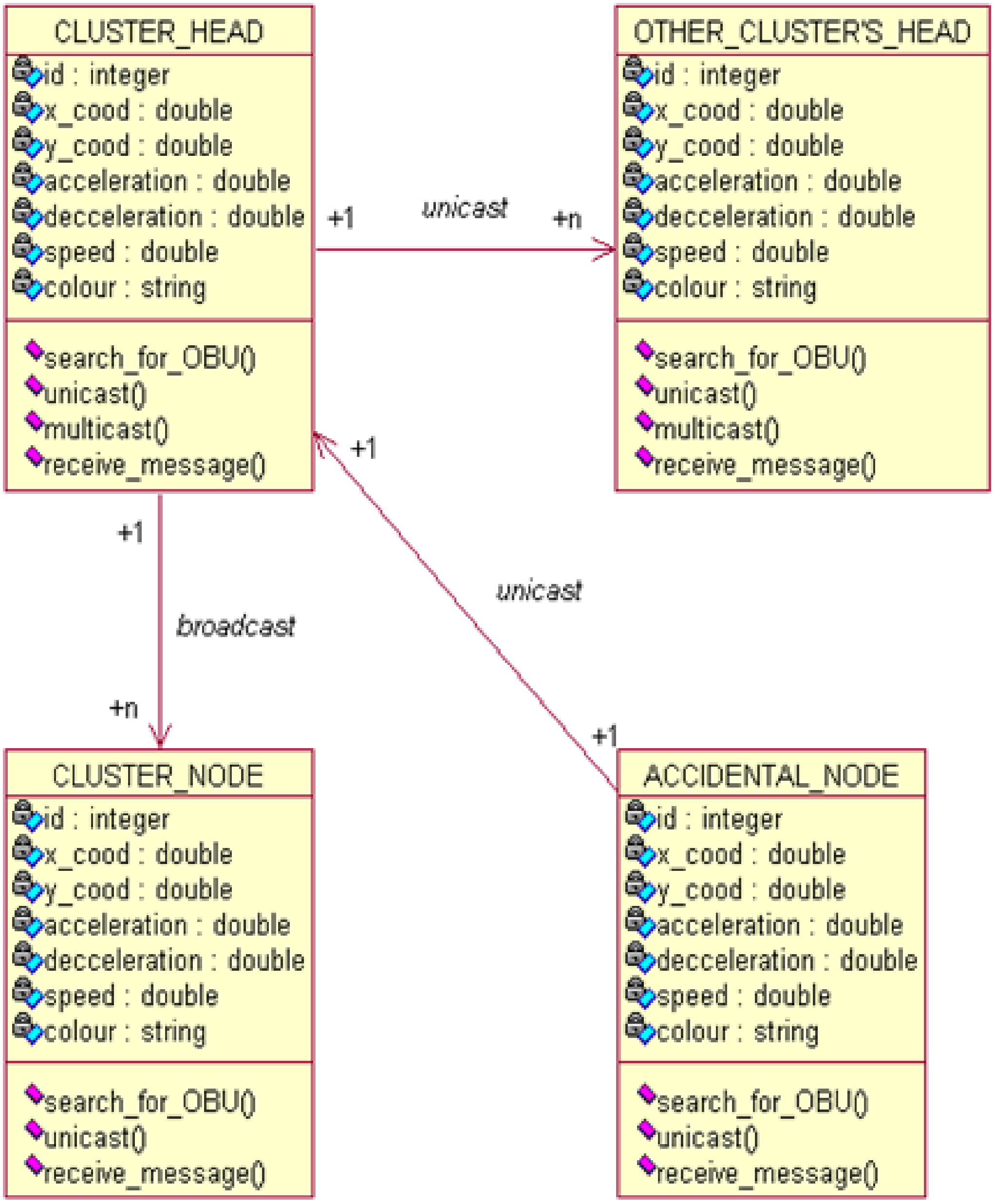

Figure 6.5: Class Diagram when OBU is not damaged

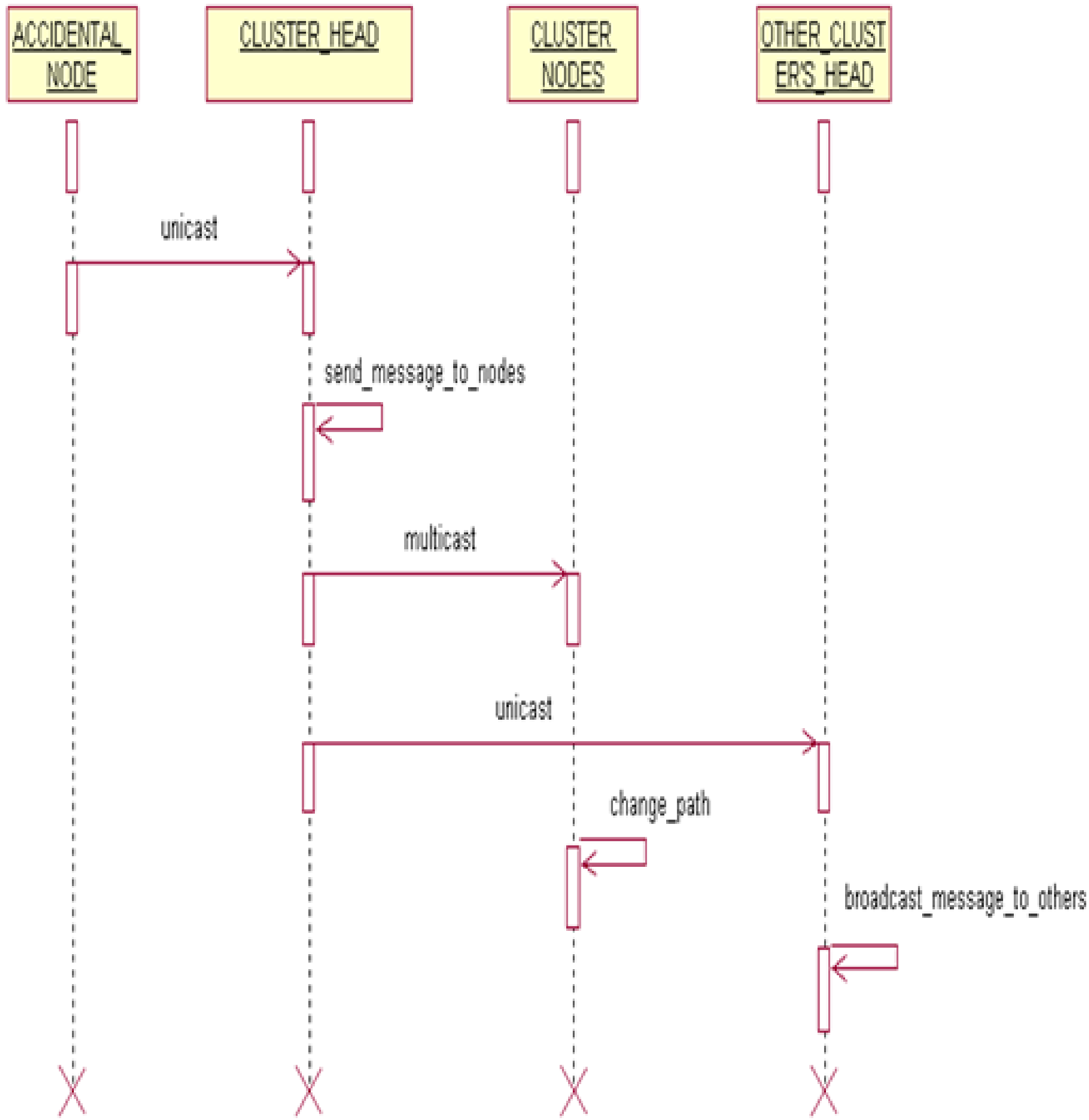

Figure 6.6: Sequential Diagram when OBU is not damaged

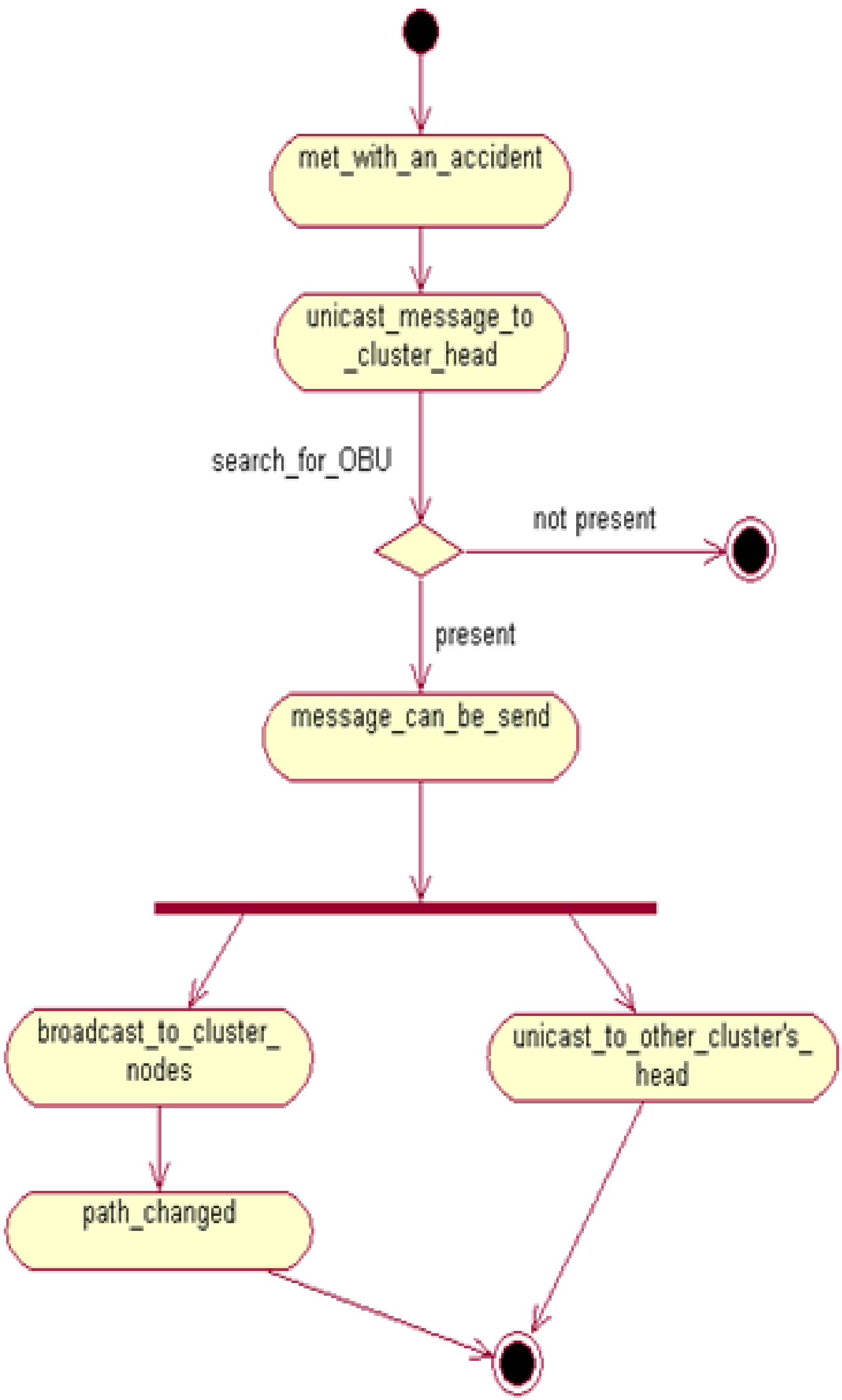

Figure 6.7: Activity Diagram when OBU is not damaged

6.4.5 Use Case Diagram when OBU is Damaged

As shown in figure 6.8. In Use case diagram it is mentioned that If a node(an actor) meets with an accident and its OBU gets destroyed then it cannot send the message to the cluster head. In this case, another node (an actor) which is within the range of accidental node will send the message to the cluster head. Cluster head will search for other OBUs. If found then the message change path will be broadcasted to all nodes(an actor) present in the cluster. Cluster head will also unicast the message to the other cluster head.

As shown in figure 6.9.In class diagram it is mentioned that if cluster head, other clusters head, cluster node, accidental node, node within range are represented by class. They have attributes like id which uniquely identifies them, x cood and y cood which gives their position, acceleration, deceleration, speed which tells about their movement. They have operations like search for OBU, unicast, receive message which helps in searching OBUs, sending and receiving messages. Cluster heads can broadcast the message and hence they have an additional operation named multicast. Accidental node depends on node within range for sending message to the cluster head.

As shown in figure 6.10.In sequential diagram it is mentioned that if here the node which is within the range of accidental node will send the message to the cluster head. Cluster head will prepare itself for sending the message. It will then send the message to cluster nodes and other cluster heads. other cluster heads will further send it all nodes present in its cluster. After receiving the message, cluster nodes will change their path.

As shown in figure 6.11. In Activity diagram it is mentioned that if When a node meets with an accident, the other node which is within the range of accidental node will send the message to its clusters head. Cluster head will check for OBUs. If OBUs are present then the head will prepare itself for sending the message. It will then send the message to cluster nodes and other cluster heads. other cluster heads will further send it all nodes present in its cluster. After receiving the message, cluster nodes will change their path.

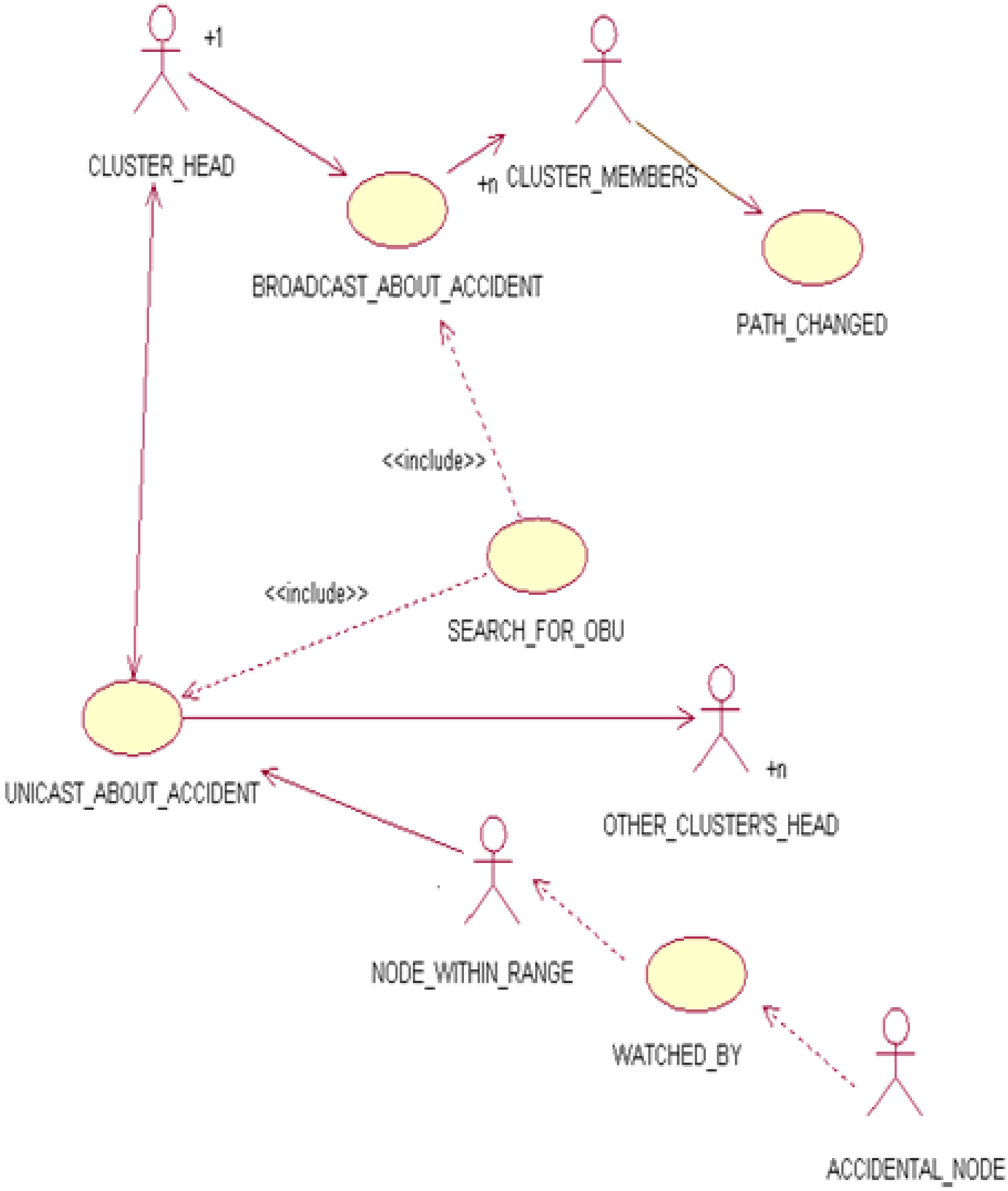

Figure 6.8: Use Case Diagram when OBU is damaged

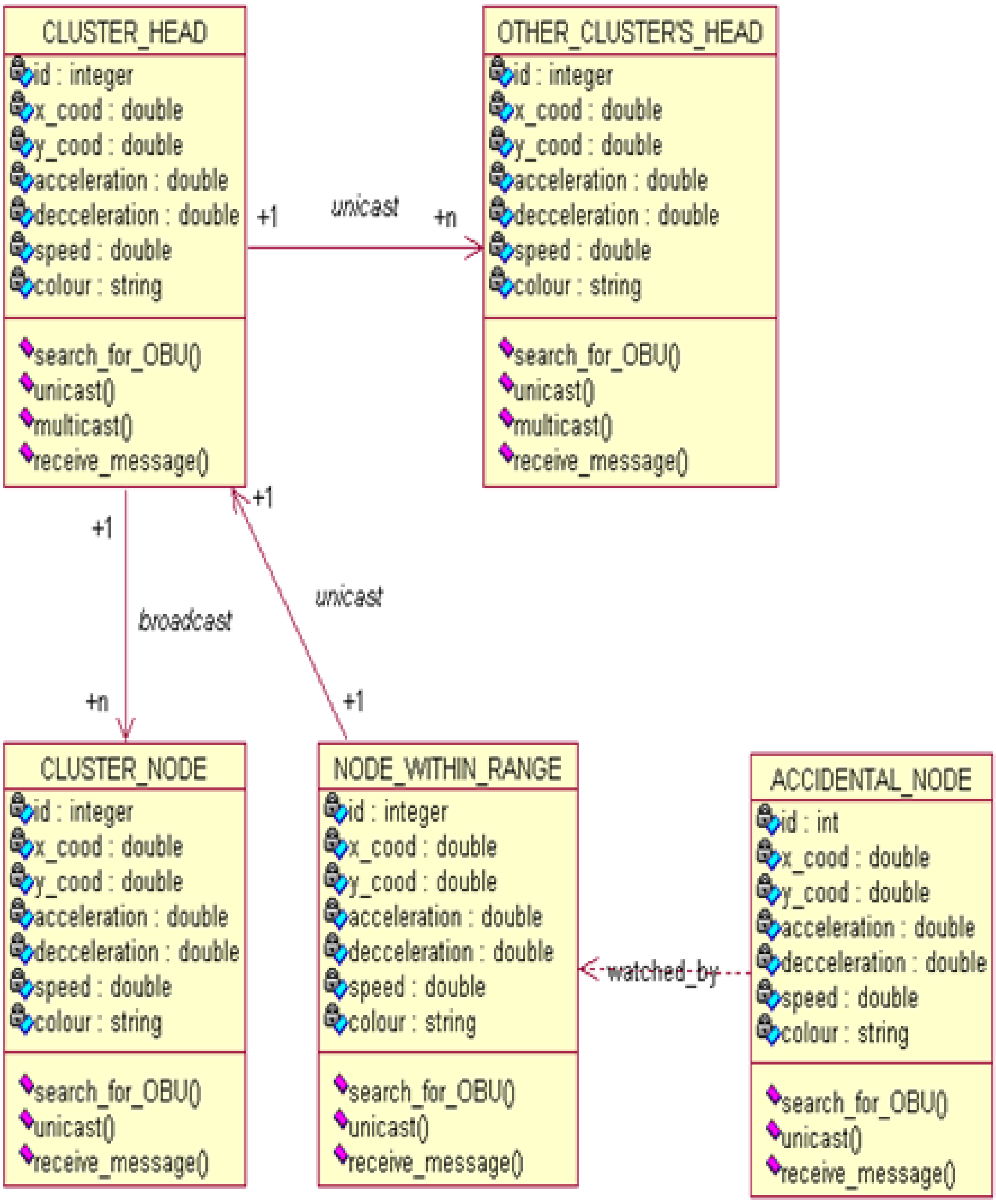

Figure 6.9: Class Diagram when OBU is damaged

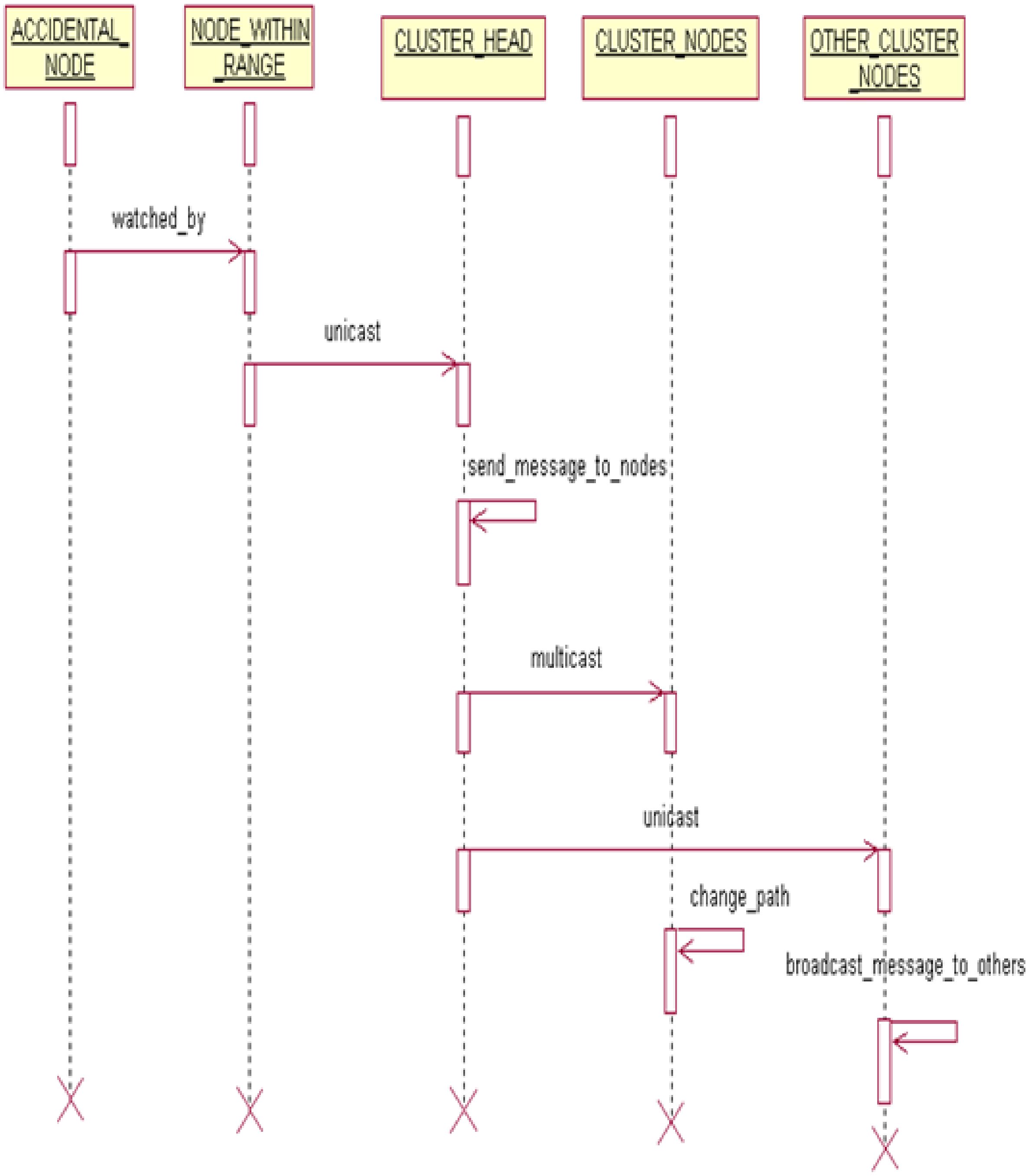

Figure 6.10: Sequential Diagram when OBU is damaged

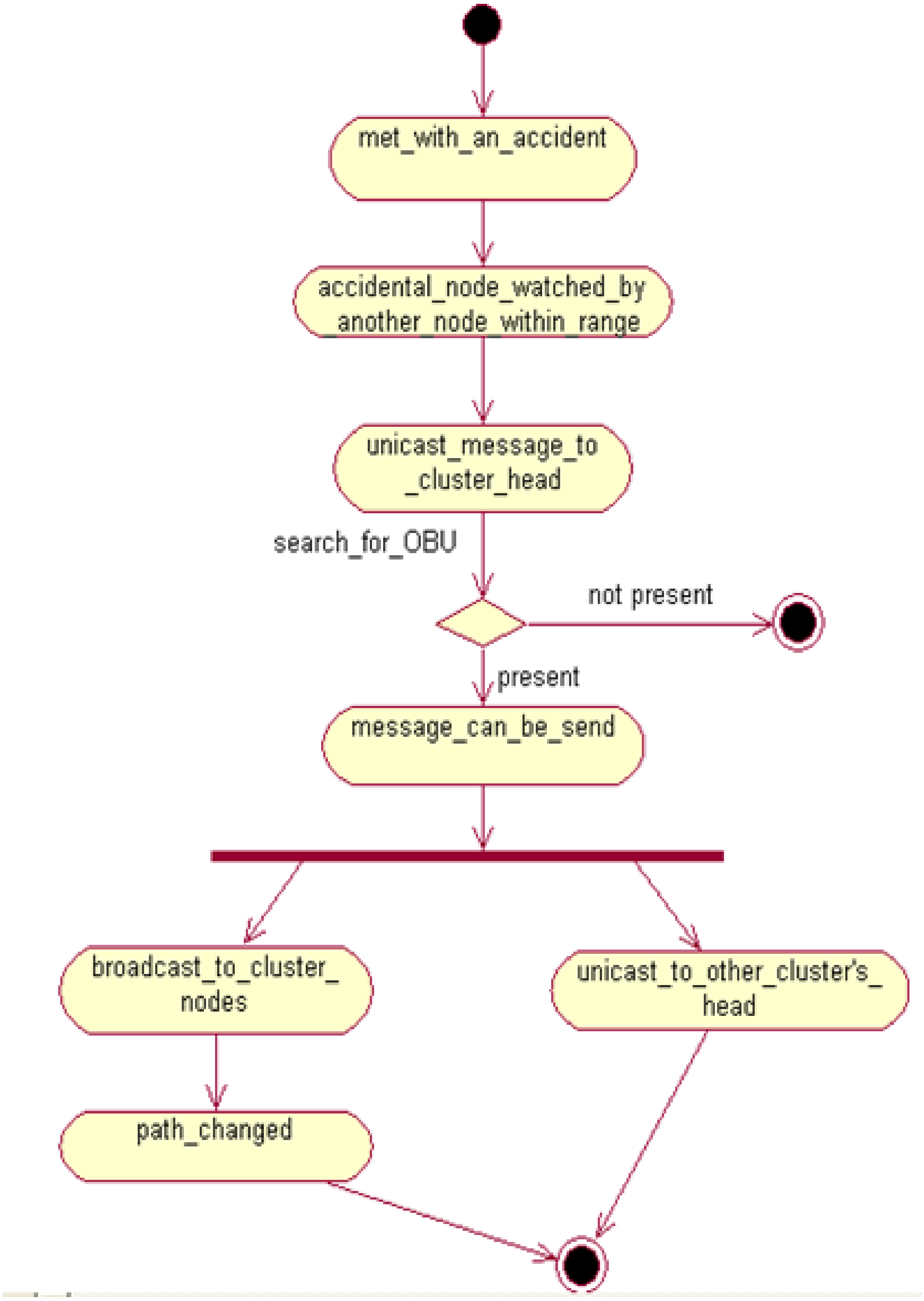

Figure 6.11: Activity Diagram when OBU is damaged

6.5 Discussion

Broadcast Protocol is an appropriate solution for VANET. First, the protocol is scalable because it only needs local or status information to perform the broadcasting task. Local or status information is obtained from beacon messages. This does not increase message overhead, because they are needed by safety applications and are mandated by on-going standards like DSRC protocol (ASTM). The only additional overhead comes from the inclusion of the acknowledgment messages, inside periodic beacons, since the sender's position is included by default. Acknowledgment message appear the best strategy in broadcast protocol using RTS and CTS, to guarantee delivery to all vehicles on Mumbai-Pune Express Highway. Receivers may malfunction, and physical layer modeling has large randomness component even if made with accurate parameters.

In order to minimize the number of message transmissions while preserving reliability, Protocol creates a broadcast delivery backbone based on a CDS heuristic and cluster formation algorithm. Vehicles in the CDS choose a shorter time-out, to give them higher priority to retransmit messages. In addition, cluster algorithm is employed to further reduce the number of redundant transmissions messages. Cluster algorithm will form cluster of vehicles on road with same speed in same direction etc. then elect the cluster head from the speed capture on Mumbai-Pune Express Highway. This cluster head will communicate with the Cluster member for transmission of messages related local information or warning information. This cluster formation will be long time and information will be shred among all members which reduces redundancy. This approach is appropriate for vehicular scenarios such as Mumbai-Pune Express Highway layouts with different intersections points on Highway road. Vehicles located at junctions which are the only ones with connectivity, with other vehicles at converging streets, will be selected as dominating, therefore, will retransmit sooner to propagate the broadcast message along those streets (see Figure 6.2). This is achieved by means of the own CDS selection mechanism for multi-hop, without ever dealing directly with the notion of 'intersection' in the protocol description. Note that VANET-specific protocols (including those designed for safety applications) in which the forwarder selection is based on the concept of progress from the trans-

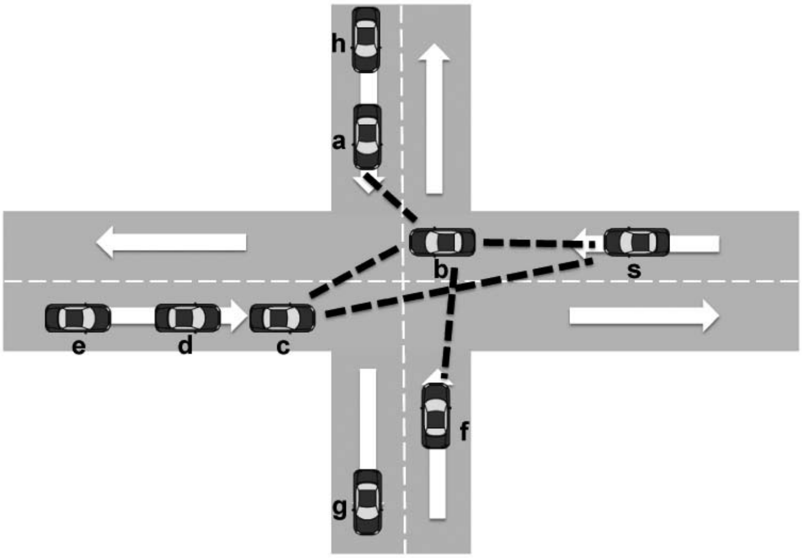

Figure 6.12: (Intersections in vehicular scenarios. Dotted lines represent connectivity between the subset of vehicles surrounding the intersection. Vehicle s initiates the broadcasting task. In PBSM, b is used as relay and therefore the message propagates for every converging street. Forwarding progress-based approaches would select c as relay, and the message would only propagate through the current street.)(Munoz)

mitter (Sjoberg) (Munoz), fail to support this scenario. In Figure 6.2, if vehicle c receives s transmission and forwards first (since it is farther from s than b), vehicles a , f located at converging streets would not receive the message. Other approaches (Korkmaz et al.), (Korkmaz, Ekici, and Uner) need to explicitly handle the case of intersections by starting new directional broadcasts.

In the unit disk graph (UDG) model, two nodes u; v are neighbors can directly communicate if distance $(u, v) \leq r$, where r is the radius of the communication range. We demonstrate that CDS concept used here is effective in VANET. Actual CDS definition in realistic physical layer is complicated because physics is complicated: the link between any two vehicles is probabilistic so it is not even clear, when to declare them neighbors. CDS was indeed here defined using UDG as approximation, but then it shows that such use of simple approximated CDS is just enough for satisfactory performance of Broadcast Protocol under realistic VANET physics. Computing a CDS in a VANET environment comes for free, since beacons with geographic information are periodically triggered. The use of acknowledgments makes the protocol more suitable to the VANET fading environment. If a message is not received by a theoretical neighbor, latter does not announce its reception in subsequent beacons and the vehicles with the message will issue new transmission. If the message is received by a theoretical non-neighbor, there will be no retransmission later, if that node suddenly becomes a neighbor. The superiority of Broadcast Protocol over PBSM is explained by this correction of UDG-based initial estimate. PBSM updates lists R and N, implicitly assuming the UDG model. The inclusion of acknowledgments in ABSM protects the protocol against this assumption, since message losses are expected to happen. This allows Broadcast Protocol to perform well in real environments.

Finally, and contrary to protocols like DV-CAST, researcher solution does not need to determine the traffic regime that is sensed by the vehicle. This simplicity is a great advantage: since there are, no different internal states, flaws due to unexpected situations are less prone to appear. Nowhere in the Broadcast Protocol, it matters what is the speed of a vehicle or if the vehicle is at an intersection. It therefore provides smooth adaptation to network dynamics including intersections, without changing its behavior. For comparison, GPCR protocol (Lochert et al., "Geographic Routing in City Scenarios") changes when vehicle is at intersection. Also, determining which nodes, are located at intersections requires downloading maps in addition to position information.

6.6 Evaluation Setup

Researcher have performed different tests, to assess the performance of Broadcast Protocol. The simulation work has been done with the Network Simulator NS-2, version 2.34 . Along with Broadcast Protocol, researcher also implemented competing algorithm DV-CAST and two variants of PBSM: PBSM-2t, which uses two-hop topology information as described in (Khan, Stojmenovic, and Zaguia); and PBSM-1p, employing one-hop position information. PBSM-1p, PBSM-2t, and Broadcast Protocol implement the CDS heuristic described in (Stojmenovic, Seddigh, and Zunic) and (Stojmenovic). Researccher have used vehicles unique identifiers as keys. In all PBSM variants, the time-out $to - ev$ is computed as in equation 6.1, while *to-ack* is fixed to a constant value in Broadcast Protocol. The effect of parameters W and *to-ack* is studied in later section.

$$to - ev = \begin{cases} \frac{W}{|N|} * 1, if in CDS within Cluster; \\ W\dot{(}1 + \frac{1}{|N|}), otherwise(CDS outside Cluster). \end{cases} \tag{6.7}$$

For DV-CAST, implementation employs the weighted p-persistence algorithm as the broadcast suppression technique, with parameters $W = 0 : 25sec$ and $\delta = \frac{W}{10}sec$. The other slot-based approaches were not chosen because, as recognized by the authors, they depend on parameters which may be hard to tune in practice (Wisitpongphan et al.). To determine the vehicle status, DV-CAST uses concepts such as, the message forwarding direction, the position inside a cluster of vehicles, and the presence of neighbors in the same or opposite direction (Tonguz et al.). The position of the sender and its direction is included in periodic beacons. In addition, data packets are augmented with a network header that indicates the position and direction of the source, as well as the position of the last forwarder (previous hop). Such information suffices to derive the status of each vehicle.

Researcher consider, specific vehicular scenarios and movements for setups, namely, highway. The former consists of a 4 km long rectilinear highway with two lanes per direction. The former consists of a 4 km^2 with two crossing streets that converge at the center of the square. Each street has two lanes in opposite direction. Vehicles must stop at intersections when others are crossing, so that traffic jams are longer here. DV-CAST has not been included in this set of simulations, because it is not designed for highway scenarios with intersections.

In order to create Mumbai-Pune Express Highway scenario, as well as, to generate the mobility traces of the vehicles at different time slot, researcher have employed the SUMO microscopic road traffic simulation package. This allows to simulate, common vehicular situations such as overtakes and stops at intersections points on Highway. This leads to intermittent connectivity and uneven distribution of vehicles. In this scenario, researcher defined several routes which are followed by the vehicles. SUMO injects vehicles in each route according to a given traffic rate, measured in injected vehicles per second. In order to get a wide range of network connectivity, researcher have varied the traffic injection rate per route from $\frac{1}{75}$ to $\frac{1}{5}$ vehicles per second. The higher the traffic injection rate, the higher the network density. Some figures and

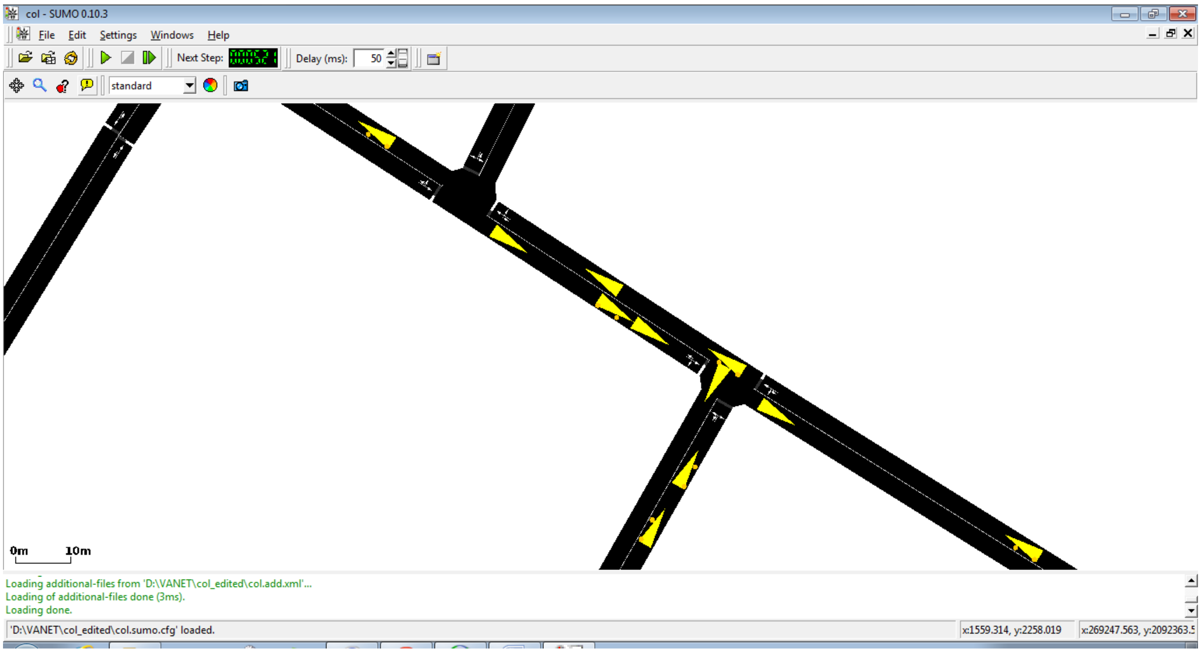

Figure 6.13: Mumbai-Pune Highway Screen Shot in SUMO

tables in this section are labeled with the reciprocal of this rate, i.e., with the interval between the injection of consecutive vehicles (from $75 to 5 sec$). Two types of vehicles have been defined, with maximum speeds of $50km/h$ and $80km/h$. Refer Figure 6.12 to Figure 6.15.

Table 6.1 summarizes the main simulation parameters used for Mumbai-Pune Express Highway Scenario. Beacon interval refers to the time between consecutive beacons. The information acquired is considered valid during the beacon hold time. Each run consists of one broadcasting task that is started by a random source, chosen from a cluster of vehicles that meet some requirements. Namely, the vehicle must be active when the steady state of the network is reached, and it must have at least 30 sec remaining before reaching its destination. The broadcasted message contains 500 $bytes$ of payload and has a lifetime of 120 sec, afterwards it is discarded. Results show the average value of 20 independent runs, along with the 95% confidence interval.

List of metrics are as follows:

- **Reliability**: Defined as the ratio between the number of vehicles which receive the broadcast message and the total number of them that could have received it: $Rel = \frac{N_{recv}}{N_{total}}$; $Rel \in 0, 1$. Note that, probably, not every simulated node, can receive the broad-casted message because some vehicles may remain partitioned

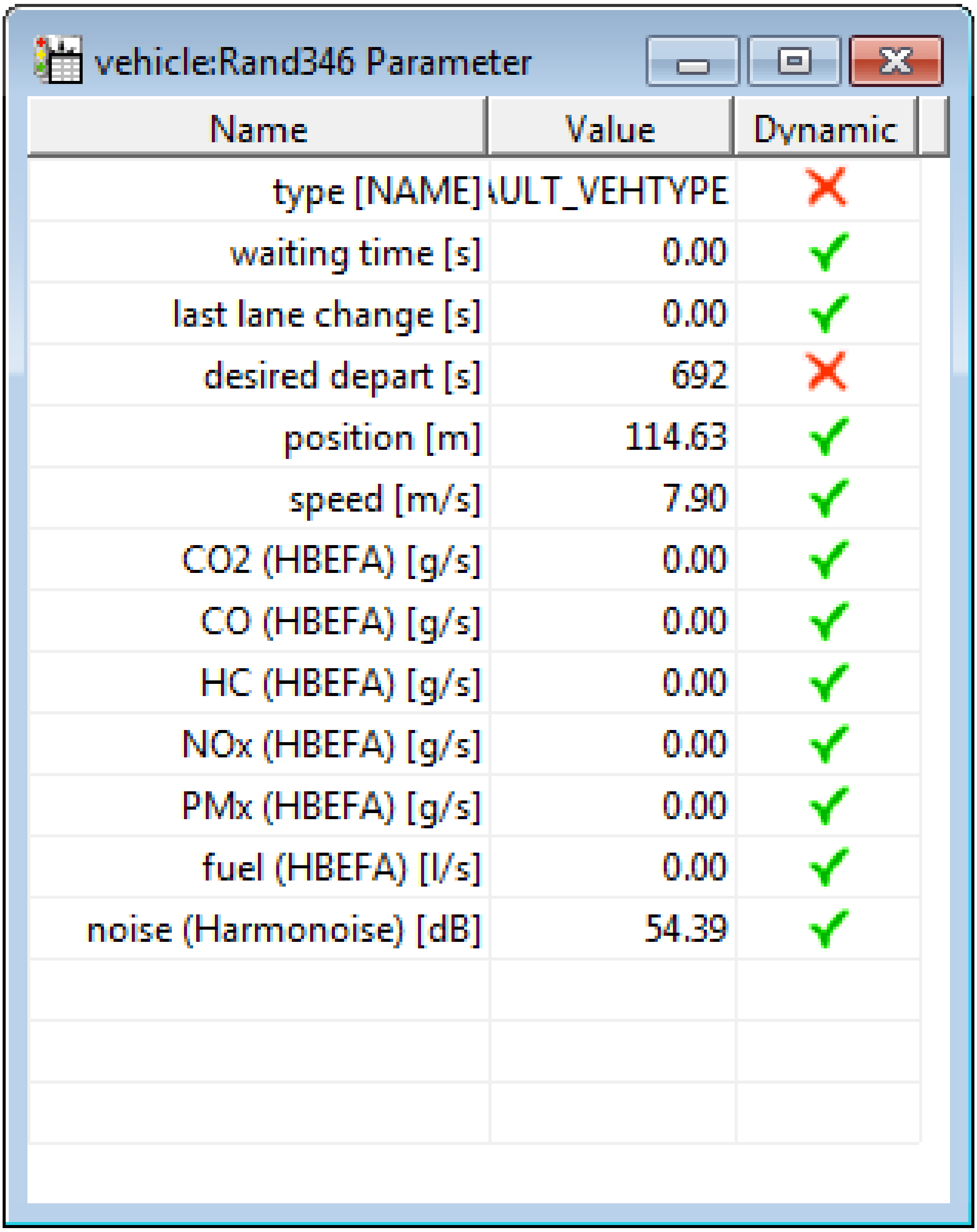

Figure 6.14: Vehicle Parameters Captured for Mumbai-Pune Highway Screen Shot in SUMO

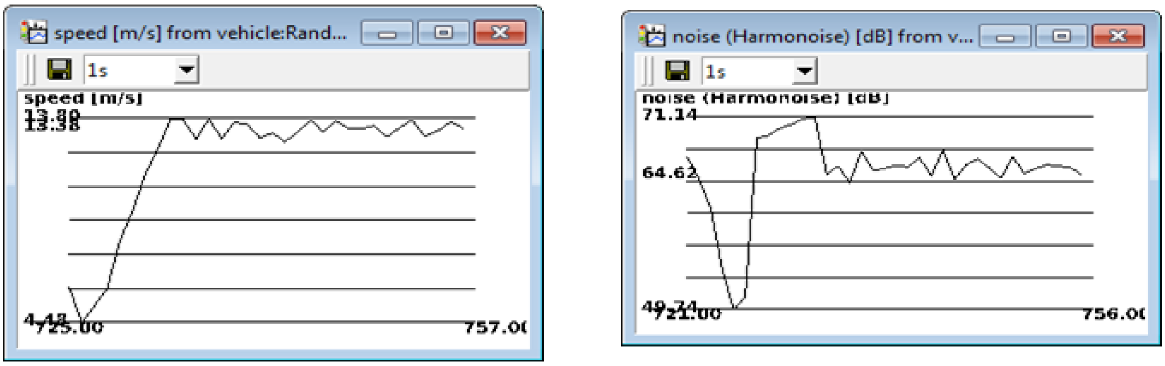

Figure 6.15: Vehicle Graph for Mumbai-Pune Highway Screen Shot in SUMO

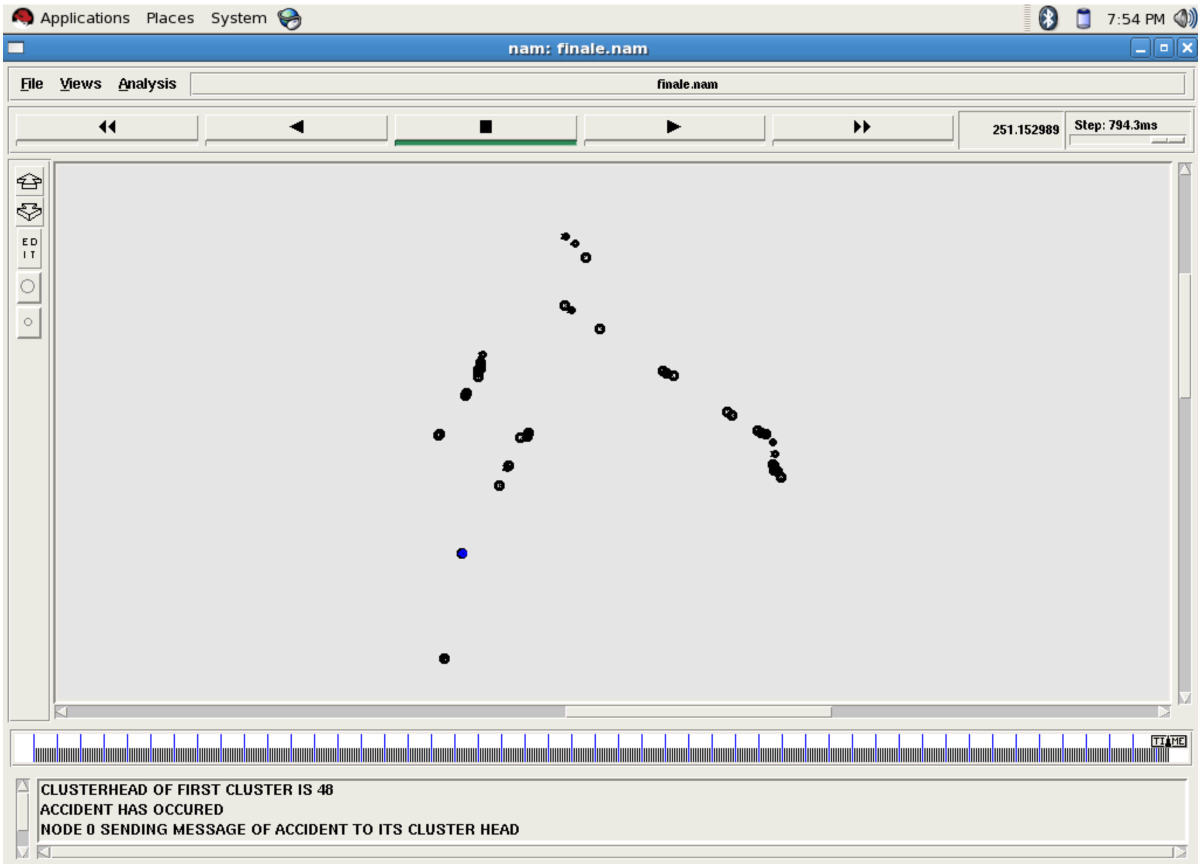

Figure 6.16: Cluster Head Selection using CDS Screen Shot on Mumbai-Pune Express Highway in VANET

Table 6.1: Simulation Parameters for the Mumbai-Pune Highway and Nerul-Vashi City Vehicular Scenario

Parameter	Value
Simulation Time	$120, 1200, 2000sec$
Area	$6780 * 7800meter, 120km$
Traffic rate	$(1/75, 1/60, 1/45, 1/30)veh/sec/route$
Maximum Speed	$(50, 80, 120)km/h$
Beacon Interval	$0.5, 0.75, 1sec$
Beacon Hold Time	$1.5, 2.0sec$
W	$(0.1, 0.25, 0.5, 1, 1.5, 1.75, 2)sec$
to-ack	$(0.6, 1.1, 1.6, 2.1, 2.6)sec$
Transmission Power	$1.52, 2.0mW$
Carrier sense Threshold	$802.11p : -94, -96dBm$
Contention Window	$802.11p : [15 - 1023]$
RTSThreshold	2346
SlotTime	0.000013
frequency	$5.85e + 9$
bandwidth	$70e6$
Data	$Local/EmergencyMessage$
Transmission Range	$100m - 600m$
Traffic direction	$TwoWay$
Number of Vehicle Nodes	$11, 60, 232, 1218, 2000$
Intersection points	4

from the source. In order to overcome this issue, researcher measure N_{total} on each simulation as follows: we have implemented and simulated with ideal MAC and PHY layers a variant of hyper flooding (Viswanath and Obraczka). The number of covered nodes N_{recv} obtained on such simulations, becomes the upper bound N_{total} for the remaining protocols.

- **Number of message transmissions per involved vehicle**: This measures the efficiency of the protocol. Given the same reliability, a protocol is said to be more efficient than another, if it needs fewer transmissions to complete the broadcasting task. The number of involved vehicles N_{total} has been computed as explained before.

- **Control overhead per vehicle**: Since the protocols are localized, the overhead comes from the periodic exchange of beacon messages. Our DV-CAST implementation also adds information, as an extra header within data packets. The total number of bytes devoted to protocol information per simulated vehicle, during every run, has been measured.

- **Delivery latency**: Measured as the time, in seconds, since the data source issues the message until it arrives at every receiver. For this metric, focus on one specific run.

- **Message Delivery Ratio (PDR)**: It is the fraction of packets generated by received packets. That is, the ratios of packets received at the destination to those of the packets generated by the source. As of relative amount, the usual calculation of this system of measurement is in percentage (%) form. Higher the percentage, more privileged is the routing protocol.

- **Average End-to-End Delay (E2E Delay)**: It is the calculation of typical time taken by message (in average packets) to cover its journey from the source end to the destination end. In other words, it covers all of the potential delays such as route discovery, buffering processes, various in-between queuing stays, etc, during the entire trip of transmission of the message. The classical unit of this metric is millisecond (ms).

6.7 Results

Researcher implemented CDS for multi-hop using NS2 version 2.35 and OTCL using C++ language. Researcher consider Mumbai-Pune Express Highway scenario and collected result for number of cluster heads i.e. cluster quality, reliability, PDR and throughput for reliable and efficient vehicle-to-vehicle communication on Mumbai-Pune Express Highway road without infrastructure. During experiments different parameters like number of nodes, mobility and density of network is considered. In the tests as the surface area decreases the density off the graph increases, it means that nodes will have more neighbors in lesser area. Speed is determined randomly by SUMO simulation within specified velocity limits. Observed the number of cluster-heads in a graph of size 20 to 50 for varying densities from 4 to 13. Typically in a graph, expect to have less cluster-heads as density increases. This can see the decrease in the cluster-head numbers in the graph as the degree value increases in Figure 6.16 and Figure 6.17 tell the throughput on Mumbai-Pune Highway. Broadcast protocol performs better in given scenario. Algorithm has less number of cluster-heads using CDS calculation for multi-hop network as compared to previous CDS algorithm, then better throughput and better reliability, PDR and E2E results as shown in below results.

As defined, performance of our CDS-based depend on a parameter $to-ev$ that represents the wait time before retransmitting a given message. In addition, Broadcast Protocol incorporates an additional time-out $to-ack$, which is employed to wait for acknowledgments of a forwarded message with respect to cluster formation algorithm. They also rely on two more parameters, namely, the beacon interval and holding time. However, latter related to $to-ev$ and $to-ack$, which are the relevant parameters to study since they are exclusive of the evaluated broad-casting protocols. Investigate how parameters W and $to-ack$ influence the behavior of the protocols, fixing the beacon interval and holding time, as shown in Table 6.1.

Figure 6.18 and 6.21 shows the impact of parameter W onto each protocol's reliability, where $to-ack = 1 : 6$ *sec* in the case of Broadcast Protocol. Focus on a moderately dense network (30 *sec* of injection interval) and a moderately sparse one (60 *sec* of injection interval)on Mumbai-Pune Express Highway. Regardless the

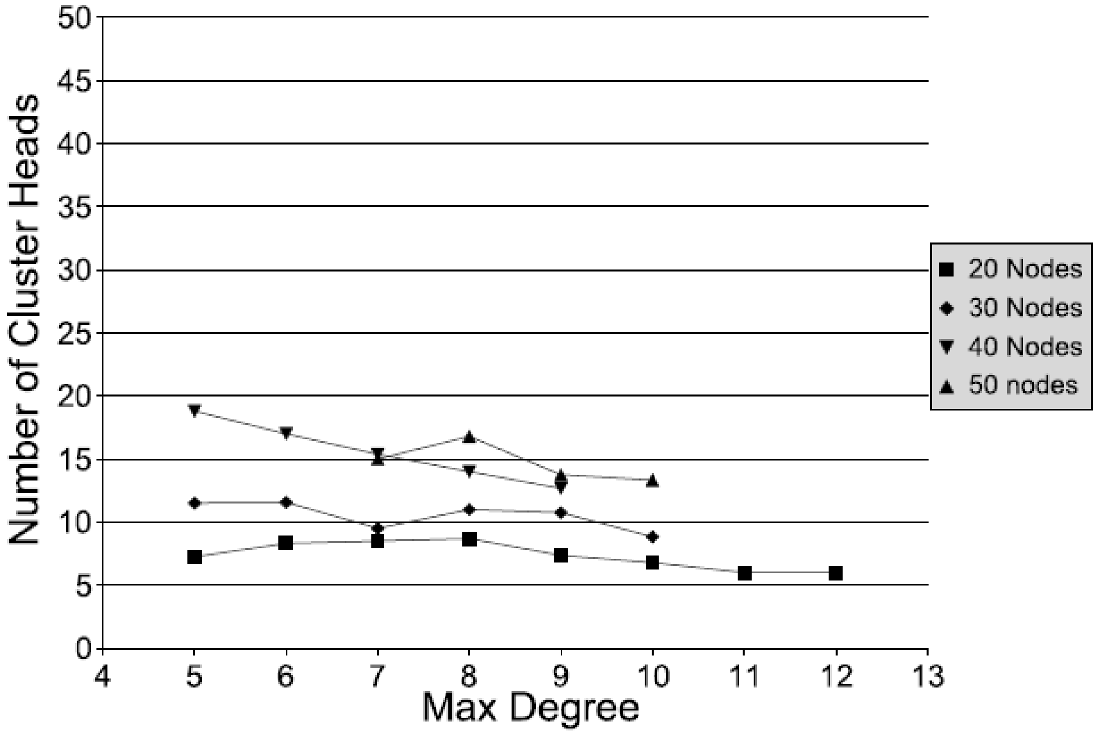

Figure 6.17: Number of Cluster Head on Mumbai-Pune Express Highway in VANET

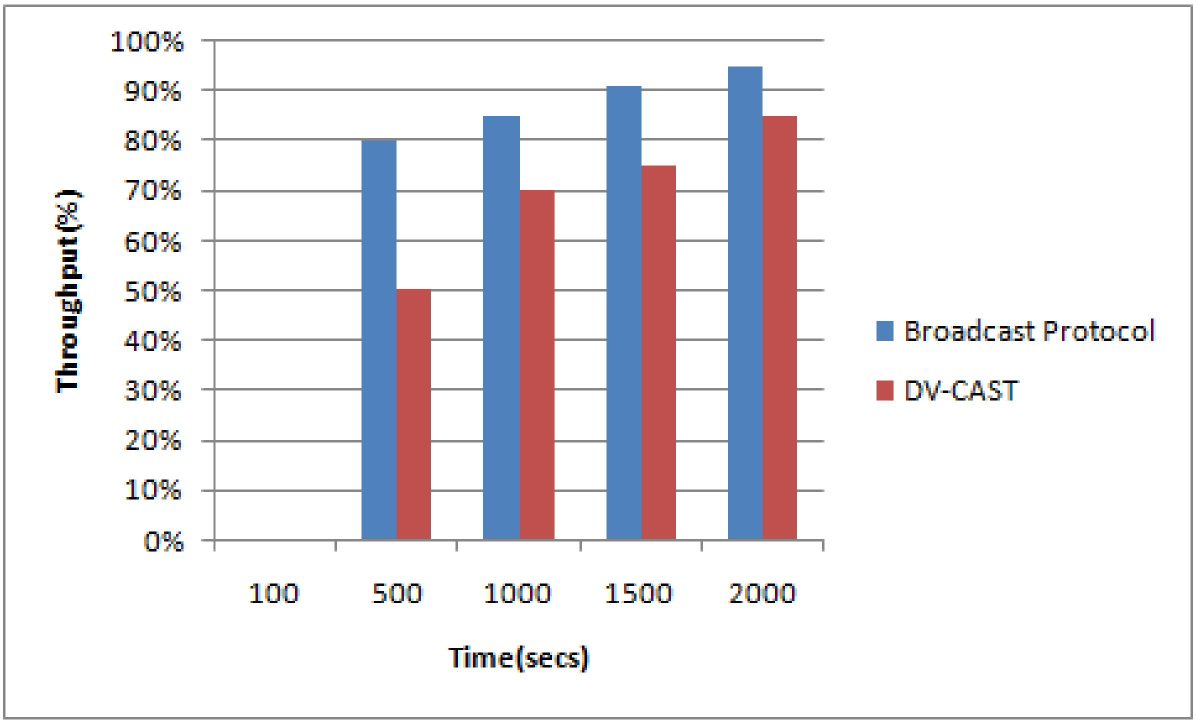

Figure 6.18: Throughput on Mumbai-Pune Express Highway in VANET

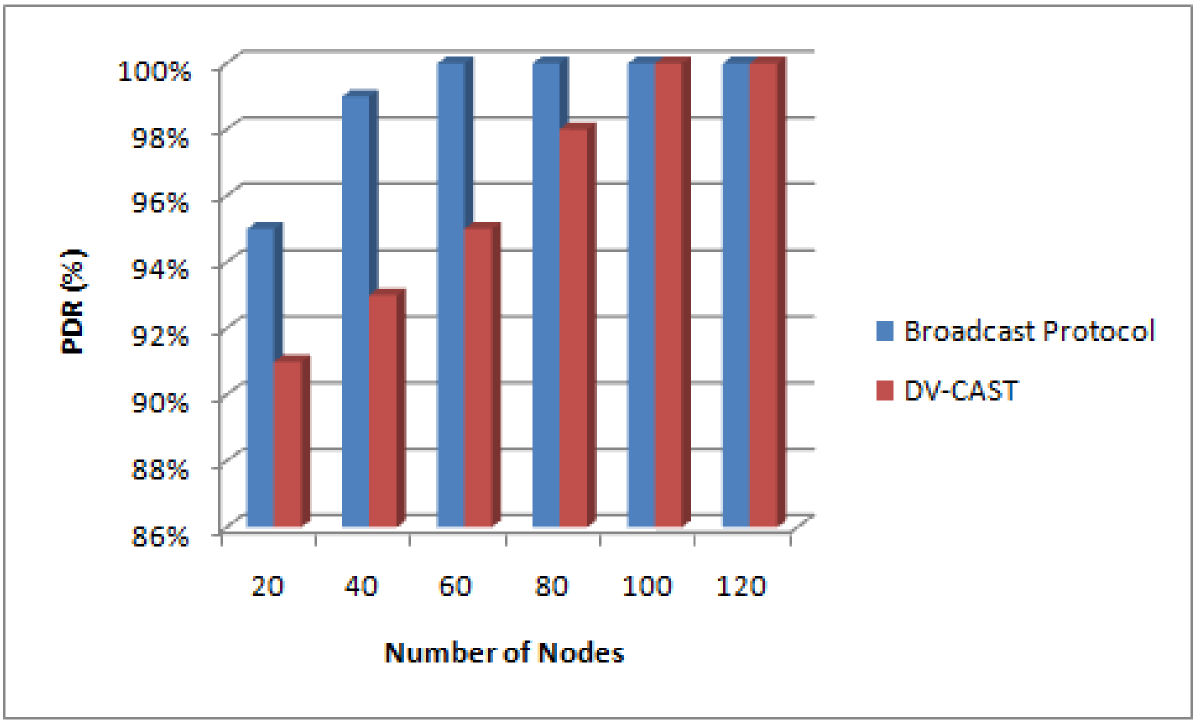

Figure 6.19: PDR on Mumbai-Pune Express Highway in VANET

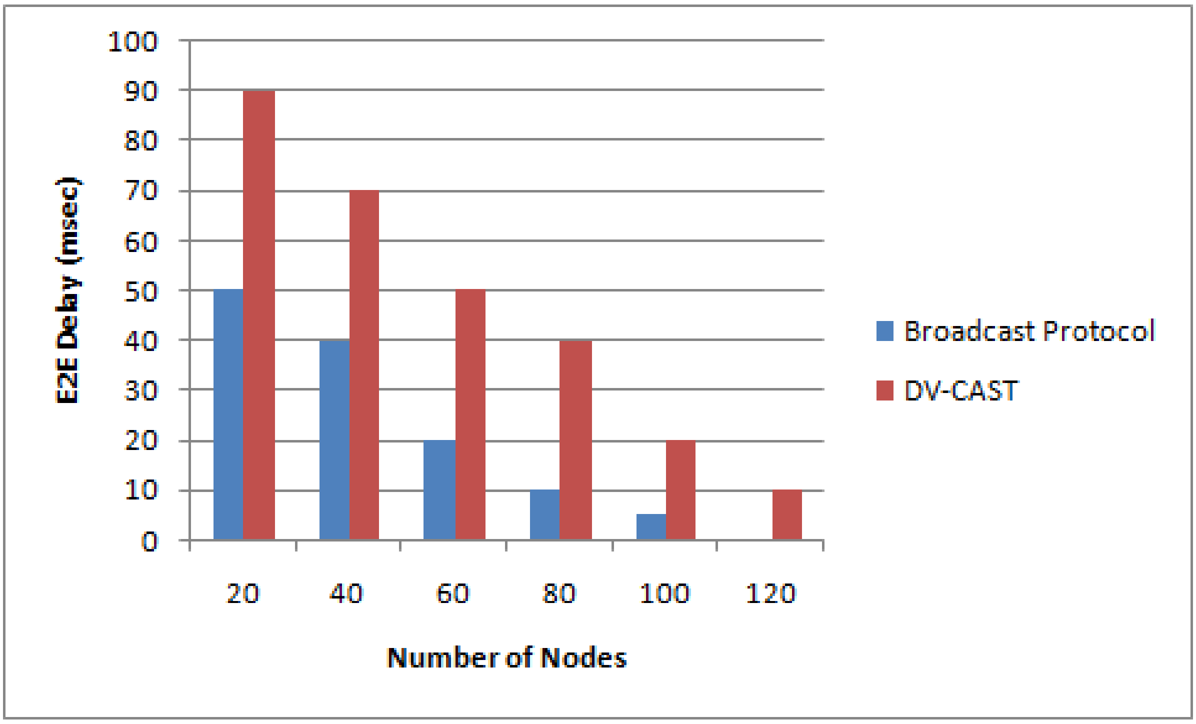

Figure 6.20: E2E on Mumbai-Pune Express Highway in VANET

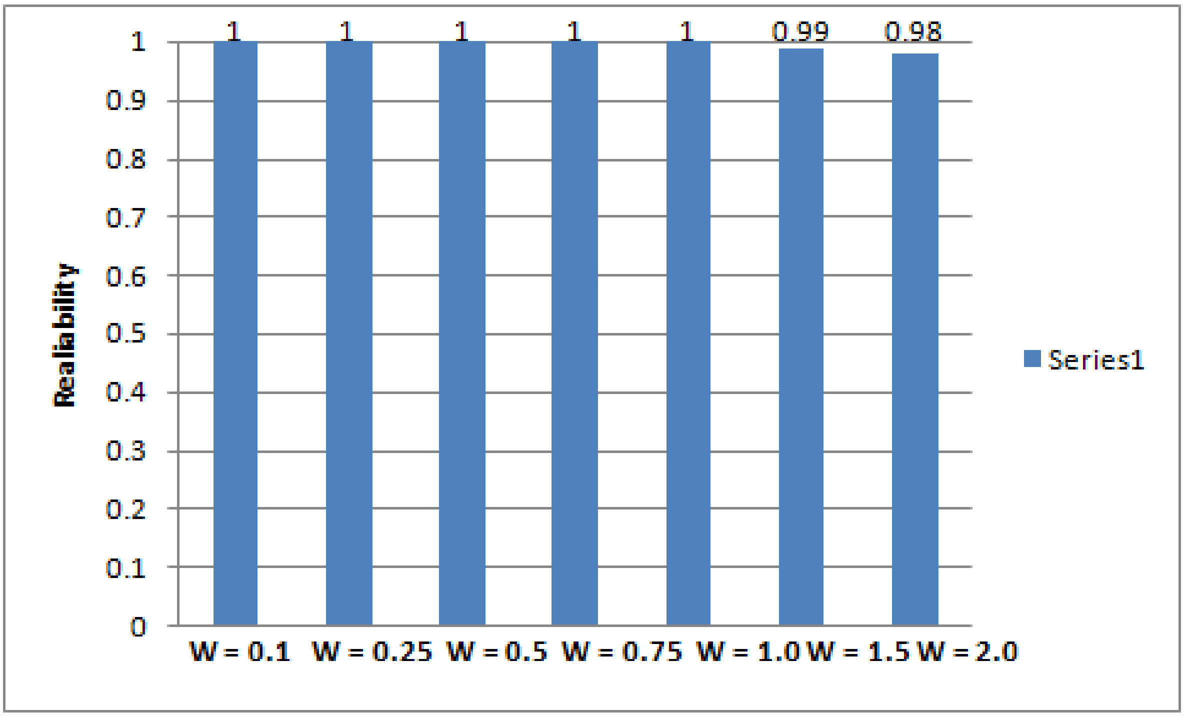

Figure 6.21: Effect of parameter W onto reliability for different traffic injection intervals for Mumbai-Pune Express Highway Scenario. (Interval = $30sec$)

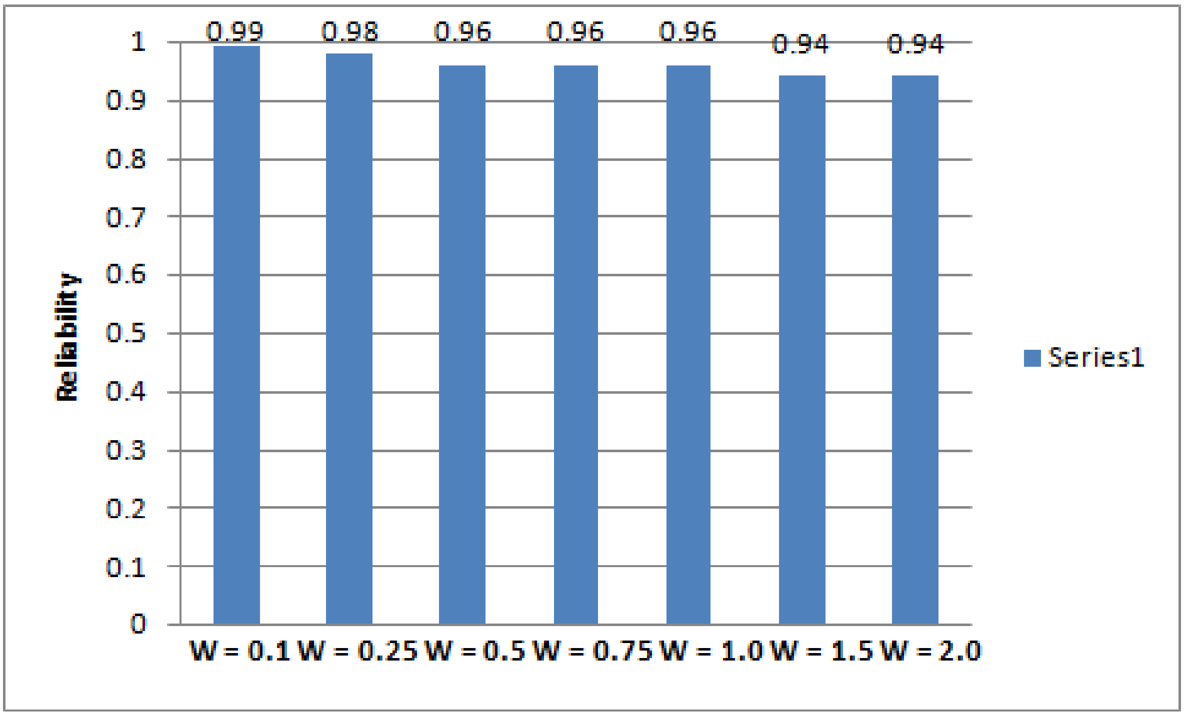

Figure 6.22: Effect of parameter W onto reliability for different traffic injection intervals for Mumbai-Pune Express Highway Scenario. (Interval = $60sec$)

Table 6.2: Reliability Result (%) on Mumbai-Pune Express Highway Scenario for different Injection Intervals (Sec between Injected Vehicles per Route)

Interval	Reliability (Broadcast Protocol)	Reliability (DV-CAST Protocol)
75	$97.1 \pm 2.1\%$	$16.7 \pm 3.1\%$
60	$97.0 \pm 0.5\%$	$20.8 \pm 3.8\%$
45	$96.3 \pm 0.6\%$	20.2 ± 4.6
30	$100 \pm 0\%$	$63.4 \pm 8.1\%$
15	$100 \pm 0\%$	$72.6 \pm 0.1\%$
5	$100 \pm 0\%$	$85.7 \pm 0.3\%$

protocol under consideration, disconnected networks can benefit from low W values. This makes sense because some vehicles might remain as neighbors during a very short period of time may be in 10 ms. If the evaluation time is too high, the link between those vehicles might not exist any longer and the forwarding opportunity would be lost. For denser networks, each protocol tends to converge at 100% reliability, for every evaluated value of W. On the other hand, low W values generally provoke more redundant transmissions, especially in congested Mumbai-Pune Express Highway Road.

The waiting time before retransmission gets higher, the number of needed forwarding decreases. This phenomenon is explained by the use of cluster algorithm, since the neighborhood might receive the message from other retransmissions. However, high W values augment the delivery latency of the broadcasting task, especially in sparse networks. This parameter is not relevant with respect to the protocol overhead. Taking these results into account, recommend low W values for disconnected networks, and slightly higher values for dense ones. Broadcast Protocol behaves very well in all the studied cases when compared to the other approaches. Broadcast Protocol provides high reliability, scalability and efficiency for broadcasting on Mumbai-Pune Express Highway (see Table 6.2) as compared to DV-CAST Protocol.

It is not surprising because they are based upon the Cluster forwarding framework, which is meant to cover the whole network. Among them, Broadcast Protocol achieves the best results. The lowest reliability offered by this scheme, is the 97.1% of the vehicles that could have received the message within cluster and inter-cluster network. On the other hand, DV-CAST offers a very poor reliability, PDR and throughput as compared to Broadcast Protocol for sparse networks, while it only covers around the 75−85% of vehicles when the highest traffic rates are simulated. The reason is that the protocol does not foresee common vehicular movements such as passing maneuvers. For example, refer Figure 6.2. Assume that vehicle f initiated the broadcasting and the message has been propagated backward up to a. All vehicles are in idle state except a, which has the forwarding responsibility at that moment. Then, a speeds up and overtakes the remaining vehicles, forwarding the message to them, and going to idle state. According to DV-CAST (Tonguz et al.), the receivers, discard the message as duplicated and the message custody is lost. No one will forward the message again, even when new vehicles $g; h$ emerge. This problem is derived from different states in which DV-CAST operates depending on the traffic regime which is sensed by a vehicle, since it is hard to foresee every possible combination of movements in vehicular setups. Approach does not suffer from this problem.

Focus now on the number of forwarding for each protocol, shown in Figure 6.22. Given the low reliability of DV-CAST, the number of broadcast messages issued by the protocol is also low. Interestingly, Broadcast Protocol obtained the best reliability, throughput, PDR and E2E delay at the expense of almost as few transmissions as DV-CAST provokes. Furthermore, the number of broadcast messages, issued by Broadcast Protocol is almost constant with respect to the simulated traffic flow rate. This indicates the suitability of Broadcast Protocol as a scalable solution for broadcasting on Mumbai-Pune Express Highway Road, India. It takes advantage of the piggy backed acknowledgments, to reduce the protocol redundancy. When a vehicle node contacts a new neighbor for the first time, new forwarding's are avoided if the latter has already received the message.

However, in the scenario, Broadcast Protocol needs around one forwarding per vehicle. This can achieve high reliability in disconnected networks without requiring every receiving node to retransmit the message.

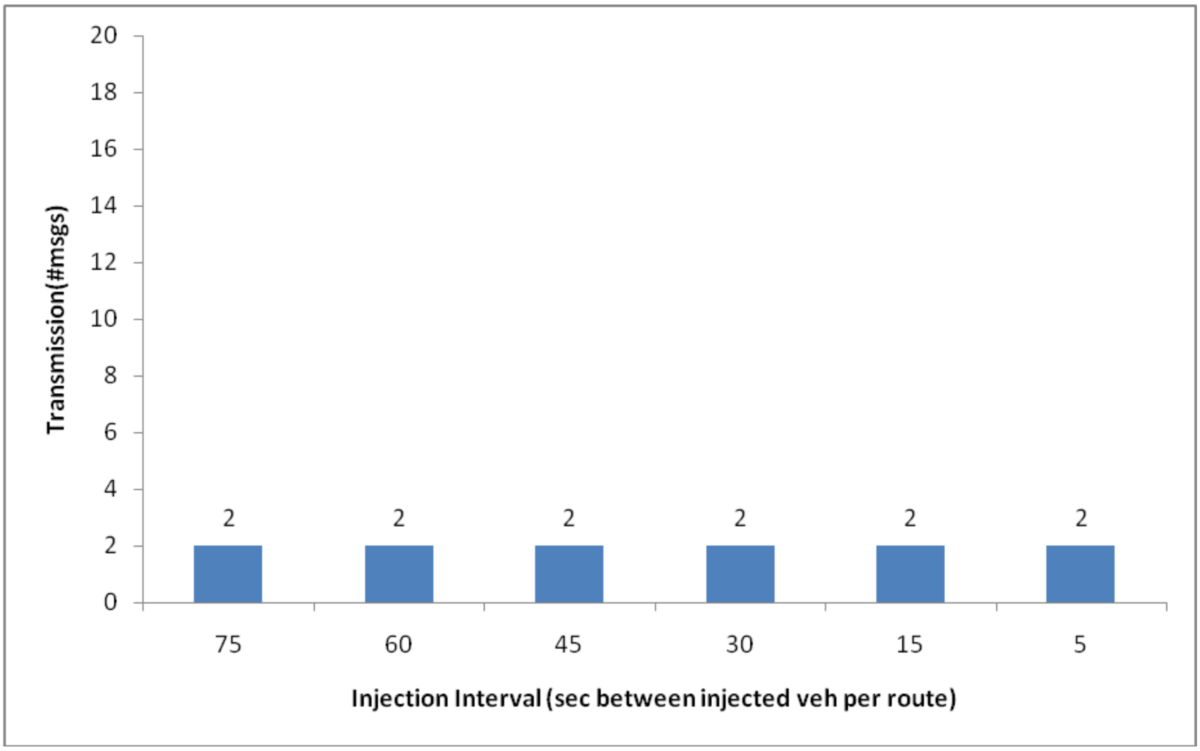

Figure 6.23: Number of data transmissions per vehicle involved on highway

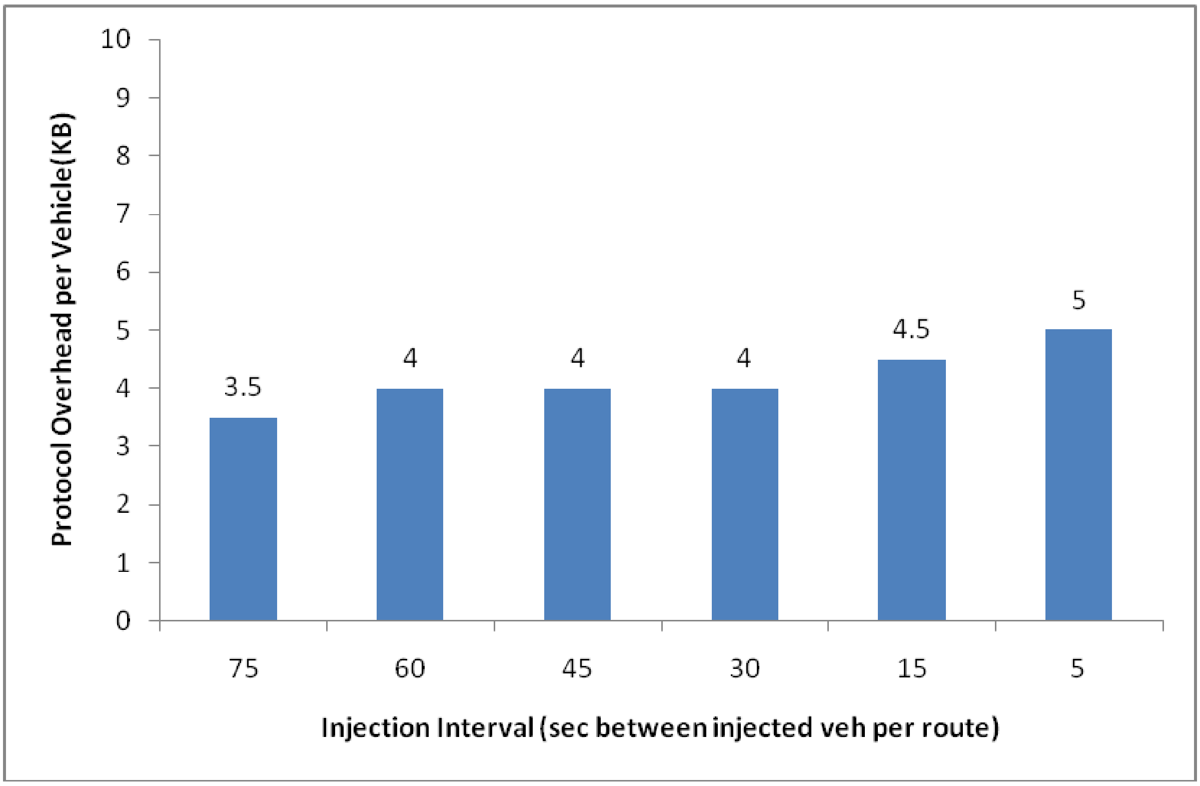

Figure 6.24: Control Overhead (KB) per vehicle on highway

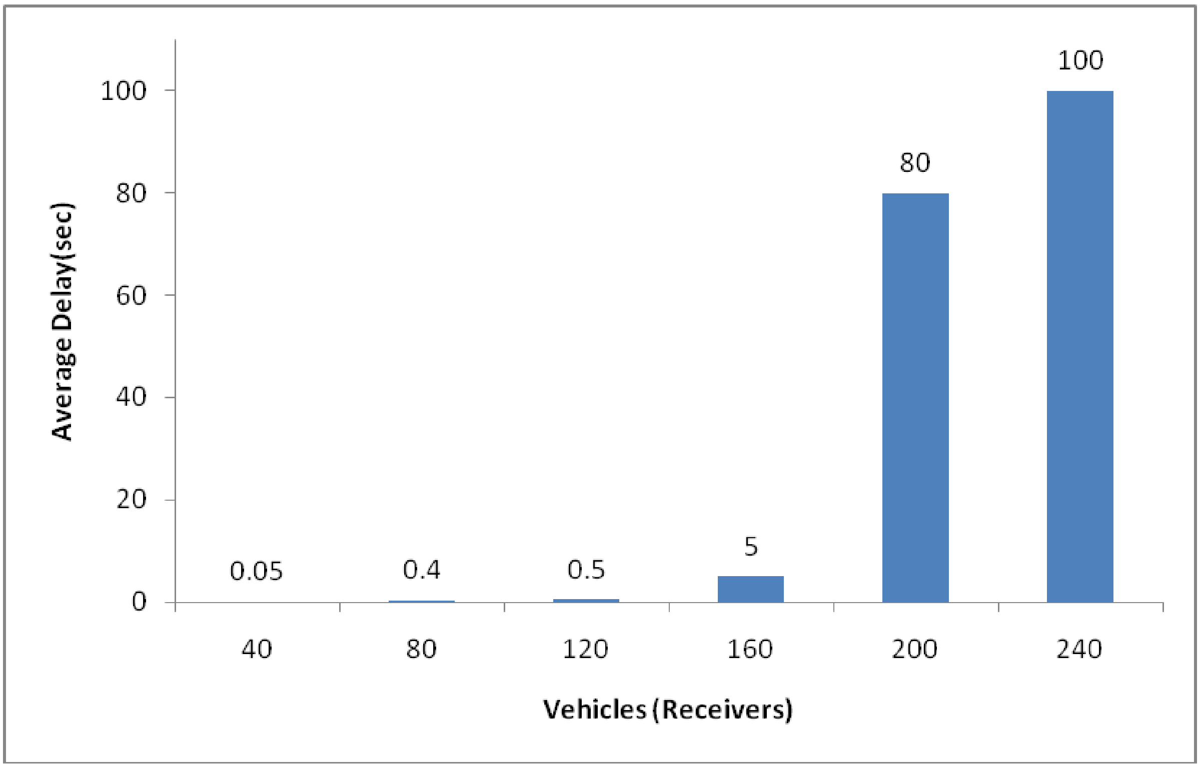

Figure 6.25: Delivery Latency (*sec*) for every receiver in highway scenario.

Simulation result shows that Broadcast Protocol can achieve the best reliability, throughput, PDR and E2E delay results, with the number of transmissions. More important, the redundancy trend of the protocol remains almost constant as density of the network changes. Hence, Broadcast Protocol scales with respect to this parameter. Also investigated, the control overhead introduced in periodic beacon messages, by each protocol. Figure 6.23 draws the values of this metric for different injection intervals. Broadcast Protocol overhead is slightly higher, because it also needs to include an identifier for each received broadcast message. Given the huge reduction in data message transmissions (Figure 6.22), Broadcast Protocol is still the most efficient approach, of all the evaluated ones. Our implementation of DV-CAST is heavier because direction information is added to the beacons. Additionally, it also includes control information inside data messages.

Investigated, the delivery latency that is experienced by Broadcast Protocol to check the message propagation delay, focuses on one run of a dense highway scenario (traffic injection interval is set to 15 *sec* between vehicles per route) and measure the time, since a message is generated until it is successfully decoded by every receiver.

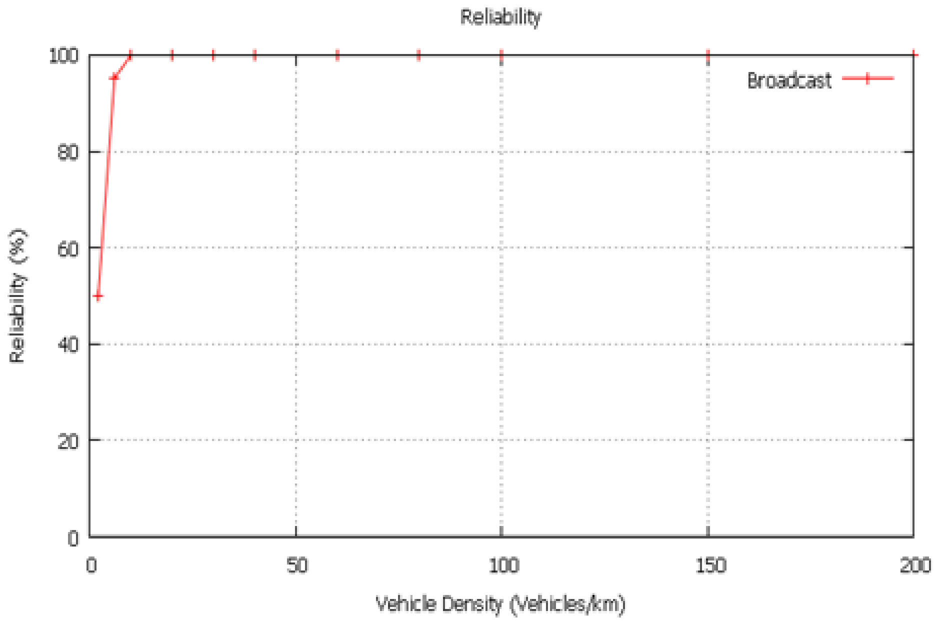

Figure 6.26: Reliability for Highway Scenario.

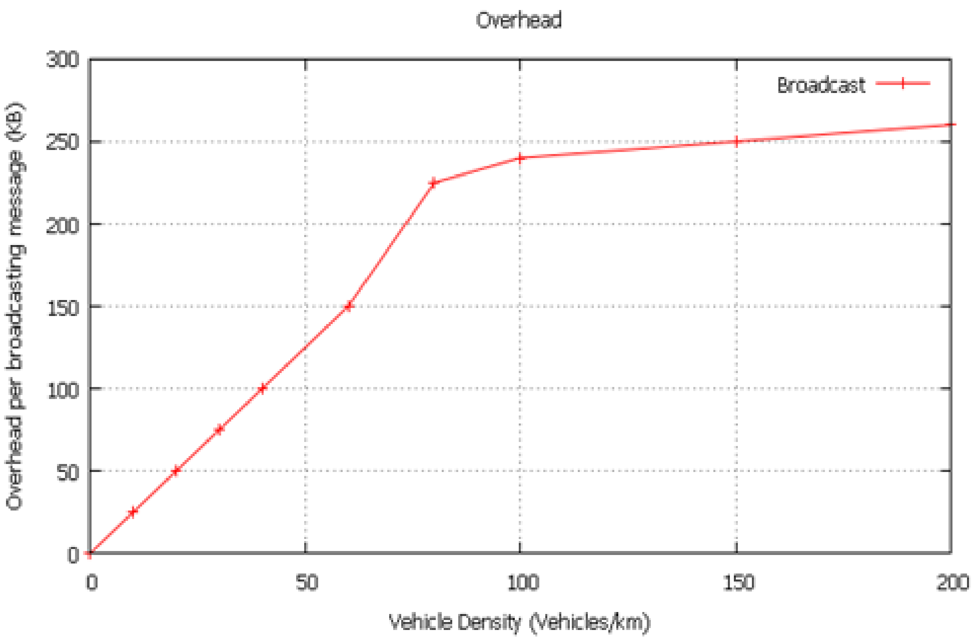

Figure 6.27: Overhead Message for Highway Scenario.

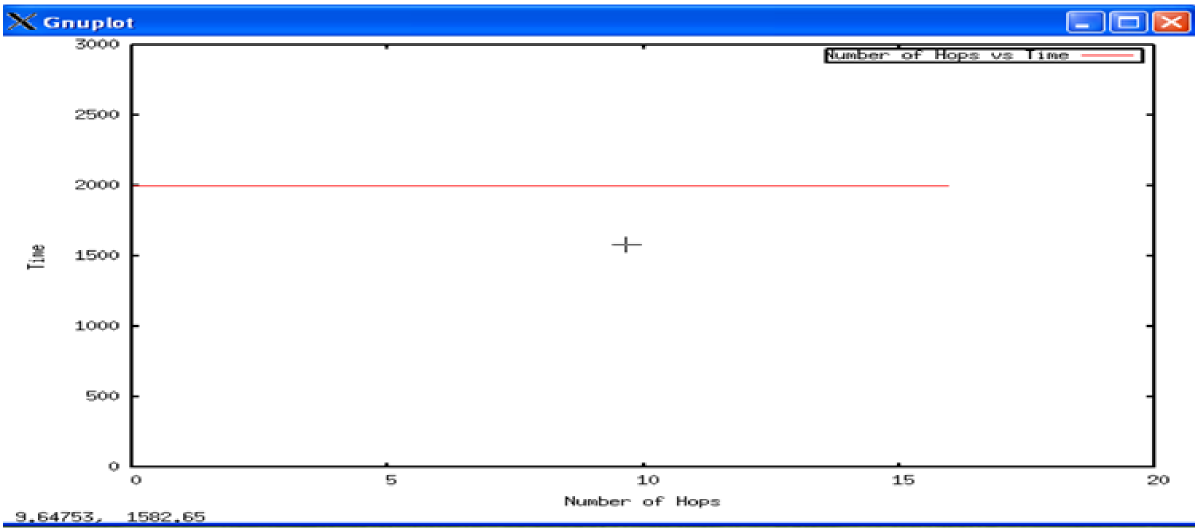

Figure 6.28: Number of Hops for Highway Scenario.

The results of this experiment are shown in Figure 6.24 to Figure 6.27 shows the results of new broadcast protocol for reliability, message overhead for dense network and number of hops for dense network. from the observation it is clearly observed that new broadcast protocol performs better as compared to DV-CAST protocol. The reception time of the message by each vehicle, have formed groups of 40 vehicles, and the average delay of each group is shown along the y-axis. It can be seen that Broadcast Protocol deliver the message faster than the other approaches. With respect to DV-CAST, it incurs larger delays, under common retransmission parameter W. In the connected part of the network, the weighted p-persistence broadcast suppression technique is applied. Hence, the waiting time before retransmission is constant (either W or $W + \delta$), contrary to our adaptive approach, in which this value depends on the local density of the network. Besides, when there are disconnected groups of vehicles that eventually merge, there is an increased latency for every protocol. However, this is higher in DV-CAST because only a subset of vehicles that own the message custody are the ones that can forward it. DV-CAST reaches fewer vehicles, than our solutions, since it cannot reach group of vehicles $161 - 200$ and $201 - 240$.

6.8 Summary

New Broadcast Protocol, which is a localized broadcast protocol for vehicular ad-hoc networks. It is built upon the Cluster algorithm framework. It implicitly uses the store-carry-forward paradigm, typical of delay-tolerant networks and cluster formation algorithm. The pseudo-code employs the position information of the multi-hop neighborhood, acknowledgments and cluster formation of the latest received broadcast messages and warning messages, improve protocol reliability, scalability and efficiency. Broadcast Protocol not only calculate reliability but also scalability and efficiency which makes the protocol better than DVCAST protocol and Khalid Abdel Hafeez protocol. Khalid Abdel Hafeez protocol does not resolves hidden terminal problem and broadcast storm problem totally only reduces redundancy but Broadcast protocol resolves problem of hidden terminal and broadcast storm problem using CDS and cluster algorithm which improves reliability, scalability and efficiency on Mumbai-Pune Express Highway India.

Algorithm 1 Pseudo-code of The Broadcast Protocol

$B \leftarrow$ neighbor set of this node;
$r \leftarrow$ communication range;
$r \leftarrow$1000 meters;
$R \leftarrow$0 ;
$N \leftarrow$0 ;
Event cluster formation and cluster head selection using relative mobility metric for distributed algorithm;
Event message copy received from neighbor s or generated by this node s;
Insert message id in subsequent beacons;
$CM \leftarrow CH$;
$CG \leftarrow CH$;
$R \leftarrow R \bigcup \{s\}$;
$N \leftarrow N/\{s\}$;
$n \in \{B\}$;
for $n \in \{B\}$ **do**
    if dist(n,s) $< r$ **then**
        $R \leftarrow R \bigcup \{n\}$;
        $N \leftarrow N/\{n\}$;
        $Schedule\ to\text{-}ack\ forn$;
    else if $n \notin R$ **then**
        $N \leftarrow N \bigcup \{n\}$;
    else*cancel to-ack*;
        Event to-ack expires;
    end if
end for
if $s = source$ **then**
    forward message via 802.11;
else if $N = 0$ **then**
    cancel to-ev;

else
    Schedule to-ev;
end if
Event beacon received from neighbor n
Add n to neighbor set with in cluster;
Compute CDS;
if beacon contains *ack* **then**
    cancel to-ack for n;
    $R \leftarrow R \bigcup \{n\}$;
    $N \leftarrow N/\{n\}$;
else if $n \notin R$ **then**
    if $n \notin R$ **then**
        Schedule to-ev;
    end if
    $N \leftarrow N \bigcup \{n\}$;
else if $N \neq 0$ **then**
    $R \leftarrow R \bigcup N$;
end if
Event to-ev expires;
if $N \neq 0$ **then**
    $R \leftarrow R \bigcup N$;
    for $n \in N$ **do**
        $schedule\ to - ack$ for n;
    end for
    $N \leftarrow 0$;
    forward message via 802.11;
end if
Event to-ack expires for neighbor n and ack from n never received
$R \leftarrow R/\{n\}$; If $n \notin N$
schedule to-ev;
$N \leftarrow N \bigcup \{n\}$;

Event beacon from n not received for last beacon-hold-time
if $N = \{n\}$ **then**
    $cancel\ to - ev$;
end if
$N \leftarrow N/\{n\}$;
Remove n from neighbor set from cluster;
Compute CDS;

Chapter 7

V2V Communication using IEEE 802.11p and STDMA

Applications for traffic safety, found within the vehicular ad-hoc network environments, can be classified as real-time system. Existing vehicle-to-vehicle safety systems together with new cooperative systems, using wireless data communication between vehicles, can potentially decrease the number of accidents on the highways/roads in India , i.e., transmit the messages within deadline time. In addition, requirements on high reliability and low delay, are imposed on wireless communication system (Blum, A.Eskandarian, and Huffman). For example, Lane departure warning messages, merge assistance and emergency vehicle routing, are all examples of applications. Information that is delivered correctly, but after the deadline in a real-time communication system, is not only useless, but can also have severe consequences for the traffic safety system. This problem is pointed out in (Bilstrup, "Evaluation of the IEEE 802.11p MAC method for vehicle-to-vehicle communication")-(Bilstrup, Uhlemann, and Storm). In most cases, the extremely low delays required by traffic safety applications, the need for ad-hoc network architectures support direct vehicle-to-vehicle communication. The original IEEE 802.11, intended for WLAN, has two drawbacks within its MAC technique CSMA/CA; it can cause unbounded delays, before channel access as well as, collisions on the channel. The MAC protocol, decides who has right data/message to transmit next, on the shared communication channel. In CSMA/CA, the node first listens to the channel, and if the channel is free for certain amount of time period, then the node transmits data/packets directly, with the implication that another node could have conducted the exact same procedure, resulting in a collision on the channel. CSMA/CA is used by IEEE 802.11 family as well as its wired counterpart IEEE 802.3 Ethernet. One of the reasons for the success of both WLAN and Ethernet, is the straightforward implementation of the standard resulting in reasonable priced equipment.

7.1 Overview of MAC Services

7.1.1 Data Services

This service provides peer entities in the LLC (Local Link Control) MAC sub-layer with the ability of exchanging MSDUs (MAC Service Data Units) using the underlying PHY-layer services. This delivery of MSDUs is performed in an asynchronous way, on a connectionless basis (IEEE, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Amendment 8: Medium Access Control (MAC) Quality of Service Enhancements").

7.1.2 MSDU ordering

In nQSTAs, the type simulated in this chapter, there are two service classes within the data service. By selecting the desired service class, each LLC entity initiating the transfer of MSDUs is able to control whether MAC entities are or are not allowed to reorder those MSDUs at reception (Alonso et al.).

7.2 MAC sub-layer functional description

7.2.1 MAC architecture

The MAC architecture can be described as shown in Figure 7.1 as providing the Point Coordination Function (PCF) and Hybrid Coordination Function (HCF) through the services of the Distributed Coordination Function (DCF) (Sjberg),(Bilstrup and Uhlemann).

7.2.2 D C F

DCF is the fundamental MAC technique in the IEEE 802.11 standard. It employs an access function performed by the CSMA/CA algorithm and a collision management function carried out by the binary exponential waiting time procedure.

7.2.3 P C F

The original IEEE 802.11 standard defines another coordination function in the MAC layer. It is only available in structure mode networks, where the nodes are interconnected, through at least one AP in the network.

7.2.4 H C F

HCF is a coordination function that enables the QoS facility. It is only usable in networks that make use of QoS, so it is only implemented in the QSTAs. The HCF combines function from the DCF and PCF with some enhanced, QoS-specific mechanisms and frame subtypes to allow a uniform set of frame exchange sequences to be used for QoS data transfers. The HCF uses both a controlled channel access mechanism, HCCA, for contention-free transfer and a contention-based channel access method mechanism, EDCA.

7.2.5 H C C A

HCCA works similarly to PCF. It uses a QoS-aware centralized coordinator, called a Hybrid Coordinator (HC), and operates under rules that are different from the PC of the PCF.

7.2.6 The EDCA Channel Access Control

Every priority queue, also called Access Category (AC), has different values of Arbitrary Inter Frame Space ($AIFS$), waiting time range. The contention window limits CW_{min} and CW_{max}, from which the random waiting time is computed are variable depending on the AC. The highest the priority, the lowest the value of $AIFS$ and the limits of the contention window [23,24].The table with the different ACs and the values assigned to each one are shown in Table 7.1. The duration $AIFS$ (AC) is a duration derived from the value $AIFSN$ (AC) by the relation:

$$AIFS(AC) = AIFSN(AC) \times SlotTime + SIFS \tag{7.1}$$

where $SIFS$ is the abbreviation for Short Inter-Frame Space period. $SIFS$ is small time interval between two data frame and its acknowledgement. These values are

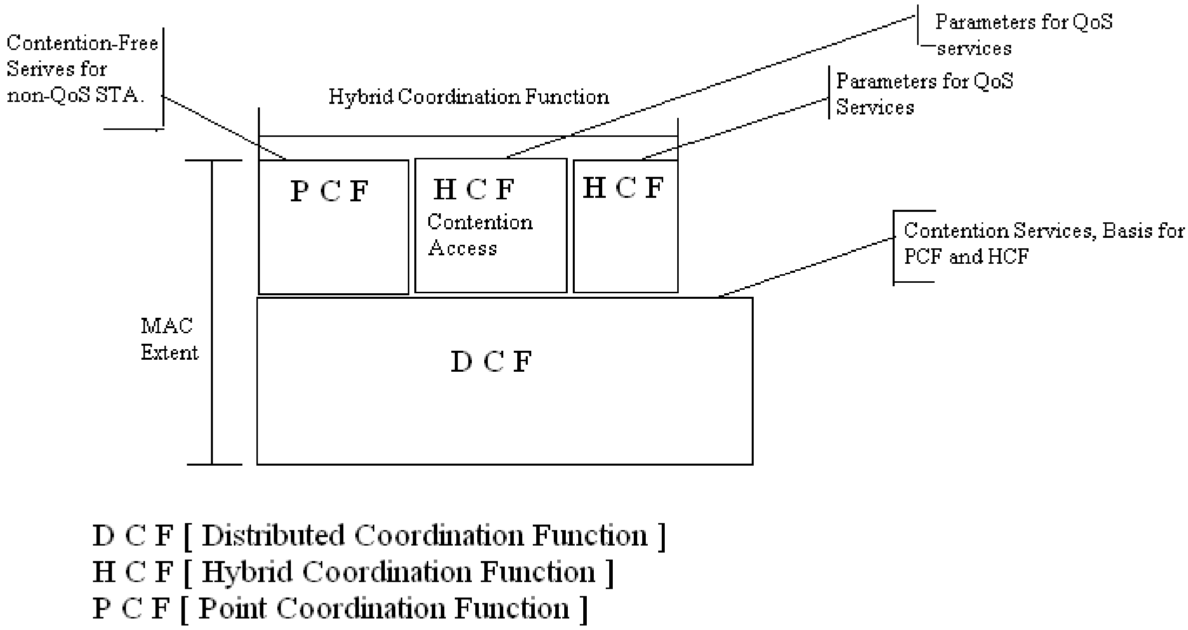

Figure 7.1: MAC architecture

defined in IEEE 802.11, the smallest of all inter frame spaces ($IFSs$) periods. A $SIFS$ duration is a constant value and depends on the amendments to the IEEE 802.11 standard. The shortest $AIFS$ possible value in IEEE 802.11p is $AIFS = 58\mu s$ and this is the value used in our simulations. The slot time is derived from the PHY layer in use: in IEEE 802.11p, *Slot Time* = 13 μs. The waiting time duration is calculated as:

$$WaitingTimeDuration = RandomWaitingtimeValue \times SlotTime \tag{7.2}$$

Apart from real collisions (physical collisions on the medium), that involve queues from two different stations, EDCA introduces of collision: Virtual collisions. Virtual collisions involve two queues belonging to the same transmitting station. If the waiting time procedures of several (up to 4) different queues within the same station finish at the same time slot, the queue with the highest priority has the right to be the first to try to access the medium, while the others will behave as if a real collision occurred, meaning that their contention window is doubled within the contention window range, and that will possibly delay its next trial to access the medium. In (Bilstrup and Uhlemann) a proposal solution to that is described. In Table 7.2, default parameter settings for the different queues in 802.11p are found together with

Table 7.1: Default EDCA parameters for each AC.

AC	CW_{min}	CW_{max}	$AIFSN$
$AC\ VO$	3	15	2
$AC\ VI$	15	31	2
$AC\ BE$	31	500	3
$AC\ BK$	31	1023	5

Table 7.2: Default parameter setting in 802.11p for the EDCA mechanism.

	$Queue-1$	$Queue-2$	$Queue-3$	$Queue-4$
$Priority$	$Highest$	$-$	$-$	$Lowest$
$AIFS$	$58\mu s$	$58\mu s$	$71\mu s$	$123\mu s$
CW_{min}	3	7	15	15
CW_{max}	511	1023	1023	1023

the CW setting.

7.3 CSMA/CA Algorithm

Not dealing with different types of messages, all packets have same priority which are send by the node. Packets with highest priority use $AIFS = 58\mu s$ and $CW = CW_{min} = 3$. Further, will not suffer in simulation from virtual collisions, but only from real collisions (Shankar and Yedla). In addition, all the messages sent are broadcasted and because of that, do not make use of the $SIFS$ concept neither. Dealing with $nQSTAs$, so HCF is not present in our simulations. What it is really of interest in this thesis from the IEEE 802.11p MAC layer are the CSMA/CA algorithm and the exponential back off procedure found in DCF. The CSMA/CA procedure according to IEEE 802.11p, it is, in the broadcast situation with periodic data traffic (CAM packets), is presented in Figure 7.2.

$$AIFS = 34\mu s Slottime = 9\mu s Waitingtime = CW_{min} * Slottime \quad (7.3)$$

The transmitter node starts, by listening to the channel activity during an $AIFS$ amount of time (which in our simulations is 58 μs). If after this time, the channel is sensed free, the message is transmitted. After that, the node checks if a new message from the upper layers is ready to be transmitted, and when there is one, it performs the same action to transmit the new message. If during $AIFS$, the channel is busy or becomes busy, then the node gets a random back off value, generated from an exponential distribution, by multiplying the integer from $[0..CW]$ with the *Slot time* = 9 μs obtaining 0, 13, 26 or 39μs. Value will be decreasing every time the node waits for an $AIFS$, senses the channel free. When the back off value gets to 0, then the message can be transmitted. While the node is getting its back off value decreased, it keeps on checking constantly if a new message was generated in the upper layers and is ready to be transmitted. When that happens, the old message is dropped, and the node starts again with the whole transmission protocol.

7.4 STDMA MAC Layer Algorithm

The Self-Organizing Time Division Multiple Access (STDMA) algorithm, invented in (Bai and Krishnan),(Blum, Eskandarian, and Hoffman), is already used in commercial applications for surveillance, i.e., the Automatic Identification System (AIS) used by ships and the VHF data link (VDL) mode 4 system, used by the avionics industry. Adding data communication based on STDMA, more reliable information can be obtained about other ships and airplanes in the vicinity and thereby accidents can be avoided. STDMA is a decentralized MAC scheme where the network members themselves are responsible for sharing the communication channel. Nodes utilizing this algorithm, will broadcast periodic data messages containing information about their position. The algorithm relies on the nodes being equipped with GPS receivers. Time is divided into frames as in a TDMA system and all stations are striving for a common frame start. These frames are further divided into slots, which typically corresponds to one message duration. The frame of AIS and VDL model 4, is one minute long and is divided into 2250 slots of approximately 26 ms each.

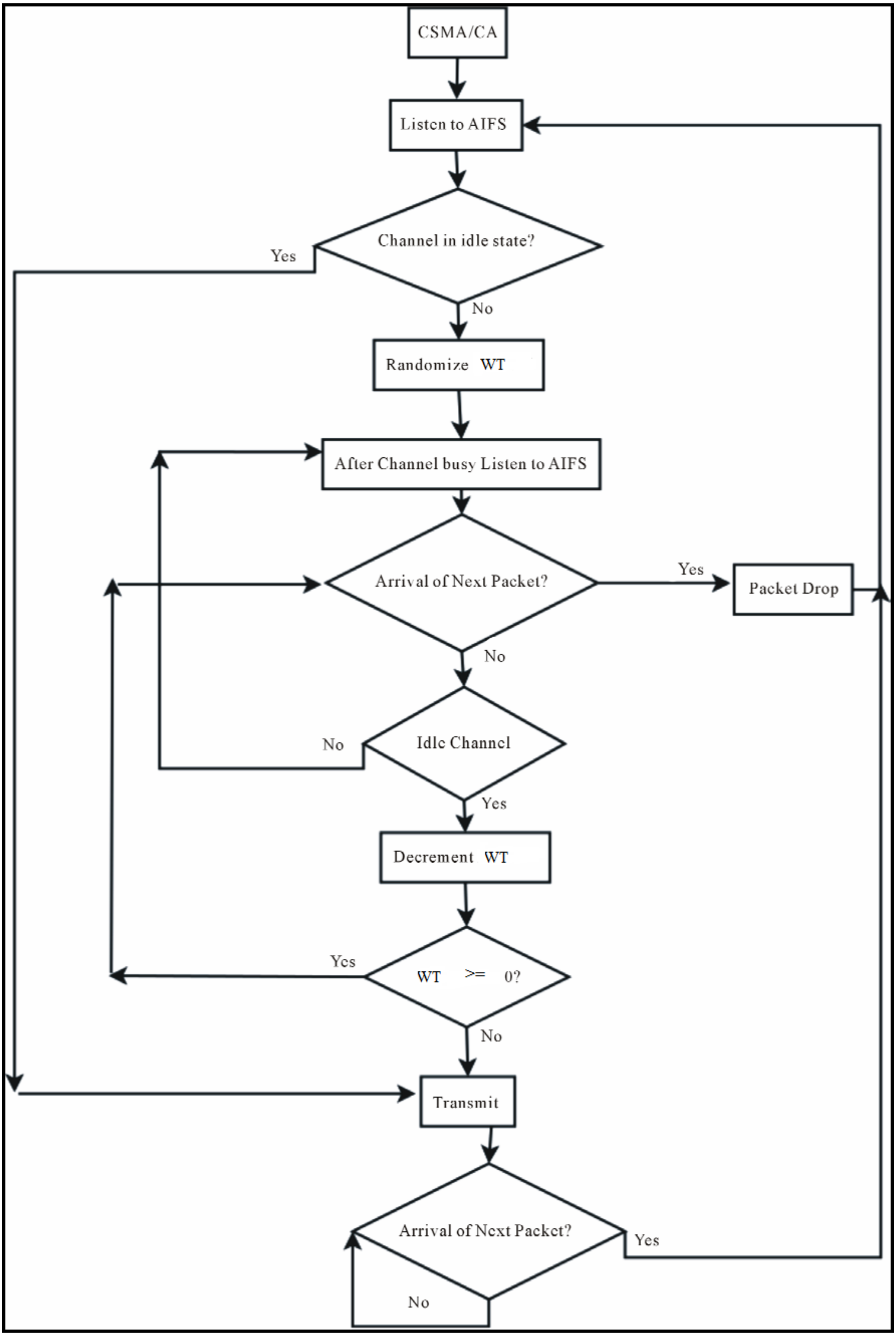

Figure 7.2: CSMA/CA Flow Diagram

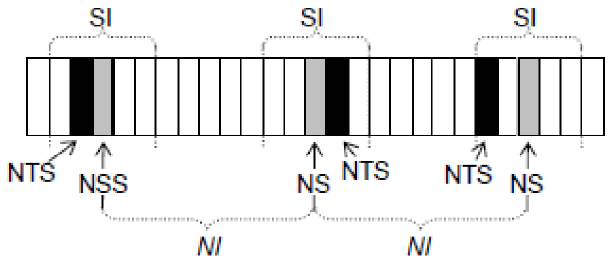

Figure 7.3: The STDMA algorithm in the first frame phase

All network members, start by determining a report rate. Then follows four different phases; initialisation, network entry, first frame, and continuous operation. During the initialisation, a node will listen to the channel activity, during one frame length to determine the slot assignments. In the network entry phase, the node determines its own transmission slots within each frame according to the following rules:

a. Calculate a nominal increment (NI) by dividing the number of slots with the report rate,

b. Randomly select a nominal start slot (NSS) drawn from the current slot up to NI,

c. Determine a selection interval (SI) of slots as 20% of NI and put this around the NSS according to Figure 7.3,

d. Now, the first actual transmission slot is determined by picking a slot randomly within SI and this will be the nominal transmission slot (NTS).

If the chosen NTS is occupied, then the closest free slot within SI is chosen. When the first NTS is reached in the super frame, the node will enter the third phase called the first frame. After the first frame phase (which lasts for one frame), when all NTS were decided, the station will enter the continuous operation phase, using the $NTSs$ decided during the first frame phase for transmission. During the first frame phase, the node draws a random integer $n \in 3, ..., 8$ for each NTS. After the NTS has been used for n frames, a new NTS will be allocated in the same SI as the original NTS.

7.4.1 Continuous Operation Phase

New concept is introduced, the n reuse factor. Every message in a slot has an n value, which decreases within every transmission. When n gets to 0, message has to reallocated in a new slot within the same SI as the former slot. If all slots are busy, then procedure is in the same second phase. Apart from a reallocation, a new n factor is assigned to the new NTS location. This factor is used to cater changes in the network topology. When a node enters in the same transmission range of other node, both of them have a message allocates in the same slot within the frame, will cause collocated transmission, in case they are close to each other packets from collocated transmitters might be lost by the receiving nodes. Without use of n reuse factor, would be suffering from a collision every time, they can get out of the same transmission range. Situation changes when one of them gets its n reuse factor value to 0, so message has to be reallocated to a new slot avoiding from that moment, suffering a collision with other node. The n reuse factor adds flexibility to STDMA, very important since dealing with VANETs, whose nodes are constantly moving. Continuous operation phase is depicted as a flow diagram in Figure 7.4.

7.5 Simulations

The real-time properties of the system, the interesting issue here is how the two MAC protocols will influence the capability, of each sending vehicle node, to timely deliver data/message packets. Dealing with an uncontrolled network, the number of network vehicle nodes, cannot be determined in advance, considering, vehicles are controlled by humans. On the highways/roads, the highest relative speeds are found and this causes the network topology to change often and more rapidly. If a traffic accident occurs, many vehicles could be gathered in a small geographic area implying troubles with access to the shared wireless communication channel, for individual vehicle nodes. The promising emerging application within VANET is a cooperative awareness system, such as the automatic identification system for ships, where vehicles will exchange location messages with each other to build up a map of its surroundings and use this for different traffic safety efficiency application (Alonso et al.). Consequently, have also chosen to use broadcasted, time-driven location messages as the data traffic model in the simulator. Many traffic safety systems will rely on vehicles periodically broadcasting messages containing their current state. Developed a simulator using Open Street Map, eWorld, SUMO version 0.12.3 (traffic simulator), NS-2 version 2.34 (Network Simulator) and TraNs version 1.2 (Intermediate simulator

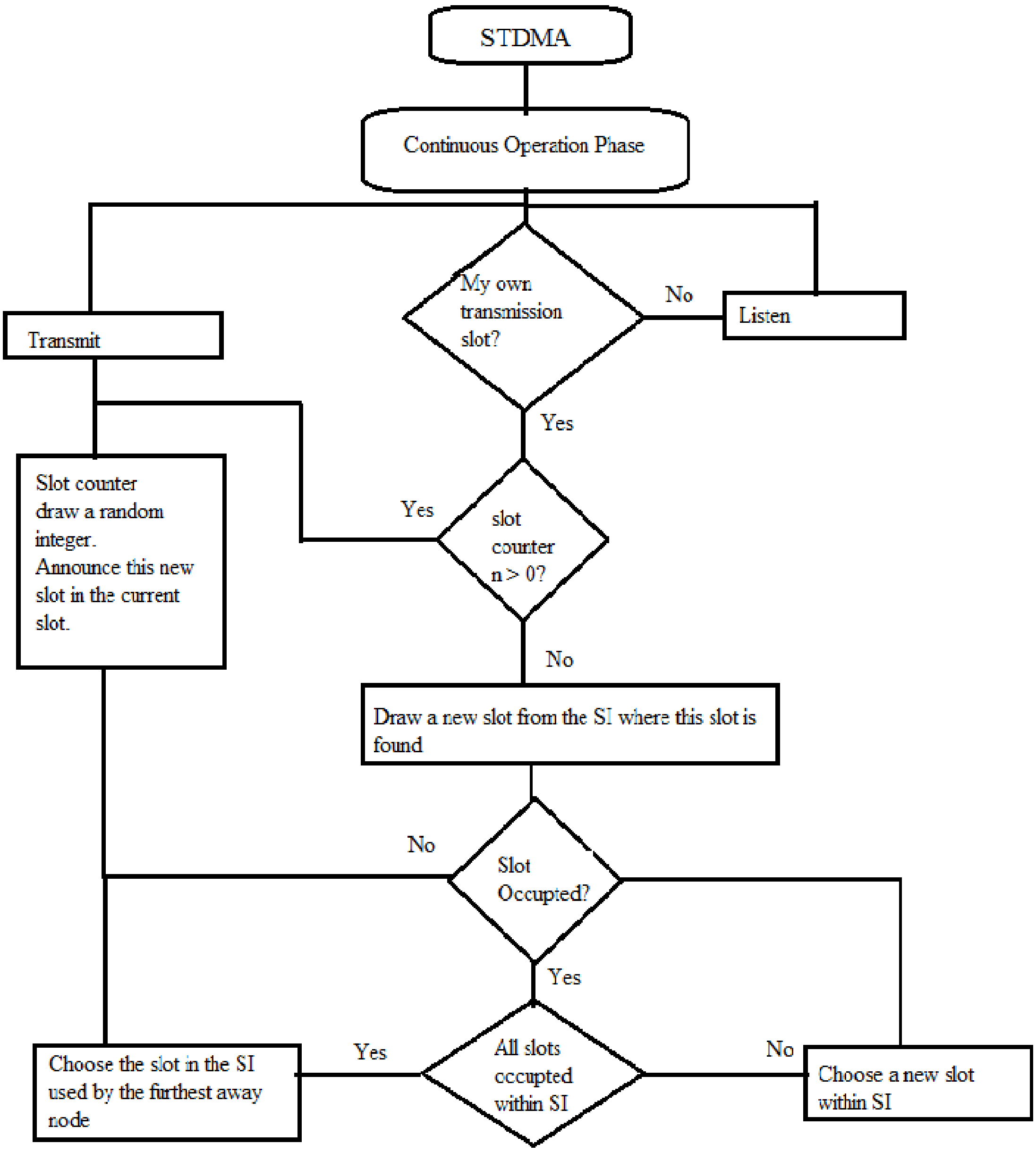

Figure 7.4: Continuous operation phase of STDMA

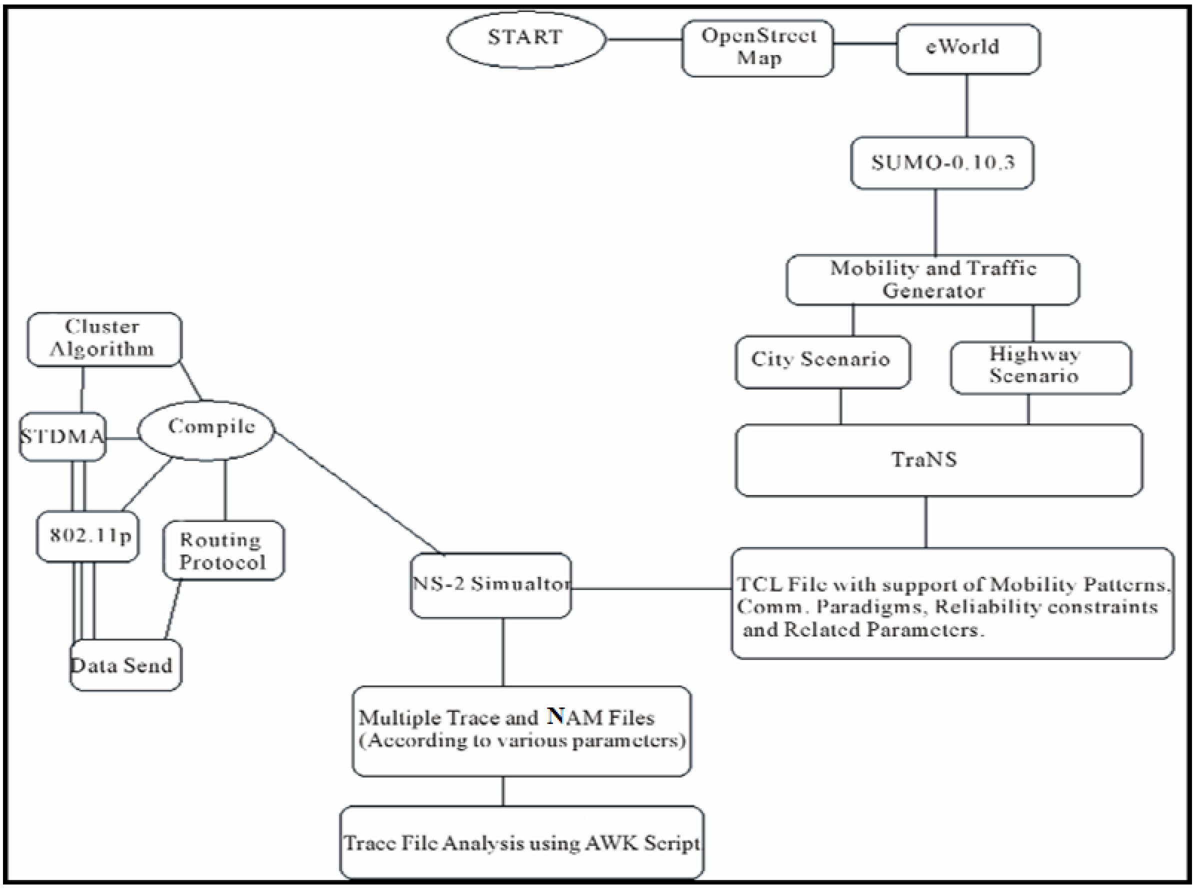

Figure 7.5: Flow diagram for analysis of STDMA protocol for Highway and City Scenario in India.

between SUMO and NS2), also have used Gnu plot, to plot the graphic presentation (Figure 7.6 for Simulation Flow diagram) where each vehicle sends a location message according to a predetermined range of 5 or 10 Hz. The vehicle traffic scenario is Mumbai-Pune Highway Road of 120km , i.e., 12000 $meters$ with 3 lanes in each direction (i.e., total 6 lanes both the directions), see Figure 7.5 and Figure 7.6 shows the simulation flow diagram.

The Mumbai-Pune Highway and Nerul-Vashi cityscenario is chosen because here, the highest relative speeds (i.e., min 80 km/h to max 120 or above km/h) in vehicular environments, are found and hence, it should constitute the biggest challenge for the MAC layer. Vehicles are entering each lane of the highway according to a Poisson process, with a mean inter-arrival time of 3 $seconds$. The channel model is a simple circular transmission model, where all vehicles within a certain sensing range will sense and receive packets perfectly. The simulated, sensing ranges are 500 m and

Figure 7.6: Scenario of Mumbai-Pune Highway Road

1000 m. Have tried to focus on, how the two MAC methods perform, in terms of time between channel access requests until actual channel access within each vehicle node (Bilstrup and Uhlemann). The transfer rate is chosen to be the lowest rate supported by 802.11p, namely $3Mbps$ as in Table 7.3 and 7.5.

Table 7.3: Simulation parameter setting for Mumbai-Pune Highway Road scenario simulation

Parameter	*Value*
Start-point	*Panvel*
End-Point	*Pune*
Simulation Time	*1 hour 30 mins*
Highway Length	120 Km *or* 12000 m
Traffic direction	2 *ways*
Number of Lanes	6 *lanes (* 3 *in each direction)*
Vehicle type	*Cars, Private vehicles, Buses, Trucks, etc.*
Number of Vehicle Nodes	2000

Speed of Vehicle nodes	$80 - 120$ km/h,
Communication Protocol	*802.11p and STDMA*
Traffic type	*UDP*
Message sending frequency	5 Hz, 10 Hz
Message length	*300 bytes,500 bytes and 1000 bytes*
Transfer Rate	3 $Mbps$
Slot time, T_{slot}	$9\mu s$
SIFS, T_{SIFS}	$16\mu s$
CW_{min}	3
CW_{max}	*1023*
Communication Range	500 $meter$, 1000 $meter$
Waiting time Time, $T_{Backoff}$	$0, 9, 18, 27\mu s$
AIFS	34 μs *(the highest priority)*
STDMA frame size	$1s$
No of slots in the STDMA frame	*1165 slots, 718 slots , 418 slots*

The channel model is a simple circular sensing range model, Figure 7.7, in which, every vehicle node within the sensing area, receives the message perfectly. Vehicle nodes could be exposed to two concurrent transmissions, where transmitters T_{X1} and T_{X2} are transmitting at the same time, since the transmitters cannot hear each other: the receivers R_{X1}, R_{X2}, and R_{X3} on Figure 7.7, will then experience collisions of the two ongoing transmissions, unless some sort of power control or multi-user detection is used. The simulation has been carried out, with three different message lengths:

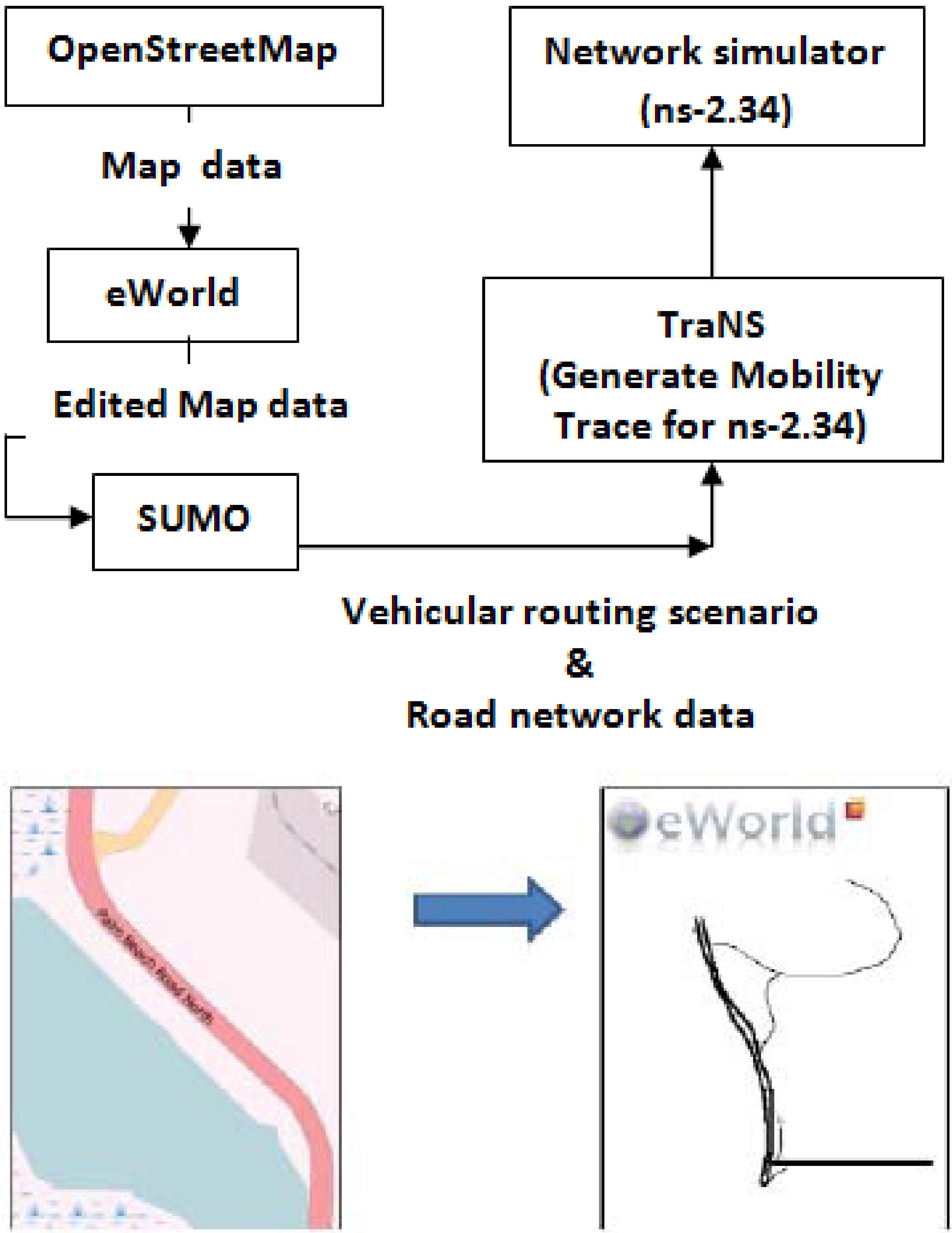

Figure 7.7: Simulation Flow Diagram

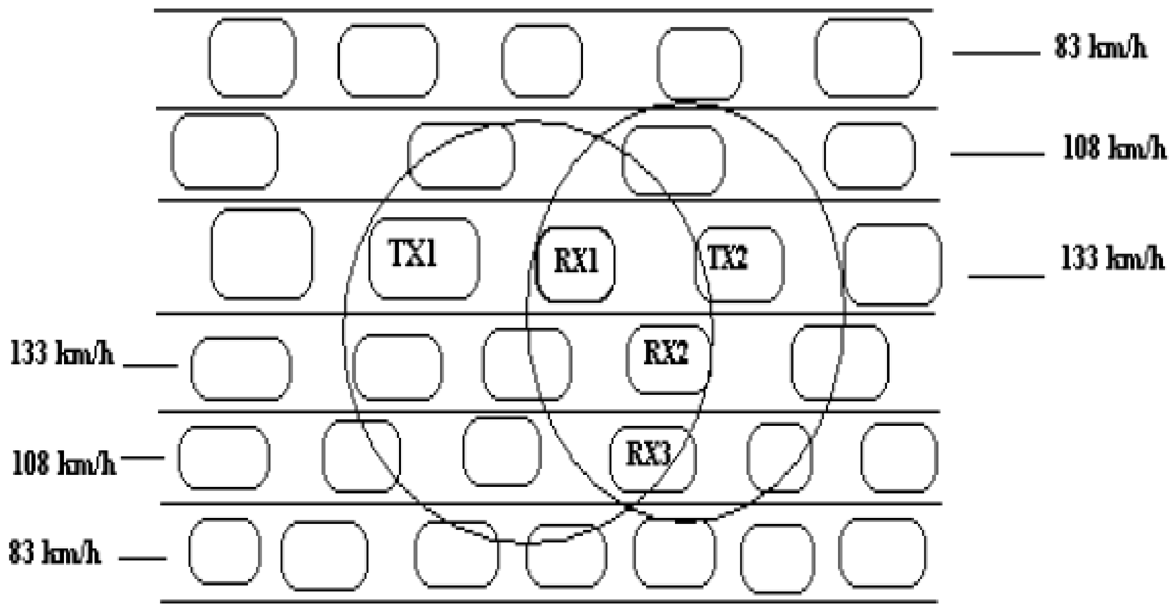

Figure 7.8: Simulation Set-up

N = 300, 500 and 1000 bytes and two different sensing ranges 500 and 1000 meters. In CSMA/CA simulations, all vehicles use the MAC method of 802.11p, and hence each vehicle must listen, before sending and waiting time if the channel is busy or becomes busy during the automatic identification system. A broadcast message, will experience at most one waiting time procedure due to the lack of ACKs in a broadcast system. Since all data traffic in our simulation scenario has the same priority, only the highest priority automatic identification system and CW_{min} have been used therefore, all transmitters will have the same T_{AIFS} value (34 μs). The waiting time time is the product of the slot time, T_{slot}, and a random integer uniformly distributed in the interval $[0, 3]$, implying four possible waiting time times, $T_{backoff}$: 0,9,18 and 27μs respectively. The STDMA algorithm, found in automatic identification system, cannot be used right away since the dynamics of a vehicular ad-hoc network and a shipping network are quite different. There is a natural inertia, inherent in a shipping system, that is not present in the vehicular environment.

MAC protocols used in the simulation, are assumed same physical layer from 802.11p. The frame duration, T_{frame}, in our simulated STDMA scheme has been set to 1 second and the number of slots is changed inside the frame to cater for different message lengths. A transfer rate, R of 3 $Mbps$ has been used and this rate is available with the PHY layer of 802.11p, which has support for eight transfer rates in total, where 3 $Mbps$ is the lowest. In the STDMA simulations, the vehicles will go through three phases:

- Initialisation
- Network entry
- First frame

, before it ends up in the continuous operations. Vehicle stays in a continuous phase after it has been through the other three. STDMA always guarantees channel access even when all the slots are occupied within an SI, in which case a slot belonging to the vehicle node located furthest away will be selected. The time parameters involved in the simulation are selected from the PHY specification of 802.11p. The CSMA/CA transmission time, $T_{CSMA/CA}$, consists of an $AIFS$ period T_{AIFS} in 38 μs, a 30 μs preamble, $T_{preamble}$, and the actual data message transmission, $T_{message}$. The STDMA transmission time, T_{STDMA}, which is the same as the slot time, consists of two guard times, TGT, of 2 μs each, $T_{preamble}$, $T_{message}$, and two $SIFS$ periods, $TSIFS$ of 18 μs each derived from the PHY layer in use. The total transmission time for CSMA/CA is

$$T_{CSMA/CA} = T_{AIFS} + T_{preamble} + T_{message} \tag{7.4}$$

and the total transmission time for STDMA is

$$T_{STDMA} = 2T_{GT} + 2T_{SIFS} + T_{preamble} + T_{message} \tag{7.5}$$

Assume, that all the vehicle nodes on Mumbai-Pune Express Highway are perfectly synchronized with each other in both MAC protocol scenarios and that in the STDMA case, they are also aware of, when the frame starts and how many time slots it contains. The delay that takes to a message sent from the transmitting vehicle until it is decoded by the receiving vehicle at the MAC layer level. This delay is expressed as:

$$T_{MM} = T_{ca} + T_p + T_{dec} \tag{7.6}$$

At the receiver side, to be a message candidate, to be decoded and sent it to higher layers, it should have arrived within maximum 100 ms, which is the maximum allowed delay, at the receiver vehicle for CAM messages to be considered.

7.6 Performance Evaluations of CSMA/CA and STDMA

Since CSMA/CA will be the prevailing MAC method of emerging standards for VANET based Mumbai-Pune Express Highway road traffic safety applications. In addition, STDMA as described will also be evaluated, since this MAC method has the potential to fulfil the requirements imposed by VANET based road traffic safety applications. The channel access delay highlights the ability of the MAC method to provide a predictable delay which is a functional requirement. The message reception probability is a non-functional requirement, i.e., a quality measure determining how well the MAC method schedules transmissions in time and space.

The performance of CSMA/CA and STDMA has been evaluated by means of computer simulations in SUMO and NS2.34. The highway scenario was selected to model the vehicle traffic pattern since the highest relative speeds are 80 km per hour to 120 km per hour are found here and therefore it is likely the most stressing case for the MAC methods since stations can show up and quickly disappear again due to high velocities.

A 120 km highway scenario with 6 lanes, three in each direction, has been used for the simulations. The vehicles arrive at the highway entrance in each direction in each lane according to a Poisson distribution with mean inter-arrival time of three seconds. The vehicle speeds are drawn independently from a Gaussian distribution with a common standard deviation of 1 m/s, but with three different mean values (23 m/s, 30 m/s, and 37 m/s) depending on lane. The vehicles maintain the same speed as long as they are on the highway and overtaking is not considered (i.e., vehicles may pass in the same lane by driving over each other). The resulting vehicle density is then approximately 120 vehicles/km of highway (in total about 1200 to 2000 vehicles on the highway at the same time). All vehicles are moved every 100 ms. Simulation is carried out by parameters setting in Table 7.3. Data from the simulations have been collected only when the Mumbai-Pune Highway Road was filled with vehicles. The results from all 20 simulated scenarios using CSMA/CA are shown in Table 7.4 where the numbers represent the data message drops in percent. A data message is

Table 7.4: Message drops on average for different data traffic scenarios.

CSMA/CA		*Sensing range*			
CSMA/CA		*500 meter*		*1000 meter*	
Data Message Rate		5 Hz	10 Hz	5 Hz	10 Hz
Message length	300 *byte*	0%	0%	0%	36%
Message length	500 *byte*	0%	23%	34%	54%
Message length	1000 *byte*	0%	30%	45%	60%

dropped or discarded by the vehicle node when the next data message is generated.

From Table 7.4 it can be seen that, if 1000 *byte* long data packets are sent every 100 ms and the sensing range is 1000 $meters$, only 45% of the channel access request will result in actual channel access for 802.11p. But, this value is averaged over all transmissions made by all vehicles in the system, which means, that certain nodes experience an even worse situation. In Figure 7.8, the best and worst performance experienced by a single user is depicted together with the average for all users in the system. In the worst case, a vehicle node achieves successful channel access only 14% of the time, i.e., 85% of all generated packets in this vehicle node are dropped. When the sensing range is 1000$meters$, a vehicle node will compete for the channel with approximately 230 other vehicle nodes.

7.6.1 Channel access delay

In Figure 7.8, the CDF of the channel access delay for CSMA/CA is depicted for all update rates when using the Nakagami channel model described above. In Figure 7.8 update rates of $2-20$ Hz is shown, no station experiences a channel access delay that is longer than 3 ms. In Figure 7.8 , depicting update rates $2 - 20$ Hz, a maximum channel access delay of 12 ms is encountered for the highest update rate, 20 Hz. It can be concluded that with an update rate of 2 Hz, 85% of all generated packets achieve channel access after the mandatory minimum waiting time of an $AIFS$ of 71 μs, whereas with an update rate of 20 Hz , less than 10% of all generated packets

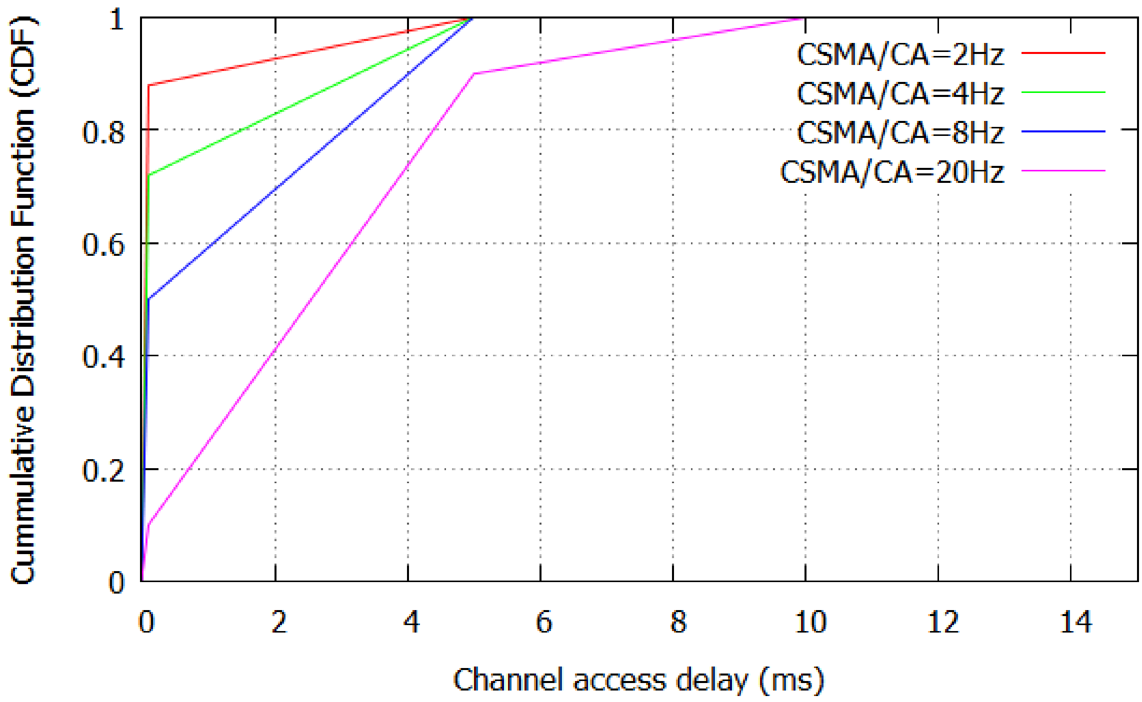

Figure 7.9: Channel access delay for CSMA/CA when using the Nakagami model; update rate of 2/4/8/20 Hz

experience the same minimum wait, implying that 90% of all initial transmission attempts result in a waiting time procedure. In STDMA, the channel access delay is upper-bounded, i.e., a station always knows when it is allowed to transmit during its SI intervals. However, the size of the SI depends on the number of packets transmitted in one second. As the update rate increases, the SI will shrink and thereby the number of slots contained in the SI also reduces. In Figure 7.9, the channel access delay for STDMA is depicted with the same update rates and channel model, as for CSMA/CA in Figure 7.8. As can be deduced from Figure 7.9, the worst case channel access delay that STDMA can exhibit is 100 ms and this occurs when the update rate is set to 2 Hz (implying 500 ms between every generated message). However, 50% of the generated packets have been transmitted after 50 ms even in this case. Conversely, the shortest channel access delay occurs for 20 Hz (i.e., 50 ms between every generated message), yielding a maximum channel access delay of 10 ms. The staircase appearance of the curves is due to the number of slots in each SI. It should be noted that the channel access delay encountered in STDMA is neither affected by the channel model nor the network load. Consequently, the same channel

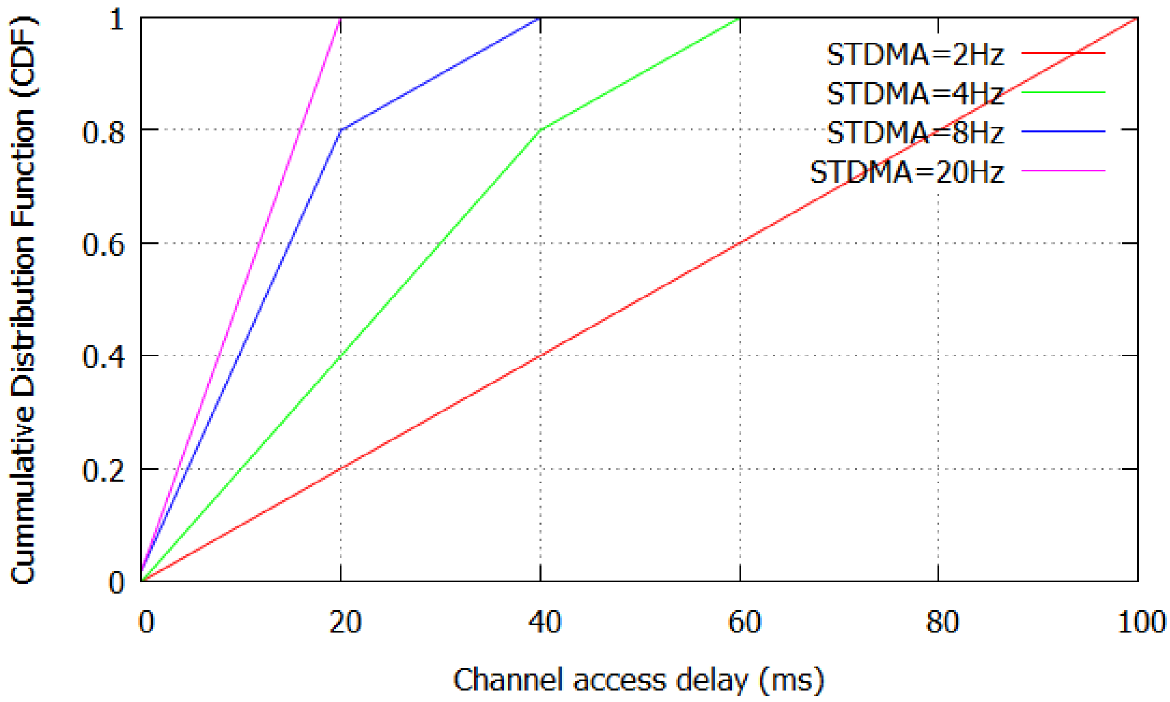

Figure 7.10: Channel access delay for STDMA; update rate of 2/4/8/20 Hz

access delays are also found for the LOS/OLOS model when STDMA is used. For CSMA/CA using the LOS/OLOS channel model, the channel access delay is depicted on Figure 7.10. On Figure 7.11, the Nakagami and LOS/OLOS models are compared for CSMA/CA. It can be concluded that, the channel access delay is affected by the channel model in use and that the LOS/OLOS model implies longer channel access delays. This is due to the fact that the LOS/OLOS channel model has a successful message reception range that is slightly longer than in the Nakagami case, implying that each station has slightly more stations within its radio range. These additional stations keep the channel occupied more often, forcing more stations into the waiting time procedure and thereby increasing the channel access delay. When evaluating the channel access delay for CSMA/CA and STDMA it can be concluded that while the minimum delay is smaller for CSMA/CA than for STDMA, the worst case delay is random for CSMA/CA. For STDMA, the worst case channel access delay is known and independent on network load and channel type.

Figure 7.12 shows the message reception probability for CSMA/CA and STDMA, respectively, with the update rates: 2/4/8/20 Hz and the Nakagami channel model. The blue upper bound curve, denoted G̈enie¨ in Figures 7.12 - Figure 7.15, is the single

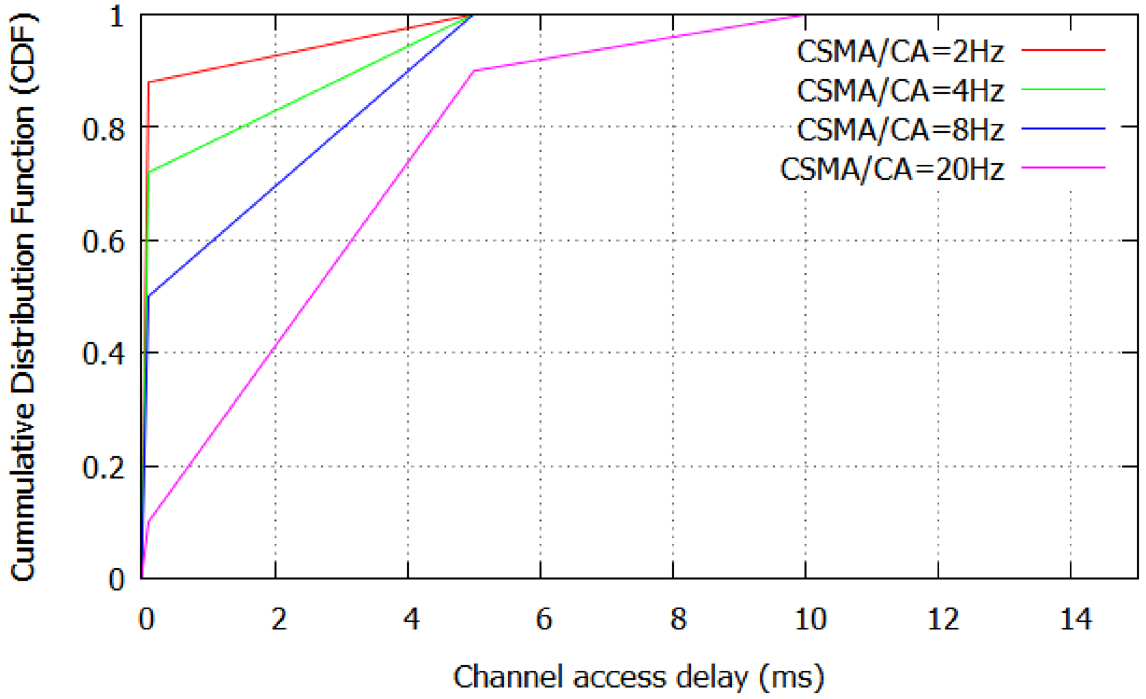

Figure 7.11: Channel access delay for CSMA/CA when using the LOS/OLOS model for the following update rates; 2/4/8/20 Hz

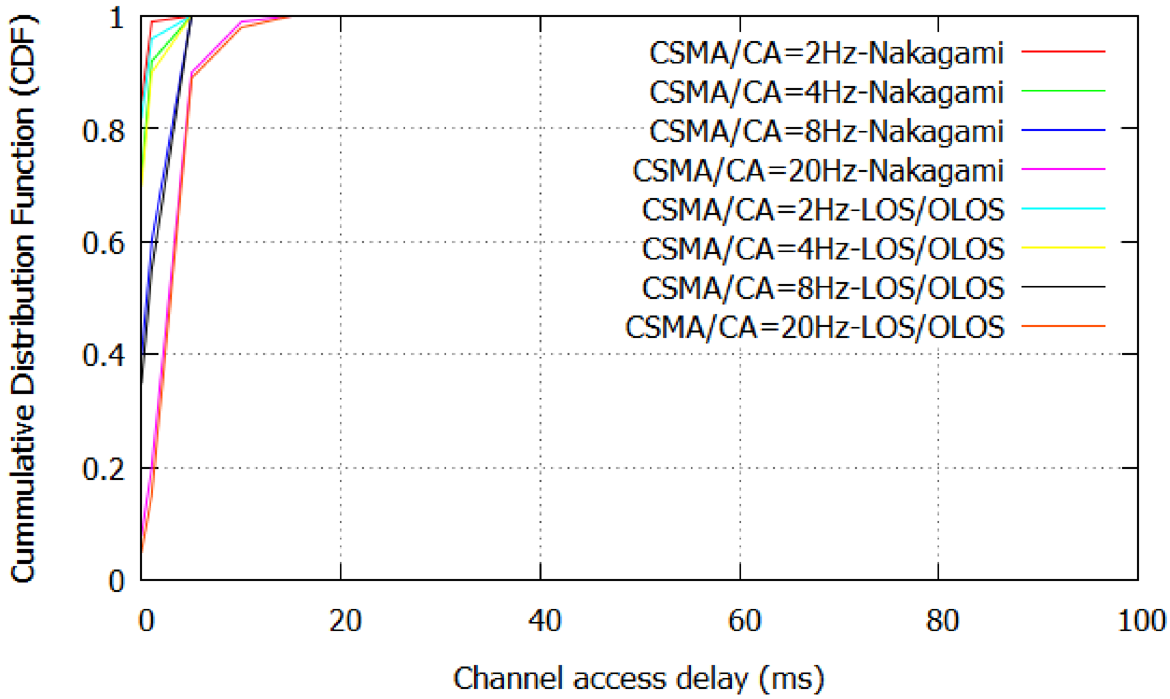

Figure 7.12: Channel access delay for CSMA/CA when using the LOS/OLOS model and the Nakagami model for the following update rates; 2/4/8/20 Hz

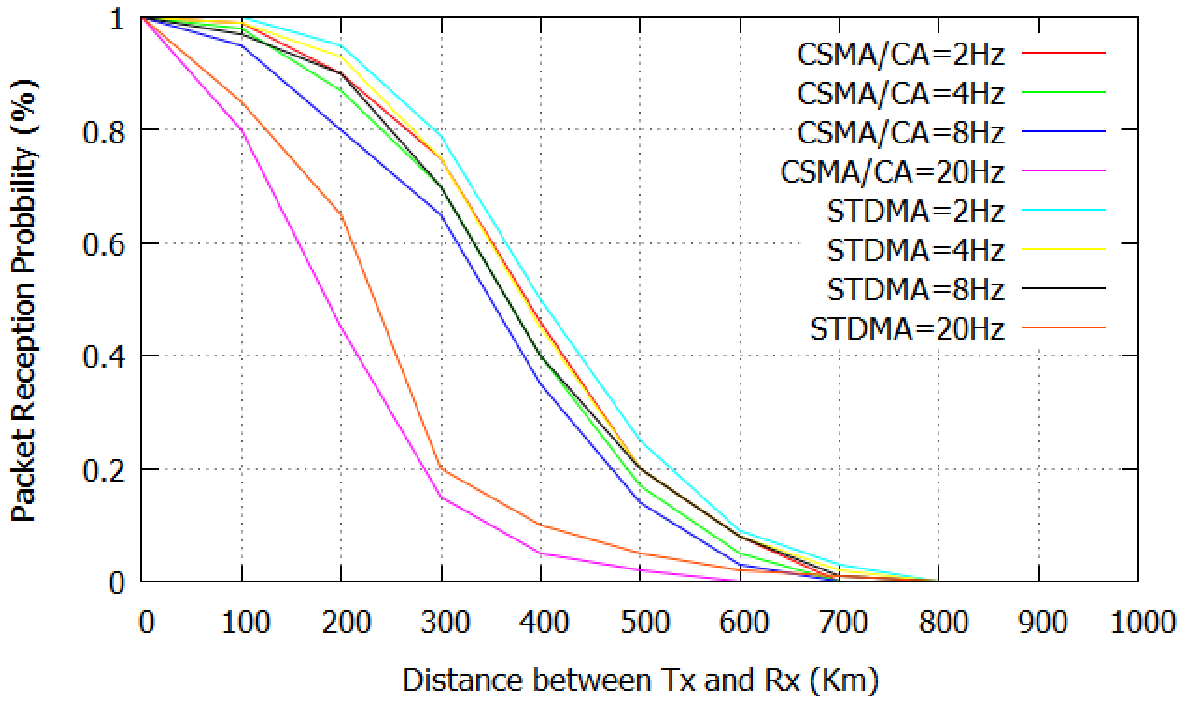

Figure 7.13: Message reception probability for update rates of $2, 4, 8, 20\ Hz$ using the Nakagami model; CSMA/CA, and STDMA

transmitter case, i.e., no MAC method is needed, as there is only one transmitter in the system and no interferes, implying that this is an unattainable upper bound for any network with more than one transmitter. Note that the update rate does not affect the message reception probability per se, but since more transmissions take place, the probability of interferers is higher, which affects the probability of successful reception. From Figure 7.12, it can be concluded that STDMA has a higher message reception probability for all considered rates, i.e., closer to the Ğenie¨ compared to CSMA/CA.

In Figure 7.13 the two MAC schemes are shown together for all considered rates. When RX is close to T_X ($< 100 meters$) both MAC methods perform equally well. However, when the T_X-R_X distance increases, STDMA achieves a higher message reception probability. At a T_X-R_X distance of 300 $meters$ and an update rate of 6 Hz (Figure 7.14) and 8 Hz (Figure 7.14), 10 Hz (Figure 7.15) and 20 Hz (Figure 7.15) there is roughly a 20% performance gain with STDMA as compared to CSMA/CA. For an update rate of 20 Hz, which can be regarded as an overloaded scenario, there is too much interference in the system, for any of the two protocols, and the gap to the

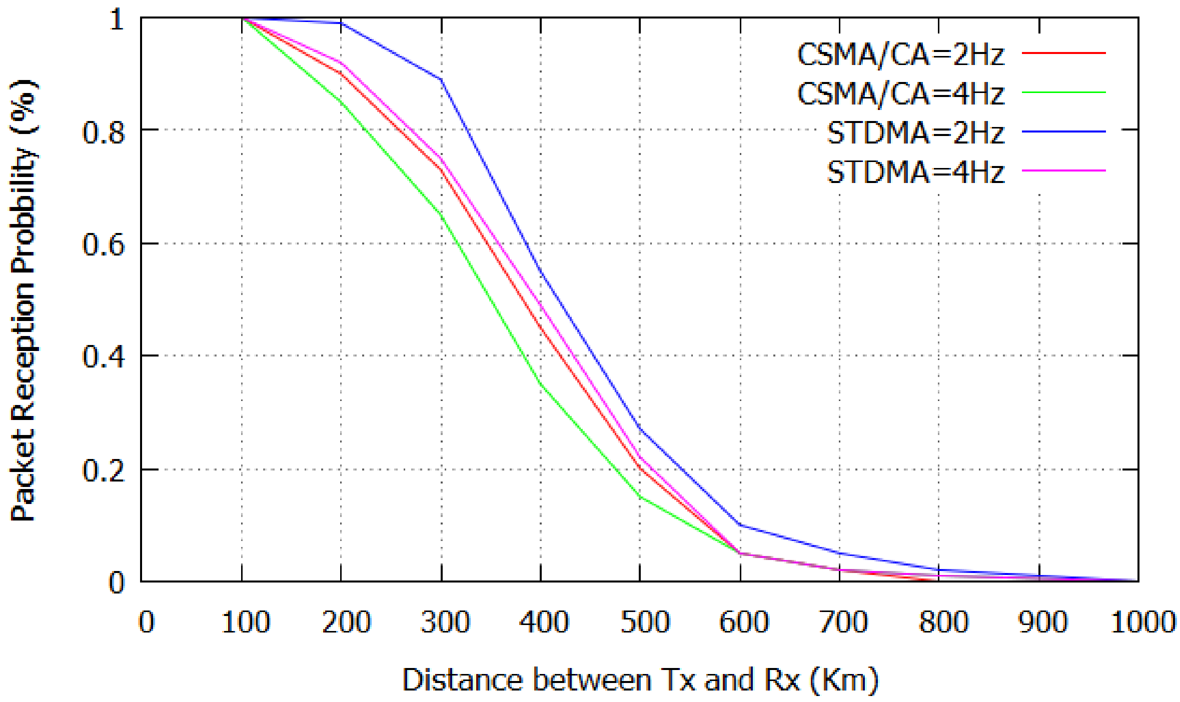

Figure 7.14: Message reception probability for CSMA/CA and STDMA when using the Nakagami model for different update rates of; 2 Hz, 4 Hz

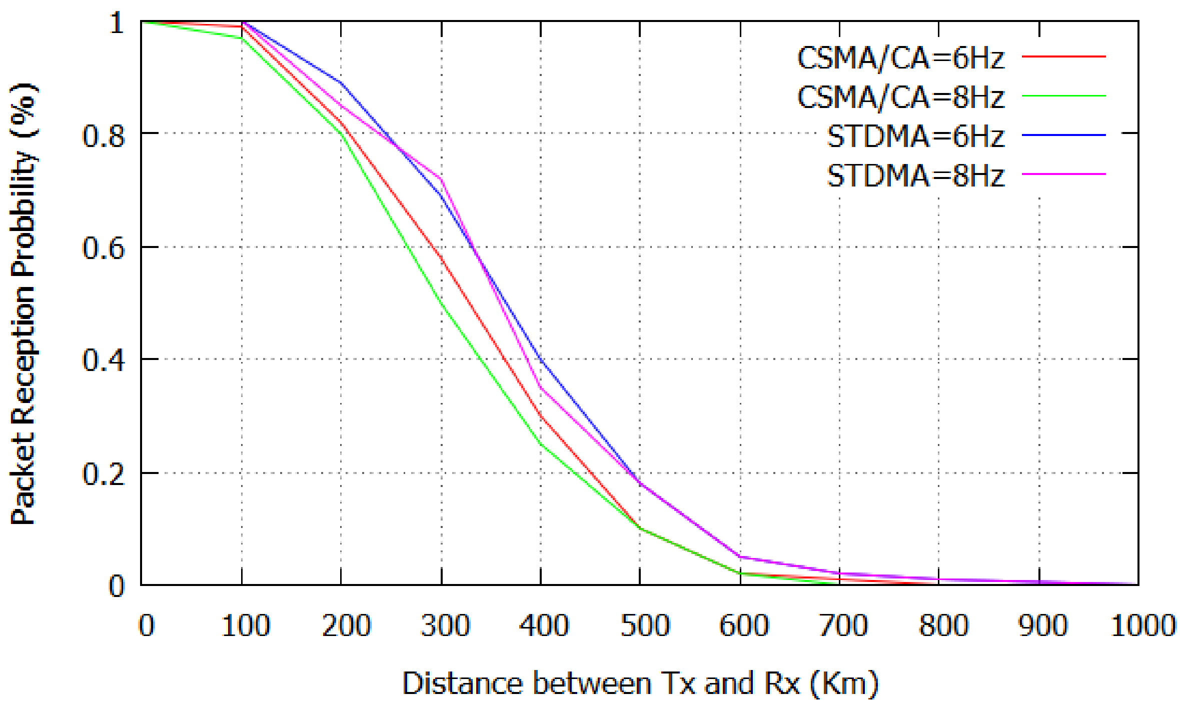

Figure 7.15: Message reception probability for CSMA/CA and STDMA when using the Nakagami model for different update rates of; 6 Hz, 8 Hz

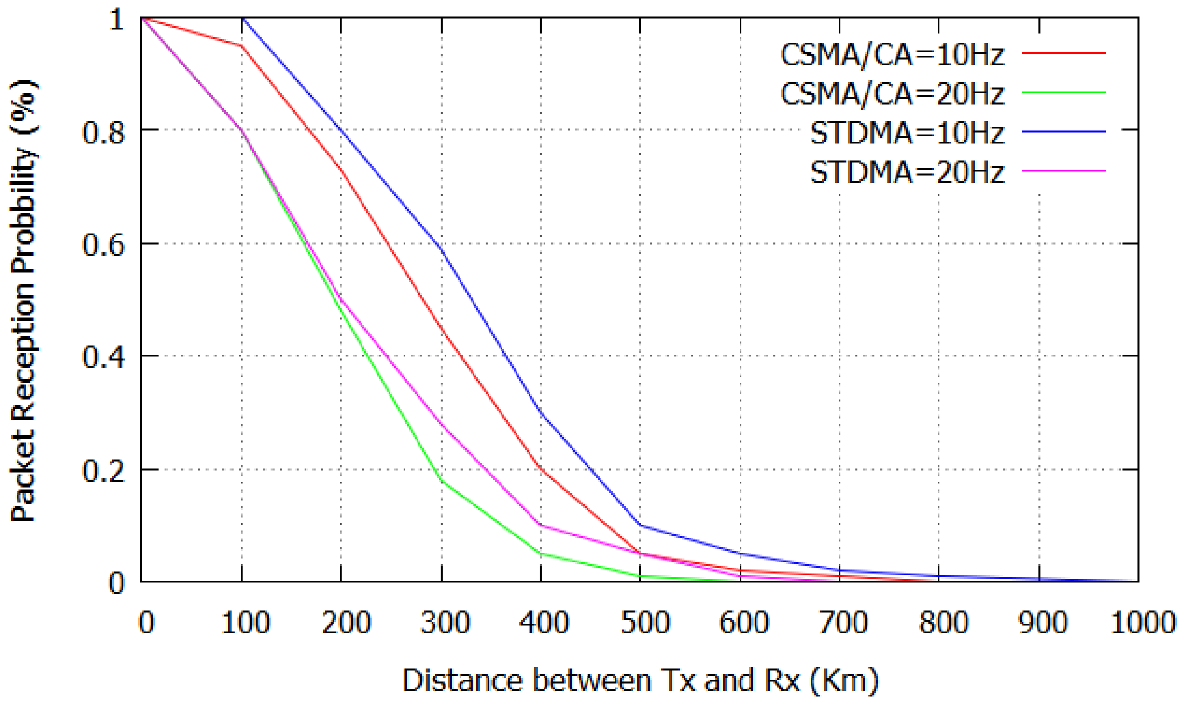

Figure 7.16: Message reception probability for CSMA/CA and STDMA when using the Nakagami model for different update rates of; 10 Hz, 20 Hz

ğenie¨ is considerable. In CSMA/CA, the overloaded scenario causes stations within radio range to transmit simultaneously, resulting in decoding failures at the receivers. The simultaneous transmissions occur as many stations are forced into waiting time, and their waiting time counters run the risk of reaching zero at the same time. For STDMA, the overloaded scenario implies that many slots are used by more than one station, resulting in a higher probability of decoding errors at the receivers and yet these slots are perceived as busy, due to signal strengths above the CS_{th}. Thereby, stations are sometimes forced to select a slot within its SI that is perceived as busy but with missing position information, i.e., the protocol cannot take advantage of its ability to schedule transmissions in space.

In Figure 7.16 the message reception probability for CSMA/CA and STDMA when using the LOS/OLOS model is depicted. It can be seen that the LOS/OLOS model has about 500 to 800 meters longer communication range than the Nakagami model, i.e., the message reception probability approaches 0 for receivers approximately 400 meters further away.

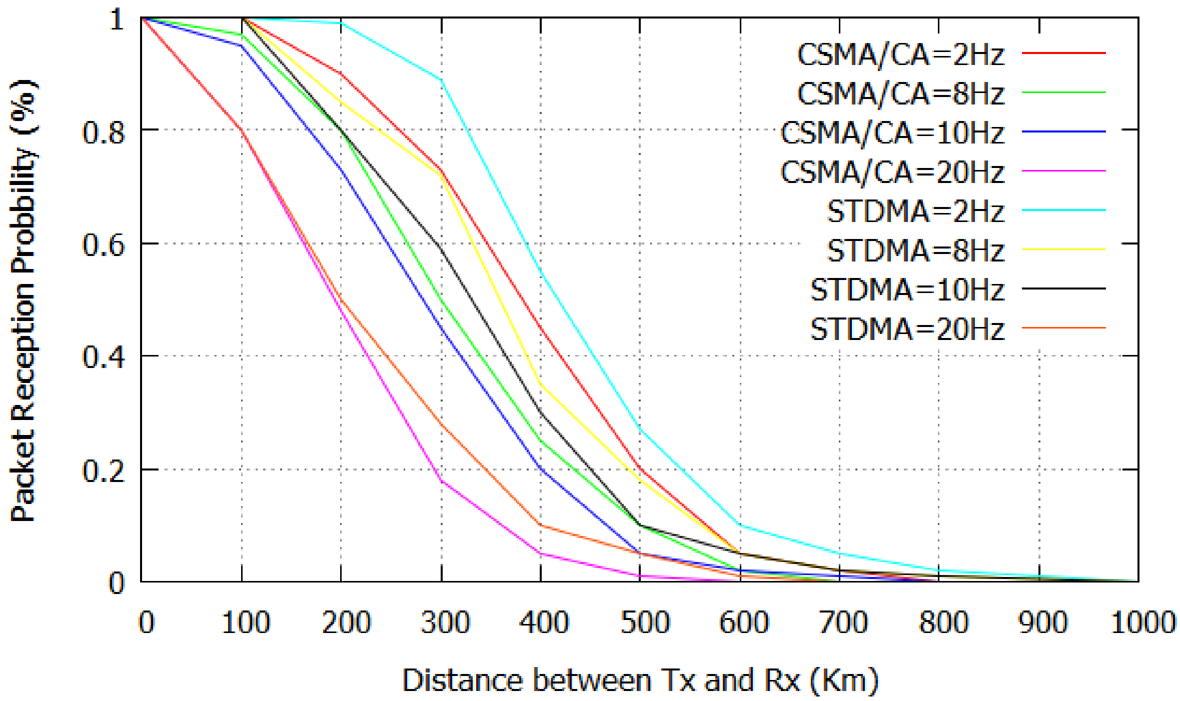

Figure 7.17: Message reception probability for update rates of 2/4/8/10/20 Hz when using the LOS/OLOS model; CSMA/CA, STDMA

In Figure 7.17 - Figure 7.21 a comparison between CSMA/CA and STDMA for different update rates is shown, when using the LOS/OLOS model. The results show that STDMA performs better than CSMA/CA for all settings also for this channel model. At a T_X-R_X distance of 300 $meters$, in Figure 7.14 update rate of $2-20Hz$, STDMA has almost 20% better performance than CSMA/CA. Consequently, STDMA is more reliable than CSMA/CA.

7.7 MAC-to-MAC Delay

MAC-to-MAC delay combines message reception probability and channel access delay into one performance measure. The CDF for the MAC-to-MAC delay, when using the Nakagami model for the update rates 2/4/8/20 Hz, is depicted in Figure 7.22 to Figure 7.25. Since the MAC-to-MAC delay is a function of the update rate, the range of the abscissa is selected, based on the specific update rate in use, i.e., the time between two message generations (e.g., $1/(2Hz) = 0.5\ s$). The convention that, message drops of any kind cause the MAC-to-MAC delay to be infinite. Message drops can occur at the transmitter (for CSMA/CA when channel access is not granted until

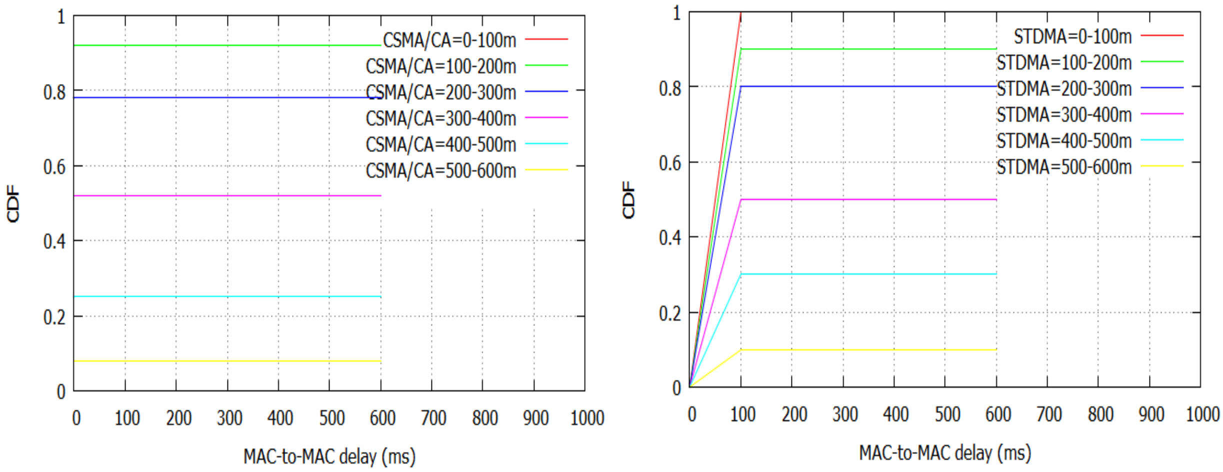

Figure 7.18: CDF for the MAC-to-MAC delay for CSMA/CA and STDMA when using the Nakagami model for the following update rates: 2 Hz

the message has expired) or at the receiver (for both CSMA/CA and STDMA when decoding fails). However, in Figure 7.22 to Figure 7.25, no packets have been dropped on the transmitting side. Therefore, the MAC-to-MAC delay is only infinite as a result of decoding failures. Every curve in the Figure 7.22 to Figure 7.25 represents all cases, when the distance between transmitter and receiver is within a certain range, i.e., S̈TDMA $100 - 300$ m¨ implies all receivers that are between $100 - 300$ $meters$ away from a transmitter.

The channel access delay for CSMA/CA increases with increased update rate, quite in contrast to STDMA, where it decreases unsteady. In Figure 7.25, showing the highest update rate, the MAC-to-MAC delay reaches its maximum value after approximately the same time for both protocols, for a T_X-R_X separation of $0 - 100$ $meters$. The largest difference in performance between the MAC protocols is found, in Figure 7.23 for an update rate of 8 Hz, where CSMA/CA shows a lower MAC-to-MAC delay for the successfully delivered packets, but where STDMA manages to deliver more packets to higher layers, implying that the CDF converges to a higher value. This illustrates the basic trade-off between delay and reliability. STDMA offers better reliability than CSMA/CA at the expense of a longer MAC-to-MAC delay. For the shortest T_X-R_X separation the MAC protocols perform equally well, which is consistent with the finding for the message reception probability curves.

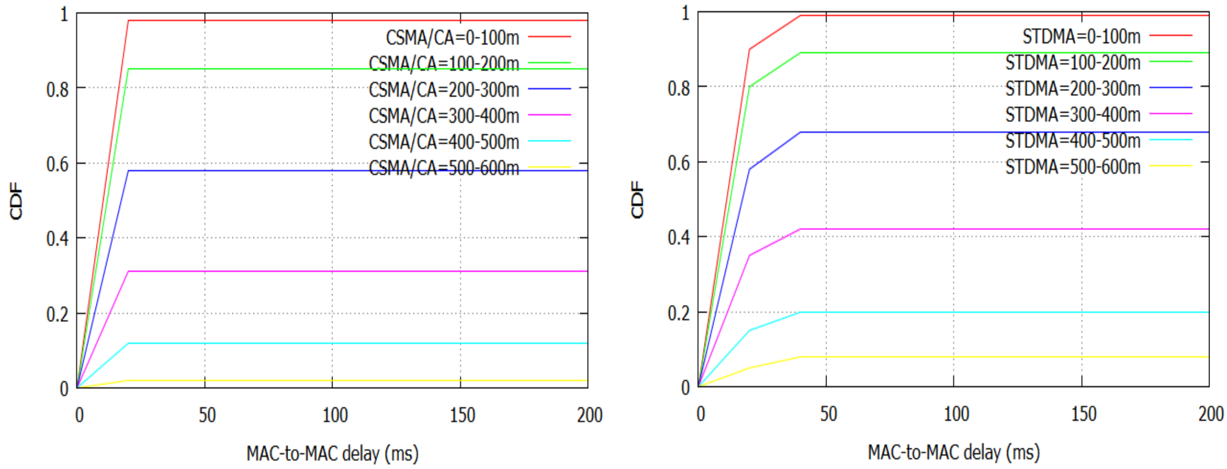

Figure 7.19: CDF for the MAC-to-MAC delay for CSMA/CA and STDMA when using the Nakagami model for the following update rates: 8 Hz

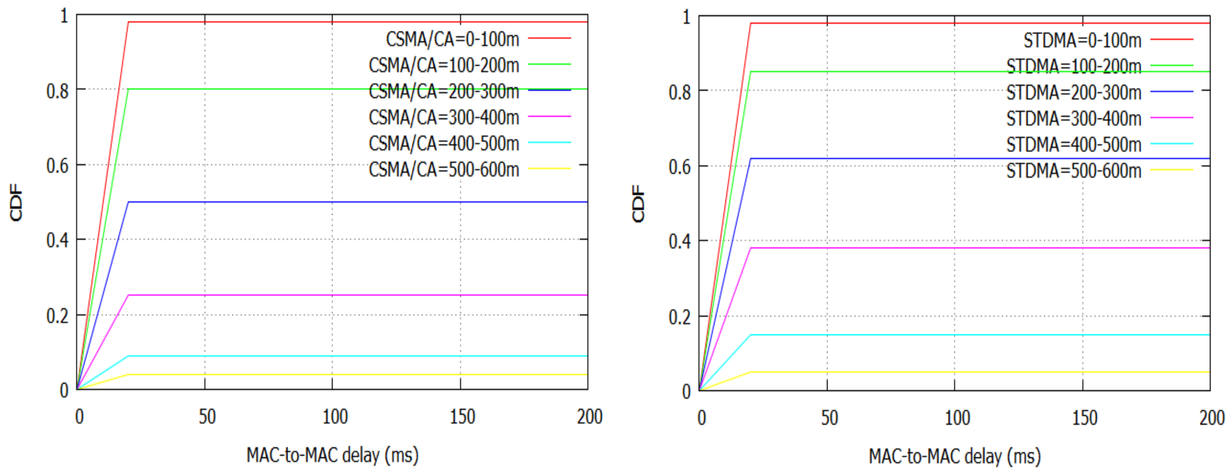

Figure 7.20: CDF for the MAC-to-MAC delay for CSMA/CA and STDMA when using the Nakagami model for the following update rates: 10 Hz

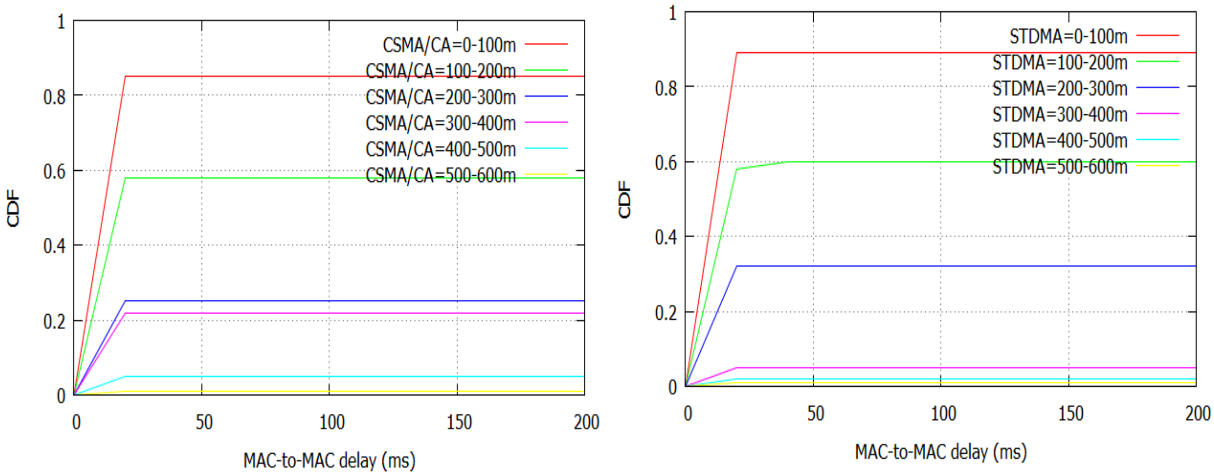

Figure 7.21: CDF for the MAC-to-MAC delay for CSMA/CA and STDMA when using the Nakagami model for the following update rates: $20Hz$

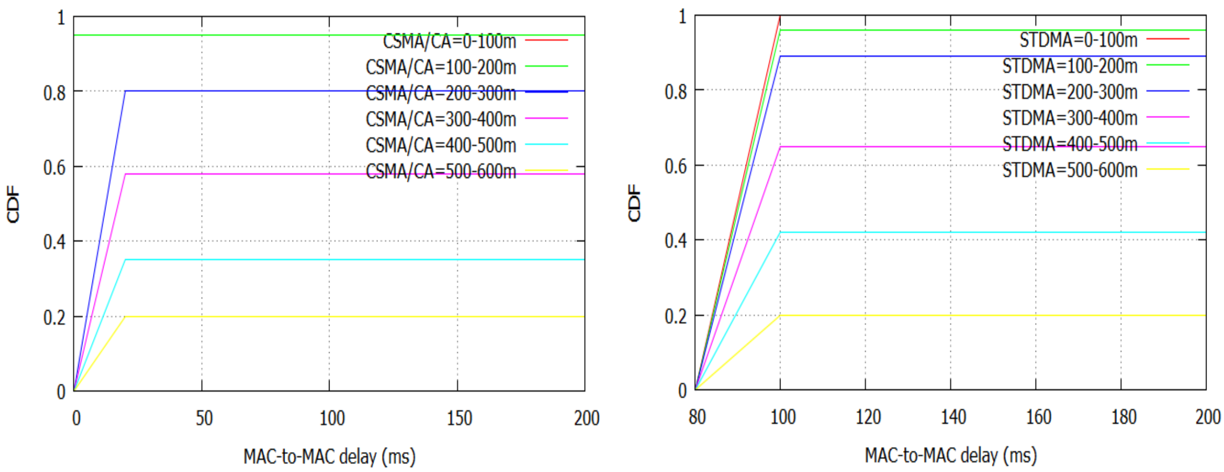

Figure 7.22: CDF for the MAC-to-MAC delay for CSMA/CA and STDMA when using the LOS/OLOS model for the following update rates: $2\ Hz$

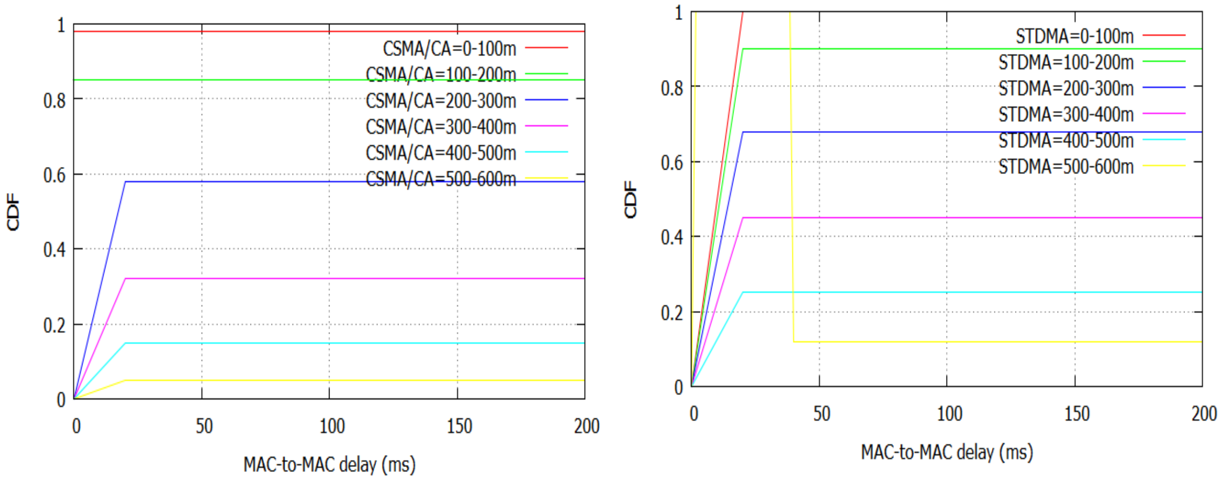

Figure 7.23: CDF for the MAC-to-MAC delay for CSMA/CA and STDMA when using the LOS/OLOS model for the following update rates: 8 Hz

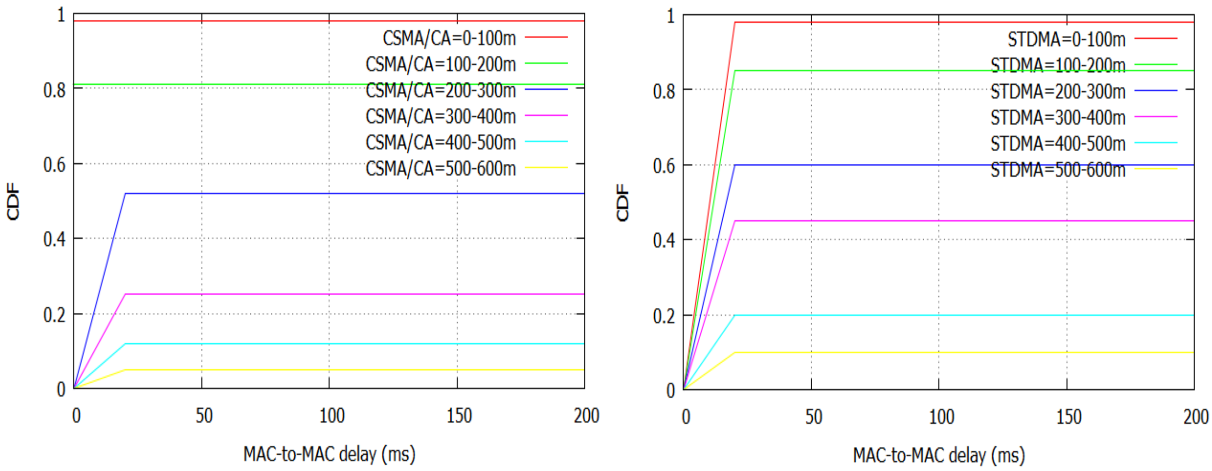

Figure 7.24: CDF for the MAC-to-MAC delay for CSMA/CA and STDMA when using the LOS/OLOS model for the following update rates: 10 Hz, and (f) 20 Hz

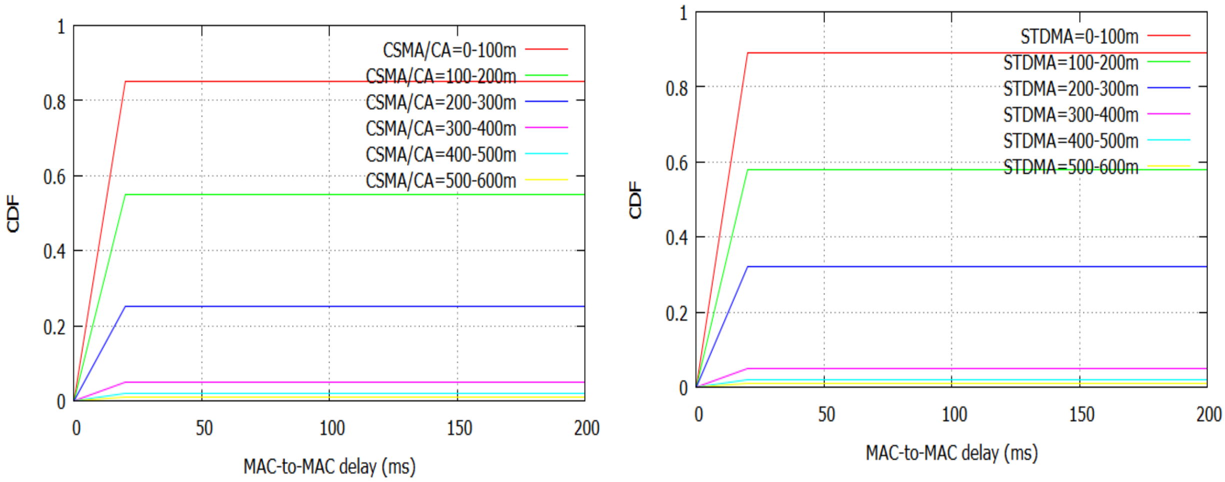

Figure 7.25: CDF for the MAC-to-MAC delay for CSMA/CA and STDMA when using the LOS/OLOS model for the following update rates: 20 Hz

The MAC-to-MAC delay for the LOS/OLOS model is depicted in Figure 7.26 - Figure 7.28 for both MAC schemes. STDMA and CSMA/CA perform equally well for a T_X-R_X separation less than 100 $meters$. For longer distances, STDMA performs better than CSMA/CA, i.e., the delay CDF flattens out at a higher value. The largest difference in performance between CSMA/CA and STDMA is also found for an update rate of 8 Hz; see Figure 7.27. For every update rate, the largest difference between the two protocols is for a T_X-R_X separation of between $200 - 400$ $meters$. It can be conclude that CSMA/CA has a lower minimum MAC-to-MAC delay, but that with STDMA, a higher percentage of all packets have a finite MAC-to-MAC delay.

7.8 City Scenario

The Palm-Beach Road (Nerul to Vashi) city scenario is chosen because here the highest relative speeds (i.e., min 60 km/h to max 100 km/h) in vehicular environments are found and hence it should constitute the biggest challenge for the MAC layer. The vehicles are entering each lane of the city road according to a Poisson process with a mean inter-arrival time of 3 seconds. The speed of each vehicle is modelled as a Gaussian random variable with different mean values for each lane; 60 km/h and 100 km/h a standard deviation of 1 m/s. For simplicity assume that no overtaking is possible and vehicles always remain in the same lane. There is no other data traffic in addition to the heartbeat broadcast messages. The channel model is a simple circular transmission model where all vehicles within a certain sensing range will sense and receive packets perfectly. The simulated sensing ranges are 500 m and 1000 m. We have tried to focus on how the two MAC methods perform in terms of time between channel access requests until actual channel access within each vehicle node. Three different packet lengths have been considered: 500, 500 and 1000 byte. The shortest packet length is just long enough to distribute the location, direction and speed, but due to security overhead, the packets are likely longer. The transfer rate is chosen to be the lowest rate supported by 802.11p, namely 3 $Mbps$. Since all vehicles in the simulation are broadcasting, no ACKs are used.

Table 7.5: Simulation parameter setting for Nerul to Vashi City Road scenario simulation

Parameter	*Value*
Start-point	*Nerul*
End-Point	*Vashi*
Simulation Time	*In-time 8.30 am & Out-time 10.00 am*
City Road Length	10 Km
Traffic direction	2 *ways*
Number of Lanes	8 *lanes (4 in each direction)*
Vehicle type	*Cars, Private vehicles, Best and School Buses etc.*
Number of Vehicle Nodes	1200
Speed of Vehicle nodes	$60 - 100\ km/h$,
Communication Protocol	*802.11p and STDMA*
Traffic type	*UDP*
Message sending frequency	5 Hz, 10 Hz

Message length	*300 bytes,500 bytes and 1000 bytes*
Transfer Rate	3 $Mbps$
Slot time, T_{slot}	$9\mu s$
SIFS, T_{SIFS}	$16\mu s$
CW_{min}	3
CW_{max}	*500*
Communication Range	500 $meter$, 1000 $meter$
Waiting time Time, $T_{Backoff}$	$0, 9, 18, 27\mu s$
AIFS	34 μs *(the highest priority)*
STDMA frame size	$1s$
No of slots in the STDMA frame	*1165 slots, 718 slots , 418 slots*

On Figure 7.29 the best and worst performance experienced by a single user is depicted together with the average for all users in the system. In the worst case, a vehicle node achieves successful channel access only 16% of the time i.e., 80% of all generated packets in this vehicle node are dropped. When the sensing range is 500 meters, a vehicle node will complete for the channel with approximately 230 other vehicle nodes. On Figure 7.30 7.32 the results from a sensing range of 500 m are depicted, and the worst-case vehicle nodes are experiencing data packets drops 55%. In this scenario, approximately 115 vehicle nodes are competing for channel access.

Figure 7.31 for different sensing ranges. Simulation statistics were collected from middle of the of the city scenario with the vehicle traffic. Dropped packets are considered to have infinite delays. Three plots in the Figure 7.31 represent CDF for the node performance in best average and worst case for different sensing range. In best

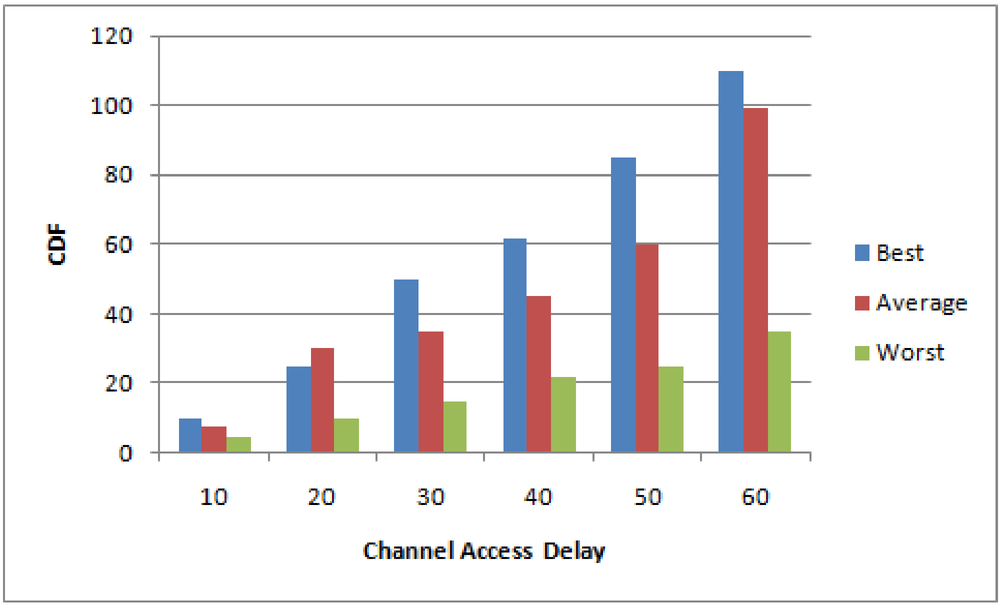

Figure 7.26: Channel access delay in CSMA/CA with a sensing range of 500m, report rate 10HZ and packet length 500 byte

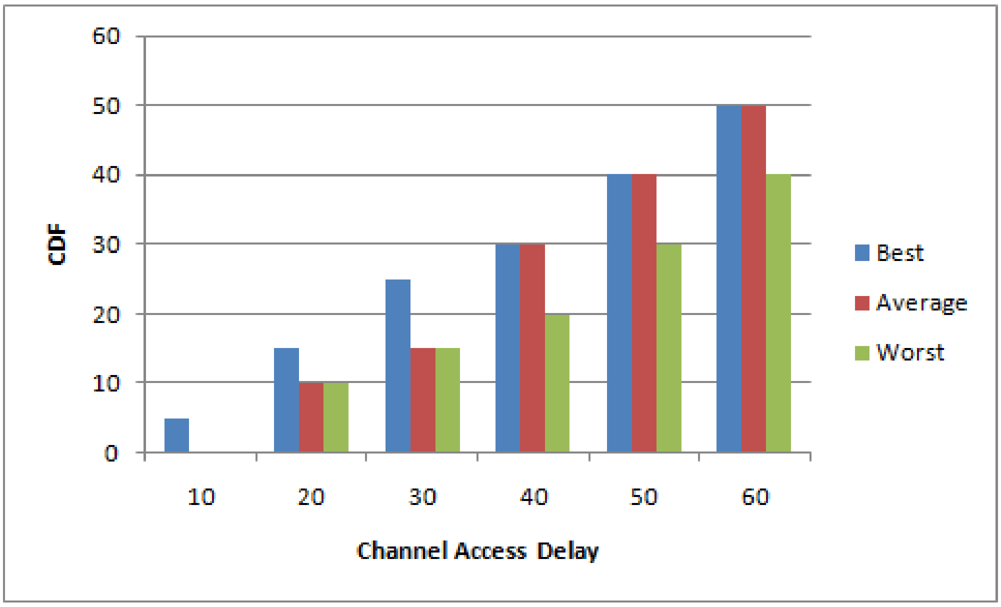

Figure 7.27: Channel access delay in CSMA/CA with a sensing range of 1000m, report rate 10HZ and packet length 1000 byte

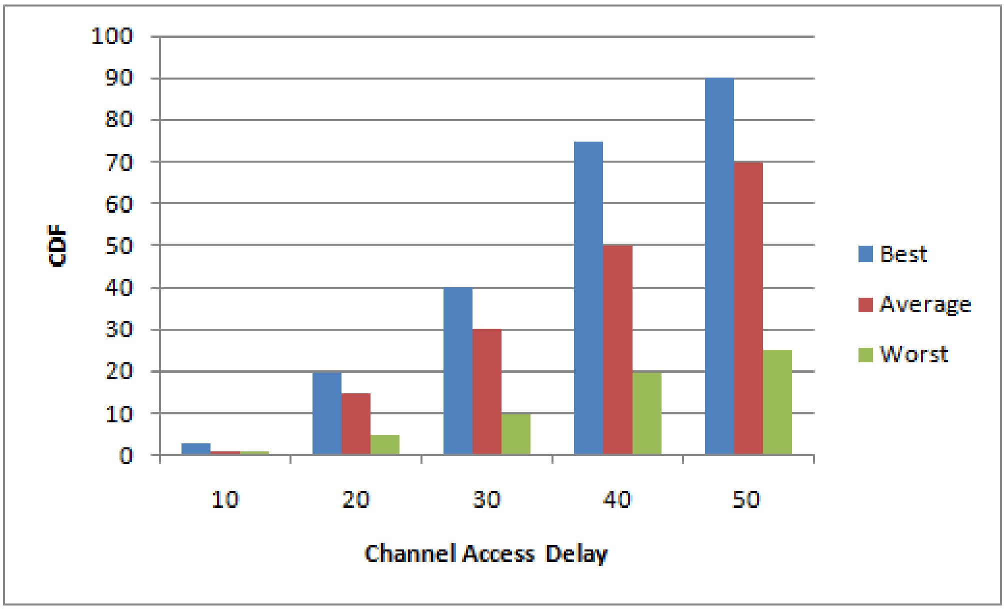

Figure 7.28: Channel access delay in STDMA with a sensing range of 500m, report rate 10HZ and packet length 500 byte

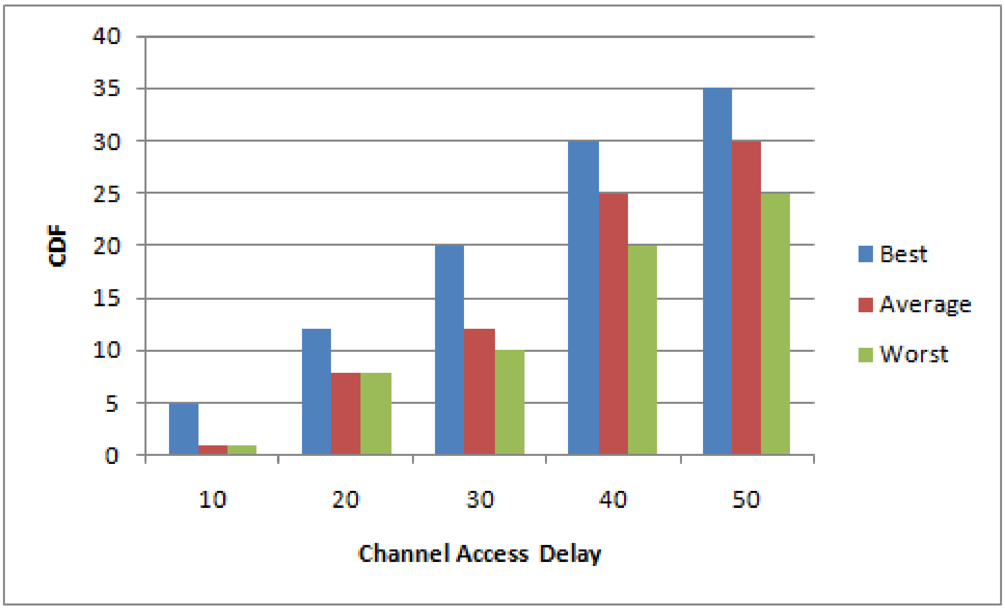

Figure 7.29: Channel access delay in STDMA with a sensing range of 1000m, report rate 10HZ and packet length 1000 byte

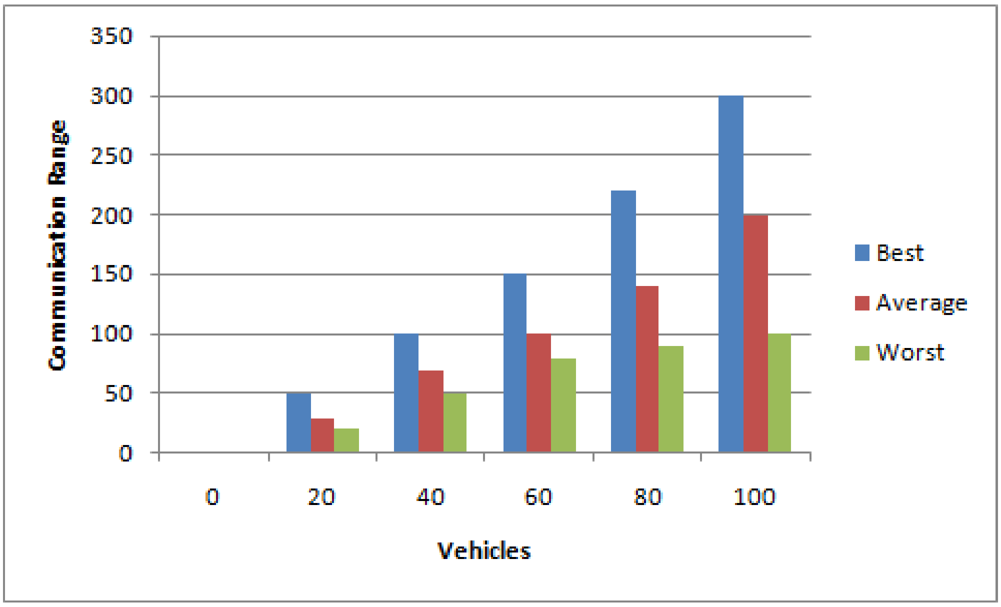

Figure 7.30: Sensing Range 500 meters

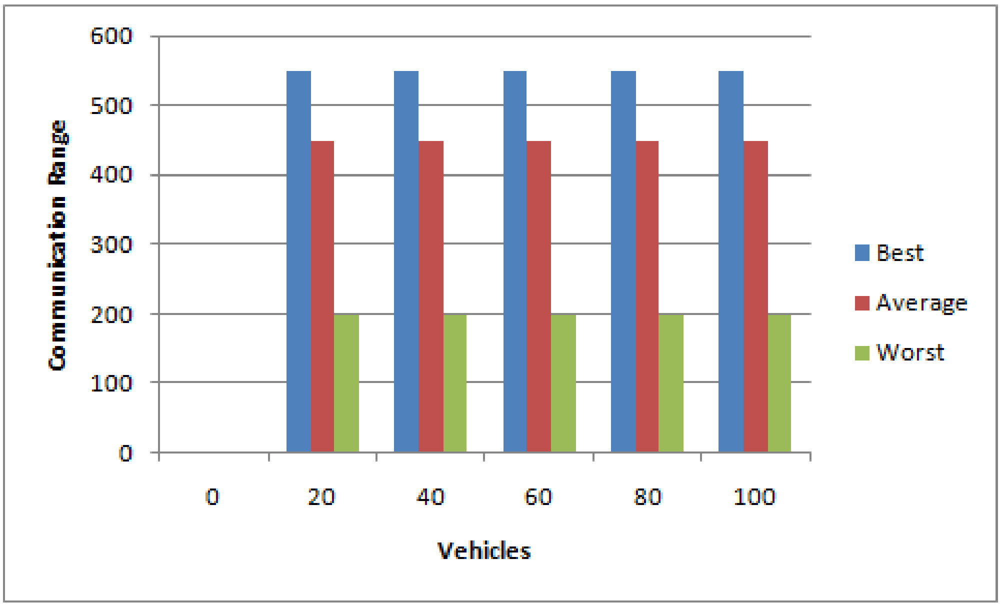

Figure 7.31: Sensing Range 1000 meters

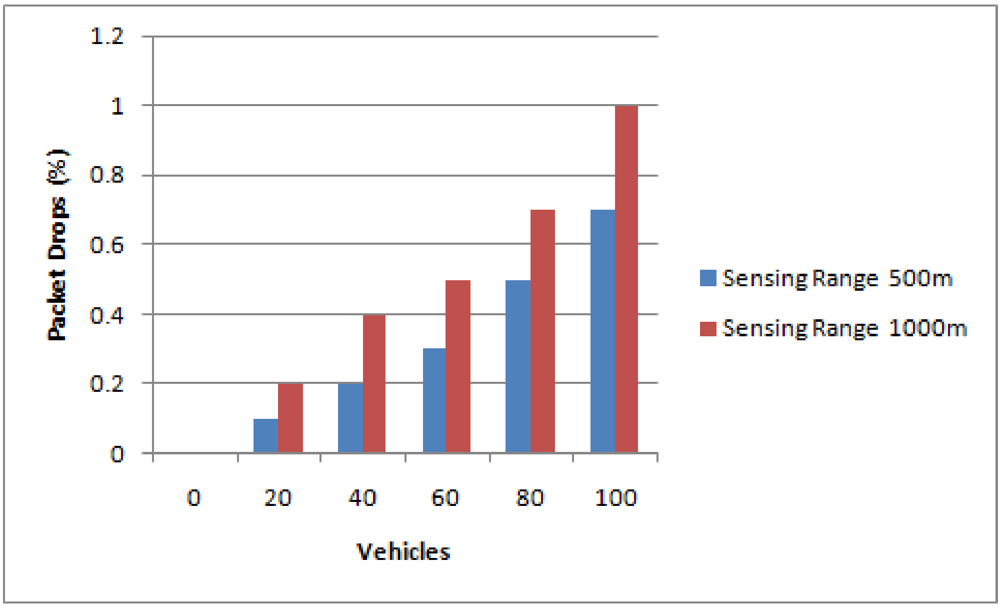

Figure 7.32: Number of Packets dropped due to no channel access

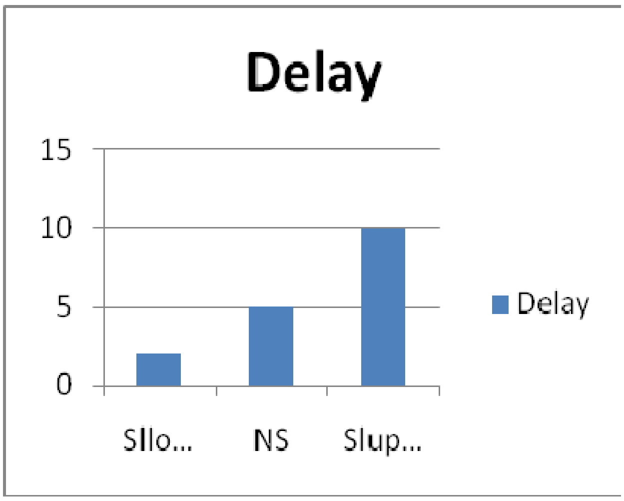

Figure 7.33: CDF for channel access delay in STDMA

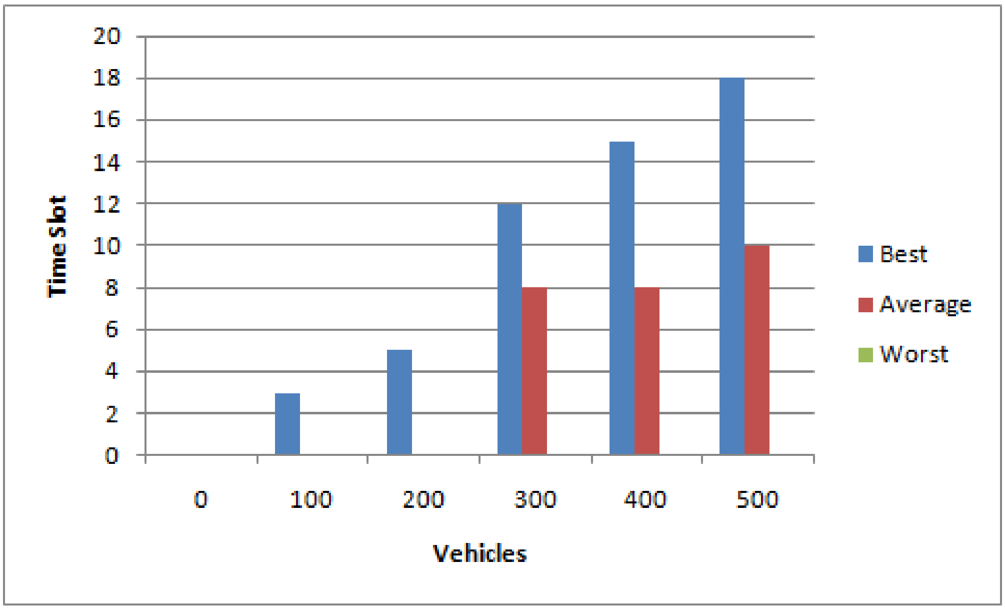

Figure 7.34: Utilizing the same time slot in STDMA to find minimum distance between two nodes

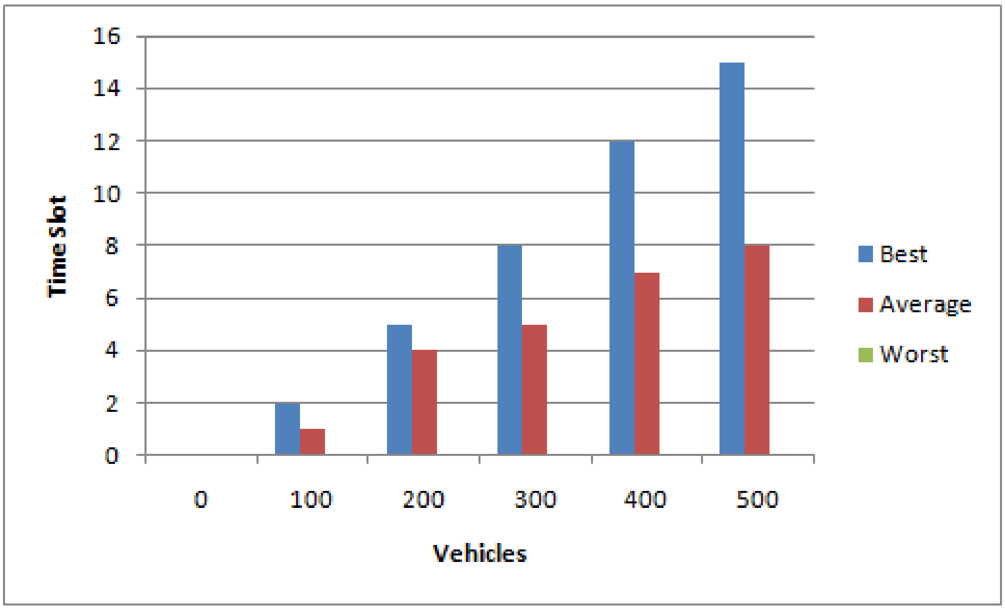

Figure 7.35: Sending at the same time in CSMA/CA using 300 bytes packets.10 Hz, sensing range 1km

case only 4% of generated and send packets are dropped while in worst case 60% packets are dropped for sensing range of 500 meters and 50% packets are dropped in average case for sensing range of 1000 meters. Lose of many consecutive packets, which will make the node invisible to the surrounding vehicles for a period of time. CDF for number of consecutive packet drops is on Figure 7.31. STDMA algorithm grants packets channel access since slots are reused if all slots are currently occupied within selection interval of the node. Node will choose the slot that is located furthest away hence there will be no packet drops at sending side when using STDMA and channel delay is small. Figure 7.32 the CDF channel delay for STDMA for all nodes will choose a slot for transmission during selection interval therefore CDF for T_{acc} in STDMA is sending at unity after a finite delay compared to CDF for T_{acc} in CSMA/CA. Figure 7.33 the CDF for the minimum distance between two nodes, which utilizing the same slot within the sensing range is depicted for different packet lengths. In CSMA/CA, all channel requests did not make it to a channel access and then nodes drop packets. In CSMA/CA there is risk when nodes gets the channel access someone else also sends the packet and collision occurs. This is due to the fact that nodes can experience the channel idle at the same time, or ongoing transmission is not detected. Figure 7.34 7.36 the CDF for minimum distance between two nodes in CSMA/CA city scenario sending at the same time for three different packets lengths with different ratio as shown in Table 7.5 above. Overall STDMA performs better in all conditions and cases in both highway and city scenario for sparse and dense network.

7.9 Summary

In future traffic safety system can be classified as real-time system for Mumbai-Pune Express Highway Road, India. It means that the data traffic sent on the wireless channel has a deadline with respect to time duration. The most important component of a real-time vehicle-to-vehicle communication system on Mumbai-Pune Express Highway Road is the MAC protocol method. In this chapter, two MAC methods have been evaluated according to their ability to meet real-time communication deadlines. The MAC of vehicular communication standard IEEE 802.11p CSMA/CA was examined through simulation i.e Openstreet, eWorld, SUMO, Google Maps, NS2.34 and

AWK or Gnuplot, the results indicate severe performance degradation for a heavily loaded system, both for individual vehicle nodes and for the system. The simulations show that 802.11p is not suitable for periodic location messages in a Mumbai-Pune Highway Road scenario, if the network load is high, since some vehicle nodes will drop over 85% to 90% of their data messages.

Evaluation of CSMA/CA and STDMA is performed through simulations on Mumbai-Pune Express Highway, modelling a 50 km Mumbai-Pune Express Highway with three lanes in each direction with bidirectional communication among the vehicles on road. Vehicles travel along the Mumbai-Pune Express Highway and broadcast local or status messages periodically.The simulation results, for CSMA/CA has on average a smaller channel access delay than STDMA on Mumbai-Pune Express Highway, India. However, STDMA always shows better reliability and scalability results than CSMA/CA, especially between transmitter and receiver.

Chapter 8

Performance Analysis of the DSRC/IEEE 802.11p for VANETs Safety Applications

In this chapter, an logical model for the reliability of the Dedicated Short Range Communication (DSRC)/IEEE 802.11p, control channel to handle safety applications in vehicular ad-hoc networks is proposed. Specifically, the model enables the determination of the probability of receiving safety messages from all vehicles within the transmitters range, and validates this model by simulation. The proposed model is built, based on the new mobility model proposed in Chapter 5 that takes into account the vehicle's follow-on safety rule, to accurately derive the relationship between the vehicle's speed and network density. Moreover, the model takes into consideration:

a. Effect of mobility on vehicle's density around the transmitter.

b. Effect of the transmitters and receiver's speeds on the systems reliability.

c. Effect of channel fading since the communication range is modeled as random variable.

d. The hidden terminal problem and transmission collisions from neighboring vehicles.

It is shown, that the current specifications of the DSRC/IEEE 802.11p may lead to severe performance degradation in dense and high mobility conditions. Therefore, an adaptive algorithm is introduced, to increase the system's reliability, in terms of the probability of packets successful reception and time delay of emergency messages, in a harsh vehicular environment.

8.1 Overview

The research and application development in vehicular ad-hoc networks have been driven by the DSRC technology or IEEE 802.11p (International) designed to help drivers to travel safely and to reduce the number of fatalities, due to road accidents. The IEEE 802.11p MAC uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and some concepts from the Enhanced Distributed Channel Access (EDCA) (for Information technology). In this technology, there are four access classes (ACs) with different Arbitration Inter Frame Space Numbers (AIFSN) to insure less waiting time, for high priority packets, as listed in Table 4.3.

The DSRC/IEEE 802.11p is licensed at 5.9GHz with 75 MHz spectrum, which is divided into seven 10 MHz channels and 5 MHz guard band. The control channel *(CCH)* will be used for safety applications, while the other six channels, called service channels, will be used for infotainment or commercial applications, to make this technology more cost effective. Vehicles will synchronize the switching between the *CCH* and one or more of the service channels *(SCH)*, hence, safety related messages will not be missed or lost. The synchronization interval *(SI)* contains a control channel interval *(CCI)* followed by a service channel interval *(SCI)* separated by a guard interval *(GI)* as shown in Figure 8.1. Increasing the *CCI* interval will enhance the reliability of safety applications and challenge the coexistence of both safety and non-safety applications, on the DSRC/IEEE 802.11p.

Vehicular ad-hoc network is a self-organizing network that works on both Vehicle-to-Vehicle Communication and Vehicle to infrastructure communication. In this analysis, Vehicle-to-Vehicle Communication is taken into consideration, where vehicles will be equipped with sensors and GPS systems to collect information about their position, speed, acceleration and direction, to be broad-casted to all vehicles within their range. In IEEE 802.11p, vehicles will not send any acknowledgement for the broad-casted packets. Therefore, the transmitter will not detect the failure of the message reception and hence will not retransmit it. This is a serious problem in collision warn-

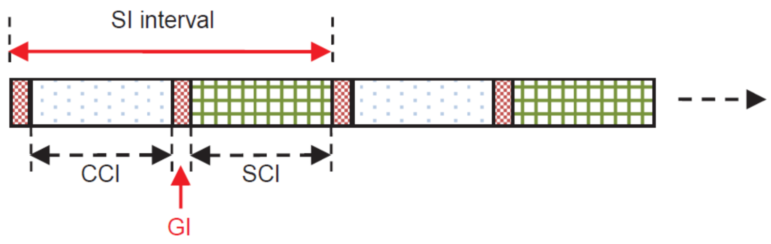

Figure 8.1: The IEEE802.11p synchronization interval.

ing applications, where all vehicles behind the accident have to receive the warning message successfully in a short time to avoid chain collisions. This problem motivates us, to propose an analytical model, for assessing the DSRC/IEEE 802.11p reliability and time delay, taking into account the Vehicular Ad-hoc Networks multi-path fading channel, vehicles high mobility, hidden terminal problem and transmission collisions.

8.2 Related Work

In the literature, there are many studies on the performance of DSRC/IEEE 802.11p (International) which are categorized into three different groups.

The first group is based on simulations and targeted only one parameter of the DSRC/IEEE 802.11p. The authors in (Hafeez et al., "The optimal radio propagation model in VANET") and (Torrent-Moreno, Jiang, and Hartenstein) study the effects of radio propagation models in vehicular ad-hoc networks, based on the probability of successful reception rate. While (Torrent-Moreno et al., "Vehicle-to-vehicle communication: Fair transmit power control for safety-critical information") focuses on how to control the load of periodic messages, to ensure the successful reception of warning messages. The authors in (Jiang, Chen, and Delgrossi) introduce a new method, for selecting the data rate in vehicular ad-hoc networks based on a simulation setup. They compare the performance of different broadcast transmissions using different data rates, while adjusting the power used in each scenario to maintain a comparable level of channel interference. In (Bilstrup et al.), the authors analyze the DSRC/IEEE 802.11p by simulations in terms of the channel access time delay. They show that using 802.11p MAC will result in an unbounded delay and compare it with a self-organizing time division multiple access (STDMA) scheme, which they prove is more suitable for vehicular ad-hoc networks real time safety applications.

In (Wang and Hassan), the authors propose, a framework for sharing the DSRC/IEEE 802.11p between vehicular safety and non-safety applications. By assuming uniform distribution of vehicles on the road, their simulations show that non-safety applications may have to be severely restricted, such that safety applications are not compromised, especially in high density networks.

In the second group, analytical models have been proposed, to study the DSRC/IEEE 802.11p MAC protocol. While (Xu, Sakurai, and Vu) and (Lee and Lee) analyze the EDCA (Bianchi), analyzes the IEEE 802.11 for uni-cast communication. Although DSRC is based on IEEE 802.11 and EDCA, their analytical models for performance evaluation of uni-cast communications, cannot be used for broadcast communication mode in IEEE 802.11p because no ACK is communicated. Therefore, the transmitter will not detect a collision from a successful transmission. The authors in (Ma and Chen, "Delay and Broadcast Reception Rates of Highway Safety Applications in Vehicular ad-hoc Networks"), introduce a one dimensional Markov chain, to calculate the delay and reception rate in vehicular ad-hoc networks but have not included the time delay in each stage due to busy channel. While in (Eichler), the authors analyze the system using, only the average delay for each access class and have not taken into account the back-off delay.

In (Ma and Chen, "Performance analysis of IEEE 802.11 broadcast scheme in ad hoc wireless LANs") and (Ma, Zhang, and Wu), the authors, study the saturation performance of the broadcast scheme in vehicular ad-hoc networks, taking into account the back-off counter consecutive freeze situation. They assume saturation conditions, stationary distribution without considering the impact of vehicles mobility on the system performance. In (Fracchia and Meo), an analytical model, for delivering safety messages within inter-vehicle communication (IVC) is derived. They assume a perfect channel access and have not accounted for the hidden terminal problem, collision probability and vehicle's mobility. The authors in (Hassan, Vu, and Sakurai) study the performance of IEEE 802.11p based on time delay of status packets, by modeling each vehicle as an M/G/1 queue with an infinite buffer, without taking vehicles mobility into consideration.

In the last group, the authors study the connectivity in vehicular ad-hoc networks, for example (Khabazian and Ali)− (Desai and Manjunath), (Jin and Recker) and (Abuelela, Olariu, and Stojmenovic). Most of these studies are based on the assumption, that nodes have a uniform stationary distribution in the network, such as (Ghasemi and Nader-Esfahani) and (Desai and Manjunath). In (Jin and Recker), the authors present, an analytical model for multi-hop connectivity, assuming that vehicles positions are known by either simulation or observation. They assume, the propagation of information is instantaneous with respect to vehicles movement.

In (Khabazian and Ali), the authors derive a mobility model for vehicular ad-hoc networks, considering the arrival of vehicles to a service area as a Poisson distribution and did not include the follow-on safety rule. While in (Abuelela, Olariu, and Stojmenovic), the authors derive the probability of no end-to-end connectivity between clusters of vehicles distributed uniformly on the road. They introduce a new opportunistic message relaying protocol that switches between data mulling and local routing, with the help of vehicles in the other direction. In contrast to our mobility model introduced in Chapter 5, all of these models, do not consider how the speed of transmitters and receivers affects the connectivity probability and the message reception rates.

In this chapter, an logical model, for the analysis of new broadcast services in the DSRC/IEEE 802.11p protocol, considering the high mobility of vehicles on highway roads, the hidden terminal problem, collision probability and non-saturation conditions are resolved. The new analysis is based on the mobility model derived in Chapter 5 which takes into consideration of the vehicle's follow on safety rules and regulation as per Indian scenario which will accurately derive the relationship between the vehicles density and their speed on highway. The new mobility model considers, how the speed of transmitters and receivers affect the connectivity probability and the message reception rates. The message reception rate is derived, considering the distance between the transmitter and receivers, speeds and direction. The proposed model uses a Markov chain approach, which includes the probability of a carrier sense busy channel in each state, to derive the probability of transmitting status and warning messages and their time delay. Based on the logical and NS2 simulation results, an new adaptive and mobility algorithm, is introduced to enhance vehicular ad-hoc networks performance.

8.3 System Model and Performance Metrics

In vehicular ad-hoc networks safety applications, vehicles broadcast different types of messages:

- Warning message.
- Emergency message.
- Local message.
- Status message.

While warning messages usually contain safety related messages, status messages are sent periodically to all vehicles, within their range and contain vehicles state information such as speed, acceleration, direction and position. Therefore, emergency messages will use AC_3 since it has the highest priority as listed in Table 4.3 while status message will use AC_1.

In the model, vehicles generate their status messages at a rate of λ_s (Hafeez et al., "The optimal radio propagation model in VANET"), indicating that the length of the synchronization interval is $SI = \frac{1}{\lambda_s}$. Assume that all packets, have the same length L bits and the whole SI interval is dedicated to safety applications, that is $CCI = SI$. Each vehicle will randomly choose a slot within the SI interval to transmit its status message. Emergency messages are sent only during emergency situations such as an accident or a warning from hazards or a jam on the road ahead. Based on these assumptions, DSRC protocol is analyzed to find the smallest channel interval that maximizes the reliability of safety applications. Thus achieve high probability of receiving a status message from each vehicle node within this interval successfully.

It is assumed, that all vehicles have the same transmitting power (P_t) and each vehicle receives the signal successfully if the received power is higher than a certain threshold P_{th}. Since fading is a major characteristic of vehicular ad-hoc networks channel, the received signal power is random and therefore, the communication range is also a random variable.

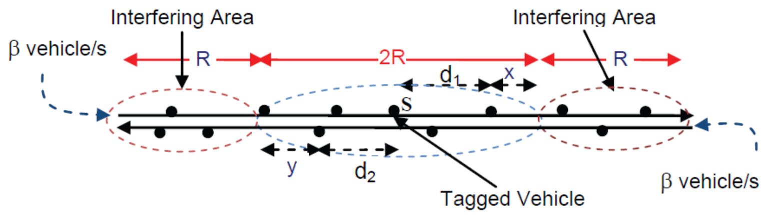

Figure 8.2: Simplified one dimensional communication model in highway scenario.(Hafeez et al., "The optimal radio propagation model in VANET")

There are different parameters that affect the DSRC/IEEE 802.11p performance such as the communication range and the mobility model, which are derived in Chapter 5. These parameters will be used to derive the link availability and duration of connection between vehicles. The new mobility model also determines, the population size of vehicles within the transmitter's range and the number of vehicles in the two interfering (hidden terminal) areas. The effect of the transmitters and receivers speed, the contention window and the carrier sense range on the message, successful reception rate is then derived.

8.4 Link Availability Probability

Two vehicles can communicate only if, they are within the communication range of each other. Therefore, the probability of successfully receiving a message depends on the relative speed between the sender and the receiver, the message transmission time and the transmitter's range R. Assume initially that the receiver is at an arbitrary distance from the transmitter but within the communication range, at the beginning of the message transmission. Let d_1 be the distance of the receiver from the sender, that is moving in the same direction as the sender as shown in Figure 8.2. Then the probability density function, of this distance is $f_{d_1}(x) = \frac{1}{2R}$. Since the status message transmission time Tt is very short, assume that the vehicles speed will not change during this time period. If the receiver is at distance d1 from the sender, then its new location from the sender at the end of the message transmission is $d_n = d_1 + (v_x - v_t)T_t$, where v_t and v_x are the transmitter's and receiver's speeds respectively. Therefore, the probability Pl that a vehicle, which is traveling in the same direction, will receive the message, successfully, is when its d_n is still within the transmitter's range as

$$P_l = P(-R < d_1 + (v_x - v_t)T_t < R). \tag{8.1}$$

From (8.1), if the receivers speed $v_x \geq v_t$, then vehicles located at distances less than $-R$ at the time of transmission are not considered. Therefore, the probability P_{l1} that a vehicle traveling at a higher speed than the transmitter will receive the message successfully is given by

$$\begin{aligned} P_{l1}(v_t) &= P(-R < d_1 < R - (v_x - v_t)T_t) \\ P_{l1}(v_t) &= \int_{v_t}^{v_{max}} \int_{-R}^{-R-(v_x-v_t)T_t} \frac{1}{2R} \frac{1}{v_{max} - v_t} d_x dv_x \\ P_{l1}(v_t) &= 1 - \frac{v_{max} - v_t}{4R} T_t \end{aligned} \tag{8.2}$$

On the other hand, if the receiver speed $v_x < v_t$, then vehicles node located at distances greater than R at the time of transmission is not considered. Therefore, the probability P_{l2} that a vehicle traveling with a speed lower than the transmitter will receive the message successfully, is given by

$$\begin{aligned} P_{l2} &= P(-R + (v_x - v_t)T_t < d_1 < R) \\ P_{l2} &= \int_{v_{min}}^{v_t} \int_{-R+(v_x-v_t)T_t}^{R} \frac{1}{2R} \frac{1}{(v_t - v_{min})} d_x dv_x \\ P_{l2} &= 1 - \frac{v_t - v_{min}}{4R} T_t \end{aligned} \tag{8.3}$$

Since a vehicle node traveling at a speed lower than the transmitting vehicles node speed with probability $\omega = \frac{v_t - v_{min}}{v_{max} - v_{min}}$, the probability $P_l(v_t)$ that a vehicle node traveling in the same direction as the transmitting vehicle node will receive the message successfully is given by

$$P_l(v_t) = P_{l1}(v_t)(1 - \omega) + P_{l2}(v_t)\omega. \tag{8.4}$$

Integrating (8.4) over the range $v_t \in [v_{min}, v_{max}]$ yields the probability of receiving a message successfully due to mobility P_l as

$$P_l = 1 - \frac{v_{max} - v_{min}}{8R} T_t. \tag{8.5}$$

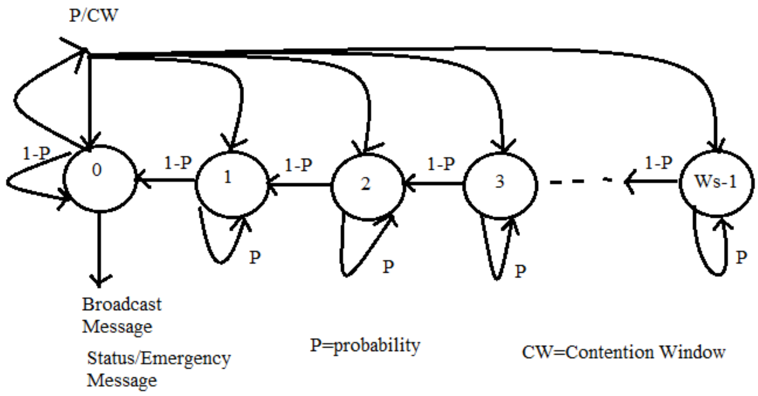

Figure 8.3: Emergency and status packets Markov chain.

8.5 Waiting Time and Contention Window Process

A model for the waiting time counter process of the IEEE 802.11p, for single access class is constructed as shown in Figure 8.3. If a vehicle has a status message, it will wait initially for a period of $AIFS = SIFS + AIFSN \times \varrho$ before it can broadcast the message, where $AIFS$ is the Arbitration Inter Frame Space for status message access class, $AIFSN$ is the Arbitration Inter Frame Space number associated with this class as listed in Table 2.3 and $\varrho = 13\mu s$ is the length of the time slot. If the channel is sensed busy (with probability p) during the $AIFS$ time. The access class (AC) will choose a contention window (W_o) uniformly and randomly from $[0, ..., W_s - 1]$ as a waiting time counter, where W_s is the minimum contention window associated with this class. At any time slot, during the waiting time process with probability $(1p)$, the AC decrements its waiting time counter if it senses an idle channel. Otherwise it freezes the counter and waits for the whole period of the ongoing transmission ($T_t = \frac{L}{r_d} + AIFS + \delta$), until the channel is idle again before decrementing its counter, where p is the conditional busy channel, probability seen by a message about to be transmitted and independent from any other vehicle, δ is the propagation delay and r_d is the data rate. Once the waiting time counter reaches the zero state, the AC broadcasts the message. There will be no subsequent retransmissions, if the message is collided and hence the message is lost (Sjoberg) (Hafeez).

To find the probability τ_s that a vehicle node transmits a status message in a randomly selected slot, to solve the Markov chain in Figure 8.3. First define $b(t) \in [0, ..., W_s - 1]$ as the random process for the status message queue in each vehicle, where t is a discrete and integer time that decrements at the beginning of each time slot. Second, define $k \in [0, ..., W_s - 1]$ as the waiting time counter value and $b_k = \lim_{t\to\infty} P\{b(t) = k\}$ as the stationary distribution of the Markov chain. Therefore, solve the discrete Markov chain as

$$b_k = \frac{W_s - k}{W_s}\frac{p}{1-p}b_0, 1 < k < (W_S - 1) \tag{8.6}$$

By using (8.6) and the normalized condition $1 = \sum_{k=0}^{W_s-1} b_k$, can solve for b_0 as follows

$$b_0 = \frac{2(1-p)}{2 - 3p + pW_s} \tag{8.7}$$

To derive the probability τ_s that a vehicle node transmits an emergency message in a randomly selected slot: First, the vehicle node has to have a status message, ready to transmit with probability $(\varrho\lambda_s)$. Second, it will transmit this mssage, with probability of $(1 - p)$, only when the waiting time counter reaches zero state. Therefore, the probability τ_s can be derived as

$$\tau_s = \frac{2(1-p)^2}{2 + pW_s - 3p}(\varrho\lambda_s) \tag{8.8}$$

If at least one vehicle node within the carrier sense range, is transmitting a message in the same time slot when the channel is sensed busy, p can be expressed as

$$\begin{aligned} p &= 1 - \sum_{k=0}^{\infty}(1-\tau_s)^k P_{2L_{CS}}(k) \\ p &= 1 - \sum_{k=0}^{\infty}(1-\tau_s)^k \frac{\left(\frac{2\beta_i R}{\mu \sqrt[\alpha]{\rho}}\right)}{k!} e^{-\frac{2\beta_i R}{\mu \sqrt[\alpha]{\rho}}} \\ p &= 1 - e^{\frac{2\beta R}{\mu \sqrt[\alpha]{\rho}}}\tau_s, \end{aligned} \tag{8.9}$$

where $P_{2L_{CS}}(k)$ is Equation (5.26) which is the probability of having k vehicles within the carrier sense range. The Newton-Raphson method is used to solve (8.8) and (8.9) since the system has a unique solution in the range of $p \in [0, 1]$ as shown in the simulation section.

The average time delay $E[T_{ss}]$ for a status message to be transmitted from the time it was ready at the MAC layer can be derived from the Markov chain in Figure 8.3 as

$$E[T_{ss}] = T_{sq} + E[T_{sf}] + T_t, \tag{8.10}$$

where T_{sf} is the time delay due to waiting time process, $Tt = \frac{L}{r_d} + AIFS_{[AC1]} + \delta$ is the message transmission time, and T_{sq} is the queuing delay, which is negligible in this case, since a vehicle will produce one status message in every SI interval and if a new message is generated it will replace the old one. Therefore,

$$\begin{aligned} E[T_{ss}] &= \sum_{i=0}^{W_s-1} \frac{p}{W_s} \sum_{k=0}^{i-1} (pT_t) + T_t \\ E[T_{ss}] &= \frac{p^2 T_t (W_s - 1)}{2} + T_t \end{aligned} \tag{8.11}$$

8.6 Probability of Successful Reception

For successful reception by another vehicle node located within the tagged vehicles node range R. It is imperative that no vehicle node within its carrier sense range ($2E[L_{CS}]$) (or within the maximum $4R$ if $E[L_{CS}] > 2R$) will transmit in the same time slot in which the tagged vehicle node is transmitting. At the same time, vehicle nodes within the interfering areas, which is at maximum, equal to $2(2RE[L_{CS}])$ if $E[L_{CS}] < 2R$. They should not transmit during the vulnerable interval of un-slotted CSMA/CA. It equals two transmission periods weighted by the time slot $T_v = \frac{2T_t}{\delta}$. The transmitted message has also to be error free and the received signal strength has to be higher than the threshold P_{th} which have been accounted for in the derivation of the average communication and carrier sense ranges in (5.5) and (5.7), respectively. Moreover the vehicle node has to stay within the range of the transmitting vehicle node, for the whole communication period. Putting all these conditions together, the probability of successful reception Ps that a vehicle node within the communication range of the tagged vehicle node receive the status message successfully can be written as

$$P_s = P_l \cdot (\sum_{k=0}^{\infty} (1 - \tau_s)^k P_{d_c}(k)) \dot{(} \sum_{k=0}^{\infty} (1 - \tau_s)^k P_{d_h}(k))_v^T, \tag{8.12}$$

where $d_c = 2\dot{m}in(E[L_{CS}], 2R)$ is the contention area and $d_h = 2\dot{m}ax(2R - E[L_{CS}], 0)$ is the hidden terminal area and can be calculated from (5.24). Therefore, Ps can be simplified as

$$P_s = \begin{cases} P_l \cdot e^{-(1+T_v(2\sqrt[\alpha]{\rho}-1))\frac{2\beta R}{\mu \sqrt[\alpha]{\rho}}\tau_s}, \rho > 0.5^\alpha \\ P_l \cdot e^{-2\frac{2\beta R}{\mu}\tau_s}, \rho < 0.5^\alpha \end{cases} \tag{8.13}$$

This probability expresses the reliability of the designed system on Mumbai-Pune Express Highway, India. The higher the success rate, the more vehicle nodes will receive the emergency and status messages successfully, which will increase the drivers awareness of potential dangers on the road ahead.

8.7 Emergency Time delay

When a vehicle node encounters an emergency situation such as an accident, lane change or slowing down below a certain threshold speed is analyzed. The vehicle node that is involved in an emergency situation will send an emergency message to all vehicle nodes behind it. These will select another vehicle nodes as a relay node to rebroadcast the message to their neighbors. The emergency message continues to propagate until it reaches a certain distance D defined within the message itself. The vehicle node uses the high priority access class (AC_3) to send the emergency message after sensing an idle channel for an $AIFSN \times \varrho\ seconds$, where $AIFSN = 2$ for this class as listed in Table 2.3. If the channel is sensed busy, the access class selects a contention window from the range $[0, W_e]$, where $W_e = 3$ in this case, and starts decrementing this counter as in the Markov chain in Figure 8.3. Therefore, the probability τ_e that the emergency message will be sent, can be derived by analyzing the Markov chain as in (8.8) except changing W_s by W_e as

$$\tau_e = \frac{2(1-p)^2}{2 + pW_e - 3p} \tag{8.14}$$

The average time delay $E[T_{se}]$ for the emergency message to be transmitted from the time it was ready at the MAC layer can also be derived as in (8.11) as

$$E[T_{se}] = \sum_{i=0}^{W_e-1} \frac{p}{W_e} \sum_{k=0}^{i-1} (pT_t) + T_t$$
$$E[T_{se}] = \frac{p^2 T_t (W_e - 1)}{2} + T_t \tag{8.15}$$

Once the vehicle nodes are located within the communication range, receive the emergency message, they have to rebroadcast the message to the next hop. Vehicle

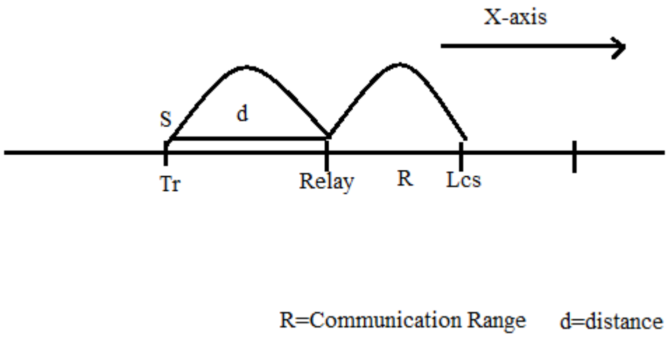

Figure 8.4: Relay vehicle distance model.

nodes calculate their probability of retransmitting the message and their waiting time based on their distance from the transmitter and the vehicle nodes density. The farthest vehicle from the transmitter will have higher retransmitting probability P_{tr} and less waiting time T_w as

$$P_{tr}(d) = \frac{1}{2}\Big[(\frac{d}{R}) + (1 - \frac{\frac{\beta}{\mu}}{\frac{N_l}{10}})\Big] \tag{8.16}$$

$$T_w(d) = (1 - \frac{d}{R})(\frac{\frac{\beta}{\mu}}{\frac{N_l}{10}})(2T_t + \delta), \tag{8.17}$$

where d is the inter distance between the transmitter and the potential relay vehicle node, (based on the received signal strength), N_l is the number of lanes on the Mumbai-Pune Express Highway Road, $\frac{\beta}{\mu}$ is the current vehicle density and $\frac{N_l}{10}$ is the maximum vehicle node density, that is, jam scenario.

To derive the total travel time, for the emergency message to reach the distance D, it is required to find the location of the farthest relay vehicle node to the transmitter, that received the message successfully and the time it waits, before it retransmits the message to the next hop. Assuming that the relay vehicle node is located at distance d from the transmitter as in Figure 8.4, then the probability P_{rec} that this relay vehicle node will receive the message successfully (assuming that the message is transmitted with probability τ_e), can be derived in two cases:

- First when $0 < d < L_{cs} - R$, in this case the relay vehicle would receive the message successfully, when all vehicle nodes within the range $[d - L_{cs}, d + R]$ do not use the channel in the same time slot as the transmitter.

- Second case is when $L_{cs} - R < d < R$, in this case, vehicle nodes within the range of $[d - L_{cs}, L_{cs}]$ should not use the channel in the same time slot as the transmitter and the vehicle nodes within the range $[L_{cs}, d + R]$ should not use the channel for the vulnerable period T_v.

Therefore, P_{rec} can be derived in the same way as in (8.13) as

$$P_{rec}(d) = \begin{cases} P_l \cdot \tau_e \cdot e^{-\frac{\beta R}{\mu}(1+\sqrt[\alpha]{\rho})\tau_s}, 0 < d < L_{CS} - R \\ P_l \cdot \tau_e \cdot e^{\frac{\beta}{\mu}(2\frac{R}{\sqrt[\alpha]{\rho}} - d + (d + R - \frac{R}{\sqrt[\alpha]{\rho}})T_v)\tau_s}, L_{CS} - R < d < R \end{cases} \tag{8.18}$$

It is obvious that farther the relay vehicle node is, the less number of hops the emergency message will travel and has less travel time delay. But as d increases, the relay vehicle is more vulnerable to the hidden terminal problem especially in high density Mumbai-Pune Highway scenario. Therefore, a condition of receiving the emergency message with probability $P_{rec}(d) \geq 90\%$ is applied to find the average, inter distance d of the relay vehicle node from the transmitter. Since this relay vehicle node has a retransmission probability of $P_{tr}(d)$, its average waiting time, till it transmits the emergency message is $\frac{T_w(d)}{P_{tr}}(d)$. The average number of hops, the emergency message will travel to reach its intended distance D is $\lfloor \frac{D}{d} \rfloor$. Therefore, the average emergency message travel time to reach a distance D is

$$T_{travel} = \lfloor \frac{D}{d} \rfloor (E[T_{se}] + \frac{T_w(d)}{P_{tr}(d)}) \tag{8.19}$$

8.8 Adaptive and Mobility Algorithm for VANET

As per above the analysis, it can be seen that there are many conflicting parameters that affect the systems reliability and its success rate. Keeping these parameters with fixed values, as specified in the standard (International), will result in undesired performance, especially in a harsh vehicular environment where vehicles are moving at very high speed and their density on the road is changing very frequently. That is, in a matter of seconds, the vehicle density could change from light density to a jam scenario. Therefore, vehicles have to change their sending rate (λ_s), communication range (R) or (transmission power), carrier sense range (L_{CS}) and/or their minimum contention window size (W_s) based on situation on the road in order to increase the success rate and VANETs reliability.

Therefore, a new Adaptive and Mobility Algorithm (AMA) in which vehicle nodes change their parameters according to their density and speed on Mumbai-Pune Express Highway road, pertaining to the following assumptions, is proposed:

a. The vehicle nodes know their current average speed (V_c) and their maximum allowed speed V_{max} on Mumbai-Pune Express Highway road.

b. The maximum communication range (or the maximum transmission power) is set to R_{max} and the minimum communication range is set to R_{min} which is used in the jam scenario.

c. The carrier sense parameter (ρ), in Equation (5.6), can take three values $\rho \in [1, 0.75, 0.5, 0.25]$.

d. The vehicle's status message sending rate can take the values in the range of $[1-20]$.

e. The minimum contention window size W_s can take on values in the range $[3-1023]$ with a step size of 16.

f. The current used vehicles average speed, range, carrier sense parameter, message sending rate and the minimum contention window are denoted as V_c, R_c, ρ_c, λ_{sc} , W_{sc}, respectively.

Vehicle nodes will execute the AMA algorithm every T_{alg} seconds, where they sense the vehicle nodes density from their current average speed and compare it with the maximum speed V_{max}. The pseudo-code of the AMA algorithm is shown as Algorithm 2. The smaller the current vehicles average speed within the previous time period T_{alg}, the higher the vehicle node density will be around that vehicle node, based on the proposed mobility model in Chapter 5. The algorithm divides the range $(R_{max} - R_{min})$ into ten steps. Each time, the vehicle node speed is dropped by a tenth of its maximum speed V_{max}, it will reduce its range and set the other parameters accordingly. The vehicle will calculate its delay (T_b) from the time it was ready to transmit its status message, until the time the message is transmitted. If the new value of T_b is higher than the old one by $\pi = 10\%$, the vehicle will increase its minimum contention window size W_{sc} ; otherwise it will decrease it or keep it the same. The carrier sense range is also set according to the sensed density. When the vehicle's density is high, the carrier sense range is decreased in order to decrease the waiting time for each vehicle to send its status message. Although decreasing the carrier sense range will increase the hidden terminal area, the algorithm deals with this problem by decreasing the communication range. Therefore, the AMA algorithm allows more vehicles to send their status messages within the synchronization interval with high successful reception rate.

Table 8.1: Value of parameters used in simulation

Parameter	*Value*
Modulation and Data rate	*BPSK* , 3 *Mbps,* 6 *Mbps*
Message and Header sizes	512 ,250 *Bytes,* 64 *Bytes*
Status packets rate λ_s	$10 - 20$ $packets/s$
vehicles speed	$80 - 120$ Km/h
vehicles arriving rate β	1 *vehicle/s*
Exponent factor α	2.00,4.00
Communication range R	300 m, 600 m
Transmission power P_t (300m)	20 mW, 30 mW
Emergency Min. Contention Window W_e	3, 15, 25
Status Min. Contention Window W_s	15, 500, 1023
Received power threshold P_{th}	$3.162e - 13$ W
Carrier sense power percentage ρ	0.25,0.5,0.75,1
Noise-floor	$1.26e - 14$ W
T_{tx} *&* T_{rx} *antennas heights*	1.5 m

T_{tx} *&* T_{rx} *antennas Gain* $G_t = G_r$	1
DIFS	58 μs,64 μs
SIFS	2 *slot time*
Slot time ϱ	9 μs, 13 μs
Propagation delay δ	1 μs, 2 μs
Percentage of drivers that follow safety rule ε	80% − 97%
Number of lanes N_l	4 *lanes*,6 *lanes*
T_{alg}	10 s

8.9 Model Validation and Simulation

The DSRC performance will be analyzed based on the probability of successful reception derived in (8.13). All vehicles send their status messages except for one vehicle that sends an emergency message in which the time it takes to propagate to a certain distance 3000 *meters* is of interest. It is assumed that all vehicles are synchronized to the control channel interval all the time and the generation time of each status message is uniformly distributed over that interval.

To validate the model, NS-2.34 with realistic mobility models generated by MOVE (Karnadi, Mo, and Lan), which is built on top of the micro-traffic simulator SUMO (Krajzewicz et al.) that has the most realistic mobility traces for VANETs (Harri, Filali, and Bonnet). The simulation setup is a one directional highway segment of 4000 m length with 4 lanes. The vehicles' speeds range from $80 - 120$ km/h, which is typical for highways.

The Nakagami-m propagation model is used, which has two distance dependent parameters, the fading factor m and the average power Ω. The authors in (Torrent-Moreno et al., "IEEE 802.11-based one-hop broadcast communications: understanding transmission success and failure under different radio propagation environments")] performed a maximum likelihood estimation of m and Ω for vehicular highway scenario. They found that Ω decreases as the distance to the receiver increases, as expected from the average power in the deterministic models, that is by d^{-2}. On the other hand, fading parameter $m = 3$ is selected for short inter distance between the transmitter and the receiver ($d < 50$), since line of sight condition is expected, then decrease it to $m = 1.5$ for medium distances ($50 < d < 100$) and make it as Rayleigh distributed, i.e., $m = 1$ for longer distances. Ω is set in each interval to be the average power calculated from a free space propagation model; hence receivers located within 100 m of the transmitter will receive the signal with Rician distribution, while others will have Rayleigh distribution. Since the receiver in NS2.34 will receive the signal, if its power is higher than the threshold P_{th}, the transmitting power is set such that the receiving power at the communication range R is the threshold P_{th} as per (5.5), and the carrier sense range $E[L_{CS}]$ is as in (5.7). Each simulation is performed for a period of 300 seconds of real time. Table 8.1 lists the simulation parameters used, unless a change is mentioned explicitly (Hafeez et al., "The optimal radio propagation model in VANET").

The following four metrics are defined to evaluate, the accuracy of the proposed model and reliability of the DSRC protocol in VANETs.

- First: the effective communication range, which is the range of most vehicles (96%) that are located around the transmitter, thus receive the transmitted message successfully and compare it with the communication range derived from (5.5).

- Second: The success rate, which is the number of vehicles that received the transmitted message successfully, divided by the total number of vehicles that are within the range of the transmitter and compare it with (8.13).

- Third: the average time delay, for a vehicle to send its status message and compare it with the time delay derived in (8.11).

- Fourth: the system reliability, which is the number of vehicles that managed to send their status message within the synchronization interval (SI) and received

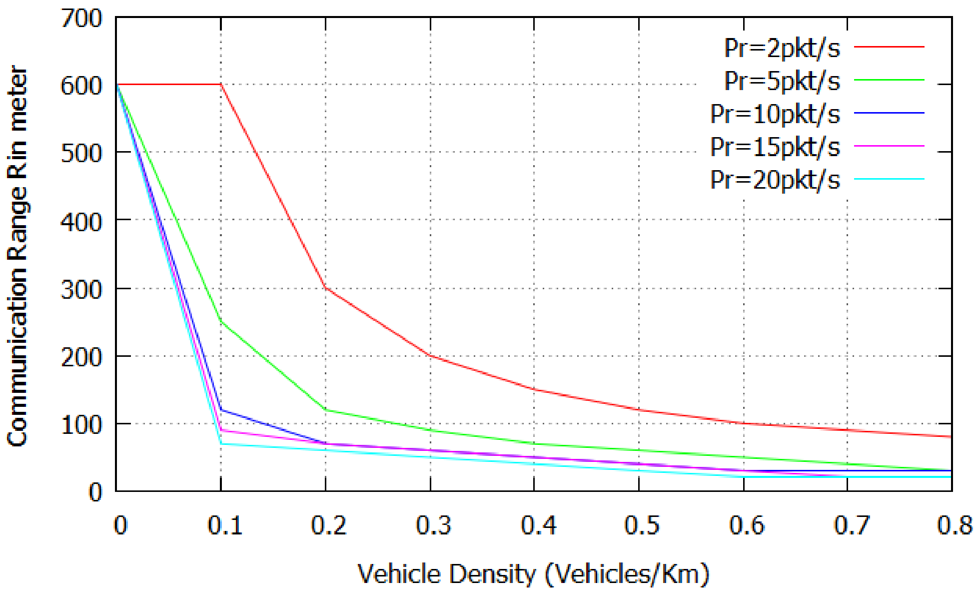

Figure 8.5: Effective communication range versus vehicle density when the success rate is set at 96% for different status message sending rates.

successfully from other vehicles, within the transmitted range divided by the total number of vehicles within the range.

The results shown in Figure 8.5 - 8.8 are based on the vehicle density and average speed corresponding to the density extracted from Figure 5.4. Specifically, Figures. 8.5, 8.6, 8.7 and 8.8 show respectively the effective communication range, the success rate, status message delay and the reliability versus the vehicle density for different status packets generation rates. It is obvious that as the vehicle density increases, the effective range and success rate will decrease. At the same time the status message delay will increase resulting in decreasing the systems reliability, since the number of vehicles that have the chance to send their status messages will decrease. This means that not all vehicles, get the chance to access the channel and send their status packets. To improve the system reliability, the status message generation rate is reduced from 10 to 5 and then 2 packets/s. This improves the system reliability and success rate but it is still below the threshold of 95%, especially when the vehicle density is high. In order to meet this threshold for any vehicle density, vehicles have to reduce their communication range based on Figure 8.5.

Figures. 8.9, 8.10, 8.11 and 8.12 show respectively, the effective communication range, the success rate, status message delay and the reliability versus the vehicle

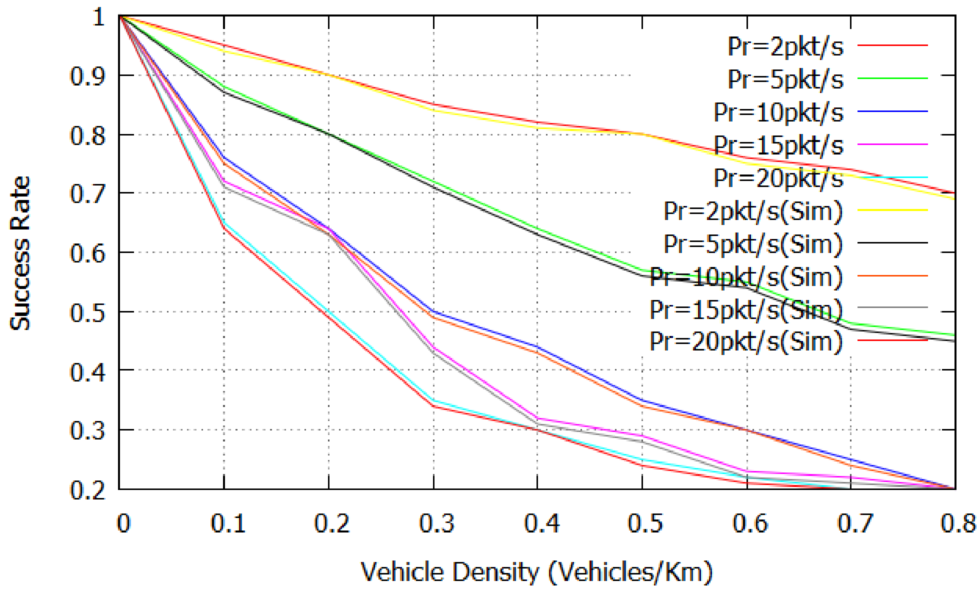

Figure 8.6: The successful rate versus vehicle density for different status message sending rates.

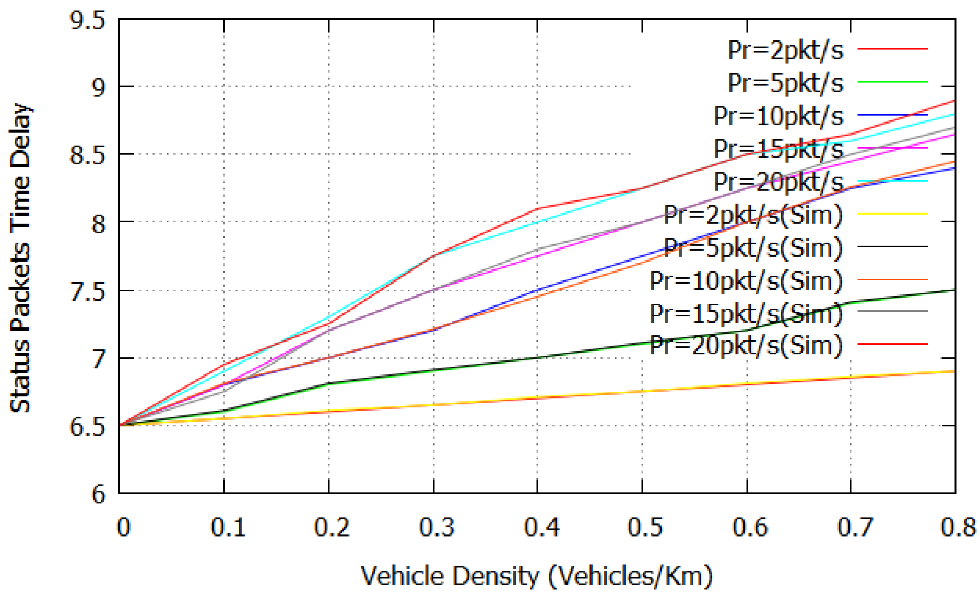

Figure 8.7: Status packets time delay versus vehicle density for different status message sending rates.

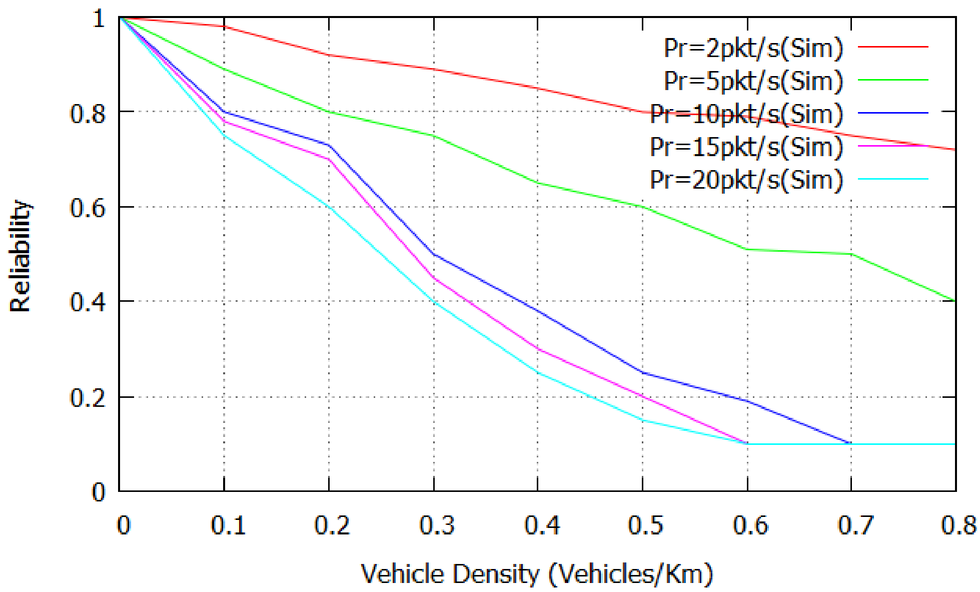

Figure 8.8: Systems reliability versus vehicle density for different status message sending rates.

density for different carrier sense ranges. The carrier sense range is increased by decreasing the carrier sense power or the parameter ρ in Equation 5.6. By decreasing ρ from 1 to 0.25, the carrier sense range doubles that of the communication range. It is evident that increasing the carrier sense range will increase the contention region and decrease the hidden terminal region. Therefore, increasing the carrier sense range will increase the success rate and the system reliability, for fixed vehicle density as shown in Figures 8.10 and 8.12, respectively. As a consequence, the effective communication range will increase as shown in Figure 8.9. At the same time, vehicles will take longer to access the channel as shown in Figure 8.11 due to the increase in the number of vehicles contending for the channel. As a result, the number of vehicles that have chance to send their status messages will decrease and can be observed from the difference between Figs. 8.10 and 8.12.

To find the impact of the minimum contention window size (W_s) on VANETs, W_s is increased from 15 to 1023. The success rate, status message delay and the reliability for different vehicle densities are plotted in Figures. 8.13, 8.14 and 8.15, respectively. It is shown that increasing the minimum contention window will decrease the probability of message collisions between vehicles, which is obvious from Figure 8.13, since the successful rate increases by the increase of W_s. It is also shown that

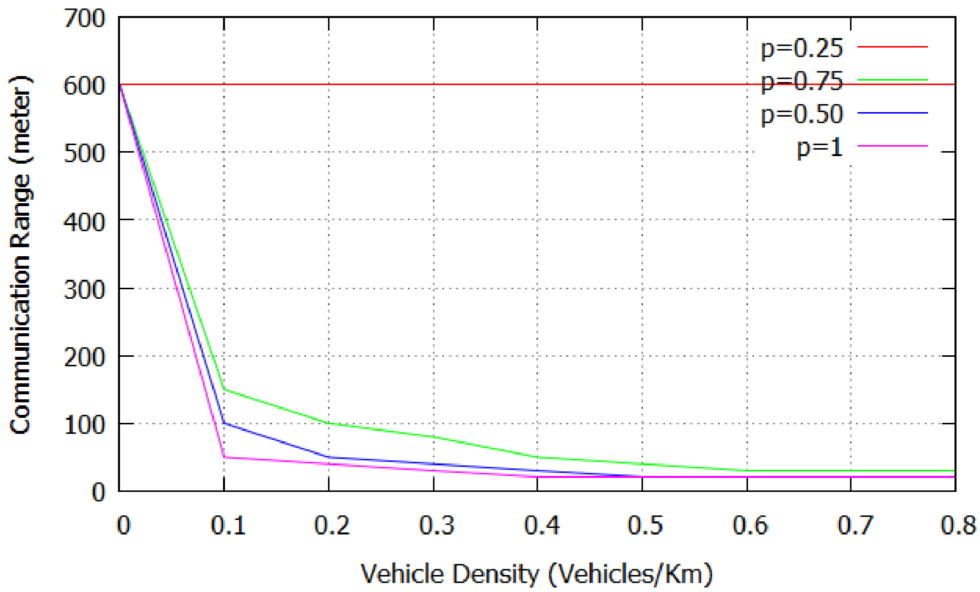

Figure 8.9: Effective communication range versus vehicle density when the success rate is set 95% for different carrier sense ranges.

there is an optimal value of W_s which gives the maximum success rate, since increasing it would not further result in much increase in the success rate. At the same time, the status message delay will increase dramatically by increasing W_s especially when the vehicle density is high. This will result in decreasing the system reliability since not many vehicles might have the chance to send their status messages as shown in Figure 8.15.

To evaluate the effect of the AMA algorithm on VANET reliability, the main simulation parameters as in Table 8.1, are applied and let one vehicle send an emergency message which should propagate for a distance of $3-4\ Km$ behind the transmitter. Figures. 8.16 and 8.17 show respectively the time delay until the emergency message reaches the intended distance and the percentage of vehicles that receive it successfully, with and without, using the AMA algorithm. It can be seen that the time needed for the emergency message, to reach the intended distance increases, as the vehicle density increases, due to the increase in channel contention and collisions. Adapting the AMA algorithm results in increasing the emergency time delay even more and this is because vehicles would decrease their communication range, as the vehicle density increases. It is also clear that the simulated time delay is close to the theoretical value derived from (8.19). On the other hand, adapting the new algorithm

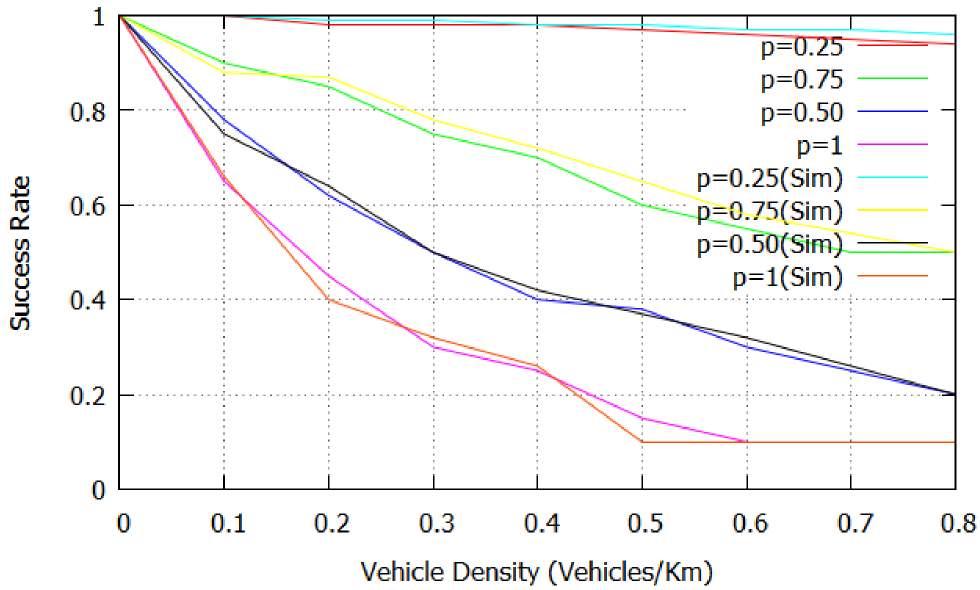

Figure 8.10: The successful rate versus vehicle density for different carrier sense ranges.

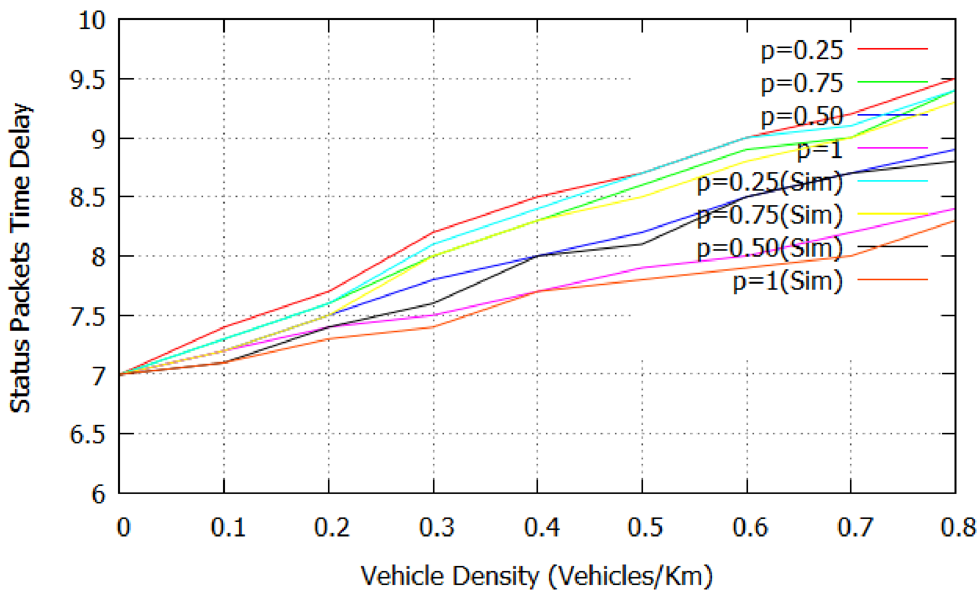

Figure 8.11: Status packets time delay versus vehicle density for different carrier sense ranges.

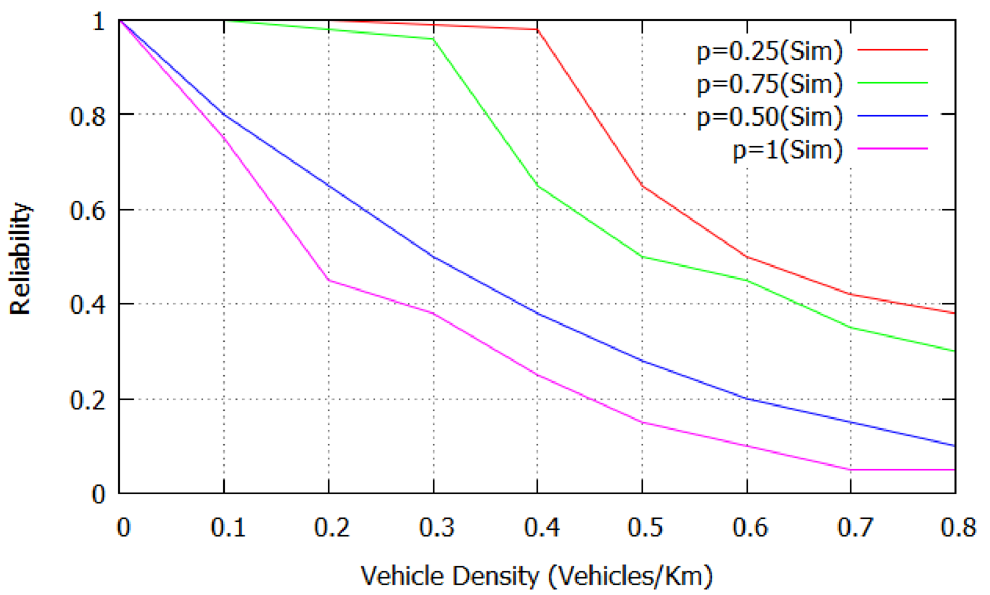

Figure 8.12: Systems reliability versus vehicle density for different carrier sense ranges.

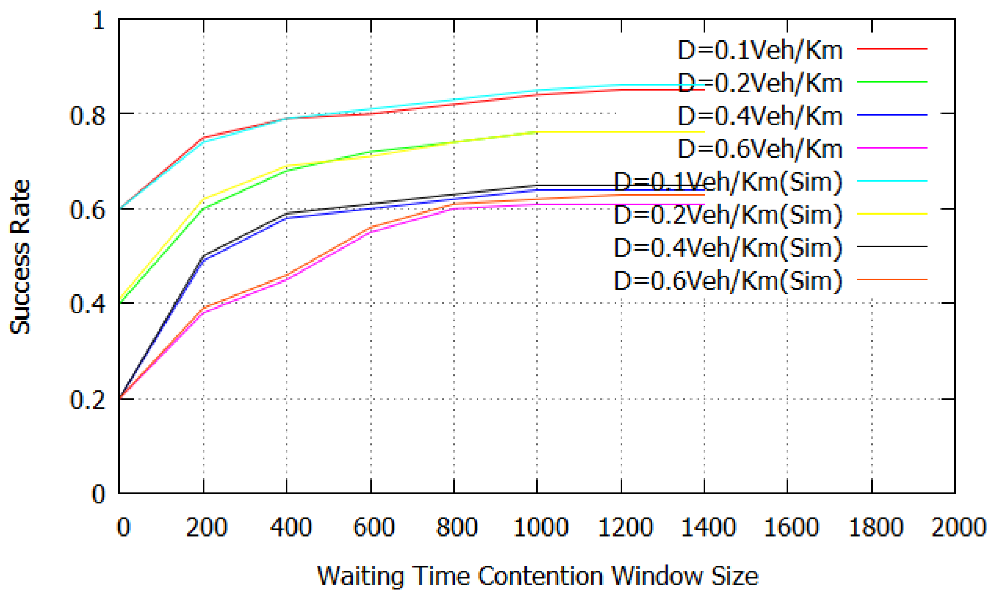

Figure 8.13: The successful rate versus contention window size for different vehicle densities.

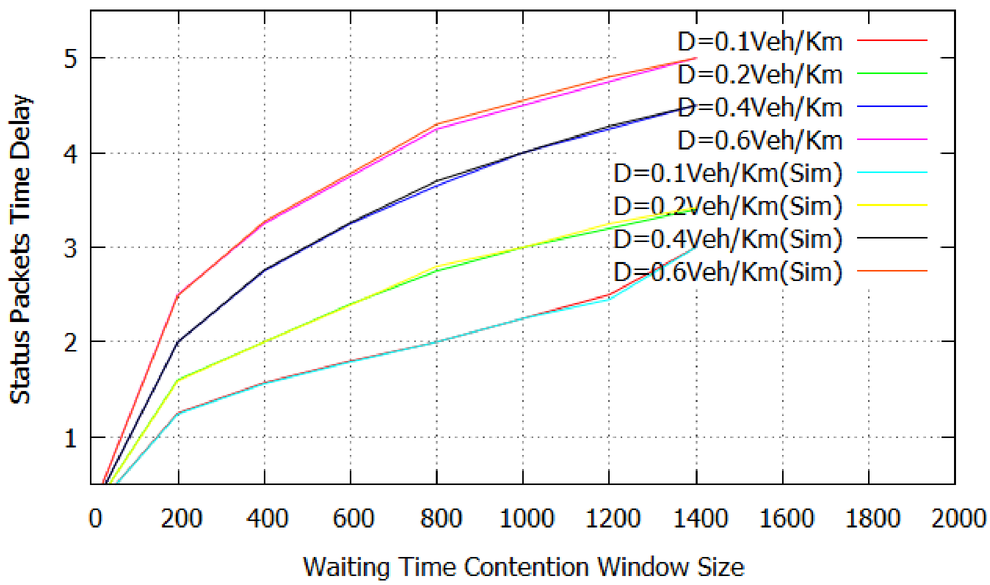

Figure 8.14: Status packets time delay versus contention window size for different vehicle densities.

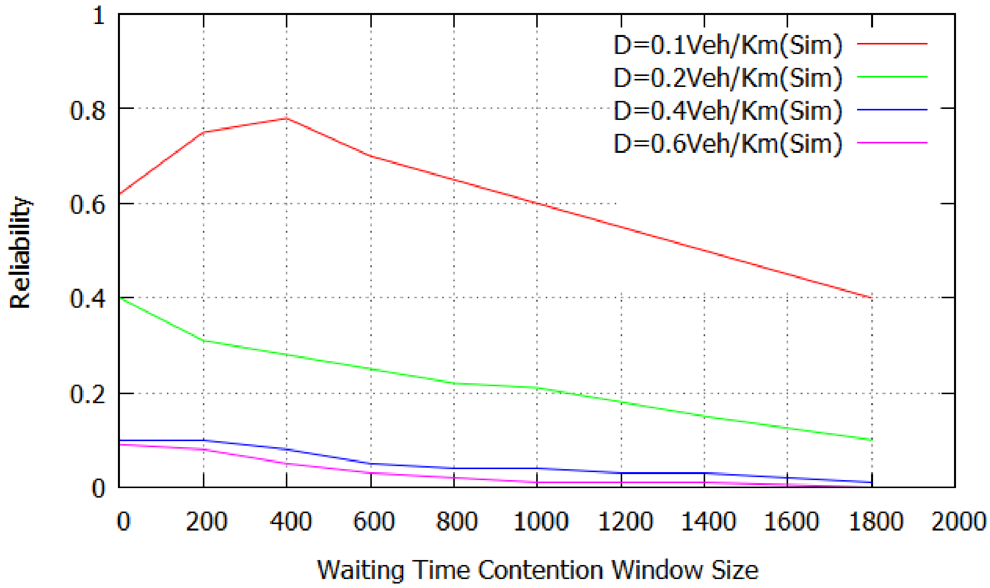

Figure 8.15: Systems reliability versus contention window size for different vehicle densities.

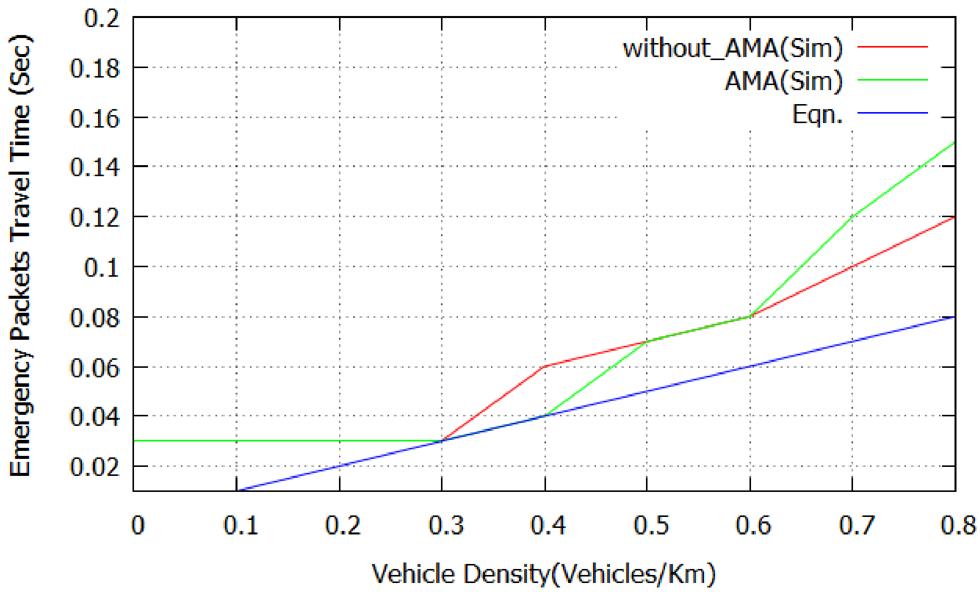

Figure 8.16: Emergency message travel time versus vehicles density.

increases the systems success rate dramatically especially in a high density scenario as shown in Figure 8.17. This means that more vehicles will be informed of the emergency situation on the road ahead, even though it arrives late but within tolerable delay as defined in (Mak, Laberteaux, and Sengupta).

8.10 Summary

An logical model is presented to analyze the reliability of the IEEE 802.11p in VANET safety and warning applications on Mumbai-Pune Express Highway, India scenario which consist of 2000 vehicles running on road. The analysis is based on a new mobility model in which the relationship between vehicles density, speed, direction and the follow-on distance rule is derived. In the analysis, several factors have been considered, such as the effect of mobility on the link availability between the transmitter and the receiver in same direction and different direction, the distribution of vehicles on the road and the average number of vehicles within the range of the transmitter. The proposed model is built on the fact that vehicles are broadcasting their status messages within the synchronization interval and model each vehicle as one-dimensional or two-dimensioal Markov chain including, the channel busy in every state. It is shown analytically and by simulation that the effective maximum communication range is 1000 meter, that can be used in certain conditions to achieve certain

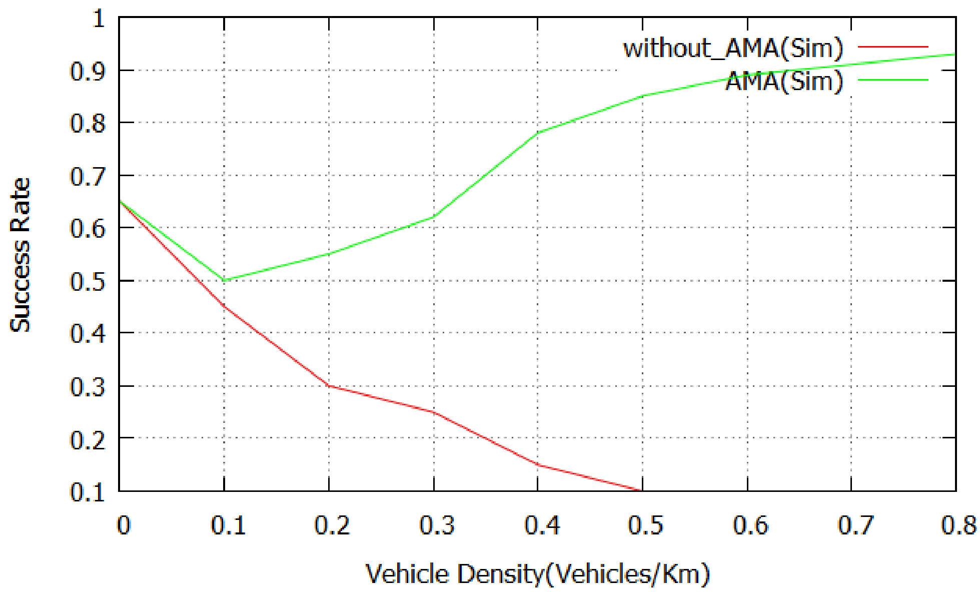

Figure 8.17: Percentage of vehicles within the distance ($3Km$) that received the emergency message successfully.

successful rate. It is shown from the analytical and simulation results that the current DSRC specifications may lead to undesirable performance under harsh vehicular environments. Therefore, a new Adaptive and Mobility Algorithm (AMA), is introduced to enhance VANET reliability. By using the AMA algorithm, vehicles are able to estimate the vehicle density and change their transmission parameters accordingly, based on their current average speed to enhance VANET performance. The simulation results, which coincide with the logical results, show that the proposed model is quite accurate to the simulation results in calculating the system reliability, scalability, efficiency which resolves the hidden terminal problem for Indian Mumbai-Pune Express Highway scenario.

Algorithm 2 Adaptive and Mobility Algorithm (AMA) to set VANETs parameters according to the vehicles density on the road.

Initial setup
$R_{max} \leftarrow 1000;$
$R_c \leftarrow R_{max};$
$P_c \leftarrow 0.25;$
$\lambda_{s_c} \leftarrow 20;$
$W_{s_c} \leftarrow 15;$
for *Every* T_{alg} *seconds* **do**
  if $V_c < V_{max}$ **then**
    $i \leftarrow \lfloor \frac{V_c}{V_{max}} \cdot 10 \rfloor$ /* *i represents a step from* 1 *to* 10 *in which the current speed falls in compared to the max. speed* */
    $R_c \leftarrow R_{min} + i \cdot \frac{R_{max} - R_{min}}{10}$ /* *use a new range based on the step* i */
    $\lambda_{s_c} \leftarrow max(i, 1)$ /* *use a new sending rate based on the step* i */
    if $i \leq 3$ **then**
      $\rho_c \leftarrow 1$ /* *in very high density,* $L_{CS} = R$ */
    else if $i \leq 5$ **then**
      $\rho_c \leftarrow 0.75$ /* *in high density,* $R \leq L_{CS} = R$ */
    else if $i \leq 7$ **then**
      $\rho_c \leftarrow 0.5$ /* *in medium density,* $R \leq L_{CS} \leq 2R$ */
    else
      $\rho_c \leftarrow 0.25$ /* *in low density,* $L_{CS} \simeq 2R$ */
    end if
  end if
  if $T_{b_{new}} \geq (1 + 3.16) \cdot T_{bold}$ **then**
    $W_{s_c} \leftarrow min(W_{s_c} + 16130)$ /* *if the time delay increases, i.e. more contention, increase* W_s */
  else
    $W_{s_c} \leftarrow max(W_{s_c} - 1620)$ *if the time delay decreases, i.e. less contention, decrease* W_s */
  end if
end for

Chapter 9

Conclusions and Future Work

9.1 Conclusions

The focus of this thesis is to develop scientifically and practically deployable solutions to support the new generation of vehicular safety applications on Mumbai-Pune Express Highway, India. The theory and design challenges of Medium Access Control (MAC) protocol, specifically for the vehicular safety application in a harsh vehicular environment are tackled. The research addresses the mobility, frequent link ruptures, stringent time delay and the multi-path propagation that are expected to be prevalent in VANET. Introduction of adaptive adjustment algorithms for the sending rates, transmission power among vehicle nodes and the contention window based on the sensed vehicle nodes density on Mumbai-Pune Road.

The IEEE community is adopting the IEEE 802.11p as the main technology for VANET to support protocols and applications over Vehicle-to-Vehicle Communications (V2V) and Vehicle-to-Roadside communication (V2R). To test the new applications and protocols on a real setup is very difficult and very costly. Hence, simulation is used to study and analyze VANET. Therefore, this thesis is analysis for PHY and MAC layers of the DSRC technology to build a simulation setup using Openstreet, eWorld, SUMO and NS2.34 that best characterize VANET wireless channel and the movements of their nodes (vehicles).

The radio channel in VANET is very complex and has many parameters that affect the amplitude and phase of the received signal. Therefore choosing the optimal propagation model that best characterize VANET channel is the challenge that faces researchers in validating and testing the new applications and protocols. Through analysis and simulations, we showed that Ricean and Nakagami (in general) distributions are the appropriate models to describe the received signal in a highway scenario. Based on these findings, the communication range in the vehicular environment is derived. Moreover, we derived the recommended maximum one hop range that minimizes the collisions probability and the impact of the hidden terminal problem.

The mobility model is a crucial part in analyzing and testing VANET. Therefore, a new mobility model is built, that takes into account the vehicles follow-on safety rule on highway road, to accurately derive the relationship between vehicles speed and network density. Also derive the distribution of vehicle nodes on the road which affects the link availability and duration of connection between vehicles.

In traffic safety system can be classified as real-time systems which mean that the data traffic sent on the wireless channel has a deadline. The most important component of a real-time vehicle-to-vehicle communication system is the MAC protocol method. In this paper, two MAC methods have been evaluated according to their ability to meet the real-time communication deadlines. The MAC of the vehicular communication standard IEEE 802.11p CSMA/CA was examined through simulation, and the results indicate severe performance degradation for a heavily loaded system, both for individual nodes and for the system. The simulations show that 802.11p is not suitable for periodic location messages in a Mumbai-Pune Highway Road and Palm-Beach Road city scenario, if the network load is high since some nodes will drop over 85% to 90% of their data packets. Location messages will be a central part of vehicle communication systems and much traffic safety application will depend on locations. In addition, when the network load increases, the benefits of scheduling transmissions in space comes into play. With CSMA/CA, transmissions may overlap in time, both completely and partially due to unsynchronised transmissions taking place outside the sensing range of concurrent transmitters. Also partially overlapping transmissions are likely to cause decoding failures at receivers situated in between the concurrent transmitters (the hidden terminal problem). Further, when the network load increases, CSMA/CA stations within radio range of each other are more likely to transmit at the same time due to reaching a back-off value of zero at the same time. This occurs since CSMA/CA stations within radio range of each other are synchronized to some extent, through the channel sensing procedure, and therefore stations tend to initiate their back-off counters at the same time, when a busy channel becomes free. The selection of back-off values is not scheduled in space and thus two or more stations can be geographically co-located when reaching a back-off value of zero, reducing the packet reception probability for many receivers.

For VANETs safety applications to run effectively, it is necessary to have a highly reliable Medium Access Control (MAC) protocol, such that vital safety messages are not lost. In fact, the efficiency of VANETs depends on the performance and reliability of their MAC protocol which must be decentralized to fit their ad-hoc nature. The MAC protocol should cope with the fast changing topology of VANETs and their uneven node density on the road. Therefore, we present an analytical model to analyze the reliability of the IEEE 802.11p in VANETs safety and warning applications. The analysis is based on the new mobility model to make it more close to reality. In the analysis, several factors have been considered, such as the impact of mobility on the link availability between the transmitter and the receiver, the distribution of vehicles on the road and the average number of vehicles within the range of the transmitter. It is shown from the analytical and simulation results that the current DSRC specifications may lead to undesirable performance under harsh vehicular environments. Therefore, a new adaptive algorithm, is introduced to enhance VANETs reliability. By using this algorithm, vehicles are able to estimate the vehicle density and change their transmission parameters accordingly based on their current average speed to enhance VANETs performance. The simulation results, which coincide with the analytical results, show that the proposed model is quite accurate in calculating the system reliability. Although this algorithm enhances the performance of the DSRC, still there is a need for a novel MAC protocol that is more suitable for VANETs to alleviate the impact of the hidden terminal problem, increase the network capacity and reliability.

Researcher have presented Broadcast Algorithm, a localized broadcast protocol for vehicular ad-hoc networks. It is built upon the CDS and Cluster algorithm framework, and implicitly uses the store-carry-forward paradigm typical of delay-tolerant networks. The algorithm employs the position information of the multi-hop neighborhood, as well as acknowledgments of the latest received broadcast messages with cluster formation algorithm. This algorithm selects the Cluster-head using cluster selection algorithm and transmits the messages appropriately. It improve the protocol reliability, scalability and efficiency. By means of a thorough simulation-based study, Broadcast Protocol has been evaluated on Mumbai-Pune Express Highway, India scenario. Different mobility degrees and network densities have been taken into account. In addition, consider the different models for wireless technologies, ranging from ideal conditions to quite realistic 802.11p simulations. Further analyzed the protocol by performing a sensitivity analysis on the parameters it depends on, and studying Broadcast Protocols scalability as the number of data sources in the network increases. The proposed algorithm has been shown to outperform competing solution specifically designed for the vehicular environment. Broadcast Protocol has turned out to be a very robust and reliable protocol, that extremely reduces the number of transmissions needed to complete a broadcasting task. Despite the algorithm is delay tolerant by nature, it does favor low delivery latencies. Broadcast Protocol not only calculate reliability but also scalability and efficiency which makes the protocol better than DVCAST protocol and Khalid Abdel Hafeez protocol. Khalid Abdel Hafeez protocol solve only hidden terminal problem but Broadcast protocol solves problem of hidden terminal and storm problem using CDS and cluster algorithm which improves reliability on Mumbai-Pune Express Highway India.

The outcomes of this work will contribute to the state-of-the-art research toward new standards and design policies for future-generation vehicular ad hoc networks. They will also facilitate the development of numerous safety and commercial vehicular applications that will increase safety, efficiency, reliability and security of the current transportation system which will revolutionize our traveling concept.

9.2 Future Work

This thesis addresses several aspects related to the design of a new MAC protocol for Vehicular ad-hoc networks. However, there are some relevant issues that warrant further consideration in the future work. For instance, researcher have considered, in this work, homogenous networks where all vehicles have the same communication range, use the same transmission rate, and message frequency. However, it is important to test the new protocols and applications on a heterogeneous network setup. Moreover, there is a need for dynamic algorithms for synchronizing the sending rates, transmission power among vehicles and adaptive adjustment techniques for the fair sharing of bandwidth between different channels.

It is also necessary to tackle the theory and design challenges of an IP routing protocol that suits vehicular networks with the integration of a security system that is built on well-established mechanisms and cryptographic primitives.

Securing VANETs communications is an indispensable prerequisite for its deployment and real world use. The special characteristics of VANETs, the huge network size they can form and their open environment make them more vulnerable to security attacks than regular WLANs. The new deployed security system should be more efficient and reliable to ensure confidentiality of drivers identities and their data. Balancing security and privacy with safety is the ultimate challenge that should be tackled in the new IP routing protocol design.

The results provided within this thesis are very promising and encouraging. Researcher can continue working on Broadcast Protocol in the vehicular context. In which researcher can address the degree of compatibility of the protocol with developing standards like DSRC. The protocol will also be analyzed when infrastructure nodes also take part in data messages dissemination. On the other hand, currently investigating how to further reduce the protocol overhead when there are multiple simultaneous broadcasting tasks, by means of probabilistic data structures to limit the size of the acknowledgment list in beacon messages. In addition, also investigate how to adapt the retransmission time-out given a delay constraint from the application, in order to make the protocol suitable to delay-critical safety applications.

Chapter 10

Summary

10.1 Summary

The radio channel in VANETs is very complex and has many parameters that affect the amplitude and phase of the received signal. Using simple models like the Free-Space and Two-Ray models is not accurate in all scenarios. simulations using NS-2.34 show very different results for different propagation models. Therefore, choosing the optimal model in each scenario, is the challenge that is faced by researchers. The best way to model the radio channel is, by conducting real experiments on the road. MATLAB simulations show that Ricean and Nakagami distributions are the appropriate models to describe the received signal in a highway scenario. results show that the simulated results agree with the analytical results.

AODV shows the best performance with its ability to maintain connection by periodic exchange of information required for TCP network. AODV performs best in case of packet delivery ratio and GPSR outperform others in case of throughput. Varying pause time, GPSR outperform others in case of packet loss and throughput, but overall AODV outperforms GPSR and DSR as in high mobility, environment topology change rapidly and AODV can adapt to the changes, but after taking everything into account GPSR is better than others. At higher node mobility, AODV is worst in case of packet loss and throughput but performs best for packet delivery ratio, GPSR performs better than AODV for higher node mobility, in case of end-to-end and throughput, but DSR performs best in case of packet loss. Hence, for real time traffic GPSR is preferred over DSR and AODV. Finally, from the above research work performance of AODV is considered best for Real-time and TCP network.

the communication range and the carrier sense range based on the physical wireless channel analysis and the propagation model that best characterize vehicular ad-hoc networks as conducted in Chapter 3. We also introduced a new mobility model in which the relationship between vehicle density, speed and the follow-on distance rule is derived. The model is accurate in deriving the number of vehicles within the communication range as shown in the simulation results. These results will help in designing and analyzing all proposed algorithms and protocols.

New Broadcast Protocol, which is a localized broadcast protocol for vehicular ad-hoc networks. It is built upon the Cluster algorithm framework. It implicitly uses the store-carry-forward paradigm, typical of delay-tolerant networks and cluster formation algorithm. The pseudo-code employs the position information of the multi-hop neighborhood, acknowledgments and cluster formation of the latest received broadcast messages and warning messages, improve protocol reliability, scalability and efficiency. Broadcast Protocol not only calculate reliability but also scalability and efficiency which makes the protocol better than DVCAST protocol and Khalid Abdel Hafeez protocol. Khalid Abdel Hafeez protocol does not resolves hidden terminal problem and broadcast storm problem totally only reduces redundancy but Broadcast protocol resolves problem of hidden terminal and broadcast storm problem using CDS and cluster algorithm which improves reliability, scalability and efficiency on Mumbai-Pune Express Highway India.

In future traffic safety system can be classified as real-time system for Mumbai-Pune Express Highway Road, India. It means that the data traffic sent on the wireless channel has a deadline with respect to time duration. The most important component of a real-time vehicle-to-vehicle communication system on Mumbai-Pune Express Highway Road is the MAC protocol method. In this chapter, two MAC methods have been evaluated according to their ability to meet real-time communication deadlines. The MAC of vehicular communication standard IEEE 802.11p CSMA/CA was examined through simulation i.e Openstreet, eWorld, SUMO, Google Maps, NS2.34 and AWK or Gnuplot, the results indicate severe performance degradation for a heavily loaded system, both for individual vehicle nodes and for the system. The simulations show that 802.11p is not suitable for periodic location messages in a Mumbai-Pune Highway Road scenario, if the network load is high, since some vehicle nodes will drop over 85% to 90% of their data messages.

Evaluation of CSMA/CA and STDMA is performed through simulations on Mumbai-Pune Express Highway, modelling a 50 km Mumbai-Pune Express Highway with three lanes in each direction with bidirectional communication among the vehicles on road. Vehicles travel along the Mumbai-Pune Express Highway and broadcast local or status messages periodically.The simulation results, for CSMA/CA has on average a smaller channel access delay than STDMA on Mumbai-Pune Express Highway, India. However, STDMA always shows better reliability and scalability results than CSMA/CA, especially between transmitter and receiver.

An logical model is presented to analyze the reliability of the IEEE 802.11p in VANET safety and warning applications on Mumbai-Pune Express Highway, India scenario which consist of 2000 vehicles running on road. The analysis is based on a new mobility model in which the relationship between vehicles density, speed, direction and the follow-on distance rule is derived. In the analysis, several factors have been considered, such as the effect of mobility on the link availability between the transmitter and the receiver in same direction and different direction, the distribution of vehicles on the road and the average number of vehicles within the range of the transmitter. The proposed model is built on the fact that vehicles are broadcasting their status messages within the synchronization interval and model each vehicle as one-dimensional or two-dimensioal Markov chain including, the channel busy in every state. It is shown analytically and by simulation that the effective maximum communication range is 1000 meter, that can be used in certain conditions to achieve certain successful rate. It is shown from the analytical and simulation results that the current DSRC specifications may lead to undesirable performance under harsh vehicular environments. Therefore, a new Adaptive and Mobility Algorithm (AMA), is introduced to enhance VANET reliability. By using the AMA algorithm, vehicles are able to estimate the vehicle density and change their transmission parameters accordingly, based on their current average speed to enhance VANET performance. The simulation results, which coincide with the logical results, show that the proposed model is quite accurate to the simulation results in calculating the system reliability, scalability, efficiency which resolves the hidden terminal problem for Indian Mumbai-Pune Express Highway scenario.

Works Cited

Abuelela, M., S. Olariu, and I. Stojmenovic. "OPERA: Opportunistic message relaying in disconnected vehicular ad-hoc networks." *5th IEEE International Conference on Mobile ad-hoc and Sensor System*. IEEE, IEEE, 2008. 285–294.

Alonso, A., et al. "Challenging Vehicular Scenarios for Self-Organizing Time Division Multiple Access." *European Cooperation in the Field of Scientific and Technical Research* (2011).

Alshaer, H. and E. Horla it. "An Optimized Adaptive Broadcast Scheme for Inter-vehicle Communication." *Proc. of IEEE Vehicular Technology Conf.(VTC)* (2005): 2840–2844.

ASTM. "E2213-03 - Standard Specification for Telecommunications and Information Exchange between Roadside and Vehicle Systems - 5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications." *ASTM* (2002).

B, H. Hartenstein. "Position-Aware Ad-Hoc Wireless Networks for Inter-Vehicle Communications: The FleetNet Project." *Proceedings of the 2nd ACM international Symposium on Mobile Ad-Hoc Networking and Computing* (2001): 259–262.

B., Karp, Kung, and H. T. "GPSR: greedy perimeter stateless routing for wireless networks." *Proceedings of the 6th Annual international Conference on Mobile Computing and Networking* (2000): 243–254.

Badarneh, O. and M. Kadoch. "Multicast Routing Protocols in Mobile Ad-Hoc Networks: A Comparative Survey and Taxonomy." *EURASIP Journal on Wireless Communications and Networking* (2009): 1–42.

Bai, F. and H. Krishnan. "Reliability analysis of DSRC wireless communication for vehicle safety applications." *In Proc. IEEE Intelligent Transportation Systems Conf.* (2006): 355–362.

Bazan, O. and M. Jaseemuddin. “Performance analysis of directional CSMA/CA in the presence of deafness.” *IET Communications* 4.18 (2010): 2252–2261.

Bianchi, G. “Performance analysis of the IEEE 802.11 distributed coordination function.” *IEEE J. Select. Areas Communications* 18.3 (2000): 535–547.

Bilal, M., P.M.L. Chan, and P. Pillai. “Fastest-Vehicle Multi-hop Routing in Vehicular Ad-hoc Networks.” *Proc. of 10th IEEE Intl Conf. on Computer and Inf. Tech. (CIT)* (2010): 773–778.

Bilstrup, K. “A survey regarding wireless communication standards intended for a highspeed vehicle environment.” *Technical Report IDE 0712* (2007).

—.“Evaluation of the IEEE 802.11p MAC method for vehicle-to-vehicle communication.” *In Proceedings of the 68th IEEE Vehicular Technology Conference (VTC’08)* (2008): 1–5.

Bilstrup, K. and E. Uhlemann. “On the Ability of the 802.11p MAC Method and STDMA to Support Real-Time Vehicle-to-Vehicle Communication.” *EURASIP Journal on Wireless Communications and Networking* 13 (2009).

Bilstrup, K., E. Uhlemann, and E.G. Storm. “Medium access control in vehicular networks based on the upcoming IEEE 802.11p standard.” *In Proceedings of the 15th World Congress on Intelligent Transport Systems (ITS’08)* (2008): 1–12.

Bilstrup, K., et al. “On the ability of the 802.11p MAC method and STDMA to support real-time vehicle-to-vehicle communication.” *EURASIP Journal on Wireless Communications and Networking* (2009).

Bilstrup, K. Sjberg, E. Uhlemann, and E.G. Strm. “Scalability issues for the MAC methods STDMA and CSMA/CA of IEEE 802.11p when used in VANETs.” *In Proceedings of the IEEE International Conference on Communications (ICC2010)* (2010).

Biswas, S., R. Tatchikou, and F. Dion. “Vehicle-to-Vehicle Wireless Communication Protocols for Enhancing Highway Traffic Safety.” *IEEE Comm. Magazine* 44.1 (2006): 74–82.

Blum, J., A. Eskandarian, and L.J. Hoffman. “Challenges of inter vehicle ad-hoc networks.” *IEEE Trans. Intelligent Transportation Systems* 5.4 (2004): 347–351.

Blum, J.J., A.Eskandarian, and L.J. Huffman. "Challenges of inter vehicle ad-hoc networks." *IEEE Transactions on Intelligent Transportation System* 5.4 (2004): 347–351.

Borgonovo, F., et al. "ADHOCMAC: a new, flexible and reliable MAC architecture for ad-hoc networks." *Vehicular Technology Conference* 5 (2003): 2789–2793.

Car, Car C. "Car 2 Car Communiaction Consortium Manifesto." *Technical Report* 1.1 (2007).

Cheng, et al. "A Measurement Study of Time-Scaled 802.11a Waveforms Over The Mobile-to-Mobile Vehicular Channel at 5.9 GHz." *IEEE Communications Magazine* 46.5 (2008): 84–91.

Choffnes, D. R. and F. Bustamante. "An integrated mobility and traffic model for vehicular wireless networks." *Proceedings of the 2nd ACM international workshop on Vehicular ad-hoc networks* (2005): 69–78.

Choi, N. "A solicitation-based IEEE 802.11p MAC protocol for roadside to vehicular networks." *In Proc. Work. on Mobile Networking for Vehicular Environments* (2007): 91–96.

Chu, Y. and N. Huang. "Delivering of Live Video Streaming for Vehicular Communication using Peer-to-peer Approach." *Proc. of IEEE Works hop on Mobile Netw. for Vehicular Environments* (2007): 1–6.

Clark, B., C. Colbourn, and D. Johnson. "Unit Disk Graphs." *Discrete Math* 86.1–3 (1991): 165–177.

D., Reichardt, et al. "CarTALK 2000 safe and comfortable driving based upon inter-vehicle-communication." *IEEE Xplore* 4 (2002).

Desai, M. and D. Manjunath. "On the connectivity in finite ad-hoc networks." *IEEE Communication Letters* 6.10 (2002): 437–439.

DNS. "Network Simulator 2 (ns2)." *Discrete Event Network Simulator* (2009).

Eichler, S. "Performance evaluation of the IEEE 802.11p WAVE communication standard." *Proc. IEEE Vehicular Technology Conf.* (2007): 2199–2203.

Ericsoun. "Communication and Mobility by Cellular Advanced Radio." *ComCar project* (2002).

Fasolo, E., A. Zanella, and M. Zorzi. "An Effective Broadcast Scheme for Alert Message Propagation in Vehicular ad-hoc Networks." *Proc. of IEEE Intl Conf. on Comm.(ICC)* (2006): 3960–3965.

Festag, P. Papadimitratos, and T. Tielert. "Design and Performance of Secure Geocast for Vehicular Communication." *IEEE Trans.on Vehicular Technology* 5.59 (2010): 2456–2471.

Festag, A. "Now-Network on Wheels: Project Objectives, Technology and Achievements." *Proceedings of 6th International Workshop on Intelligent Transportations (WIT), Hanburg, Germany* (2008).

For Information technology, IEEE Standard. "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 8: Medium Access Control (MAC) Quality of Service Enhancements." *EEE Std. 802.11e-2005 Amendment to IEEE Std 802.11* (2007).

Four, T. G. "IEEE 802.15 WPAN Task Group 4 (TG4)." *IEEE802.org* (2009).

Fracchia, R. and M. Meo. "Analysis and design of warning delivery service in intervehicular networks." *IEEE Trans. Mobile Computing* 7 (2008): 832–845.

Fujiki, T., et al. "Efficient Acquisition of Local Traffic Information using Inter-Vehicle Communication with Queries." *Proc. of IEEE Intelligent Transportation Systems Conf.(ITSC)* (2007): 241–246.

Gallagher, B., H. Akatsuka, and H. Suzuki. "Wireless Communications for Vehicle Safety: Radio Link Performance and Wireless Connectivity Methods." *EEE Vehicular Technology Magazine* 1 (2006): 4–24.

Gerla, M., and Tsai. "Multicluster, mobile, multimedia radio network, wireless networks." *The IEEE International Conference on Networks* 13.1 (1995): 255–265.

Ghasemi, A. and S. Nader-Esfahani. "Exact probability of connectivity one-dimensional ad-hoc wireless network." *IEEE Communication Letters* 10.4 (2006): 251–253.

Gla. "IEEE 802.15 WPAN Task Group 1a (TG1a)." *IEEE802.org* (2009).

Guo, M ., M. Ammar, and E. W. Zegura. "V3:A Vehicle-to-Vehicle Live Video Streaming Architecture." *Pervasive and Mobile Computing* 1.4 (2005): 404–424.

Hafeez. "Performance Analysis and Enchancement of the DSRC for VANET's Safety Applications." *IEEE Transaction on Vehicular Technology* 62.7 (2013): 3069–3083.

Hafeez, K., et al. "The optimal radio propagation model in VANET." *Fourth International Conference on Systems and Networks Communications (ICSNC)* (2009): 6–11.

Hafeez, K. A., et al. "A new broadcast protocol for vehicular ad-hoc networks safety applications." *Proc. IEEE Globecomm Conf.* 2010.

—. "Impact of mobility on VANETs safety applications." *Proc. IEEE Globecomm Conf.* (2010).

Hall, R. J. "An Improved Geocast for Mobile Ad-Hoc Networks." *IEEE Trans. on Mobile Computing* 10.2 (2011): 254–266.

Harri, J., F. Filali, and C. Bonnet. "Mobility models for vehicular ad-hoc networks: a survey and taxonomy." *IEEE Communications Surveys and Tutorials* 11.4 (2009): 19–41.

Hartenstein, H. and K. Laberteaux. "A Tutorial Survey on Vehicular ad-hoc Networks." *IEEE Comm. Magazine* 46.6 (2008): 164–171.

Hassan, M., H. Vu, and T. Sakurai. "Performance analysis of the IEEE 802.11 MAC protocol for DSRC safety applications." *IEEE Trans. Vehicular Tech.* 60.8 (2011): 3882–3896.

Hsiao-Kuang, C., et al. "Routing in clustered multihop, mobile wireless networks with fading channel." *The IEEE Singapore International Conference on Networks* (1997).

IEEE. "IEEE P802.11p/D5.0 Draft Amendments for Wireless Access in Vehicular Environments (WAVE)." *IEEE Xplore* (2008): 1–36.

—. "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Amendment 8: Medium Access Control (MAC) Quality of Service Enhancements." *IEEE Std. 802.11e-2005* (2005).

IntelliDrive. "DSRC and Proof of Concept Test." *http://www.intellidriveusa.org/library/rept-dsrc-poc.php* (2009).

International, ASTM. "Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems 5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications." *American Society for Testing and Materials* 03 (2010).

Jiang, D., Q. Chen, and L. Delgrossi. "Optimal data rate selection for vehicle safety communications." *Proceedings of the fifth ACM international workshop on VehiculAr Inter-NETworking* (2008): 30–38.

Jiang, D. and L. Delgrossi. "IEEE 802.11: Towards an International Standard for Wireless Access in Vehicular Environments." *Tehnical Draft* (2007).

—. "IEEE 802.11p: Towards an international standard for wireless access in vehicular environments." *Proc. IEEE Vehicular Technology Conf.* (2008): 2036–2040.

Jin, K. and D. Cho. "Multi-code MAC for multi-hop wireless ad-hoc networks." *Vehicular Technology Conference* 2 (2002): 1100–1104.

Jin, W.-L. and W. Recker. "An analytical model of multihop connectivity of intervehicle communication systems." *IEEE Trans. Wireless Communications* 9.1 (2010): 106–112.

Junhai, L., et al. "A Survey of Multicast Routing Protocols for Mobile Ad-hoc Networks." *IEEE Communications Surveys Tutorials* 11.1 (2009): 8–91.

Kadi, N. and K. Agha. "MPR-based Flooding with Distributed Fountain Network Coding." *Proc. of IFIP Annual Mediterranean ad-hoc Networking Workshop* (2010): 1–5.

Karnadi, F. K., Z. H. Mo, and K. C. Lan. "Rapid generation of realistic mobility models for VANET." *Proc. IEEE Wireless Communications and Networking Conf.* (2007): 2506–2511.

Katti, S., et al. "XORs in the Air: Practical Wireless Network Coding." *IEEE/ACM Trans. on Networking* 16.3 (2008): 497–510.

Kaushikl, Sapna S. and P.R.Deshmukh. "Comparison of effectiveness of AODV, DSDV and DSR routing protocols in Mobile Ad-hoc Network." *IJITKM* 2.2 (2009).

Khabazian, M. and M. Ali. "A performance modeling of connectivity in vehicular adhoc networks." *IEEE Trans. Vehicular Tech* 57.4 (2008): 2440–2450.

Khan, A., I. Stojmenovic, and N. Zaguia. "Parameterless Broadcasting in Static to Highly Mobile Wireless ad-hoc, Sensor and Actuator Networks." *Proc. 22nd IEEE Intl Conf. Advanced Information Networking and Applications (AINA 08)* (2008).

Kleinrock, L. and Queueing Systems. *Volume I - Theory.* New York: Wiley Interscience, 1975.

Korkmaz, G., E. Ekici, and F. Ozg Uner. "An Efficient Fully Ad-hoc Multi-Hop Broadcast Protocol for Inter-vehicular Comm.Sys." *Proc.of IEEE Intl Conf. on Comm. (ICC)* (2006): 423–428.

Korkmaz, G., et al. "Urban Multi-Hop Broadcast Protocol for Inter-Vehicle Communication Systems." *Proc. First ACM Intl Workshop Vehicular ad-hoc Networks (VANET 04)* (2004): 76–85.

Krajzewicz, D., et al. "SUMO (Simulation of Urban MObility). ; An open-source traffic simulation." *In 4th Middle East Symposium on Simulation and Modelling (MESM2002), Sharjah, United Arab Emirates* (2002): 183–187.

Krishna, C.M. and K.G. Shin. *Real-Time Systems.* New York: McGraw-Hill, 1997.

Lee, J. Y. and H. S. Lee. "A performance analysis model for IEEE 802.11e EDCA under saturation condition." *IEEE Trans. Communications* 57.1 (2009): 56–63.

Lee, U., et al. "FleaNet: A Virtual Market Place on Vehicular Networks." *Proc. Third Ann. International Conf. Mobile and Ubiquitous Systems: Networking and Services.* 2006. 1–8.

Li, D., et al. "A Distance-Based Directional Broadcast Protocol for Urban Vehicular ad-hoc Network." *Proc. of IEEE Intl Conf. on Wireless Communication, Networking and Mobile Computing (WiCom)* (2007): 15201523.

Li, F. and Y. Wang. "Routing in Vehicular Ad-Hoc Networks: A Survey." *IEEE Vehicular Technology Magazine* 2.2 (2007): 12–22.

Li, L., et al. "Network Coding-based Broadcast in Mobile ad-hoc Networks." *Proc.of IEEE Conf.on Inf.Computing (INFOCOM)* (2007): 1739–1747.

Li, M., W. Lou, and K. Zeng. "OppCast: Opportunistic Broadcast of Warning Messages in VANETs with Unreliable Links." *Proc. IEEE Sixth Intl Conf. Mobile Ad-Hoc and Sensor Systems (MASS 09)* (2009).

Lochert, et al. "Geographic routing in city scenarios." *SIGMOBILE Mob. Comput* (2005): 69–72.

Lochert, C., et al. "A routing strategy for vehicular ad-hoc networks in city environments." *Proceedings of IEEE Intelligent Vehicles Symposium* (2003): 156–161.

Lochert, C., et al. "Geographic Routing in City Scenarios." *ACM SIGMOBILE Mobile Computing and Comm. Rev.* 9.1 (2005): 69–72.

Lua, E. K., et al. "A Survey and Comparison of Peer-to-Peer Overlay Network Schemes." *IEEE Comm. Surveys Tutorials* 7.2 (2005): 72–93.

Ma, X. and X. Chen. "Performance analysis of IEEE 802.11 broadcast scheme in ad hoc wireless LANs." *IEEE Trans. Vehicular Tech.* 57.6 (2008): 3757–3768.

Ma, X. and X. B. Chen. "Delay and Broadcast Reception Rates of Highway Safety Applications in Vehicular ad-hoc Networks." *Mobile Networking for Vehicular Environments* (2007): 85–90.

Ma, X., J. Zhang, and T. Wu. "Reliability analysis of one-hop safety-critical broadcast services in VANETs." *IEEE Trans. Vehicular Tech.* 60.8 (2011): 3933–3946,

Mak, T. K., K. P. Laberteaux, and R. Sengupta. "A multi-channel VANET providing concurrent safety and commercial services." *Proceedings of the 2nd ACM international workshop on Vehicular ad-hoc networks* (2005): 1–9.

Martinez, F. J., et al. "A survey and comparative study of simulators for vehicular ad-hoc networks (VANETs)." *The 11th Communications and Networking Simulation Symposium* (2008): 155–163.

McDonald, A. and T. Znati. "A mobility-based framework for adaptive clustering in wireless ad-hoc networks." *IEEE J. Select. Areas Communications* 17.8 (1999): 1466–1487.

Michael, L. and M. Nakagawa. "Power control and sector antennas for improved DS/SS inter-vehicle communication." *The Ninth IEEE International Symposium on Personal, Indoor and Mobile Radio Communications* 2 (1998): 921–925.

Miorandi, D. and E. Altman. "Connectivity in one-dimensional ad-hoc networks: a queueing theoretical approach." *Wireless Networks* 12.5 (2006): 573–587.

Morsink, D. Reichardt M. Miglietta L. Moretti P. and W. Schulz. "CarTALK 2000: Safe and Comfortable Driving Based upon Inter Vehicle Communication." *IEEE Intelligent Vehicle Symposium* 2 (2003): 545–550.

Munoz, F. Javier Ros. "Scalable Data Delivery in Mobile Multi-hop Ad-hoc Networks Application to Gateway Discovery Protocols." Diss. University of Murcia, 2011.

Nadeem, T., et al. "TrafficView: A Scalable Traffic Monitoring System." *Proc.of IEEE Intl Conf. on Mobile Data Management (MDM)* (2004): 1–14.

Nekovee, M. "Epidemic Algorithms for Reliable and Efficient Information Dissemination in Vehicular ad-hoc Networks." *IET Intelligent Transportation Systems* 3.2 (2009): 104–110.

Ni, S., et al. "The Broadcast Storm Problem in a Mobile ad-hoc Network." *Proc. of ACM Intl Conf. on Mobile Computing and Netw. (MOBICOM)* (1999): 151–162.

OMNeT++. "Component-based, Modular and Open-architecture discrete event simulation framework." *http://www.omnetpp.org/* (2011).

P1609.1, IEEE. "Trial-use standard for wireless access in vehicular environments (WAVE) resource manager." *IEEE Xplore* (2006).

P1609.2, IEEE. "Trial-use standard for wireless access in vehicular environments (WAVE) security services for applications and management messages." *IEEE Xplore* (2006).

P1609.4, IEEE. "Trial-use standard for wireless access in vehicular environments (WAVE) multi-channel operation." *IEEE Xplore* (2006).

P802.11p/D0.21, IEEE. "Draft Amendment to Standard for Information Technology Telecommunications and Information Exchange between Systems LAN/MAN Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Wireless Access in Vehicular Environments (WAVE)." *IEEE* (2006).

P802.11p/D3.0, IEEE. "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Amendment: Wireless Access in Vehicular Environments (WAVE), Draft 3.0." *IEEE Draft* (2007).

Panichpapiboon, S. and W. Pattara-atikom. "A Review of Information Dissemination Protocols for Vehicular Ad-Hoc Networks." *IEEE Communications Surveys & Tutorials* (2011): 1–15.

Peng, W. and X. Lu. "On the Reduction of Broadcast Redundancy in Mobile ad-hoc Networks." *Proc. ACM MobiHoc* (2000).

Proakis, J. G. and M. Salehi. *Digital Communications*. McGrawHill, 2008.

Qayyum, L. Viennot, and A. Laouiti. "Multipoint Relaying for Flooding Broadcast Messages in Mobile Wireless Networks." *Proc.of IEEE Hawaii Intl Conf.on Systems Sciences (HICSS)* (2002): 3866–3875.

R., Morris, et al. "CarNet: A Scale ad-hoc wireless network system." *ACM SIGOPS European Workshop* (2000).

Rahman, Md. Arafatur, Farhat Anwar, and Jannatul Naeemand Md. Sharif Minhazul Abedin. "Simulation Based Performance Comparison of Routing Protocol on Mobile Ad-hoc Network (Proactive, Rective and Hybrid)." *International Conference on Computer and Communication Engineering (ICCCE), Kuala Lumpur, Malaysia.* (2010).

Rappaport, T. S. *Wireless Communications Principles and Practice.* Ed. Printece-Hall. Printece-Hall, 2002.

Roess, P., E. S. Prassas, and W. R. Mcshane. *Traffic Engineering 3rd edn. Englewood Cliffs.* Pearson Prentice Hall, 2004.

S, I T. "Intelligent Transportation System." *Intellegent Transportation Canada* (2011).

S., M. Torrent-Moreno. "NoW Network on Wheels: Project Objectives Technology and Achievements." *5th International Workshop on Intelligent Transportation (WIT)* (2008): 211–216.

Saoud, M. Abou El, H. Al-Zubaidy, and S. Mahmoud. "Connectivity Model for Wireless Mesh Networks." *Proc. IEEE Intl. Conf. Communications* (2008): 2889–2894.

Schwartz, R. S., et al. "A Simple and Robust Dissemination Protocol for VANETs." *Proc. of IEEE European Wireless Conf.* (2010): 214–222.

Sebastian, A., et al. "A Multicast Routing Scheme for Efficient Safety Message Dissemination in VANET." *Proc. of IEEE Wireless Communications and Networking Conf. (WCNC)* (2010): 1–6.

Shankar, S. and A. Yedla. "MAC layer extensions for improved QoS in 802.11 based vehicular ad-hoc networks." *In Proc. IEEE Int. Conf. on Vehicular Electronics and Safety* (2007): 1–6.

Shea, C. "APROVE: A Stable and Robust VANET Clustering Scheme using Affinity Propagation." *University of Toronto* (2009).

Shevade, U., et al. "Enabling High Bandwidth Vehicular Content Distribution." *Proceeding of ACM Intl Conf. on Emerging Networking Experiments and Technologies (CoNEXT)* (2010): 1–12.

Sjberg, K. "Standardization of Wireless Vehicular Communications within IEEE and ETSI." *IEEE VTS Workshop on Wireless Vehicular Communications* (2011).

Sjoberg, K. "Medium Access Control for Vehicular ad-hoc Networks." *University of Halmstad* (2013).

Sommer, C. and F. Dressler. "Progressing toward realistic mobility models in VANET simulations." *IEEE Communications Magazine* 46.11 (2008): 132–137.

Sommer, C., R. German, and F. Dressler. "Bidirectionally Coupled Network and Road Traffic Simulation for Improved IVC Analysis." *IEEE Trans. Mobile Computing* 10.1 (2011): 3–15.

Stibor, L., Y. Zang, and H .J. Reumermann. "Evaluation of communication distance of broadcast messages in a vehicular ad- hoc network using IEEE 802.11p." *In Proc. IEEE Wireless Communications and Networking Conf.* (2007): 254–257.

Stojmenovic, I. "Comments and Corrections to Dominating Sets and Neighbor Elimination Based Broadcasting Algorithms in Wireless Networks." *IEEE Trans. Parallel and Distributed Systems* 15.11 (2004): 1054–1055.

Stojmenovic, I., M. Seddigh, and J. Zunic. "Dominating Sets and Neighbor Elimination Based Broadcasting Algorithms in Wireless Networks." *IEEE Trans. Parallel and Distributed Systems* 13.1 (2002): 14–25.

Sun, M., et al. "GPS-Based Message Broadcast for Adaptive Inter-Vehicle Communications." *Proc. 52nd IEEE Vehicular Technology Conf. (VTC 00)*. 2000. 2685–2692.

Suthaputchakun, C. and A. Ganz. "Priority based inter-vehicle communication in vehicular adhoc networks using IEEE 802.11e." *In Proc. IEEE Vehicular Technology Conf.* (2007): 2595–2599.

Taha, M. and Y. Hasan. "VANET-DSRC Protocol for Reliable Broadcasting of Life Safety Messages." *Proc. of IEEE Intl Symp. on Signal Processing and Inf. Tech.* (2007): 104–109.

Three, T. G. "IEEE 802.15 WPAN Task Group 3 (TG3)." *IEEE802-org* (2009).

Times. "Times of India." *Newspaper* (2014).

Tokuda, K., M. Akiyama, and H. Fujii. "DOLPHIN for inter-vehicle communications system." *Intelligent Vehicles Symposium* (2000): 504–509.

Tonguz, O., et al. "Broadcasting in VANET." *Proc. Mobile Networking for Vehicular Environments* (2007): 7–12.

Torrent-Moreno, M., D. Jiang, and H. Hartenstein. "Broadcast reception rates and effects of priority access in 802.11-based vehicular ad-hoc networks." *Proceedings of the 1st ACM international workshop on Vehicular ad-hoc networks* (2004): 10–18.

Torrent-Moreno, M., et al. "IEEE 802.11-based one-hop broadcast communications: understanding transmission success and failure under different radio propagation environments." *Proceedings of the 9th ACM international symposium on Modeling analysis and simulation of wireless and mobile systems* (2006): 68–77.

Torrent-Moreno, M., et al. "Vehicle-to-vehicle communication: Fair transmit power control for safety-critical information." *IEEE Trans. Vehicular Tech.* 58.7 (2009): 3684–3703.

Transportation, U. S. "Vehicle safety communications project task 3 final report: Identify intelligent vehicle safety applications enabled by DSRC." *Technical Report* (2005).

Tuteja, Asma, Rajnessh Gujrl, and Sunil Thalia. "Comparative Performance Analysis of DSDV, AODV and DSR Routing Protocols in MANET using NS2." *International Conference on Advances in Computer Engineering* (2010).

Ullah, Fasee, Muhammad Amin, and Hamid ul Ghaffar. "Simulation AODV and DSDV For Adynamic Wireless Sensor Networks." *International Journal of Computer Science and Network Security* 10.7 (2007).

Usop, Nor Surayati Mohamad, Azizol Abdullah, and Ahmad Faisal Amri Abidin. "Performance Evaluation of AODV, DSDV and DSR Routing Protocol in Gird Environment." *IJCSNS International Journal of Computer Science and Network Security* 9.7 (2009).

VII. "Vehicle Infrastructure Integration (VII) Initiative." *Technical Report* (2011).

Viswanath, K. and K. Obraczka. "An Adaptive Approach to Group Communications in Multi-Hop ad-hoc Networks." *Proc. IEEE Intl Symp. Computers and Comm. (ISCC 02)* (2002): 559–566.

Wang, Z. and M. Hassan. "How much of dsrc is available for non-safety use?" *Proceedings of the fifth ACM international workshop on VehiculAr Inter-NETworking* (2008): 23–29.

Wegener, et al. "AutoCast: An Adaptive Data Dissemination Protocol for Traffic Information Systems." *Proc. of IEEE Vehicular Technology Conf.(VTC)* (2007): 1947–1951.

Wegener, A., et al. "TraCI: An interface for coupling road traffic and network simulators." *Wireless Communcations and Mobile Computing* (2009): 813–828.

Wellen, M. and B. Westphal. "Performance evaluation of IEEE 802.11-based WLANs in vehicular scenarios." *In Proc. IEEE Vehicular Technology Conf.* (2007): 1167–1171.

W.Franz, H. Hartenstein, and M. Mauve Eds. "Inter-Vehicle-Communications Based on Ad-hoc Networking Priciples-The Fleet Net." *Germany Project* (2005).

WHO. "World Health Organization (WHO)." *World report on road traffic injury prevention* (2010).

Willke, T., P. Tientrakool, and N. Maxemchuk. "A Survey of Inter-Vehicle Communication Protocols and their Applications." *IEEE Comm.Surveys & Tutorials* 11.2 (2009): 3–20.

Wischhof, L., A. Ebner, and H. Rohling. "Information Dissemination in Self-Organizing Inter-vehicle Networks." *IEEE Trans. on Intelligent Transportation Systems* 6.1 (2005): 90–101.

Wisitpongphan, N., et al. "Broadcast Storm Mitigation Techniques in Vehicular ad-hoc Networks." *IEEE Wireless Communications* 14.6 (2007): 84–94.

Wu, J. and H. Li. "A Dominating Set Based Routing Scheme in ad-hoc Wireless Networks." *Telecomm. Systems* 18.1 (2001): 13–36.

Xiang, W., P. Richardson, and J. Guo. "Introduction and preliminary experimental results of wireless access for vehicular environments (WAVE) systems." *In Proc. Int. Conf. Mobile and Ubiquitous Systems: Network and Services* (2007): 1–8.

Xu, D. X., T. Sakurai, and H. L. Vu. "An access delay model for ieee 802.11e EDCA." *IEEE Trans. Mobile Computing* 8.2 (2009): 261–275,

Xu, Q., et al. "Vehicle-to-vehicle safety messaging in DSRC." *Proceedings of the 1st ACM international workshop on Vehicular ad-hoc networks* (2004): 19–28.

Yang, S. and J. Wu. "Efficient Broadcasting using Network Coding and Directional Antennas in MANETs." *IEEE Trans. on Parallel Distributed Systems* 21.2 (2010): 148–161.

Yin, J., et al. "Performance evaluation of safety applications over DSRC vehicular ad-hoc networks." *Proceedings of the 1st ACM international workshop on Vehicular ad-hoc networks* (2004).

Young-Bae, K., V. Shankarkumar, and N. Vaidya. "Medium access control protocols using directional antennas in ad-hoc networks." *Proceedings of the Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM)* 1 (2000): 13–21.

Yousefi, S., et al. "Analytical model for connectivity in vehicular ad-hoc networks." *IEEE Trans. Vehicular Tech.* 57.6 (2008): 3341–3356.

Yu, Q. and G. Heijenk. "Abiding Geocast for Warning Message Dissemination in Vehicular Ad-Hoc Networks." *Proc. of IEEE Intl Conf. on Comm.(ICC)* (2008): 400–404.

Zhong, T., B. Xu, and O. Wolfson. "Disseminating Real-Time Traffic Information in Vehicular Ad-hoc Networks." *Proc. of IEEE Intelligent Vehicles Symposium (IV)* (2008): 1056–1061.

Zhou, L., et al. "Distributed Media Services in P2P based Vehicular Networks." *IEEE Trans. in Vehicular Technology* 60.2 (2011): 692–703.

Publications related to Thesis

International Journal Publications

- Vaishali D Khairnar, Dr. Ketan Kotecha, *"Propagation Models for V2V Communication in Vehicular Ad-hoc Networks"*, Journal of Theoretical and Applied Information Technology, Vol. 61, 3 (2014), 686-695.

- Vaishali D Khairnar, Dr. Ketan Kotecha, *"Simulation Based Performance of Mumbai-Pune Expressway Scenario for Vehicle-to-Vehicle Communication Using IEEE 802.11 P"*, Transport and Telecommunication, Vol. 14, 4 (2013), 300-315.

- Vaishali D Khairnar, Dr. Ketan Kotecha, *"Simulation-Based Performance Evaluation of Routing Protocols in Vehicular Ad-hoc Network"*, International Journal of Scientific and Research Publications, Vol. 3, 10 (2013), 1-14.

- Vaishali D Khairnar, Dr. Ketan Kotecha, *"Simulation-Based Performance Evaluation of Routing Protocols in VANET with Different Scenarios"*, International Journal of Advanced Research in Computer Science and Software Engineering (IJARCSSE), Vol. 3, 6 (2013).

- Vaishali D Khairnar, Dr. Ketan Kotecha, *"Performance of Vehicle-to-Vehicle Communication using IEEE 802.11p in Vehicular Ad-hoc Network Environment"*, International Journal of Network Security & Its Applications (IJNSA), Vol. 5, 2 (2013), 143-170.

- Vaishali D Khairnar, Dr. S. N. Pradhan, *"Simulation based evaluation of highway road scenario between DSRC/802.11 p MAC protocol and STDMA for vehicle-to-vehicle communication"*, Journal of Transportation Technologies, Vol. 3 (2013), 88.

- Satish Kale, Vaishali D Khairnar, *"Car to Car Communication Protocol Issues"*, International Journal of Global Technology Initiatives, Vol. 1, 2 (2012), 26-33.

- Vaishali D Khairnar, Dr. S. N. Pradhan, *"Simulation Based Study and Analysis of Routing Protocol in Vehicular Ad-hoc Network"*, International Journal of

Electronics Communication and Computer Engineering, Vol. 3, 3 (2012), 198-205.

- Saurabh D Patil, DV Thombare, Vaishali D Khairnar, *"DEMO: Simulation of Realistic Mobility Model and Implementation of 802.11p (DSRC) for Vehicular Networks (VANET)"*, International Journal of Computer Applications, Vol. 43, 10 (2012), 33-36.
- Vaishali D Khairnar, Dr. S. N. Pradhan, *"Simulation Based Study and Analysis of Routing Protocol in vehicular Ad-hoc Network"*, International Journal of Computer Technology and Applications, Vol. 3, 2 (2012), 617-625.
- Vaishali D Khairnar, Dr. S. N. Pradhan, *"Study of V2V Communications on Mumbai-Pune Express Highway"*, Asian Journal of Engineering and Applied Technology, Vol. 1, 1 (2012), 19-21.
- Vaishali D Khairnar, Dr. S. N. Pradhan, *"V2V COMMUNICATION SURVEY - (WIRELESS TECHNOLOGY)"*, International Journal Computer Technology & Applications (IJCTA), Vol. 3, 1 (2012), 370-373.
- Vaishali D Khairnar, Dr. S. N. Pradhan, *"Mobility Models for Vehicular Ad-hoc Network Simulation"*, International Journal of Computer Applications, Vol. 11, 4 (2011), 8-12.
- Vaishali D Khairnar, Dr. S. N. Pradhan, *"Comparative study of simulation for vehicular ad-hoc network"*, International Journal of Computer Applications, Vol. 4, 10 (2010), 15-18.

International Conference Publications

- D Bavkar, Vaishali D Khairnar, *"A survey on Data Dissemination in VANET"*, International Conference on Advance Computer Sciences, Communication and Information Technologies (ICACSIT), IRD India, (2012), 75-79.
- Vaishali D Khairnar, Dr. S.N. Pradhan *"Propagation Models for Vehicular Ad-hoc Network"*, iCOST 2011 First International Conference on Sunrise Technologies, India, (2011), CSE-13.

- Vaishali D Khairnar, Dr. S. N. Pradhan, *"Mobility Models for Vehicular Ad-hoc Network Simulation"*, International Conference on Computers & Informatics (ISCI), 2011 IEEE Symposium in Kuala Lumpur Malaysia , (2011), 460-465.

National Conference Publications

- S B Patil, Vaishali D Khairnar, *"Survey on Routing Protocols in VANET"*, National Conference organized by Terna Engineering College Nerul, Navi-Mumbai, India, (2011).

- Prof. Vaishali D. Khairnar, *Traffic Management in VANET Using Clustering*, National Conference organized by Terna Engineering College Nerul, Navi-Mumbai, India, (2012).

- Prof. Vaishali D. Khairnar, *Broadcast Protocol in VANET Using Clustering*, National Conference organized by Vidyalankar Institute of Technology, Mumbai, India, (2012).

- Vaishali D Khairnar, *"Improve of Broadcast Reliability in VANET"*, National Conference on emerging trends in computers,communications & Information Technology, India, (2009), 190-193.

- Vaishali D Khairnar, *"Survey on Mobile Ad-hoc Networks"*, National Conference on wired and wireless communication co sponsored by IEEE Mumbai Section, India, (2008), 231-234.

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