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UNIVERSITI TEKNOLOGI PETRONAS

AN ADAPTIVE INFORMATION DISSEMINATION MODEL FOR VANET COMMUNICATION

By

MASOOD UR REHMAN

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AN ADAPTIVE INFORMATION DISSEMINATION MODEL FOR VANET

COMMUNICATION

by

MASOOD UR REHMAN

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DECLARATION OF THESIS

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DEDICATION

To my family, specially my parents who offered me unconditional love and support throughout the course of my life

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ABSTRACT

Vehicular ad hoc networks (VANETs) have been envisioned to be useful in road safety and many commercial applications. The growing trend to provide communication among the vehicles on the road has provided the opportunities for developing a variety of applications for VANET. The unique characteristics of VANET bring about new research challenges. Well studied structures for information dissemination find it hard to maintain the quick changing network topology due to the high mobility vehicles in VANET. Frequent disconnections and bottlenecks due to congestion in the highly dynamic vehicle density on the road are other challenges. Reusability issues, lack of aggregation mechanisms, lack of the categorical division of information, improper co-relation mechanisms for optimal link selection, lack of use of the full utilisation of vehicular networks, link life time and link stability are the factors which have led to the proposal of this adaptive information dissemination model for VANET communication. The proposed model comprises three major components i.e. an information type splitter, an application domain and a communication domain. The categorised information from the Information Splitter is directed to the distinct domains of the proposed model for dissemination. Application Domain uses the capabilities of the packet centric forwarding (PCF) of the OSI model to execute safety and non-safety information. It has the capabilities of aggregation, information alteration and invalidation, etc. The Communication Domain uses the information centric forwarding (ICF) of the OSI model. It is responsible for the dissemination of safety-of-life information in the proposed model. This domain has the capabilities of location services and repository management, beaconing, packet reception and distribution, priority assignment, link life time and link stability calculations. The proper congestion control feature is implemented using the aggregation mechanism in a dense network situation for both of the domains. The adaptive nature of the model tries to achieve efficient memory utilisation and interpretability of various modules in various network scenarios. Forwarding

decisions are taken on the basis of the positions, inter-vehicle distances, and relative speeds of the communicating vehicles and other state related information from the location table. Handling the uncertainty issue in a highly unpredictable VANET environment, inter-domain operational co-operation for information load adaptability and categorisation of information are the major contributions of this research work. These contributions play a major role for a better packet delivery ratio, reduction of end-to-end delays, better throughput and reduction of routing overhead as compared to information dissemination models like ZGPSR, GSR and PDGR.

ABSTRAK

Vehicular ad hoc networks (VANET) dijangka dapat memberi manfaat dalam meningkatkan keselamatan jalan raya dan belbagai aplikasi komersial. Kecenderungan dalam menyediakan sistem komunikasi bagi kenderaan di jalan raya yang semakin meningkat ini telah memberi banyak peluang untuk membangunkan pelbagai aplikasi dalam vanet. Ciri-ciri istimewa vanet telah membawa kepada penyelidikan baru. Struktur penyebaran maklumat juga telah dikaji dan ianya didapati agak sukar untuk mengekalkan perubahan topologi kerana mobility kenderaan yang tinggi dalam vanet. Talian yang kerap terputus dan kepadatan jumlah kenderaan di jalan raya juga merupakan cabaran-cabaran lain. Faktor-faktor yang telah membawa kepada cadangan penyesuaian maklumat untuk model penyebaran komunikasi vanet adalah isu-isu boleh digunapakai semula, kekurangan mekanisme pengumpulan, kekurangan pem bahagian kategori maklumat, ketidakwajaran mekanisme berhubung pemilihan pautan optimum dan kekurangan penggunaan rangkaian kenderaan sepenuhnya. Model ini terdiri daripada tiga komponen utama ia itu pembahagi genis informasi, domain aplikasi dan domain komunikasi. Maklumat yang dikategorikan daripada maklumat pembahagi akan ditujukan kepada domain yang berbeza di dalam model yang dicadangkan. Domain aplikasi menggunakan keupayaan paket penghantaran centric (PCF) daripada model OSI untuk melaksanakan maklumat-maklumat keselamatan dan bukan-keselamatan. Ia mempunyai keupayaan pengumpulan, pengubahan maklumat, ketidaksahihan dan lain-lain. Domain komunikasi menggunakan maklumat penghantaran centric (ICF) daripada model OSI. Ia juga bertanggungjawab untuk menyebarkan maklumat mengenai keselamatan hayat dalam model yang dicadangkan. Domain ini mempunyai keupayaan perkhidmatan lokasi dan pengurusan sumber, inspirasi, penerimaan paket dan penyebaran keselamatan, keutamaan tujuan, puatan jangka hayat dan pautan pengiraan kestabilan. Kawalan kesesakan telah dilaksanakan dengan baik dengan menggunakan mekanisme pengumpulan dalam rangkaian padat bagi kedua-dua domain. Asas penyesuaian

model ini mencuba untuk mencapai penggunaan memori yang efisien dan interpretasi pelbagai modul dalam pelbagai scenario rangkaian. Keputusan penghataran data telah diambil atas dasar kedudukan, jarak antara kenderaan dan kelajuan relatif antara kenderaan berkomunikasi dan lain-lain maklumat yang berkaitan yang ternyata dalam jadual lokasi. Bagi menangani isu ketidaktentuan persekitaran dalam vanet, domain operasi bekerjasama bagi menyesuaikan beban maklumat dan pengkategorian maklumat adalah fector utama dalam penyelidikan ini. kerja penyelidikan ini clapat meningkat nisbah penghaantaran paket menpengurangan kelewatan, pemprosesan berbanding dengan model penyebaran maklumat seperti ZGPSR, GSR dan PDGR.

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LIST OF ABBREVIATIONS

AIDVC	An adaptive information dissemination model for VANET communication
AODV	Ad hoc On-Demand Distance Vector
CBR	Carrier Bit Rate
CDS	Connected Dominating Sets
CSM	City Section Mobility
DSDV	Destination-Sequenced Distance Vector
DSRC	Dedicated Short Range Communications
DSR	Dynamic Source Routing
GAMER	Adaptive Mesh Environment for Routinging
GPRS	General Packet Radio Service
GSR	Greedy source aware routing
HSDP	A High-Speed Downlink Packet Access
ICF	Information Centric Forwarding
ID	Information Dissemination

IMM	Integrated Mobility Model
IR	Information repository
MAODV	Multicast AODV
MANET	Mobile ad hoc networks
META	Metropolitan Taxis
MM	Manhattan model
MOVE	Mobility model generator for Vehicular networks
NCTUNs	National Chiao Tung University Network Simulation
NS-2	Network Simulator 2
OLSR	Optimized Link State Routing
PCF	Packet Centric Forwarding
PDGR	Predictive Directional Greedy Routing
PDR	Packet Delivery Ratio
SRW	Street Random Waypoint
SSM	Stop Sign Model
TSM	Traffic Sign Model

UMTS	Universal Mobile Telecommunications System
UWB	Ultra Wide Band
VANET	Vehicle Ad hoc Networks
WiFi	Wireless Fidelity
WiMax	Worldwide Interoperability for Microwave Access
ZPR	Zone Routing Protocol

CHAPTER 1

INTRODUCTION

This chapter covers the stimulus, the widespread issues in the existing information dissemination approaches and the research objectives to be accomplished. The relevant research questions are also described in this chapter. The methodology adopted for the proposed model and the research workflow are discussed. This chapter concludes with the contribution and the organisation of this thesis.

1.1 Background

A vehicular ad hoc network or VANET is a technology that uses moving cars as nodes in a network to create a mobile network. VANET turns every participating car into a wireless router or node. This allows cars approximately 100 to 300 metres of each other to connect and, in turn, create a network with a wide coverage range. Various types of applications like Mac and physical layer applications, security and privacy applications, mobility models and simulator designing are considered as hot topics for research communities in the area of VANET. However, this thesis has considered information dissemination (ID) as an indispensable requirement for various VANETs applications. ID is a mechanism for communication or disbursement of data related to real life applications in VANETs.

Some research communities have tried a variety of methodologies to address the challenges in designing effective and efficient ID techniques. These ID models are classified as proactive, reactive, geographic, content based and hybrid models. ID models need to address various VANET environmental issues. These issues are related somewhat to the frequent topology changes, rapid fragmentation, small effective network diameter, variable network density, behavioural aspects of drivers and many more. Most of the available research about ID discusses specific or a partial portion of the issues mentioned earlier. There is a need to develop ID models which can adapt themselves to different network scenarios. In most of the models, the resources are somehow underutilised. Some of the existing ID models contain adaptive capabilities at the module level, thus satisfying the situational demands.

Packet delivery ratio, end-to-end delay and congestion phenomena are the factors that are directly affected by the ID architecture in VANETs. Many researchers have tried to provide vehicles with internet connections using the IEEE 802.11 protocol and other low cost communication technologies in the recent past [1]. At the initial stages, static gateway points alongside the roads were considered. Internet would be provided to the vehicles on the road through these static gateways. Heavy investment and context switching leading to long delays are the major drawbacks of such static gateways.

On the other hand, the use of access points can be another possible way for connectivity among vehicles. It may have the advantage that new infrastructure deployment would not needed, but the drawback is the frequent gateway switching [2].

One of the most fundamental changes that can be expected from VANETs for transportation management purposes is the nature of the information involved in the decision-making. The decision making process resolves around what information should be processed first (safety-of-life, safety or non-safety), and which is the best processing channel for its forwarding etc. Although the existing models for ad hoc networks are well-established and perhaps deep-rooted, there is a need for them to be re-thought exclusively in order to best meet the demands of future VANET applications. One of the reasons is that the existing simulation tools that may be used for testing VANET applications were built biased to the old paradigms. One has to be at least suspicious that these paradigms may not be directly extensible to the new VANET environments.

Another important task that needs to be taken into consideration is to develop an information model that describes the types, frequencies etc. of the information packets that are expected to be used by models supported by VANETs. These models should be able to describe their collection and distribution mechanisms. There is a need for a new model for ID that is capable of handling the data load in highly unpredictable VANET environments. Sensing these VANET requirements, the Information Dissemination model for VANET has thus been proposed.

1.2 Motivation

Researchers have expressed reservations in utilising the existing MANET protocols in their original form [3]. On the other hand, the unique aspects of VANET have given the research community a competitive platform for designing a secure, dependable, and scalable routing protocol.

The rapid development of vehicular ad hoc network applications especially in the field of ID has gained the attention of the researchers to develop and contribute state-of-the-art methodologies in VANET. To design such systems, automobile companies and governments have been investing heavily since nearly two decades ago. But, the problem of these systems is that they have been designed for specific hardware and vehicles. Consequently, the research being conducted this way has a specific purpose.

The current ID methods are unable to handle effectively and efficiently, a variety of information separately. The information involved in the information dissemination process contains three basic categories i.e. safety-of-life, safety and non-safety information. Safety-of-life is the type of information that is directly related to life threats to human beings. A doctor’s text messages to a hospital from an ambulance, heart beat information and hospital correspondence regarding emergency measures to the ambulance on the road are some of the examples of safety-of-life information. The safety information is the type of information related to the road condition, cooperative collision warning, accident warning, weather and fog information etc. Finally, the non-safety information includes the leisure related information. It includes parking space information, distributed games, talking and peer-to-peer communication.

The layered architectural approach of the OSI model may be handy in settling the variety of information issue [4]. Safety and non-safety related data is executed by the application layer of the OSI model as its capabilities are a derived class[1] of the packet centric forwarding approach (PCF). During the process of dissemination, the application layer has the capabilities of aggregation, alteration in the information, invalidation etc. Its capabilities are a derived class of the information centric approach (ICF). All safety-of-life related data is processed in the Communication Domain which is supported by the network layer of the OSI model. The application layer of the OSI model does not support direct forwarding of information. Delay critical capabilities and information are addressed in this domain; for that purpose, dump nodes are utilised.

Several ID models for VANETs are available but the main problem is on their performance inconsistency in various network scenarios. These models can be enhanced by applying proper aggregation techniques, full utilisation of resources, and a proper co-relation mechanism for various link selection parameters, calculating link stabilities and link life time. Such weaknesses in the existing ID models have motivated the research in this PhD study.

1.3 Research Problems

Initially, some of the ID models which were specially designed for MANETs, like DSR [5] and AODV [6] were considered to be a spontaneous solution for ID in VANETs. But despite their brilliance in MANETs, they could not get a considerable standing in the vehicular environment. One of the reasons is that these protocols could not cope with the requirement of high speed mobility and heavy data flow, resulting in network congestion. A number of ID approaches specifically designed for VANET are mentioned in the literature review chapter. But they possess a number of performance issues mentioned as follows.

[1] Derived class is object oriented programming terminology. It is defined as “The class that inherits all of the properties of the base class and may have some additional properties as well”.

a) The categorical division of information is not considered in most of the available researches. It is believed that the information for realistic dissemination systems should be categorised as non-safety, safety and safety-of-life information. This is very important for the realistic future ID models.

b) Full use of resources is considered obvious for every dissemination model. Better use of system resources may increase the ID model performance. Most of the ID models to date lack the adaptive nature to adjust the information load on either the Information Domain or Application Domain. Due to this lack of adaptability, in specific network scenarios (e.g., dense network scenarios), the resources of the ID model are not used or are only partially used. Thus, there must be a mechanism in ID models to adjust the underutilised resources based on specific scenarios.

c) The lack of utilisation of aggregation techniques in the existing ID techniques causes the problem of high bandwidth consumption. This results in network congestion leading to long network delays and ultimately, the systems show poor Packet Delivery Ratio, End-to-end delays, Throughput and Routing Overhead. The existing models for ID rarely use the proper aggregation mechanism in deployment.

d) In considering the optimal link for ID, most of the research conducted lacks the correlation of important selection parameters or they use only a single selection parameter. This can cause a costly computational link recalculation process that may affect the network performance. Some of the existing ID models for VANET have tried to use the fuzzy set theory or genetic algorithm approaches to address the high uncertainty of the links for forwarding data. But the computational cost based on genetic algorithms is too high to disseminate the data. Further, the existing real time models do not possess the computational powers for the huge amount of calculations needed by the genetic algorithm-based approaches.

e) Most of the research conducted in ID has not prioritised the types of information according to information demands (time vs. delay). The existing models lack the tradeoffs between time and accuracy. Most of the existing system models are based on the first come first serve principle. But in real time applications, the information that is related to the safety-of-life should be treated as the highest priority in comparison to the other types of information. Similarly, the safety information should be treated as a higher priority than non-safety information. The prioritisation of a variety of information is rarely addressed in the existing ID models.

1.4 Research Questions

Based on the above mentioned issues and research problems, the research questions have been derived as the following:

a) Should the information be categorised as non-safety, safety and safety-of-life information for the realistic future ID models?

b) Why consider the effect of the categorical division of information for the development of realistic ID models for VANET?

c) How and to what extent is the categorical division of information helpful for maximising the usage of ID model resources?

d) How much does the adaptive nature of the ID model adjust the information load on either the Information Domain or Application Domain?

e) What type of aggregation techniques should be used with ID models to address the problem of high bandwidth consumption?

f) Which type of aggregation technique best suits current VANET setups? Should this be reactive or proactive?

g) How can the uncertainty in the mobility patterns of vehicles in the VANET be handled and how feasible in usage are the fuzzy set theory and genetic algorithms for addressing the link uncertainty problems in current realistic VANET environments?

h) What are the important parameters and their weighted correlations in the link selection for ID?

i) How much is the link selection decision supported by link stability and link life time calculations?

j) Which simulators are best suited to verify the proposed ID model against the other well established ID models?

k) What performance parameters should be used for benchmarking in the performance evaluation process for the proposed ID model?

1.5 Objectives and Goals

The main objective of this research is to develop an adaptive ID model for VANETs that can process categorical information using two distinct processing domains, i.e., Application Domain and Communication Domain in a robust way. To achieve this objective, a number of specific goals have been defined as follows:

a) To find out the basic and key link selection parameters in the ID process in VANET and to investigate the impact of these link selection parameters like velocity, position and distance in ID models.

b) To identify a correlation among the basic link selection parameters through a weighted function. Calculation of link stability and link stability for the semi prediction behaviour of the network and hence, the ID model deals with uncertainty.

c) To develop a mechanism for the separation of safety-of-life, safety and non-safety information for raw information in the ID model for VANET.

d) To process the various types of information through separate domains in order to meet the time vs. reliability requirements of distinct types of information.

e) To maximise the ID model resource utilisation. For example, the Communication Domain would use the dump nodes (RSUs which don’t have the processing capabilities) for forwarding the safety-of-life information.

f) To develop and implement an adaptive ID model that possesses the capability of processing categorical data.

g) To enhance the capabilities of the ID model through making use of underutilised bandwidth resources of either domains of the ID model. The adaptive nature of the proposed model will enforce both domains to send the information to the other domain in case of underutilised bandwidth in that domain. Ultimately, this will be helpful in maximising the system performance.

h) To utilise a proper and dynamic aggregation mechanism to address the bandwidth utilisation and congestion control.

i) To enhance overall network performance (increased packet delivery ratio, reduced packet drop ratio and increased throughput).

j) To evaluate the performance of the proposed ID model against some previous ID models by implementation through NS-2 and NCTUNs simulators.

1.6 Methodology

The overall research has been divided into several phases; each phase was concerned with the specific goals to finally fulfil the main objective. These phases are illustrated in Figure 1.1

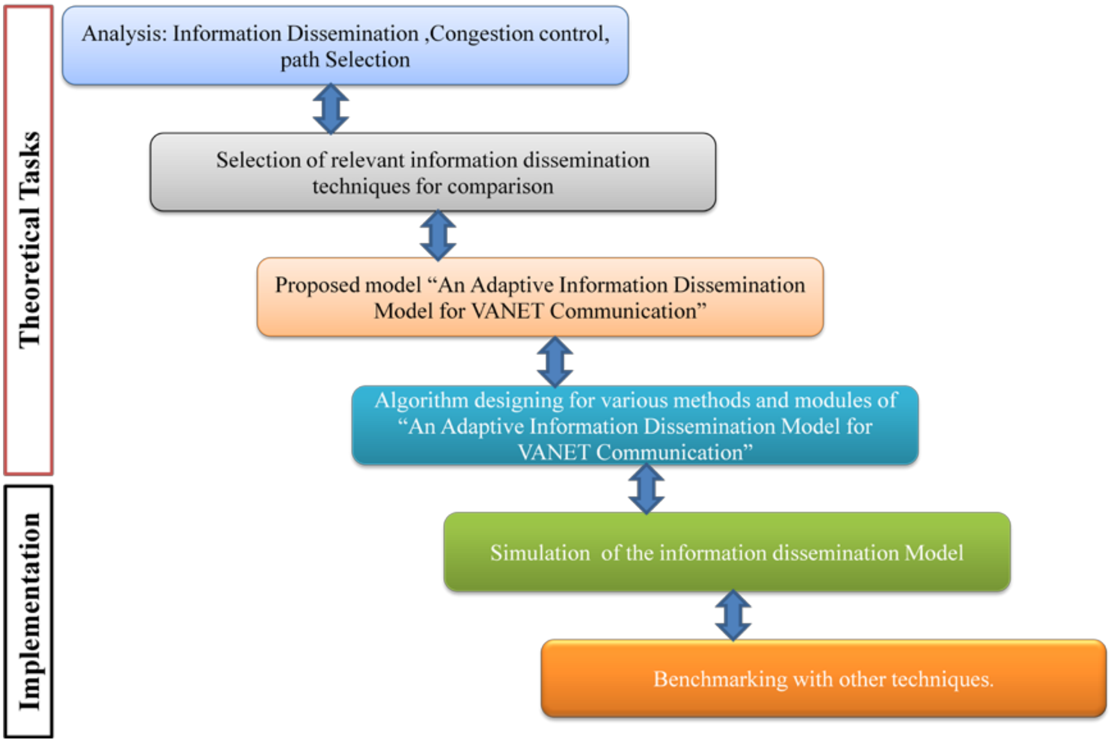

Figure 1.1: Research Methodology Phases

1.6.1 Analysis

In this phase, various ID techniques were studied. Specifically, the techniques that handle ID on the highway were of high priority and how valuable these techniques are for dense and sparse network scenarios and which type of ID method they apply (opportunistic, probabilistic etc). Then, the congestion control mechanisms, their relevance and effectiveness at various levels of ID and in various network scenarios were analysed. Various studies related to path selection mechanisms were also considered. The drawbacks and benefits for single path and multipath mechanisms were taken into consideration. The affects of the multipath selection on overall network and specifically on the dissemination performance were also considered.

1.6.2 Selection of related ID techniques for comparison

In this phase, relevant ID models, their relevant behaviour for identical network conditions were observed. Out of these models, some of the most relevant dissemination models were selected for comparative study purposes with the proposed adaptive ID model for VANET communication.

1.6.3 Proposed Model

This phase described the proposed model, the modules of the proposed model (Communication Domain, Application Domain, and Information Splitter) and the basic idea about their working principles. Also, the interrelation of the Communication Domain and Application Domain was described. The dependencies and importance of various system modules in the two distinct domains on each other was also mentioned here. Hence, the complete workflow of the system model was designed in this phase.

1.6.4 Algorithm designing for various modules

This phase described the algorithm designing of various modules mentioned in the proposed model for ID in VANET. These modules included the congestion control mechanism, link stability and link life time calculations (optimal link calculation), priority assignment, packet reception and distribution, forwarding decisions and many more.

1.6.5 Simulation of the system model

This phase consisted of the implementation details of the system model using simulation tools. This phase elaborates the implementation details of the various modules using NCTUNs and NS2. The use of the translation program and the way to integrate the translated NS2 code to the NCTUNs kernel were also presented here.

.

1.6.6 Result comparison

Finally, the results of the proposed model were compared with ZGPSR, GSR and PDGR models to verify the system improvement. Packet delivery ratio, end-to-end delays, network overhead and network throughput were the key performance parameters for the comparative study.

1.7 Contributions

This research has a significant positive impact on the performance of ID in vehicular ad hoc networks. The main contribution is the design and development of "An adaptive information dissemination model for VANET communication". Three measureable contributions are described below.

1.7.1 Handling the uncertainty problem

In VANET, the network situation always changes in a very rapid and unpredictable manner. To find an exact and best path from a source to the destination is almost impossible. This is why, finding the best available links for an immediate sender and destination is a much better choice. The proposed model provides a comprehensive mechanism to deal with the uncertainty problem in VANET dissemination models. The proposed model provides a mechanism to find out the link life time, the link stability and the weighted factor for every available link. The weighted factor is calculated to adjust the key link selection parameter involved in the dissemination model for VANET. This model considers velocity, mutual distance and position as key link selection parameters. The best available link chosen for the dissemination of data addresses the uncertainty issue well and the results show that the proposed model performs better in sparse and dense network situations than other models in comparison.

1.7.2 Adaptability

In this adaptive ID model, the Communication Domain and Application Domain are responsible for disseminating diverse types of data. The Communication Domain has the capability of forwarding the safety-of-life data and the Application Domain is responsible for forwarding safety and non-safety data. Sometimes, either domain can be overburdened. Being a realistic dissemination system, the resources (bandwidth and domain resources) are shared in overloaded situations to eliminate the load on the network domains. The data load on the Communication Domain and the Application Domain depends on the work place and the nature of the concerned drivers on the road. In the situations where the data related to safety and non-safety is heavier than that of the safety-of-life data and most of the bandwidth in the Communication Domain is not used at all or is underutilised, the model shall direct the part of the heavy data load to the Communication Domain for forwarding and vice versa. This adaptive nature of the dissemination model limits the congestion created due to the heavy data load on the network and results in a higher packet delivery ratio, throughput and reduced end-to-end delays.

1.7.3 Information splitter for system domains

This research work has introduced a module called the Information Splitter module. It has the capability of dividing the information coming from the source node into three main categories of information, i.e., safety-of-life, safety and non-safety information. The designed data packet has a 2-bit field called the “data type” field. It can be decoded and the type of information packet can be identified from the decoded value. It filters out the raw information into three categories of information (safety-of-life, safety and non-safety). After that, the Information Splitter sends this categorised information to the appropriate domains for further processing. The Information Splitter also sets the priority of the information packets before sending them to the appropriate domains. In most of the previous research works, the various domains have to filter out the appropriate data for processing or forwarding. In this way, the time critical data may face significant delays before being forwarded. Safety-of-life data is time critical data which needs to be forwarded to the destination as soon as possible. In this way, the proposed dissemination model eliminates the delays found in the previous dissemination models. On the other hand, filtering the data for the appropriate processing domains minimises the context switching[2]. This results in a high packet delivery ratio and high throughput.

1.8 Scope and limitations

The proposed adaptive ID model has some limitations as well. First of all, it is designed for the dissemination of information for the vehicles on the highway. The model considers dense or sparse network scenarios on the highway. The range of vehicles for dense and sparse network has also some limitations. The proposed dissemination model failed to deliver the desired results in city or urban area vehicular traffic. Similarly, the security and authentication process while sending the data from a source to the destination is not considered. This is because the ID model proposed can be a part of some application specifically designed for a VANET environment, which may already have security or authentication features integrated.

1.9 Thesis organization

The remainder of the thesis is organised as follows:

Chapter 2 describes the basics of vehicular ad hoc networks to provide the reader with the necessary level of knowledge. This chapter presents the main characteristics of vehicular ad hoc networks. It also summarises the main wireless access technologies and routing protocols used in VANETs. It also lists a representative set of proposed applications to exploit both the main research groups and consortia that work or have worked in designing this kind of networks. This chapter also presents an overview of mobility and traffic models. Finally, an outline of challenges and future works for VANET are presented.

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[2] Context Switching refers the extra time consumption by the model to handover the control of the information held by either domain to the other domain. This process reduces the overall performance of the ID model.

In Chapter 3, different phases of methodological framework for the proposed model are discussed. The chapter further explains the conceptual framework for the proposed model. Further, the simulation setup is discussed in detail. Finally, the performance parameters to be used for benchmarking purpose are presented in this chapter.

Then the Chapter 4 describes the research design and procedures incorporated into the work of proposed model. This chapter explains the high level architecture of the model proposed. The chapter further explains the common procedures used in application domain and communication domain of the proposed model. Finally, the extended view of Communication Domain and Application Domain is presented

A comprehensive analytical evaluation, comparative studies with respect to “An adaptive information dissemination model for VANET communication” and a discussion on the simulation results are presented in Chapter 5.

Finally, conclusive remarks and future work are presented in Chapter 6. This chapter consists of the summary of the results, and performance of the proposed ID model. This chapter presents the discussion about the possible future opportunities for the upcoming researchers at the end. The list of publications during this research work is listed after chapter 6. Finally, Appendix ‘A’ consists of the Bridge code and Appendix ‘B’ containing the comprehensive study of application based models proposed in VANET are presented.

CHAPTER 2

LITERATURE REVIEW

This chapter provides an overview about state-of-the-art applications in vehicular ad hoc networks (VANETs). First of all, it introduces the idea of MANET and VANET. It is followed by the main characteristics of such networks. Then, a summary of the main wireless access technologies and routing protocols used in VANETs is presented. After that, the representative set of the proposed applications is presented to exploit the work in designing this kind of network's applications and systems. Then, the next section presents the overview of the mobility and traffic models. Finally, an outline of challenges and future works that arise in the networks are presented in this chapter.

2.1 Mobile ad hoc networks

MANETs are wireless mobile nodes that cooperatively form a network without infrastructure. Before setting up MANET, there is no coordination between the mobile nodes. There are lots of research challenges in MANET, namely: routing packets in a highly frequent topology environment, issues in wireless communications, and resource issues (limited power). Simulation has been the leading research way for finding out the solutions to these challenges. The quality of signals or availability of a mobile connection heavily depends upon the position of the receiver node with respect to the field area of other antennas. These networks can be thought of like a honeycomb in which every antenna covers one of the cells. A network like MANET possesses weak spots after its building phase. The reason is that the real world MANET has to exist with geographical hindrances, such as forests, roads, rivers etc. Sometimes, building a MANET is not even realistic. The reason is that in many situations supplying the required amount of energy to the antennas is almost impossibility.

In MANET, mobile devices form a peer-to-peer network to exchange data or channels. This exchanged data may be in the form of speech or of other kinds (e.g. text). For file sharing and other peer-to-peer services, MANET can surely add something to the possibilities of the currently available technologies such as 3G (UMTS and by products). The final impact of this technology heavily relies on the way in which the telecommunication and hardware supplier's communities will act on its appearance on the wireless communication scene.

The emergence of mobile ad hoc networks is a result of the advances in wireless networking technologies[7]. An interconnected bunch of independent mobile wireless nodes which don't require any underlying infrastructure is called MANET. Each and every node that constitutes and participates in MANET is free to shift autonomously in any direction, and the links between them change frequently. The network may contain the nodes as personal computers, laptops, or small mobile devices as sensors, PDA (personal digital assistants), cell phones, and other devices etc. Figure 2.1 shows a generic overview of a simple MANET network.

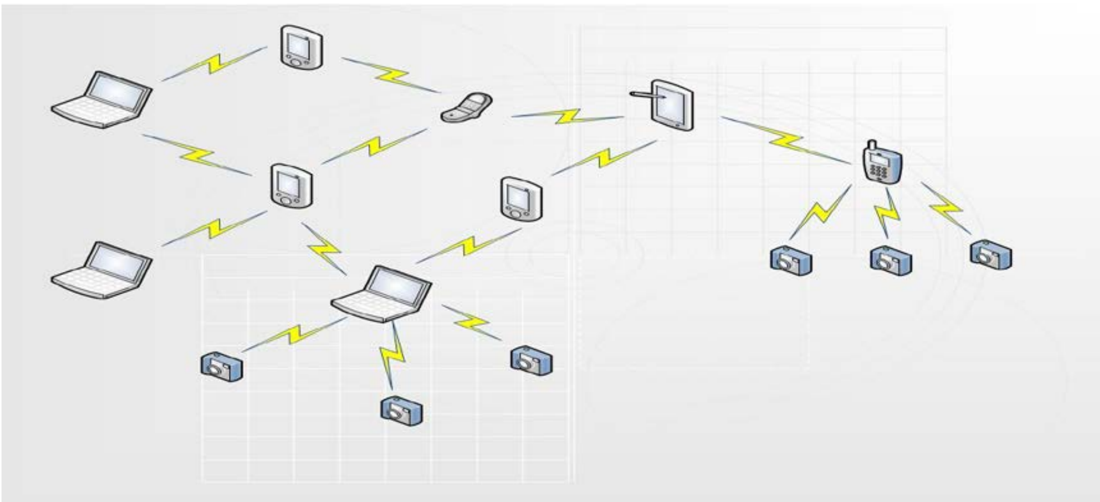


Figure 2.1: Example of MANET Network

MANET has gained reasonable attention and attraction due to its ability to be used as direct applications for mankind. It can be used for accessing communication in the areas where it is very difficult to install and use it without any infrastructure. It is useful in a situation like an earthquake or a major fire which may have damaged the communication infrastructure or the infrastructure may have just become useless [8].

2.2 Vehicle Ad hoc Networks

Due to the importance of MANET, the academic institutions and automotive industries started their research of MANET to be deployed in vehicles. According to the researches, the use of mobile smart phones and available GPS may be handy in such scenarios. As a result, two different technologies emerged. The first was Inter-Vehicle Communications (IVC) and the second was the Road-Vehicle Communications (RVC). Vehicle-to-Vehicle (V2V) facilitates the vehicles to communicate with each other. This is known as RVC and is a way to provide the communication means between vehicles on the road and the roadside units (RSU). RSUs are responsible for gathering and broadcasting communication without any alteration in the source information. This type of communication between vehicles and RSUs is also termed as Vehicle-to-Infrastructure (V2I). The union of IVC and RVC technologies has grown into vehicular ad hoc networks or VANETs. A simple VANET is shown in Figure 2.2. Using this technology, vehicles can communicate with each other to transmit different kinds of information. The exchange of real time traffic information conditions among vehicles can make driving safer and more efficient. This is the reason that the research community is focusing to develop VANET applications. For example, warnings about the existence of an accident are useful. In this case, the drivers of the vehicles are able to reduce the speeds of their vehicles. Moreover, they can use alternative routes to avoid the accident area (as shown in Figure 2.2).

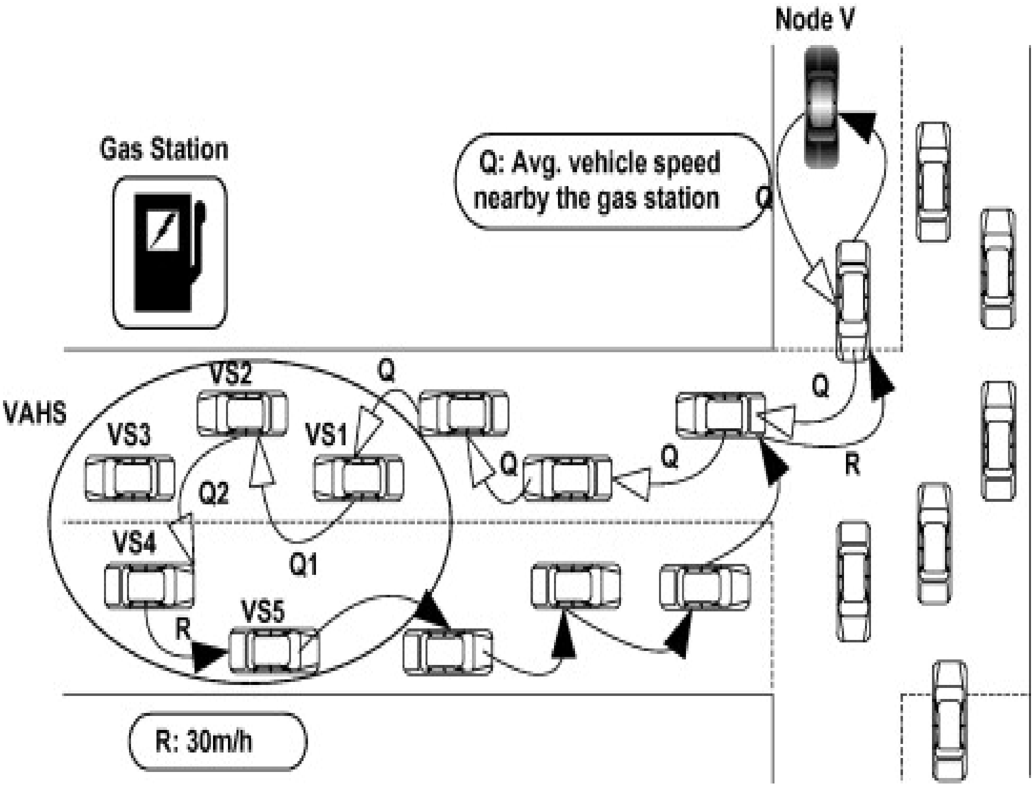


Figure 2.2: Example of VANET Application: Warning of Traffic Accidents

The roadside constituents, such as road traffic signs or traffic lights, are naturally used to have visual information. They serve the drivers or people on the road with predictable changing pattern. But with the use of VANET technology, roadside elements acting as RSUs can become more active as far as the information to the users is concerned. For example, a dangerous curve sign could warn the driver of a vehicle travelling at an excessive speed before reaching it. Similarly, a “men at work” signal can broadcast information about of the existence of road works. In this way, the drivers would know their existence in advance as shown in Figure 2.3.

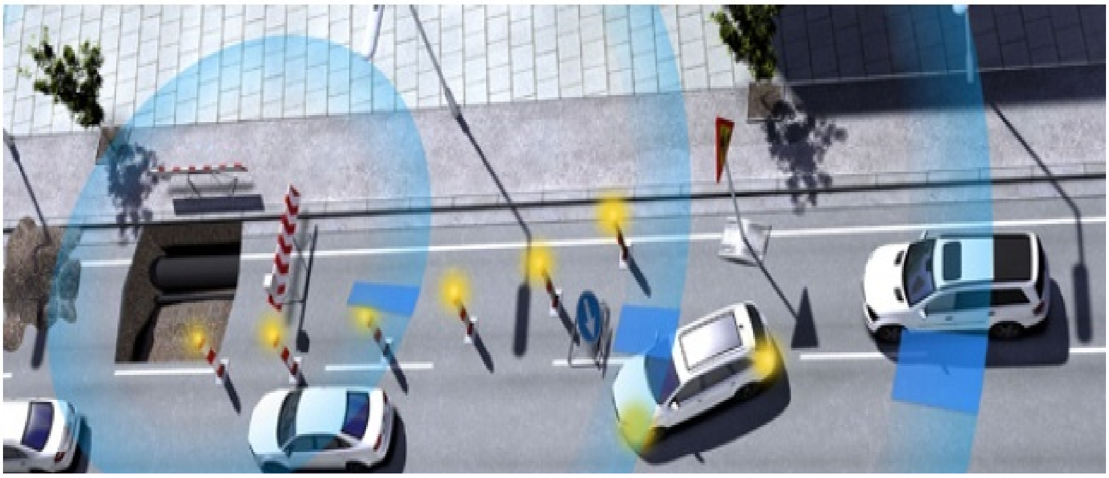


Figure 2.3: Example of VANET application: Warning of Obstacles on the Road

2.2.1 Preliminary concerns of VANET

If it is possible that the vehicles on the road can directly correspond to each other through fewer infrastructures, then a new paradigm for vehicle safety/non-safety applications can be generated. Road and vehicle efficiency can be met through some non-safety commercial applications as well.

High vehicle mobility and dynamic vehicular environments have created new research challenges. New safety-of-life applications require new expectations of high packet delivery ratios and low packet drops. Further, customer acceptance and governmental oversight bring very high expectations of privacy and security. Even today, vehicles produce and investigate a huge sum of information, though classically, this data is self-reliant within a single vehicle [9]. VANET has created the possibility of knowledge for the vehicle or drivers. Communication in VANETs can be either performed directly between vehicles as one-hop communication, or vehicles can retransmit messages, thereby enabling the so called multihop communication. The coverage of signals or the robustness of communication systems can be increased by deployment of relays at the roadside. Roadside infrastructure in some cases is utilised as a gateway to the Internet. In this way, data and context information can be gathered, stored and processed at distant places like Cloud Computing. These phenomena justify that the interest in VANET is strongly provoked by increased number of future applications in the said area. Active safety-of-life, safety and non-safety applications can gain the interest of the research community from this most direct form of communication. Then, traffic flow on the roadside can be improved by collecting traffic status data from a wider area. Travel times could be reduced by the timely updating of the drivers about some hazardous situation [10]. It was concisely stated as the tenet of the Intelligent Transportation System World Congress in 2008: save time, save lives.

2.2.1.1 Key technical challenges in VANET

While being theoretically simple, the design and usage of VANET is a technically and economically challenging attempt. Key technical challenges include the followings:

a) Inherent characteristics of the radio channel

VANET poses a situation with poor characteristics for developing wireless communications. As an example, multiple reacting objects are capable of lowering the strength and quality of the received signal. Getting information about the mobility of the surrounding objects and the sender and receiver themselves requires the desertion of the signal strength to get into act [11].

b) Lack of an online centralised management and coordination entity

The fair and efficient utilisation of the system bandwidth is not an easy task in a totally decentralised and self-organising VANET environment. The less efficient treatment of mobile channel states and excessive packet collisions may be due to the lack of an entity being able to synchronise and manage the transmission events.

c) High mobility and scalability requirements, and the wide variety of environmental conditions

The high vehicular speeds stress the challenges of a decentralised self-organising network. Their high mobility presents a challenge to most iterative optimisation algorithms aimed at making better use of the channel bandwidth or the use of predefined routes to forward information .

d) Security and privacy

Balancing the security and the privacy demands are another challenge in a vehicular environment. Firstly, the receiving vehicles demand to be ensured that they can trust the source of the information. Secondly, there might be a contradiction between the trust and privacy requirements of the sender vehicles.

e) Standardisation versus flexibility

Till date, there is no standardisation mechanism between the automotive companies. There is a requirement for standardising communications for allowing VANET to work across various vendors and brands of original equipment manufacturers (OEMs). It is hoped that the OEMs will want to produce some merchandise separation with their VANET material goods. These goals are yet to be achieved.

2.2.1.2 Application and socio-economic challenges

From an application and socio-economic point of view, key challenges have been identified as:

a) Investigating and measuring the advantages of VANET for life safety, traffic safety and transport efficiency.

Relatively very rare research work has been carried out to count the influence of VANET as a new source of information. Clearly, the related challenge in addressing the issue of impact estimation is the modeling of the related human factor aspects.

b) Investigating and measuring the cost/benefit relationship of VANET.

   A cost/benefit study can hardly be performed due to the lack of studies on the benefits of VANET.

c) Designing deployment strategies for this type of VANET that are not based on a single infrastructure and/or service provider.

   To find such a willing VANET technology adopter companies, who can buy VANET equipment when it is rare to find communication partners, is the challenge. Balance between security and privacy demands is another challenge. The buyers of VANET equipment want the surety of trust in the source of the information. There might be a contradiction between trust and privacy requirements of the sender vehicles.

d) Embedding VANET in intelligent transportation system architectures.

   Truly accommodating systems for VANET need to be developed. VANET has to be considered as a part and parcel of an intelligent transportation system by the automotive industry. Similarly, public and individual transportation have to be considered in a joint fashion.

The above lists of technical, application, and socio-economic aspects suggest that VANET and inter-networking technologies needs interdisciplinary measurements in the cross section of communication and networking, automotive electronics, road operation and management, and information and service provisioning. Consequently, VANET is considered as a vital part of Intelligent Transportation Systems (ITS).

2.2.2 Network requirements in VANET applications

This section introduces the main technological demands of VANET. These demands need to cover many elements for their efficient utilisation. The most important of these technological demands are discussed as follows.

2.2.2.1 Mobility

Wireless network technologies gives communication devices as a free hand in mobility. However, potential permanent access to the network is affected by this mobility and lots of other problems are caused by this mobility access. In [12], experimental evaluations give the real results of these effects. The distance between the sender and receiver is an important factor in 802.11 transmissions. The more the distance, the smaller the probability of the reception of packets [13]. Throughput decreases if the mobile terminal is moving at locations far away from other nodes without performing a handoff [14]. However, this distance factor is not the only obvious outcome of mobility. Due to the use of the 2.4 GHz frequency band, the interference with other radio equipment in VANET also has its importance and it should be considered [12]. The bad placement of equipment used in the communication system can also cause communication problems. The existence of other vehicles or buildings are considered in realistic mobility patterns for VANET solutions [15]. Table 2.1 shows the list of applications that require mobility.

Table 2.1: Applications in VANET require mobility

Application / App.Req	**Location Awareness**	**Geocast Capability**	**Penetration rate dependence**	**Time Awareness**	**Permanent Access**	**Mobility**
Safety						
• Cooperative collision	suited	suited	suited	suited	needed	suited
• Accident warning	suited	suited	suited	suited	needed	suited
• Emergency video streaming	suited	suited	suited	suited	needed	suited
Traffic management and monitoring						
Platooning	suited	suited	suited	suited	needed	suited
Vehicles tracking	needed	none/not needed	needed	needed	suited	needed
Notification service	needed	none/not needed	needed	needed	needed	needed
Comfort						
Parking place management	suited	suited	needed	needed	needed	suited
Distributed games/talk	needed	suited	suited	needed	needed	suited
Peer-to-peer	needed	none/not needed	needed	needed	suited	needed

2.2.2.2 Permanent access to the network

Permanent access to the network is the main drawback of vehicular communications. VANET uses a non-physical infrastructure because of its naturally decentralised design. As an example, in a city or urban environment, the network coverage is very good, and the amount and position of a mobile terminal for connection are really high. At rural or highway areas, however, this deployment is not very good. At the application level, a file transfer service or downloading is required to have a permanent communication link. The election of a suited vehicular network is essential for this kind of application services.

2.2.2.3 Location Awareness

In VANET, the vehicles are expected to exchange information from beyond immediate neighbouring vehicles as well as from line-of-sight with other vehicles. They also communicate with the road infrastructure and Internet databases for real time effectiveness. To anticipate trajectories, warn oncoming traffic of an icy patch, report road traffic conditions, locate parking lots, coordinate merging maneuvers, notify a braking action to vehicles behind, or simply entertain passengers, this data is very important. In this context, the knowledge of their actual position and trajectory is necessary. This information is only meaningful to vehicles in a scrupulous geographic area. Reliable and extendable communication capabilities are required in the vehicles in VANET to exchange information. This is called geographical routing and addressing in a VANET environment. This function depends on the information given by GPS receivers. GPS, on the other hand, has some limitations like lack of coverage in some environments and weak robustness for some critical safety-to-life related applications. Other positioning techniques, such as cellular or WiFi localisation, dead reckoning (by using last known position and velocity) [16], and image/video localisation, have been identified in the vehicular field [17] due to the GPS limitations. A highly accurate localisation mechanism is needed for safety application services; namely, alert cooperative collision warning, incident management and comfort application services, such as parking booking. The zone of relevance can be accurately defined with the help of an accurate positioning system. Peer to peer and vehicle tracking like application services need a low accurate localisation mechanism.

2.2.2.4 Time awareness

VANET often requires a dependable communication control that supports time critical message transmissions [18]. Communication delay is considered the most important measurement of the quality of the network for all types of data in the communication data. Road safety and safety-of-life application data have their time constraints. Due to this, a challenge in vehicular networks is providing a real-time behaviour. In order to enable the driver to react quickly, the information must reach the destination in a very small delay following the event. It is not an easy task in this type of highly mobile environment. The other characteristics of the vehicular environment poses even more hurdles in this connection Thus, robust and efficient communication can ensure a real-time communication capabilities.

2.2.2.5 Penetration rate dependency

The penetration rate is defined as the percentage of vehicles equipped with the necessary on board data unit (OBU) on the road. A low penetration rate is obviously a problem in safety applications, such as collision avoidance, an excess of equipped vehicles also bring about transmission problems. However, non-safety related applications do not need to worry about this factor. The high penetration in cellular networks is a problem. In cases of a fewer number of vehicles being equipped with the resources, the performance is not much affected. When the load is high, the network shows a poor performance in the case of a higher number of users [19]. It is also worth remembering that the penetration rate is directly affected by the wireless bandwidth used. The higher the penetration rate, the higher the wireless bandwidth that should be used.

2.2.2.6 Geocast capability

Geocast provides the ability to deliver a message to nodes within a geographical region [20]. The application sets the shape and size of the geographical area. The complexity of defining this region can vary depending upon the number of vehicles before or after the carrier vehicle. Table 2.2 shows the geocast forwarding schemes for various wireless technologies.

Table 2.2: Geocasting forwarding schemes for various wireless technologies.

Technology	**Range**	**Link type**	**Frequency band**	**Standard**	**Data rate**	**Vehicular applicability**		
						V2V	**V2I**	**I2V**
Bluetooth	100 m	1 to n	2.4 GHz	IEEE 802.15.1	1Mbps	needed	not	not
WLAN	200m	1 to 1 1 to n	24.5 GHz	IEEE 802.11a/b/g	10-50 Mbps	suited	needed	needed
DSRC	1Km	I to 1	5.9 GHz	IEEE 802.11p	50 Mbps	suited	suited	suited
WiMAX	10Km	1 to n	24.5 GHz	IEEE 802.16e	~20 Mbps	not	suited	suited
Cellular	10Km	1 to n	700-2600 GHz	n/a	~10 Mbps	not	suited	suited
RDS/TMC	80 Km	1 to n	87.5-108 MHz	CENELEC EN50067 CEN ENV 12313	1187.5 bps	not	not	suited
Satellite	>10000 Km	1 to n	950-1450 MHz	n/a	300-500 Kbps	not	needed	suited

The range is not fixed and defining this range depends upon the vehicles inside this geographic area. The same situation is for near a designated spot (such as a smog area). Talking about the general communication architecture in a vehicular environment in which unicast and geocast capabilities can both be implemented. One can propose a hybrid networking architecture. Platooning is a service that requires unicast communications and always has good performances. Geocast is of better use when information is forwarded in both sparse and dense geographical areas, and efficiency improves with better bandwidth. Scalability has been introduced in [21] to prove this point. Scalability is defined as the ability to handle the addition of nodes or objects without suffering a noticeable loss in performance or an increase in administrative complexity.

2.3 VANET Characteristics

VANET networks can be viewed as a subclass of MANETs where nodes are vehicles or roadside infrastructure elements. The mobility pattern in both types of ad hoc network nodes is the main and most critical difference. The driver's behaviour is the influential criterion for VANET nodes along with road restrictions and high vehicular speeds. These characteristics play a vital role for the development of VANET applications. The major characteristics of VANET are presented here.

a) VANET topology can change very rapidly which is very difficult to manage. Due to the high relative speed between cars, network topology changes very fast. Different authors have tried to find solutions to this problem for both highway scenarios [22-23] and urban environments [24]. However, it is not feasible to use one solution for both types of network situations at the same time.

b) VANET networks adapt themselves to frequent fragmentation. Due to this fragmentation, information faces challenges to reach to the desired destination vehicles.

c) Such networks have a small effective network diameter. It is mainly due to the speed, the high number of obstacles, and the height of the used antennae. For this reason, links between nodes can be broken frequently.

d) The devices used to deploy these networks do not need to worry about the significant power constraints. These devices use the power generated by the vehicles in which they are deployed.

e) The network density is not constant and it varies with the vehicular density. This may be high in some situations, for example, during rush hours at the entrance of major cities, or it can be light in low-traffic highway environments.

f) The driver's behaviour is vital factor. Their behaviour can change the whole topology of VANET. The behaviour may be changed when new information is received by the drivers i.e. means that the content of the messages can change network topology.

2.4 Wireless Access Technologies

This section presents several access standards that could be used for VANET connectivity. The aim is to provide a set of air interfaces and parameters for high speed vehicular communications using one or more available communication media. Note that, currently, the WiFi (IEEE 802.11 based) technologies are the most common for connecting vehicles in the research and development of VANETs [25-27]. Several connection technologies that have been considered to deploy vehicular networks are presented in the following subsections. In this study, two distinct groups of wireless access technologies (commonly used for VANET deployment in most VANET research groups) have been identified; namely, ad hoc networks (without any infrastructure) and cellular technologies (with infrastructure)

2.4.1 Ad-hoc Network based wireless access

As the ad-hoc connection technologies improved, there has been a significant improvement in the VANET networks. The technologies which are infrastructure less for vehicular networks are discussed here.

2.4.1.1 Wireless Fidelity (WiFi)

IEEE 802.11 wireless protocol in general is referred to as WiFi. Specifically, WiFi Alliance has defined WiFi as the industry standard for communication products. They have conformed WiFi to be a part of IEEE 802.11 standard [28]. WiFi standard defines over-the-air protocols which are used to support communication behavior for local area. The local area indicates physical (PHY) and medium access control (MAC) layers in OSI model.

Several other specifications have been defined in the IEEE 802.11 family. These specifications extend the capabilities of original IEEE 802.11. Originally IEEE 802.11 supports 1 or 2 Mbps transmission in the 2.4 GHz band. IEEE 802.11b and IEEE 802.11g that provide 11 Mbps and 54 Mbps transmission in 2.4 GHz band with a maximum range of 500 m, respectively are considered to be most popular extended specifications. PDAs, smart phones or laptops these days are generally equipped with the necessary hardware to use IEEE 802.11b and IEEE 802.11g. IEEE 802.11a extends 802.11 and it provides up to 54 Mbps in 5GHz band by using OFDM (Orthogonal Frequency Division Multiplexing) encoding scheme [29]. IEEE 802.11n standard with a bandwidth up to 500 Mbps is used for increased transfer rates in the communication medium. There has been a number of others 802.11 extensions like, WG activities define inter access point protocol (IEEE 802.11f), MAC enhancements for security (IEEE 802.11i), MAC enhancements for QoS (IEEE 802.11e), etc. IEEE 802.11 b is considered to be one of all time maximum used extensions by the research groups due to its burly existence in the communication market [30]. IEEE 802.11b has provided very encouraging outcomes by both simulations and real tests.

2.4.1.2 Worldwide Interoperability for Microwave Access (WiMax)

WiMax is another standard which is developed by the IEEE 802.16 [31]. This standard was originally defined to be an alternative to cable and DSL for long range wireless broadband communication. This kind of connections operates on licensed or unlicensed spectrum. WiMax can deliver 70 Mbps over 50 Km. WiMax can operate at higher bitrates as well as over longer distances. Both the qualities cannot be obtained at same time. WiMax operating at the range of 50 Km may experience an increased bit error rate. Due to this fact it attains much lower bit rate. Conversely, reducing the range allows a device to operate at higher bitrates.

In [32], the authors have measured the performance of different WiMax scenarios using a bandwidth of 20 Mbps and used transmission range of 6 Km. A lot of objections have emerged for WiMax after IEEE 802.16 standard release in 2002. Keeping these reservations in view the IEEE 802.16e standard was launched in December 2005 for mobile devices.

2.4.1.3 Bluetooth

A Mobile phones company Ericsson2 in 1994 developed and launched Bluetooth technology called IEEE 802.15.1 [33]. It is a short range radio communication system. It is specifically designed as a wireless alternative to the serial communication RS-232 to communicate between the mobile phones, PDAs, notebooks, PCs, headsets, etc. Bluetooth is considered to be cheap and low power consumption technology for mobile devices.

For Wireless Personal Area Networks (WPAN), Bluetooth is considered to date as the most used communication technology. There are different classes of Bluetooth according to their coverage and power as shown in Table 2.3, getting transfer rates up to 3 Mbps and ranges up to 100 meters. Using robust security algorithms the Bluetooth networks can operate on a free frequency band.

Table 2.3: Status of Bluetooth class

Class	**Maximum allowable power**	**Coverage (approximate) (m)**
Class 1	100 mW (20 dBm)	100
Class 2	2.4 mW (4dBm)	10
Class 3	1 mW (0 dBm)	1

2.4.1.4 Ultra Wide Band (UWB)

The UWB uses IEEE 802.15.3 standard and is considered as an advancement of the Bluetooth technology. By the use of a large portion of radio spectrum, UWB is a radio technology which can be used at very low power levels. But the limitations are that it can only be use for short-range (10 m) high-bandwidth (> 500 MHz) communications. It offers transmission bitrates in the range up to 480 Mbps. UWB uses very low powers, which is considered to be its most important feature [34].

2.4.1.5 ZigBee:

Ad hoc WSN (Wireless Sensor Networks) uses ZigBee technology which is based on the IEEE 802.15.4 standard. It has the capability of a fairly limited bandwidth up to 250 Kbps and range of communication up to 75 m. ZigBee is used for transferring little amount of information to small distance [35]. ZigBee uses very low power consumption for sending the information on the communication link.

2.4.1.6 Dedicated Short Range Communications (DSRC)

DSRC has been designed as the communications standard specifically for V2V and V2I communication. More precisely, it is a short medium range communication service to provide assistance to many applications that require a small latency level and a high data rate. There are compatibility issues for various versions of DSRC systems in the world. DSRCs in Europe, Japan, and the US are not compatible [36]. In the US, DSRC has been based on the IEEE 802.11p standard of the IEEE 1609 family. It is supposed to use seven 10 MHz-wide channels in the 5.85-5.925 GHz bandwidth.

IEEE 802.11p is based on IEEE 1609. The ASTM (American Society for Testing and Materials) proposed the IEEE 802.11p standard as a modification in IEEE 802.11a. The reason to develop this standard was to implement VANET technology in a better way. To add Wireless Access in the Vehicular Environment (WAVE), IEEE 802.11p was developed as an extension to 802.11 standards. It allows communication between vehicles moving up to 200 Km/h and inter-vehicle distances in the range from 100 to 500 meters. In order to deal with very low latency in VANET applications, very short duration communication exchanges are required. Regarding the physical layer, IEEE 802.11p is very similar to IEEE 802.11a. IEEE 802.11p is also an OFDM-based protocol. This protocol is emphasised mainly to reduce channel spacing from 10 MHz instead of 20 MHz. The reduced channel spacing is considered to deal with the higher multi-path effect in urban environments. The data rate range is from 3 to 27 Mbps for each channel. Lower rates are preferred in order to obtain robust communication in an urban vehicular environment.

The DSRC spectrum is divided in seven channels as shown in Figure 2.4. Channel 178 is the control channel (CCH), which is restricted to safety communications. The two channels at the ends of the spectrum band are reserved for special uses. The rest are service channels (SCH) available for both safety and non-safety usage. At the MAC layer level, DSRC is based on access control provided by the CSMA/CA (Carrier Sense Multiple Access, Collision Avoidance) but modified to avoid the hidden terminal problem. In order to avoid the hidden terminal problem, DSRC applies the message exchanges, Request-to-Send/Clear-to-send (RTS/CTS) [31]. This is performed in order to avoid the data collisions in the channels. Collisions are controlled in this way, but it will introduce overload and delayed transmissions. To reduce the affect of this problem, RTS/CTS is not implemented in the CCH channel.

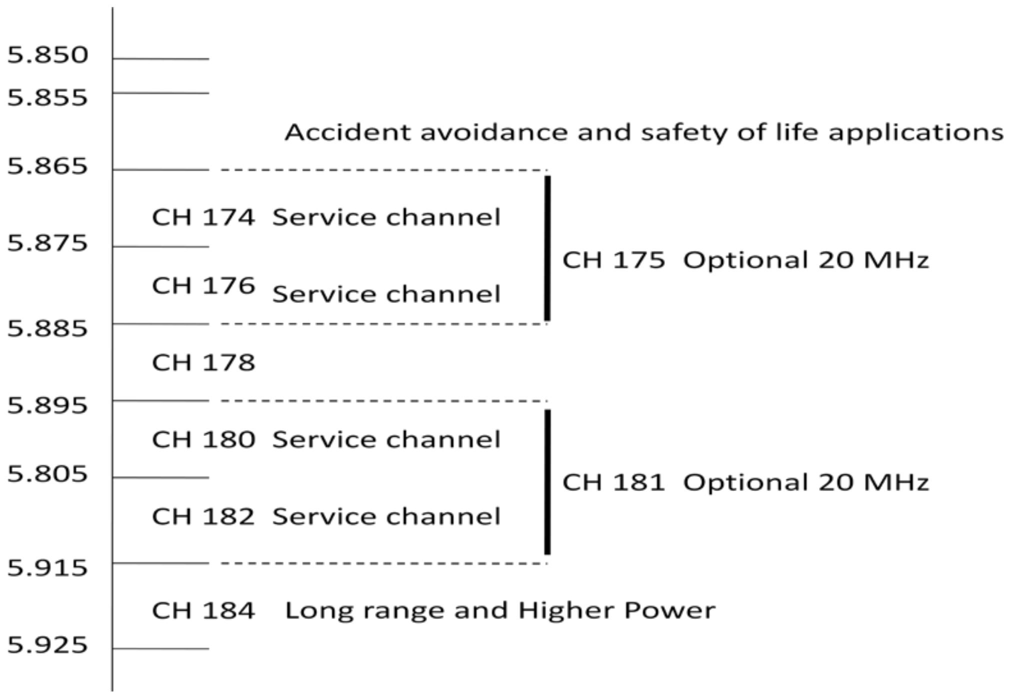


Figure 2.4: DSRC channel assignment in North America

Table 2.4 summerises the main features of the wireless ad-hoc network technologies discussed above.

Table 2.4: Features of Wireless access technologies proposed for VANET

Name	Coverage (m)	Transfer data rate (Mbps)	Power consumption
WiFi	500	54	High
WiMax	5000	70	High
Bluetooth	20	3	Medium
UWB	10	480	Low
ZigBee	75	250	Very low
WAVE	500	27	High

2.4.2 Cellular Technologies

The wireless ad hoc connection technologies have many flaws in their operations. There may occur a link loss problem in a case when nearby vehicles are not present. This problem is provoked specifically in a VANET environment due to high mobility nodes. To avoid this problem, cellular connection technologies, such as GPRS, UMTS or HSDPA, is considered to be beneficial to VANET. This feature is illustrated in Figure 2.5.

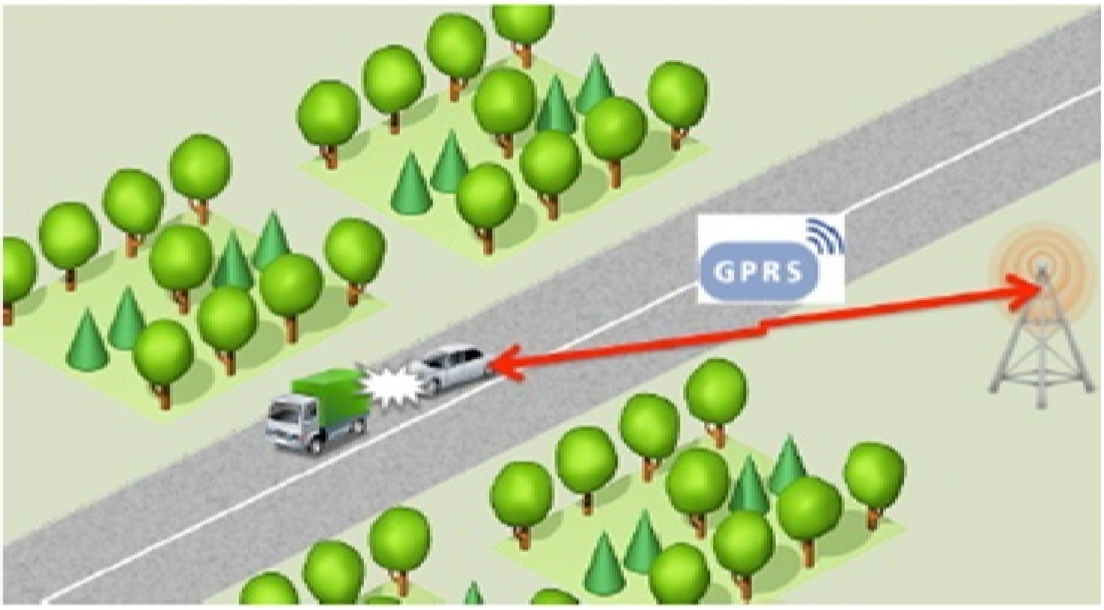


Figure 2.5: Collision Warning using GPRS

2.4.2.1 General Packet Radio Service (GPRS)

GPRS [37] is an extension of Global System for Mobile Communications (GSM). GPRS is a packet oriented mobile data service. 2G cellular communication system users can use this service. GPRS provides data rates between 56 and 114 Kbps. 2G cellular systems combined with GPRS called 2.5G. It is a technology that is considered to be the intermediate service between the second (2G) and third (3G) generations of cellular communication technologies. The services are provided by cellular networks like Short Message Service (SMS), Multimedia Messaging Service (MMS), Wireless Application Protocol (WAP) and Internet access through GPRS.

2.4.2.2 Universal Mobile Telecommunication System (UMTS)

UMTS [38] is a third-generation (3G) cellular communication technology. The extended capabilities of UMTS are to provide the opportunities to make video-calls to users of cellular phones. Due to its upgraded data rate which is up to 2Mbps, UMTS can also offer Internet access. Moreover, high quality multimedia services can also be obtained through UMTS.

2.4.2.3 High-Speed Downlink Packet Access (HSDPA)

HSDPA is an optimisation of UMTS hence, it is known as 3.5G. An increased transfer data rate to 14 Mbps can be obtained from HSDPA due to the improvements made in its design. But in reality, the rates obtained from HSDPA are nearly up to 3 Mbps. These data rates are enough for the services of emerging technologies including the access to television content via the mobile terminal streaming. These days, new cellular telecommunication technologies, forth (4G) and fifth (5G) generations, are in the process of being developed [39].

2.5 Routing Protocols in VANET

A routing protocol is required when a packet has to be sent to a determinate node through several vehicles. Hence, one of the most challenging problems in VANETs is recognized as the design of an efficient and reliable routing strategy. In case of wireless ad-hoc networks, all nodes behave as routers. These nodes participate in rout discovery and route maintenance in the mobile ad hoc network. An adaptable routing strategy is required since network conditions change continuously such as: network topology, traffic density, and network partitioning. Additionally, the routing protocol may need to provide different levels of QoS to different types of applications and services. The first solution has been the use of MANET routing protocols directly or by modification in those protocols. However these protocols are unsuitable due to the critical differences in VANETs and MANETs (discussed in Section 2.2). In parallel with this, some VANET specific protocols are also proposed. This section presents different approaches trying to solve the routing problem in VANETs.

2.5.1 Communication Patterns

C Communication pattern refers to the aspects of which nodes will receive the packets sent by the data source. Mainly, two different communication patterns can be found in the literature work, namely, unicasting and multicasting.

2.5.1.1 Unicasting

Unicasting describes communications in which the source node sends information just to one receiver node [40].

2.5.1.2 Multicasting

Multicasting is the communication pattern where a packet is transmitted to multiple nodes by one node. The easiest multicasting strategy is to generate a separate copy for each destination and transmit them separately. However, this is considered to be the most costly approach. The reason behind this fact is that this approach does not use information about the path the packets followed. But, it can be observed that the routes between the source and destinations may follow the same path up to a certain node (when multi-hop communication is carried out). Multicasting can be a challenging technique but there are enough solutions for this type of communication pattern in the literature [24].

Three distinct multicast approaches exist in the literature: namely, broadcasting, anycasting, and geocasting.

a) Broadcasting strategies, theoretically, send information to all nodes in a network. It is observed that in practice, the information is only received by the nodes on the broadcasting domain in the network.

b) The Anycasting sends a packet to just one destination out of number potential destination nodes; the node which receives the packet is not specified.

c) The geocasting is considered to be the most promising approach for VANET and MANET networks. This strategy sends packets to a group of receiver nodes that are located within a certain geographic area. There is not any group of the mobile network specifically defined or addressed for a terminal as broadcasting. The geographical location defines whether a node will receive packets or not in the specific group in the network.

2.5.2 Routing Protocol Classification

Routing protocols can be classified in two major categories depending on when and how the routes are discovered; these are:

2.5.2.1 Proactive (table-driven) Protocols

In proactive routing protocols, all nodes have consistent and up-to-date routing information to each node permanently. Each node maintains one or more tables containing routing information to every other node in the network [41]. The up-to-date information is ensured by the careful propagation of information in the network in case of topology changes. All the individual nodes propagate messages throughout the network. These routing protocols differ 1) in the method by which the topology change information is distributed across the network 2) the number of necessary routing tables.

2.5.2.2 Reactive (on-demand) Protocols

In reactive routing, the routes are created only when they need to be made available to the source node. This strategy is quite different from the on-demand routing protocols because the route is established only in case it is required for a network connection [42]. When a source node, S, needs to connect to a destination node, D, S invokes a routing discovery process to find a route between them. After route establishment, nodes S and D as well as intermediate nodes store the information regarding the route from S to D in their routing tables. The information about the route searched in this way is maintained until either the destination is unreachable or the route has been used and is no longer needed.

Proactive routing protocols have the advantage of reduced end-to-end delay since upon generation of a network connection request, the route is already established. The costly route finding mechanism is no longer needed. But the disadvantage is that routing information is disseminated to all network nodes increasing the traffic and power consumption. Consequently, bandwidth for user traffic is reduced and the life time of the battery powered mobile nodes is limited. Reactive routing protocols have a lower power consumption and demand less control signaling. However, the end-to-end connection delay is higher since upon generation of a connection request between two nodes, the connection needs to wait some time for the link between the nodes to be established [43].

Some works have studied the possibility of applying the actual Mobile IP protocol over vehicular networks [44-46]. However, these protocols cannot fulfil the requirements for routing in VANET which not only the hosts but also the backbone is mobile and multi-hop wireless connections composed of many links with varying QoS are allowed. Therefore, more adaptive network layer protocols are required. Proactive or reactive approaches can be adopted when designing a routing algorithm for ad hoc networks [47].

2.5.3 Classification based routing protocols for VANETs

There are a high number of routing protocols that can be applied over vehicular ad hoc networks in offering different QoS. This section will give a brief overview of a representation of them. Some of these protocols are shown in Table 2.5.

Table 2.5: Main classification features of routing protocols applied on VANETs.

Protocol	**Common pattern**	**Scheme**	**Use of geograph information**
Blinding-Flooding	Broadcasting	-	No
MPR	Broadcasting	-	No
NES	Broadcasting	-	No
CDS	Broadcasting	-	No
DSR	Unicasting	Reactive	No
AODV	Unicasting	Reactive	No
TORA	Unicasting	Reactive	No
DSDV	Unicasting	Proactive	No
LAR	Unicasting	Proactive	Yes
FSR	Unicasting	Proactive	No
OLSR	Unicasting	Proactive	No
ZRP	Unicasting	Hybrid	No
MAODV	Multicasting	Reactive	No
GeoTORA	Geocasting	Reactive	Yes
GeoGRID	Geocasting	Reactive	Yes
LBM	Geocasting	Proactive	Yes
GAMER	Geocasting	Proactive	Yes

2.5.3.1 Blind-Flooding:

The Blind-Flooding protocol [48-49] is the simplest broadcasting protocol. Each node receiving a packet repeats it by broadcasting as shown in Figure 2.6, unless a maximum number of hops for the packet are reached, the packet has been already sent or the destination of the packet is the node itself. It does not require costly topology maintenance or complex route discovery algorithms. However, it does not take into account the available resources at the nodes or links, i.e., resource blindness, and the nodes may receive duplicated packets as shown in Figure 2.6.

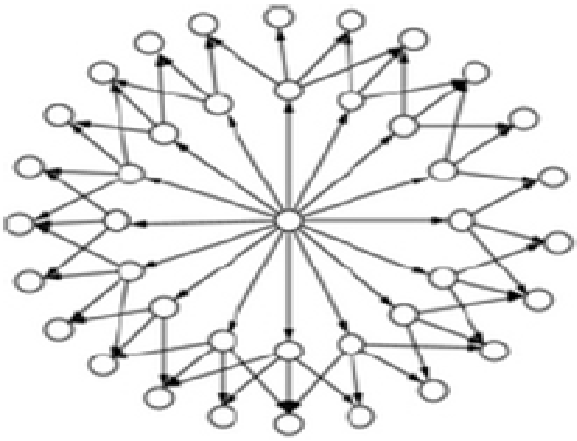


Figure 2.6: : Blind-Flooding protocol

2.5.3.2 Connected Dominating Sets (CDS)

CDS uses a technique to classify the network nodes as active or passive in order to institute a pecking order within the nodes in the network [50]. Initially, transmissions are carried out in such a way that the whole network is covered for the communication purpose as shown in Figure 2.7. This algorithm has the capability of reducing the network traffic. However, the computation of the minimum connected dominating set over a given graph, in general, is an NP-Complete problem [51]. Thus, an approximation mechanism must be deployed in practice.

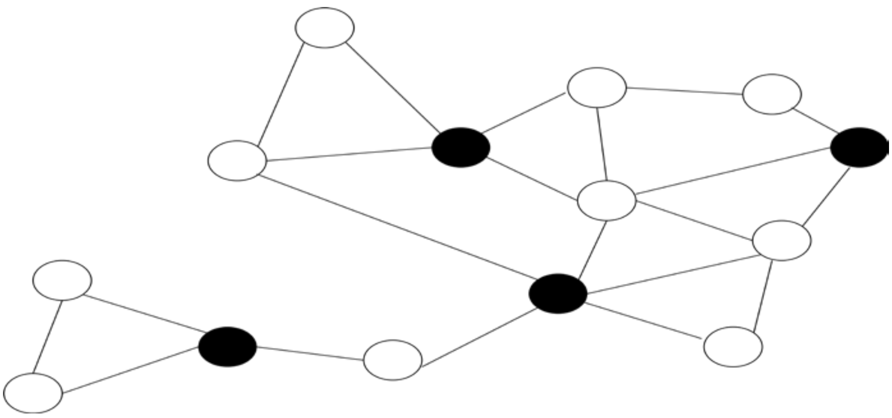


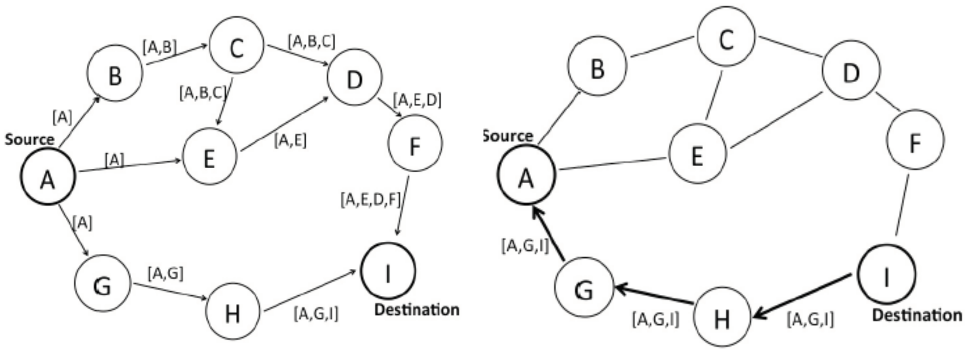
Figure 2.7: CDS protocol representation with dominant nodes in black and passive nodes in white.

2.5.3.3 Destination-Sequenced Distance Vector (DSDV)

DSDV [52] is a distance vector-based proactive unicast routing protocol. When there is a significant change in the topology of the network, there is a process of sending the routing tables to the network for updating. Each route in the network is given a specific sequence number in the DSDV routing tables. This is primarily generated from the destination node. It is based on the information of how old the current route is in the network. An even sequence number is maintained by every node by a greater value of the serial number from the old number it was assigned. The older route is deleted or updated in the location table upon reception of a new route. In case of different routes with the same sequence number, the route with the better metrics is used.

2.5.3.4 Dynamic Source Routing (DSR)

DSR is one of the reactive unicast routing protocols [44]. It works with the idea of discovering the best route for information dissemination on the basis of the cost of the routes discovered. When a node has a packet to send and it does not know the route for the destination, it sends out a route request packet as shown in Figure 2.8.a. The packet header has the information of all the nodes traversed during the process of the route request. A node that knows the route to the destination does not forward the packet further; but, it appends the route to the route information already accumulated in the packet and returns a route reply packet to the source node as shown in Figure 2.8 b. The route cache is constantly updated on the source node and by using this information packet; it is delivered to the destination. A route error packet is received by the sender node in case of the failure of the already discovered route and the route discovery procedure starts again.



(a) Route Request Packet delivery (b) Route reply packet received

Figure 2.8: Discovery procedure used by DSR routing protocol.

2.5.3.5 Ad hoc On-Demand Distance Vector (AODV)

AODV [6] is a reactive version of the DSDV protocol[53]. As compared to DSDV, in AODV, all of the nodes have the ability to maintain routing tables at the local level. Every sender may have multiple entries in the destination field. Every entry in the local table includes some specific fields; namely, the neighbour node as a relay node, the packet destined to a specific node, and the cost of the selected route for the information dissemination.

The route table maintenance mechanism in the nodes in AODV is totally different from the distance vector algorithm. In case there is no entry in the packet for the next hop router destination, a RREQ packet is sent over the network to find out a new route by the broadcasting mechanism. This RREQ packet is composed of the following fields; namely, the source address, source sequence number, destination sequence number, request id, destination address and hop count. This source address is basically the address of the first packet sending node in the route requesting.

2.5.3.6 Zone Routing Protocol (ZRP)

The first routing protocol that was considered as a hybrid nature was ZRP [54]. Its first release came in the year 1997. This protocol was equipped with both proactive and reactive routing components. There is a mechanism in ZRP that defines a zone around each node consisting of its k-neighbourhood. This zone is called the routing zone of the node. This protocol is a combination of two sub-protocols. The first one is a proactive routing protocol called the Intra-zone Routing Protocol (IARP). This sub-protocol is used inside routing zones. The second sub-protocol is a reactive routing protocol called the Inter-zone Routing Protocol (IERP). This sub-protocol is used between the routing zones. The proactively established cache by the proactive sub-protocol, IARP, is responsible for possessing route information from its local caches in case the source and the destination nodes are with the similar zone.

2.5.3.7 Optimised Link State Routing (OLSR)

One of the most popular unicast reactive routing protocols for VANET is OLSR [55]. OLSR discovers a route only in case of an existing link failure. Hello messages are periodically broadcast by every node in the network containing the information of their neighbouring nodes. Due to the hello messages being sent in the network instead of the whole routing tables, it reduces the size of the data over network decreases. The nodes create and maintain their own individual routing table. After that, all of the nodes in the network are able to calculate, with a shortest path algorithm, the route to every destination node.

2.5.3.8 Multicast AODV (MAODV)

MAODV is a multicast extension of AODV. MAODV uses the allowing mechanism for creating bidirectional shared trees that connect multiple source and destination nodes in all of the multicast groups. These multicast routes are discovered on demand [56]. First of all, the multicast route request is broadcast like the unicast route request in the whole network, but the route reply is only sent back to the nodes that are part of the authorised multicast group in that particular network. In MAODV, every multicast group is maintained by a unique leader. This leader maintains the sequence number of the group. AODV uses this number to indicate the relevance of the route information.

2.5.3.9 Geo Adaptive Mesh Environment for Routing (GAMER)

GAMER is a geocasting routing protocol and it is specifically used for many VANET infrastructures. For a geocast area, the route is always very weak due to the very fast mobility in the VANET environment and it can vanish in no time [57]. The authors of GAMER have proposed this protocol to solve this problem. Redundant paths from the source node are identified from the geocast area. In this process, a join demand packet is sent from the source node by the flooding mechanism in the forwarding zone to any node in the geocast area. At the reception of the packet, a join-table is sent to the sender node from the receiver. At the reception of this join-table at the sender, the sender is able to start sending the geocast packets.

2.5.4 Information forwarding techniques for VANET over communication link

The nature of data and network popularity conditions divide Information Dissemination techniques into two categories. Over the years, these two techniques have been implemented in the aforementioned domains.

2.5.4.1 Packet Centric Forwarding

Packet centric forwarding refers to the conventional methodical approach for packet-switched communication where the source breaks the information into data packets and addresses them to one or more network nodes. In VANETs, this group contains nodes located inside a geographic area [58]. In PCF, the responsibility of information dissemination resides with the network layer. This phenomenon refers to specific forwarding algorithms. These algorithms reside at the network layer in the stacked protocol architecture as in the OSI model. They seek to provide efficient and reliable delivery of these packets via potential multiple wireless hops. This approach makes a vehicle realize the hazardous situation by its ‘own means’ and not by a warning message. It automatically creates a data packet and generates information containing the application payload. Such a data packet commonly contains the type of emergency, location and its noticing time. In order to geographically disseminate the packet, the application also determines the packet header, area of validity and the time of validity. To keep information 'alive' inside the area of validity, nodes upon receiving a message stores it at the network layer. The authors in [56-57] have discussed these approaches in detail and they have also defined the 'alive' message as being capable of forwarding the message to nodes located outside the radio range.

2.5.4.2 Information Centric Forwarding

In contrast to PCF, the information centric forwarding approach does not rely on an end-to-end semantically implemented network layer. At every receiving node, the safety information issued as a single-hop broadcast by a source node is processed. Afterwards, it is redistributed, if required, irrespective of the fact that it has been modified or not. This redistribution mechanism implies that the responsibility of information dissemination resides on the application itself. So, whenever a vehicle detects a hazard, its 'single-hop' broadcasts a packet. That data packet carries the information about the type of hazard and the time and location that the hazard was detected.

The correspondent application receives this message (data packet) directly from the vehicle without any further action required from the network layer. Once the correspondent application receives that information, it merges and compares the newly received information with the locally-stored safety information. This amalgamated information forms the decision base for further procedures with respect to the hazard. If required, a new single-hop broadcast to the wireless channel will be issued [58].

2.5.5 Comparative study of information forwarding models for various types of applications

Both packet centric and information centric forwarding represent two extremes. Both of these approaches stay valid for the dissemination of information. It is worthy to mention that a node (or communication system) is basically comprised of two main interconnected entities: a Communication Domain and an Application Domain.

A comparative study of different models proposed in VANET is shown as a table in appendix B. This table presents the basic type of protocol, its subtype and models, and their advantages and disadvantages. On the basis of the comparative study, the type of data for which the model is best suited is also mentioned.

2.5.6 Application of VANETs

Antecedently, the literature establishes that the research community and industry are taking the aforementioned technologies into account in order to deploy VANETs. Recently, an extensive list of potential applications and services were proposed for their subsequent application over such networks. The main factors that have led to this development are:

a) The progress made in the required technologies.

b) Huge investment by the automobile companies who sees this potent technology as a way to increase both the safety and comfort of their products.

c) Gamble of governments and institutions because they understand that it can improve the daily lives of the citizens.

These points are well reflected by the large number of projects and consortia that are currently working on developing VANETs. In order to summarize it, some existing and potential applications that have been proposed for VANETs are presented. Important requirements of these applications are also mentioned.

2.5.6.1 Safety Related Applications

. These applications are designed to minimise the number of traffic accidents to make trips safer. Different consortia have designed applications to accomplish this objective, e.g., the VSC consortium identified eight potential applications [59] which are: the traffic signal violation warning, curve speed warning, emergency electronic brake light, pre-crash sensing, cooperative forward collision warning, left turn assistant, lane-change warning, and stop sign movement assistant. They are shown in Figure 2.9

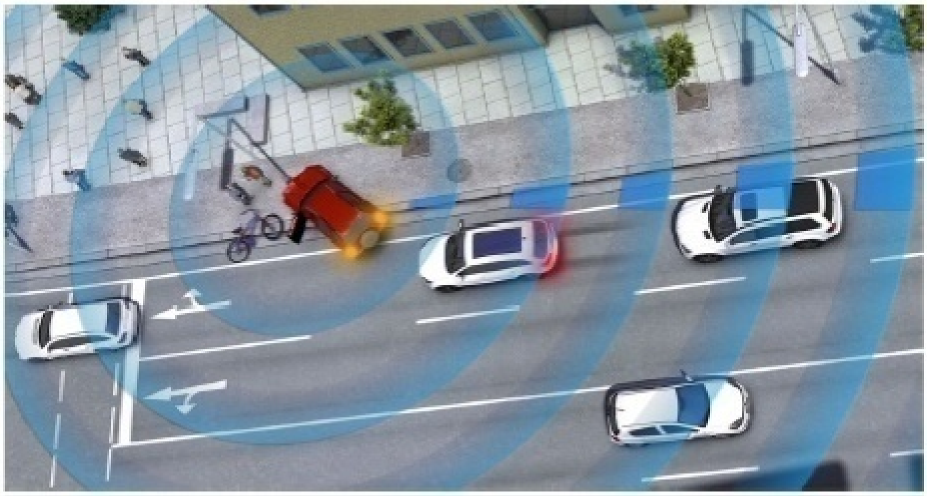


Figure 2.2.9: VANET application: Cooperative forward collision warning

To add up to the safety-related application presented before, C2C-CC the consortium proposed some more safety-related applications. They can be used in conjunction with the one that is presented as follows, e.g., the approaching motorcycle warning shown in Figure 2.10 and one presented earlier, e.g. a road works warning shown in Figure 2.3. Similarly, CARLINK presented an application of real time weather information and forecast broadcasting. This application is particularly useful for regions like Scandinavian countries where the weather can change very quickly [60]. Such live and real time weather information can be used to good effect to avoid any accidents as a result of bad weather.

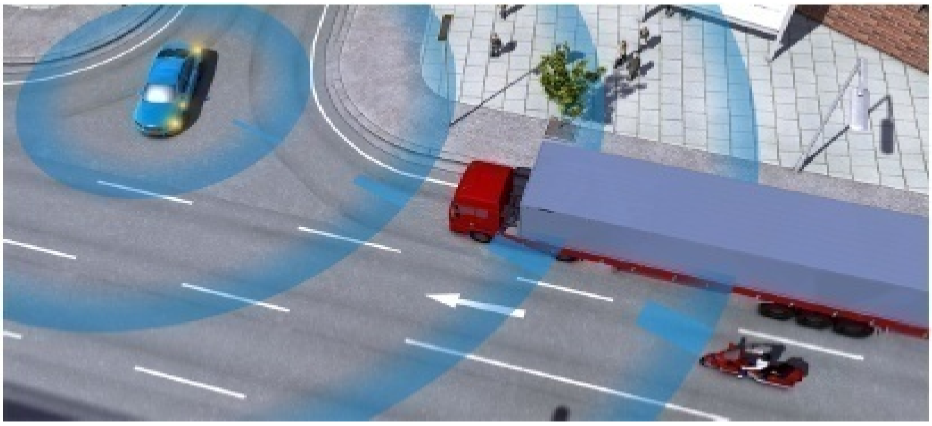


Figure 2.2.10: VANET application: Approaching motorcycle warning.

It is deemed important to mention that all of these applications mentioned above need vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. The derived technical requirements show the importance of one-hop broadcast communication. That is, a vehicle simply transmits a packet and every vehicle that is able to receive it directly is considered a one-hop neighbour. This comes in two types: event-driven or periodic [61].

2.5.6.2 Transportation Efficiency Applications

CARLINK consortium came up with an innovative user guidance approach for this second group of transportation efficiency applications. Their approach is capable of offering optimal routes which may involve different transportation models. This approach is known as optimal multimodal transport service [62].

With the help of this concept, the user is presented with the information about the optimal trip. This recommendation about optimal trip is available for all three modes i.e. walk, drive and taking public transport. C2C-CC approach analyzed efficient route guidance and navigation applications, green light, optimal speed advisory, and lane merging assistants. But as it was stated before, the applications developed to increase safety on roads, also influence the efficiency.

The requirements of these applications are readily available network technologies to communicate. These technologies also need a global positioning system as offered by the American GPS (Global Positioning System) or the European Galileo. The fact that low cost GPS receiving devices with or without a constant internet connection is also influential in reducing the cost for its common use. These phenomena results in growth of this field.

2.5.6.3 Information and Entertainment Applications

Finally, information and entertainment applications include a set of applications of a variety of flavors. A representation of this set of applications are: automatic tolling payment, point of interest notification, fuel consumption management, podcasting services and multi-hop wireless Internet access [63]. This is shown in Figure 2.11.

CARLINK has also proposed some other utility applications like file sharing services, searching free parking spaces in an area and even multiplayer games for the car passengers of different vehicles via ad-hoc wireless connections.

Figure 2.11: VANET application: Publicity board podcasting of a cinema.

Since these applications have less necessity of fault tolerance and response time, they have specialized communication requirements to those presented previously. The rational is that the information transmitted is not as critical as in traffic safety and efficiency applications. Natures of these applications are more of a utility than safety.

Thus, an important consideration for all information and entertainment applications is whether the application is ideally implemented using the same communication platform for all application groups or whether they could be better implemented using competing/separate network technologies.

2.6 Vehicular Mobility Models in VANET

For this very application domain, most of the researchers have been bound to using a simulator. The reason being is the prohibitive cost of deploying and implementing such a system in the real world. Concerning VANET simulations, a key component is the realistic vehicular mobility model. Mobility models represent real world scenarios for vehicular ad hoc networks. In the performance evaluation of routing protocols, mobility models play a vital role. The research focus is now shifting to the development of realistic mobility models for VANETs. Researchers have experimented with a variety of mobility models and empirically studied their impact on the performance of the routing protocols. To get closer to the optimum results, it has been modelled as realistically as it could be. It includes road maps with all the constraints and facilities related to the vehicular movement. There are a number of mobility models which fulfil that task. Some of them are described below.

2.6.1 Integrated Mobility Model (IMM)

The Integrated Mobility Model (IMM) describes an integration of the Manhattan mobility model, freeway mobility model, stop sign model, traffic sign model and some other characteristics like stationary nodes [64]. The advantageous factor of IMM remains to be its ability to collect results based on detailed scenarios of both rural and urban areas. After simulating with three different routing protocols, AODV, DSR and OLSR, the results were compared. It was concluded that OLSR and AODV performed better than DSR in a more stressed urban scenario. The future dimensions of this work are that they will add more realistic parameters to IMM and will enhance it for VANET simulations for more comprehensive results. The code, available at [64], has been developed by M. Alam, M. Sher and S. A. Husain at the Quad-e-Azam University Of Islamabad, Pakistan.

2.6.2 Metropolitan Taxis (META)

Shanghai Jiao Tong University, in collaboration with the State University of New York at Buffalo proposed the Metropolitan Taxis (META) mobility model. META was designed to generate a synthetic trace for the movement of taxis in an urban area[65]. To regulate the taxi’s movement, the authors designed three model parameters which were: road section speed, turn probability and travel pattern. By a variety of different validation results, they have shown that META had a good approximation to a real scenario. That, in turn, proved the effectiveness of these parameters. Hence, based on the validation, synthetic traces can be generated. They get closer to the real world scenario by using such parameters. Since these parameters are easier to be modelled than the real trace, the META model can somehow replace the high cost of a real trace to some extent. The same META mobility model was adopted for other VANET researches.

2.6.3 Mobility model generator for Vehicular networks (MOVE)

The mobility model generator for vehicular networks (MOVE) is a tool that allows users to rapidly generate realistic mobility models for VANET simulations. MOVE is used by many popular network simulators. It proves advantageous in that the output of MOVE is a realistic mobility model [66]. The authors warn that if simple mobility models are used for evaluation of VANET, the results might not be as close to reality as expected. So, they showed that the details of a mobility model such as the existence of traffic lights, driver route choice and car overtaking behaviour can have a significant impact on the simulation results.

2.6.4 Bonn motion

Bonn motion is basically Java software. This creates and analyses mobility scenarios. The name 'Bonn' is in reference to the Institute of Computer Science of the University of Bonn. It was developed by their Communication Systems group. It was developed as a tool for the investigation of mobile ad hoc network characteristics [67]. The scenarios can also be exported for the network simulators NS-2, GloMoSim/QualNet, COOJA, MiXiM, ONE and NCTUNs using a conversion script developed in the UPC (Polytechnic University of Catalonia). This good work was performed by Guillermo Diaz. Several mobility models are supported (Random Waypoint, Random Walk, Gauss-Markov, Manhattan Grid, etc.).

2.6.5 CityMob

CityMob was developed in the Polytechnic University of Valencia [68]. CityMob is a mobility pattern generator for VANETs. It was designed to be used with the NS-2 simulator. CityMob was able to generate traces for VANET scenarios using three different mobility models: Simple, Manhattan, and Downtown. CityMob has been the main mobility generator in this project.

2.7 Vehicular Traffic Models in VANET

The transportation and traffic research area classifies traffic models according to the granularity with which traffic flows are examined. Macroscopic models [69] model traffic at a large scale, treating traffic like a liquid applying the hydrodynamic flow theory to the vehicle behaviour. The simulation in a macroscopic model takes place on a section-by-section basis rather than by tracking individual vehicles. However, they do not have the ability to analyse transportation improvements in as much detail as the microscopic models [70].

Microscopic and macroscopic simulation models combine their properties to form Mesoscopic models [71]. Just like in microscopic models, the Mesosocopic models' unit of traffic flow is the individual vehicle. However, their movements follow the approach of the macroscopic model and are governed by the average speed on the travel link. In this way, movements do not consider individual dynamic vehicle speed or volume relationships.

Microscopic simulations, which model the behaviour of single vehicles and the interactions between them, are the most appropriate mobility models for simulating VANETs. A number of simulation models were developed by the transportation and traffic science model. Each one of them took a dedicated approach ranging from coarse to fine grain. Some authors have distinguished between macro-mobility and micro-mobility while dealing with vehicular mobility modelling. For macro-mobility, they refer to all of the macroscopic aspects which influence vehicular traffic, e.g., the road topology, constrained car movements and per-road speed limits. Micro-mobility refers instead to the driver's individual behaviour when interacting with other drivers or with the road infrastructure; for instance, travelling speed under different traffic conditions, acceleration, deceleration and overtaking criteria. For a trustworthy VANET simulation, it is necessary that both macro-mobility and micro-mobility descriptions are jointly considered when modelling vehicular movements. There are some models proposed in the general MANET context usable in VANET. The criteria of applicability considered are the employment of road maps and limiting the nodes movements to the roads instead of moving in a wide area. The considered parameters differ from one model to another. For instance, some models use traffic control mechanisms at intersections, and some others just assume continuous movement at these points. Some assume roads to be a single-lane, but some others support multi-lane roads. Some define the security distance, while others just ignore this parameter. The following section describes the main features of the vehicular traffic models.

2.7.1 Freeway Model

Freeway is a generated map-based model, defined in the simulation area, represented by a generated map which includes many freeways. Each side of which is composed of many lanes. There are no urban roads laid down, thus no intersections are considered in this model. At the beginning of the simulation, the nodes are randomly placed on the lanes, and they move using history-based speeds, where the speed of each vehicle smoothly changes following a random acceleration [72].

In addition to the realism related to the acceleration and the history-based speed, the model defines a security distance that should be maintained between two subsequent vehicles in a lane. If the distance between two vehicles is less than this required distance, the second one decelerates to enable the forward vehicle to move away. The change of lanes is not allowed in this model. The vehicle moves on the lane it is placed in until reaching the simulation area limit, and then it is placed again randomly in another position and repeats the process.

2.7.2 Manhattan model

The Manhattan model is also a generated map-based model introduced to simulate an urban environment [73]. Before starting a simulation, a map with vertical and horizontal roads is generated. Each road includes two lanes, allowing the movement in the two directions (north/south for the vertical roads and east/west for the horizontal ones) at the beginning of a simulation; vehicles are randomly put on the roads. Afterwards, they move continuously according to history-based speeds (exactly like Freeway).

When reaching a crossroads, the vehicle randomly chooses a direction to follow. That is, continuing straight forward, turning left or turning right. The probability of each decision is set by the authors, respectively to 0.5, 0.25 and 0.25. The security distance is also used in this model and nodes follow the same strategy as in the freeway model to maintain this distance. But contrary to the previous model, a vehicle can change a lane at a crossroads. Nonetheless, there is no control mechanism at these points (crossroads), where nodes continue their movements without stopping.

2.7.3 City Section Mobility (CSM)

CSM can be viewed as a hybrid model between the Random Waypoint Model (RWP), in which mobile nodes move randomly and freely without restrictions, and Manhattan as it introduces the principle of RWP, especially the pause-time and random selection destination, within a generated map-based urban area. At each step of the vehicle's movement, a random point is selected from the generated road map, towards which it moves following the shortest path [74].

After reaching that destination, it remains there for a pause-time, and then repeats the process. The speed of the nodes is constrained by the security distance, along with the maximum speed limit of the road.

2.7.4 Stop Sign Model (SSM)

Contrary to the previous models, SSM integrates a traffic control mechanism. In every crossroad, a stop signal is set, which obliges vehicles to slow down and make a pause there [64]. This model is based on the real maps of the TIGER/Lines database [75] but all of the roads are assigned a single lane in each direction. A vehicle should never overtake its successor (like in all of the models presented before) and should tune its speed to keep the security distance. If many vehicles arrive at an intersection at the same time, they make a queue, and each one waits for its successor to traverse the crossroads. This results in the gathering of nodes and hugely affects the network connectivity as well as the mobility (average speeds). According to the authors, the problem with this model is the unrealistic disposition of the spot signals since it is impossible to find a region with spot signals at each intersection. Therefore, they improved SSM and they proposed TSM.

2.7.5 Traffic Sign Model (TSM)

In the TSM model, stop signals are replaced by traffic lights. A vehicle stops at crossroads if it encounters a red stoplight; otherwise, it continues its movement [76]. When the first vehicle reaches the intersection, the light is randomly turned red with a probability, p, (thus, it is turned green with a probability of 1-p). If it turns red, then it remains so for a random delay (pause-time) forcing the vehicle to stop, as well as the ones behind it. After the delay, it turns green, and then the nodes traverse the crossroads one after the other until the queue is empty. When the next vehicle arrives at the crossroads the process is repeated.

2.7.6 Street Random Waypoint

STRAW is also a model using the real maps of TIGER/Line [75]. Like the other models, except freeway, roads include one lane in each direction and it is divided into segments. The model is basically composed of three modules: intra-segment mobility manager, inter-segment mobility manager, and finally, the route management and execution module [77]. At the beginning of the simulation, the nodes are placed randomly one behind the other; they move using the car following and try to accelerate until reaching the maximum speed of the segment. The first module manages this movement until reaching an intersection. The security distance is maintained but overtaking is not allowed.

At crossroads, the vehicles always slow down, even when they change a segment and turn without a full stop, which is realistic. The second module defines the traffic control mechanism including both stop signals and traffic lights, which are put on crossroads according to the class of the intersected roads. In addition to this usual control form, the module makes sure that the next segment to take contains enough available space before moving the vehicle towards it.

If it is fully busy, the vehicle waits at the crossroads (at the end of the first segment). The last module selects the routes to be taken by each vehicle during the simulation. In the first one, the direction is randomly selected at each intersection. For example, when reaching an intersection, the vehicle randomly decides whether to continue straight forward or to turn and change the road.

On the other hand, in the second approach, a destination is selected towards which the vehicle moves using the shortest path.

2.8 Research Challenges in VANETs

Advances in wireless ad hoc communication technologies have made possible the emergence of VANET. However, the involved research community and industry still have to address several problems to offer a complete VANET development ready to be deployed. This section covers current research challenges, grouping them in different topics.

2.8.1 Wireless access technology

Nowadays, there are several wireless access technologies that could be used to deploy VANETs. In general, the research community is working on the specification of a set of air interface protocols and the parameters for high-speed node (vehicles) communication using available media. Most efforts are focusing on two different technologies: IEEE 802.11 based and cellular technologies.

2.8.2 Spectrum issues

The use of IEEE 802.11 based technologies for VANET communications needs to allocate these communications at the free spectrum. In the US, the FCC has already allocated 75 MHz of spectrum at 5.9 GHz (from 5.850 to 5.950 GHz) for V2V and V2I communications [78]. However, in Europe, there is not a continuous free spectrum band of 75 MHz in DSRC. Hence, the Car-2-Car consortium has proposed a derivative of the US approach, allocating 2 × 10 MHz for the primary use of safety critical applications at 5.9 GHz [79] .

2.8.3 Routing strategies

The performance of MANET routing protocols have improved quite a lot during the last years with the appearance of several specialised approaches. Unfortunately, in the case of vehicular networks, certain characteristics make most of these protocols unsuitable. The research community is currently working on three different approaches. The first approach is opportunistic forwarding [80] in which the data is stored until there is an opportunity to forward it. The second approach is trajectory forwarding [81] in which the roadside infrastructure serves as an overlay directed graph. The last approach is geographical forwarding [82] in which the packets are forwarding towards the destination based on the node's geographical location. These three approaches may be used for developing solutions for:

a) *Message dissemination*

VANET applications require broadcast information continuously, thus finding an optimal broadcasting technique is critical in this kind of network. Nowadays, several broadcasting approaches are taken into account, e.g., location-aware broadcasting [83], which limits the broadcast range only to the area of interest reducing overhead (avoiding the broadcast storm problem), or clustering where neighbour nodes form clusters limiting the broadcasting range [84].

b) *Security and privacy*

The potential of the proposed applications for such networks and the information they may manage could cause some malicious entity to make use of them. Different kinds of threats could exist like fake message broadcasting, which could cause disruption of traffic or even danger. Thus, security is an issue that needs to be carefully addressed in the design of VANETs. Privacy and anonymity must be preserved avoiding identification or vehicle tracking for non-trusted parties [85-86].

c) *VANET simulation*

Testing the impact of VANET applications before their deployment is an important issue. Nowadays, simulation seems to be the most feasible solution for this purpose. However, it requires the modelling of driver behaviour in different contexts, such as an accident, apart from wireless ad hoc communication as close as possible to the real world [87]. This is not trivial and is still an open problem.

Additionally, one has to take into account some socio-economic challenges since the market introduction of VANET technologies suffers the network effect. That is, the added value for one customer depends on the number of customers in total who have equipped their vehicle with VANET technology. Therefore, the main question is how to convince early-adopters to buy VANET equipment. There are several options that are being discussed like the enforcement by law or the attractive deployment applications. This problem is also still open. As it can be seen from the presented list of challenges, the study of vehicular ad hoc networks is an open problem that involves different areas of knowledge. It involves communication technologies, metaheuristics for optimisation problems [88], cryptography and intrusion detection for security [89], sociological studies and mathematical modelling of driver behaviour [90], and so on.

2.9 Summary

To abound the reader with the essential level of knowledge, this chapter has described the basics of vehicular ad hoc networks. It further presented the main characteristics and also summarised the popular wireless access technologies and routing protocols used in VANETs. It listed a representative set of proposed applications to exploit both main research groups and consortia that work and have worked designing this kind of network. This chapter also presented an overview of mobility and traffic models. Finally, an outline of the challenges and future works that arise in the networks were presented in this chapter.

CHAPTER 3

RESEARCH METHODOLOGICAL FRAMEWORK

This chapter introduces the research methodological framework for the proposed "An adaptive information dissemination model for VANET communication". It discusses different phases of methodological framework for the proposed model. The chapter further explains the conceptual framework for the proposed model. Further, the simulation setup is discussed in detail. Finally, the performance parameters to be used for benchmarking purpose are presented in this chapter.

3.1 A prelude of information dissemination models for VANET communication

The emergence of VANET is the result of advances in wireless ad-hoc communication technologies [91]. However the involved research community and the industry still have to address several problems to offer a VANET ready to be deployed. There are four active research areas in VANET. They can be classified as mac and physical layer, mobility model and simulator, security and privacy and information dissemination [92]. Out of these researches, information dissemination is concerning establish the link between a source to a destination to exchange information.

The information exchange between vehicles on the road is categorized into three different types, namely safety-of-life, safety and non-safety [93]. The nature of various type of information for dissemination is quite different from each other. The dissemination of safety and non-safety information need originator and recipient(s) of unicast and multicast messages digital addresses. These addresses can be calculated from the information repository data. In this way the application layer of OSI model supported by Information Centric Forwarding (ICF) in the protocol stack can handle dissemination independently. Safety-of-life applications are different. The information needs to preserve the contents and they are time critical. The safety or non-safety data may change with the passage of time. The protocol stack must first identify an initial target and then disseminate the information as soon as possible. The communication stack of OSI model used the carry and forward approach called as Packet Centric Forwarding (PCF) [94]. Basic sketch of the VANET applications is shown in Figure 3.1. Figure 3.1 explains the overview of various VANET applications and research possibilities.

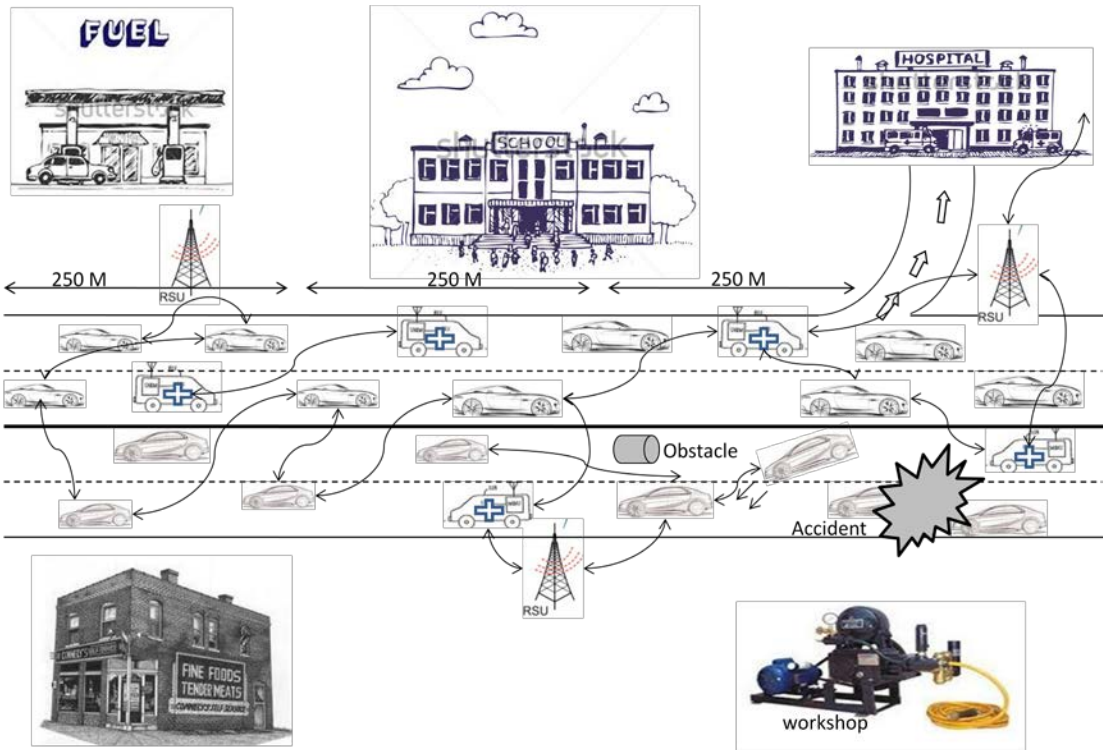


Figure 3.1: VANET applications

Depending upon the nature of the information dissemination, the information dissemination system can identify two distinct domains: Application domain for ICF and Communication domain for PCF [4]. These domains can disseminate variety of information separately for safety-of-life, safety and non-safety applications. The detailed study of various models for distinct application types can be found in appendix B. The study shows that most of the information dissemination models tend to use a single domain to meet the needs of particular dissemination demands.

Furthermore, for most of the information dissemination models discussed in Section 2.5.3, if they are handling the ICF and PCF at the same time, they lack the capability to fully use the system resources. The adaptability factor is also missing in most of these models. They tend to use the system domains separately. In many circumstances one of the system domain resources remains unused or underused. Consider a situation when the information dissemination model has to disseminate safety-of-life information, and safety/non-safety information is rare to disseminate. In this situation the Application domain resources (e.g. bandwidth) may remain underutilized. Similarly the Communication domain resources may remain underutilized when the dissemination system may need to forward information related to safety and non-safety applications. So, there is a need to re-think the ways a model can adapt itself according to the demands of information dissemination in VANET communication.

3.2 Research Methodological Framework for Proposed Model

In VANET, the demands for information involved (safety-of-life, safety and non-safety) change regularly in dissemination process [95]. The existing traffic data paradigms for the existing ad hoc networks are well-established and perhaps deep-rooted. But, there is a need to re-think these paradigms exclusively in order to best meet the challenges of VANET environment [58]. As discussed in the prelude section, an adaptive information dissemination model combining PCF and ICF is proposed. It enables the receiver vehicles to include both remote and local knowledge before forwarding the safety and non-safety information. At the same time, geo-addressing capabilities are offered from the network layer, e.g., for dissemination of safety-of-life data and the compatibility of smart and dumb nodes are ensured. The proposed model is capable of adaptive functionality. It means that the resources of one domain may be utilised in the other domain when needed. The dissemination model thus introduced is called “An adaptive information dissemination model for VANET communication”. Before elaborating the detailed architecture of the proposed model, the methodological framework for the proposed model has been shown in Figure 3.2.

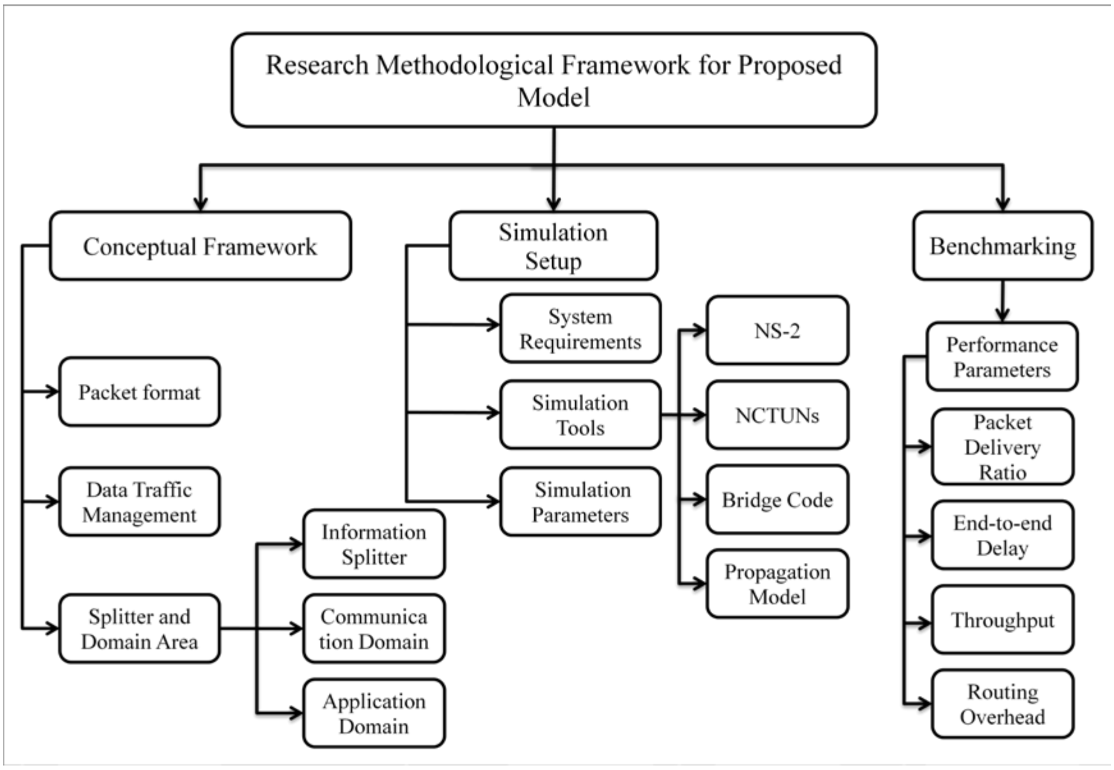


Figure 3.2: Research Methodological Framework for "An Adaptive information dissemination model for VANET communication"

The proposed methodological framework consists of three basic modules, namely conceptual framework, simulation setup and benchmarking. The detailed description for the modules of research methodological framework for the proposed model is given in the following sections.

3.2.1 Conceptual Framework

The conceptual framework consists of three sub modules i.e. information packet format, data traffic management and splitter and domain area. These modules are explained as follows

3.2.1.1 Information Packet Format

One of the tasks for conceptual framework is to develop an information packet architecture that describes the type of the information that is expected to be used by the proposed adaptive model. It could also describe it data collection and distribution mechanisms. This information packet format is influenced from the packet formation given in [96]. Each packet contains 9 fields comprises of 512 bytes as shown in the Figure 3.3.

Carrier Node(4B)	Immediate Receiver Node(4B)	Destination (4B)	Time stamp (3B)	Flow ID(4B)	Priority bit (1B)	Feedback Flag(1B)	Information Type(1B)	Data (490 B)

Figure 3.3: Packet format for the proposed model

The detailed description of the packet fields shown in the figure 3.3 is given in the Table 3.1.

Table 3.1: Detailed description of the proposed packet fields

Field	**Description**
Carrier Node	This field has a size of 4 bytes and it contains the information (position, speed etc) of the current information carrying vehicle.
Immediate Receiver Node	This is 4 byte field. It consists of the information (position, speed etc) of the potential receiving candidate. It may be the intermediate vehicle in the whole dissemination process.
Destination	This is a 4 byte field. Destination field in the packet format will remain unchanged during the process of data dissemination. Information carrying vehicle and immediate next hop fields will be updated though the update mechanism provided in the proposed model.
Time stamp	Every vehicle that processes the data to be sent will continuously update the Time stamp field. This field will be utilized for comparing the timeout limits. It is only possible when all the vehicles in the process use a common system clock reference. This synchronisation process is handled by the simulator itself. That’s why this factor has been assumed in the simulation

	process. The size of the field is set to 3 bytes
Flow ID	To uniquely recognize a flow of the packets, Flow ID field is used. The size of this field is 4 bytes. When the packets are sent to the immediate receiver, the whole information is divided into packets of information. These packets are given some unique identity. This identity is used to unite the packets into original information at the receiving vehicle. This field “flow of packet” is used to keep the identity of each packet sent.
Priority bit	Priority bit is used to set the priority for safety and non-safety information dissemination process. Its size is 1 byte. But the right most (last one) bit of this byte is used for priority purpose. It is 0 for safety information and 1 for non safety information.
Feedback flag	Feedback mechanism in the proposed model uses this data when feedback flag is set to 1. It represents the acknowledgement from the receiver (immediate receiver or destination receiver). The size is 1 byte. But actually only 1 bit is used for the process
Information type	This field has its significance in the proposed model. As this field is utilized to separate information that is processed in distinct domains presented in the proposed model. The size of the packet field is 1 byte but only 2 bits (last 2 bits) are actually used in the process.
Data	The data field contains the actual data to be forwarded from sender to the destination vehicles. 490 bytes size is used for this packet field.

3.2.1.2 Computational data traffic management

Computational data traffic management is a process of distributing data load on various distinct computational domains of the proposed information dissemination model according to situational demands [97]. For example, there might be a situation on the road where there is no/less safety related data is to be disseminated and there is a high demand for dissemination of safety-of-life related data. Computational data traffic management should be part and parcel of the information dissemination model. The adaptability feature of the propped model depends on the computational load management feature. Depending on the network density on the highway (dense or sparse), the system has the capability to shift the data load from one domain (heavily data loaded) to the other (less data loaded) domain. Furthermore, the information for dissemination is divided into various categories (mentioned in the coming sections). These information types have their specific demands with respect to reliability and time. Consequently, these information types must be given their due priority in the dissemination model when the specified domain's resources seem reaching the limit of the model's efficiency.

In the literature, there are two distinct approaches for information dissemination in VANET: packet Centric Forwarding (PCF) and Information Centric Forwarding (ICF) [4]. These approaches argue the possible ways for node connectivity and data dissemination. Both approaches have clear edge on each other when there are possibilities of diverse type of information (reliability vs. delay). This information is divided into three main categories.

a) Safety information type

Safety information like hazard detection should be sent periodically. This type of data should be kept alive. From time to time, these type of data needs to be altered (addition, modification, aggregation etc) because the safety situation may change over the two intervals of time during dissemination process. In the dense scenarios, there should be special mechanisms to avoid congestion control created due to periodic beaconing.

b) Safety-of- life information type

This type of information has real time demands and they are needed to be sent to the receiving end without delay. The hurdle in real time disseminating for this type of information is the existence of two distinct network situations i.e. sparse and dense networks. For sparse networks, longer delays in data dissemination or even the loss of data are the major issues due to link disconnection between the sender and receiver vehicles. While network congestion in dense network scenarios may cause the real time applications working ineffectively.

c) Non-safety information type

Like the safety related data, non-safety information data may tolerate the delays. This data type should not affect the real time data dissemination. This type of data should be handled by specific domain (Application domain) of the dissemination model.

3.2.1.3 Information Splitter and Domain Area

In the following section a conceptual design for "An adaptive information dissemination model for VANET communication" is presented. The proposed adaptive model tries to fulfil all the basic requirements presented in Section 3.2. Both, packet-centric and information-centric forwarding approaches represent two extreme but are valid approaches for dissemination of information. A communication node (or communication system) in VANET is basically comprised of two distinct domains: a communication domain (radio modem, medium access, and routing and transport protocols) and an application domain [4]. The proposed model is based on interconnection features that both domains are shareable. Furthermore, there will be an Information Splitter module responsible for separating the various types of information (shown in Section 3.2.1.2). This module is important in the sense that the information categorized in this module is to be used by the distinct domains of the adaptive dissemination model. Figure 3.3 shows the information splitter and domain areas. The flow of information between these modules is also shown. This is the basic view of the proposed model for VANET communication.

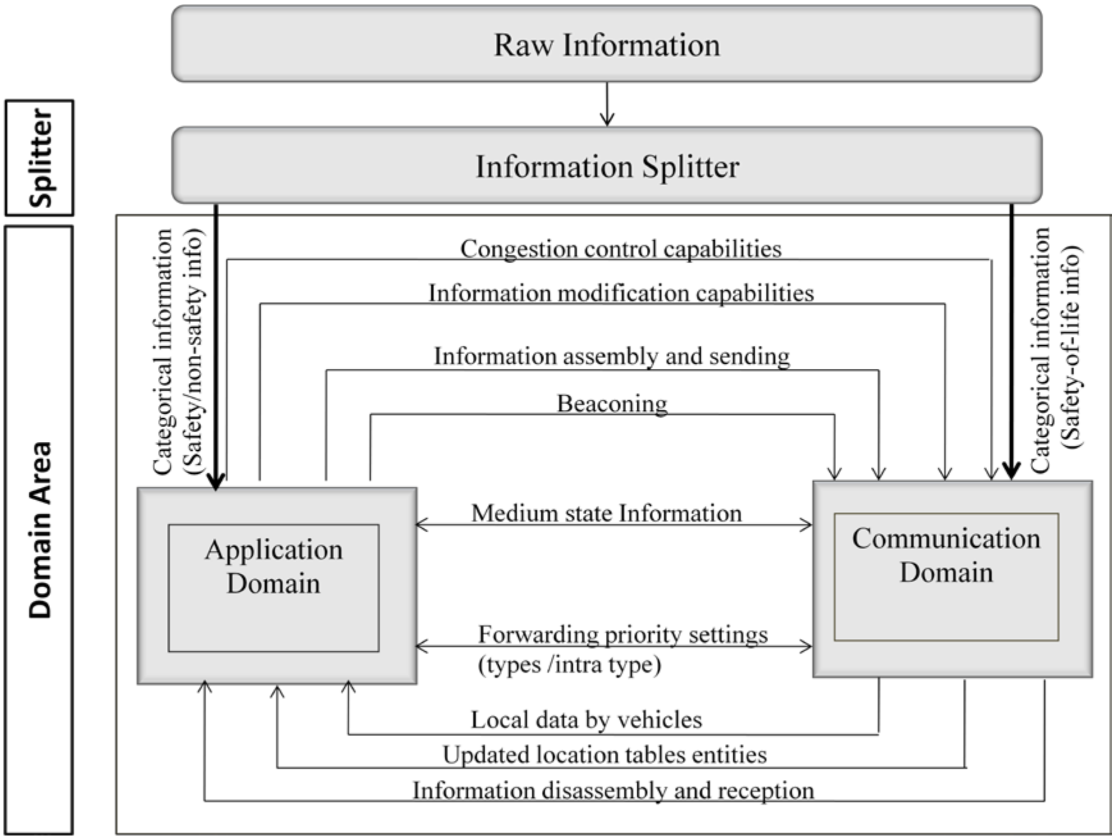


Figure 3.4: Conceptual view of "An adaptive information dissemination model for VANET communication"

The information splitter categorise the information into safety-of-life, safety and non-safety categories. The safety-of-life information is sent to the communication domain. Similarly, the safety and non-safety information is sent to application domain for dissemination. The application domain has the capabilities of information modification (contents of safety or non safety information may change during the process of dissemination, because these types of information are based on the user perception), congestion control, information assembly and sending, and beaconing. The application domain provides these functionalities to the communication domain where and when they are needed. The communication domain may provide the local data to the vehicles in the dissemination process, updated location table entities and information disassembly and reception features to the application domain when and where needed in the dissemination process. Both the domains share the medium state information and priority settings within each other.

3.2.1.3.1 Key Characteristics of Domain Area in proposed model

Based on the two different strategies for information dissemination in VANET, i.e., Packet Centric Forwarding (PCF, network layer) and Information Centric Forwarding (ICF, application layer), an adaptive information dissemination model for VANET communication has been developed with the following key characteristics.

1. Forwarding of safety information is executed by application layer in the OSI model (not managed by network layer).
2. Capabilities of aggregating, modifying, and invalidating safety information during the dissemination process.
3. Packet forwarding supported at the network layer for specific types of information, e.g., of safety-of-life.
4. Capability to adapt to domain states.
5. Support heterogeneous network architecture with smart and dumb nodes.

3.2.2 Simulation setup

The simulation environment is discussed in this section. Firstly, the core simulation environment with respect to the simulators used is discussed. Then the "bridge code" that provides translation of NS-2 readable file to NCTUNs readable file is presented. After which procedure of extracting the data from simulation results is discussed. Finally the performance parameters are discussed in the later part of this section. These performance parameters are used to compare the performance of the proposed model with the performance of GSR, ZGPSR and PDGR models.

3.2.2.1 System Requirements

The software and hardware requirements for installation and usage of NCTUNs 5 simulation tool are given in table 4.1

Table 3.2: Software and hardware requirement for simulation setup

Operating System	**Software**	**Hardware**
Fedora 10	Compiler gcc++, c programming language editor, NS-2.34. NCTUNs5, OTcl support.	1.6 GHz process 256 Mb RAM 20 GB Disk Space

For simulation purpose the computer system used was equipped with the following specifications

- CPU: Intel(R) Core(TM) i5-2410M CPU @_2.3 GHz
- System Memory: 4GBytes
- Cache Memory: 512 kBytes/3Mbytes
- OS version: Microsoft windows 7 Home premium with service pack1.

When the simulator starts on the virtual machine “VMware” the memory utilization is set as 2 GB. All the delays due to VMware are accepted during the simulation process.

3.2.2.2 Simulation Tools

Various network scenarios were simulated using proposed model in three distinct phases and using two important simulation tools i.e. NS-2.31 and NCTUNs 5. Some specific routines were written in C language in NS-2 editor. These routines were translated to NCTUNs readable file by a translation program called “Bridge Code”. NCTUNs is then used to simulate the specific network scenario. A block diagram in Figure 4.1 describes this procedure

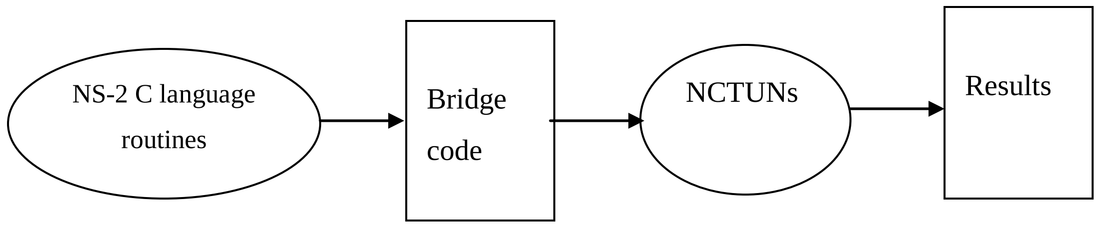


Figure 3.5: Simulation Process

3.2.2.2.1 NS-2

NS2 (Network Simulator 2nd edition) is widely known as variant of real network simulator (1989) in the research community. NS2 is a discrete event simulator for wired as well as wireless networks. The simulation scenarios are defined in OTcl programming language. Network protocol models and the simulator core are written in C++. The rest of modules are written in OTcl. NS2 capabilities can be increased by defining the desired modules in its editor by the programmers themselves. NS2 is yet under development phase[98].

NS2 is for developing and modeling protocols for wired, wireless and satellite networks. More briefly these protocols can be named as TCP, UDP, SCTP, unicast and multicast related with Web, telnet, CBR and many more[98].

NS2 functionalities can be grouped into various fields as listed below.

1. Transportation and Routing like TCP, UDP etc
2. Traffic sources like ftp, web and telnet.
3. Queuing disciplines
4. QoS like intServ and Diffserv.
5. Emulation for wired systems.
6. Ad hoc routing and mobile IP.
7. Traffic traces and their analysis.

One of the key help and support for the research community is that source code is available for everyone. Users can change and modify the source code as well as write up their own routines for specific models to be implemented in NS2. But there are some weaknesses in NS2 which need to be discussed and highlighted. These weaknesses are the reasons for using other simulator in parallel with NS2.

1. Creating nodes and the simulation scenarios in the absence of GUI is a drawback for user friendliness.

2. Protocols and features related to VANET are not documented and there is not a well known commercial and technical support for these features.

3. Most of the time patching process for external modules is technically difficult.

4. Optical layer simulation at this point of time is very poor.

5. There is no clean and clear separation between the NS2 supporting languages i.e. C++ and OTcl.

3.2.2.2.2 NCTUNs

NCTUNs (National Chiao Tung University Network Simulation) [99] is a simulator as well as an emulator for various networks. This software is open source which runs on Linux or Fedora 10. The special advantage is that it has integrated Graphical User Interface (GUI). The important edge of NCTUNs over the other simulation environments is its ability of using real life TCP/IP protocol for executing more realistic and high fidelity results through simulation. Another advantage of NCTUNs is its ability for controlling the vehicles mobility patterns and designing the maps with integrated simulation capabilities using external movement simulators. Figure 4.2 describes the architecture for NCTUNs.

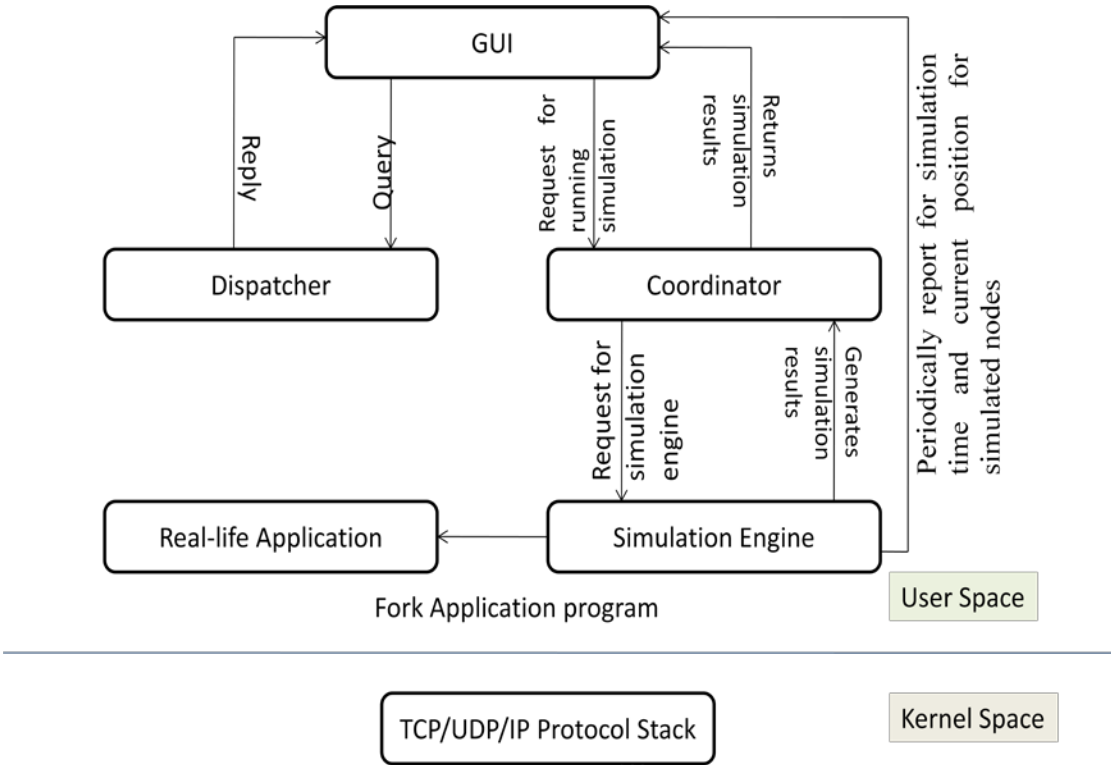


Figure 3.6: NCTUNs Architecture

3.2.2.2.3 Bridge Code

Bridge code is a program that translates the NS_2 readable file to NCTUNs5 readable file. The source code is a modified program influenced from the translation program given in [100]. The code of the program is written in C language over Linux. Read, translate and write are three major parts in this program. Same directory is used for the translator program and the NS-2 readable file is called as "source.txt". The output of translation program is a NCTUNs file "dest.mdt" is obtained.

The three main parts are defined as global function so that every other function can call them. In first phase the main function generates two main structures which are NS2 structure and NCTUNs structure. NCTUNs structure and NS2 structure have the properties like translation size, location and node attribute. It then opens the NS-2 file "soure.txt" and "dest.mdt" file and writes the NCTUNs information in that.

The read function is then called. It composed of two parameters. File descriptor “source.txt” is opened pointed towards NS-2 structure. The information in NS-2 readable file is stored in the NS-2 structure. Some translation related parameters are set which are not available in NS-2 file. These parameters are related to the number of nodes, fixing the simulation area dimensions according to the simulation area defined in NCTUNs and translation function is called. NS2 and NCTUNs structures, pointers, simulation area and the number of nodes are needed for the Bridge Code (BC). The information present in the NS-2 structure is called by reference to NCTUNs structure. And lastly the file descriptor related to output file “dest.mdt” is used to write the output file which is directly readable by NCTUNs. Finally the BC program closes the output descriptor and the program finalizes the output. The complete algorithm for the bridge code program can be obtained from the appendix A.

3.2.2.2.4 Propagation Model

In a simulator, the propagation environment is utilized to find the result of dissemination of electro-magnetic waves in air. The medium used for VANET environment is usually air. This propagation environment gives an idea about success and failure of message reception for a certain sender vehicle. Propagation models are classified into two distinct categories namely, large scale and fading models. For this simulation environment, the proposed model used deterministic propagation model called “Free space model”. The reason for using this type of propagation model is that a deterministic model allows computing of the received signal strength, based on actual distance between a sender and potential receiver. The other reason for using deterministic propagation model is its ability to be very complex for multipath information dissemination. Free space model sometimes uses a single unobstructed communication path. The received signal power is dependent on the transmitted power the antenna poses, and the distance between the sender and the receiver in the communication system. The idea is that, as a radio wave travels away from an (Omni-directional) antenna, the power decreases with the square of the distance.

3.2.2.3 Simulation parameters

Table 3.3 lists the parameters used in the simulation process. The expected values for the simulation parameters are also mentioned in the Table.

Table 3.3: list of simulation parameters and their expected values

Parameter	**Value**
Simulation Area	3000m x 3000m
No of vehicles	50 to 240 vehicles (low dense scenario)
	250-450 vehicles (high dense scenario)
No of packet senders (packet forwarders)	30-60 (used for congestion control mechanism)
Types of information	Safety-of-life, safety and non-safety
Communication range (R)	250 m
Distance (x)	Distance between communicating vehicles ≤ R
Simulation Time	200 sec
Transmission power	90.4 dB to 94.4 dB
Vehicle Velocity	4 -7 m/ sec
CBR (packets / sec)	0.1, 0.2, 0.5, 0.8,1, 2, 3, 4
Packet size	512 bytes
Vehicle beacon Interval	0.5 sec
Weighting Factors(α, β and γ)	0.9 - 0.1(for α), 0.05 - 0.4(for β), 0.05 – 0.4 (for γ)
Max allowed re-tries	3 to 5

3.2.3 Benchmarking

The performance of the proposed model against GSR, ZGPSR, and PDGR is evaluated by using the following performance parameters.

3.2.3.1 Packet Delivery Ratio (PDR)

Packet delivery is evaluated by resting the amount of packet dropped by the Access Point from the total amount of packet sent by the source node.

$$Packet\ Delivery = \sum packet\ transmitted - \sum packet\ lost\ in\ transmission \quad (3.1)$$

$$Packet\ delivery\ ratio = \frac{packet\ delivery \times 100}{packet\ transmitted} \tag{3.2}$$

3.2.3.2 End-to-end Delay

End to end delay is calculated by subtracting the time the packet was received at the destination from the time it was sent from the source vehicle.

$$End\ to\ end\ delay = time\ stamp\ at\ destination - time\ stamp\ at\ source \tag{3.3}$$

3.2.3.3 Throughput

It is calculated by dividing the total amount of data received by the time of simulation.

$$throughput = \frac{received\ packet \times packet\ size}{simulation\ time} \tag{3.4}$$

3.2.3.4 Routing Overhead

It is defined as the excessive number of intermediate hops used for dissemination of information from source vehicle to the destination vehicle.

3.3 Summary

This chapter proposed research methodological framework for the proposed adaptive information dissemination model for VANET communication. The methodological framework had three main categories i.e. conceptual framework, simulation setup and benchmarking. In the conceptual framework information packet format, data traffic management and splitter and domain area were discussed in detail. It further presented the simulation setup elements i.e. system requirements for the proposed model, simulation tools and simulation parameters in detail. Finally, the performance parameters to be used for benchmarking purpose were presented in this chapter.

CHAPTER 4

RESEARCH DESIGN AND PROCEDURES

This chapter describes the research design and procedures incorporated into the work of “An adaptive information dissemination model for VANET communication”. This chapter explains the high level architecture of the model proposed. The chapter further explains the common procedures used in application domain and communication domain of the proposed model. Finally, the extended view of Communication Domain and Application Domain is presented.

4.1 High Level Architecture of “An adaptive information dissemination model for VANET communication”

High level architecture has 3 main modules. They are information splitter, application domain and communication domain. The idea is to assign the information dissemination responsibilities to different domains of the proposed model. The division of domain area into two distinct domains is helpful to disseminate distinct information types in robust manner. However the main focus of this research is on domain area (application domain and communication domain). The information splitter provides the categorized information (safety-of-life, safety and non-safety) to the modules in the domain areas. The high level architecture of the proposed model is provided as follows.

4.1.1 Information Splitter

The information in most of the VANET dissemination systems is considered categorical (safety-of-life, safety, and non-safety). These types information are disseminated at different domains in the dissemination models for VAENT communication [101-103]. In most of these models, when the information from the sending vehicle is received, the domains judge the nature of information within themselves. There are two major drawbacks in this type of information dissemination. Firstly, the domains of the model have to exchange the data within themselves in order to disseminate it. This may cause huge amount of context switching between the domains. It may cause delays in the communication system which is undesirable in most of cases. Secondly, the undue information sharing may cause wastage of system bandwidth resources.

To avoid the shortcomings in the previous models, this Information Splitter module is introduced in the proposed adaptive information dissemination model. Information splitter has the capability to divide and distribute the categorized information from the source vehicle to appropriate domains of the proposed model. As discussed in section 3.2.1.1, the data packet has two bit field “data type” in its format. The two bit data is decoded to identify the type of information. The splitter gets the type of information i.e. safety, non-safety or safety of life information from the decoded data. It filters out the information and sends it to appropriate domain for further processing. It also sets the priority of the information packet. The basic view of information splitter is shown in the Figure 4.1.

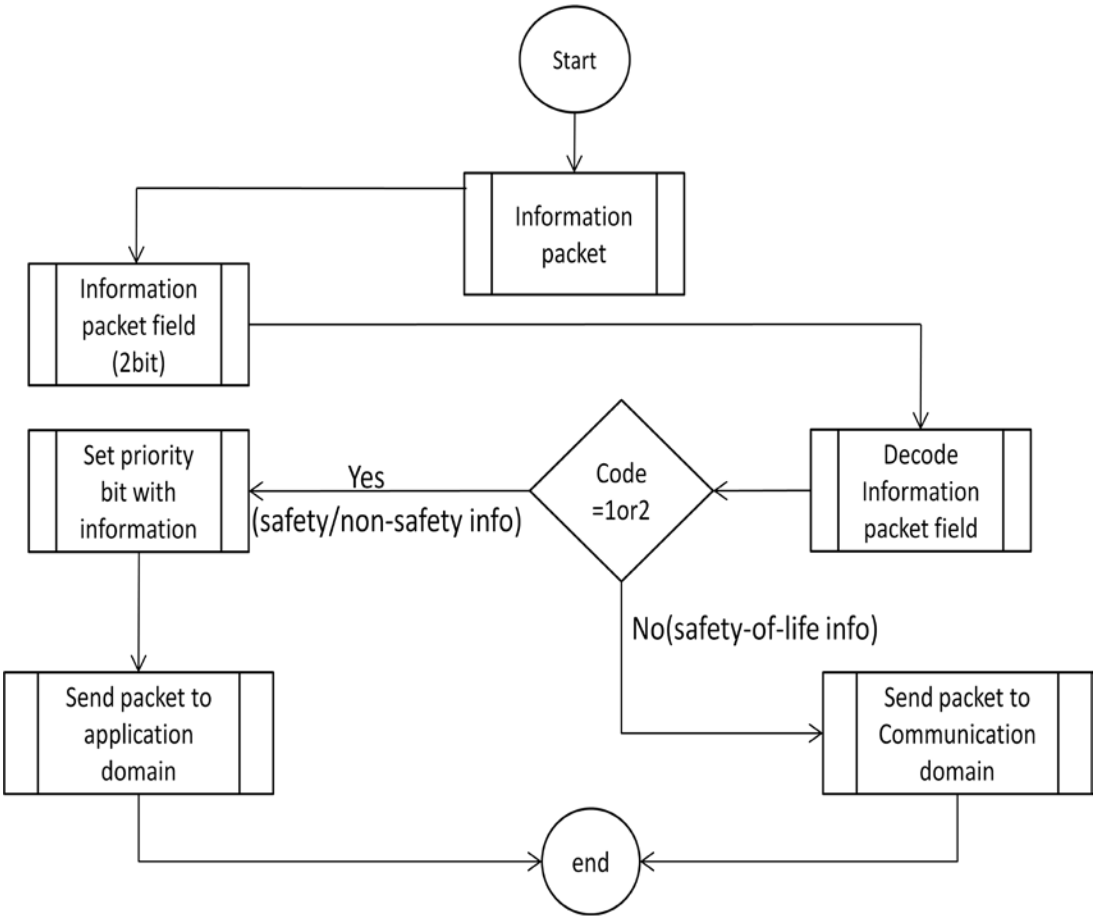


Figure 4.1: Basic view of information splitter

4.1.2 Application Domain

The application domain is regarded as a component that comprises all safety and non-safety information. This domain gathers all safety information available to inform the driver of unsafe situations and assist other nodes forwarding relevant safety data. High level conceptual framework for application domain of proposed model is shown in Figure 4.2

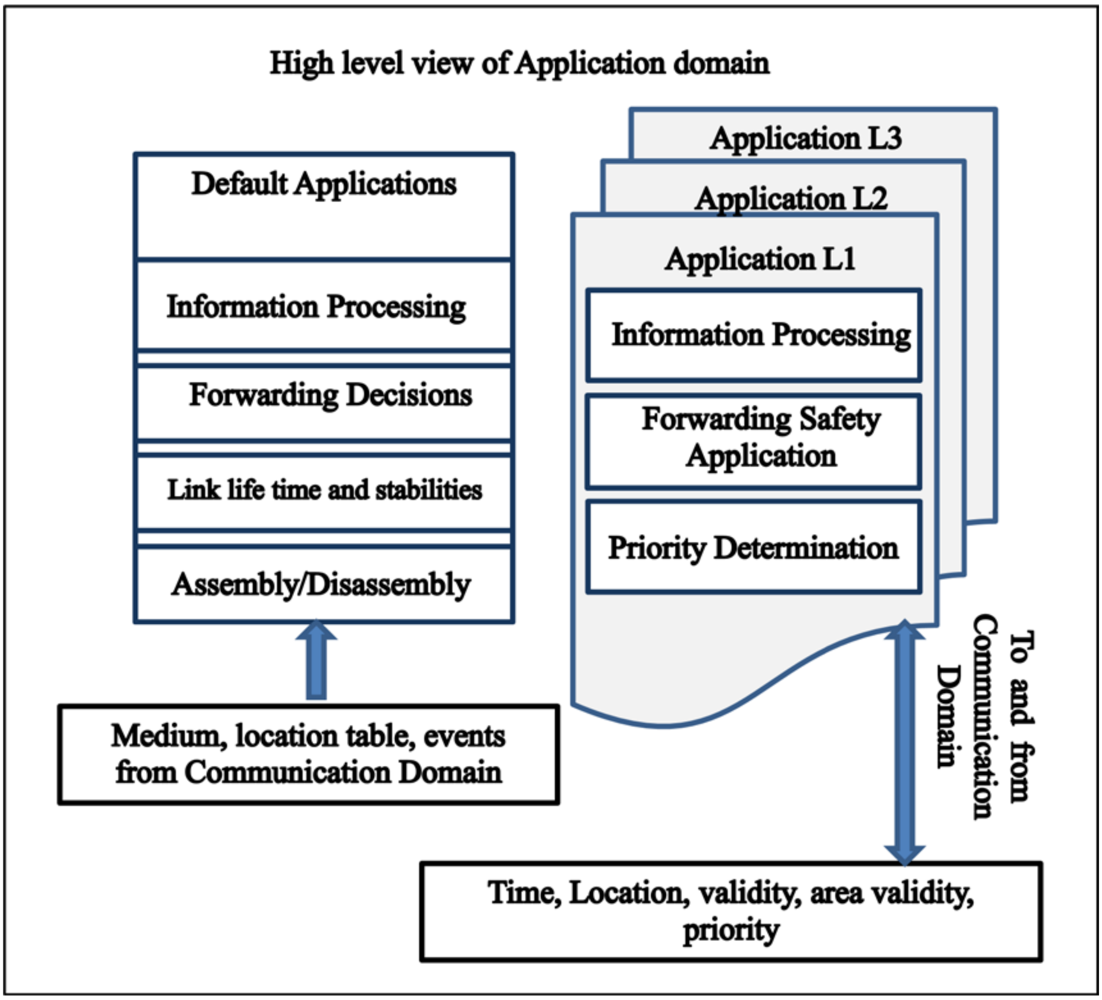


Figure 4.2: High level conceptual framework for information processing in Application domain

The Application domain is responsible for information dissemination for safety and non-safety related data types. The filtered data from the information splitter is sent to the modules in Application domain for further processing and dissemination. The priority determination module in the application domain determines which data (safety or non-safety) to be processed first. Application domain comprises modules for packet assembly and disassembly before and after the packet forwarding. Due to the adaptive nature of proposed model (as discussed section 3.1 of chapter 3), the application domain has the capabilities to adjust themselves according to the variety of network situations (dense or sparse networks).

4.1.3 Communication Domain

The communication domain is composed of all mechanisms and protocols needed to deliver the safety-of-life information to the destinations with the reliability required (information should be sent to the destination without any change) through available forwarders (when possible). High level Conceptual Framework for communication domain of proposed model is shown in Figure 4.3. The proposed model intends to use reactive and proactive approaches for establishing a link between two neighboring nodes. The adaptive dissemination model behaves like proactive within the domain area and reactive when observed as a dissemination model.

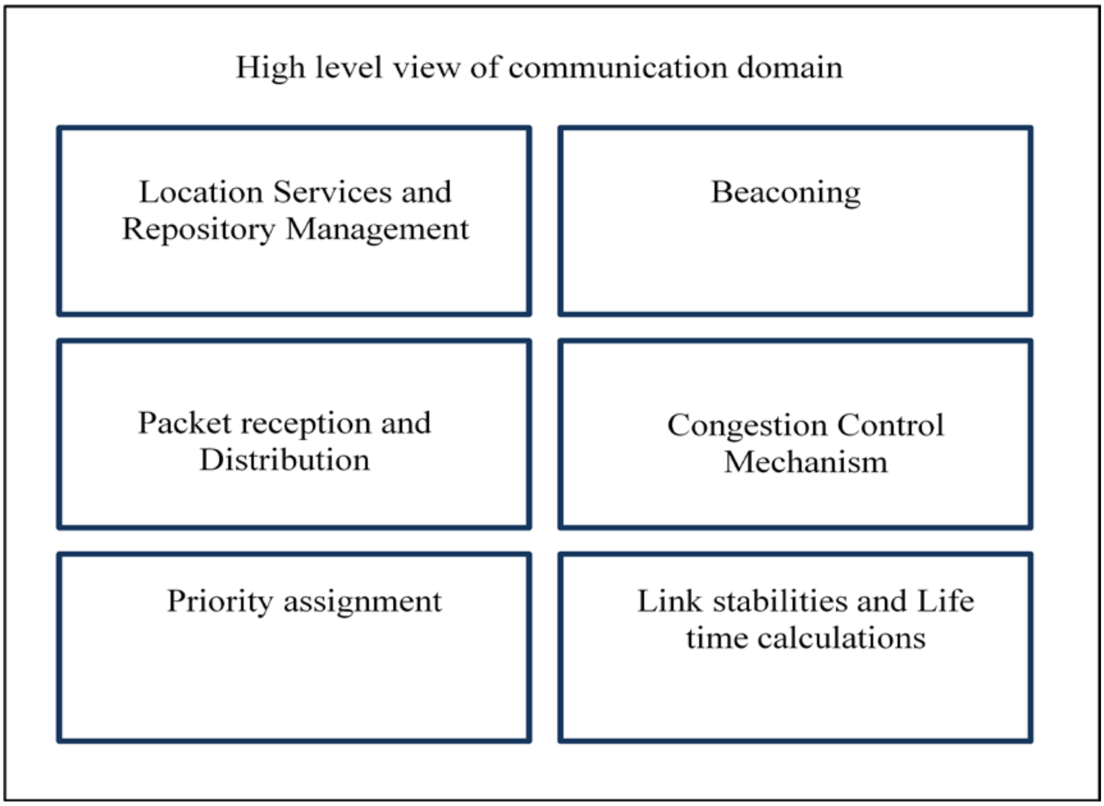


Figure 4.3: High level conceptual framework for information processing in Communication Domain

The Communication Domain is responsible for information dissemination of safety-of-life related data. The filtered data from the information splitter is sent to the modules in Communication Domain for further proceeding. Communication domain comprises modules for forwarding packets without any alteration in the packet mass. The information dissemination system model utilizes its full computational capabilities, i.e. the dump nodes (RSUs) may be used to forward safety-of-life data in case of the situation when the forwarder and receivers are not moving in same direction or the selected link is overloaded. Communication domain has the capabilities for adaptability (as discussed section 3.1 of chapter 3) in case when the allocated domain bandwidth is not utilized or rarely utilized.

4.2 Common procedures used in Application Domain and Communication Domains

In VANETs a routing between a source and destination vehicles is seen like a multi hop wireless communication through several intermediate vehicles as shown in Figure 3.7. Thus, a route is composed of several communication links (pair of vehicles) connected to each other from the source to the destination. Therefore, the stability of any route in terms of communication lifetime depends directly to the stability of each communication link in that route. In this study, the movement characteristics (positions, speeds and directions) are considered between sources and sink vehicle(s). The following assumptions are made for the proposed model

- Each vehicle communicates in bidirectional manner with its neighbors.
- Vehicles are neighbors of each other only if they are within the communication range of each other which is R meters, where R = 250 m in calculations.
- Every vehicle in the network has the constant velocity termed as V in the calculations.
- S_L $[M, N] \in [0, 1]$: is the Link Stability between M and N. Where 0 and 1 represent as extreme bounds of week and strong stabilities respectively.

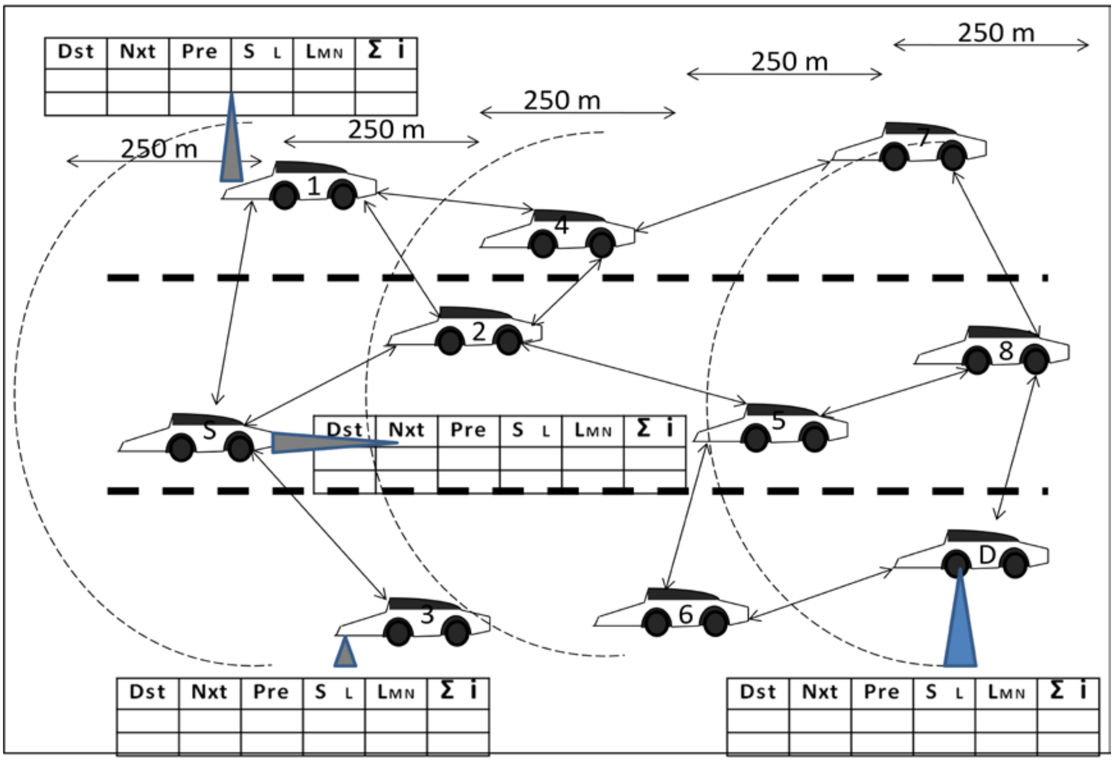


Figure 4.4: Vehicles moving in a highway scenario

As a simple vehicular network shown in Figure 4.4, there are source (*S*), destination (*D*), and 1, 2, …,8 etc as the intermediate vehicles. Figure 3.8 describes the basic structural overview of the information dissemination procedures used in systems domains of “An adaptive information dissemination model for VANET communication”.

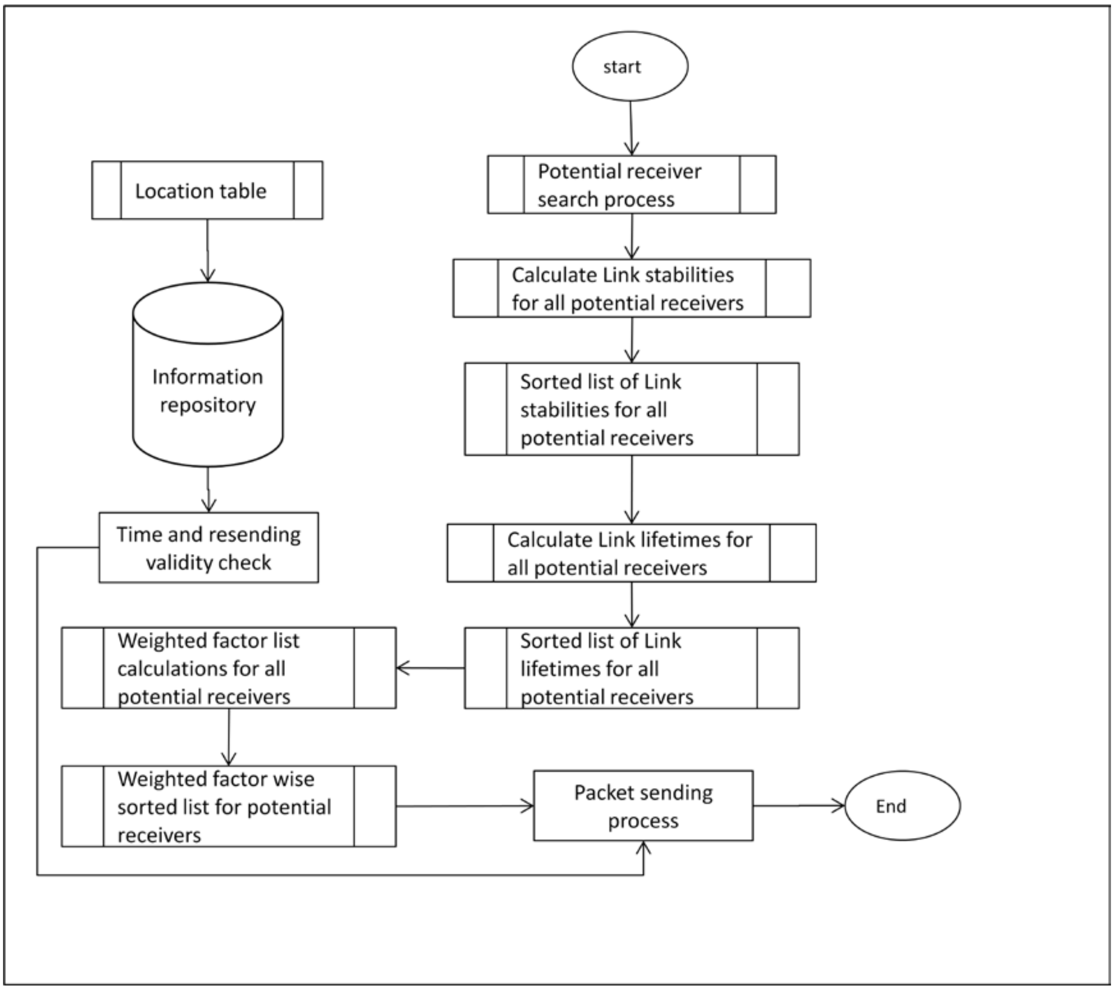


Figure 4.5: Procedure before packet sending process

4.2.1 List of potential destination candidates

The first task of the dissemination model is to find out potential candidates for data forwarding. This process uses a Link Search Packet (LSP) for finding out all possible vehicles within the communication range of the sending vehicle. The flow chart for finding the potential candidate list is given in the Figure 4.6. In this figure link search packet is abbreviated as LSP and link reply packet is abbreviated as LRP.

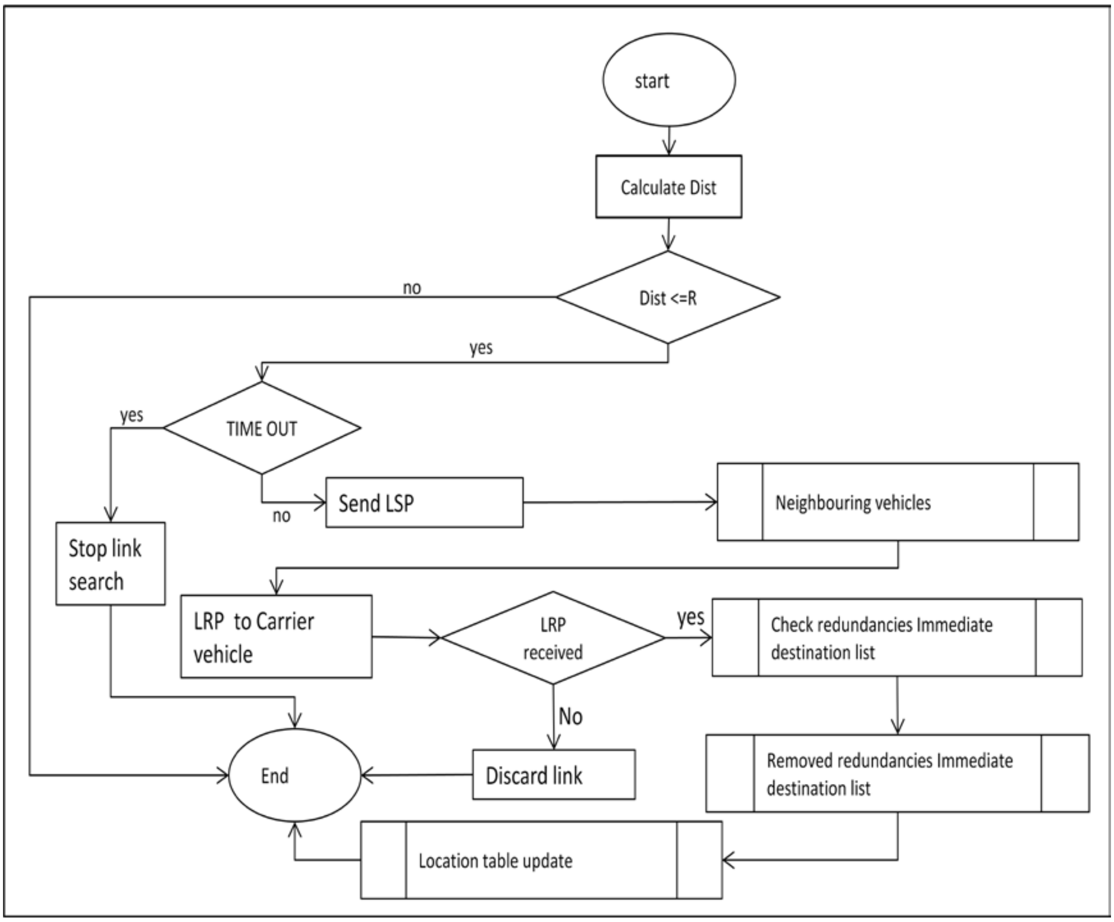


Figure 4.6: Flow chart for potential information receiving vehicles search

The algorithm description for generating the list of potential candidate receiving vehicle list is shown in the Figure 4.7. The algorithm is composed of the notations used for searching potential receivers. It is followed by the procedure description for finding the potential receiver vehicles. The algorithm depicts the steps and decisions taken for generating the list of potential candidates for immediate receiver vehicle.

Notations:
LSP: Link Search Packet
C_Src: Packet carrier source vehicle
P_Dst: Potential destination vehicles
LRP: Link Reply Packet
U_list: List for potential receiver end vehicles.
RR: Route request
R: Range of Communication

Input: C_*Src (ID, LOC) and LSP (Link Search Packet)*
Output: *List of potential destination vehicles (P_Dst (ID, LOC))*

```
C_Src initiate the RR and forward LSP to all potential destination vehicles
LSP(ID, LOC)
U_list=NULL
foreach P_Dst (where  d_{C_Src P_Dst} ≤ R)
/* distance between two vehicles d_{C_Src P_Dst} can be calculated using the
                mechanism given in section 3.6.6 */
            Send LSP(ID,LOC)
 end foreach
 /*link reply mechanism*/
  foreach P_Dst (where  d_{C_Src P_Dst} ≤ R)
            Generate LRP(C_Src(ID,LOC))
             if (P_Dst(ID,LOC) ∈ U_list) then
                Insert P_Dst(ID,LOC) in the U_list
             end if
              if (P_Dst(ID,LOC) ∉ U_list) then
                 Discard P_Dst(ID,LOC)
              end if
              Update the location table 1
   end foreach
```

Figure 4.7: Algorithm for potential receiving vehicles search

4.2.2 Link stability estimation

Figure 4.8 explains the basic criteria of message dissemination. In the proposed work, the movement characteristics (positions, speeds and directions) of intermediate vehicles with respect to the source and the destination vehicles are considered. In the first step the source node sends the data to the intermediate vehicles and a link is established. Equation 4.1 shows how the link stability for each of these vehicles is calculated. In these calculations the value 1 is considered as most stable value and the values near 0 are considered less stable.

$$S_L = \begin{cases} 1 & if\ x \le \frac{R}{2} \\ 1 - \frac{2x - R}{R} & otherwise \end{cases} \quad (4.1)$$

where R is range of communication and x is the distance between communicating vehicles.

For example if R = 250 m and if the distance between neighbouring vehicles i.e. x<=R/2 then for all values of x the value of link stability can be calculated as 1. But if the distance is greater than that, like if x=200, then the value of link stability SL is 0.2.

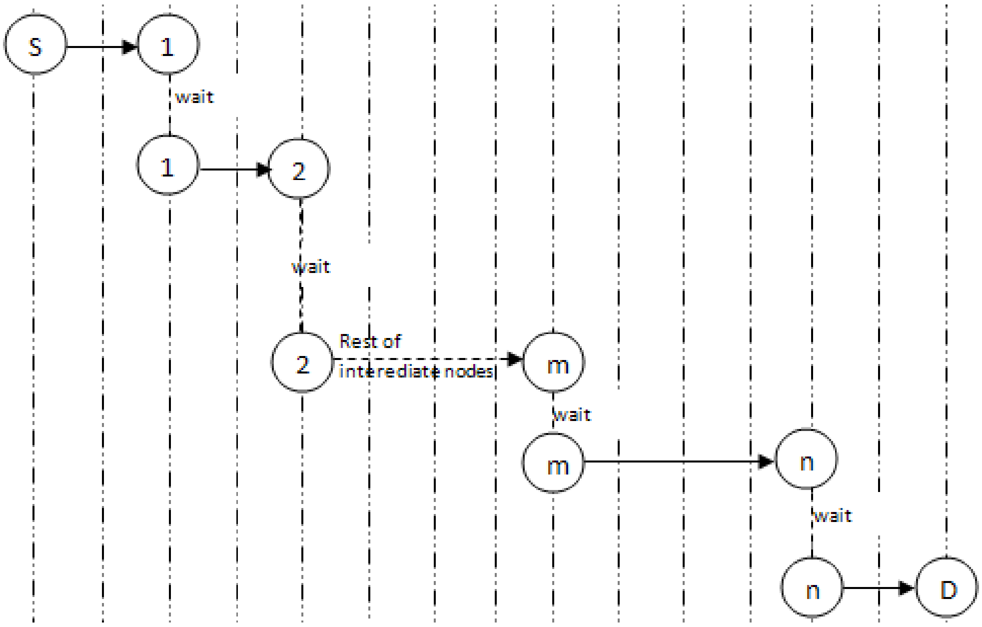


Figure 4.8: Simplest Message dissemination technique (wait-send) from source to destination

4.2.3 Link stability assignment to all potential receiving vehicles

This section provides the procedure for calculating the link stabilities between the potential receiving vehicles and the sender vehicle. Figure 4.9 shows the flow chart for assigning the link stabilities between various potential candidate receivers and the immediate sender vehicle. The flow chart shows various calculations and decisions needed for the process.

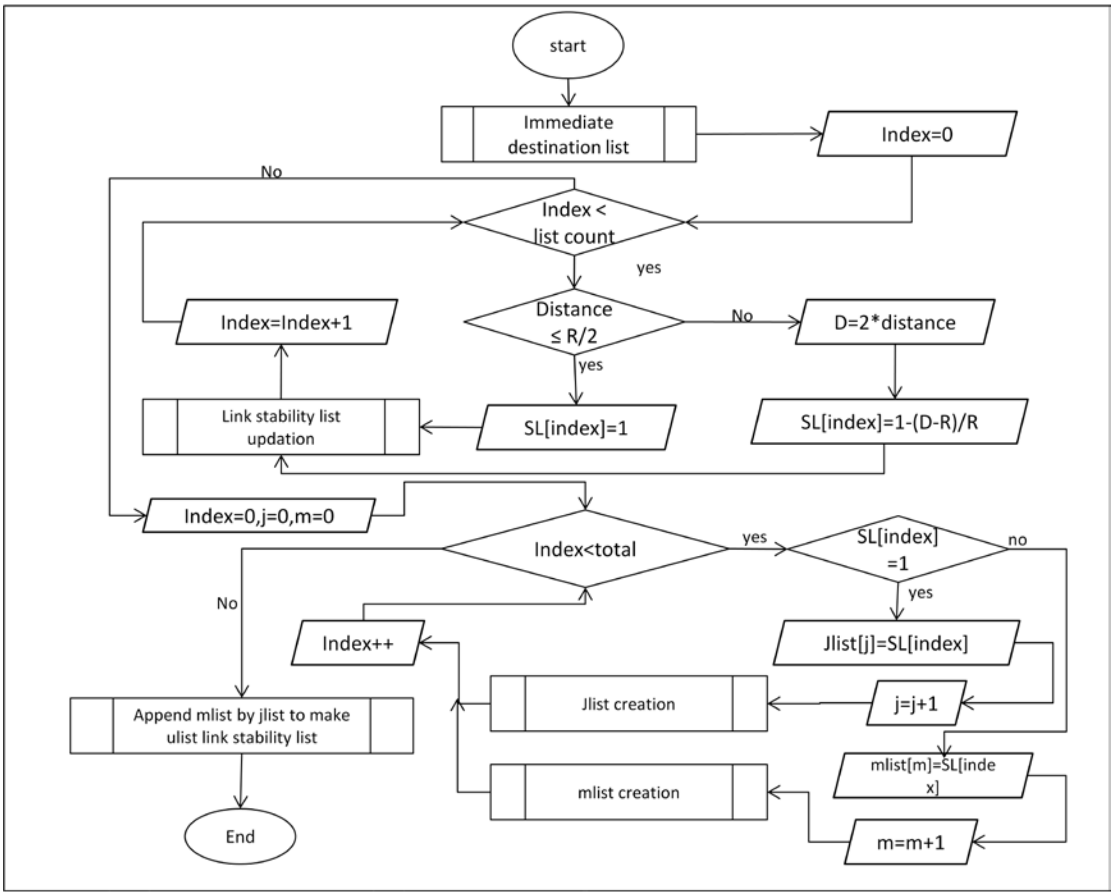


Figure 4.9: Flow chart for assigning link stabilities to all potential receivers

The algorithm description for assigning link stability values to all potential receiving vehicles is shown in the Figure 4.10. The algorithm shows how the values are set for stability on distance between the sending and receiving vehicles. The algorithm also shows how to maintain the link stabilities list for the potential receiving candidate vehicles and the immediate sender.

Notation:
U_list: List of potential receiving candidate vehicles
S_list: List of stability values for all receiving candidates
$d_{C\_Src\ P\_Dst[i]}$: Distance between sender and candidate receiver i.
D: Double the value of $d_{C\_Src\ P\_Dst[i]}$

Input: *List for potential candidate vehicles U_list*
Output: *List of potential candidates stabilities S_list*

```
Set the initial value of a variable i as 0
total as total number of elements in the U_list
do
    if |d_C_Src P_Dst[i]|≤R/2 then
        set the value of stability S_L as 1
    end if
    else
        calculate the value of D as 2×|d_C_Src P_Dst[i]|
        set the value of  S_L as 1- (D-R)/R
        increment the value of i by 1
    end else
while (i<total)
initialize the value of variable i, j and m with 0
do
    if value of U_list[i] is equal to 1 then
        set the value S1_list[j] as U_list[i]
        increment the value of j by 1
    end if
    else if U_list[i] is lesser than 1 & it is greater than 0
        set the value S0_list[m] as U_list[i]
        increment the value of m by 1
     end else if
     increment value of i by 1
while (i<total)
Append and merge S0_list with S1_list to make S_list
```

Figure 4.10: Algorithm for assigning stabilities to all potential receiver vehicles

4.2.4 Link stability based optimal link selection

Equation 4.1 plays a key role in selection of next optimal link for sending the information. In the proposed model the link stability and the link lifetime are key factors for information dissemination. Link stability can be accurately calculated from

Equation 4.1. The main goal of this work is to increase the routing performances by increasing the route stability. Suppose if there are *n* various neighbouring vehicles near a carrier vehicle. First the link stabilities of all the links are calculated as shown by Equation 4.2.

$$S_L = \{S_L[C, N_1], S_L[C, N_2], S_L[C, N_3], \ldots., S_L[C, N_L]\} \qquad (4.2).$$

where N_1, N_2, N_3, ……, N_L denotes the vehicles which are directly connected and are within the communication range of the carrier vehicle. The most stable link from the set of link stabilities as shown in Equation 4.2 can be calculated as in Equation 4.3.

$$O(S_L) = max\{S_L[C, N_1], S_L[C, N_2], S_L[C, N_3], \ldots., S_L[C, N_L]\} \qquad (4.3)$$

where

$O(S_L)$ = the optimal stable link among all links.

It is observed that sometimes the optimal link stabilities for more than one links have equal values. The sorted list in this case is maintained on first come first serve basis (Section 4.2.5 provides mechanism in detail). The carrier vehicle gives priority to the link from where link reply packet reaches first.

4.2.5 Link stability based sorted list creation

Figure 4.11 describes the flow chart for sorted list creation mechanism based on the calculations mentioned the Section 4.2.4. The basic calculation, decisions and loops used for the creation of sorted list are used here.

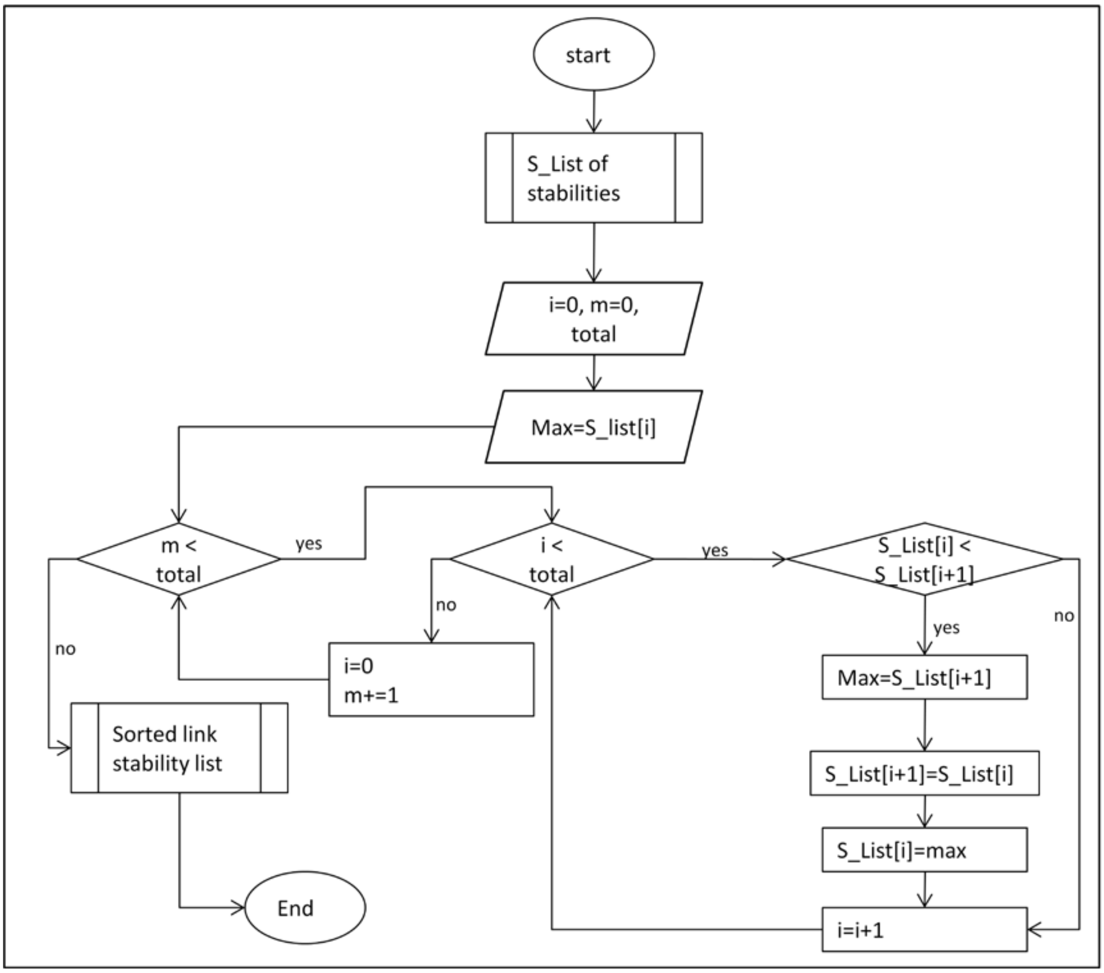


Figure 4.11:Flow chart for sorted link stabilities

The algorithm in Figure 4.12 shows the steps to create link stability based sorted list. The sorted list is helpful in eliminating the candidates having low link stabilities. This mechanism is used to reduce the heavy load on the network created by sending data to all possible receiving vehicles.

Notation:
S_list: list of link stabilities
SS_list: Descending value wise sorted link stability list

Input: *potential receiving end vehicle's stabilities list S_list*
Output: *link stability wise sorted list SS_list*

```
initiate the variables i and  m with zero and total is equal to the number
of elements in the S_list.
set the variable max as the first value in the S_list i.e. S_list[i]
do
    do
        if the value of S_list[i] is lesser than the value of S_list[i+1] then
            assign the value of S_list[i+1] to variable max
            assign the value of S_list[i] to S_list[i+1]
            assign the value of max to S_list[i]
        end if
        increment the value of i by 1
    while value of i is lesser than total
  increment the value in m by 1
  assign the value of i to 0
while value in m is lesser than the total.
copy the list element in S_list to SS_list which is sorted stabilities list
```

Figure 4.12: Algorithm for creation of sorted link stability list

4.2.6 Link life time calculation mechanism

The link life time of all links from a carrier node uses the following assumptions. Figure 4.13 shows two neighboring vehicles *M* and *N*. The vehicles are moving on a stationary Cartesian coordinate system. The Figure 4.13 is inspired from the stationary Cartesian coordinate system mentioned in [104].

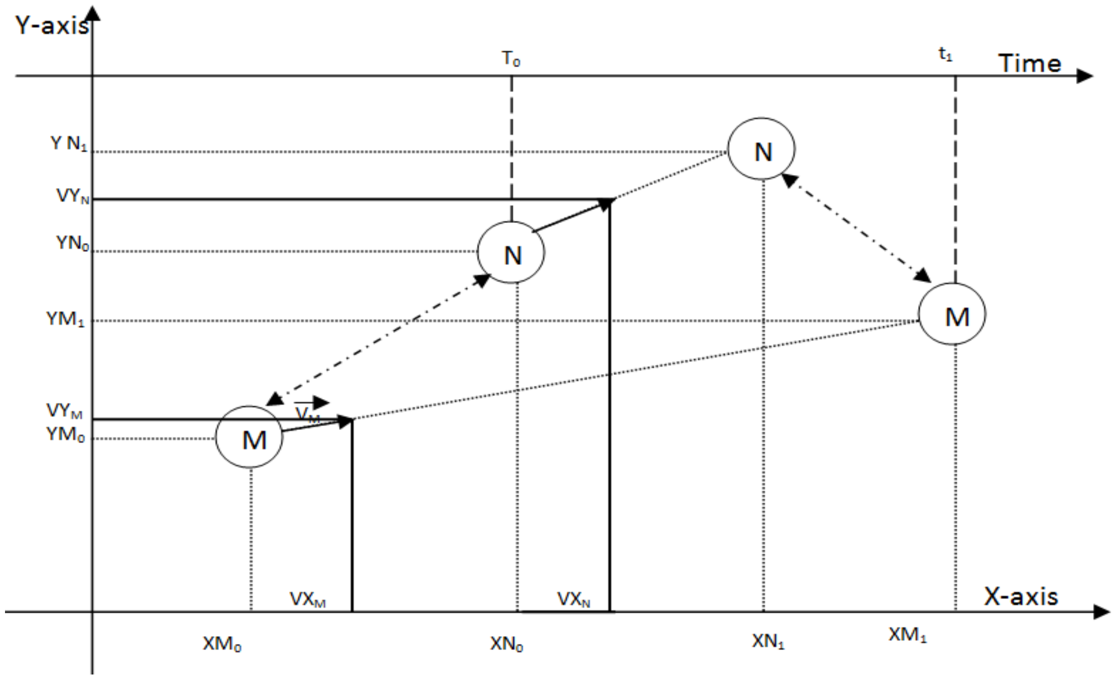


Figure 4.13: velocity estimation in static Cartesian coordinate system

The orthogonal unit vectors are x̂ and ŷ along the *X* and *Y* axes. The velocities of the vehicles are measured as in Equations 4.4 and 4.5.

$$V_M = VX_M\,\hat{x} + VY_M\hat{y} \tag{4.4}$$

and

$$V_N = VX_N\hat{x} + VY_N\hat{y} \tag{4.5}$$

Consider the link life time as $L_{MN} = t_1 - t_0 = \Delta t$ and d_{MN} is the distance between two vehicles *M* and *N* in time Δt where t_0 and t_1 are intial and 2nd time when $d_{MN} <= R$.

The relative distance of the two communicating vehicles considered as $d_{MN,}$ can be calculated by Equation 4.6 and Equation 4.7 given below

$$d_{MN}^2 = ||\, XM_1 - XN_1||^2 + ||YM_1 - YN_1||^2$$

$$= ||XM_0 - VX_M\,\Delta t\,||^2 + ||\,XN_0 - VX_N\,\Delta t\,||^2 + ||YM_0 - VY_M\,\Delta t\,||^2 + ||YN_0 - VY_N\,\Delta t\,||^2$$

$$= A\Delta t^2 + B\,\Delta t + C \tag{4.6}$$

where

$$A = (VX_M - VX_N)^2 + (VY_M - VY_N)^2$$

$$B = 2[(XM_0 - YN_0)(VX_M - VX_N) + [(XM_0 - YN_0)(VY_M - VY_N)]$$

$$C = (XM_1 - XN_1)^2 + (YM_1 - YN_1)^2 \tag{4.7}$$

From Equation 4.6 the value of d_{MN} becomes

$$d_{MN} = \sqrt{A\Delta t^2 + B\,\Delta t + C} \tag{4.8}$$

The link which has the greatest link stability is given the highest priority. The second greatest link stability is given next priority value and so on. The link life time of the all links from a carrier node are calculated using the following assumptions

If the range of communication is denoted by R, distance between the two immediate node M and N be d_{MN}, M and N are moving with velocities V_M and V_N respectively, the life time L_{MN} of link can be calculated as in Equation 4.9

$$L_{MN} = \frac{R - |d_{MN}|}{|V_N - V_M|} \tag{4.9}$$

Replacing the value of d_{MN} from the equation 4.8, the value of L_{MN} becomes

$$L_{MN} = \frac{R - |\sqrt{A\Delta t^2 + B\,\Delta t + C}|}{|V_N - V_M|} \tag{4.10}$$

where

L_{MN} = the link life time between the Vehicles M and N

R = max range of communication

V_M = velocity of vehicle M

and

V_N = velocity of vehicle N

Equation 4.10 shows a near optimal measurable value of link life time in a real like scenario of vehicles on road.

4.2.7 Link life time based sorted list

Once the list of sorted stabilities is created, the link life time for all the vehicles in the sorted stabilities list is assigned. This list is further sorted according to the maximum values. The procedure for assigning the life time to the potential candidate list in a sorted fashion is given as the flow chart shown in the Figure 4.14.

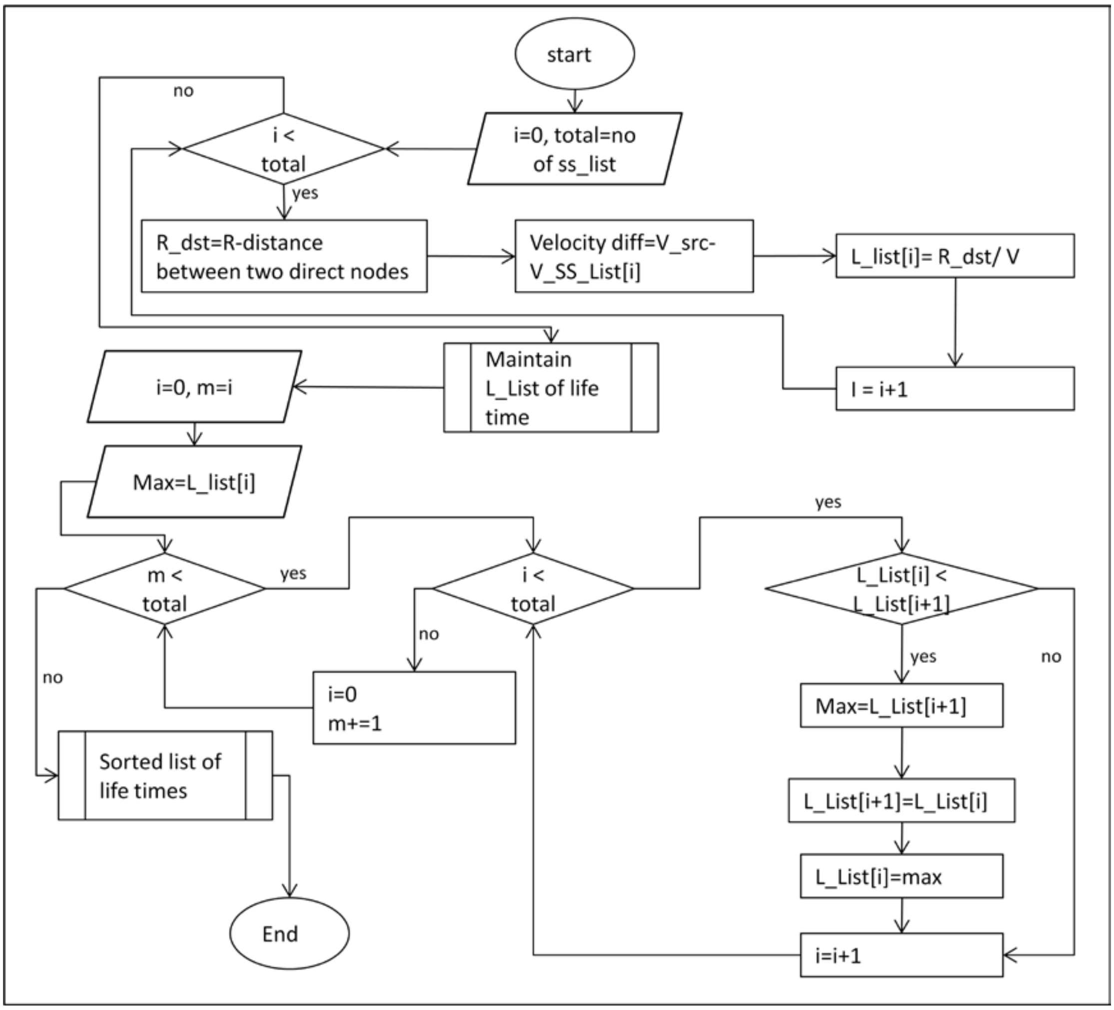


Figure 4.14: Flow chart of sorted link life times of all potential candidate vehicles

The creation of link life time list for all the potential receiving candidate vehicles is shown in the Figure 3.18. The algorithm description shows the notations used and the input for the algorithm for sorted link life time. It also describes the output from the procedure followed in the algorithm.

Notation:
P_Dst: Potential destination vehicle
SS_list: Sorted link stability list
R_Dst: Difference of range of communication and mutual distance of vehicles
S_L_list: Sorted link life time list

Input: *Link stability sorted list SS_list*
Output: *Sorted list of assigned link life time S_L_list*

assign variable total equal to the number of elements in SS_list.
initialize the value if variable i with 0.
do for every P_Dst in SS_list
    calculate R_Dst $d_{C\_Src\ SS\_list[i]}$
    /* $d_{C\_Src\ SS\_list[i]}$ is the distance between carrier vehicle and the
        SS_list element I */
    calculate velocity difference V as $|V_{C\_Src}-V_{SS\_list[i]}|$
    calculate L_list[i]
    Increment i by 1
while(i < total)
set value of i as 0 , m as i and set the variable max as the first value in
the L_list i.e. L_list[i]
do
    do
        if the value of L_list[i] is lesser than the value of L_list[i+1] then
            assign the value of L_list[i+1] to variable max
            assign the value of L_list[i] to L_list[i+1]
            assign the value of max to L_list[i]
        end if
        increment the value of i by 1
    while value of i is lesser than total
    increment the value in m by 1
    assign the value of i as 0
while value in m is lesser than the total.
copy L_list in S_L_list

Figure 4.15: Algorithm for link life time based sorted list

4.2.8 Correlation mechanism of link selection parameters for information dissemination

This information dissemination strategy is based on point to point forwarding. In this approach the importance of node mobility is considered. It is designed in such a way that it performs considerably better where the traditional Greedy forwarding schemes fail. The core function is to assign priority to the neighbouring vehicles for next hop selection by a weighted function. The weighted function [105] is a terminology used in statistics but in this study this term has been customized for local purpose. This weighted function $\sum_i$ is based on three main factors which are the velocity of vehicles V_i in consideration, the distance D_i between the neighbouring vehicles and the relative position of the vehicles P_i under consideration. The value for the weighted function $\sum_i$ for the next hop is calculated by in Equation 4.11

$$\sum_i = \alpha V_i + \beta P_i + \gamma D_i \tag{4.11}$$

where α, β, and γ are used as weights of above given evaluation factors for velocity, position and distance respectively and combination of weight factors is shown in Equation 4.12.

$$\alpha + \beta + \gamma = 1 \tag{4.12}$$

The velocity factor α is considered as follows: from all the vehicles within the communication range of the message sending vehicle, the vehicle with the minimum difference in the velocities is selected. The position factor β favours the selection of vehicle making the highest progress towards the immediate destination vehicle. The third factor γ favours the minimum distance from sender to the receiver. Series of experiments have been carried out to find the best combination of α, β and γ. For this research, 148 experimental scenarios have been created. Twenty sets of α,β and γ *are* used for each scenario (i.e. different velocities, positions, mutual distances and network densities). For each experiment scenario, 10 different sets of [α, β and γ] presenting the best result for dissemination of data are preserved in a list. For α, it has been observed that the values providing good dissemination results are in the range 0.1 to 09 (for all the experiment). Similarly, for β and γ these values are in the range 0.05 to 0.4. Different combinations of α,β and γ have been selected to find out 450 sets. The variations in the set of [α, β and γ] are so adjusted that the combined sum of these factors never exceeds to 1. For example a set of α, β and γ may be [0.43,0.36,0.21]. In this way, all the values α, β and γ are obtained .The sum of α, β and γ remain 1 in this approach as shown in the Equation 4.12.

4.3 Extended view of the model domains

In this section, the extended view of the model is described by explaining the module and their working within the domains. High level architecture of the model domains shown in the sub section 4.1.2 is the basic structure of the domains and it only explains the working relationship of various modules within each domain. The extended view of the model domain shows the relationship of various domain modules with each other. This extended view shows how various modules communicate with each other within the same domain and how they link to the outer modules in the other domain.

4.3.1 Modules in Application Domain

The application domain is regarded as a component that comprises processing of all safety/non-safety information. This domain consists of Information repository (IR), Information processing, Driver presentation, Forwarding state/safety information, Priority determination and Message assembly. The correlation of these modules is shown in the Figure.4.16

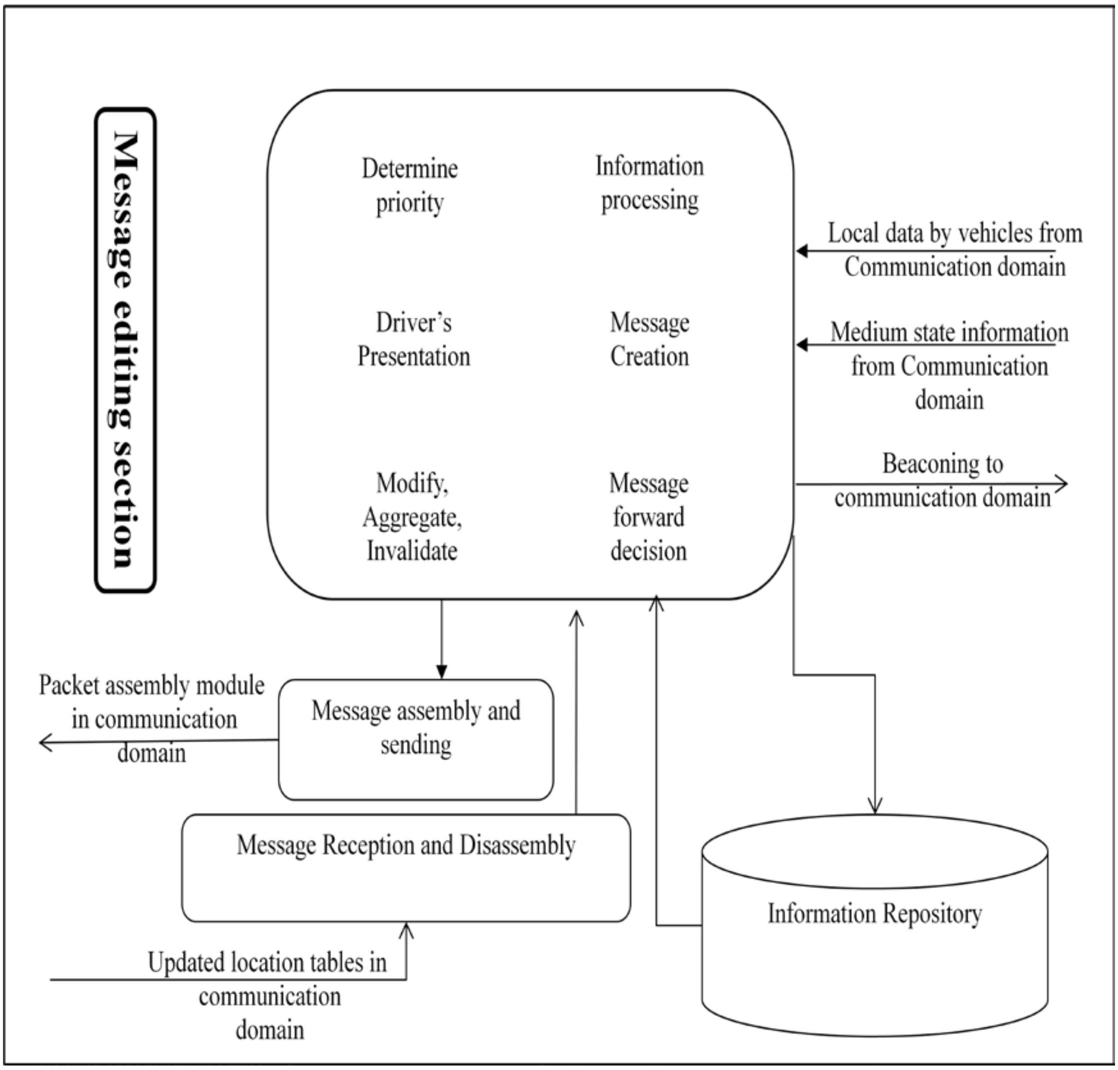


Figure 4.16: Extended view of Application Domain

Some of the application domain modules are discussed here. These modules play key role in dissemination process of safety and non-safety related information in the proposed model.

4.3.1.1 Information repository (IR)

During some unsafe scenarios, Application domain has to take certain decisions. These decisions are carried out with the help of information repository (IR) module with the Application Domain. IR has the updated surrounding information of application domain. Modification, aggregation, and invalidation of information received by the Application Domain are served through local functions of the domain assisted by the information in IR. The IR fields are updated regularly. Using a common IR for all the modules in the Application Domain helps in efficient memory utilization and better aggregation outcomes. Similarly IR is helpful in better inter-module co-operations in the application domain.

4.3.1.2 Driver presentation

The application domain has the capabilities to provide the variety of road situations (safety and non-safety) through some predefined interface. This interface may have different presentation for various automotive vender vehicles. It may come through text format or some audio format.

4.3.1.3 Forwarding state/safety information

If an application is aware of a hazardous situation or itself detects some safety or non-safety related data, it can decide to send it at once or forward it after some time depending upon the nature of the data needs. Greater frequencies of communication domain may come into action if some higher priority safety-of- life data is detected.

4.3.1.4 Priority determination

The application domain also determines the safety value on some priority setting at a time when the decision to issue some safety information to other vehicles is taken. Priority considerations are driven through some key factors namely, type of hazard, elapsed time of hazard occurrence, inter-vehicle distances and the hazard position, and network density state. The result of the function is a single priority value that is assigned to the message and passed to the communication system. In the perspective of safety related data, the priority value will be assigned and used by the application domain’s congestion control module.

4.3.1.5 Aggregation Mechanism

Proper aggregation is implemented in order to reduce the number of message forwarding vehicles. The proposed model for information dissemination uses generic aggregation scheme defined in [106] with some variations according to the demands of the proposed information dissemination model. In this mechanism every now and then, the potential receiving vehicles are recalculated. This mechanism is helpful to reduce the overhead of number of relay nodes. The objective of this aggregation mechanism is to support variety of data types in the proposed model for information dissemination. Before sending the actual information in the network, the aggregation mechanism takes two types of situation into consideration. One is the number of receiving vehicles be within due limit (30-60) and secondly, limiting the beaconing issued for potential receivers in the communication system. As a first step, the aggregation mechanism assumes that all types of information in the dissemination model require aggregation before forwarding. But at the same time it takes one counting measure about information itself, number of tries for sending, number of potential receivers, beaconing count etc.

The aggregation mechanism keeps a strict check on the data according the different application requirements. The Section 4.2.1 to Section 4.2.7 shows the implementation details about how number of potential receiving vehicles is aggregated in the proposed adaptive model. The implementation of the aggregation scheme is helpful to reduce the extra bandwidth utilization at two levels i.e. before actual application data dissemination and during the dissemination process. This results in congestion control in dense network situation. Moreover, depending on the desired dissemination range and requirements on dissemination frequency, as a fully generic dissemination scheme, it can dynamically decide on the communication channel to be used.

4.3.1.6 Information processing

When receiving state (safety) information, either from local sensors or through Communication Domain’s internal processing, Application Domain accepts the information and updates the safety state of the IR. After the calculation of the weighted priority factor $\sum i$ of all the neighbouring vehicles from the carrier vehicle defined in the Equation 4.11, a sorted list of next hop is maintained. Thus the most suitable candidate for dissemination of information is selected form the sorted list. Still there is a chance that the selected candidate may be in the lowest range of link lifetime calculated in Equation 4.10. By predicting the lifetime duration of link connection only those neighbours still within the transmission range will be considered as valid candidates for next hop. The packet forwarding procedure is described as flow chart in Figure 4.17.

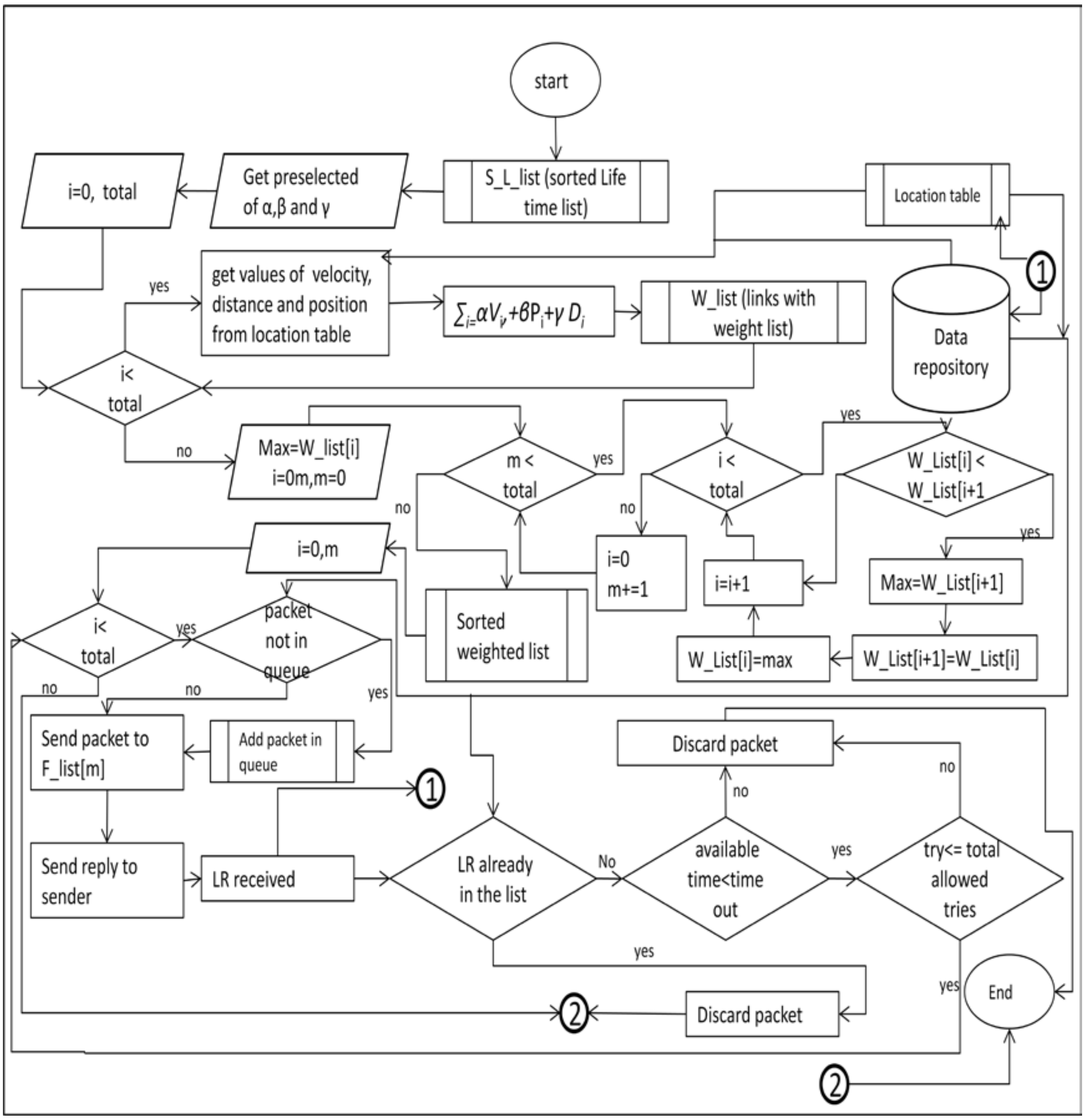


Figure 4.17: Flow chart for packet forwarding in Application Domain

The algorithm in Figure 4.18 shows the steps to forward the packet on the selected link in application domain. The algorithm consist of basic notations used, the intended input and possible output from algorithm and the sequence of steps taken to forward the data on the desired link in application domain for safety and non-safety information.

```
Notations:
C_Src: Immediate source vehicle
SS_list: Sorted list with respect to suitability of potential candidate vehicle
F_list: weighted factor based list
N_hop : Selected candidate from the SS_list
∑i: weighted factor for the vehicle i

Input: List of potential candidate for sending packets
Output: Transmission of data over the selected link in application domain
1.      Initialize the vehicle direction and value of i as 0  and total as number
2.      of elements in the S_L_list
3.      repeat (For each vehicle in the S_L_list)
4.              calculate weighted factor ∑_i
5.              F_ list[i] = ∑_i
6.              increment value of i by 1
7.      until (i < total)
8.      sort list F_list according to the values of ∑_i
9.      /* sorting procedure can be found in algorithms in Figure 4.12 and 4.15
10.      for any packet do
11.           if packet is not in the queue
12.              add packet to the queue
13.              if (the first element is F_list has maximum weighted
14.               factor ∑_i with max link stability and life time)
15.                  if (∑_i= with max value of weighted factor)
16.                  /* distance value of vehicles increase as function of velocity*/
17.                     send packet on the link
18.                     link reply to the sender
19.                     if (LR ϵ F_List)
20.                        update location table
21.                        discard sending the packet
22.                        send next packet from the sender and go to step 2
23.                     end if
24.                          if(! Time out and number of try<= total number of tries)
25.                            go to step 13
26.                         else
27.                           drop the packet
28.
29.                  else
30.                        Check next max value of weighted factor ∑_i+1 and go to
31.                        step13
32.                    end if
33.               else
34.                    select the next element in the list S_L_list
35.                    update the queue according to routing table settings.
36.                    forward the packet to N_hop
37.               end else
38.                    store in the list till validity of time
39.               end for
```

Figure 4.18: Algorithm for data forwarding on the selected link in Application Domain

The link stability, priority of the links selection, the life time of the link from a carrier (sender) vehicles to the sender and the relative weighted factor of the vehicles are important for choosing the link for packet sending .The link priority identified based on the above mentioned factors is used to switch to next link for the process of packet forwarding in case of link life time expiry.

4.3.2 Modules in Communication Domain

The adaptive model for information dissemination is intended to augment many selection parameters (addressed in many research efforts for ad hoc networks), such as relative speed of vehicles, lane information, queue occupancy, link state and number of intermediate hops in a route. This mechanism will ensure a prediction of link breakage between two neighboring nodes before actual breakage occurs. The Communication Domain commonly uses the smart and dumb nodes, and provides the following main functions. The operation of Communication Domain for the proposed adaptive model is given in Figure 4.19.

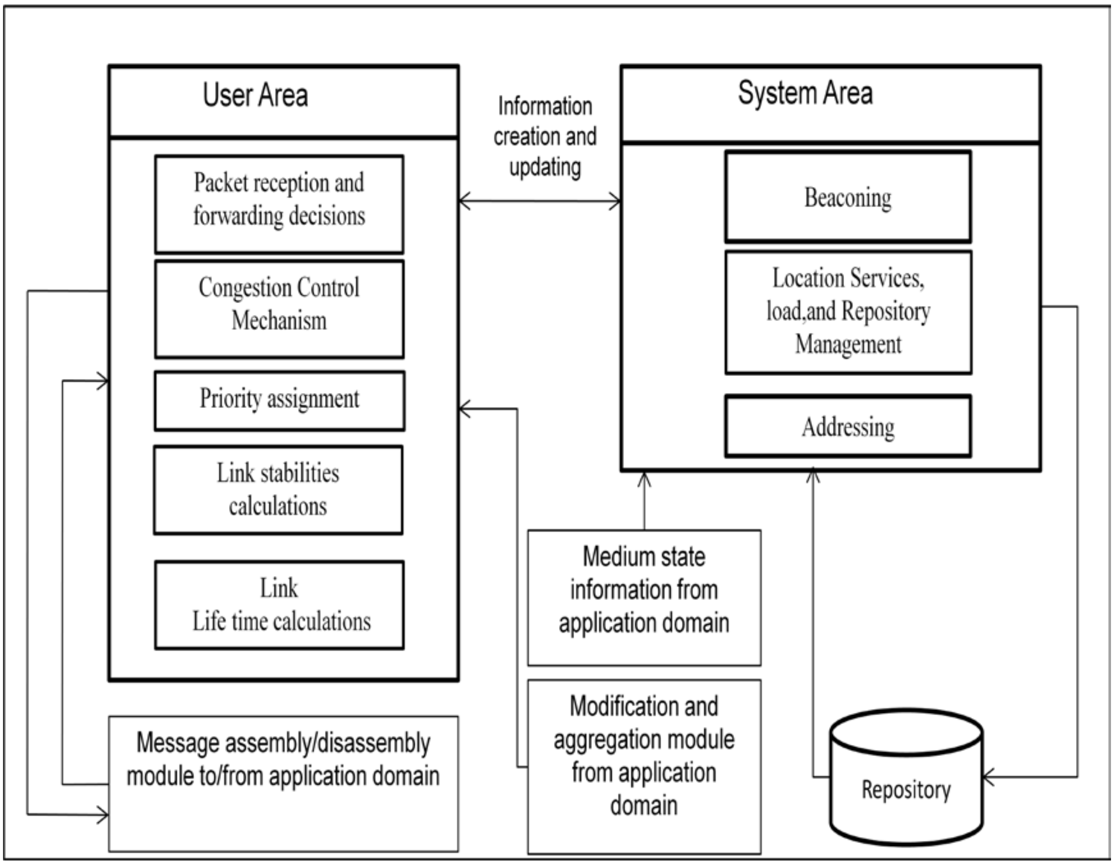


Figure 4.19: Extended view of Communication Domain

The detailed description of some of the modules in the user area and the system area are as follows.

4.3.2.1 Congestion control

The communication domain has the goal of ensuring a perfect stability of the network at all times. It prevents network congestion by monitoring the network utilization (bandwidth and other system resources) and controlling the packets transmission [4]. Congestion control mechanism in Communication Domain is assisted by Application Domain's aggregation control module. In case the data from the Application Domain needs to be forwarded from the Communication Domain, proposed model proposes the use of a simple priority value. The value of information in Communication Domain is set high and the value of priority for the information from Application Domain is set low. In this way, the Communication Domain determines the priority based on the relevance of the information and assigns the value to each message. This value is used by the communication domain to take adequate decisions when controlling the load on the channel. Basically, it is considered that congestion control strategy combines a set of mechanisms including deferring packet transmission, smart discard of low-priority packets, and dynamic setting of transmission parameters on a per packet basis

4.3.2.2 Addressing

The communication domain is capable of different address types. A unicast address identifies a single node and it is used for point-to-point communication. A broadcast address refers to all nodes within one wireless hop. A geocast address identifies all nodes that are located inside a geographical area.

4.3.2.3 Beaconing

Beacons are defined as the periodic messages broadcasted by the communication domain to support ad hoc forwarding protocols and the applications. The beacons contain the position of a vehicle and state information common to relevant applications, e.g., speed and direction. On reception of a beacon, a vehicle is conscious of their surrounding conditions and eventually detects safety-of-life data.

Note that due to the different requirements between safety-of-life applications and routing/forwarding protocols, applications could motivate the increase of the message generation period. This system model also consider the possibility of sending more than the own state information, i.e., sending other nodes learned state to increase the vicinity awareness further than one hop distance.

4.3.2.4 Location Service

The communication domain is responsible to supply to the Application Domain a distributed mechanism that resolves the location of other nodes in the network. This module is also responsible of maintaining the Location Table (LT) to assist both routing/forwarding protocols and applications. The updated information is utilized after almost each single packet is forwarded in the Communication Domain.

4.3.2.5 Packet delivery mechanism in Communication Domain

The Communication Domain provides different modes of packet delivery for unicast, broadcast, and geocast. The geocast mechanism must provide reliability and efficiency (i.e., to avoid redundant messages) in order to fulfill the time requirements of safety-of-life information. Broadcast messages, on the other hand, are considered as a one time (unreliable) transmission addressed to nodes in communication range only. This decision responds to the different reliability requirements of the possible future applications and the existing tradeoffs with overhead efficiency, e.g., higher reliability could be achieved for safety-of-life at higher cost, but controlled. By predicting the lifetime duration of link connection only those neighbours that are still within the transmission range will be considered as valid candidates for next hop. In case the selected candidate from the list has opposite direction, if there is any road side unit available, or some other packet is utilizing the bandwidth, the safety to life packet is sent to the RSU. RSU takes the packet and without taking any alteration decision, sends packet to the next candidate in the sorted list and the location table entries are updated. The packet forwarding procedure is described as flow chart in figure 4.20

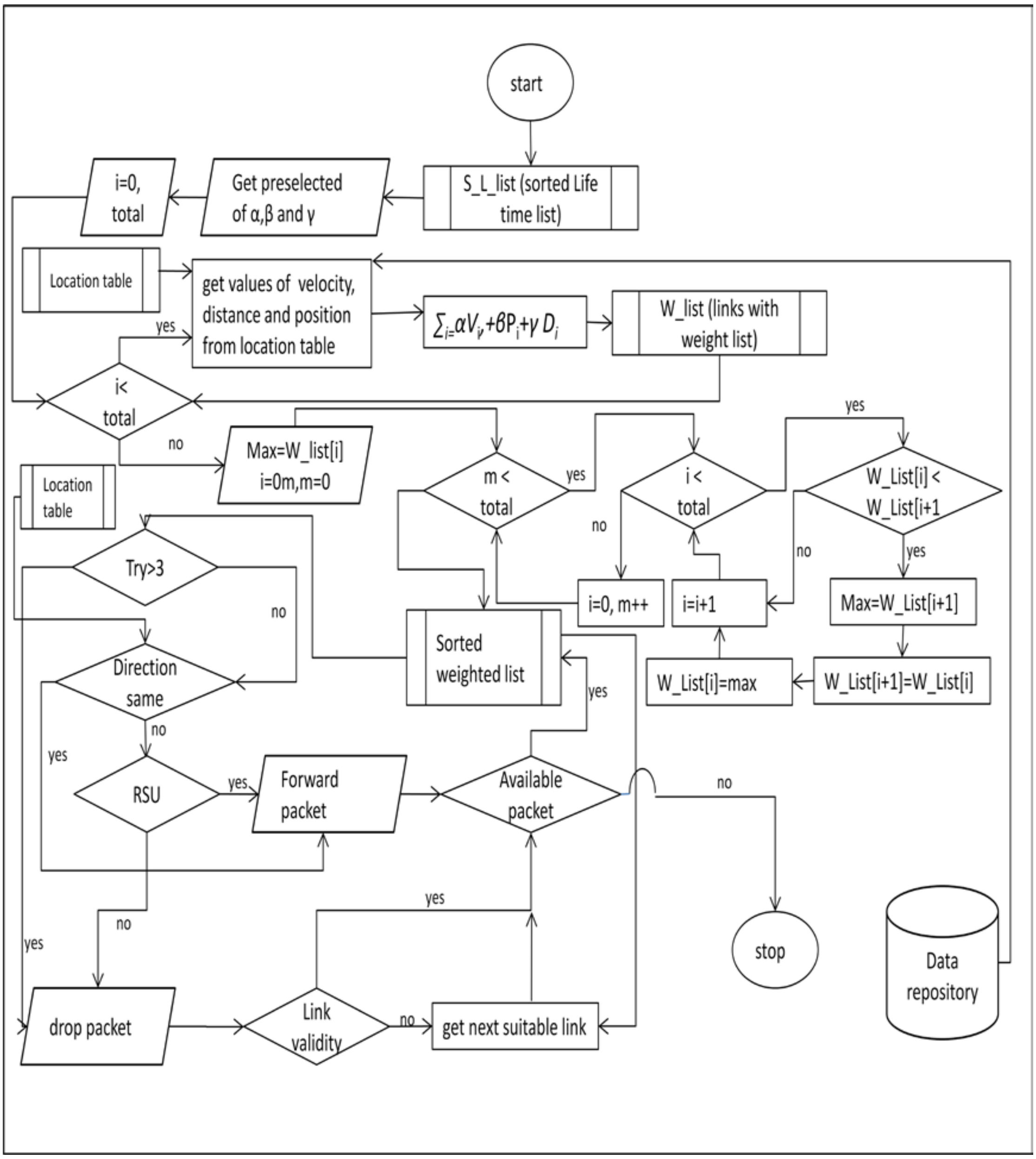


Figure 4.20: Flow chart for packet forwarding in Communication Domain

The algorithm in Figure 4.21 shows the steps to forward the packet on the selected link in Communication Domain. The algorithm consist of basic notations used, the intended input and possible output from the algorithm and the sequence of steps taken to forward the data on the desired link.

```
Notations:
F_list: weighted factor based list
N_hop : Selected candidate from the SS_list
∑i: weighted factor for the vehicle I
C_Src: Immediate source vehicle
SS_list: Sorted list with respect to suitability of potential candidate vehicle
```

Input: *List of potential candidate for sending packets*
Output: *Transmission of data over the selected link in communication domain*

```
1.    Initialize the vehicle direction and value of i as 0  and total as number
2.    of elements in the S_L_list
3.    repeat (For each vehicle in the S_L_list)
4.            calculate weighted factor ∑i
5.             F_ list[i] = ∑i
6.             increment value of i by 1
7.    until (i < total)
8.    sort list F_list according to the values of ∑i
9.    /* sorting procedure can be found in algorithms in Figure 4.12 and 4.15
10.    for any packet do
11.        if (the first element is F_list has maximum weighted
12.            factor ∑i with max link stability and life time)
13.                if (∑i= with max value of weighted factor)
14.                  if (no of tries are lesser than or equal3)
15.                     if (direction of carrior is not same as final destination)
16.                           /* this is judged from location table current values*/
17.                       if(there is any RSU available)
18.                         send the packet on RSU
19.                          /*only for forwarder of safety-of-life packet */
20.                          if (more packets available)
21.                            get link for highest weighted fector
22.                             go to step 11
23.                          end if
24.                           else stop
25.                        end if
26.                         forward packet and go to step 20
27.                      else
28.                           if (link is valid)
29.                              go to step 20
30.                            else
31.                                 get next priority link and go to step 11
32.                            end else
33.                           drop the packet and go to step 20
34.                        end if
35.                     end if
36.                 end if
37.                 update location table and repository
38.            end for
```

Figure 4.21: Algorithm for packet forwarding in Communication Domain

Depending on the nature of data and the utilization of bandwidth in the Communication Domain, the communication Domain may be used as a forwarder for the data in Application Domain. It is observed that very often the bandwidth associated with communication domain remains unused which affects the system performance over all.

4.4 Summary

This chapter presented the research design and procedures incorporated into the work of “An adaptive information dissemination model for VANET communication”. The high level architecture of the model proposed model had been described. The chapter further explained the common procedures incorporated in application domain and communication domain of the proposed model. Algorithms designed for various modules in the proposed model were discussed in detail. Finally, the extended view of Communication Domain and Application Domain were presented.

CHAPTER 5

THE EVALUATION AND VALIDATION OF PROPOSED MODEL

This chapter presents a comprehensive analytical evaluation with detailed discussions of the results with respect to “An adaptive information dissemination model for VANET communication”. Simulation is used as a tool to evaluate the proposed model. Performance comparison is used as a validation for the proposed model with GSR, ZGPSR and PDGR.

5.1 Simulation results

From the series of simulations the results, it can be observed that the proposed model for information dissemination has outperformed the other three models for information dissemination in VANET namely ZGPSR (Zonal Greedy Perimeter Stateless Routing), GSR (Greedy source aware routing) and PDGR (Predictive Directional Greedy Routing) in terms of packet delivery ratio, end-to-end delay, throughput and routing overhead. The abbreviation for “An adaptive information dissemination model for VANET communication” will be coined as AIDVC from now on. There are two possible network scenarios for VANET in this simulation setup. One is defined as low network scenario in which the number of vehicles is between 40 to 240 vehicles for the predefined road segment. The vehicles in the range 250 to 450 are considered as a high dense network situation. The results in the following sections describe the performance of various information dissemination models based on two factors: one is described earlier i.e. low density and high density networks, and the other is fixed and variant Constant Bit Rate (CBR).

5.1.1 Packet delivery ratio

As a matter of fact packet loss cannot be tolerated in any transmission system[107]. Unfortunately Packet delivery ratio is affected by the network density and traffic situation on the road. The following subsections describe the performance comparison of AIDVC with three other dissemination models for VANETs for different network scenarios and fixed and variant CBR.

5.1.1.1 Performance comparison for low density network scenario and fixed CBR

The Figure 5.1 shows the comparative study of number of vehicles on a specified segment of road in a low dense network scenario (number of vehicles ranges from 40-240) against packet delivery ratio. This graph presents the PDR as a function of CBR. The value of CBR in this comparison is taken as 2 (p/s).

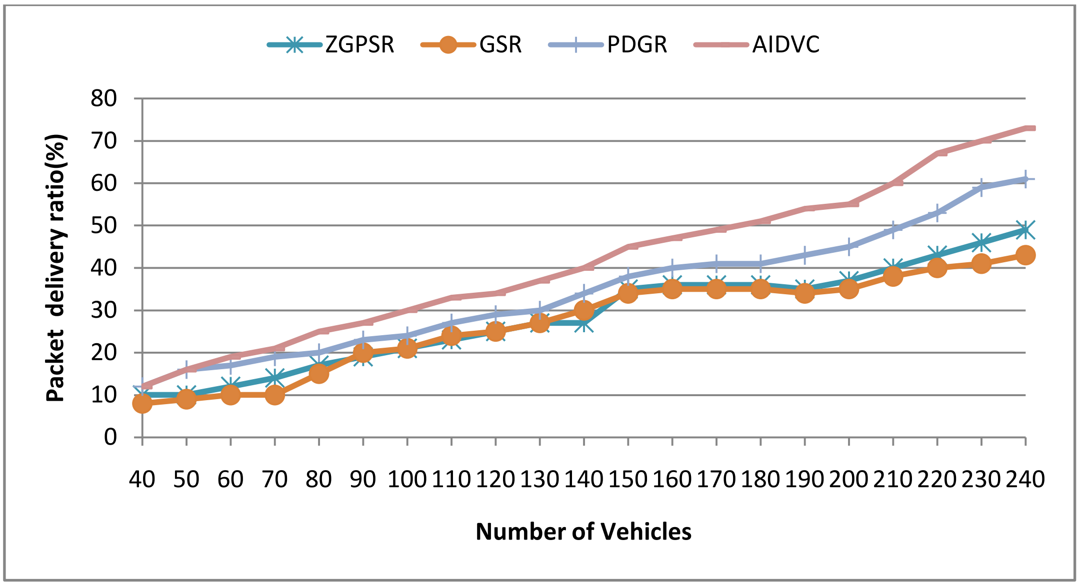


Figure 5.1: Packet delivery ratio for fixed CBR and low density network situation (lesser than or equal to 240 vehicles per road segment)

As it can be seen from the Figure 5.1, Packet delivery ratio for all the four system models is at lower side at the beginning because it is very difficult to get a complete path for information sending from the source to the receiving vehicle. The value of PDR for both GSR and ZGPSR are almost similar till the number of vehicle reach150. After that PDR for ZGPSR is on the higher side because as the number of vehicle increase, there is a greater chance for a vehicle carrying the data to be sent or forward it to in a greedy fashion. Although ZGPSR has the tendency for perimeter phase when greedy forwarding is not available[108], it has greater chance for the greedy forwarding in populated small zones of network. The maximum value for PDR achieved is 49% when the number of vehicles is around 240. The GSR uses the pre-selected paths for sending the information to the receiver. When the network density is very low it is very difficult to have all the links connected. But when the network density becomes on the higher side more links are available and PDR for GSR becomes higher. The maximum value for PDR achieved is 42% when the number of vehicles is 240. It is lowest as compared to all other dissemination models. PDGR and AIDVC have better PDR, because they have no restriction on the routing path. At any instant of time they can change their selected path. Moreover they consider the vehicles going in same direction/ opposite direction to forward data. AIDVC is more careful when the optimal link selection is concerned. It uses semi prediction mechanism as compared to the Greedy forwarding used by PGDR. The network load is distributed using the various types of domains used by AIDVC. PGDR is better in terms of PDR than that of ZGPSR and GSR in low dense network scenario. PGDR attains maximum PDR as 61% where as AIDVC has 73% as max PDR at 240 vehicles.

5.1.1.2 Performance comparison for low density network scenario (fixed number of vehicles 160) and variant CBR

Figure 5.2 shows the comparative study of number of vehicles on a specified segment of road in a low dense network scenario (number of vehicles is fixed at 160) against packet delivery ratio. This graph presents the PDR as a function of CBR. In this comparison, the values of CBR are variant ranging from 0.1 to 4 p/s. The results show that the GSR has relatively better PDR when the CBR value is low. GSR can find enough preselected paths for sending the data. But when the CBR value gets high i.e. from 1.5 to 4, the preselected path gets heavily congested and more and more packet drop due to congestion resulting in low PDR.

The performance of ZGPSR is affected at higher CBR. Although the perimeter phase can be helpful in absence of greedy forwarding when there are enough forwarders available. The zone based architecture also helps in controlling the amount of data to be forwarded. But higher values of CBR create the congestion. ZGPSR performs better than GSR in PDR and the maximum PDR is 37% when the CBR is 1.25 as compared to the maximum value of 34% at same CBR. Whereas the opportunistic behavior of PGDR favors the higher values of CBR till it becomes 2.75. It performs better than ZGPSR and GSR but nearly equivalent to AIDVC tills this point of time.

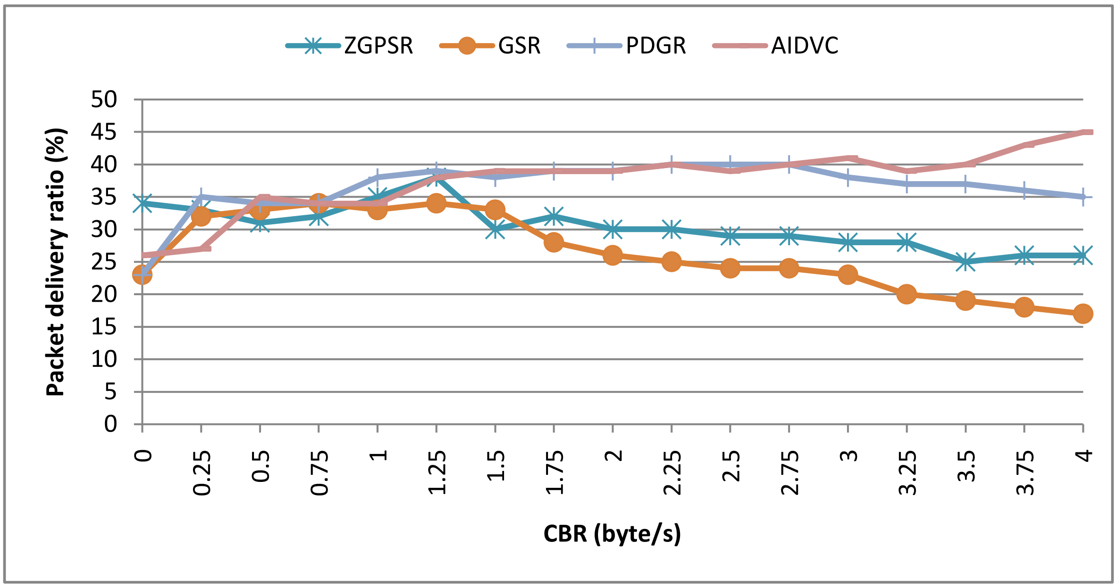


Figure 5.2: Packet delivery ratio for variant CBR (0.1 to 4) and low density network situation (number of vehicles fixed at 160)

At higher values of CBR i.e. more than 2.75 PGDR is unable to handle the congestion created by the size of information in the network and from 2.75 to 4 the packet delivery ratio is declining and ends up at 33% when CBR is 4. The graph presented in Figure 4.4 also suggests that AIDVC during this phase i.e. from 2.75 to 4 performs much better than other three models. It handles the congestion created by higher values of CBR well and packet delivery ratio is much better than other techniques in the comparative process.

5.1.1.3 Performance comparison for high density network scenario and fixed CBR

This section explains the comparison of PDR in a high density network scenario (number of vehicles ranges from 240-450). The graphs in Figure 5.3 present the PDR as a function of Constant bit rate (CBR). The value of CBR in this comparison is taken as 2 (p/s)

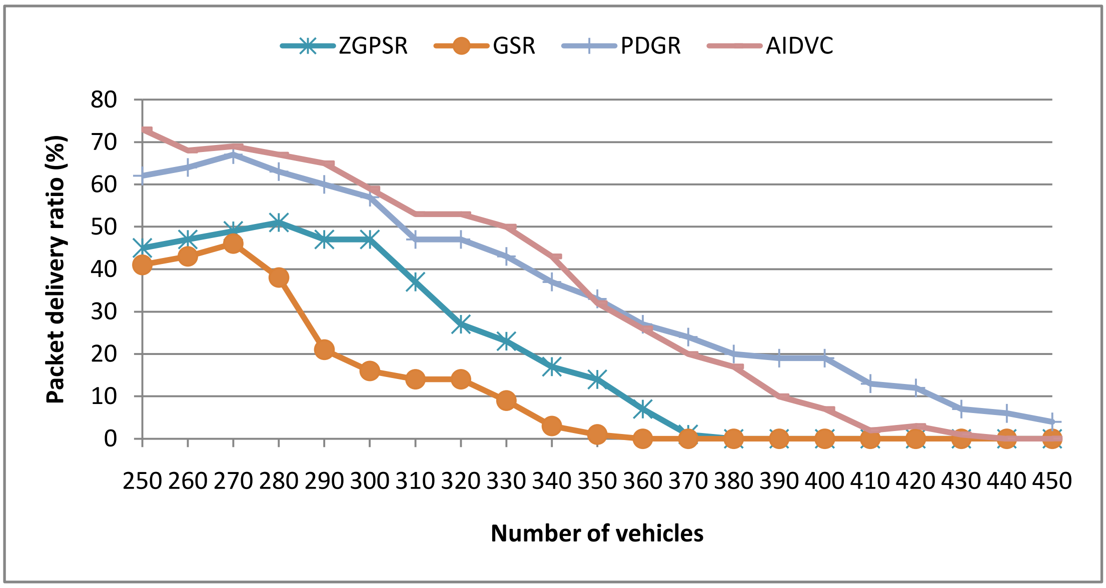


Figure 5.3: Packet delivery ratio for fixed CBR and high dense network situation (vehicles greater than 240 and lesser than or equal to 450)

The value of PDR for GSR tends to grow till the number of vehicles reaches 270 with maximum PDR of 47% but after that it is declining and fails when the number of vehicle reaching 350. The preselected links become heavily congested and the packet drop rated due to time constraints become very high ultimately resulting bottleneck situation. ZGPSR on the other hand behaves slightly better than GSR. ZGPSR have maximum value of PDR when the number of vehicles is 280. The advantage of having zones in ZGPSR make the performance better in terms of PDR but the inter-zonal congestion due to heavy data load makes the model fail to deliver when number of vehicles becomes 370. In a high dense scenario as shown in this graph the heavy data load affect the performance of both PDGR and AIDVC. AIDVC performs better than all other models. The maximum PDR it attains is 74% when the number of vehicles is 250. The maximum value of PDR for PDGR is 66% when number of vehicles is 260. But when the number of vehicles becomes higher than 350, AIDVC performance is worse than PDGR. This is because PDGR uses opportunistic approach for forwarding the data. There are quite a number of vehicles in dense situation which leads the information to the destination. Although AIDVC uses congestion control mechanism and best optimal link for forwarding the data, the limited time factor affect its performance and AIDVC fail to deliver when number of vehicles exceeds to 420.

5.1.1.4 Performance comparison for high density network scenario (fixed number of vehicles 320) and variant CBR

The Figure 5.4 shows the comparative study of number of vehicles on a specified segment of road in a high density network scenario (number of vehicles is fixed to 320) against packet delivery ratio. This graph presents the PDR as a function of carrier bit rate (CBR).

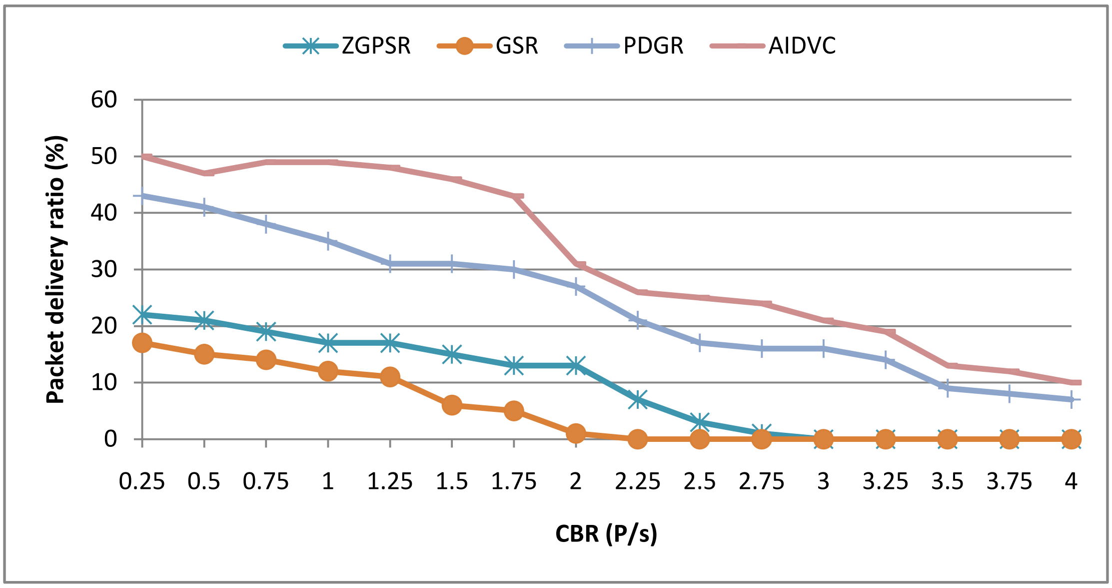


Figure 5.4: Packet delivery ratio for variant CBR (0.1 to 4) and high density network situation (number of vehicles fixed at 320)

In high vehicle density, GSR with lower CBR tends to deliver packets better. But due to its ability of pre-selected path mechanism, the best and dynamic links created during highly mobile network may not be chosen. It results in low PDR. As the CBR increases, ZGPSR also gets the PDR lower side due to its ability of perimeter phase activation in absence of greedy forwarding. The perimeter phase tendency is at lower side as a number of links available for greedy forwarding are enough. Also its zonal activities are well within its control. But the CBR ratio increases the network load which results in packet drop. Both GSR and ZGPSR fail to send data over the link when the CBR value exceed to 2 for GSR and 2.75 for ZGPSR. Maximum values of PDR for GSR and ZGPSR are 17% and 23% respectively when CBR value is 0.25. PGDR works fine in this scenario as it can be seen from the graph above. The performance of PDGR declines with the increase in CBR. Prediction of link breakage and greedy nature of PDGR is able to handle the network load in a reasonable manner and the PDR although is very low when the CBR is 4, still it is able to handle the network congestion well. Maximum value of PDR for PDGR is 43% when CBR is 0.25 and minimum value of PDR is 7% when CBR is 4. AIDVC has outperformed all three techniques in this scenario.

Although increased CBR values also affects its performance. The methods for better load management, optimal link selection for sending the information, congestion control mechanism and the modular approach used for different type of information help to deliver better PDR. Maximum value of PDR for AIDVC is 49% when CBR is 0.25 and minimum value of PDR is 10% when CBR is 4.

5.1.2 End-to-end delay

End-to-end delay in packet transmission is also affected by the network density and traffic on the road in a vehicular network system. The following subsections describe the performance comparison of AIDVC with GSR, ZGPSR and PDGR for different network scenarios and CBR values.

5.1.2.1 Performance comparison for low density network scenario and fixed CBR

The comparative study of number of vehicles on a specified segment of road in a low dense network scenario (number of vehicles ranges from 40-240) against end-to-end delay is shown in Figure 5.5. This graph presents the end-to-end delay as a function of carrier bit rate (CBR). The value of CBR in this comparison is taken as 2 (p/s).

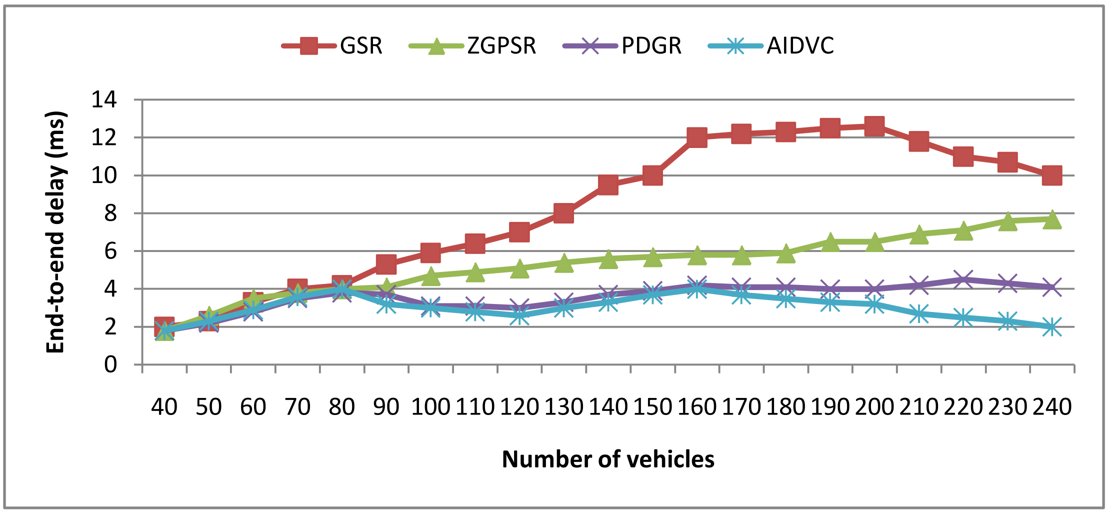


Figure 5.5: End-to-End Delay for fixed CBR (2 p/s) in low density network situation (vehicles less than or equal to 240)

Initially when the number of vehicles is low the end-to-end delay is low for all participating models. But as the number of vehicles increases the end-to-end delay for all the models is affected. It can be seen that the highest increased in the end-to-end delay is in GSR. Initially there are enough pre-selected links available for information to be disseminated. As the number of pre-selected paths increase the network load increase and due to heavy congestion the end-to-end delays increase. On the other hand, initially the value of end-to-end delay for ZGPSR is low and it increases till the range of vehicle is from 40 to 80. There is gradual increase in the end-to-end delay thereon. But the performance is much better than that of GSR due to its opportunistic nature. The greedy dynamic nature of PDGR makes it better in terms of end-to-end delay than that of GSR and ZGPSR and it shows stability for vehicle density from 80 onwards. Maximum end-to-end delay for GSR is 13 ms when the number of vehicles becomes 200 and 7.9 ms when the number of vehicles in the network becomes 240. The self-healing process in GSR is activated when the number of enough relay nodes are available i.e. 200. Then its performance gradually becomes better in terms of end-to-end delay. AIDVC initially like all the three models, it shows the tendency to increase as far as the end-to-end delay is concerned. But as the number of vehicles increases from 160 it becomes more stable than other models. Increase in the number of vehicles does not have an effect on its performance as it applies good congestion control mechanism than the other models. Moreover its selection of optimal link as has the positive impact. AIDVC has maximum end-to-end value 4.2 ms when the number of vehicle is 160.

5.1.2.2 Performance comparison for low density network scenario (fixed number of vehicles 160) and variant CBR

The performance comparison of CBR vs. end-to-end delay is shown in the Figure 5.6. This is a low dense scenario in which number of vehicles is fixed as 160 and the CBR is kept variant. End-to-end delay is a function of CBR. As the graph shows that the value of end-to-end delay for all the models is affected by the increase of CBR value. AIDVC performs much better than all other models due to its modular approach and better congestion control mechanism. The end-to-end value remains almost same for all ranges of CBR below 0.5. PDGR although is much better than GSR and ZGPSR due to its greedy forwarding nature. There are enough links available for PDGR for greedy forwarding at 160 vehicles in the network.

The maximum value of end-to-end delay for PDGR is 6.9 ms as compared to that of AIDVC which is 5.1 ms for the same value of CBR i.e.4. End-to-end value of GSR gradually increases due to the load on the network by increased CBR value. It is 19.7 ms when CBR is 4. It is due to the fact that the pre-selected paths for data forwarding gets overload. The more loss of packets will requires sending the desired information again and again, thus increases in end-to-end delays.

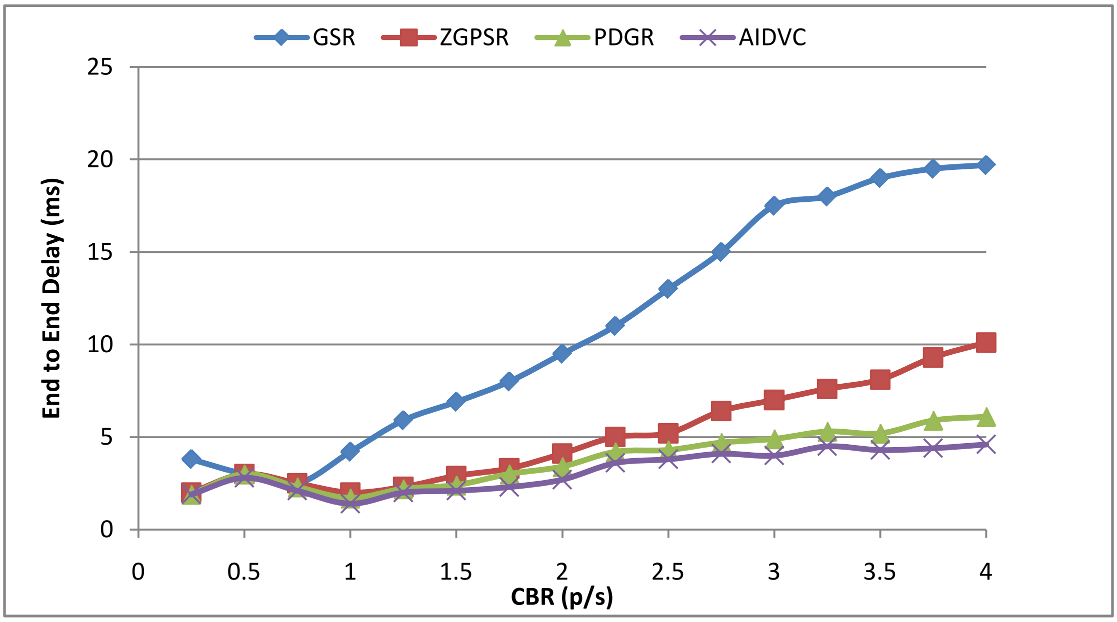


Figure 5.6: End-to-End Delay for variant CBR with fixed no of vehicles in low density scenario (number of vehicle=160)

The greedy forwarding for ZGPSR is most likely available when the number of vehicles in the network is 160 and there is a little need of perimeter phase to be activated. On the other hand maintaining the zones also help to handle the network congestion and resulting in better performance for end-to-end delay than that of GSR. The maximum end-to-end delay for ZGPSR is 10.1 ms when CBR is 4. The results shown in the Figure 5.6 suggest that AIDVC performs much better that the other models for the specific scenario.

5.1.2.3 Performance comparison for high density network scenario and fixed CBR

Figure 5.7 shows the comparative study of number of vehicles on a specified segment of road in a high dense network scenario (number of vehicles ranges from 250-450) against end-to-end delay. The value of CBR in this comparison graph is fixed at value 2 (p/s). This graph presents the end-to-end delay as a function of CBR. It can be seen from the graph that increases in the number of vehicles increases the end-to-end delay for all the models.

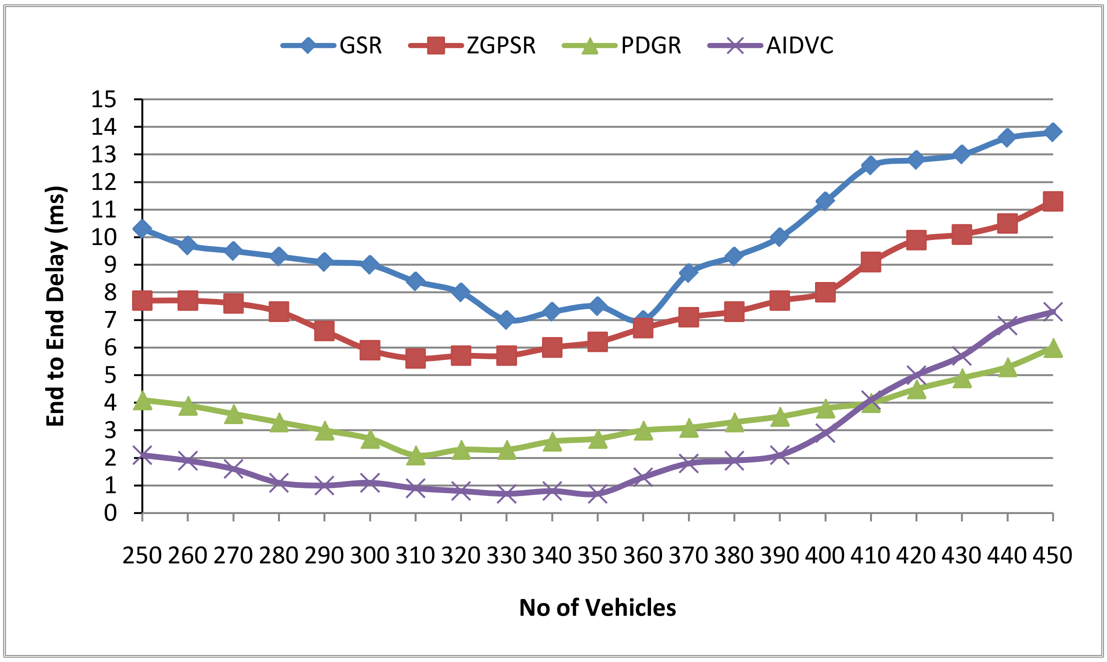


Figure 5.7: End-to-End Delay for fixed CBR (2 p/s) in high density network situation (vehicles greater than 240 and smaller than or equal to 450)

The end-to-end delay for GSR is the highest when the number of vehicles is 250. At this point the available of pre-selected links gets higher and it activates its self healing process. The end-to-end delay gets better till the number of vehicles become 360. After that the number of pre-selected links gets over loaded, increase and heavy congestion is created resulting in high end-to-end delays. Minimum and maximum end-to-end delays for GSR for this scenario are 6.9 ms and 13.9 ms when number of vehicles is 330 and 450 respectively. Initially for the number of vehicles 250, the value of end-to-end delay for ZGPSR is 7.8 ms. It gets as low as 5.5 ms when number of vehicle become 310. After which it increases gradually due to network overload till 450 and at this point end-to-end delay becomes 11.8 ms. But the performance is better than that of GSR due to its opportunistic nature. The greedy dynamic nature of PDGR makes it better in terms of end-to-end delay than that of GSR and ZGPSR and it shows stability when vehicle density increases. AIDVC shows stability as far as end-to-end delay is concerned as compared to other models due to good congestion control mechanism. But when the number of vehicles becomes more then 410 end-to-end delay becomes more than PDGR. And PDGR due to its greedy nature has an edge on AIDVC. Minimum and maximum end-to-end delays for PDGR are 2.1 ms and 6.1 ms when number of vehicles is 310 and 450 respectively and for AIDVC the minimum and maximum values are 0.8 ms and 7.3 ms when number of vehicles is 350 and 450.

5.1.2.4 Performance comparison for high density network scenario (fixed number of vehicles 320) and variant CBR

This section is the comparison of performance of CBR vs end-to-end delay for high dense scenario. This scenario considers the number of vehicles is fixed at 320 and the CBR is kept variant. End-to-end delay is a function of CBR. Figure 5.8 shows the comparison results of various models.

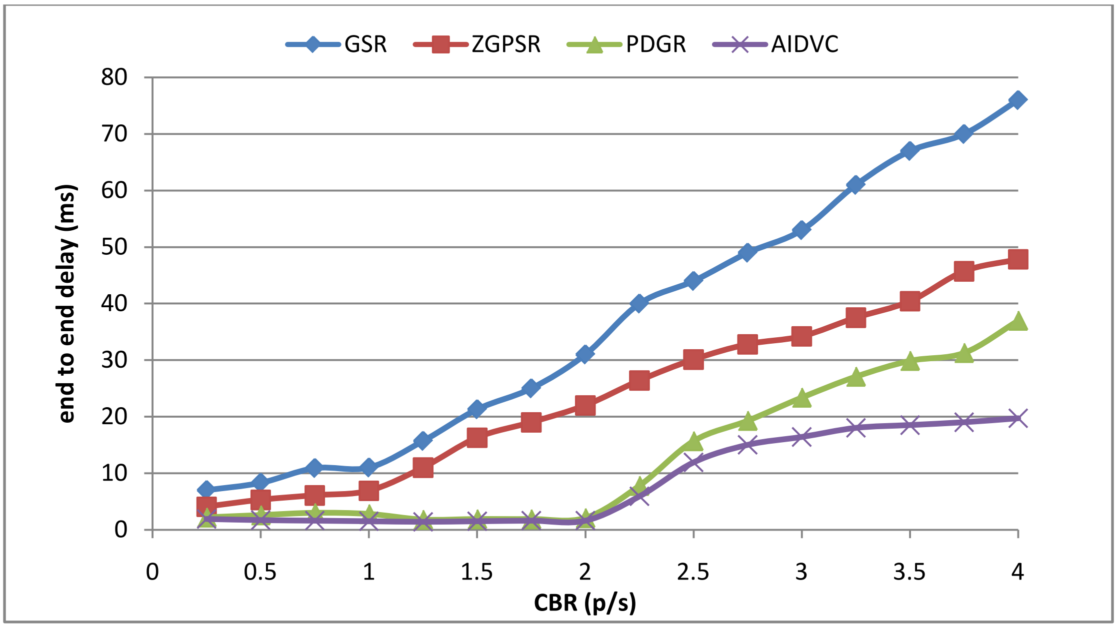


Figure 5.8: End-to-End Delay for variant CBR in high density network situation (number of vehicles fixed at 320)

The graph shows that AIDVC has better end-to-end delay than all other models. As the CBR value increases the performance of all the contesting models lowers. The performance of AIDVC and PDGR is almost similar till the CBR value is 2. But after that better congestion control mechanism applied by AIDVC gets over all other models. Minimum value of end-to-end delay for AIDVC is 1.5 ms when the CBR value is 2.25 ms and maximum value is 19.7 ms when CBR is 4. The minimum and maximum values for PDGR are 1.8 ms and 37 ms when CBR is 1.25 and 4 respectively. Maximum values of end to end delay for GSR and ZGPSR are 76 ms and 47.8 ms respectively for maximum CBR. The performance comparison shows that AIDVC has outclass all three models in terms of better end-to-end delay for this specific scenario.

5.1.3 Throughput

Throughput is defined as the successful rate for the delivered packets over the communication channel (or the number of successful data bytes received by the device per unit time). The following result analysis was done for two variant density situations, Low density in which number of vehicles range is 40-240 and High dense network situation for 250-450 vehicles. This range of vehicles may change according to the situations affecting the network performance throughput. AIDVC and other three dissemination models for VANETs are examined for throughput for different network scenarios and CBR values.

5.1.3.1 Performance comparison of number of vehicles vs throughput in low density network (40-240 vehicles) with fixed CBR

. Figure 5.9 shows the comparative study of number of vehicles on a specified segment of road in a low dense network scenario (number of vehicles ranges from 40-240) against packet delivery ratio. This graph presents the PDR as a function of carrier bit rate (CBR). The value of CBR in this comparison is taken as 2 (p/s).

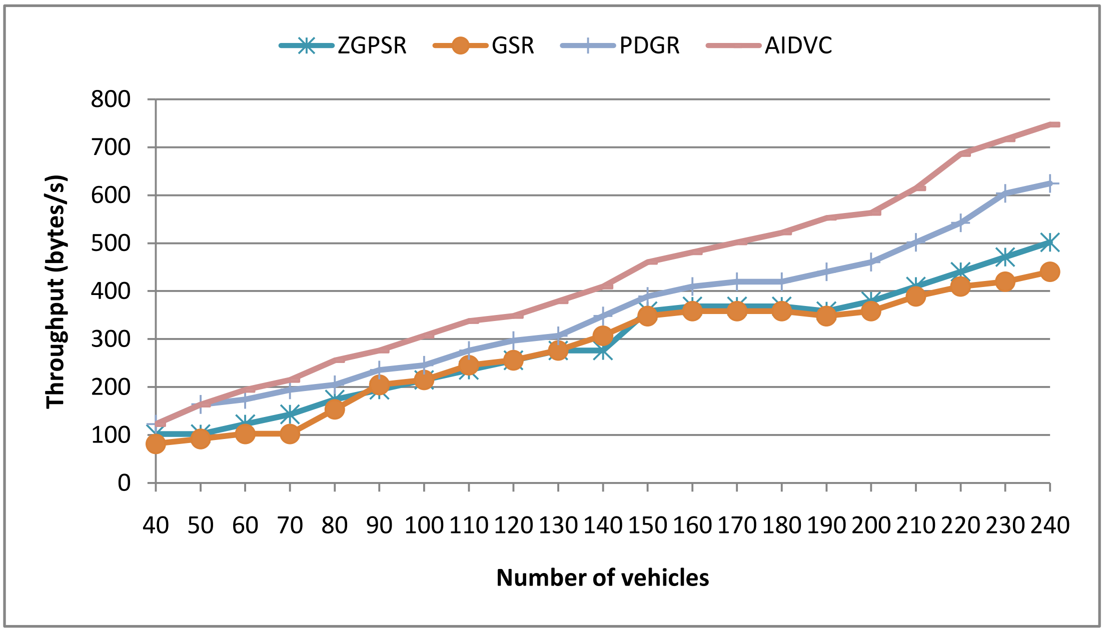


Figure 5.9: Throughput for fixed CBR (2 p/s) and low density network scenario (number of vehicle 40-240)

Throughput for all the four models is at lower side at the beginning because it is very difficult to get suitable link for sending information from the source to the receiving vehicle. Throughput values for both GSR and ZGPSR are almost identical till the number of vehicle reach 200. Throughput for ZGPSR gets better than GSR because as the number of vehicle increase, there is a greater chance for a vehicle carrying the data to be sent in a greedy way. ZGPSR has greater chance for the greedy forwarding rather than perimeter phase activation in populated small zones of network. The maximum value for throughput achieved is 502 bytes/s when the number of vehicles is 240. The GSR uses the pre-selected paths for sending the information to the receiver. When the network density is very low it is very difficult to have all the links connected. At better density more links are available. Throughput for GSR becomes higher. Throughput gains maximum value of 440 bytes/s at 240 vehicle number. PDGR and AIDVC have better throughput overall, because they have no restriction on the routing path direction and selection. At any instant of time they can change their selected path. AIDVC is more careful when the optimal link selection is concerned. It uses semi prediction selection mechanism as compared to the Greedy forwarding used by PGDR. The network load is distributed using adaptive features by AIDVC. PGDR attains better throughput for low dense network scenario. Maximum throughput value for PGDR is 525 bytes/s as compared to 747 bytes/s for AIDVC when number of vehicle reaches 240.

5.1.3.2 Throughput for variant CBR value and low density network scenario (number of vehicle fixed at 160)

Figure 5.10 illustrates the throughput against variant values of CBR in a low dense network scenario (number of vehicles is fixed at 160). This graph presents the throughput as a function of CBR. The values of CBR are ranging from 1 p/s to 4 p/s. The results show that although the GSR has relatively better throughput when the CBR value is low. GSR can find enough preselected paths for sending the data when the number of vehicles is 160. But when the CBR value gets high i.e. from 2.75 to 4, the preselected path gets heavily congested and more and more packet drop due to congestion causing low throughput.

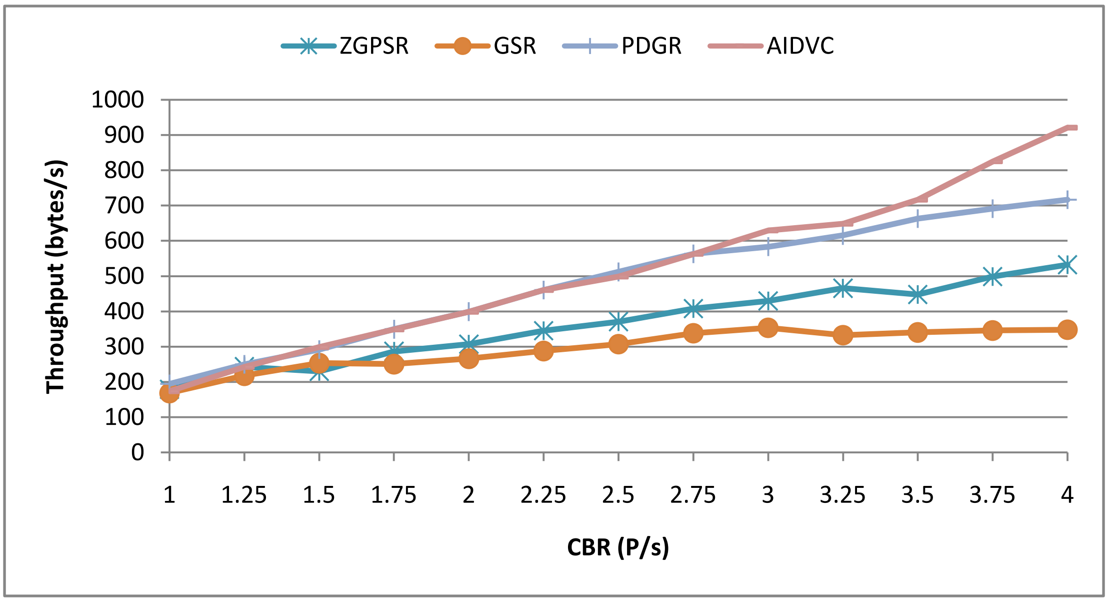


Figure 5.10: Throughput for variant CBR (1 to 4) and low density network situation (number of vehicles fixed to 160)

The performance of ZGPSR is affected at higher CBR. The zonal based architecture also helps in controlling the amount of data to be forwarded in a greedy fashion. But higher values of CBR create the congestion. ZGPSR performs better than

GSR in terms of throughput when the value of CBR is 1.75 or higher. Maximum and minimum values are 353 bytes/s and 169 bytes/s for GSR and 533 bytes/s and 179 bytes/s for ZGPSR. The opportunistic behavior of PGDR favors the higher values of CBR till it becomes 2.75. PGDR performs better than ZGPSR and GSR. It performs nearly equivalent to AIDVC till the value of CBR becomes 2.75. At higher values of CBR i.e. more than 2.75 PGDR is unable to handle the congestion created by the size of information in the network and from 2.75 to 4 the throughput does not have that rapid progress it ends up at 717 bytes/s when CBR is 4. The graph presented in Figure 4.12 also suggests that AIDVC during this phase i.e. from 2.75 to 4 performs much better than other three models. It handles the congestion created by higher values of CBR well and throughput is much better than other techniques. The maximum value of throughput for AIDVC in this scenario is 921 bytes/s.

5.1.3.3 Throughput performance comparison for high density network scenario and fixed CBR

This section explains the comparison of throughput in a high dense network scenario (number of vehicles ranges from 240-370). The graph shown in the Figure 5.11 presents the throughput as a function of CBR. The value of CBR in this comparison is taken as 2 (p/s)

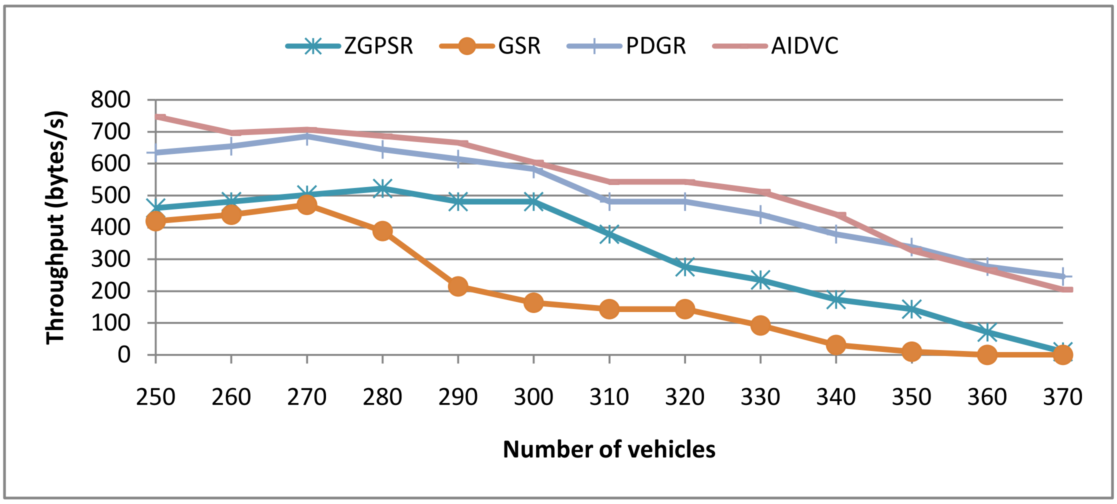
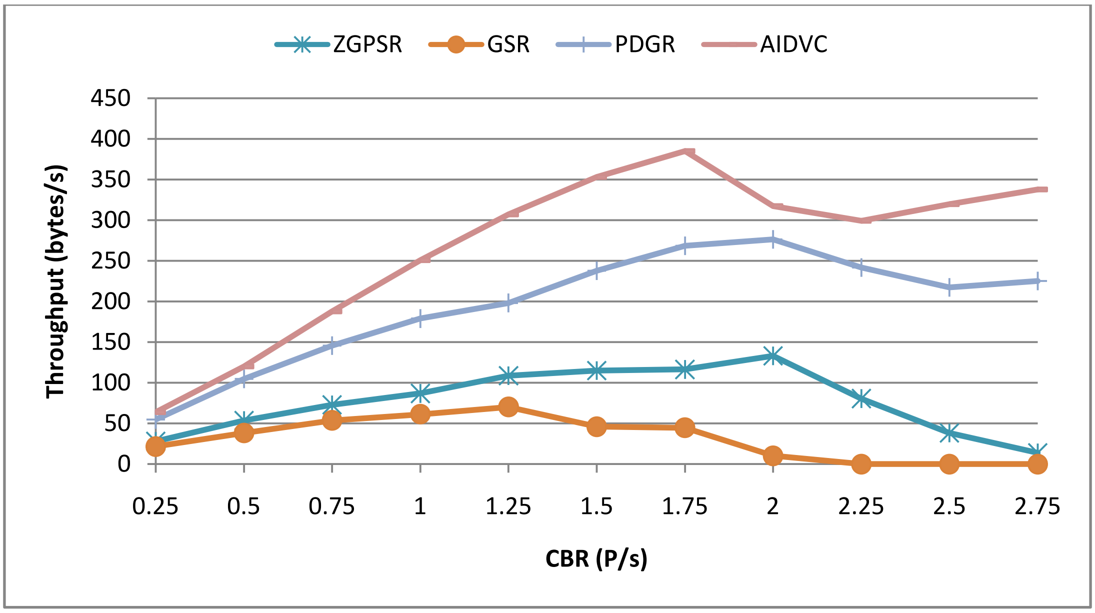


Figure 5.11: Throughput for fixed CBR and high density network situation (vehicles greater than 240 and lesser than or equal to 370)

Throughput for GSR is at higher note till the number of vehicles becomes 270. The maximum throughput value for GSR is 471 bytes/s. when the number of vehicles becomes greater than 280 the value for throughput declines and it fails when the number of vehicles becomes more than 350. ZGPSR on the other hand behaves slightly better than GSR. ZGPSR have maximum value of throughput i.e. 522 bytes/s when the number of vehicles is 280. The advantage of having zones make the performance better in terms of throughput but the inter-zonal congestion due to heavy data load makes the model fail to deliver when number of vehicles become 370. In a high dense scenario, as shown in this graph the performance of both PDGR and AIDVC are also affected by increase in number of vehicles. AIDVC performs better than all other models. The maximum throughput value it attains is 747 bytes/s when the number of vehicles is 250 and maximum value of PDGR is 686 bytes/s when number of vehicles is 270. When the number of vehicles becomes 340 or more, AIDVC performance for throughput lowers than PDGR. PDGR uses opportunistic approach for forwarding the data which leads small amount of information to the destination. Despite of the fact that AIDVC uses congestion control mechanism and best optimal link for forwarding the data, the limited time factor affect its performance.

5.1.3.4 Throughput for high density network scenario (fixed number of vehicles 300) and variant CBR

This section shows the comparative study of variant CBR in a high dense network scenario (number of vehicles is fixed to 300) against throughput. This graph in the Figure 5.12 presents throughput as a function of CBR.



.Figure 5.12: throughput for variant CBR (0.25 to 2.75) and high dense network situation (number of vehicles fixed to 300)

Pre-selected path mechanism opted by GSR tends to neglect best and dynamic links created during highly dynamic network. It results in low throughput values. ZGPSR also has lower throughput due to its ability of perimeter phase activation in absence of greedy forwarding. Although the perimeter phase tendency is at lower side as a number of links available for greedy forwarding are enough. Also its zonal activities are well within its control. The CBR increases the load on the network resulting in lowering the throughput of the network. Both GSR and ZGPSR fail to send data over the link when the CBR value exceed to 2 for GSR and 2.75 for ZGPSR. Maximum values of throughput for GSR and ZGPSR are 70 bytes/s and 133 bytes/s when CBR values are 1.25 p/s and 2 p/s respectively. PGDR works fine in this scenario as it can be seen from the graph above. The performance of PDGR lowers with the increase in CBR. Prediction of link breakage and greedy nature of PDGR is able to handle the network load in a reasonable manner and the throughput although is very low when the CBR is 2.75; still it is able to handle the network congestion well enough. Maximum value of throughput for PDGR is 276 bytes/s when CBR is 2 and minimum value is 55 bytes/s when CBR is 0.25. AIDVC has outperformed all other three techniques in this scenario, although the increased CBR values also affect AIDVC performance. The methods for better load management, optimal link selection for sending the information, congestion control mechanism and the modular approach used for different type of information help to produce better throughput in AIDVC. Maximum value of throughput for AIDVC is 385 bytes/s when CBR is 1.75 and minimum value of AIDVC is 64 bytes/s when CBR is 0.25.

5.1.4 Routing Overhead

In this section, comparative study of routing overhead is discussed. The routing overhead may include the beacon messages and excessive number of intermediate hops in the dissemination model. But for all these models in the comparison, beacon messages use almost the same method. Therefore average number of hops is used to calculate the routing overhead here. It is observed in general that when the number of intermediate hops increases in the dissemination process, it may increase the congestion and ultimately may increase the delays. This will result in less packet delivery ratio and throughput. Packet transmission is also affected by the network density and traffic on the road in a vehicular system because in dense network situations the intermediate hops increases dramatically. It is observed that smaller but enough the number of vehicles on the road constitutes the lesser number of intermediate hops. The following subsections describe the performance comparison with respect to average number of hops (called the routing overhead in this calculation).

5.1.4.1 Performance comparison of routing overhead vs number of vehicles in low density network scenario and fixed CBR

The graph in the Figure 5.13 presents the performance of all participating dissemination models in terms of intermediate hops (routing overhead) for a low dense network scenario when the number of vehicles ranges from 40 to 240 and the CBR is fixed at 2 p/s. When the number of vehicles is smaller, then the routing overhead for all the models is a bit high. GSR has the highest overhead as pre-selected paths are not available. When it gets some pre- selected path, due to high mobility it may break and find some other path. Due to this factor at initial stages the over head is quite high. Maximum value of overhead is 9.7 when the number of vehicles is 40. It becomes better with the increase in the number of vehicles. When the number of vehicles becomes greater than 160 there is slight increase in overhead due to increase of information in the network. The overhead value ends up at 7.3 when the number of vehicle becomes 240.

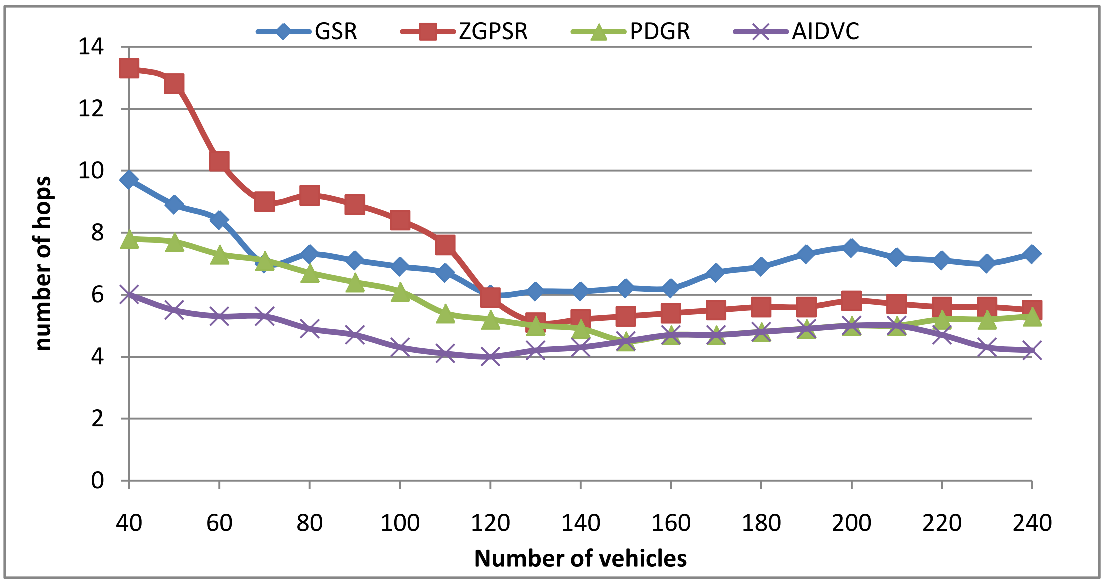


Figure 5.13: Routing overhead for fixed CBR (2 p/s) and low density network scenario (number of vehicle 40-240)

ZGPSR is worst as far as the network overhead is concerned in the beginning. Initial value for average number of hops is 13.3 when number of vehicle is 40 and its gets better than GSR when the number of vehicles reaches 120 due to its greedy forwarding behavior and less number of perimeter phases. It becomes stable till 240 vehicles from thereon having 5.3 as average number of hops at this stage. Initial value of average number of hops for PDGR like GSR and ZGPSR is quite high as 7.8. It is much better than other two techniques. AIDVC starts smoother than all other three and increase in the number of vehicle has very little effect on its throughput performance. PDGR behaves quite similarly to AIDVC in the range 150-210. After that AIDVC has improved performance than PDGR when the number of vehicles is in the range of 210-240. Maximum values of average number of intermediate hops for AIDVC and PDGR at 240 vehicles in the network are 4.2 and 5.3 respectively.

5.1.4.2 Performance comparison of routing overhead vs number of vehicles in low density network scenario and variant CBR

Figure 5.14 shows the comparison of average number of intermediate hops as a function of CBR. The value of CBR is variant and the number of vehicle in the network is kept fixed at 160. As the graph suggest, the performance of all the models is affected by the increase in CBR rate. Higher CBR value adds extra network load on the network.

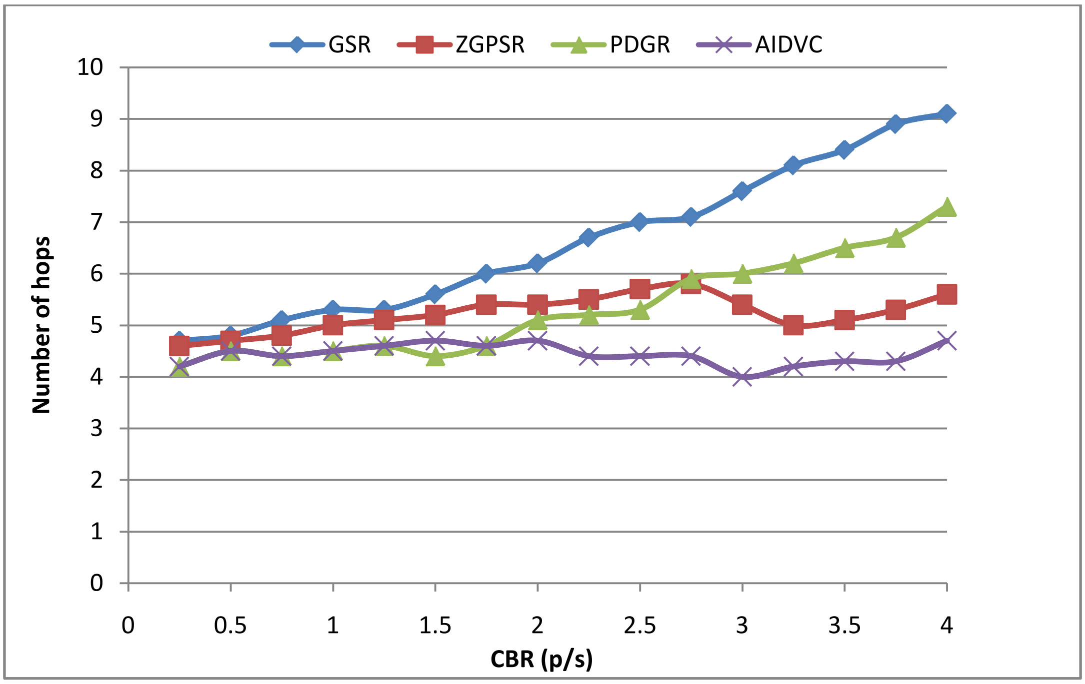


Figure 5.14: Routing overhead for variant CBR and low density network scenario (number of vehicles fixed at160)

Initially as there is enough number of vehicles in the network the average number of intermediate hops is reasonable. But as the CBR value increases the performance of all the models deteriorates. Most affected model is GSR in which the minimum and maximum value ranges from 4.7 to 9.1. The pre-selected paths gets overload due to the higher values of CBR and dissemination of packets is hard in this model. ZGPSR performs better than GSR and PGDR when CBR value is greater than 2.75. As the overload created by the increase in CBR is catered efficiently within the zone created by ZGPSR. Load is fairly distributed and it performs well. AIDVC and PDGR behave almost similarly till the CBR becomes 1.75. PDGR being opportunistic forwarding technique, less optimal forwarding links tend to become overloaded and the performance gets better. PDGR performs even worse than ZGPSR when CBR becomes 2.7 onwards. AIDVC outperforms all other models due to its modular approach. It can handle data load more efficiently due to its selection of optimal links for forwarding. Due to the link life time estimation mechanism less forwarders are required. It may help AIDVC for better average number of forwarding hops as compare to other models.

5.1.4.3 Performance comparison of routing overhead vs number of vehicles in high density network scenario and fixed CBR

The Figure 5.15 shows the comparative study for average number of hops against number of vehicles for a high dense network scenario. The number of vehicle ranges from 240 to 450. The value of CBR is kept constant at 2 p/s.

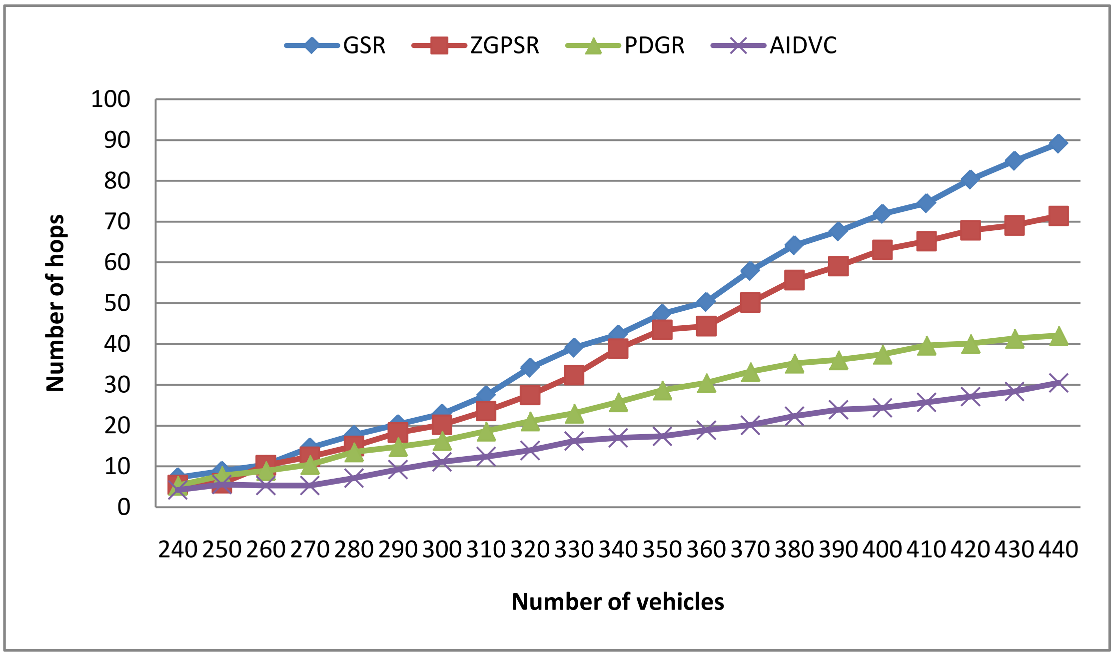


Figure 5.15: Routing overhead for fixed CBR (2 p/s) and high density network scenario (number of vehicle 240-450)

As the number of vehicles increases the performance of all the dissemination models is affected. As the number of preselected paths in GSR increase due to the increase in the number of vehicles, it sends more and more data on the links and due to the high mobility of the network these preselected links tend to break more frequently. This can cause resending the data on the links again and again. ZGPSR although gets enough amount of perimeter stages for forwarding packet in absence of greedy forwarding, it also tries to maintain the zones. Keeping zonal activities within control it may send data to various unrated links causing extra number of intermediate hops in high density. But still it performs better when compared with GSR. PDGR due to its predictive behavior predicts the suitable links and forward the data. On the other hand it also senses the direction of receiving node. This is why it works better than GSR and GPSR. AIDVC on the other hand have a semi predictable behavior. It not only senses the direction to have better link selection mechanism. Link life time calculation and optimal link selection in AIDVC gives clear advantage over all other models in the comparison. As the graph suggests, AIDVC has outclass all other models.

5.1.4.4 Performance comparison of routing overhead vs number of vehicles in low density network scenario and variant CBR

This section examines the performance of GSR, ZGPSR, PDGR and AIDVC when the network is highly dense (number of vehicles is fixed at 320) and the CBR is kept as variant. When the CBR is below 1.25 the performance of all the models is almost identical but as the CBR increases the network tends to overload. More and more links are needed to send packets on. Figure 5.16 shows the network situation for average number of hops for various models. The most effected model in this comparison is the GSR. Firstly as shown in the Figure 5.15, increased number of predefined links can cause its performance on the lower CBR. Secondly, increased value of CBR generally, but for GSR specially cause network congestion. For handling the situation, more and more alternative preselected links are discovered causing increase in number of hops.

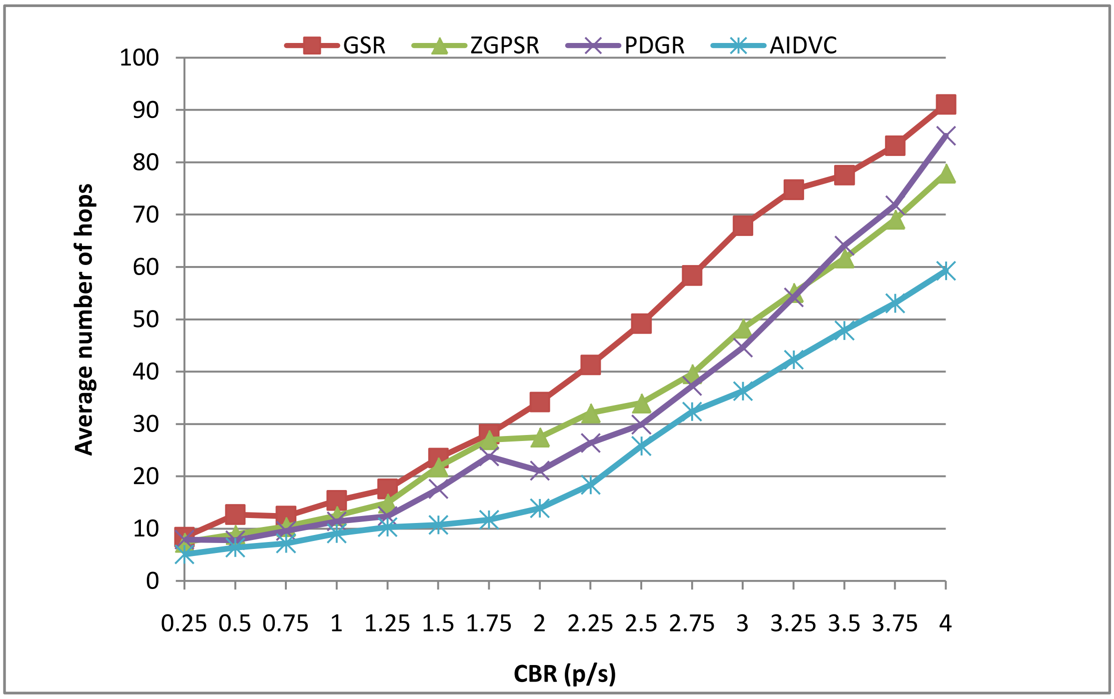


Figure 5.16: Routing overhead for variant CBR and high density network scenario (number of vehicles fixed at320)

PGDR and ZGPSR behave almost identical till CBR value reaches to 3.5. After that ZGPSR performs slightly better than PDGR. It is due to the local calculation in the zones that ZGPSR somehow mitigate the network congestion effect. AIDVC outperforms all other models for this specific scenario. Its optimal link selection on the basis of link stability and life time makes a clear difference as far as average number of hops is concerned. Maximum average number of hops for AIDVC is 59.3 where as for PDGR, ZGPSR and GSR, the values are 85.1, 79.9 and 91.1 respectively.

5.2 Summary

This chapter described the results obtained by the proposed model. The results obtained from the proposed model were evaluated against GSR, ZGPSR and PDGR for different network densities and CBR values. The comparative results were carefully discussed. From the simulation results obtained and analyzed, it was found that the proposed model had performed better for various performance parameters than that of GSR, ZGPSR and PDGR. The proposed model bears the following advantages: better packet delivery ratio, reduced end-to-end delays, small overhead values and better throughput values for variety of network situations.

CHAPTER 6

CONCLUSION AND FUTURE WORK

This chapter concludes the work accomplished with emphasis in the vertical of the information dissemination in VANETs. The achievements of this research work are also discussed. The limitations of this work and some recommendations/suggestions for future work are proposed in the later section in this chapter.

6.1 Conclusion

Both academia and the automotive industry have contributed towards the development of state-of-the-art applications in VANET. The growing trend to provide on the road communication from vehicle-to-vehicle (V2V), vehicle to infrastructure (V2I) and vice versa has provided many opportunities to develop non-safety, safety and safety-of-life applications for VANETs. With information dissemination being the focus of this dissertation, the advantages and disadvantages of the previous work in information dissemination have been sorted out. Some shortcomings of previous information dissemination models, namely, reusability issues, lack of aggregation mechanisms, categorical division of information, improper co-relation mechanisms for optimal link selection, lack of use of full utilisation of vehicular networks, link life time and link stability, have been identified. Keeping in mind these shortcomings in the previous research works, “An adaptive information dissemination model for VANET communication” is proposed. The proposed model comprises three major components i.e. an information type splitter, an Application Domain and a Communication Domain. The objectives achieved in this research work can be summarised as follows.

a) Based on the relevant information dissemination models by other researchers, key link selection parameters were identified. These were velocity, position and inter-vehicle distances. The key link selection parameters identified were used to address the uncertainty issue in the highly unpredictable behaviour of the VANET environment. Calculation of link stability and link life time for the semi prediction behaviour of the network were used to deal with the uncertainty issue. Details of the link stability and link life time implementation were described in Chapter 4, Section 4.2.2 and Section 4.2.6, respectively.

b) Handling the uncertainty issue was made possible by defining a correlation mechanism among the basic link selection parameters. The implementation details of this correlation mechanism were described in Chapter 4, Section 4.2.8.

c) In order to develop a mechanism for separation of data into categories, the Information Splitter is a module was designed. The categorised data are directed to the distinct domains of the proposed model. Safety-of-life data is processed and disseminated mainly in the Communication Domain and safety and non-safety related data are processed and disseminated at the Application Domain. The information splitter working was shown in Chapter 4, section 4.1.1.

d) To process various types of information and keeping the time vs. reliability requirements of various types of information, the proposed model has been divided into two separate domains, namely, the Application Domain and Communication Domain. The Application Domain was designed for disseminating of safety and non-safety information, and the Communication Domain was for disseminating safety-of-life information. Both of the domains have working relationships at various levels. The implementation details and inter-domain relationship of the dissemination model was found in Chapter 3, Section 3.2.1.3 and in Chapter 4, Section 4.3.

e) The inter-working relationship of these domains is vital for the adaptability of the overall model's resources of when and where needed. The Communication Domain is responsible for forwarding the safety of life information. This information needs a vehicle that acts as a forwarder. The road side units (RSUs) may not have computational powers to alter the data, but they may be used as forwarders in the network. This feature was exploited in the Communication Domain. Sections 3.2.1.3 in chapter 3 and section 4.3 in chapter 4 explained how the Communication Domain would use the dump nodes (RSUs which don't have the processing capabilities) for forwarding the safety-of-life information.

f) The proposed ID model is capable of processing variety of information at two distinct domains. The Application Domain was designed for disseminating of safety and non-safety information, and the Communication Domain was for disseminating safety-of-life information. Both of the domains have working relationships at various levels. The implementation details and inter-domain relationship of the dissemination model was found in Chapter 3, Section 3.2.1.2 and chapter 4, sections 4.1 and 4.3.

g) In order to utilise the unused bandwidth resources, the proposed ID model utilises an adoptive mechanism. The adaptive nature of the proposed model enforced both domains to send the information to the other domain in case of underutilised bandwidth in that domain. In this way, the maximum bandwidth utilisation was insured. Ultimately, this was helpful in maximising the system performance. The categorisation of data, the Information Splitter functionalities and data load management were explained in Chapter 3, Sections 3.2.1.2 and Sections 3.2.1.3.

h) Both the Communication Domain and Application Domain have used proper dynamic aggregation mechanisms. The aggregation mechanism was developed and used at two basic levels. Firstly, the request/reply phase and secondly, the potential receiving vehicle level to address the bandwidth utilisation and congestion control. Chapter 4, Sections 4.2, Sub-sections 4.3.1.5 and 4.3.2.1

explained the details of the aggregation mechanism. This aggregation mechanism addresses the congestion problem at the said two levels.

i) The performance of the proposed ID model was evaluated against GSR, ZGPSR and PDGR by implementation through NS-2 and NCTUNs simulators. The results in Chapter 4 showed better overall network performance (increased packet delivery ratio, reduced packet drop ratio, increased throughput and reduced routing overhead).

6.2 Research Contributions

This research has a significant positive impact on the performance of information dissemination in vehicular ad hoc networks. The designed and developed information dissemination model has outperformed the existing information dissemination approaches in terms of improved packet delivery ratio, lowered packet drop ratio, reduced end-to-end delays, lower overhead and improved throughput.

The major contributions in this research work are as follows:

a) In VANET, the network situation changes in a very rapid and uncertain manner. To find a fixed full path from the source to transfer the data from the source to the destination is almost impossible. Thus, instead of finding the exact fixed path from the source to the destination, finding the best available links for the immediate sender and destination approach is a much better choice. The proposed model is able to deal with the uncertainty problem in VANET dissemination systems. For this purpose, this model provides a mechanism to find out the link life time, link stability and weighted factor for every available link. The weighted factor is calculated for adjusting the key link selection parameter involved in the data dissemination model for VANET. This model considers velocity, mutual distance and position as key link selection parameters. The best available link chosen for the dissemination of data is to address the uncertainty issue well. The results show that the system performs better in sparse and dense network situations than other models in comparison. Section 3.6 in Chapter 3 provided the detailed description about handling the uncertainty issue in the information dissemination in VANET.

b) In this dissemination model, the Communication Domain and Application Domain are responsible for disseminating diverse types of data. The Communication Domain has the capability of forwarding the safety-of-life data and the Application Domain is responsible for forwarding safety and non-safety data. Sometimes, either domain can be overburdened. Being a realistic dissemination model, the resources (bandwidth and domain resources) are shared in this situation to reduce the load on the network domains. This adaptive nature of the model limits the congestion created due to a heavy data load on the network and results in a higher packet delivery ratio and throughput, and reduced end-to-end delays. In Chapter 3, Sections 3.2, 3.3, 3.4, 3.5 and 3.7 explained the distinct domains in detail.

c) This work has introduced a module called the Information Splitter. It has the ability to divide the raw information coming from the source node into three main categories of information, i.e., safety-of-life, safety and non-safety information. The designed data packet has a two bit field known as a “data type” field. From which the type of information packet can be identified from the decoded value. It filters out the information and sends it to the appropriate domain for further processing and it also sets the priority of the information packet. Section 3.5.1 of Chapter 3 described the details of the Information Splitter.

In this research work, an optimised information dissemination in vehicular ad hoc networks approach which is known as “An adaptive information dissemination model for VANET communication” has been proposed and implemented. The performance of this model was analysed and benchmarked against GSR, ZGPSR and PDGR. The results demonstrated that the proposed model performs much better when compared with GSR, ZGPSR and PDGR.

6.3 Future work

Some of the potential future works are listed and elaborated here.

a) The proposed model for VANET communications has been specifically designed for high speed vehicle networks, especially for the highway environment. The congestion control mechanism that has been used is dynamic in nature. The researches in this field suggest that proactive algorithms which use transmission power and packet generation rate control at the same time are more useful for a congestion mechanism. This is especially more fruitful in a network containing a very large number of vehicles like in city scenarios [109]. This way they are based on a dynamic carrier sense threshold to provide different priorities for various types of packets in the network. This model, however, has failed to deliver in a congested network like in a city. A proper proactive congestion control mechanism can be utilised in future to overcome this deficiency.
b) Security for the network and data in the network is very important for any application in the field of vehicular ad hoc networks. This research has focused on information dissemination and has ignored the security and authentication procedures during the data transmission process. In future applications, the generic nature of the proposed model for VANET communication can be utilised to disseminate data in a secure manner.
c) The correlation mechanism for selecting the optimal link for information dissemination works fine for small networks. The uncertainties available in the vehicular ad hoc networks may be resolved using the fuzzy set theory and other intelligent systems like genetic algorithms with the hope to obtain a better system output.

REFERENCES

[1] B. H. Vladimir Bychkovsky, Allen Miu, Hari Balakrishnan,Samuel Madden, "A measurement study of vehicular internet access using in situ Wi-Fi networks," presented at the Proceedings of the 12th annual international conference on Mobile computing and networking, Los Angeles, CA, USA, 2006.

[2] L. L. Zhuoqun, Sun Ifeachor., "Range-Based Relative Velocity Estimations for Networked Mobile Devices," *Vehicular Technology, IEEE Transactions on*, vol. 58, pp. 2095-2099, 2009.

[3] L. Congyi and C. Chunxiao, "RPB-MD: A Novel Robust Message Dissemination Method for VANETs," in *Global Telecommunications Conference, 2008. IEEE GLOBECOM 2008. IEEE*, 2008, pp. 1-6.

[4] A. F. M. Torrent Moreno, H. Hartenstein, "System Design for Information Dissemination in VANETs," in *3rd International Workshop on Intelligent Transportation (WIT)*, Hamburg, Germany, 2006, pp. 27-33.

[5] D. A. M. David B. Johnson, Josh Broch, "DSR: the dynamic source routing protocol for multihop wireless ad hoc networks," in *Ad hoc networking*, ed: Addison-Wesley Longman Publishing Co., Inc., 2001, pp. 139-172.

[6] C. Perkins, E. Belding-Royer, and S. Das, *Ad hoc On-Demand Distance Vector (AODV) Routing*: RFC Editor, 2003.

[7] S. Biswas, R. Tatchikou, and F. Dion, "Vehicle-to-vehicle wireless communication protocols for enhancing highway traffic safety," *Comm. Mag.*, vol. 44, pp. 74-82, 2006.

[8] L. Yao-Nan, J. Hung-Chin, and T. Tzu-Chieh, "A MANET Based Emergency Communication and Information System for Catastrophic Natural Disasters," in *Distributed Computing Systems Workshops, 2009. ICDCS Workshops '09. 29th IEEE International Conference on*, 2009, pp. 412-417.

[9] "Front Matter," in *VANET*, ed: John Wiley & Sons, Ltd, 2009, pp. i-xxx.

[10] T. Nadeem, S. Dashtinezhad, C. Liao, and L. Iftode, "TrafficView: traffic data dissemination using car-to-car communication," *SIGMOBILE Mob. Comput. Commun. Rev.*, vol. 8, pp. 6-19, 2004.

[11] M. Bakhouya, J. Gaber, and P. Lorenz, "An adaptive approach for information dissemination in Vehicular Ad hoc Networks," *J. Netw. Comput. Appl.*, vol. 34, pp. 1971-1978, 2011.

[12] C. C. Wewetzer, M.Meier, K.Luebke, A., "Experimental Evaluation of UMTS and Wireless LAN for Inter-Vehicle Communication," in *Telecommunications, 2007. ITST '07. 7th International Conference on ITS*, 2007, pp. 1-6.

[13] T. ElBatt, S. K. Goel, G. Holland, H. Krishnan, and J. Parikh, "Cooperative collision warning using dedicated short range wireless communications," presented at the Proceedings of the 3rd international workshop on Vehicular ad hoc networks, Los Angeles, CA, USA, 2006.

[14] A. Alexiou, C. Bouras, and V. Igglesis, "Performance evaluation of tcp over umts transport channels," in *International Symposium on Communications Interworking*, 2004.

[15] V. Naumov, R. Baumann, and T. Gross, "An evaluation of inter-vehicle ad hoc networks based on realistic vehicular traces," presented at the Proceedings of the 7th ACM international symposium on Mobile ad hoc networking and computing, Florence, Italy, 2006.

[16] T. King, H. F, ler, M. Transier, and W. Effelsberg, "On the application of dead-reckoning to position-based routing for vehicular highway scenarios," presented at the Proceedings of the 2005 ACM conference on Emerging network experiment and technology, Toulouse, France, 2005.

[17] A. Boukerche, H. A. B. F. Oliveira, E. F. Nakamura, and A. A. F. Loureiro, "Vehicular Ad Hoc Networks: A New Challenge for Localization-Based Systems," *Comput. Commun.*, vol. 31, pp. 2838-2849, 2008.

[18] B. Hughes, Ren, Meier, R. Cunningham, and V. Cahill, "Towards real-time middleware for vehicular ad hoc networks," presented at the Proceedings of the 1st ACM international workshop on Vehicular ad hoc networks, Philadelphia, PA, USA, 2004.

[19] J. Landman and P. Kritzinger, "Delay analysis of downlink IP traffic on UMTS mobile networks," *Perform. Eval.*, vol. 62, pp. 68-82, 2005.

[20] C. Maihofer, "A survey of geocast routing protocols," *Communications Surveys & Tutorials, IEEE*, vol. 6, pp. 32-42, 2004.

[21] B. C. ord Neuman, "Scale in distributed systems," *ISI/USC*, 1994.

[22] G. Fenu and M. Nitti, "Strategies to Carry and Forward Packets in VANET," in *Digital Information and Communication Technology and Its Applications*. vol. 166, H. Cherifi*, et al.*, Eds., ed: Springer Berlin Heidelberg, 2011, pp. 662-674.

[23] K. Naveen and K. Karuppanan, "VCAR: Scalable and Adaptive Data Dissemination for VANET," in *Advances in Computing and Communications*. vol. 192, A. Abraham*, et al.*, Eds., ed: Springer Berlin Heidelberg, 2011, pp. 615-623.

[24] A. Singh, M. Kumar, R. Rishi, and D. K. Madan, "A Relative Study of MANET and VANET: Its Applications, Broadcasting Approaches and Challenging Issues," in *Advances in Networks and Communications*. vol. 132, N. Meghanathan*, et al.*, Eds., ed: Springer Berlin Heidelberg, 2011, pp. 627-632.

[25] S. Vassilaras and G. S. Yovanof, "Wireless Innovations as Enablers for Complex & Dynamic Artificial Systems," *Wirel. Pers. Commun.*, vol. 53, pp. 365-393, 2010.

[26] J. L. Janech, A.Krsak, E., "Comparation of Strategies for Data Replication in VANET Environment," in *Advanced Information Networking and Applications Workshops (WAINA), 2012 26th International Conference on*, 2012, pp. 575-580.

[27] N. Seh Chun, Z. Wuxiong, Z. Yu, Y. Yang, and M. Guoqiang, "Analysis of Access and Connectivity Probabilities in Vehicular Relay Networks," *Selected Areas in Communications, IEEE Journal on,* vol. 29, pp. 140-150, 2011.

[28] F. Gebali, "IEEE 802.11 wireless protocol: user performance using discrete-time Markov chains," in *Circuits and Systems, 2003 IEEE 46th Midwest Symposium on*, 2003, pp. 459-462 Vol. 1.

[29] G. L. S. Ye Li, Orthogonal Frequency Division Multiplexing for Wireless Communications: Springer US, 2006.

[30] A. Raniwala, "Architecture and protocols for a high-performance, secure ieee 802.11-based wireless mesh network," State University of New York at Stony Brook, 2009.

[31] S. Maru and T. X. Brown, "Denial of service vulnerabilities in the 802.16 protocol," presented at the Proceedings of the 4th Annual International Conference on Wireless Internet, Maui, Hawaii, 2008.

[32] B. Dusza, C. Ide, and C. Wietfeld, "A Measurement Based Energy Model for IEEE 802.16e Mobile WiMAX Devices," in *Vehicular Technology Conference (VTC Spring), 2012 IEEE 75th*, 2012, pp. 1-5.

[33] "IEEE Standard for Telecommunications and Information Exchange Between Systems - LAN/MAN - Specific Requirements - Part 15: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs)," *IEEE Std 802.15.1-2002,* pp. 1-473, 2002.

[34] Y. Liuqing and G. B. Giannakis, "Ultra-wideband communications: an idea whose time has come," *Signal Processing Magazine, IEEE,* vol. 21, pp. 26-54, 2004.

[35] K. Benkic, P. Planinsic, and Z. Cucej, "Custom wireless sensor network based on ZigBee," in *ELMAR, 2007*, 2007, pp. 259-262.

[36] C. Cseh, "Architecture of the dedicated short-range communications (DSRC) protocol," in *Vehicular Technology Conference, 1998. VTC 98. 48th IEEE*, 1998, pp. 2095-2099 vol.3.

[37] R. J. Bates, *Gprs: General Packet Radio Service*: McGraw-Hill, 2002.

[38] A. Samukic, "UMTS Universal Mobile Telecommunications System development of standards for the third generation," in *Personal, Indoor and Mobile Radio Communications, 1998. The Ninth IEEE International Symposium on*, 1998, pp. 978-984 vol.2.

[39] J. Voigt, J. Deissner, J. Hubner, D. Hunold, and S. Mobius, "Optimizing HSDPA performance in the UMTS network planning process," in *Vehicular Technology Conference, 2005. VTC 2005-Spring. 2005 IEEE 61st*, 2005, pp. 2384-2388 Vol. 4.

[40] J. Bernsen and D. Manivannan, "Review: Unicast routing protocols for vehicular ad hoc networks: A critical comparison and classification," *Pervasive Mob. Comput.*, vol. 5, pp. 1-18, 2009.

[41] S. R. Chaudhry, A. N. Al-Khwildi, Y. K. Casey, H. Aldelou, and H. S. Al-Raweshidy, "WiMob Proactive and Reactive Routing Protocol Simulation Comparison," in *Information and Communication Technologies, 2006. ICTTA '06. 2nd*, 2006, pp. 2730-2735.

[42] S.-J. Lee, J. Hsu, R. Hayashida, M. Gerla, and R. Bagrodia, "Selecting a routing strategy for your ad hoc network," *Comput. Commun.*, vol. 26, pp. 723-733, 2003.

[43] K. CheolGi, Y. B. Koy, and N. H. Vaidya, "Link-state routing protocol for multi-channel multi-interface wireless networks," in *Military Communications Conference, 2008. MILCOM 2008. IEEE*, 2008, pp. 1-7.

[44] Z. Yingji and Y. Dongfeng, "Dynamic source routing protocol for wireless ad hoc networks in special scenario using location information," in *Communication Technology Proceedings, 2003. ICCT 2003. International Conference on*, 2003, pp. 1287-1290 vol.2.

[45] R. F. Sari, A. Syarif, K. Ramli, and B. Budiardjo, "Performance evaluation AODV routing protocol on ad hoc hybrid network testbed using PDAs," in *Networks, 2005. Jointly held with the 2005 IEEE 7th Malaysia International Conference on Communication., 2005 13th IEEE International Conference on*, 2005, p. 6 pp.

[46] M. S. Bouassida and M. Shawky, "A cooperative congestion control approach within VANETs: formal verification and performance evaluation," *EURASIP J. Wirel. Commun. Netw.*, vol. 2010, pp. 1-12, 2010.

[47] D. Kumar, A. Srivastava, and S. C. Gupta, "Performance comparison of pro-active and reactive routing protocols for MANET," in *Computing, Communication and Applications (ICCCA), 2012 International Conference on*, 2012, pp. 1-4.

[48] C. E. Perkins and E. M. Royer, "Ad-hoc on-demand distance vector routing," in *Mobile Computing Systems and Applications, 1999. Proceedings. WMCSA '99. Second IEEE Workshop on*, 1999, pp. 90-100.

[49] Y.-C. Tseng, S.-Y. Ni, Y.-S. Chen, and J.-P. Sheu, "The broadcast storm problem in a mobile ad hoc network," *Wirel. Netw.*, vol. 8, pp. 153-167, 2002.

[50] H. Bo and J. Weijia, "Design and analysis of connected dominating set formation for topology control in wireless ad hoc networks," in *Computer Communications and Networks, 2005. ICCCN 2005. Proceedings. 14th International Conference on*, 2005, pp. 7-12.

[51] R. Impagliazzo, "A personal view of average-case complexity," presented at the Proceedings of the 10th Annual Structure in Complexity Theory Conference (SCT'95), 1995.

[52] E. Mahdipour, A. M. Rahmani, and E. Aminian, "Performance Evaluation of Destination-Sequenced Distance-Vector (DSDV) Routing Protocol," presented at the Proceedings of the 2009 International Conference on Future Networks, 2009.

[53] M. S. El-azhari, O. A. Al-amoudi, M. Woodward, and I. Awan, "Performance Analysis in AODV Based Protocols for MANETs," in *Advanced Information Networking and Applications Workshops, 2009. WAINA '09. International Conference on*, 2009, pp. 187-192.

[54] P. Sinha, S. V. Krishnamurthy, and S. Dao, "Scalable unidirectional routing with zone routing protocol (ZRP) extensions for mobile ad-hoc networks," in *Wireless Communications and Networking Confernce, 2000. WCNC. 2000 IEEE*, 2000, pp. 1329-1339 vol.3.

[55] P. J. T. Clausen, *Optimized Link State Routing Protocol (OLSR)*: RFC Editor, 2003.

[56] W. A. Mobaideen, H. M. Mimi, F. A. Masoud, and E. Qaddoura, "Performance evaluation of multicast ad hoc on-demand distance vector protocol," *Comput. Commun.,* vol. 30, pp. 1931-1941, 2007.

[57] T. Camp and Y. Liu, "An adaptive mesh-based protocol for geocast routing," *J. Parallel Distrib. Comput.,* vol. 63, pp. 196-213, 2003.

[58] H. B. H. a. I. A. S. Masood-ur-Rehman "Enhanced Adjustable Parameter Based Information Dissemination Model (eAPIM) for VANET," *Computer Science Journal,* vol. 1, pp. 58-68, 21 March 2011 2011.

[59] D. R. S. R. B. Ramakrishnan, R. S. Shaji, "Analysis of Routing Protocols for Highway Model without Using Roadside Unit and Cluster," *International Journal of Scientific and Engineering Research(IJSER),* vol. 2, pp. 22-27, January 2011 2011.

[60] P. Papadimitratos and J.-P. Hubaux, "Report on the "secure vehicular communications: results and challenges ahead" workshop," *SIGMOBILE Mob. Comput. Commun. Rev.,* vol. 12, pp. 53-64, 2008.

[61] S. Andrews, "Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) Communications and Cooperative Driving," in *Handbook of Intelligent Vehicles*, A. Eskandarian, Ed., ed: Springer London, 2012, pp. 1121-1144.

[62] M. P. Hollier, A. N. Rimell, D. S. Hands, and R. M. Voelcker, "Multi-modal Perception," *BT Technology Journal,* vol. 17, pp. 35-46, 1999/01/01 1999.

[63] Y. Wang and F. Li, "Vehicular Ad Hoc Networks," in *Guide to Wireless Ad Hoc Networks*, S. Misra*, et al.*, Eds., ed: Springer London, 2009, pp. 503-525.

[64] M. Alam, M. Sher, and S. A. Husain, "Integrated Mobility Model (IMM) for VANETs simulation and its impact," in *Emerging Technologies, 2009. ICET 2009. International Conference on*, 2009, pp. 452-456.

[65] H. Hongyu, Z. Yanmin, L. Xu, L. Minglu, and W. Min-You, "META: A Mobility Model of MEtropolitan TAxis Extracted from GPS Traces," in *Wireless Communications and Networking Conference (WCNC), 2010 IEEE*, 2010, pp. 1-6.

[66] F. K. Karnadi, M. Zhi Hai, and L. Kun-chan, "Rapid Generation of Realistic Mobility Models for VANET," in *Wireless Communications and Networking Conference, 2007.WCNC 2007. IEEE*, 2007, pp. 2506-2511.

[67] N. Aschenbruck, R. Ernst, E. Gerhards-Padilla, and M. Schwamborn, "BonnMotion: a mobility scenario generation and analysis tool," presented at the Proceedings of the 3rd International ICST Conference on Simulation Tools and Techniques, Torremolinos, Malaga, Spain, 2010.

[68] F. J. Martinez, J. C. Cano, C. T. Calafate, and P. Manzoni, "CityMob: A Mobility Model Pattern Generator for VANETs," in *Communications Workshops, 2008. ICC Workshops '08. IEEE International Conference on*, 2008, pp. 370-374.

[69] Z. Wuxiong, Y. Yang, Q. Hua, Z. Yi, J. Minduo, and Y. Tao, "Macroscopic traffic flow models for Shanghai," in *Communications (ICC), 2012 IEEE International Conference on*, 2012, pp. 799-803.

[70] T. Umer, D. Zhiguo, B. Honary, and H. Ahmad, "Implementation of microscopic parameters for density estimation of heterogeneous traffic flow for VANET," in *Communication Systems Networks and Digital Signal Processing (CSNDSP), 2010 7th International Symposium on*, 2010, pp. 66-70.

[71] S. Öztürk, J. Mišić, and V. Mišić, "Reaching spatial or networking saturation in VANET," *EURASIP Journal on Wireless Communications and Networking,* vol. 2011, pp. 1-12, 2011/11/18 2011.

[72] F. Bai, S. Narayanan, and A. Helmy, "IMPORTANT: a framework to systematically analyze the Impact of Mobility on Performance of Routing Protocols for Adhoc Networks," in *INFOCOM 2003. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications. IEEE Societies*, 2003, pp. 825-835 vol.2.

[73] N. Meghanathan, "On the Connectivity, Lifetime and Hop Count of Routes Determined Using the City Section and Manhattan Mobility Models for Vehicular Ad Hoc Networks," in *Contemporary Computing*. vol. 40, S. Ranka*, et al.*, Eds., ed: Springer Berlin Heidelberg, 2009, pp. 170-181.

[74] M. S. Hossain and M. Atiquzzaman, "Stochastic Properties and Application of City Section Mobility Model," in *Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE*, 2009, pp. 1-6.

[75] U. s. c. bureau. (2013, *Tigher Product Data Base*. Available: http://www.census.gov/geo/maps-data/data/tiger.html

[76] C. Lin and R. Shakya, "VANET worm spreading from traffic modeling," in *Radio and Wireless Symposium (RWS), 2010 IEEE*, 2010, pp. 669-672.

[77] D. R. Choffnes, Fabi and n. E. Bustamante, "An integrated mobility and traffic model for vehicular wireless networks," presented at the Proceedings of the 2nd ACM international workshop on Vehicular ad hoc networks, Cologne, Germany, 2005.

[78] Y. Liu, J. Bi, and J. Yang, "Research on vehicular ad hoc networks," presented at the Proceedings of the 21st annual international conference on Chinese control and decision conference, Guilin, China, 2009.

[79] T. Sukuvaara, P. Nurmi, D. Stepanova, S. Suopajärvi, M. Hippi, P. Eloranta, E. Suutari, and K. Ylisiurunen, "Wireless Traffic Service Communication Platform for Cars," in *Modelling, Computation and Optimization in Information Systems and*

Management Sciences. vol. 14, H. Le Thi*, et al.*, Eds., ed: Springer Berlin Heidelberg, 2008, pp. 548-557.

[80] N. An, J. Riihijarvi, and P. Mahonen, "Studying the Delay Performance of Opportunistic Communication in VANETs with Realistic Mobility Models," in *Vehicular Technology Conference, 2009. VTC Spring 2009. IEEE 69th*, 2009, pp. 1-5.

[81] L. Campelli, M. Cesana, and R. Fracchia, "Directional broadcast forwarding of alarm messages in VANETs," in *Wireless on Demand Network Systems and Services, 2007. WONS '07. Fourth Annual Conference on*, 2007, pp. 72-79.

[82] K. Dar, M. Bakhouya, J. Gaber, and M. Wack, "Evaluating Geographic Routing Protocols for Vehicular Ad-hoc Networks," in *New Technologies, Mobility and Security (NTMS), 2009 3rd International Conference on*, 2009, pp. 1-5.

[83] M. J. Lok, B. R. Qazi, and J. M. H. Elmirghani, "Characterisation of data dissemination in vehicular ad hoc networks in a city environment," presented at the Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly, Leipzig, Germany, 2009.

[84] F. J. Martinez, C.-K. Toh, J.-C. Cano, C. T. Calafate, and P. Manzoni, "A Street Broadcast Reduction Scheme (SBR) to Mitigate the Broadcast Storm Problem in VANETs," *Wirel. Pers. Commun.*, vol. 56, pp. 559-572, 2011.

[85] H.-J. Lim and T.-M. Chung, "A Survey on Privacy Problems and Solutions for VANET Based on Network Model," in *Algorithms and Architectures for Parallel Processing*. vol. 7017, Y. Xiang*, et al.*, Eds., ed: Springer Berlin Heidelberg, 2011, pp. 74-88.

[86] H. H. Irshad Ahmed Sumra, Jamalul-lail, Masood-ur-Rehman, "Trust And Trusted Computing In VANET," *computer Science Journal (CJS)*, vol. 1, p. 12, march 2011 2011.

[87] A. Aravind and H. Tahir, "Towards Modeling Realistic Mobility for Performance Evaluations in MANET," in *Ad-Hoc, Mobile and Wireless Networks*. vol. 6288, I. Nikolaidis and K. Wu, Eds., ed: Springer Berlin Heidelberg, 2010, pp. 109-122.

[88] J. Garc, a-Nieto, J. Toutouh, and E. Alba, "Automatic tuning of communication protocols for vehicular ad hoc networks using metaheuristics," *Eng. Appl. Artif. Intell.*, vol. 23, pp. 795-805, 2010.

[89] G. Yan, W. Yang, E. Shaner, and D. Rawat, "Intrusion-Tolerant Location Information Services in Intelligent Vehicular Networks," in *Intelligent Computing and Information Science*. vol. 135, R. Chen, Ed., ed: Springer Berlin Heidelberg, 2011, pp. 699-705.

[90] B. K. Chaurasia and S. Verma, "Haste induced behavior and VANET communication," in *Vehicular Electronics and Safety (ICVES), 2009 IEEE International Conference on*, 2009, pp. 19-24.

[91] J. Jakubiak and Y. Koucheryavy, "State of the Art and Research Challenges for VANETs," in *Consumer Communications and Networking Conference, 2008. CCNC 2008. 5th IEEE*, 2008, pp. 912-916.

[92] S. Zeadally, R. Hunt, Y.-S. Chen, A. Irwin, and A. Hassan, "Vehicular ad hoc networks (VANETS): status, results, and challenges," *Telecommunication Systems,* vol. 50, pp. 217-241, 2012/08/01 2012.

[93] M. U. Rehman, H. B. Hasbullah, and I. A. Somra, "Designing a hybrid system model for information dissemination in vehicular ad hoc networks," in *Computer Applications and Industrial Electronics (ICCAIE), 2011 IEEE International Conference on*, 2011, pp. 503-508.

[94] R. Kumar and M. Dave, "A Review of Various VANET Data Dissemination Protocols."

[95] M. W. Boto Bako, *Efficient Information Dissemination in VANETs*, 2011 ed.: InTech, 2011.

[96] A. Daunou, "Design of a privacy-aware routing protocol for vehicular ad hoc networks," 2012.

[97] M. Killat, F. Schmidt-Eisenlohr, H. Hartenstein, C. Rössel, P. Vortisch, S. Assenmacher, and F. Busch, "Enabling efficient and accurate large-scale simulations of VANETs for vehicular traffic management," in *Proceedings of the fourth ACM international workshop on Vehicular ad hoc networks*, 2007, pp. 29-38.

[98] T. Issariyakul and E. Hossain, *Introduction to Network Simulator NS2*: Springer Publishing Company, Incorporated, 2008.

[99] C.-C. L. Shie-Yuan Wang, "NCTUns 5.0: A Network Simulator for IEEE 802.11(p) and 1609 Wireless Vehicular Network Researches," presented at the 68th IEEE Vehicular Technology Conference (VTC), 2008.

[100] D. Pastor Perez, "Performance evaluation of realistic scenarios for vehicular ad hoc networks with CityMob and NCTUns simulators," 2011.

[101] R. Kumar and M. Dave, "A comparative study of Various Routing Protocols in VANET," *arXiv preprint arXiv:1108.2094*, 2011.

[102] I. Leontiadis and C. Mascolo, "Geopps: Geographical opportunistic routing for vehicular networks," in *World of Wireless, Mobile and Multimedia Networks, 2007. WoWMoM 2007. IEEE International Symposium on a*, 2007, pp. 1-6.

[103] P.-C. Cheng, J.-T. Weng, L.-C. Tung, K. C. Lee, M. Gerla, and J. Haerri, "GeoDTN+ Nav: A hybrid geographic and DTN routing with navigation assistance in urban vehicular networks," *MobiQuitous/ISVCS*, 2008.

[104] H. Menouar, M. Lenardi, and F. Filali, "Improving Proactive Routing in VANETs with the MOPR Movement Prediction Framework," in *Telecommunications, 2007. ITST '07. 7th International Conference on ITS*, 2007, pp. 1-6.

[105] G. Shen and G. Glinka, "Determination of weight functions from reference stress intensity factors," *Theoretical and Applied Fracture Mechanics*, vol. 15, pp. 237-245, 1991.

[106] S. Dietzel, F. Kargl, G. Heijenk, and F. Schaub, "On the potential of generic modeling for VANET data aggregation protocols," in *Vehicular Networking Conference (VNC), 2010 IEEE*, 2010, pp. 78-85.

[107] Z. Xiliang and X. Cheng-Zhong, "Delay-constrained energy-efficient wireless packet scheduling with QoS guarantees," in *Global Telecommunications Conference, 2005. GLOBECOM '05. IEEE*, 2005, pp. 5 pp.-3340.

[108] G. Jiayu, X. Cheng-Zhong, and J. Holle, "Predictive Directional Greedy Routing in Vehicular Ad hoc Networks," in *Distributed Computing Systems Workshops, 2007. ICDCSW '07. 27th International Conference on*, 2007, pp. 2-2.

[109] L. Wischhof and H. Rohling, "Congestion control in vehicular ad hoc networks," in *Vehicular Electronics and Safety, 2005. IEEE International Conference on*, 2005, pp. 58-63.

PUBLICATIONS

1. Masood-ur-Rehman, Halabi B. Hasbullah. Irshad A. Somra. "Enhanced Adjustable Parameter Based Information Dissemination Model (eAPIM) for VANET," Computer Science Journal, vol. 1, pp. 58-68, 21 March 2011 .

2. Irshad Ahmed Sumra, Halabi. B. Hasbullah, Jamalul-lail, Masood-ur-Rehman, "Trust And Trusted Computing In VANET," computer Science Journal (CJS), vol. 1, p. 12, march 2011 2011.

3. Masood Ur Rehman, and Halabi B. Hasbullah. "Optimal path selection in Bluetooth Scatternet based on fuzzy set theory." Information Technology (ITSim), 2010 International Symposium in. Vol. 2. IEEE, 2010

4. Masood Ur Rehman, Halabi B. Hasbullah, and Irshad Ahmad Somra. "Designing a hybrid system model for information dissemination in vehicular ad hoc networks." Computer Applications and Industrial Electronics (ICCAIE), 2011 IEEE International Conference on. IEEE, 2011.

5. Masood Ur Rehman, Halabi B. Hasbullah, and Irshad Ahmad Somra. "A comparative analysis of routing architecture for information dissemination in Vehicular Ad Hoc Networks." Computer & Information Science (ICCIS), 2012 International Conference on. Vol. 2. IEEE, 2012.

APPENDIX A

BRIDGE CODE

Bridge code is a program that is written in C over Linux. This program converts an NS-2 file into an NCTUNs file. The detailed working of the program is shown chapter 4. The program code is as shown below:

```
******************************************************************

 /*   Bridge Code  Program for translation of NS-2 routines in NCTUNs*/

/* It's a modified code for this research work. A special thanks to the authors of */

#include <stdio.h>

#include <stdlib.h>

#include <fcntl.h>#

include "structs.h"

#include <string.h>

#include <unistd.h>

float ReadNumber(int fd, char *s)

    {

    int i,b;

    char a;

    float n;

    i=0;

    b=1;

    while(b==1)

            {

            read(fd,&s[i],i);
```

```
			a=s[i];
			if(a==')')
				b=0;
			if(a==' ')
				 b=0;
			if(a==10)
				 b=0;
			if(a=='\"')
				b=0;
			else
				i++;
	}
	s[i]='\0';
	n=atof(s);
	return n;
	  }
```

/* there are three basic functions in this translation program which are read function, translated function and write function*/

/* Read Function*/

* The function Read has to read the NS2 file and store the information in a
NS2 struct.

```
*/
int read(int fichNS2, NS2 *sNS2)
	{
	char i;
	char info[18], num[10];
	int a,n;
	float time;
	seek(fichNS2,0,SEEK_SET);
	while((read(fichNS2,&l,1))>0)
		{
		a=1;
		if(i=='$')
		{
			seek(fichNS2,1,SEEK_CUR);
			read(fichNS2,&i,1);
			if(i=='o')
			{
			//set line
			//move the pointer for reading the number
			seek(fichNS2,4,SEEK_CUR);
			//read the number
			n=ReadNumber(fichNS2,num);
			while(i)
				{
				//read character by character searching for the
				coordinates, if not sure it is a fixed distance to seek
				read(fichNS2,&l,1);
				if(i=='X')
					{
					//for setting at the beginning of the number
					seek(fichNS2,2,SEEK_CUR);
					//read the number
```

```
                sNS2->node[n].locationNS[0].x=
                ReadNumber(fichNS2,info);
                break;
                }
            else if(i=='Y')
                {
                seek(fichNS2,2,SEEK_CUR);
                sNS2->node[n].locationNS[0].y=
                ReadNumber(fichNS2,info);
                break;
                }
            else if(i==10)
                {
                //if it is not a X or Y, sometimes is Z and we do
                not care.
                break;
                }

            }
            //check the number of nodes

            if(n>sNS2->numberNodes) sNS2->numberNodes=n;
        }
        else if(i=='s')
        {
        //Node movement line
        seek(fichNS2,5,SEEK_CUR);
        time=ReadNumber(fichNS2,info);
        while(1)
            {
            read(fichNS2,&i,1);
            if(i=='(')
```

```
                    break;
                }
            //get node number
            n=ReadNumber(fichNS2,num);
            sNS2->node[n].numberLocations++;
            sNS2->node[n].locationNS[sNS2>node[n].numberLocations]
            .time=time;
            //copy time
            seek(fichNS2,9,SEEK_CUR);
            //copy coordinate X
            sNS2->node[n].locationNS[sNS2-node[n].numberLocations].x
            =ReadNumber(fichNS2,info);
            //copy coordinate Y
            sNS2->node[n].locationNS[sNS2->node[n].numberLocations].
            y=ReadNumber(fichNS2,info);
            //copy speed
            sNS2->node[n].locationNS[sNS2-
            >node[n].numberLocations].speed=ReadNumber(fichNS2,inf);
            }
        }
        else
        {
        while(a==1)
            {
            read(fichNS2,&l,1);
            if(l==10)
                a=0;
            }
            }
        }
}
```

/* Translate Function*/

/* This function makes the calculations for the translation of the NS2 structure to NCTUns structure */

```
void translate(NS2 *sNS2, NCTUns *sNCTUns, int n, int x, int y)
        {
          int i.j=0;
          int dist,semaforo;
          sNCTUns->size.x=x;
          sNCTUns->size.y=y;
          sNCTUns->numberNodes=n;
          for(i=0;i<sNCTUns->numberNodes;i++)
               {
               sNCTUns->node[i].numberTurnings=
               sNS2->node[i].numberLocations-1;
               for(j=0;j<=sNCTUns->node[i].numberTurnings;j++)
                    {
                    sNCTUns->node[i].locationNC[j].x=
                    sNS2->node[i].locationNS[j].x;
                    sNCTUns->node[i].locationNC[j].y=
                    sNS2->node[i].locationNS[j].y;
                    if(j==0)
                         {
                          // Node initial position
                         sNCTUns-
                    >node[i].locationNC[j].arrivalTime=0;
                         sNCTUns->node[i].locationNC[j].pausedTime=
                         sNS2->node[i].locationNS[j+1].time;
```

```
			}
		else
			{
			// distance is calculated only for Manhattan case
			dist=sNS2->node[i].locationNS[j].x-sNS2-
			>node[i].locationNS[j-1].x;
			if(dist==0)
				{
				dist=sNS2->node[i].locationNS[j].y-
			sNS2-
				>node[i].locationNS[j-1].y;
				}
			if(dist<0)
				 dist=-dist;
			if(((dist/sNS2-
		>node[i].locationNS[j].speed)+0.5)
			<((sNS2->node[i].locationNS[j+1].time)-(sNS2-
			>node[i].locationNS[j].time)))
				semaforo=1;
			else
				semaforo=0;
		if(semaforo==1)
			{
			 // If there is a light signal
			sNCTUns->node[i].locationNC[j].arrivalTime=
			(dist/sNS2-
			>node[i].locationNS[j+1].speed)+sNS2-
			>node[i].locationNS[j].time;
			sNCTUns->node[i].locationNC[j].pausedTime=
			sNS2->node[i].locationNS[j+1].time-sNCTUns-
			>node[i].locationNC[j].arrivalTime;
			}
```

```
                    else
                        {
                        sNCTUns->node[i].locationNC[j].arrivalTime=
                        sNS2->node[i].locationNS[j+1].time;
                        sNCTUns-
                    >node[i].locationNC[j].pausedTime=0;
                        }
                        //Possible negatives values in pausedTime
                    if(sNCTUns->node[i].locationNC[j].pausedTime<0)
                        {
                        sNCTUns-node[i].locationNC[j].pausedTime=0;
                        }
                    }
            sNCTUns->node[i].locationNC[j].speed=
                                    sNS2-
                                >node[i].locationNS[j+1].speed;
                }
            }
        }
```

/* Write Function*/

/ The function write writes the information stored in the NCTUns struct in a file./

```
void write(int fichNCTUns, NCTUns *sNCTUns)
    {
    int i, j=0;
    printf(fichNCTUns,"# The size of the working area.\n");
    printf(fichNCTUns,"%d %d 1000\n",sNCTUns >size.x,sNCTUns->size.y);
    printf(fichNCTUns," Number of mobile nodes\n");
    printf(fichNCTUns,"%d\n",sNCTUns->numberNodes);
```

```
for(i=0;i<sNCTUns->numberNodes;i++)
          {
           if(i!=0)
           printf(fichNCTUns,"\n");
           printf(fichNCTUns,"NODE_BEGIN
          ID_NODE_80211B_ADHOC\n"); printf(fichNCTUns,"# Node %d\n#
          initial location x(m) y(m) arrival_time(s) pause_time(s)
          speed(m/s)\n",i);
          // Node intial position:

          printf(fichNCTUns," %d %d %.9f %.9f %.9f\n",
                    sNCTUns->node[i].locationNC[0].x,
                    sNCTUns>node[i].locationNC[0].y,
                    sNCTUns->node[i].locationNC[0].arrivalTime,
                    sNCTUns->node[i].locationNC[0].pausedTime,
                    sNCTUns->node[i].locationNC[0].speed);
          printf(fichNCTUns,"# PATH_BEGIN number_of_turning_points\n");
          if(sNCTUns->node[i].numberTurnings-1>0)
                    printf(fichNCTUns," PATH_BEGIN %d\n",
                    sNCTUns->node[i].numberTurnings-1);
          else
                    printf(fichNCTUns," PATH_BEGIN %d\n",0);
                    printf(fichNCTUns,"# x(m) y(m) arrival_time(s)pause_time(s)
                                        speed(m/s)\n");
          for(j=1;j<sNCTUns->node[i].numberTurnings;j++)
                    {
                    printf(fichNCTUns," %d %d %.9f %.9f %.9f\n",
                              sNCTUns->node[i].locationNC[j].x,
                              sNCTUns->node[i].locationNC[j].y,
                              sNCTUns->node[i].locationNC[j].arrivalTime,
                              sNCTUns->node[i].locationNC[j].pausedTime,
                              sNCTUns->node[i].locationNC[j].speed);
```

```
                    }
          printf(fichNCTUns," PATH_END\n");
          printf(fichNCTUns,"NODE_END\n");
          }
}
```

*** Main Function*/**

```
int main(int argc, char** argv)
          {
          int fd,fd2,n,x,y;
          NS2 sNS2;
          NCTUns sNCTUns;
          fd=open("source.txt", O_RDONLY);
          if (fd==-1)
                    {
                    printf("Error charging NS2 file. Remember it must be called
          source.txt\n");
                    return;
                    }
          fd2=fopen("dest.mdt", "w");
          if (fd2==-1)
                    {
                    printf("Error creating or charging NCTUns file. Try to create a file
                    calling it dest.mdt");
                     return;
                    }
          read(fd, &sNS2);
          close(fd);
          n=sNS2.numberNodes + 1;
          x=3000;
```

```
    y=3000;
    translate(&sNS2,&sNCTUns,n,x,y);
    write(fd2,&sNCTUns);

close(fd2);
```

APPENDIX B

COMPARATIVE STUDY FOR APPLICATION BASED MODELS PROPOSED IN VANET

Type of protocol	Subtype	Name of protocol	Advantages	Disadvantages	Nature of usage
a) Proactive routing protocols	Table driven	FSR	• No Route Discovery is required. • Low Latency for real time applications	• Unused paths occupy lots of bandwidth.	Non-safety, safety, leisure applications
b) Reactive routing protocols	On demand	AODV	• Up-to-date path to destination by using destination sequence number. • Reduction in excessive memory requirements and the route redundancy. • Responses to the link failure in the network. • Can be utilized to large scale ad hoc network.	• More time for connection setup and link establishment than others. • Old entries can lead inconsistency in the route. • For a single route reply packet sending on multiple routes will lead to heavy control overhead. • Periodic beaconing consumes extra bandwidth.	Non-safety, safety, leisure application
		DSR	• Beacon less. • It uses caching which reduce load on the network for future route discovery. • No periodical update requirements in DSR.	• Route information within the header will lead to byte overhead for assistive nodes. • Unnecessary flooding overburden the network. • Unable to repair broken links locally.	Non-safety, safety, leisure application
		TORA	• Creates direct acyclic graph	• DSR & AODV perform	Non-safety and leisure

			when necessary. • Reduced network overhead by reducing rebroadcast. • Perform well in dense network	well than TORA. • It is not scalable	application
c) Geographic Routing Protocols	DTN	VADD	• Higher delivery ratio than GPSR (with buffer), epidemic routing and DSR, VADD. • Suitable for multi-hop data delivery.	• large delay due to change of topology and traffic density	Non-safety, safety, leisure application
		GeOpps	• Location-Based Greedy and Move routing algorithms it has high delivery ratio. • Less intermediate encounters needed. • The delivery ratio of GeOpps rely on the mobility patterns & the road topology but not on high densities	• Privacy is an issue due to navigation info propagations.	Safety of life and safety application
	Beacon	GPSR	• One hop neighbor location is required to be remembered for forwarding of packet. • Dynamically made forwarding decisions	• For high mobility unnecessary state information is included in the neighbor table. • Packet header of intermediate node is never updated for current carrier.	Safety of life application

		GPSR+AGF	• Packet header of intermediate node is updated dynamically. • State of nodes for neighbors table is updated dynamically.	• For shortest connected path it may not give desired optimal solution as the links in the path may disconnected dramatically.	Safety of life application
		PBR-DV	• Packet delivery ratio & overhead lowered for high dynamic network behavior.	• Excessive flooding is needed for non-greedy part.	Safety of life application
		GRANT	• For city scenario with obstacles this extended approach works better than the usual greedy approach	• Performance evaluation of GRANT is done on static traces. • Beacon and possible inaccuracy in packet delivery overheads are not measured	Non-safety, safety, leisure application
	Overlay	GPCR	• Don't need global or external information. • For representing the planar graph it uses the underlying roads. • It does not have planarization problem like unidirectional links, planar sub-graphs & so on.	• Due to dependence on Junction detection this approach fails on curved road and a sparse road.	Non-safety, safety, safety of life and leisure applications

		GPSRJ+	• The PDR for GPCR increases managed by GPSRJ+. • Overhead of hops in recovery mode of GPSR is reduced by 200%. • A costly planarization strategy is not required in GPSRJ+	• Not good for the delay sensitive applications. • It doesn't use the realistic city maps. • It requires simple line trajectory but realistic roads carries complex trajectory	Non-safety, safety, leisure applications
		CAR	• Digital map is not needed and no local maximum issues. • CAR ensures the shortest connected path • Packet delivery ratio is higher than GPSR and GPSR+AG	• CAR is not able to adjust with different sub paths for changed traffic environment.	Non-safety, safety, leisure applications
		GyTAR	• Topological changes due to high mobility create network fragmentation. It is catered efficiently by GyTAR. • Throughput, delay and routing overhead are better than that of GSR	• GyTAR depends on roadside units only for forwarding the data. • Gytar cannot avoid the obstacles intelligently and reduce in reflection time.	Safety of life applications
		GSR	• Performance of GSR as for as Packet delivery ratio is	• Does not perform forwarding packets in	

			concerned is better than that of GSR AODV & DSR. • GSR has the tendency for scalability more than AODV & DSR	sparse network. • GSR poses higher routing overhead than GyTAR using hello messages as control messages.	
		A-STAR	• A-STAR ensures for finding an end-to end connection for low density. • Combining the greedy approach of GSR & the perimeter mode of GPSR, A-STAR creates a new local recovery strategy. • Path selection of A-STAR ensures high connectivity.	• Packet delivery ratio of A-STAR is lower than GSR & GPSR. • Static information is used for path creation based on city bus routes which causes connectivity	Non-safety, leisure applications
		STBR	• It goes across least spanning multiple junctions for long distance communication	• STBR is not appropriate for mixed scenarios because it would try to send junction beacons along a highway. • Complexity increases due to transferring the two-hop neighbor table to the new sender when the old sender leaves the junction	Safety of life applications
		LOUVRE	• Estimation of Peer-to-peer density avoids backtracking.	• Due to unsuccessful packets it has a little higher hop count than GPCR.	Non-safety and leisure applications

			• Packet delivery ratio is higher than GPCR & GPSR. • Ensures an obstacle free geographic routing.	• Scalability issue is there for LOUVRE.	
d) Content based Forwarding	Nil	TO-GO	• All nodes can hear one another and no hidden terminal occurs. • TO-GO, GPCR, GPSRJ+ have identical packet delivery ratio. • Low signal to voice ratio	• End-to-End latency in TO-GO is higher than GPCR, GPSR, GPSRJ+	Non-safety, safety, leisure applications
e) Hybrid routing	Nil	GeoDTN+Nav	• Non-DTN to DTN mode can be switched easily in GeoDTN+Nav. • Partition in the network can be easily sited in GeoDTN+Nav	• When GeoDTN+Nav switches to DTN mood latency increases and PDR decreases in sparse networks on highway. • In a partitioned network shows that DTN achieves slightly better PDR and lower latency than GeoDTN+Nav	Safety, and safety of life applications